From Sea to Shore:

The Impact of Ocean Acidification on Child Health*

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Abstract

Since the Industrial Revolution, ocean water acidity has risen by 26% due to anthropogenic emissions—a process known as *ocean acidification*—posing a risk for marine life and the communities depending on it. This paper examines the consequences of ocean acidification for child health, using data from coastal regions in 36 low- and middle-income countries from 1972 to 2018, encompassing 41% of the world's coastal population. Leveraging short-term exogenous shifts in ocean acidity near human settlements for identification, we find that prenatal exposure to higher water acidity significantly raises the risk of death in the first months of life and impacts early childhood development. We show evidence consistent with these effects being associated with maternal malnutrition, as increased acidity reduces catches for small-scale fisheries, increasing seafood prices and reducing consumption of crucial nutrients. Our findings indicate limited adaptation to these impacts. We estimate that, absent intervention, ocean acidification could contribute to as many as 77 million neonatal deaths in this region by 2100—a consequence that should not be ignored in the projected cost of climate change. (*JEL* I15, Q20, Q54, O10)

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Since the Industrial Revolution, ocean water acidity has risen by 26%—a phenomenon known as *ocean acidification* (Doney et al., 2020). This outcome originates from the ocean's key role in regulating the climate by absorbing carbon dioxide from the atmosphere. Due to increased emissions from human activities, the amount absorbed has surged over the past two centuries, disrupting the ocean's chemical balance. The resulting increased acidity affects marine life and is likely endangering human communities whose economic development depends on marine resources (Dalgaard et al., 2020; IPCC, 2022b). Nevertheless, empirical evidence on these consequences remains limited, with most findings derived from economic or ecological models projecting the hypothetical effects of ocean acidification (see, e.g., Brander et al., 2012; Colt and Knapp, 2016).

This paper investigates the consequences of ocean acidification for child health, focusing on the region where the impact is expected to be most pronounced—in low- and middle-income countries (L&MICs). These countries are home to most of the over 3 billion people worldwide who depend on ocean-harvested resources to survive (FAO, 2022). In their coastal regions, seafood consumption forms a significant part of nutritional intake, predominantly supported by small-scale fisheries operating near human settlements (World Bank, 2012). This form of dependency is particularly vulnerable to local disruptions to marine resources, such as those caused by acidification, with children being particularly at risk (see Section 1 for a detailed discussion of these processes).

We exploit local dependency on marine resources to analyse the effects of ocean acidification in the coastal areas of 36 L&MICs, spanning large regions of Africa, Asia, and Latin America from 1972 to 2018. In 2020, these countries accounted for 39% of the world's population, rising to 41% when focusing on coastal areas (United Nations, 2024). Our approach compares individuals and communities over time by matching their locations to temporal variation in the acidity of the nearest waters, as measured by pH—a logarithmic scale where lower values indicate the higher acidity of a solution. For identification, we focus on short-term exogenous changes in pH at these locations. In the short run, and similarly to weather patterns, pH in a specific point in the ocean deviates exogenously around a long-run (decreasing) trend, with waters being relatively more (or less) acidic.[1] Exploiting this property, we capture deviations using a linear framework accounting for unobserved heterogeneity through multi-way fixed effects (FEs). We support this approach with several checks described in Sections 3 and 4.

Following this approach, we first establish a link between ocean acidity and child health. Comparing marine catches in coastal areas over time, we show that higher acidity reduces the quantity and value of seafood caught by small-scale fisheries, suggesting a net negative effect of water acidity on species harvested in proximity to coastal settlements. These effects operate in the absence of contemporaneous changes in the catch of commercial fisheries or overall economic activity. Our findings indicate that the negative shocks to small-scale fisheries increase local prices for seafood, translating into a diminished probability of seafood consumption and increased malnutrition for local populations, particularly affecting pregnant women. Maternal malnutrition is a critical risk factor for children's health, and can lead to developmental deficits and even to death (Victora et al., 2021).

Motivated by this link, we study the consequences of early-life exposure to varying degrees of ocean acidity. We use data from up to 1.5 million live births from 1972 to 2018, leveraging individuals' geolocation and month and year of birth to compute exposure. Comparing children (or siblings) born in the same location, but at different points in time, we reveal that experiencing higher acidity in nearby waters while *in utero* leads to increased mortality in the first months of life. A 1% increase in acidity raises neonatal mortality (death during the first month of life) by approximately 1.5 deaths per 1,000 live births in coastal communities. This effect represents a 5% increase relative to the sample average of neonatal mortality in the period of study. The largest impacts are observed in areas with a higher dependence on seafood and in regions where forms of fishing that deplete marine biodiversity are prevalent, in line with evidence on the cascading effects of over-exploitation (see, e.g., Frank and Wilcove, 2019). Experiencing higher acidity while *in utero* has instead no effect on mortality beyond the first months

[1] Ocean pH is affected by wind, temperature, sea ice, precipitation, runoff, and ocean circulation (Feely et al., 2008). As such, its local variation is analogous to weather patterns (Appendix B.1), whose short-run deviations have been used in the literature to identify climatic shocks (Dell et al., 2014).

of life.

The increase in neonatal mortality following ocean acidification confirms a mechanism rooted primarily in changes in maternal health. However, investments in maternal and child health are unaffected, suggesting the lack of adaptation. Our results indicate that differential access to medical care and nutrient supplementation, as well as behavioural changes that could occur after parents observe their child's health, are unlikely to be at play.[2] The results also confirm the absence of significant income changes at the household level, as such changes would typically prompt adjustments in investment (see, e.g., Baird et al., 2011).

Finally, exposure to ocean acidity *in utero* not only impacts mortality rates, but also influences infants' development. Objective anthropometric measurements indicate that mortality due to prenatal exposure to ocean acidity is more common among children who would have otherwise had worse health outcomes. On average, children who survive past their first month of life have slightly better health indicators and thus represent a positively selected group. However, when examining gendered effects, we observe a significant increase in stunting among female children, which outweighs this positive selection. We present evidence consistent with these negative effects lasting into women's adulthood, accompanied by worse economic outcomes.

These results enable projections of the aggregate effects of ocean acidification in the future. By combining the estimated effect of *in-utero* exposure to ocean acidity with various emissions and adaptation scenarios, we project neonatal mortality rates in the study area through 2100. Continued carbon dioxide emissions are projected to lower average surface ocean pH by as much as 0.38 units by 2100, compared to 1975 levels (IPCC, 2022a). Under a high-emissions scenario with no adaptation, the cumulative neonatal deaths attributable to ocean acidification could reach 77 million for the period 1975–2100. This outcome equates to an average neonatal mortality rate of 23 per 1,000 live births, similar to the rates seen in Northern Africa and Western Asia in 1990

[2] We lack direct measures of maternal stress. However, evidence indicates that maternal stress plays a significant role in response to traumatic events (see, e.g., Aizer et al., 2016; Persson and Rossin-Slater, 2018; Menclova and Stillman, 2020; Berthelon et al., 2021), as opposed to the relatively mild changes in maternal health that we examine in later sections.

or Southern Asia in 2020 (UNICEF, 2024). The introduction of adaptation measures could significantly dampen these estimated consequences. However, given the limited adaptation to ocean acidification observed from 1972 to 2018, our findings underscore the importance of shifting away from high-emissions pathways.

Our findings contribute to different strands of the literature. First, we further our understanding of the current and future effects of climate change. By providing evidence on the consequences for coastal communities of altering ocean acidity and projecting them to the future, our results contribute to the emerging literature on the impacts of ocean acidification on human communities (see, e.g., Colt and Knapp, 2016), an essential dimension to integrate into the general literature measuring the costs of climate change (see, e.g., Auffhammer, 2018). While many studies have explored the impact of climate change on human behaviour—focusing on issues like rising temperatures and shifting rainfall patterns (Deschênes et al., 2009; Deschênes and Moretti, 2009; Barreca et al., 2016)—the ocean has received far less attention. In addition, due to the open-access nature of ocean resources, changes in their productivity are not comparable to changes in land and agricultural productivity (see, e.g., Collier, 2010), which have been more extensively studied in relation to climate change.

Second, we provide new evidence regarding the early stages of children's development. Numerous studies have examined shocks that are either directly observable or have direct effects on health, thus leading to adaptation or avoidance behaviour (Almond et al., 2018 provides a review of this literature).[3] Ocean pH is not directly observed or felt by individuals (e.g., it is not reported in weather forecasts or newspapers), it has no direct effect on health, and public awareness about its changing nature is highly limited.[4] Our results suggest that shocks with these characteristics—being largely imperceptible, lacking direct health impacts, and receiving minimal public attention—generate a

[3]Studies related to our setting cover atmospheric events (Maccini and Yang, 2009; Heft-Neal et al., 2018; Geruso and Spears, 2018a; Adhvaryu et al., 2024) and environmental contamination or degradation (Chay and Greenstone, 2003; Arceo et al., 2016; Isen et al., 2017; Geruso and Spears, 2018b; Black et al., 2019; Berazneva and Byker, 2022). On avoidance behaviour, see Moretti and Neidell (2011) on air pollution.

[4]The tangible effects of ocean pH could be discerned from seafood catch. However, awareness among the general public of a link between water acidity and fisheries is severely limited. Surveys conducted in richer countries suggest that only a tiny segment of the population is aware of this influence (Gelcich et al., 2014; Lotze et al., 2018).

limited behavioural response, contrasting with evidence on adaptation following nutritional shocks such as famines and prolonged fasting (Razzaque et al., 1990; Almond and Mazumder, 2011; Majid, 2015), or nutrient supplementation (Adhvaryu and Nyshadham, 2016). In our setting, parents are likely either unaware of the consequences of altering their diets, or their health is not sufficiently affected to induce behavioural changes. These findings align with evidence on the limited knowledge of dietary consequences in poorer settings (see, e.g., Hirvonen et al., 2017) and with the high prevalence of micronutrient deficiency in L&MICs (Lowe, 2021). Such deficiency can occur without deficits in caloric intake, making detection difficult for non-experts.

Finally, this study provides new evidence on the importance of wildlife for human and economic development (Michalopoulos and Papaioannou, 2013; Bowles and Choi, 2019; Dalgaard et al., 2020; Mayshar et al., 2022). Our findings complement the recent literature on biodiversity and poverty (see, e.g., Dasgupta, 2021) and on the role of overly exploitative practices such as deforestation (Burgess et al., 2012; Jayachandran, 2013), overfishing (Stavins, 2011), and poaching (Kremer and Morcom, 2000). Closely related to our study is the work of Frank and Sudarshan (2023), which highlights the role of the functional extinction of vultures in India on human mortality, and that of Feir et al. (2023), which shows how the loss of the bison in North America led to persistent negative consequences for Native Americans.

1 Background

This section summarises how ocean acidity can impact marine life and human behaviour, while we test these channels in Section 4.1. Concerning marine life, the scientific literature highlights two channels.

First, water acidity directly affects the physiology of marine species: at lower pH levels, many organisms must invest additional energy to maintain their metabolic processes and biological functions, with consequences for their survival, growth, development, and reproduction (Gattuso and Hansson, 2011). Although these effects are heterogeneous across and within species, biological effects are generally large and negative (Kroeker et al., 2010; Alter et al., 2024). Laboratory experiments indicate negative responses to acidity in approximately 50% of species tested (Wittmann and Pörtner, 2013).

Second, water acidity degrades key marine habitats such as coral reefs and macroalgal forests. These areas serve as crucial feeding grounds for fish, making them important catchment areas for subsistence and artisanal fisheries (Doney et al., 2020). Degradation of these ecosystems disrupts marine food chains, not only reinforcing the direct effects of pH on the physiology of marine species, but also altering competition for food across species (Sunday et al., 2017). Scientific evidence indicates that commonly-consumed species, which typically boast better nutritional content, are more vulnerable to these effects, particularly in the presence of overfishing (Jones and Cheung, 2018; Hicks et al., 2019; Maire et al., 2021).

The overall net effect of these two channels on marine life is uncertain (IPCC, 2022b). Some species might benefit from the consequences of acidic conditions, resulting in compositional changes (i.e., an increase in the quantity or quality of some species and a reduction in others) rather than reduced seafood stock.[5] Nevertheless, any change in species occurrence can impact harvest composition and, consequently, human nutrition and health. The reduced availability of commonly harvested species could result in income deterioration (Colt and Knapp, 2016), potentially reducing investments in health and nutrition among those relying on fisheries as a source of income, and in dietary shifts driven by price adjustments or changes in seafood quality.[6]

The resulting effects on nutrition are expected to be more pronounced in vulnerable coastal and island communities in L&MICs. In these countries, seafood is a crucial source of nutrients, providing 26% of all consumed animal proteins, as compared to the global average of 17% (FAO, 2022). Countries such as Bangladesh, Cambodia, the Gambia, Ghana, Indonesia, Sierra Leone, and Sri Lanka reach peaks of at least 50% reliance on seafood for protein. In addition, most of this nutrient intake is supported by small-scale fisheries, definitionally more vulnerable to local shocks as compared to

[5] Appendix B.1 discusses variables with a more direct effect on quantity, such as rising global sea surface temperatures (Keeling et al., 2010).

[6] The biological changes to marine life induced by water acidity are expected to result in reduced protein intake and compromised seafood quality (Falkenberg et al., 2020).

larger fisheries (FAO, 2023). L&MICs host 97% of all workers employed in marine capture, and more than 90% of them are engaged in small-scale fisheries supporting local consumption (see, e.g., Simmance et al., 2022). The ability to balance changes in local supply with imports is limited because L&MICs tend to export higher-quality seafood caught in their waters and supplement local demand with imports of lower-quality fish (McCauley et al., 2018).

Children, particularly, are at risk. Because nutritional alternatives and access to micronutrient supplementation are limited, seafood is recognised as an important source of macronutrients, such as proteins, and micronutrients, such as iron, iodine, zinc, vitamin A, vitamin D, vitamin B12, calcium, and essential fatty acids (United Nations, 2021). These nutrients are essential for maternal health and for fetal and child development.[7] Early-life deficiencies in these nutrients can lead to severe health consequences, even including death (Victora et al., 2021).

2 Data

We collate myriad data sources. Appendices A.1–A.2 further detail the variables and data sources. Figure 1 shows the geographical coverage of the study.

Mortality, human capital, and adaptive behaviour. We collate and homogenise 92 household surveys from 36 countries collected by the Demographic and Health Surveys (DHS) from 1990 to 2018. Individual surveys provide nationally representative data on health and population in L&MICs, with a particular focus on maternal and child health, and they have been widely used to calculate mortality rates among children. The dataset is supplemented with objective measurements of human development and nutrition, such as height, weight, and hæmoglobin concentration in blood samples. The programme surveys women aged 15–49 and includes information about their demo-

[7] *Iron* and *iodine* support brain development and help prevent stillbirth. *Zinc* and *vitamin A* promote childhood survival and growth. *Calcium* and *vitamin D* reduce the risk of preterm delivery, while *vitamin B12* is vital for a healthy pregnancy and the development of the nervous system and brain in children. *Essential fatty acids* help prevent preeclampsia, preterm delivery, and low birth weight, and support children's cognitive development.

graphics, including wealth and human capital accumulation. Each surveyed woman's birth history is recorded and includes information on their children's year and month of birth, sex, birth order, whether they are twins, and the date of death when applicable. We assume measurement error related to mortality is minimal, as the timing of a child's death, being a tragic event, is unlikely to be forgotten.[8]

The primary sampling unit is a community (or cluster), representing a village or neighbourhood. Our dataset includes all available surveys with geographical coordinates and considers only countries with direct access to the ocean. We use all available surveys and re-weight observations to correct for oversampling of countries surveyed multiple times. Appendix A.1 provides the full list of countries and surveys. Results are robust to different selection criteria. For questions omitted in specific survey rounds, we re-compute weights to account for this selection.

We restrict the sample to coastal areas. Using geolocation for communities, we compute the minimum straight distance to the shoreline, and following United Nations (2003), we define a *coastal area* as the buffer extending landward from the ocean's shore up to a distance of 100 km. Individual characteristics tend to be comparable in magnitude between communities in the coastal and inland areas, but households in proximity to the ocean are slightly richer and exhibit lower mortality rates (Appendix A.2).

Ocean acidity. We capture this chemical feature of the ocean using water pH—a logarithmic scale that indicates the acidity (basicity) of an aqueous solution at lower (higher) values—measured at the surface. Measurement of ocean pH using satellites for our time-space dimension is currently unavailable (Land et al., 2019). We therefore obtain the chemical features of the ocean from the Hadley Global Environment Model 2 – Earth System or HadGEM2–ES, developed by Collins et al. (2011) and Jones et al. (2011), which combines historical climate data, physical equations, and simulations to reconstruct past climate conditions, extrapolating from observations where observed data are incomplete.[9] Section 4 discusses estimates controlling for confounders that

[8]The history of terminated pregnancies (i.e., pregnancies that did not result in a live birth regardless of the cause) is not recorded. Appendix B.3 shows that ocean acidity in nearby waters does not affect the probability of experiencing a terminated pregnancy and that results are robust to accounting for recall bias in the reporting of a child's death.

[9]Although the series matches well the available information from observational data of ocean features

could influence the pH measurement, such as anthropogenic waste.

Data are monthly global raster data at the $1° \times 1°$ resolution for the period 1972–2018.[10] We match raster points to communities or coastal areas using a proximity criterion (see Section 3 for details about the matching procedure). In Appendix B.1, summary statistics for matched points highlight that pH varies locally both within and across years around its long-run level, showing a high similarity to weather systems. Variation in pH originates from both the time and geographic dimensions, with comparable contributions from its between and within components.

We supplement our data with other variables that could jointly determine ocean acidity and outcomes in the coastal areas. First, we gather information about additional chemical features of the ocean with the same source used for pH. Second, we draw on the ERA5 database to supplement the data with other meteorological features in the same location in the ocean where pH is measured, including temperature and wind speed. Third, to control for weather characteristics inland, we include yearly rainfall and temperature data at the community level from the PRIO-GRID database.

Ocean exploitation. Data about seafood catch at the temporal and geographical resolution of the DHS data is unavailable, forcing us to work with data aggregated at the country level or for a restricted temporal horizon.

First, we gather data about quantity, price, and landed value of catches within the exclusive economic zones (EEZs) of each country in our sample from the Sea Around Us initiative (Pauly et al., 2020). An EEZ is a sea zone prescribed by the United Nations Convention on the Law of the Sea (UNCLOS) extending up to 200 nautical miles from the coast. Within this zone, the coastal state has special rights over the exploration and use of marine resources. Figure 1 shows the geographical coverage of these zones.

(see, e.g., Totterdell, 2019), our estimates might suffer from measurement error due to extrapolation. The possibility that such measurement error is correlated with unobservable determinants of local development or health is minimised by the climatology-based framework of the data (i.e., by construction, data cannot capture pH at the coast, where it may be influenced by local human activity). While there may be unobserved factors that influence both the outcome variables analysed in the paper and pH, we interpret our results assuming measurement error is uncorrelated with both. Regarding the use of climatology-based data in economics, see, e.g., Carleton et al. (2022); Adhvaryu et al. (2024); Matranga (2024).

[10] Data in this format was provided by the European Space Agency (ESA) Pathfinders–OA project.

Data are disaggregated at the levels of fishing sector (industrial or small-scale), seafood group (defined by 11 commercial categories), and destination of use (direct human consumption or other uses). Quantities are reported in kilotons (kt), while landed values are computed using nominal ex-vessel prices in local currency and converted into 2010 US$ real equivalents. Using ex-vessel species-level prices, we build yearly median prices for each commercial group.

We include catches whose destination of use is direct human consumption and distinguish between two sectors of activities: the *industrial sector* is large-scale and commercial, and it includes catch from large motorised vessels that is overwhelmingly sold commercially; the *small-scale fishing sector* comprises artisanal and subsistence fishing and includes vessels that primarily supply local consumption.[11] The resulting dataset is a yearly time series at the seafood group–country level covering the full period under analysis (1972–2018). In our selected group of countries, both quantities and landed values have been steadily increasing for both small-scale and industrial fishing (Appendix B.4).

Second, for heterogeneity analyses, we supplement these data with more geographically granular data about exploitation intensity and type, but restricted to a shorter time period due to data availability. We consider a form of *extractive fishing* by focusing on industrial fishing. The Global Fishing Watch dataset provides us data on the hours industrial fishing vessels spend at specific geolocations. Because data are available only for 2012–2016, we build a global grid at the $1°\times1°$ resolution summing fishing hours within each cell over the available period.

In addition, we define *night-time fishing* using the Automatic Boat Identification System for VIIRS Low Light Imaging Data (Elvidge et al., 2015). This system provides the time and geolocation of boats using nightlight as measured from satellite imaging. Because only 16% of fishing detected with this algorithm is also captured by industrial fishing (Kroodsma et al., 2018), night-time fishing tends to capture boats operating on a smaller

[11]Catch from small-scale fisheries is notoriously under-reported in national statistics (Pauly and Zeller, 2016). The Sea Around Us explicitly accounts for this limitation, and it applies under-reporting adjustments to better reflect actual catches. Any measurement error related to under-reporting is not expected to correlate with local changes in ocean acidity.

and local scale, thus potentially contributing to the local economy. As with the measure of extractive fishing, we build a global grid at the $1° \times 1°$ resolution with the sum of all detected boats for the period in which data are available (2017–2019).

We normalise intensity from both activities to be between 0 (no presence) and 1 (high intensity). These measures aim to capture longer-run fishing patterns by averaging daily information over the full period in which data are available. However, if patterns of fishing were very different in the past, we would be capturing heterogeneity specific to exploitation in the period for which we have data availability. At least for extractive fishing, which tends to have low sensitivity to economic and environmental variation (Kroodsma et al., 2018), time-invariant heterogeneity is likely capturing suitability for industrial fishing. Appendix B.4 shows that fishing patterns are primarily driven by differences in geography, while individual characteristics are comparable in areas with high versus low intensities of both types of fishing. The intensity of night-time fishing is comparable in areas with varying intensities of extractive fishing. Dependency on fish for nutrition is also highly stable over time.

Economic activity. We complement the data with the average night-time light emission from the calibrated DMSP-OLS Night-time Lights Time Series 4. Night-time luminosity measured by satellite images is a widely used proxy for economic activity and human development (see, e.g., Bruederle and Hodler, 2018). Yearly data are available for the period of 1992–2012. We normalise luminosity by population in the grid cell using the PRIO-GRID database, performing the analysis using night-time luminosity in a gridded dataset at the $0.5° \times 0.5°$ resolution, selecting only grid cells in the coastal area of sampled countries.

3 Empirical strategy

To estimate the impact of ocean acidification, we exploit temporal and geographical variation in ocean pH to compare communities as they face varying degrees of ocean acidity near their locations. We match communities with ocean pH using the nearest data point in the ocean. This point is likely the fishing ground of small-scale fisheries based in or near the community. Available evidence highlights that 84% of all small-scale fisheries operate within 20 km from the shoreline (FAO, 2023).

We denote as $R_{c,mt}$ the ocean pH (multiplied by 100 to focus on changes of 0.01 units) matched to community or country c and measured at time mt, where m indicates the month and t the year. To match geographical and temporal variation in the unit of analysis with $R_{c,mt}$, we follow two approaches. First, contemporaneous exposure is computed by matching $R_{c,mt}$ either with the location and time of observation of the outcome variable. Second, early-life exposure is computed by matching $R_{c,mt}$ with an individual's location, month, and year of birth. As is standard in the literature, we assume that the survey location corresponds to the location of birth, also supported by the evidence suggesting the absence of selective migration in our setting (Section 4.2). When exposure is computed over multiple months, we average pH over that period. For instance, exposure *in utero* is the average $R_{c,mt}$ during the nine months preceding the date of birth.

Because pH is a logarithmic scale, we can interpret a decrease of 0.01 units as approximately a 1% increase in acidity. In our sample, 0.01 units correspond to the median within-year variation that a specific location experiences (i.e., the difference between the minimum and maximum pH in a specific year is on average 0.01), and to one-third of a standard deviation in *in-utero* exposure to pH.[12] To better understand the magnitude of the estimated effects, we also quantify the historical change in pH in the sampled area. The average reduction in pH from 1972 to 2018 was 0.075 units (0.016 units per decade). Therefore, the unit we analyse corresponds to the average reduction in pH experienced over approximately 6.25 years. Considering future projections of ocean acidity, the Intergovernmental Panel on Climate Change (IPCC, 2022a) predicts, under a business-as-usual emissions scenario, an average reduction of approximately 0.31 units of pH between 2018 and 2100 (0.037 units per decade). Under this scenario, a 0.01 decrease in pH would occur in just 2.67 years. See Section 5 for a detailed discussion of future projections.

[12]The standard deviation of pH is amplified by the large geographical area we cover. Conditional on FEs, a change of 0.01 in pH is roughly three standard deviations of residual variation (Appendix B.1).

For identification, we exploit short-run exogenous deviations in pH levels from the spatially specific long-run trend (correcting for seasonality if the unit of analysis varies within year). Deviations are computed by capturing unobserved heterogeneity in the estimating equation using a set of FEs, which allows the isolation of deviations from the raw variation in pH. These FEs capture the time-invariant characteristics of the location of birth or observation (*location effects*); the common characteristics at the time of birth or observation (*non-spatial time effects*); and the trends and seasonality components of the ocean pH and the outcome variable of interest that are specific to a geographical region (*spatially specific time effects*). The latter are particularly important for identification because ocean acidification is spatially heterogeneous, with some regions experiencing faster or slower acidification, and more amplified or compressed within-year variation than others. The nature of abnormal deviation in the pH of our main independent variable is reinforced by the evolution over time of the sample average short-run deviation (Appendix Figure B1). Exogeneity is supported by the balance of observable characteristics in areas affected by different deviations (Appendix B.6).

We adapt this approach based on the geographical and temporal variation of the unit of analysis. When analysing data about seafood catch, the unit of analysis is at the seafood group–country–year level. We therefore estimate the effect of ocean pH in the nearest area of the ocean using the following specification:

$$y_{ic,t} = \beta\, R_{c,t} + \mathbf{X}_{c,t}\gamma + \Omega_{c,t} + \epsilon_{ic,t} \tag{1}$$

where $y_{ic,t}$ is the catch in the seafood group i fished in the EEZ of country c in year t. Because the unit of analysis covers an area of ocean larger than the resolution at which pH is observed, to compute $R_{c,t}$, we average all data points within the EEZ of country c in a year t. We label this variable *pH in proximity to the coast*. The specification includes a vector of weather control variables, $\mathbf{X}_{c,t}$, and the set of FEs that defines the identifying variation in terms of deviations from long-run patterns, $\Omega_{c,t}$.[13] Location effects are captured by seafood group by country FEs; non-spatial effects by year of

[13]Controls include the average temperature and rainfall (and their interaction) of coastal areas, and the average oxygen concentration in the EEZ, another chemical feature of the ocean that is strongly correlated with ocean temperature (Free et al., 2019).

observation FEs; and spatially specific time effects by fishing area by year FEs. Fishing areas are geographical regions used for fisheries management and reporting, grouping multiple countries together (FAO, 2020). Finally, the idiosyncratic errors, $\epsilon_{vc,t}$, are assumed to be clustered at the EEZ level.

When analysing data about children and women, the unit of analysis is at the individual level. We estimate the effect of ocean pH in the nearest area of the ocean using the following specification:

$$y_{ic,mt} = \beta\, R_{c,mt} + \mathbf{X}_{ic,mt}\gamma + \Omega_{c,mt} + \epsilon_{ic,mt} \tag{2}$$

where $y_{ic,mt}$ is the outcome of interest for individual i at time mt in community c.

Because the geographical area of a community is smaller than the resolution at which pH is observed, $R_{c,mt}$ is the pH corresponding to time mt at the closest data point in the ocean, matched using the shortest straight-line distance. We label this variable as *pH in the nearest waters*. The specification includes a vector of demographic and weather control variables, $\mathbf{X}_{ic,mt}$, and the set of FEs that defines the identifying variation in terms of deviations from long-run patterns, $\Omega_{c,mt}$.[14] Non-spatial time effects are captured by controlling for (interview or birth) month by year FEs. Spatially specific time effects are captured by macro-region by (interview or birth) year FEs, capturing local trends and, when within-year variation is observed, by macro-region by (interview or birth) month FEs, capturing local seasonality. A macro-region is a geographical area including multiple communities. We consider alternative definitions, such as administrative units like the district or the country of the community, and grid cells of different resolutions.[15] Location effects depend instead on whether we are focusing on contemporaneous or early-life exposure. For contemporaneous impacts, we cannot

[14]When the outcome variable refers to children, *demographic controls* include the child's gender and birth order, the number of twins born with the child, mother's age at birth and at the time of the interview (including their square terms), mother's years of education, the household head's gender and age, and household size. When the outcome variable refers to adult women, these controls are limited to mother and household head characteristics. *Weather controls* are the same as in equation (1). In Section 4, we discuss the sensitivity to estimates of adding additional controls.

[15]Grids allay concerns about the potential endogeneity of administrative boundaries. To guarantee sufficient variation in the measurement of ocean pH, which varies at the $1°\times1°$ resolution, we consider grids at $5°\times5°$ and $10°\times10°$ resolutions.

exploit within-community variation because almost every individual in the community is interviewed in the same month. In this case, the *benchmark* specification includes location FEs, grouping multiple communities using grid cells. For early-life exposure, the *benchmark* specification includes community FEs, leveraging within-community temporal variation originating from birth dates. In this scenario, we can further exploit within-family variation by adding mother-specific FEs, controlling for mothers' time-invariant characteristics (*within-sibling* specification). Finally, the idiosyncratic errors, $\epsilon_{ic,t}$, are assumed to be clustered at the ocean raster data point (see Section 2).

We support the validity of the identifying assumptions in equations (1) and (2) with a variety of tests discussed in Section 4. In particular, we address issues related to non-random selection driven by FEs, which occurs from the loss of groups with only one observation and can lead estimates to differ from the population-wise average effect (Cameron et al., 2011). For example, the within-sibling identifying assumptions restrict the sample to mothers with at least two live births, who are generally older, have fewer years of education, were younger at the time of their first birth, and live in poorer households and communities (Appendix A.2). Threats from this form of selection are limited by our measure of shocks being not only continuous, but also exhibiting a high degree of variation (the within-community variance in the identifying sample used by the benchmark specification is always positive). Nevertheless, in all estimation tables, we report the number of observations used in the estimation (*identifying observations*), and the number of observations dropped due to the identifying restrictions (*singleton observations*).

4 Results

We apply the methodology presented in Section 3 to estimate the impact of ocean pH on child health. Section 4.1 begins by discussing the causal pathway between ocean acidity and child health, focusing on the impact of contemporaneous exposure on fishing and on human nutrition. Section 4.2 presents results on the effect of early-life exposure on child mortality and development, and on health investments. Section 4.3 analyses how these effects vary according to the prevalent method of marine resource exploitation near the community.

4.1 Defining the causal pathway of ocean acidity

We begin by looking at the impact of contemporaneous ocean pH on fisheries. Table 1 shows estimates of equation (1) of the impact of ocean pH in the EEZ on the quantity and value of seafood catch, on the median price of seafood, and on aggregate economic activity proxied by satellite-based night-time luminosity. Dependent variables are reported using an inverse hyperbolic sine transformation to account for zero values. Results are robust to alternative transformations (Appendix B.4).

We begin by focusing on small-scale fishing in columns (1)–(2). This activity primarily serves local consumption, and impacts the nutrition of coastal communities, as confirmed by a positive correlation between seafood catch derived from this activity and better nutritional indicators among women (Appendix B.4). We observe that a decrease of 0.01 in pH leads to a significant decline of 0.13 log-points in the quantity caught and 0.20 log-points in the landed value. These results highlight that, at least for species harvested by small-scale fisheries, ocean acidification has a net negative effect (see Section 1). Effects are larger for seafood with a lower price, whose primary nutrient is essential fatty acids, and with a lower resilience to ocean acidification, but not statistically different (Appendix B.4).

In columns (3)–(4), we focus instead on industrial fishing. Neither the quantity of seafood caught nor its value is influenced by ocean pH in the EEZ. These results highlight the resilience of industrial fishing to the shock and is consistent with evidence showing this sector's ability to absorb shocks by diversifying catch or relocating fishing activities outside EEZs (see, e.g., Anderson et al., 2017), a possibility that is more limited for small-scale fishing.

Column (5) provides estimates on the effect on the overall median price of seafood. We observe that a decrease of 0.01 in pH leads to a significant increase of 0.09 log-points in the media price of seafood. Overall, these results suggest that the effects on small-scale fishing are enough to influence the median price of seafood, thus potentially influencing consumption choices.

Because fishing is an important economic activity in coastal areas, we want to exclude any income changes that occur alongside price changes. In column (6), we test whether ocean pH induces a short-term deterioration in the overall economic activity of coastal areas. We look at the effect of ocean pH on the average satellite-based night-time luminosity in the coastal area of each selected country. For this analysis, and for comparison with estimates in columns (1)–(5), we average night-time luminosity according to the definition of the coastal area of a country (see Section 2) and estimate equation (1) at the country level.

We find no effect on night-time luminosity. While we cannot exclude the possibility that ocean acidification may eventually influence the overall economic activity, these results suggest that the consequences of short-run variations in ocean pH do not operate through an aggregate income channel. One possibility is that the effects on fishing, which are specific to small-scale fisheries, are too small to influence the whole economy or are specific to regions where night-time luminosity is not very responsive to changes in economic activity, such as poorer areas. Another alternative is that night-time luminosity responds to these shocks only over the long term.

Appendix B.7 shows that these results are not specific to coastal areas. We show that a drought in the coastal area, a shock to agricultural productivity known to generate income changes (see, e.g., Barrios et al., 2010), leads to significant reductions in night-time luminosity. In addition, the lack of changes in labour supply induced by ocean acidity further suggests the absence of short-term impacts on the aggregate economic activity.

In the absence of income changes, the effects on seafood prices should reflect on consumption choices. We examine whether ocean acidity induces responses in nutrition by estimating the contemporaneous effect on women's fish consumption. With a limited number of surveys and respondents, the DHS programme asked whether a mother consumed different kinds of food in the 24 hours prior to the interview. Columns (1)–(2) in

Table 2 show that a decrease in ocean pH lowers the probability of seafood consumption by 2.6 percentage points (or 8.8% over the sample mean of 29.6%). This reduction is specific to the consumption of seafood, as we observe no significant effect on the probability of consuming other food items (Appendix B.8). These results suggest that adults do not compensate by adapting their diets.[16]

Columns (3)–(5) in Table 2 focus instead on malnutrition among women. For women who are not pregnant, we measure malnutrition using an indicator variable for whether the respondent is underweight, defined as having a body mass index (BMI) below 18.5. We supplement this measure with micronutrient deficiency, a direct measure of malnutrition for all women and for pregnant women. We proxy deficiency using objective measurements of anæmia, performed by the DHS enumerators on a random subset of women in the sample. Anæmia is characterised by low levels of hæmoglobin, a protein in red blood cells that carry oxygen in the blood, and is often caused by iron deficiency.

In line with the evidence discussed in Section 1, the results indicate a pattern in which ocean acidification leads to changes in fish harvesting that impacts nutrition. A 0.01 decrease in ocean pH in nearby waters increases the probability of nearby women being underweight by 0.4 percentage points (or 3.3% over the sample mean of 12.0%). In addition, it leads to a higher prevalence of anæmia, but only among pregnant women. The existence of an effect specific to this vulnerable population is unsurprising because, during pregnancy, the human body requires more iron to supply the growing fetus, and with limited nutritional alternatives, seafood is an important source of iron (Luke, 1991; FAO, 2023). A 0.01 decrease in pH at the time of the measurement leads to an increase in anæmia prevalence of 1.7 percentage points among pregnant women (or 3.7% over the sample mean of 45.4%).

[16]The DHS provides only information on whether the respondent consumed a food item, but not the quantity consumed. We cannot exclude the possibility that respondents adapt their diets by increasing/decreasing the quantities consumed.

4.2 The effect of early-life exposure

This section focuses on the effect of being exposed early in life to varying degrees of ocean acidity in nearby waters. We analyse relevant effects on mortality, parental adaptation, and child development.

Mortality. To investigate the effect on early-life mortality and to isolate a channel operating through maternal malnutrition, we begin by studying *in-utero* exposure to varying degrees of ocean acidity in the waters nearest to people's places of birth.[17] We estimate impacts on the likelihood of mortality at age x (in months). For each age x ranging from 1 month to 60 months, we estimate equation (2), restricting the sample to children who, at the time of the interview, were born at least x months before (independently from being alive). We select the sample based on time from birth to avoid selecting children who are alive and younger than x.[18] The dependent variables are indicator variables equal to 1 if the child has died by age x from birth, and 0 otherwise (multiplied by 1,000 to relate coefficients to changes in deaths per 1,000 live births).

Figure 2 plots the coefficients. We observe that experiencing higher degrees of ocean acidity while *in utero* has a substantial impact on mortality. The effect peaks in the first month of life (corresponding to neonatal mortality), and remains significant across the very first months of life. A smaller net effect is observed beyond the first months of life, while the effect is not statistically different from zero after the first year of life. Because the initial increase in mortality is offset by later decreases, the pattern is consistent with a displacement of mortality hastened by experiencing worse conditions *in utero*—a mechanism known in the literature as *death harvesting* (see, e.g., Heutel et al., 2021).

Given the results on mortality, we focus on neonatal mortality. Table 3 presents estimates of the effect on the neonatal mortality rate (NMR)—the number of deaths in

[17] We approximate the actual gestation period assuming a gestation period of nine months. Estimates assuming a gestation period of eight months, which can be interpreted as a lower bound of the effect, remain negative and statistically significant in most specifications (Appendix B.9).

[18] The heaping of deaths at 1 year of age is common, while mortality at ages 2, 3, 4 and 5 is hardly affected by heaping (Croft et al., 2018). We observe no effect on the estimates due to these potential issues. Appendix B.10 presents estimates of the effect on mortality rates at standard times.

the first month of life per 1,000 live births. Panel A uses the benchmark specification, while Panel B uses the within-sibling specification. Columns (1)–(3) remove seasonality at the country level, while columns (4)–(6) remove seasonality at the grid cell level. Columns (1) and (4) do not include any control variables, columns (2) and (5) add weather controls, and columns (3) and (6) further add demographic controls. Figure 3 shows estimates using alternative specifications, including alternative sets of control variables, different time FEs, and different definitions of macro-regions.

A 0.01 decrease in pH significantly increases NMR by 1.42–2.12 deaths per 1,000 live births in our benchmark specification (panel A). Estimates using the within-sibling specification are similar (panel B). In terms of standardised effects (conditional on FEs), a one-standard-deviation negative shock leads to an increase in NMR of 0.53–0.56 deaths per 1,000 live births in the benchmark specification and 0.53–0.67 deaths per 1,000 live births in the within-sibling specification (Appendix Table B1).[19] Adding control variables has a limited impact on the estimates of the effect, providing further evidence in support of the exogeneity of short-run deviations in pH. Significant effects are also found when varying the definition of coastal area, with the most affected communities living within 40 km from the shore (Appendix B.2).

Estimates in Table 3 are robust to a wide variety of checks. First, while changing the set of FEs alters our identifying assumptions and our definition of deviation, estimates are always negative and significantly different from zero at standard confidence levels (Figure 3). Second, in Appendices B.1, B.2, and B.7, we show that estimates are robust to adding controls for (potentially endogenous) confounders in both the location of birth and the location where pH is measured, such as adverse weather events (see, e.g., Gröger and Zylberberg, 2016), the presence of human activity proxied by pollution in coastal water, and the presence of conflict (see, e.g., Axbard, 2016), or to excluding areas that are generally subjected to vast anthropogenic waste, such as estuaries (see, e.g., Kennish, 2017). Third, selective migration does not drive estimates, as restricting our

[19] The magnitude of these point estimates is smaller compared to interventions providing medical services to pregnant women. Nyqvist et al. (2019) show that introducing community health promoters in Uganda reduced neonatal mortality by 28%. Lazuka (2023) shows instead that introducing maternity wards in Sweden reduced neonatal mortality by 56%. Note, however, that the historical reduction in pH in the study period is seven times larger than the deviation in pH described by the estimate.

sample using information on whether the mother was living in the same location of the interview before the gestation period does not affect our conclusions (Appendix B.5). Fourth, results are not driven by selection into identification and are robust to potential sources of measurement error associated with distances from the shore (Appendix B.6). Finally, statistical inference is robust to alternative clustering assumptions about standard errors in equation (2) and to permutation-based inference, which artificially varies the exposure to the shock in both time and space (Appendix B.11). The latter allows a rejection of the null hypothesis of a nil effect at the 5% significance level for all estimates in Table 3.

Figure 4 presents a heterogeneity analysis of the effect on neonatal mortality, distinguishing by exposure type. We highlight two main features. First, evidence suggests that the effect is driven by exposure during gestation to lower levels of pH. Panel A presents a binned analysis, rather than a continuous one, and shows estimates of equation (2) replacing ocean pH while *in utero* with the share of time that children were exposed to values of the ocean pH within a specific range during gestation. The effect is significantly different from zero only for negative deviations, indicating that accelerated acidification has a stronger negative impact than the potential positive effect of slowed acidification. Panel B shows the estimates of equation (2) by adding ocean pH in the nearest waters one month before conception (10 months before birth), the month of birth, and 1–4 months after birth (a placebo period posterior to the period considered for the death). Effects are specific to the gestation period, reinforcing the role of maternal malnutrition. Further, we find no evidence of short-term responses in fertility or in the probability of a mother experiencing a terminated pregnancy (Appendix B.3).

Second, impacts are concentrated in communities relying more heavily on the ocean's resources. Panel C of Figure 4 shows estimates of the effect on NMR, allowing estimates to vary flexibly with distance from the ocean's shore, and from other water bodies, like lakes and rivers. The largest effect is observed at the shore, while the estimate is not statistically different from zero at higher distances. On the contrary, the effect is homogeneous with respect to distance from other water bodies. In line with these results, effects are larger where seafood represents a higher share of total animal proteins consumed, in countries with a positive trade balance for fish products, and where small-scale fisheries are central, such as in proximity to reefs (Appendix B.4).[20]

Adaptation in health investments. Section 4.1 highlighted limited adaptation to ocean acidity in terms of dietary choices. In Table 4, we examine whether a mother alters health investments (before and after a child's birth) in response to experiencing varying degrees of ocean acidity during gestation. Columns (1)–(2) examine birth-level information regarding investments in antenatal care (attendance to health visits during pregnancy and the presence of health professionals during these visits) and care at the time of delivery (presence of health professionals during delivery and whether delivery was performed in a health centre). Both variables range from 0 (no) to 2 (high investment). Columns (3)–(5) focus on investments after the birth: postnatal healthcare, the completion of the cycle of basic vaccinations, and whether the child has ever been breastfed.[21] Estimates are based on equation (2).

For both antenatal and delivery investments, we do not observe any significant effect. In line with these results, the effect on neonatal mortality is homogeneous in the birth order and sex of the child—two predictors of differential parental investments (Baird et al., 2011)—and across a wide array of individual characteristics (Appendix B.12). Given that antenatal care is closely linked with nutrient supplementation plans during pregnancy, we also exclude this pathway. The lack of observable effects on postnatal care suggests limited adjustments in response to their child's health. We observe no effect on morbidity and anæmia prevalence among children at the time of the measurement (Appendix B.12), suggesting no dietary changes among living children, and no evidence of adaptation through post-delivery migration (Appendix B.5).

Appendix B.12 provides further evidence suggesting the absence of adaptation. First, the effects on health investments are homogeneous with respect to the ability to purchase more nutritious food, as measured by household's wealth, and the marital status

[20] In Appendix B.4, we show that *in-utero* exposure to higher seafood prices in the local market significantly contributes to the probability of neonatal death. Due to data limitations, we limit the analysis to the sample of the Philippines, one of the most fish-dependent countries globally.

[21] Because information on parental investments is not recorded for all children, but only for a subset within the household (generally the youngest child), we cannot estimate the effect on adaptation using the within-sibling specification.

and education of the mother. Second, following Dell et al. (2014), we estimate equation (2) by interacting the ocean pH in the nearest waters while *in utero* with the 1972–1975 average pH in the same location. The larger effect on NMR in areas historically exposed to more acidic waters suggests an absence of long-run adaptation, despite the extended time these regions have had to adjust to acidification.

Child development. Table 5 shows the effects of *in-utero* exposure to varying degrees of ocean acidity on early-life physical development, as assessed through anthropometric measurements—an important form of human capital accumulation. Columns (1)–(2) focus on the effects on weight-for-height (w/h), which captures insufficient food intake or high incidence of infectious diseases in temporal proximity to the measurement, and on height-for-age (h/a), which captures the past or cumulative effects of under-nutrition and infectious diseases since conception. Estimates in columns (3)–(4) focus instead on indicator variables for abnormally low values of w/h (*wasting*) and of h/a (*stunting*). All measures rely on objective measurements performed by the DHS enumerators on a random subset of children alive at the time of the interview, and they therefore need to be interpreted in light of the results on mortality. Panel A estimates the overall effects using equation (2), while panel B looks at heterogeneity by sex, introducing in equation (2) an interaction term between the ocean pH and an indicator variable for whether the child is female.[22]

Among all children (panel A), we do not highlight any significant effect on w/h, h/a, or the prevalence of stunting, but we do observe a significant effect on the prevalence of wasting. A 0.01 decrease in pH in nearby waters reduces the probability of being wasted by 0.6 percentage points, or 7.5% over the sample mean of 8%. This effect is also captured by examining the probability of being underweight in the first months of life, which potentially indicates differences in birth weight (Appendix B.12). While only the effect on wasting is statistically significant, the coefficients in panel A suggest that mortality selection prevails over a scarring effect, as living children who experienced higher degrees of water acidity tend to have better, rather than worse, indicators.[23]

[22] Appendix B.13 provides estimates of equation (2) splitting the sample into male and female children and shows results trimming z-scores at the 1st and 99th percentiles.

[23] Refer to Deaton (2007) for a discussion on adult height and childhood mortality in poorer countries.

Although the effect on neonatal mortality is not heterogeneous by sex, when looking at heterogeneity by sex in the effect on child development (panel B), we highlight that the effects in panel A are driven primarily by male children. Among female children, results suggest the prevalence of a scarring effect (i.e., living children who experienced higher degrees of water acidity tend to have worse as compared to those that experienced lower degrees), concentrated in measures associated with height. Among boys, a 0.01 decrease in pH increases h/a by 0.03 standard deviations and the probability of being stunted by 1.1 percentage points (with a p-value of 0.15). Among girls, these outcomes are statistically different from those of boys. A 0.01 decrease in pH decreases h/a by 0.06 standard deviations and increases the probability of being stunted by 2.3 percentage points, as compared to boys. The effect on stunting is not only statistically different between male and female children, but it is significantly negative for girls (Appendix B.13).

To understand whether these effects persist into adulthood, in Appendix B.13 we examine these indicators for adult women, building their *in-utero* exposure to ocean pH in nearby waters by exploiting their month and year of birth, and the location of the interview. Because the temporal distance between exposure and the date of measurements is much larger than that of Table 5, these estimates implicitly assume no migration. While female migration in poorer settings is expected to occur within limited geographical distances (see, e.g., Rosenzweig and Stark, 1989; Mbaye and Wagner, 2017; Corno et al., 2020), we cannot exclude this possibility.

The results suggest that the scarring effect on girls is persistent in the long run. A 0.01 decrease in pH significantly decreases h/a by 0.1 standard deviations and increases the probability of being stunted by 0.7 percentage points. Adaptation at later ages could also play a role as the magnitude of the effect is smaller among adults than children. We also consider the impacts on women's economic well-being. A 0.01 decrease in pH significantly decreases adulthood wealth by 0.5% relative to the sample mean. This impact is accompanied by statistically significant decreases in the number of births per woman and the probability of working of 0.01 children and 1.4 percentage points, respectively. We do not observe any effect on schooling and cognitive skills.

4.3 Heterogeneity by resource exploitation

Due to the centrality of ocean exploitation for nutrition in coastal areas, we turn our attention to the heterogeneity of the effects discussed in Section 4.2 with respect to the type and intensity of fishing activities (see Section 2 for definitions and limitations related to this measure). For comparability, we quantify the effect of a one-standard-deviation decrease in nearby waters' pH that is experienced while *in utero* (labelled as an *acidity shock*), and we report estimates in terms of a percentage change with respect to the sample mean. Figure 5 plots the estimated effects at different intensities of night-time fishing (panel A), capturing the activity of boats operating on a smaller and more local scale, and of extractive fishing (panel B), which captures the activity of industrial fleets. In terms of outcomes, we consider impacts on NMR and an index of physical development among children, built by averaging available z-scores for w/h and h/a to capture multiple anthropometric insufficiencies. By averaging z-scores, our approach is similar to the multiple-inference approach of Anderson (2008), using as a control group the reference population used by DHS to compute z-scores.

Extractive fishing significantly reduces the ability to counteract shocks, amplifying their impacts. The effects on both NMR and physical development are homogeneous along the intensity of night-time fishing. Conversely, we observe heterogeneous effects by intensity of extractive fishing. Areas characterised by high intensity present a significantly larger effect on NMR compared to areas without extractive fishing. An acidity shock leads to a 1.4% increase in NMR in areas where extractive fishing is absent and a 5.0% increase in areas where extractive fishing is largest. The mortality selection induced by these effects is captured in the heterogeneity of the impact on physical development. An acidity shock leads to an improvement in physical development by 0.7% in areas where extractive fishing is absent and by 4.3% in areas where extractive fishing is largest. Formal tests of heterogeneous impacts confirm these results (Appendix Table B11). Appendix B.13 shows a similar analysis for outcomes among adults by focusing on economic well-being and on the physical development index among adult women, highlighting a similar pattern for the persistence of the effects presented in Figure 5.

5 Projections on the effect of ocean acidification

The results in Section 4 have highlighted the magnitude and the mechanisms through which ocean acidification impacts coastal areas in L&MICs, highlighting the important role of neonatal mortality. We use these estimates to compute the aggregate number of neonatal deaths attributable to ocean acidification from 1975 to 2100. For this exercise, we focus on the coastal area of the sample of L&MICs used in the paper. Appendix C details this procedure, including further descriptive statistics.

To develop these projections, we decompose the time series of NMR for a country into two additive components: a counterfactual measure of NMR in the absence of ocean acidification (NMR^{CF}), reflecting broader trends such as economic development, and a component attributable to ocean acidification (NMR^{OA}), which is driven by variation in ocean acidity near human settlements. We compute NMR^{CF} estimating equation (2) in our sample of births, predicting NMR holding ocean acidity at its 1975 levels, and averaging this predicted value at the country–year level. This step allows us to obtain the series for the period 1975–2018, from which we extrapolate values until 2100 fitting an exponential decay curve. We then compute NMR^{OA} combining the estimated effect of experiencing varying degrees of ocean acidity in nearby waters while *in utero* on NMR (discussed in Section 4) with the 1975–2100 series for ocean pH obtained from the IPCC's Sixth Assessment Report (IPCC, 2022a). We consider two emission trajectories: a low-emissions scenario targeting global warming limits of around 1.5°C–2°C by 2100 through strong mitigation efforts (RCP2.6) and a worst-case high-emissions scenario leading to increases in temperatures by 4°C–5°C or more by the end of the century (RCP8.5).

Computing NMR^{CF} and NMR^{OA} under these emission scenarios and population growth projections for coastal areas, we obtain the cumulative number of neonatal deaths attributable to ocean acidification under different assumptions concerning adaptation to ocean acidification. First, we consider *no adaptation*, assuming that the effect of ocean acidification on NMR is constant over time and equal to the value reported in column (3) of Table 3. This assumption, combined with the high-emissions scenario, can be considered the worst-case hypothesis. Second, we consider alternative types of adaptation. We introduce the possibility of internal migration, assuming that the coastal population decreases linearly by 20% between 2024 and 2100 (*migration away from coast—low*) or by 50% (*migration away from coast—high*).[24] We also consider alternative forms of adaptation, such as changing diets or increasing health investments, assuming the effect on NMR decreases over time. Because there is limited evidence on the rate and the functional form of adaptation (see, e.g., Moore and Diaz, 2015), we assume that the effect diminishes linearly over time, halving in 2100 (*decreasing effect—slow*), or reaching a nil effect in 2100 (*decreasing effect—fast*). Finally, we consider *optimistic adaptation* by combining the assumptions in *migration away from coast—high* and *migration away from coast—low*. We report the evolution over time of the cumulative number of deaths attributable to ocean acidification in Figure 6. Appendix C provides estimates, confidence intervals, and the evolution of NMR^{CF} and NMR^{OA} for each case.

The total number of births in our study area from 1975 to 2100 is estimated at 3.28–3.29 billion. In the same period, we estimate that counterfactual neonatal deaths account for 31.1 million, corresponding to an average NMR over the whole period of 9.45–9.48. Absent any form of adaptation, the cumulative number of neonatal deaths from ocean acidification could reach 77.2 million by 2100 under the high-emissions scenario, as compared to 38.0 million under the low-emissions scenario. Uncertainty about the effect of ocean acidity on NMR generates wide confidence intervals for these estimates. Using the 90% confidence interval for the effect of ocean acidification on NMR is 20.5–133.8 million under the high-emissions scenario, and 10.1–65.8 million under the low-emissions scenario.

Introducing migration away from coastal areas as a form of adaptation has limited effects. Under the low-emissions scenario, the cumulative number of deaths decreases to 34.5 million if migration is relatively small, and to 30.0 million if a larger share migrates. Introducing adaptation measures that reduce the effect of ocean acidifica-

[24]For some countries, like the Philippines, this assumption is not relevant because the whole or most of the country is considered coastal area.

tion over time is more effective, with the cumulative number of deaths reducing to 14.6–26.3 million in the low-emissions scenario. Under optimistic adaptation, the number is further reduced to 12.9 million under the low-emissions scenario, as compared to 18.1 under the high emission scenario. These statistics correspond to an average NMR attributable to ocean acidification for the period 1975–2100 ranging from 11.58 (low-emissions) to 23.47 (high-emissions) when assuming no adaptation, and from 3.92 (low-emissions) to 5.51 (high-emissions) when assuming optimistic adaptation.

Overall, these projections highlight the importance of considering adaptation measures in conjunction with reduced emissions when analysing deaths induced by climate change. Reducing emissions leads to a reduction in cumulative deaths from ocean acidification by 50.8% in the case of no adaptation, but in presence of optimistic adaptation the returns from reduced emissions are lower, at 29.1%. Because we observe limited adaptation to ocean acidification (Section 4), these results highlight the importance of reducing emissions to minimise neonatal deaths in the future.

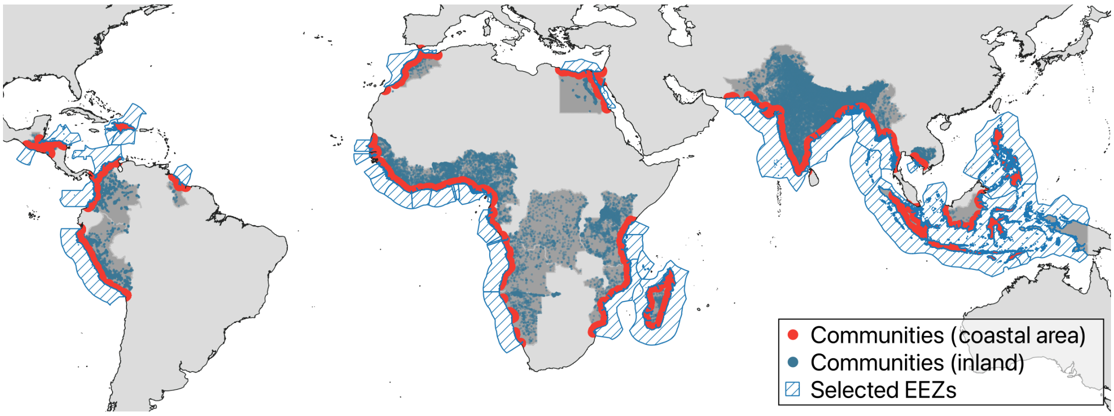
6 Conclusions

Small changes in the ocean's chemical composition can have significant impacts on coastal communities. Our research demonstrates that increased ocean acidity negatively affects local fishing, in turn compromising nutritional quality in these areas. Deteriorating conditions in people's early lives raise neonatal mortality rates and influences mortality selection. Accordingly, in the absence of emissions-reduction strategies, the IPCC (2022a) predicts further significant increases in ocean water acidity by 2100. We should be cautious about the substantial mortality effects of ocean acidification, even with improvements in mitigation efforts due to economic development.

Our findings highlight the need for future research in two key areas. First, studies on climate change impacts should probe various alternative channels that have not yet been thoroughly investigated, through which climate-related shifts influence human and economic development. For instance, evidence concerning the ocean's role in these dynamics remains limited. While our research focuses on water acidity and its effects on marine life, this represents only one dimension of how a changing ocean could impact communities, especially those heavily reliant on marine resources. Gaining a deeper understanding of these mechanisms would enhance the design and targeting of policies to support vulnerable communities as they cope with climatic risks.

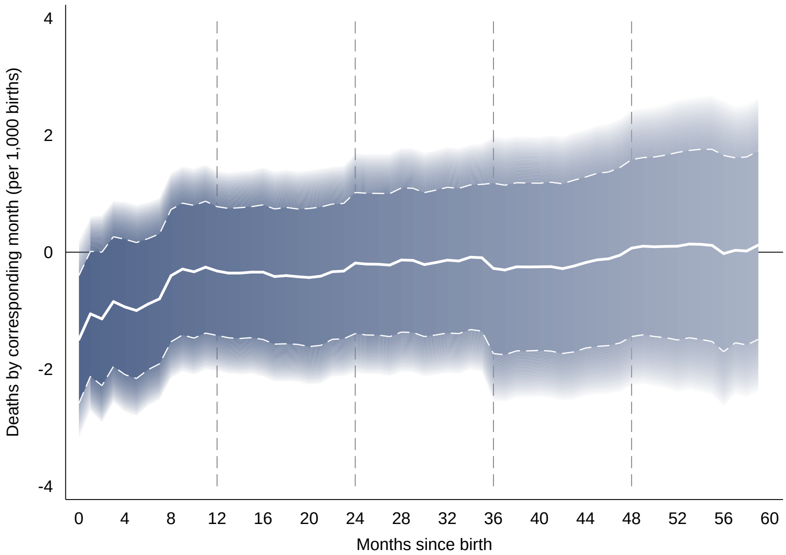
Second, by illustrating that wildlife serves as a crucial buffer against negative shocks, we emphasise the importance of research not only on policies promoting wildlife conservation, but also on strategies to mitigate the effects of reduced biodiversity. For instance, prioritising regulations in the industrial fishing sector and establishing exclusive artisanal fishing zones can be vital. While recent studies have highlighted the potential for effective policies (Frank and Oremus, 2023; Oremus et al., 2023), challenges remain, especially in countries with weak governance of natural resources. In the absence of effective conservation incentives, further research is necessary to allocate resources efficiently to communities in need of mitigation support. Our results suggest a rationale for investing in targeted nutritional interventions early in life to address the reduced nutrient availability caused by negative shocks to natural resources. Such interventions have proven effective in mitigating both the short- and long-term consequences of malnutrition (see, e.g., Gertler et al., 2014). In addition, in light of the centrality of parental investments for early childhood development (Attanasio et al., 2020), our findings underscore the importance of awareness and education in influencing parental decisions regarding nutrition in low-income settings.

Figure 1: Area covered by the study



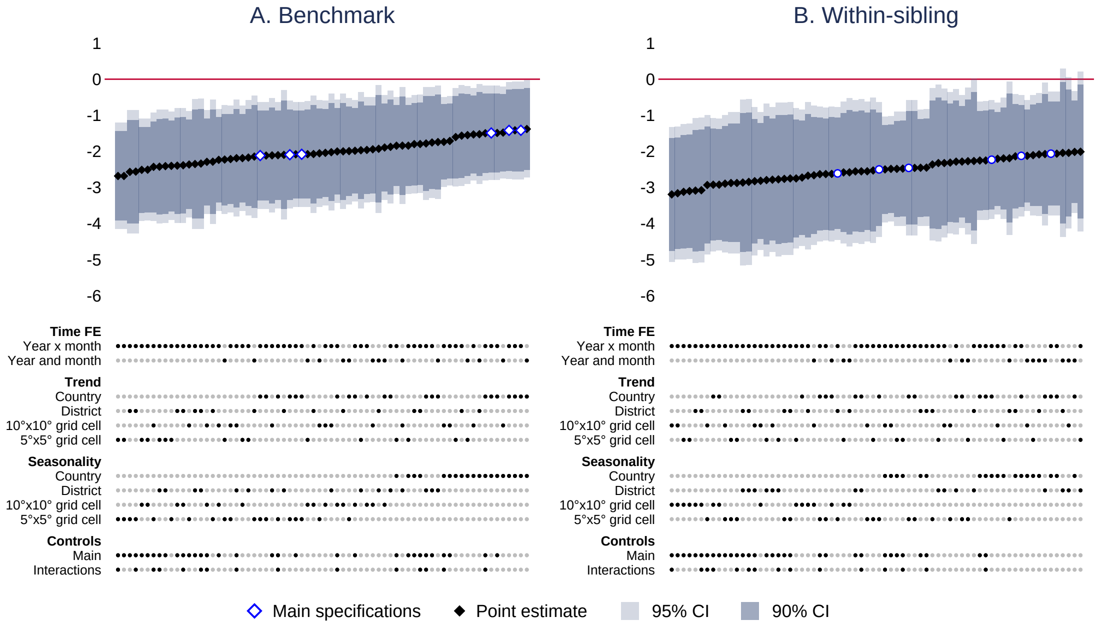
Note. Geographical distribution of DHS communities. The darker shaded area represents all countries surveyed by the DHS with access to the ocean (the full list is reported in Appendix A.1). *Communities (coastal area)* are villages and neighbourhoods within 100 km from the ocean's shore. Most estimates in the paper include only these observations. *Communities (inland)* are villages and neighborhoods further than 100 km from the ocean's shore. Appendix A.2 details the procedure followed to compute the distance from the shore. *Selected EEZs* refer to the Exclusive Economic Zones of all ocean-access countries included in the DHS survey (see Section 2 for the definition). In line with Pauly et al. (2020), we apply current EEZ boundaries (as depicted in the figure) to the whole study period to maintain consistency across years.

Figure 2: Early-life exposure and mortality



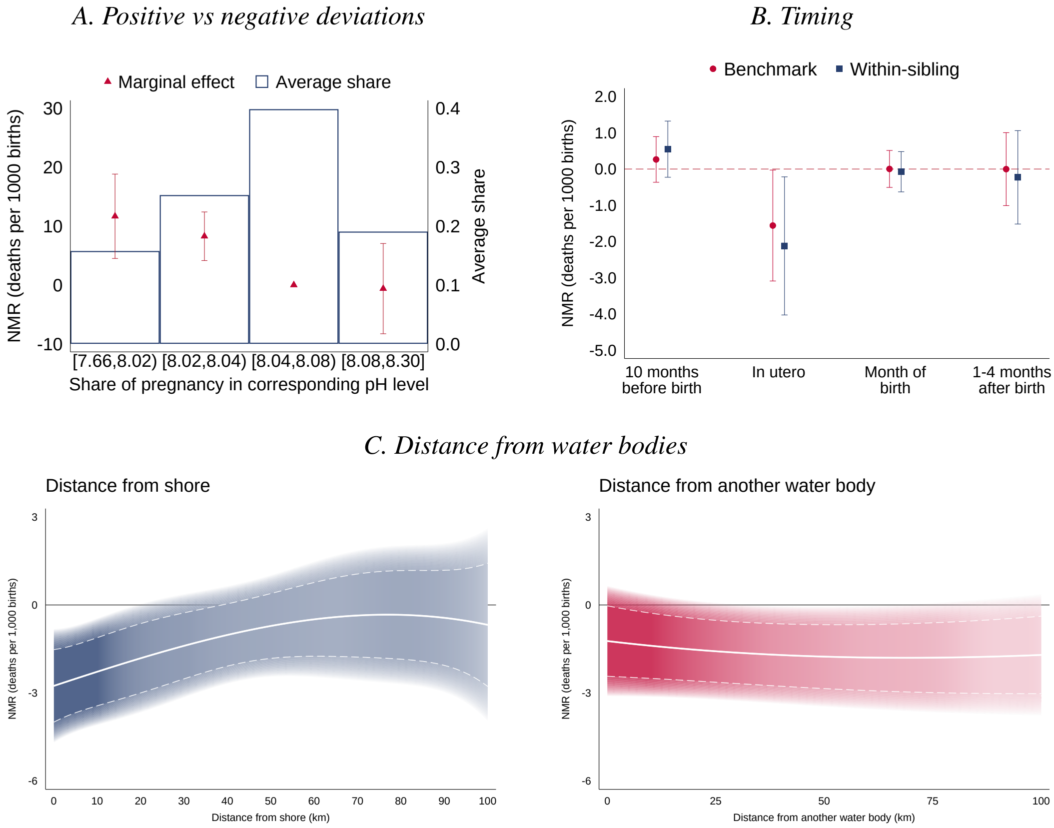
Note. Marginal effect of *in-utero* exposure to ocean pH in the nearest waters on the probability of death at month x (indicated on the horizontal axis). The dependent variable is an indicator variable equal to one if the child is dead at month x from birth, and zero if the child is alive, multiplied by 1,000. Estimates are based on equation (2), including community FEs, birth month by birth year FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). The sample is restricted to communities in the coastal area (see Section 2). Standard errors are clustered at the ocean raster data point. The 90% confidence interval is indicated by dotted lines, beyond which the intervals are progressively shaded up to the 99% level. Within confidence bounds, color intensity reflects the relative density of observations across iterations. It is calculated by comparing the density in each iteration to a range between the lower bound (adjusted by 0.7) and the 99$^{\text{th}}$ percentile of densities across all iterations. These parameters were chosen to improve visibility. Appendix A.1 provides further information on the variables and the list of surveys included in the study.

Figure 3: Early-life exposure and neonatal mortality – alternative specifications



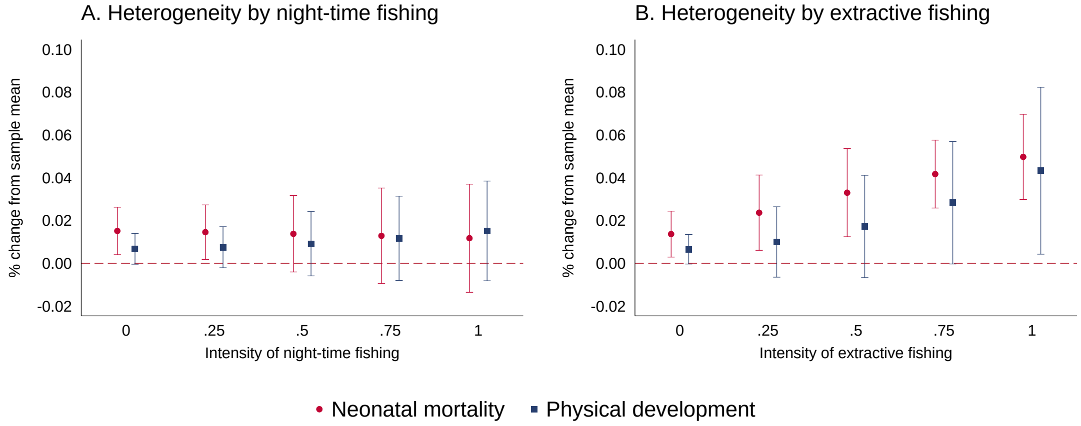
Note. Marginal effect of *in-utero* exposure to ocean pH in the nearest waters on NMR under alternative sets of FEs in the benchmark specification (panel A), and in the within-sibling specification (panel B). The dependent variable is an indicator variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *pH in the nearest waters (in utero)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the child's community during the 9 months before birth. Marginal effects are estimated using equation (2) with the set of controls reported in the bottom panel. *Main controls* are the weather and demographic controls (see Section 3). *Interactions* are interaction terms between the birth month and indicator variables for different oceans. *Main specifications* highlight the estimates presented in Table 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors are clustered at the ocean raster data point. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Figure 4: Early-life exposure and neonatal mortality – heterogeneity



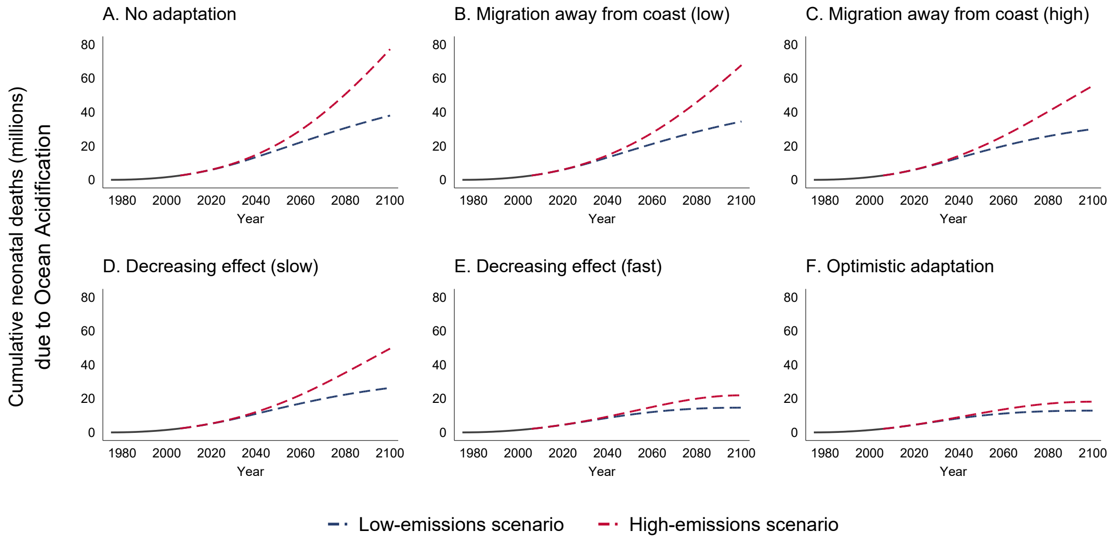
Note. Marginal effects of *in-utero* exposure to ocean pH in the nearest waters on NMR, by type of pH deviation (panel A), timing of exposure (panel B), and distance from water bodies (panel C). In panel A, estimates are based on equation (2) where $R_{c,t}$ is substituted by the share of time children were exposed *in utero* to different levels of ocean pH. We classify values in four bins using the historical minimum and maximum in the sample. For each bin, the right vertical axis presents the sample average (the third bin includes the historical median and mean of pH in sampled areas). In panel B, estimates are based on equation (2), in which the *pH in the nearest waters* at different points in time is the pH (multiplied by a factor of 100) in the ocean grid cell closest to the individual's community in the corresponding period relative to birth; when the period refers to multiple months, the value is averaged. In panel C, estimates are based on equation (2) introducing interactions between $R_{c,t}$ and a cubic polynomial in distance. In all panels, estimates are based on the benchmark specification (see Section 3), and the dependent variable is *NMR*, an indicator 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 sample is restricted to communities in the coastal area (see Section 2). In panels A and B, confidence intervals are computed at 90% level. In panel C, the 90% confidence interval is indicated by dotted lines, beyond which the intervals are progressively shaded up to the 99% level. Within confidence bounds, color intensity shows the relative density of observations by distance from shore. It is calculated by comparing the square root of the density at each point to the square root of the 90$^{\text{th}}$ percentile of the overall density. These parameters were chosen to improve visibility. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Figure 5: Ocean acidity and resource exploitation



Note. Estimated impacts (and 90% confidence intervals) of a one-standard-deviation increase in water acidity (experienced *in utero*) on neonatal mortality and on physical development as a function of intensity of fishing (0 = no presence / 1 = high intensity). Panel A (B) focuses on night-time (extractive) fishing (see Section 2 for the definitions). Estimates are based on equation (2) introducing interaction terms between pH in the nearest waters (*in utero*) and a quadratic polynomial in the corresponding intensity. *Neonatal mortality* is an indicator variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *Physical development* is the average *z*-score of available anthropometric measures. *pH in the nearest waters (in utero)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the individual's community during the 9 months before birth. The sample is restricted to communities in the coastal area (see Section 2). Standard errors are clustered at the ocean raster data point. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures. We exclude surveys for Peru as information for the intensity of night-time fishing is not available.

Figure 6: Neonatal deaths attributable to ocean acidification, 1975–2100



Note. Cumulative number (in millions) of neonatal deaths attributable to ocean acidification from 1975 to 2100, by year. The *low-emissions scenario* is the RCP2.6 scenario, targeting global warming limits of around 1.5°C–2°C by 2100 through strong mitigation efforts. The *high-emissions scenario* is the RCP8.5 scenario, a worst-case high-emissions scenario with rising emissions potentially increasing temperatures by 4°C–5°C or more by the end of the century. Scenarios are obtained from IPCC (2022a). Each panel makes alternative assumptions concerning adaptation, detailed in Section 5, ranging from lowest (panel A) to highest (panel F). Appendix C details the methodology followed to compute these estimates. Appendix Table C1 reports the values in the year 2100, including the confidence intervals accounting for uncertainty in the estimate of the effect of ocean acidity experienced while *in utero* on neonatal mortality.

Table 1: Ocean acidity and marine catches

Dependent variables:	Marine catch for human consumption					Economic activity
	Small-scale fishing		Industrial fishing		Median	Night-time
	Quantity	Value	Quantity	Value	price	luminosity
	(1)	(2)	(3)	(4)	(5)	(6)
pH in proximity to the coast	0.131	0.199	0.019	0.033	-0.090	0.004
	(0.068)	(0.081)	(0.088)	(0.099)	(0.043)	(0.045)
	[0.061]	[0.019]	[0.826]	[0.741]	[0.045]	[0.934]
Mean (dep.var.)	1.50	1.51	1.00	1.00	1.00	2.27
Identifying observations	19,129	19,129	19,129	19,129	13,561	777
Singleton observations	0	0	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1992–2012

Note. Estimates are based on equation (1). Dependent variables in column headers are transformed using an inverse hyperbolic sine transformation to account for zero values (Appendix B.4 reports results using alternative transformations). In columns (1)–(5), each observation is the catch or landed value or the median price for a specific seafood group in the corresponding Exclusive Economic Zone (EEZ; see, Section 2 for a definition). In column (5), each observation is a country's yearly average night-time luminosity in its coastal area (see Section 2). *pH in proximity to the coast* is the yearly average pH in the corresponding EEZ (multiplied by a factor of 100). Specifications in columns (1)–(4) include country by seafood group FEs, and fishing area by year FEs. The specification in column (5) includes country FEs, and fishing area by year FEs. All specifications include weather controls (see Section 3). Standard errors clustered at the EEZ level are reported in parentheses, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table 2: Ocean acidity and nutrition among women

Dependent variable:	Nutrition		Prevalence of anæmia	
	Consumed seafood	Underweight	Overall	In pregnancy
	(1)	(2)	(3)	(4)
pH in the nearest waters	0.026	-0.004	0.001	-0.017
	(0.012)	(0.002)	(0.005)	(0.007)
	[0.028]	[0.076]	[0.837]	[0.014]
Mean (dep.var.)	0.296	0.120	0.427	0.454
Identifying observations	49,045	407,229	272,541	14,671
Singleton observations	2	3	2	36
Communities	5,952	24,301	17,371	8,993
Countries	14	32	26	26
Interview year range	2005–2016	1992–2018	2000–2018	2000–2018

Note. Estimates are based on equation (2). Dependent variables are reported in column headers: *consumed seafood* is an indicator variable equal to 1 if the respondent consumed seafood in the 24 hours previous to the interview, and 0 otherwise (information is available for mothers in the sample and for a selected number of countries; see Appendix A.1); *underweight* is an indicator variable equal to 1 if the respondent has a BMI below 18.5, and 0 otherwise (information is available for all women with anthropometric measurement); *prevalence of anæmia* is an indicator variable equal to 1 if the respondent has hæmoglobin levels below 110 g/L, and 0 otherwise (information is available for all women with blood samples). *pH in the nearest waters* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the female respondent's community in the month of the interview. The sample is restricted to communities in the coastal area (see Section 2). All specifications include location FEs using grid cells at the $1° \times 1°$ resolution, interview month FEs, interview year FEs, country by interview month FEs, country by interview year FEs, and control variables (see Section 3; weather controls correspond to the year of interview). Standard errors clustered at the ocean raster data point are reported in parentheses, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table 3: Early-life exposure to ocean acidity and neonatal mortality

Dependent variable:	**Neonatal mortality rate (deaths per 1,000 births)**					
	(1)	(2)	(3)	(4)	(5)	(6)
A. Benchmark specification						
pH in the nearest waters (*in utero*)	-1.417	-1.419	-1.491	-2.117	-2.094	-2.083
	(0.691)	(0.683)	(0.664)	(0.754)	(0.761)	(0.738)
	[0.041]	[0.038]	[0.025]	[0.005]	[0.006]	[0.005]
Mean (dep.var.)	30.473	30.473	30.474	30.474	30.474	30.475
Identifying observations	1,583,706	1,583,706	1,581,815	1,583,703	1,583,703	1,581,812
Singleton observations	25	25	25	28	28	28
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
B. Within-sibling specification						
pH in the nearest waters (*in utero*)	-2.065	-2.126	-2.232	-2.459	-2.502	-2.612
	(0.874)	(0.855)	(0.838)	(0.953)	(0.951)	(0.935)
	[0.019]	[0.013]	[0.008]	[0.010]	[0.009]	[0.005]
Mean (dep.var.)	31.476	31.476	31.476	31.476	31.476	31.476
Identifying observations	1,474,945	1,474,945	1,474,945	1,474,941	1,474,941	1,474,941
Singleton observations	108,786	108,786	108,786	108,790	108,790	108,790
Communities	31,356	31,356	31,356	31,356	31,356	31,356
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). The dependent variable is an indicator variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *pH in the nearest waters (in utero)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the child's community during the 9 months before birth. The sample is restricted to communities in the coastal area (see Section 2). All specifications include community FEs, birth year by birth month FEs, country by birth year FEs. Seasonality is captured by either country by birth month FEs or $5° \times 5°$ cell by birth month FEs. In panel B, community FEs are replaced by mother FEs. The full list of controls is presented in Section 3. Standard errors clustered at the ocean raster data point are reported in parentheses, p-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table 4: Early-life exposure to ocean acidity and health investments

Dependent variables:	**Antenatal**	**Delivery**	**Postnatal**		
			Healthcare	Breastfed	Vaccinated
	(1)	(2)	(3)	(4)	(5)
pH in the nearest waters (*in utero*)	0.004	-0.004	0.004	0.001	-0.005
	(0.007)	(0.004)	(0.009)	(0.003)	(0.005)
	[0.590]	[0.374]	[0.630]	[0.691]	[0.318]
Mean (dep.var.)	1.698	1.299	0.441	0.972	0.293
Identifying observations	263,697	256,548	101,075	206,350	210,372
Singleton observations	1,100	1,191	3,078	2,336	2,212
Communities	29,942	29,822	18,445	28,029	27,964
Countries	36	36	34	36	36
Birth year range	1985–2018	1985–2018	2002–2018	1987–2018	1987–2018

Note. Estimates are based on equation (2). The dependent variables are reported in column headers: *antenatal* and *delivery* aggregate different investment indicators (see Appendix B.12), ranging from 0 (no investment) to 2 (larger investment); *healthcare* is an indicator variable equal to 1 if the mother or the child younger than 2 years old received postnatal care within 2 days of birth; *breastfed* is an indicator variable equal to 1 if the mother reports ever breastfeeding the child, and 0 otherwise; *vaccinated* is an indicator variable equal to 1 if the mother reports or the vaccination card shows the completion of the basic cycle of vaccinations according to the World Health Organization (WHO), and 0 otherwise. *pH in the nearest waters (in utero)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the child's community during the 9 months before birth. The sample is restricted to communities in the coastal area (see Section 2). Column (3) excludes the surveys for Indonesia and Morocco because information is not available in the corresponding surveys. For cross-survey comparability, the sample in columns (1)–(3) is restricted to the last birth, independently from the child being alive at the time of the interview, while in columns (4)–(5) is restricted to living children under three years old and can therefore be affected by mortality selection. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Standard errors clustered at the ocean raster data point are reported in parentheses, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table 5: Early-life exposure to ocean acidity and physical development

Dependent variables:	*z*-scores		Indicators	
	Weight-for-height	Height-for-age	Wasted	Stunted
	(1)	(2)	(3)	(4)
A. Overall effect				
pH in the nearest waters (*in utero*)	-0.021	-0.012	0.006	0.004
	(0.016)	(0.015)	(0.003)	(0.004)
	[0.191]	[0.407]	[0.091]	[0.285]
Mean (dep.var.)	-0.309	-0.984	0.080	0.234
Identifying observations	232,339	232,575	232,339	232,575
Singleton observations	1,106	1,124	1,106	1,124
Communities	24,824	25,110	24,824	25,110
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018
B. Heterogeneity by sex				
pH in the nearest waters (*in utero*)	-0.001	-0.033	0.008	0.011
	(0.017)	(0.020)	(0.006)	(0.007)
	[0.977]	[0.099]	[0.182]	[0.149]
× female	-0.015	0.057	-0.011	-0.023
	(0.020)	(0.028)	(0.010)	(0.010)
	[0.436]	[0.047]	[0.307]	[0.023]
Mean (dep.var.)	-0.312	-0.993	0.080	0.236
Identifying observations	226,567	226,685	226,567	226,685
Singleton observations	6,878	7,014	6,878	7,014
Communities	23,979	24,248	23,979	24,248
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018

Note. Estimates are based on equation (2). Dependent variables are reported in column headers: *weight-for-height (w/h)* and *height-for-age (h/w)* are *z*-scores from a reference scale; *wasted* and *stunted* are indicator variables equal to 1 for an abnormally low weight-for-height and height-for-age, respectively, and 0 otherwise. *pH in the nearest waters (in utero)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the individual's community during the 9 months before the birth of the child. The sample is restricted to communities in the coastal area (see Section 2). All panels exclude the surveys for Indonesia, Pakistan, and the Philippines because information is not available in the correspondent surveys. Specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables. In panel B, FEs are sex-specific. Standard errors clustered at the ocean raster data point are reported in parentheses, -values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

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ONLINE APPENDIX

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

Alex Armand and Iván Kim Taveras

A Data and methodological procedures

A.1 Variables, data sources, and the selection of DHS surveys

Variable	Description
Adaptation	Information is based on parental health investments obtained from the DHS Programme (ICF, 2019). We homogenize information across surveys and make use of the following variables: *Antenatal investment* is equal to 0 if no antenatal visit is completed, 1 if at least one visit is completed but without a health professional, and 2 if at least one visit is completed with a health professional. In Appendix B.12, this indicator is split into individual variables. *Any visit* is an indicator variable equal to 1 if the mother attended any visit during pregnancy for antenatal care, and 0 otherwise. *Number of antenatal care visits* is the number of visits attended 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 1 if the mother was attended by a health professional (doctor, nurse or other professional) during pregnancy, and 0 otherwise. *Delivery investment* is equal to 0 if delivery is performed outside a health center without a health professional, 1 if performed outside a health center with a health professional, and 2 if delivery is performed in a health center with a health professional. In Appendix B.12, this indicator is split into individual variables. *In health center* is an indicator variable equal to 1 if the mother gave birth in a health center, and 0 otherwise. *With health professional* is an indicator variable equal to 1 if delivery was attended by a health professional (doctor, nurse or other professional), and 0 otherwise. For *postnatal investment*, *healthcare* is an indicator variable equal to 1 if the mother or the child younger than 2 years old received postnatal care within 2 days of birth. *Breastfed* is an indicator variable equal to 1 if the mother reports ever breastfeeding the child, and 0 if the mother reports to have never breastfed the child. For cross-survey comparability, the sample is restricted to children who live with their mother and are alive, and are less than 3 years old. *Vaccinated* is an indicator variable equal to 1 if the mother reports or shows a vaccination card for the following doses: BCG, 3 doses of DPT-containing vaccines, 3 doses of polio vaccine (excluding polio vaccine given at birth), and 1 dose of MCV. It is 0 otherwise. The sample is restricted to children under 3 years old for comparability (Croft et al., 2018).
Altitude	Communities' elevation in meters from the SRTM–Digital Elevation Model for the specified coordinate location. The variable is available in the DHS surveys (ICF, 2019).
Agricultural land	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 $0.5°\times0.5°$ covering all terrestrial areas of the world that is spatially merged to DHS clusters using their geolocation.
Basemaps	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*.
Child mortality	Information is based on the DHS Programme surveys (ICF, 2019). DHS surveys collect respondents' full birth history and includes information on all children's year and month of birth, sex, birth order, whether they are twins, and the date of death when it applies. Note that only live births are recorded. This information is also used to create *age at first delivery*, and *fertility* (the number of live births at the time of the interview). We build mortality rates by multiplying the following indicators by 1,000 (the variables are set to missing if the date of the interview is before the end of the period considered for defining mortality): *neonatal (NMR)*: indicator equal to 1 if the child died before their first month of life, and 0 otherwise ; *post-neonatal (PMR)*: indicator equal to 1 if the child died between the ages of 1–11 months, and 0 otherwise; *child (CMR)*: indicator equal to 1 if the child died between the ages of 12–59 months, and 0 otherwise; *infant (IMR)*: indicator equal to 1 if the child died between the ages of 0–11 months, and 0 otherwise; *under-5 (U5MR)*: indicator to 1 if the child died between the ages of 0–59 months, and 0 otherwise. Note that the DHS Programme 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 Programme (Croft et al., 2018). We also use 67 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), but results are robust to dropping these cases.
Chlorophyll	Chlorophyll concentration in coastal waters is measured in mg/m^3 (AWV weights). 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.
Conflict	Number of violent events (and fatalities) in each cell for a specific year. The data are obtained from the Uppsala Conflict Data Programme (UCDP) (Sundberg and Melander, 2013).

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Variable	Description
Distances	For shorelines, distance (in a straight line) between the DHS cluster and the closest shoreline. Water bodies are identified from the GSHHG database (Wessel and Smith, 1996). We use the following two bodies. For the *ocean's shoreline*, we consider level 1 (continental land masses and ocean islands, except Antarctica). For *other water bodies*, we consider levels 2, 3 and 4 (lakes, islands in lakes, and ponds in islands within lakes and all levels included in the river database). See Appendix A.2 for details about the procedure. For *coral reefs*, distance (in a straight line) between the DHS cluster and the closest coral reef from UNEP-WCMC (2018).
Economic well-being	DHS asset-based wealth index ranging from 1 (poorest) to 5 (richest).
Extractive fishing	Total number of hours from industrial fishing activities in the cell built using data from the Global Fishing Watch (Kroodsma et al., 2018), which tracks more than 70,000 industrial fishing vessels from 2012 to 2016. Because variation is available only for the period 2012–2016, we first compute total fishing hours in a global grid at $1°\times1°$ resolution and then average each cell over the available period.
Fish dependency	Average fish protein supply as proportion of all animal protein supply (FAO, 2019).
Fishing area	Geographical regions used for fisheries management and reporting, grouping multiple countries together (FAO, 2020). Because countries might have access to multiple areas, we use the primary fishing area, defined as the one covering the largest part of a country's EEZ. For country-level regressions, we merge fishing areas assigned to a single country to avoid collinearity. This is the case of Peru-Guatemala, and of Egypt-East Africa.
Food intake	DHS surveys collect respondents' food consumption for a variety of items (ICF, 2019). This information is available only for a restricted number of surveys: 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). Beyond fish consumption, we consider the following variables: *other proteins* includes all types of animal proteins excluding seafood, eggs, legumes, and beans which are protein-rich; *carbohydrates* includes simple carbohydrates such as bread, noodles and other grains and excludes starches (complex carbohydrates); *fats* includes any type of oil, animal fat, and butter; *other iron-rich food* includes any poultry, red meat, liver, beans, legumes, nuts and dark leafy greens.
Human capital	We make use of *schooling*, i.e., the number of completed years of education based on the respondent's self-reported highest level of education (comparable across countries), and of *cognitive skills*, i.e., an indicator variable of whether the respondent is able to read a whole sentence in her native language (as observed by enumerators) or has, at least, completed secondary schooling.
Labour supply	Indicator variable equal to 1 if the respondent is working, and 0 otherwise. DHS surveys record the employment status of respondents at the time of the interview.
Marriage	DHS surveys collect respondents' civil status, date of birth and, when available, their partner's age in years. We make use of the following variables. *Married* is an indicator variable equal to 1 if the respondent is currently married or living in an union, and 0 otherwise.
Migration	We build migration indicators using DHS question *V104*, described as the "number of years the respondent has lived in the village, town, or city where she was interviewed," was not included in DHS-VI surveys (ICF, 2018). Information is unavailable in the following surveys: Bangladesh 2011 and 2014, Benin 2012, Cambodia 2010 and 2014, Cameroon 2011, Comoros 2012, Congo Democratic Republic 2013, Côte d'Ivoire 1998 and 2012, Dominican Republic 2013, Egypt 2014, Gabon 2012, Ghana 2014, Guatemala 2015, Guinea 1999 and 2012, Haiti 2012, Honduras 2011, Indonesia 2003, Liberia 2013, Mozambique 2011, Myanmar 2016, Namibia 2013, Nigeria 2013, Pakistan 2006, Senegal 2010–2016, Sierra-Leone 2013, Tanzania 2010, and Togo 2013.
Night-time luminosity	Average night-time light emission from the $0.5°\times0.5°$ DMSP-OLS Night-time Lights Time Series Version 4 calibrated (Elvidge et al., 2014). Values range between 0 (lowest) and 1 (highest observed value). The time series are available from 1992–2012 from Tollefsen et al. (2012). Data are spatially merged to DHS clusters using their geolocation. To compute values in the coastal area of country, we consider only values with the coastal area (see Section 2 for the definition).
Night-time fishing	We use Automatic Boat Identification System for VIIRS Low Light Imaging Data (Elvidge et al., 2015) to identify detections. Using individual daily detections (which include geolocation), we build a $1°\times1°$ global grid with the sum of detections for the period 2017–2019. We classify as boats only the strongest detections (quality flag rating equal to 1). Data are not available over the South Atlantic Anomaly (DHS surveys for Peru are the only ones affected).
Nutrition	The DHS records objective measurements performed by the DHS data collection team. Standardised distributions are the CDC Standard Deviation-derived Growth Reference Curves (Croft et al., 2018). The following indicators are used: *anæmia* is an indicator variable equal to 1 if the woman has hæmoglobin levels below 110 g/L, and 0 otherwise; *underweight* is, for children, an indicator variable equal to 1 if the weight-for-age z-score is smaller than 2 or, for adults, if the BMI is lower than 18.5, and 0 otherwise; *w/h (weight-for-height)* is the z-score from the reference curve, while *wasted* is an indicator variable equal to 1 if the weight-for-height z-score is smaller than 2, and 0 otherwise; *h/a (height-for-age)* is the z-score from the reference curve, while *stunted* is an indicator variable equal to 1 if the height-for-age z-score is smaller than 2, and 0 otherwise; *Physical development* is the average between height-for-age and weight-for-height z-scores from the reference curves.

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Variable	Description
Ocean chemistry	Data are obtained from the Hadley Global Environment Model 2 - Earth System or HadGEM2–ES, originally developed by Collins et al. (2011); Jones et al. (2011). Data are provided as monthly global rasters at the 1°×1° resolution for a series of chemical features of the ocean. We use two variables: pH at surface and dissolved O_2 concentration.
Population	Data are downloaded from the History Database of the Global Environment (HYDE) 3.3 (Kees, 2023). These data are provided as yearly global rasters at approximately 0.0833°×0.0833° resolution. We sum all HYDE cells within a PRIO-GRID cell for the years 1972–2018, and these, in turn, are spatially merged to DHS clusters. To compute values in the coastal area of country, we consider only values within the coastal area (see Section 2 for the definition).
Seafood catch/prices	Quantity (in kilotons) and landed value in US$ of catches within each Exclusive Economic Zones (EEZ). Data source is Sea Around Us initiative (Pauly et al., 2020). We select EEZs of the countries in our sample; we drop the only contested area in our sample (i.e., Western Sahara region) because DHS did not sample households in this region. Data on catches is at the level of seafood commercial categories, including: anchovies; cod-likes; crustaceans; flatfishes; herring-likes; molluscs; perch-likes; salmon and smelts; scorpionfishes; sharks and rays; tuna and billfishes; and other fishes and inverts. We merge the category salmon and smelts with tuna and billfishes as the fishing of the former category is almost non-existent in the study area. We include catches direct human consumption from industrial and small-scale fisheries; we exclude catches from the recreational sector. *Median prices* are computed as the median ex-vessel species-level within each commercial group-year-EEZ. Abnormally small and large prices are set to missing using the 1st and the 99th percentiles of the distribution of prices within the corresponding commercial group in the full timeframe analyzed.
Trade balance	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 ocean acidity, we opt for a time-invariant version for the period 1976-2017.
Weather	Yearly total amount of precipitation (in millimeters) in the cell is based on monthly meteorological statistics from the GPCP v.2.2 Combined Precipitation Data Set, available for the years 1979–2014. Yearly mean temperature (°C) in the cell is based on monthly meteorological statistics from GHCN/CAMS, which is available for the period 1948–2014. Data are downloaded from the PRIO-GRID v2.0 database (Tollefsen et al., 2012), a vector grid network with a resolution of 0.5°×0.5°, and spatially merged to DHS clusters using their geolocation. We supplement this information with weather data from the ERA5 dataset (C3S, 2017), which provides a 0.25°× 0.25° hourly gridded dataset for a variety of weather and climatic variables. We obtain sea surface temperature (SST), measured at the same point as ocean pH, and wind speed, total precipitations and air (2-meter) temperature, measured at closest location to a community. For all variables, we average daily values to monthly data.

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

Table A2 presents the Demographic and Health Surveys (DHS) included in the analysis. The availability of multiple surveys for some countries can lead to issues related to survey selection. Table A3 presents estimates of equation (2) assuming different rules for the selection of surveys. When including multiple surveys for the same country, each observation is weighted by the product of the DHS sampling weight with a re-weighting factor, i.e., the ratio between the sum of the DHS sampling weights at the country-survey level and the sum of the DHS sampling weights at the country level. For adult-level estimates, we re-weight observations following the same procedure, repeating the computation of weights for different variables because the inclusion in each survey is variable-dependent. For adult outcomes relative to schooling and work, we include only observations that completed both the education and work module. This selection affects only the India 2015–2016 survey, for which we select only the women that completed the *state module*), and we use the corresponding weights (IIPS and ICF, 2017).

Table A2: Sampled countries

Country	DHS surveys available	Birth years matched
Angola	2015	1978-2016
Bangladesh	2000, 2004, 2007, 2011, 2014	1972-2014
Benin	1996, 2001, 2012	1972-2012
Cambodia	2000, 2005, 2010, 2014	1972-2014
Cameroon	1991, 2004, 2011	1972-2011
Colombia	2010	1973-2010
Comoros	2012	1975-2012
DR Congo	2007, 2013	1972-2014
Côte d'Ivoire	1994, 1998, 2012	1972-2012
Dominican Republic	2007, 2013	1972-2013
Egypt	1992, 1995, 2000, 2005, 2008, 2014	1972-2014
Gabon	2012	1974-2012
Ghana	1993, 1998, 2003, 2008, 2014	1972-2014
Guatemala	2015	1978-2015
Guinea	1999, 2005, 2012, 2018	1972-2018
Guyana	2009	1974-2009
Haiti	2000, 2006, 2012, 2016	1972-2017
Honduras	2011	1974-2012
India	2015	1975-2016
Indonesia	2003	1972-2003
Kenya	2003, 2008, 2014	1972-2014
Liberia	2007, 2013	1972-2013
Madagascar	1997, 2008	1972-2009
Morocco	2003	1972-2004
Mozambique	2011	1974-2011
Myanmar	2016	1980-2016
Namibia	2000, 2006, 2013	1972-2013
Nigeria	1990, 2003, 2008, 2013, 2018	1972-2018
Pakistan	2006	1972-2007
Peru	2000, 2004, 2009	1972-2009
Philippines	2003, 2008, 2017	1972-2017
Senegal	1993, 1997, 2005, 2010, 2012, 2014, 2015, 2016	1972-2016
Sierra Leone	2008, 2013	1973-2013
Tanzania	1999, 2010, 2015	1972-2016
Timor-Leste	2009, 2016	1974-2016
Togo	1998, 2013	1972-2014

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 primary sampling units. *Birth years matched* refers to child-level information and includes all observations in the birth histories (*DHS birth recode*) that are matched with data on ocean pH.

Table A3: Robustness to selection of surveys

Dependent variable:	**NMR (deaths per 1,000 births)**			
DHS surveys:	*All*	*Latest*	*Largest*	*Random*
	(1)	(2)	(3)	(4)
pH in the nearest waters (*in utero*)	-1.491	-1.420	-1.803	-1.609
	(0.664)	(0.701)	(0.654)	(0.675)
	[0.025]	[0.043]	[0.006]	[0.018]
Mean (dep.var.)	30.474	26.601	27.328	29.036
Identifying observations	1,581,815	794,713	861,938	757,132
Singleton observations	25	32	35	30
Communities	31,380	17,389	18,476	16,416
Countries	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and controls (see Section 3). In column (1), observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.1). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. *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. Appendix A.1 provides further information on the variables and the list of surveys included in the study.

A.2 Descriptive statistics

For each household, distance is the minimum straight distance from the DHS geocoded coordinates to the coast and closest alternative water source, computed using *v.distance* function in GRASS. Table A4 presents descriptive statistics for households living within and beyond 100 km from the shore. Figure A1 presents an example of the procedure. Table A5 shows the observable differences between mothers with a single child (excluded in the within-sibling specification) and mothers with multiple children.

Table A4: Descriptive statistics for coastal and inland areas

	Coastal area		**Inland area**		
	Mean (1)	Std. dev. (2)	Mean (3)	Std. dev. (4)	Observations (5)
A. Children					
Child is alive	0.92	0.27	0.91	0.29	4555492
Child is female	0.48	0.50	0.48	0.50	4555492
Birth order	2.54	1.81	2.66	1.84	4555492
Number of twins born with the child	0.03	0.23	0.03	0.22	4555492
Years since birth	12.28	7.87	12.09	7.76	4555492
Mother's age at birth	24.43	5.77	24.16	5.54	4555492
pH in the nearest waters (*in utero*)	8.05	0.03	8.06	0.03	4555492
B. Adult women					
Age at first delivery	20.88	4.23	20.45	3.82	1385467
Current age	30.65	9.80	29.97	9.76	1951250
Years of schooling	7.25	4.84	6.04	4.90	1376076
pH in the nearest waters (*in utero*)	8.06	0.03	8.07	0.03	977187
Primary education or less	0.41	0.49	0.49	0.50	1951201
Married	0.67	0.47	0.70	0.46	1950104
Working	0.54	0.50	0.55	0.50	1304776
Household head is female	0.22	0.41	0.17	0.38	1951247
Household head's age	46.10	13.11	46.37	13.17	1949918
Household members	5.62	3.03	6.06	3.11	1951250
Household wealth	3.72	1.28	3.22	1.39	1776572
Living in urban area	0.53	0.50	0.34	0.47	1951250
Distance from shore	31.26	30.21	462.44	289.57	1951250
Distance from another water body	47.32	102.12	24.87	23.98	1951250
Altitude	190.22	408.72	489.97	613.08	1951244
Temperature (° C)	26.09	3.21	24.92	3.70	1951250
Precipitations (mm)	1557.41	674.18	1298.33	673.22	1951250
Intensity of extractive fishing	0.06	0.20	0.05	0.13	1951250
Intensity of night-time fishing	0.09	0.20	0.08	0.16	1951250
C. Mortality rates					
Neonatal	27.51	163.55	37.24	189.34	4545390
Postneonatal	23.67	152.02	24.28	153.90	4200570
Child	21.69	145.68	27.67	164.02	3265547
Infant	50.66	219.30	60.78	238.93	4355601
Under-five	74.22	262.12	89.55	285.54	3504461

Note. Descriptive statistics by proximity to the ocean for all communities in selected countries with access to ocean. Coastal area includes all communities within 100 km from the ocean's shore (see Section 2). Inland area includes all communities 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 total number of observations. *Years since birth* is measured at the time of the interview and is independent from the child being alive. *Mortality rates* are relative to 1,000 live births. *pH in the nearest waters (in utero)* is defined in Section 3; it refers to the date of birth of the child In panel A and to the date of birth of the woman In panel B. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

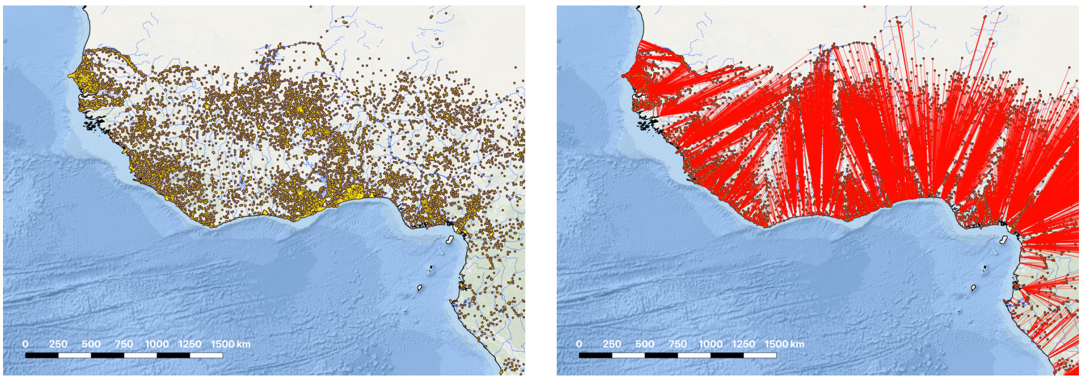
Table A5: Comparison of mothers with a single child versus multiple children

	One child		**Multiple children**		
	Mean (1)	SD (2)	Mean (3)	SD (4)	Observations (5)
A. Children					
Child is alive	0.97	0.16	0.92	0.27	1587285
Child is female	0.47	0.50	0.49	0.50	1587285
Birth order	1.00	0.00	2.68	1.82	1587285
Number of twins born with the child	0.00	0.00	0.04	0.24	1587285
Years since birth	6.04	6.55	12.86	7.73	1587285
Mother's age at birth	22.51	4.71	24.61	5.82	1587285
B. Adult women					
Age at first delivery	22.51	4.71	20.37	3.94	495310
Current age	28.54	7.99	36.19	7.66	495310
Years of schooling	8.39	4.62	5.99	4.82	441192
Primary education or less	0.31	0.46	0.55	0.50	495286
Married	0.81	0.40	0.89	0.31	495309
Working	0.54	0.50	0.60	0.49	425306
Household head is female	0.23	0.42	0.19	0.39	495310
Household head's age	45.04	15.18	44.62	11.97	494936
Household members	5.13	3.08	5.72	2.89	495310
Household wealth	3.82	1.25	3.58	1.32	434418
Living in urban area	0.57	0.49	0.49	0.50	495310
Distance from shore	31.14	30.00	32.47	30.23	495310
Distance from another water body	39.07	81.02	46.61	100.49	495310
Altitude	179.28	396.98	187.48	401.10	495310
Temperature (° C)	26.17	3.12	26.19	3.06	495310
Precipitations (mm)	1609.01	659.60	1549.09	683.53	495310
Intensity of extractive fishing	0.06	0.20	0.06	0.19	495310
Intensity of night-time fishing	0.09	0.19	0.09	0.20	495310

Note. Descriptive statistics by the number of children of the mother (reported in column headers). Means are reported in columns (1) and (3), standard deviations in columns (2) and (4). Column (5) presents the total number of observations. *Years since birth* is measured at the time of the interview and is independent from the child being alive. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

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

A. All DHS communities **B. Distance from shore**



Note. Geolocation of DHS communities (panel A) and closest points to the ocean's shore (panel B). Lines represent straight distance from a community to the closest point on the coast's shoreline or on the shoreline of another water body. Basemap source: Esri. See Appendix A.1 for data sources and attributions.

B Supplementary results

B.1 Coastal features and income processes

Figure B1 shows descriptive statistics of average pH at surface (panel A), the evolution of the average deviation in pH over time (panel B), and the between and within decomposition of the overall variation of ocean pH while *in utero* as compared to NMR (panel C). Table B1 shows descriptive statistics of the measure of shock under the different specifications presented in Table 3, and the correspondent standardised effect.

Table B1: Standardised effects in Table 3

	Benchmark specification				**Within-sibling specification**			
	Mean	SD	Effect	Std. effect	Mean	SD	Effect	Std. effect
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shock (specification 1)	-0.00	0.38	-1.42	-0.54	-0.00	0.30	-2.06	-0.63
Shock (specification 2)	-0.00	0.37	-1.42	-0.53	0.00	0.30	-2.13	-0.64
Shock (specification 3)	-0.00	0.37	-1.49	-0.56	0.00	0.30	-2.23	-0.67
Shock (specification 4)	-0.00	0.26	-2.12	-0.55	-0.00	0.22	-2.46	-0.53
Shock (specification 5)	-0.00	0.25	-2.09	-0.53	-0.00	0.21	-2.50	-0.53
Shock (specification 6)	-0.00	0.25	-2.08	-0.53	-0.00	0.21	-2.61	-0.55

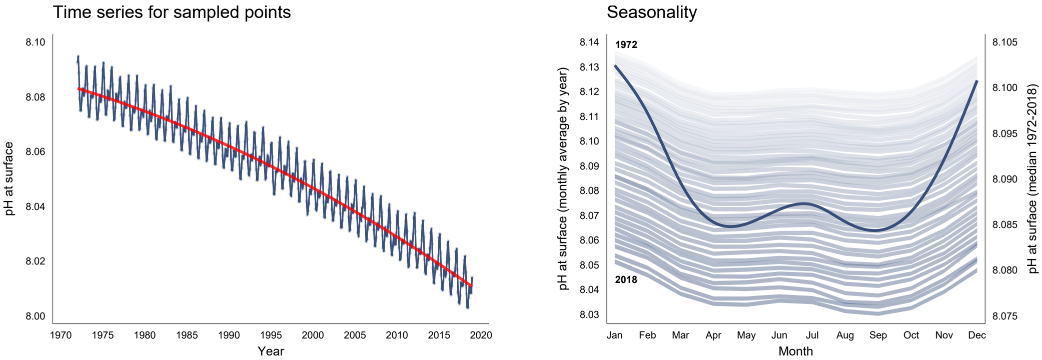
Note. Descriptive statistics of shocks in ocean pH in the nearest waters (*in utero*) under the benchmark and the within-sibling specifications. Columns (3) and (7) report to the point estimates in Table 3. The standardised effect is rescaling point estimates in terms of standard deviations in the residual variation of ocean pH in the nearest waters (*in utero*). Residual variation is obtained from the residuals of a linear regression using ocean pH experienced *in utero* as dependent variable and the set of FEs used in equation (2) as independent variables.

We focus next on other features in the ocean and in coastal areas that could influence income processes in sampled communities. In terms of **other ocean's characteristics**, Table B2 presents estimates of the effect of ocean acidity in the nearest waters (*in utero*) on NMR using equation (2) and controlling for various ocean characteristics and inland weather conditions obtained from the ERA5 dataset. Panels A–D in Figure B2 show the time series and the seasonality component for these variables.

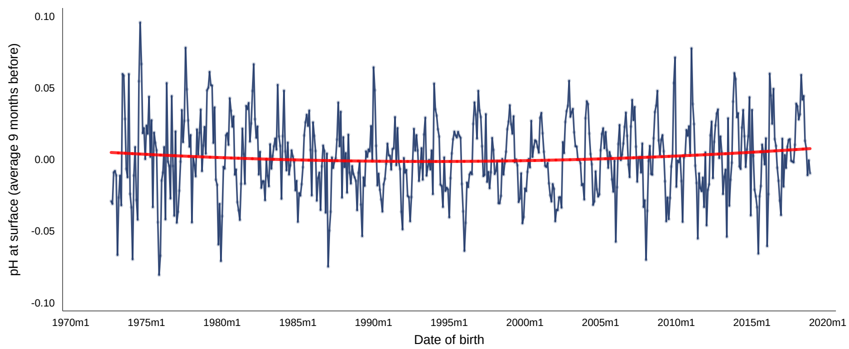
In terms of **pollution and other chemical features of the ocean**, Columns (3)–(4) in Table B2 present estimates controlling for pollution in coastal waters, proxied by satellite-based algae abundance (chlorophyll concentration) from the GlobColour project from 1997–2018. The presence of pollution also impacts the availability of another input to marine life that is more closely related to fish survival: oxygen. At low levels of concentration (hypoxic conditions), marine wildlife changes behaviour to reach areas with higher oxygen levels, while at extremely low levels (dead-zones), mortality prevails. Oxygen concentration is also affected by climate change because higher tem-

Figure B1: Variation in ocean acidity for communities in the coastal area

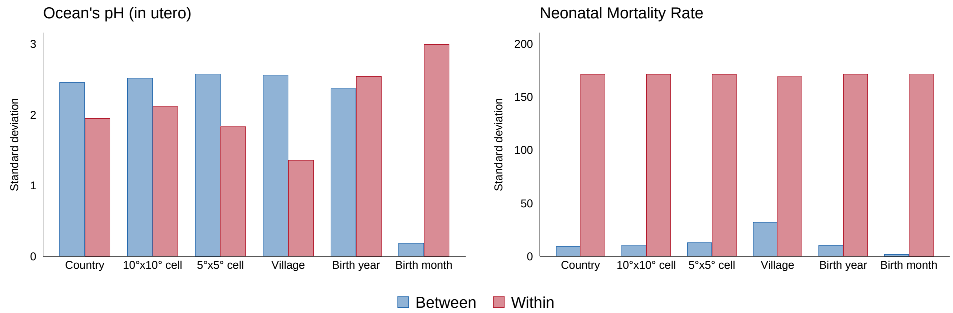
A. Yearly and monthly variation of pH in raster points matched with DHS



B. Average shock in ocean acidity (*in utero*)



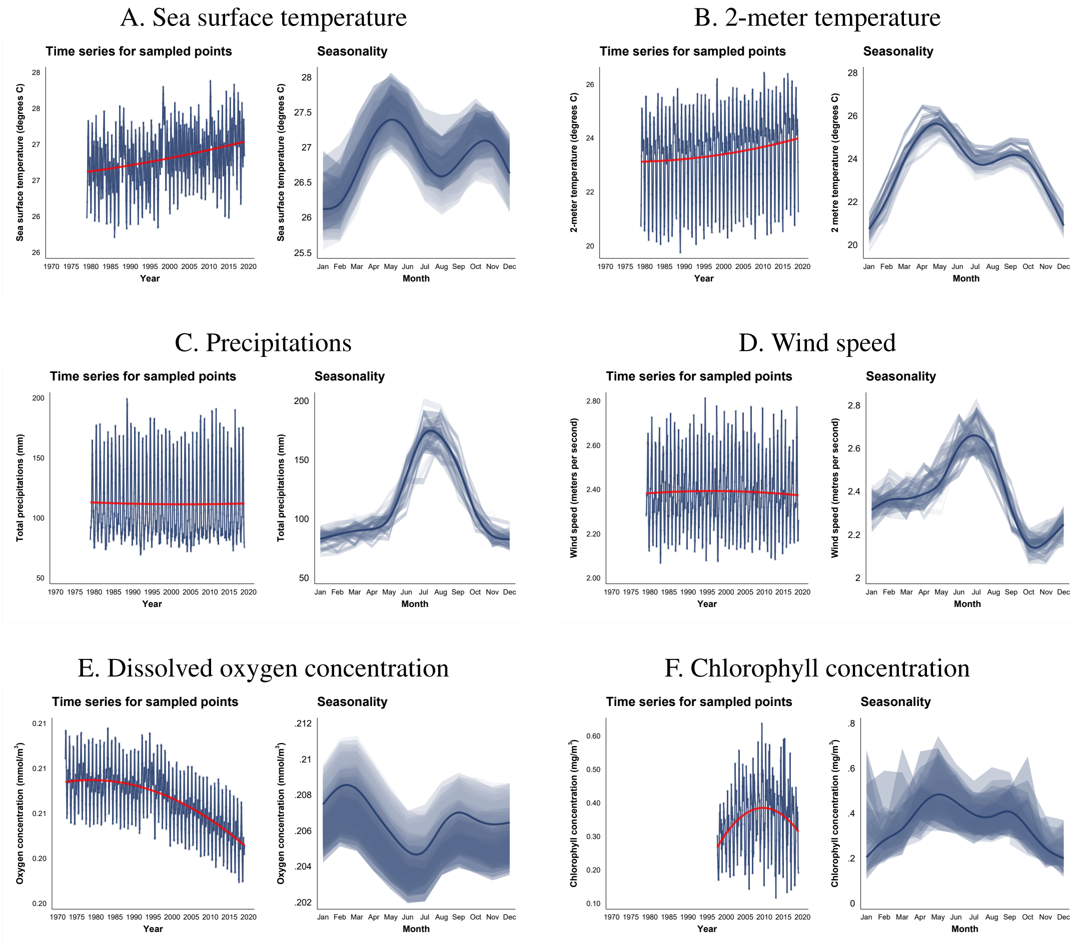
C. Between and within variation decomposition of ocean pH (*in utero*) and NMR



Note. In panel A, yearly average pH at surface in the period 1972–2018 (left figure), and monthly comparison between mean pH for each year in the left axis, and median pH for the whole period in the right axis (right figure). Variation is restricted to cells matched to the sample's communities. In panel A, the solid red line shows the quadratic trend in the series. In panel B, evolution over time of the average deviation in acidity levels from spatially specific (and seasonally-adjusted) long-run trends. *pH in the nearest waters (in utero)* is defined in Section 3 and is computed using the benchmark specification. Variation is restricted to cells matched to the sample. The solid red line shows the quadratic trend over the period. In panel C, decomposition of the sample standard deviation of ocean pH experienced *in utero*, as compared to NMR. The sample is restricted to communities in the coastal area (see Section 2). Geographical and time variables for which the decomposition is computed are reported at the bottom of each figure. Appendix A.1 provides further information on the variables and the list of surveys included in the study.

peratures lead to reduced oxygen concentration (Free et al., 2019). In column (7), we also control for this variable obtained from the HadGEM2-ES model. Because pH and oxygen concentration are chemical properties determined by common factors, we always include as control the residual variation in oxygen concentration, rather than its levels. Residual variation is computed as residuals of a linear regression of oxygen concentration in grid cell i at time t on the contemporaneous pH in the same grid cell. Controlling for other chemical features does not affect these estimates. Panels E–F in Figure B2 depict the time series and the seasonality component for these variables.

Figure B2: Additional weather characteristics in the ocean's matched areas



Note. Descriptive statistics of weather characteristics are measured either at the same point as ocean pH (panels A, E, F) or at the location of the closest community (panels B, C, D). The figures on the left display yearly averages, with a solid red line indicating the quadratic trend in the series. The figures on the right illustrate monthly averages for each year in the sample, with the darker line representing the median over the entire period. Variation is limited to cells matched to the sample's communities. Appendix A.1 provides further information on the variables.

Table B2: Neonatal mortality and shocks to income processes

Dependent variable:	**NMR (deaths per 1,000 births)**								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Closest point in the ocean									
pH in the nearest waters (*in utero*)	-2.034		-3.280		-2.192		-2.140		-2.012
	(0.745)		(1.513)		(0.744)		(0.741)		(0.743)
	[0.007]		[0.031]		[0.003]		[0.004]		[0.007]
In-utero sea surface temperature	1.467	1.695							1.633
	(0.925)	(0.918)							(0.913)
	[0.113]	[0.066]							[0.074]
In-utero chlorophyll concentration			0.292	0.299					
			(0.583)	(0.584)					
			[0.617]	[0.610]					
In-utero oxygen concentration									-0.083
									(0.306)
									[0.786]
Location of birth									
In-utero wind speed					1.752	1.596			1.958
					(1.510)	(1.505)			(1.558)
					[0.247]	[0.290]			[0.210]
In-utero total precipitations, ERA5							0.008	0.007	
							(0.008)	(0.008)	
							[0.289]	[0.351]	
In-utero 2-meter temperature, ERA5							0.674	0.902	
							(0.898)	(0.892)	
							[0.453]	[0.312]	
In-utero temperature									-0.130
									(0.417)
									[0.756]
In-utero total precipitations									-0.002
									(0.002)
									[0.153]
Mean (dep.var.)	29.645	29.645	24.937	24.937	29.645	29.645	29.645	29.645	29.645
Identifying observations	1,518,357	1,518,357	451,212	451,212	1,518,357	1,518,357	1,518,357	1,518,357	1,518,357
Singleton observations	23	23	247	247	23	23	23	23	23
Communities	31,380	31,380	16,409	16,409	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36	36	36	36
Birth year range	1979–2018	1979–2018	1998–2018	1998–2018	1979–2018	1979–2018	1979–2018	1979–2018	1979–2018

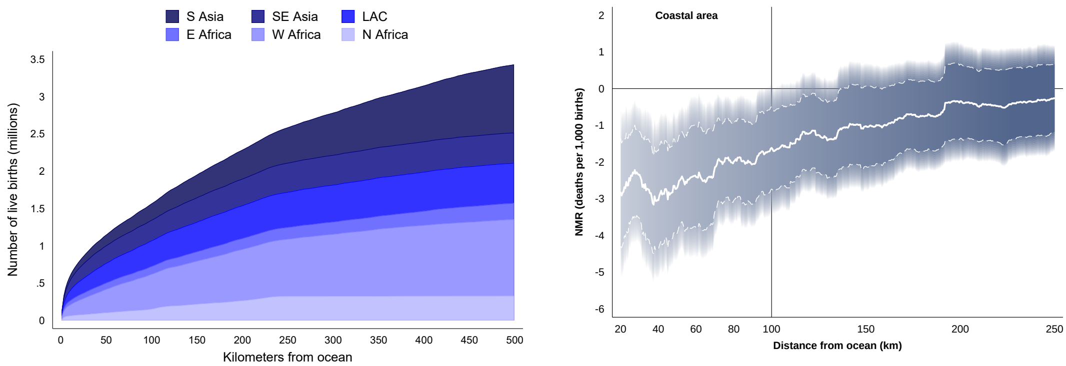
Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. *In utero* indicates that the variable is the average value in the ocean grid cell closest to the child's community during the 9 months before birth. *Year of birth* indicates that the variable is the average value in the child's community's grid cell in the year of birth. The sample is restricted to communities in the coastal area (see Section 2). In columns (3)–(4), the sample is further restricted to births between 1997–2018 due to data availability (observations are reweighted to account for dropped surveys), and to areas away from estuaries to alleviate endogeneity concerns. Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, $5°\times5°$ grid cell by birth month FEs, and demographic controls (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.2 Alternative definitions of coastal area

In terms of **proximity**, we vary the distance from the ocean's shore, which affects the total number of live births considered and the estimate of the effect on NMR (Figure B3). In terms of **altitude**, we combine proximity with elevation requirements (see, e.g., Christian and Mazzilli, 2007; Figure B4 shows this selection process in our sample). Finally, we can exclude areas with higher contamination, such as **estuaries**. Table B3 shows how estimates of the effect of ocean pH in the nearest waters (*in utero*) on NMR varies under different definitions of a coastal area.

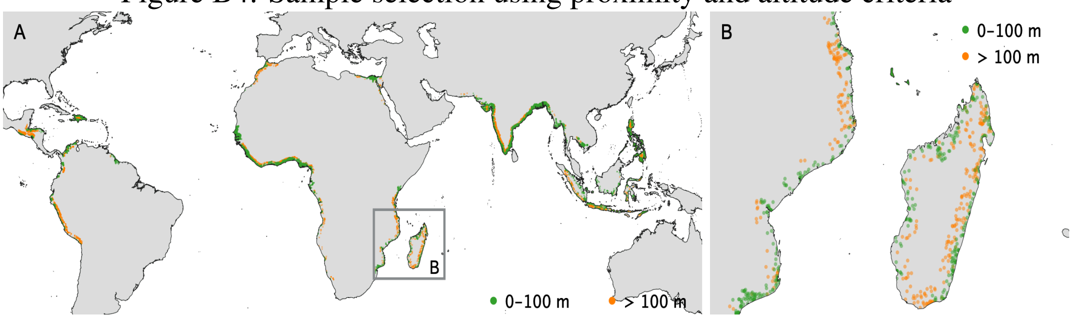
Figure B3: Sample selection by distance from shore

A. Number of live births B. Effect of ocean pH (*in utero*)



Note. Number of live births included in the sample (panel A), and marginal effects of ocean pH in the nearest waters (*in utero*) on NMR (panel B) by sample selection according to the distance from the shore. *pH in the nearest waters (in utero)* is defined in Section 3. Estimates are based on equation (2) when the sample is selected according to distance (reported in the horizontal axis). Each specification includes community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). The 90% confidence interval is indicated by dotted lines, beyond which the intervals are progressively shaded up to the 99% level. Within confidence bounds, color intensity shows the relative density of observations by distance from shore. It is calculated by comparing the square root of the density at each point to the square root of the 90th percentile of the overall density. These parameters were chosen to improve visibility. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Figure B4: Sample selection using proximity and altitude criteria



Note. Communities in coastal areas distinguished by altitude (panel A), and an example (panel B). The full list of countries and surveys included in the study is reported in Appendix A.1. See Section 2 for a definition of coastal area.

Table B3: The effect on neonatal mortality: varying sample selection criteria

Dependent variable:	**NMR (deaths per 1,000 births)**					
Altitude criteria:	$\leq$ *100m*	$\leq$ *100m*	-	-	$\leq$ *100m*	$\leq$ *100m*
Distance restriction:	-	-	$\leq$ *40km*	$\leq$ *40km*	$\leq$ *40km*	$\leq$ *40km*
Exclusion of estuaries:	-	*Yes*	-	*Yes*	-	*Yes*
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.627	-1.593	-2.923	-3.072	-2.942	-3.071
	(0.776)	(0.759)	(0.797)	(0.944)	(0.836)	(0.996)
	[0.037]	[0.036]	[0.000]	[0.001]	[0.000]	[0.002]
Mean (dep.var.)	31.116	31.431	29.489	29.631	29.938	30.113
Identifying observations	1,137,356	978,016	1,061,342	893,056	845,155	685,815
Singleton observations	19	15	25	21	22	18
Communities	22,612	18,801	21,682	17,616	17,600	13,789
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to coastal areas (see Section 2) and according to the criteria reported in column headers. *Estuaries* are defined as communities that are at a distance of 10 km or less from the ocean's shore and at a distance of 10 km or less from another water source. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (the full list of controls in Section 3). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.3 Fertility

We examine the timing of a woman's first birth and the occurrence of her last terminated pregnancy (defined as any pregnancy not resulting in a live birth). DHS surveys only provide information on age at first birth and the year of the last terminated pregnancy. We approximate a duration model by building a panel that tracks each woman from the age of 12 until she either experiences one of these events, or until she turns 33 years old. In our sample, 99% of women experience their first birth by age 33. If a woman who experienced any of these two events is missing information on her age at first birth or the year of her last terminated pregnancy, she is dropped from the panel. When considering terminated pregnancies, if a woman had a successful pregnancy prior to her most recent terminated pregnancy, we track her from the time of her last successful pregnancy instead of the age of 12. We estimate the effect of the average ocean pH in the nearest waters in the year $t-1$ on the probability of a woman experiencing her first birth or last terminated birth in year t using the following specification:

$$y_{ivc,tab} = \beta \; R_{vc,t-1} + \mathbf{X}_{vc,t-1}\gamma + \Omega_{ivc,tab} + \epsilon_{ivc,tab} \tag{3}$$

where $y_{ivc,tab}$ is the outcome of interest for a woman i born in year b with age a located in community v of country c in year t, which takes the value 1 in the year the woman has her first successful birth, and 0 otherwise. $\mathbf{X}_{vc,t-1}$ is a vector of weather control variables, $\Omega_{ivc,tab}$ is a set of FEs, and $\epsilon_{ivc,tab}$ are idiosyncratic errors assumed to be clustered at the ocean raster data point. We include individual FEs to remove time-invariant characteristics at the individual, household, and location levels; country by age FEs to flexibly allow for the probability of first birth by age to vary across countries; country by year of birth FEs to account for cohort-specific effects; and country by year FEs to account for local trends. Table B4 presents results for first birth and last terminated pregnancy, respectively.

Table B4: Exposure, first birth and terminated pregnancies

Dependent variable:	**First birth**		**Last terminated pregnancy**	
	(1)	(2)	(3)	(4)
pH in the nearest waters (previous year)	0.001	0.000	-0.001	-0.001
	(0.002)	(0.002)	(0.001)	(0.001)
	[0.716]	[0.873]	[0.395]	[0.418]
Mean (dep.var.)	0.099	0.099	0.017	0.017
Identifying observations	1,232,452	1,232,452	993,614	993,614
Singleton observations	1,092	1,092	107	107
Communities	19,568	19,568	14,853	14,853
Countries	28	28	26	26
Birth year range	1960–2003	1960–2003	1961–2002	1961–2002
Weather controls	-	Yes	-	Yes

Note. Estimates are based on equation (3). The dependent variable is an indicator variable equal to 1 when the woman experienced the event described in the header, and 0, otherwise. *pH in the nearest waters (previous year)* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the child's community in the year before. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include individual FEs, country by age FEs, country by year of birth FEs, and country by year FEs. Additionally, even-numbered columns include weather controls. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

In addition, Table B5 estimates the effect of exposure to changes in ocean pH at the time of the interview on the probability of being pregnant and allows for heterogeneous effects by socioeconomic status and education. We found no significant differential effect of the ocean pH on current fertility across different socioeconomic statuses or education levels. Table B6 replicates Panel A in Table 3 excluding women who report ever experiencing a terminated pregnancy. Finally, Table B7 replicates Panel A in Table 3 by restricting the sample to recent births (at most 10 years prior to the interview).

Table B5: Ocean acidity and current fertility

Dependent variable:	**Currently pregnant**		
	(1)	(2)	(3)
pH in the nearest waters	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
	[0.492]	[0.691]	[0.431]
× Richer household		0.000	
		(0.001)	
		[0.446]	
Richer household		-0.006	
		(0.002)	
		[0.000]	
× At least primary schooling			0.000
			(0.001)
			[0.690]
At least primary schooling			-0.007
			(0.003)
			[0.011]
Mean (dep.var.)	0.062	0.059	0.062
Identifying observations	690,835	601,419	690,835
Singleton observations	4	2	4
Communities	30,932	26,589	30,932
Countries	36	36	36
Birth year range	1972–2017	1972–2017	1972–2017

Note. Estimates are based on equation (2). The dependent variable is an indicator variable equal to 1 if the woman reports being pregnant at the time of the interview, and 0, otherwise. *pH in the nearest waters* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include location FEs using grid cells at the $1° \times 1°$ resolution, interview month FEs, interview year FEs, country by interview month FEs, country by interview year FEs, and control variables (see Section 3; weather controls correspond to the year of interview). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B6: Table 3 – exclude women reporting at least one terminated pregnancy

Dependent variable:	**NMR (deaths per 1,000 births)**					
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.867	-1.938	-1.959	-1.902	-1.953	-1.931
	(0.841)	(0.828)	(0.806)	(0.855)	(0.861)	(0.834)
	[0.027]	[0.020]	[0.015]	[0.027]	[0.024]	[0.021]
Mean (dep.var.)	29.125	29.125	29.128	29.125	29.125	29.127
Identifying observations	1,145,187	1,145,187	1,143,788	1,145,180	1,145,180	1,143,781
Singleton observations	66	66	66	73	73	73
Communities	28,764	28,764	28,764	28,764	28,764	28,764
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs. Seasonality is captured by either country by birth month FEs or $5° \times 5°$ cell by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B7: Table 3 – restricting the sample to recent births

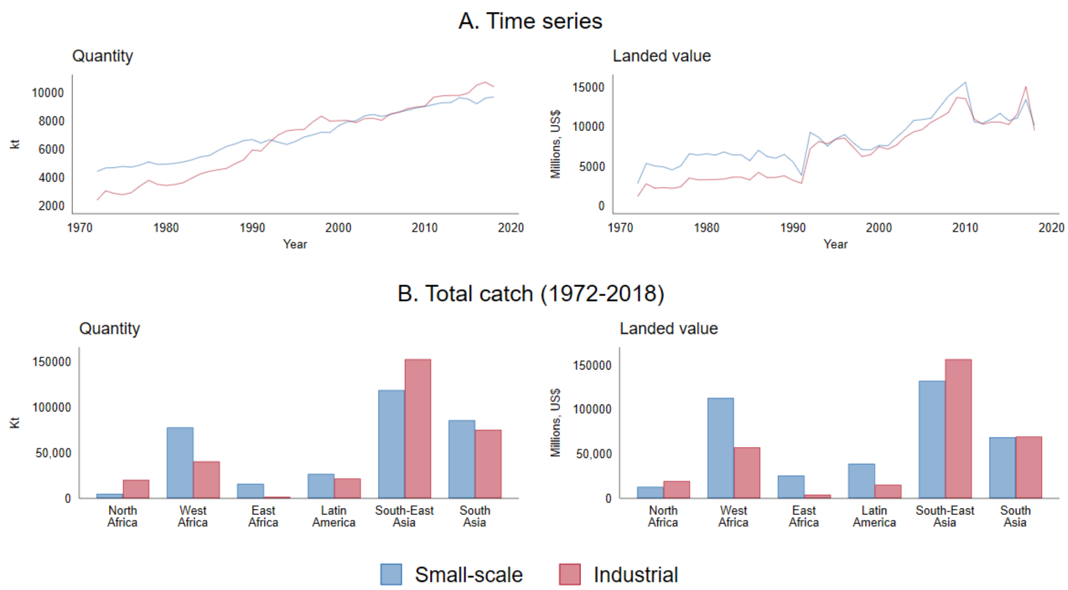
Dependent variable:	NMR (deaths per 1,000 births)					
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-2.552	-2.418	-2.460	-2.059	-2.055	-2.142
	(1.316)	(1.331)	(1.307)	(1.143)	(1.149)	(1.133)
	[0.053]	[0.070]	[0.060]	[0.072]	[0.074]	[0.059]
Mean (dep.var.)	26.914	26.914	26.917	26.914	26.914	26.918
Identifying observations	746,982	746,982	745,962	746,960	746,960	745,940
Singleton observations	142	142	142	164	164	164
Communities	31,183	31,183	31,183	31,182	31,182	31,182
Countries	36	36	36	36	36	36
Birth year range	1980–2018	1980–2018	1980–2018	1980–2018	1980–2018	1980–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2) restricting the sample to births within 10 years of the interview. *pH in the nearest waters (in utero)* is defined in Section 3 The sample is restricted to communities in the coastal area (see Section 2). All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, and control variables (see Section 3). Controls for local seasonality are either country by birth month FEs or 5°×5° cell by birth month FEs. Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.4 Fishing and seafood dependency

Sea Around Us. Figure B5 plots the time series of fish catch (in quantity and value) for the countries in the study sample, differentiated by sector of activity during the period 1972—2018 (panel A), and the total catch over the same period by geographical region, again restricting the sample to the countries being part of the study (panel B).

Figure B5: Descriptive statistics about fish catch in the study area



Note. Evolution over time of the quantity and landed value of fish catch in the study area (panel A), and total quantity and landed value by geographical region in the period 1972–2018 (panel B). Source is Pauly et al. (2020). See Section 2 for further details.

Table B8 shows estimates of the effect of pH on landed value, distinguishing by the price of the commercial group, by the main nutrient of fish in the commercial group, and by resilience to acidification. Lower resilience is among crustaceans and molluscs (Alter et al., 2024). Table B9 replicates Table 1 in the main text, but using alternative transformations of the outcome variables. Table B10 estimates (conditional) correlations of measures of nutrition among women and country-level landed value at the time of the interview. Because variation is available only yearly and at the level of the country, we control for FAO fishing zone-specific FEs, trends and seasonality.

Table B8: Ocean acidity and marine catches – by type

Dependent variables:	**Landed value, by category of seafood caught**					
	Price		**Main nutrient**		**Resilience**	
	Low	High	Fatty fish	Lean fish	Lower	Higher
	(1)	(2)	(3)	(4)	(5)	(6)
A. Landed value (small-scale)						
pH in promixity to the coast	0.214	0.198	0.229	0.188	0.292	0.178
	(0.113)	(0.080)	(0.098)	(0.083)	(0.111)	(0.084)
	[0.066]	[0.017]	[0.025]	[0.030]	[0.012]	[0.041]
Mean (dep.var.)	1.80	1.35	1.44	1.54	2.07	1.39
Identifying observations	6,751	12,342	5,217	13,912	3,478	15,651
Singleton observations	29	7	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
B. Landed value (industrial)						
pH in proximity to the coast	0.024	0.034	0.065	0.021	-0.032	0.047
	(0.110)	(0.095)	(0.132)	(0.102)	(0.144)	(0.102)
	[0.829]	[0.723]	[0.625]	[0.840]	[0.827]	[0.645]
Mean (dep.var.)	1.21	0.89	0.73	1.11	1.70	0.85
Identifying observations	6,751	12,342	5,217	13,912	3,478	15,651
Singleton observations	29	7	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
C. Median price						
pH in proximity to the coast	-0.029	-0.068	-0.087	-0.090	-0.121	-0.079
	(0.025)	(0.045)	(0.046)	(0.051)	(0.077)	(0.040)
	[0.265]	[0.139]	[0.065]	[0.088]	[0.125]	[0.059]
Mean (dep.var.)	0.49	1.52	0.78	1.09	1.18	0.94
Identifying observations	6,751	6,749	3,876	9,683	3,215	10,312
Singleton observations	29	32	2	0	34	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (1). Dependent variables in column headers are the landed value, by type of catch. Landed values are reported using an inverse hyperbolic sine transformation to account for zero values. In columns (1)–(2), price heterogeneity is defined by computing the average unit price by seafood group within each country for the whole period 1972–2018. *Low* (*high*) indicates values that are smaller or equal (larger) than the median value. In columns (3)–(4), *fatty fish* indicates seafood groups whose primary nutrient content are essential fatty acids, while *lean fish* indicates seafood groups whose primary nutrient content are essential proteins. In columns (5)–(6), *lower* (*higher*) indicates seafood groups whose resilience to acidification is lower (higher). *pH in proximity to the coast* is defined in Section 3. Specifications include country by seafood group FEs, and fishing area by year FEs. Standard errors (in parentheses) are clustered at the EEZ level, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B9: Ocean pH and marine catches – robustness checks

Dependent variables:	**Marine catch for human consumption**					**Activity**
	Small-scale fishing		Industrial fishing		Median	Night-time
	Quantity	Value	Quantity	Value	price	luminosity
	(1)	(2)	(3)	(4)	(5)	(6)
A. Levels						
pH in proximity to the coast	7.195	9.734	3.543	4.131	-0.225	-0.204
	(2.731)	(3.595)	(5.045)	(5.148)	(0.110)	(0.150)
	[0.012]	[0.010]	[0.487]	[0.428]	[0.049]	[0.182]
Mean (dep.var.)	16.13	18.64	13.88	13.30	1.52	5.54
Identifying observations	19,129	19,129	19,129	19,129	13,561	777
Singleton observations	0	0	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1992–2018
B. Log-levels						
pH in proximity to the coast	0.122	0.175	0.023	0.037	-0.069	-0.003
	(0.060)	(0.070)	(0.079)	(0.088)	(0.033)	(0.034)
	[0.048]	[0.017]	[0.771]	[0.673]	[0.045]	[0.938]
Mean (dep.var.)	1.25	1.26	0.83	0.84	0.79	1.77
Identifying observations	19,129	19,129	19,129	19,129	13,561	777
Singleton observations	0	0	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1992–2018

Note. Estimates are based on equation (1). Dependent variables are reported in column headers with different transformations depending on the panel. In panel A, we use the variables in levels, but top-coding them at the 99$^{\text{th}}$ percentile of the distribution to limit the effect of outliers on the estimates. In panel B, we compute the logarithm of the variables, add unity before computing logarithms to avoid creating missing values. In columns (1)–(4), each observation is the catch or landed value for a specific commercial group in the correspondent exclusive economic zone (EEZ). In columns (5)–(6), each observation is the country correspondent to the EEZ. *pH in proximity to the coast* is defined in Section 3. Specifications in columns (1)–(4) include country by commercial group FEs, and fishing area by year FEs. The specification in column (5) includes country FEs, and fishing area by year FEs. Standard errors (in parentheses) are clustered at the EEZ level, p-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B10: Fisheries and nutrition among women

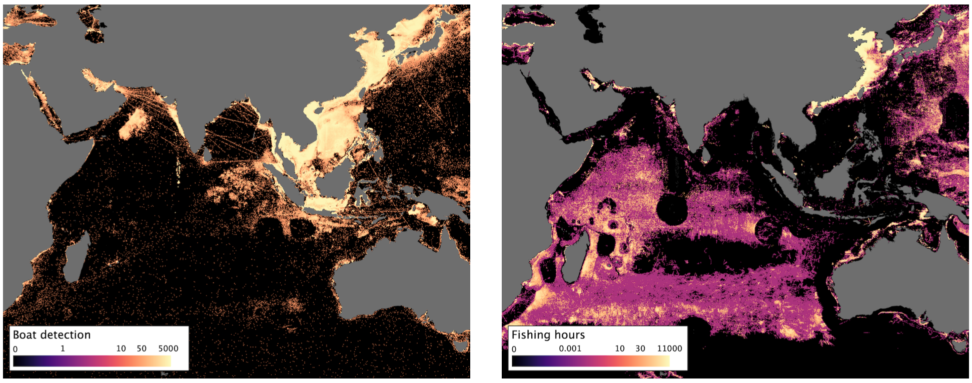
Dependent variable:	**Nutrition**		**Prevalence of anæmia**	
	Consumed seafood	Underweight	Overall	In pregnancy
	(1)	(2)	(3)	(4)
Landed value (small-scale)	0.020	0.003	-0.005	-0.010
	(0.006)	(0.000)	(0.001)	(0.003)
	[0.001]	[0.000]	[0.000]	[0.000]
Landed value (industrial)	-0.029	-0.003	0.005	0.007
	(0.005)	(0.000)	(0.001)	(0.003)
	[0.000]	[0.000]	[0.000]	[0.025]
Mean (dep.var.)	0.296	0.120	0.427	0.455
Identifying observations	49,047	407,232	272,543	14,707
Singleton observations	0	0	0	0
Communities	5,954	24,301	17,371	9,027
Countries	14	32	26	26
Interview year range	2005–2016	1992–2018	2000–2018	2000–2018

Note. Estimates are based on equation (2). Dependent variables are reported in column headers and defined in Appendix A.1. *Landed values* are defined in Section 2. The sample is restricted to communities in the coastal area (see Section 2). All specifications include location FEs using FAO fishing zone, interview month FEs, interview year FEs, fishing zone by interview month FEs, fishing zone by interview year FEs, and control variables (see Section 3; controls include ocean pH in the nearest waters; weather controls correspond to the year of interview). Standard errors (in parentheses) are clustered at the DHS community level, p-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Night-time and extractive fishing. Figure B6 shows an example of the geographical variation. Table B11 reports F-statistics and p-values of a test of heterogeneous effects by intensity of extractive and night-time fishing, produced estimating equation (2) on the set of outcomes presented in Figure 5 by adding interaction terms between ocean pH while *in utero* and each of these variables and testing for joint equality to 0 of the coefficients on the interaction term(s). Table B12 shows descriptive statistics comparing areas with low versus high intensity of both types of fishing.

Figure B6: Geographical distribution of fishing: an example

A. Night-time fishing B. Extractive fishing



Note. Example of the geographical distribution of the intensity of night-time fishing (panel A), and extractive fishing (panel B). The resolution is 0.1°×0.1° In panel A, and 0.25°×0.25° In panel B. Color scales are based on quantiles. Appendix A.1 provides further details about the variables.

Table B11: Test of heterogeneous effects

Type of interaction:	**Linear**		**Linear+quadratic**	
	F (1)	p-value (2)	F (3)	p-value (4)
NMR				
Intensity of extractive fishing	32.111	0.000	16.769	0.000
Intensity of night-time fishing	0.165	0.685	0.260	0.771
Physical development				
Intensity of extractive fishing	2.009	0.157	1.253	0.287
Intensity of night-time fishing	0.447	0.504	1.403	0.248

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 (2) adding interaction terms between *pH in the nearest waters (in utero)* and the variables presented in the left column. The sample is restricted to communities in the coastal area (see Section 2). Standard errors are clustered at the ocean raster data point. All specifications include cluster fixed effects, birth 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 (climatic/weather and demographic). The full list of controls is presented in Section 2. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.1). *pH in the nearest waters (in utero)* is defined in Section 3. Appendix A.1 provides further information on the variables and the list of surveys included in the study. We exclude DHS surveys for Peru as information for the intensity of night-time fishing is not available (see Appendix A.1).

Table B12: Descriptive statistics by degree of extractive and night-time fishing

	Extractive fishing				Night-time fishing			
	High		Low		High		Low	
	Mean (1)	SD (2)	Mean (3)	SD (4)	Mean (5)	SD (6)	Mean (7)	SD (8)
A. Children								
Child is alive	0.91	0.28	0.93	0.26	0.93	0.26	0.92	0.27
Child is female	0.48	0.50	0.48	0.50	0.48	0.50	0.49	0.50
Birth order	2.53	1.79	2.55	1.81	2.49	1.75	2.59	1.86
Number of twins born with the child	0.04	0.25	0.03	0.22	0.03	0.24	0.03	0.23
Years since birth	12.11	7.87	12.36	7.87	12.36	7.86	12.21	7.88
Mother's age at birth	24.34	5.78	24.47	5.76	24.38	5.65	24.47	5.88
pH in the nearest waters (*in utero*)	8.05	0.03	8.05	0.03	8.06	0.03	8.05	0.03
B. Adult women								
Age at first delivery	20.87	4.28	20.89	4.21	20.98	4.22	20.78	4.25
Current age	30.35	9.73	30.79	9.84	30.82	9.72	30.47	9.89
Years of schooling	6.54	5.03	7.54	4.73	7.33	4.89	7.18	4.79
pH in the nearest waters (*in utero*)	8.06	0.03	8.07	0.03	8.07	0.03	8.06	0.03
Primary education or less	0.42	0.49	0.40	0.49	0.40	0.49	0.42	0.49
Married	0.65	0.48	0.68	0.47	0.69	0.46	0.65	0.48
Working	0.59	0.49	0.51	0.50	0.51	0.50	0.56	0.50
Household head is female	0.21	0.41	0.22	0.41	0.19	0.39	0.25	0.43
Household head's age	46.49	13.14	45.91	13.09	46.55	13.10	45.64	13.11
Household members	5.88	3.38	5.50	2.84	5.76	3.24	5.48	2.79
Household wealth	3.78	1.30	3.69	1.28	3.77	1.25	3.66	1.32
Living in urban area	0.64	0.48	0.49	0.50	0.56	0.50	0.50	0.50
Distance from shore	28.56	30.88	32.53	29.80	31.39	30.03	31.13	30.39
Distance from another water body	33.34	30.96	53.89	121.41	28.71	34.67	66.05	137.88
Altitude	189.37	479.06	190.63	371.10	99.23	206.89	281.77	524.73
Latitude	8.78	13.34	11.38	11.38	14.05	11.35	7.03	11.82
Longitude	24.97	58.04	34.16	74.98	45.87	59.94	16.49	76.32
Temperature (° C)	25.80	3.93	26.22	2.79	26.49	2.54	25.68	3.72
Precipitations (mm)	1344.55	591.54	1657.39	687.29	1608.57	722.23	1505.94	617.84
Intensity of extractive fishing	0.20	0.31	0.00	0.00	0.11	0.26	0.02	0.06
Intensity of night-time fishing	0.08	0.10	0.09	0.23	0.17	0.25	0.00	0.00
C. Mortality rates								
Neonatal	29.41	168.95	26.65	161.05	28.28	165.76	26.74	161.33
Postneonatal	25.13	156.53	23.01	149.94	21.67	145.60	25.66	158.11
Child	26.56	160.78	19.54	138.41	20.57	141.94	22.82	149.33
Infant	54.00	226.01	49.16	216.20	49.44	216.79	51.87	221.77
Under-five	81.81	274.08	70.84	256.55	71.72	258.02	76.72	266.15

Note. Descriptive statistics of coastal areas by degree of extractive and night-time fishing. We define areas with above-median extractive or night-time fishing intensity as *high* intensity. We define areas with below-median extractive or night-time fishing intensity as *low* intensity. Coastal area includes all communities within 100 km from the ocean's shore (see Section 2). Means are reported in columns (1), (3), (5), and (7); standard deviations are reported in columns (2), (4), (6), and (8). *Years since birth* is measured at the time of the interview and is independent from the child being alive. *Mortality rates* are relative to 1,000 live births. *pH in the nearest waters (in utero)* is the average pH in the ocean grid cell closest to an individual's community during the 9 months before birth; it refers to the date of birth of the child In panel A and to the date of birth of the woman In panel B. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Seafood prices in the Philippines. We gather prices for the Philippines, a relevant setting in our context: its coastline is the 5$^{\text{th}}$ largest in the world, it is home to 9% of global coral reefs, and depends highly on fish. We gather monthly retail seafood prices at the province level for the period 1990–2018 from the Philippine Statistics Authority (2020). We compute exposure to the average seafood price while *in utero* matching retail prices with individual information using the date and the province of birth. For identification, we rely on deviations in average retail seafood prices in logarithms from the spatially specific (and seasonally-adjusted) long-run trend by adding this variable in equation (2). Table B13 shows the results.

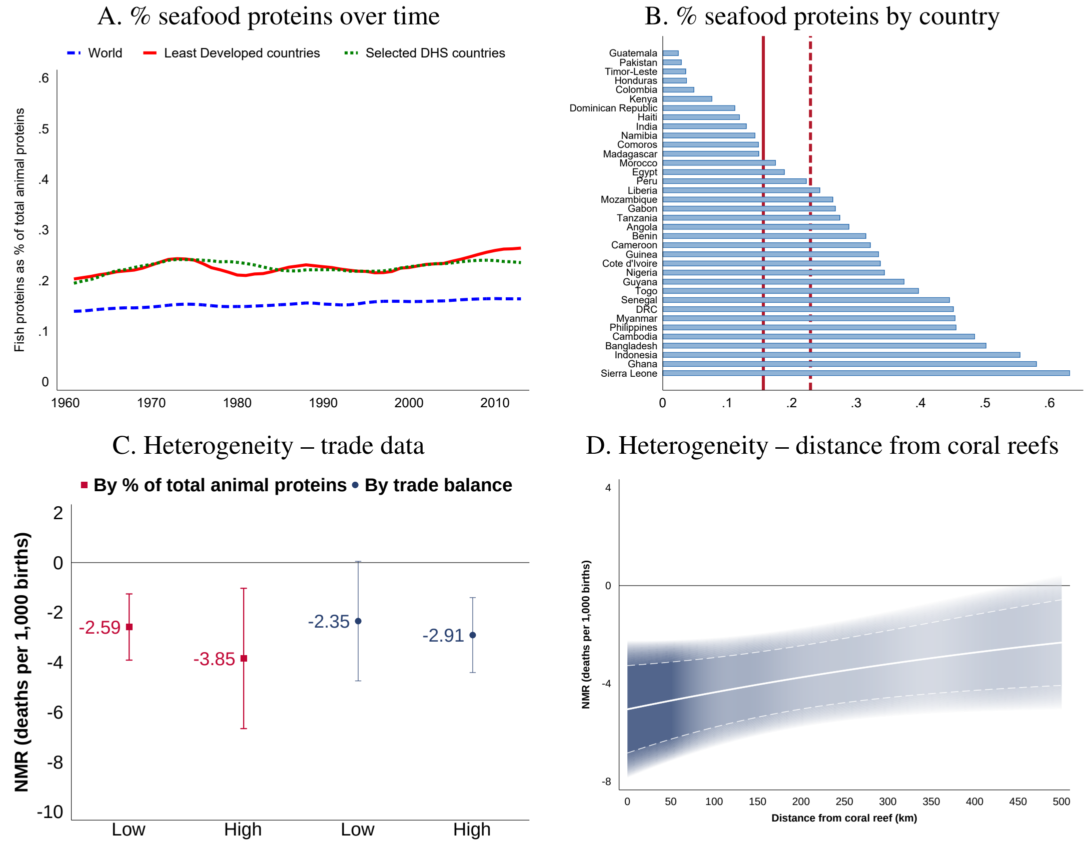
Table B13: Early-life exposure and market prices in the Philippines

Dependent variable:	**NMR (deaths per 1,000 births)**			
	(1)	(2)	(3)	(4)
Average seafood price (*in utero*)	7.274	7.361	7.243	7.580
	(3.445)	(3.443)	(3.436)	(3.368)
	[0.036]	[0.034]	[0.036]	[0.026]
pH in the nearest waters (*in utero*)		-4.997	-4.643	-4.728
		(2.630)	(2.629)	(2.685)
		[0.059]	[0.079]	[0.080]
Mean (dep.var.)	15.410	15.410	15.410	15.412
Identifying observations	82,739	82,739	82,739	82,730
Singleton observations	9	9	9	9
Communities	2,751	2,751	2,751	2,751
Birth year range	1990–2017	1990–2017	1990–2017	1990–2017
Weather controls	-	-	Yes	Yes
Demographic controls	-	-	-	Yes

Note. Estimates are based on equation (2) using the benchmark specification. The sample is restricted to communities in the coastal area of the Philippines and to the period 1990–2018 (due to data availability; see Section 2). *pH in the nearest waters (in utero)* is defined in Section 3. *Average seafood price (in utero)* is the average fish price (including all available prices and reported in logarithms) in the province of birth of the child during the 9 months before birth. Standard errors (in parentheses) are clustered at the district by ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, district by birth year FEs, and district by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Seafood dependency. Figure B7 presents descriptive statistics for seafood dependency and estimates of the heterogeneous effect of ocean pH in the nearest waters (*in utero*) on NMR distinguishing by a country's fish dependency. As a separate measure of dependency on artisanal fishing, panel D focuses on heterogeneity by proximity to **coral reefs** (conditional on being at the shore).

Figure B7: Early-life exposure and neonatal mortality – by seafood dependency



Note. Panels A and B shows the average value of seafood proteins as share of total animal proteins by selected area (weighted by population) or by country, obtained from FAO (2019). In panel B, vertical lines indicate the world's average (solid) and the average among the selected countries (dashed). Panel C shows heterogeneous effects of ocean pH while *in utero* on NMR by dependency on fish proteins as a % of total animal proteins (*high* indicates the top tercile of the 1960–2013 sample distribution), and by trade balance for fish products (*high* indicates the top tercile of the 1976–2017 sample distribution). Marginal effects are estimated using equation (2) restricting the sample to the corresponding group. Because the heterogeneity variable is at country-level, the specification includes community FEs, birth year by birth month FEs, 5°×5° grid cell by birth year FEs, 5°×5° grid cell by birth month FEs, and control variables (see Section 3). Panel D shows marginal effect of ocean pH in the nearest waters (*in utero*) on NMR as a function of shortest distance from a coral reef, estimated using equation (2) interacting ocean pH in the nearest waters (*in utero*) with distance from shore and distance from coral reefs and assuming 0km-distance from the shore. The specification includes community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). The dependent variable is an indicator variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors are clustered at the ocean raster data point. In panel C, we report the 90% confidence interval. In panel D, the 90% confidence interval is indicated by dotted lines, beyond which the intervals are progressively shaded up to the 99% level. Within confidence bounds, color intensity reflects the relative density of observations across iterations. It is calculated by comparing the density in each iteration to a range between the lower bound (adjusted by 0.7) and the 99th percentile of densities across all iterations. These parameters were chosen to improve visibility. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.5 Selective migration

DHS surveys collect information on women's location at the time of the interview and, in only some of our selected surveys, the years a woman has lived in that location. If the respondent migrated, DHS does not provide information on the location before migration. We leverage data for the available countries and assess migration responses following the shock. Table B14 presents estimates of the effect of ocean acidity on the probability that the mother migrated to the community of the interview within the first five years following delivery. Mothers do not adapt along this margin.

Table B14: Post-delivery selective migration

Dependent variable:	**Mother migrated to community 0-4 years after delivery of child**					
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	0.000	-0.000	0.000	0.001	0.002	0.002
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
	[0.994]	[0.954]	[0.966]	[0.752]	[0.518]	[0.530]
Mean (dep.var.)	0.112	0.112	0.112	0.112	0.112	0.112
Identifying observations	1,016,246	1,016,246	1,015,068	1,016,242	1,016,242	1,015,064
Singleton observations	15	15	15	19	19	19
Communities	21,884	21,884	21,884	21,884	21,884	21,884
Countries	28	28	28	28	28	28
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). The dependent variable is an indicator variable equal to 1 if the mother of the child migrated to the community of the interview in the first 5 years of life of the child, and 0 otherwise. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, and control variables (see Section 3). Controls for local seasonality are either country by birth month FEs or 5°×5° cell by birth month FEs. Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Results presented in Figure B10 in Section B.11 indicate that our effect is indeed specific to the location of the interview. To further address concerns about matching children with the correct exposure location, Table B15 estimates the effect of ocean acidity on neonatal mortality for different sub-samples selected based on whether the respondent was present in the location of the interview at the time of exposure. Estimates are based on our preferred specification (specification 3 in Table 3).

To address missing migration data in surveys, we identify respondents who were not present in the location of the interview at the time of exposure to ocean pH in the nearest waters using two approaches. First, we utilize information collected by DHS surveys. We refer to these surveys as *surveys with migration data*. Second, we expand information about migration to all surveys conducted for a country if at least one round of data collection includes the migration question. In this case, we impute missing information using (Poisson) LASSO regressions. In each regression, we consider as predictors numerical variables (various aspects of women's characteristics, including current age, age at first birth, total number of births, number of children, number of living children, number of deceased children, age of the household head, and years of education), and factor variables (categorical variables that are included as indicators for each of their values, including a woman's pregnancy status, year of birth, and whether she has ever been married, finished at least primary education, has access to electricity, owns a television, owns a radio, owns a refrigerator, and owns a car). For each country, we train the model on a random half of the sample with available information on migration, employing three different selection methods: cross-validation, Bayesian information criterion, and adaptive cross-validation. We predict the number of years a woman has spent in the location of the interview in the surveys with missing information about migration using the selection method that performs best in out-of-sample prediction.

In columns (1)–(4), we focus on our full sample, but exclude children whose mothers moved to the location of the interview after the gestation period. Thus, we exclude children who, according to available information, were not in the location of the interview while *in utero*. In columns (1)–(2), we exclude those whose mothers migrated after the gestation period (assumed to be the year before the year of birth). In columns (3)–(4), we also exclude those who migrated after the year prior to the gestation period (assumed to be two years before the year of birth). Columns (1) and (3) use only survey data, while columns (2) and (4) integrate imputed data. Note that this approach combines surveys with and without information. Despite this limitation, estimates are, in absolute terms, larger but not statistically different compared to column (3) in Table 3. This suggests that excluding children who were not in the location of the interview while *in utero* for all surveys would lead to larger estimates.

In columns (5)–(6), we instead focus on the sample of migrants by restricting the sample to surveys with migration data and selecting children whose mothers reported having relocated to the location of the interview at some point during their life. In column (5), we include only children whose mothers migrated to the location of the interview in the year before the year of birth (during the gestation) or earlier. In column (6), to exclude temporary or short-term migrants, we further restrict the sample by including only long-term migrants, i.e., those who migrated to the location of the interview at least 17 years before (the median time a migrant has been living in the location).

Table B15: Table 3 – excluding children not in the interview location while *in utero*

Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample of children:	All	All	All	All	Mother is migrant	Mother is long-term migrant
	(1)	(2)	(3)	(4)	(5)	(6)
A. Benchmark specification						
pH in the nearest waters (*in utero*)	-1.915	-1.954	-1.912	-1.966	-1.964	-2.650
	(0.774)	(0.770)	(0.771)	(0.765)	(1.143)	(0.981)
	[0.014]	[0.011]	[0.013]	[0.011]	[0.087]	[0.007]
Mean (dep.var.)	30.070	29.582	30.158	29.549	27.631	30.399
Identifying observations	1,316,559	1,281,700	1,274,374	1,230,702	305,710	157,800
Singleton observations	115	117	149	153	885	836
Communities	31,236	31,233	31,175	31,170	19,766	15,193
Countries	36	36	36	36	28	28
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
B. Within-sibling specification						
pH in the nearest waters (*in utero*)	-2.378	-2.480	-2.465	-2.561	-2.014	-2.802
	(1.016)	(1.012)	(0.905)	(0.899)	(1.755)	(1.165)
	[0.020]	[0.015]	[0.007]	[0.005]	[0.252]	[0.017]
Mean (dep.var.)	31.386	30.941	31.572	31.022	30.106	31.413
Identifying observations	1,203,429	1,165,331	1,161,902	1,114,350	259,911	150,065
Singleton observations	114,805	118,046	114,129	118,013	46,998	8,717
Communities	30,987	30,981	30,767	30,760	18,992	14,945
Countries	36	36	36	36	28	28
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Selected surveys:	All (Appendix Table A2)				With migration data	
Exclusion condition:	Mother migrated after gestation		Mother migrated after the year before gestation		Mother migrated after gestation	
Source of migration data:						
Survey	Yes	-	Yes	-	Yes	Yes
Survey + imputed	-	Yes	-	Yes	-	-

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to coastal areas (see Section 2), and to the sub-samples reported at the bottom of the table. *Surveys with migration data* includes all surveys in which information about migration is available. The *exclusion condition* indicates when the children is dropped from the sample and refers to the time when the mother of the child migrated to the location of the interview (if the condition is true, the observation is dropped). *Long-term migrants* are respondents that migrated to the location of interview at least 17 years before the interview (the median time in the location of interview among migrants). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, and country by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.6 Issues related to identification and measurement

Selection into identification. To verify the validity of our estimates of selection into identification, columns (1)–(3) in Table B16 present estimates of the benchmark specification restricting the sample to the identifying observations of the within-sibling specification, while columns (4)–(6) provide estimates of the effect using the identifying sample of the within-sibling specification and re-weighting as in Miller et al. (2021). To estimate the probability of being in the identifying sample of the within-sibling specification, we use a probit model and include mother and weather characteristics.

Table B16: The effect on neonatal mortality: identification checks

Dependent variable:	**NMR (deaths per 1,000 births)**					
Check:	*Benchmark specification with within-sibling identifying sample*			*Re-weighting procedure*		
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.939	-1.950	-2.000	-2.740	-2.785	-2.883
	(0.792)	(0.790)	(0.776)	(0.996)	(1.001)	(0.990)
	[0.015]	[0.014]	[0.010]	[0.006]	[0.006]	[0.004]
Mean (dep.var.)	31.476	31.476	31.476	31.478	31.478	31.478
Identifying observations	1,474,941	1,474,941	1,474,941	1,474,349	1,474,349	1,474,349
Singleton observations	0	0	0	108,741	108,741	108,741
Communities	31,356	31,356	31,356	31,356	31,356	31,356
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes

Note. In columns (1)–(3), estimates are based on equation (2) using the benchmark specification and restricting the sample to the identifying sample of the within-sibling specification. In columns (4)–(6), estimates are based on equation (2) using the within-sibling specification and the re-weighting procedure of Miller et al. (2021). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, and 5°×5° cell by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Balance of mother characteristics. Table B17 presents estimates of equation (2) without control variables where the dependent variable is replaced by demographic controls.

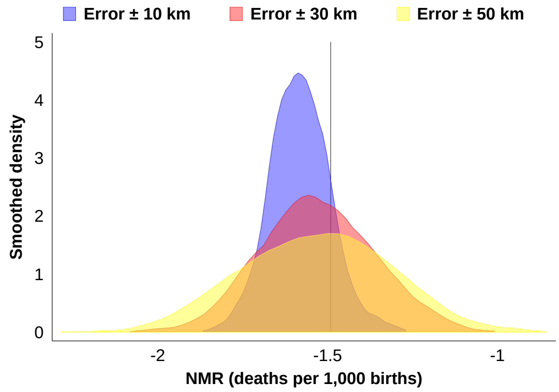
Table B17: Placebo test: balance on observable characteristics

Dependent variable:	**Age**			**Education**		**Other characteristics**		
	First delivery	Delivery	Interview	Years	Primary or less	Married	Working	Wealth
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
pH in the nearest waters (*in utero*)	0.009	0.002	0.002	0.014	0.000	-0.000	-0.001	0.002
	(0.016)	(0.021)	(0.021)	(0.016)	(0.002)	(0.001)	(0.002)	(0.003)
	[0.558]	[0.934]	[0.935]	[0.382]	[0.981]	[0.787]	[0.654]	[0.396]
Mean (dep.var.)	20.094	25.086	36.682	4.916	0.669	0.887	0.558	3.120
Identifying observations	1,583,706	1,583,706	1,583,706	1,583,065	1,583,630	1,583,705	1,454,950	1,339,312
Singleton observations	25	25	25	25	25	25	28	31
Communities	31,380	31,380	31,380	31,380	31,380	31,380	28,828	27,039
Countries	36	36	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (2) without control variables. The dependent variable is an indicator variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. The full set of controls is reported in the bottom panel of the table, control variables are excluded. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Measurement error in the distance from the ocean. Figure B8 shows the distribution of the coefficients estimating iteratively equation (2) simulating a random error in the measurement of the distance from the shoreline of ±10, 30, and 50km.

Figure B8: The effect on neonatal mortality, by magnitude of measurement error



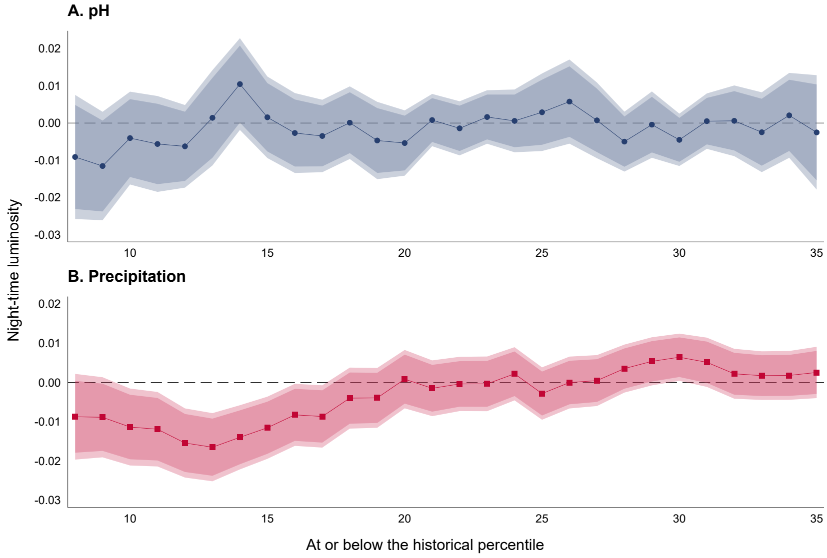
Note. Distribution of the marginal effect of ocean pH in the nearest waters (*in utero*) on NMR, estimated using equation (2) and introducing measurement error in the distance from the ocean. *pH in the nearest waters (in utero)* is defined in Section 3. The procedure performs 1,000 iterations. The vertical line represents our benchmark point estimate (column 3 in Table 3). 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 communities in the coastal area (see Section 2). Appendix A.1 provides further information on the variables and the full list of surveys included in the study.

B.7 Aggregate shocks

Comparison with droughts. We compare two shocks: one to agricultural productivity, as captured by the presence of a drought, and one to ocean pH. The first surely captures an income shock given the importance of rainfall on agriculture and the reliance of L&MICs on this economic activity. We generate a gridded dataset with a spatial resolution of 0.5°×0.5°, and construct a yearly panel of night-time luminosity for the grid cells containing coastal DHS communities. We estimate equation (2) at the grid-cell level, matching each grid to shock measures. To deal with zeros, we apply the inverse hyperbolic sine transformation on night-time luminosity. We define droughts using indicator variables taking value one when annual precipitations in the grid cell are at or below a defined percentile of the grid cell's historical precipitations distribution (see, e.g., Burke et al., 2015 for this approach). For comparability, we follow the same approach to define an *acidity shock*. These shocks do not occur simultaneously, with a raw contemporaneous correlation of -14.4%. Figure B9 presents the estimates of the effect on night-time luminosity of an acidity shock (panel A) and a drought (panel B) across various percentile bounds (reported in the horizontal axis) used to define these events.

Comparison with conflict. Using information about conflict events from the Uppsala Conflict Data Programme (UCDP) database at the 5°×5° resolution, we estimate equation (2) adding controls for the presence and the intensity of conflict while *in utero*. Table B18 presents estimates of the effect on NMR. Due to data availability, the birth year range is reduced to children born after 1984. For comparability, columns (3) and (6) are therefore restricted to the sample included in column (1) and (4), respectively.

Figure B9: Night-time luminosity: comparing acidification with droughts



Note. Estimates are based on equation (2). The dependent variable is the inverse hyperbolic sine-transformed satellite-based night-time luminosity at year t in grid cell i, ranging in levels between 0 (lowest) and 1 (highest). In panel A, an *acidity shock* is defined by a binary variable with a value of 1 when the yearly average pH in the nearest ocean grid cell is below the x^{th} percentile of the historical distribution of grid cell i, and 0 otherwise. In panel B, a *drought* is defined by a binary variable with a value of 1 when annual precipitations in grid cell i are below the x^{th} percentile of its historical precipitations distribution, and 0 otherwise. All specifications include grid cell FEs and year by macro-region FEs. Macro-regions are defined by 2.5°×2.5° resolution grid cells to guarantee sufficient variation over time of both acidity shocks and droughts. In panel A, standard errors are clustered at the ocean raster data point, and *controls* include the oxygen concentration in the nearest ocean grid cell, rainfall, temperature, and their interaction. In panel B, standard errors are clustered at the grid cell level, and *controls* include temperature levels. The sample is limited to grid cells containing coastal DHS communities (see Section 2). Further information on variables and the list of surveys is provided in Appendix A.1.

Labor supply. Table B19 estimates the effect of the contemporaneous ocean pH in the nearest waters on the labour supply of female respondents and their partners (when available). Columns (1) and (3) focus on any job, while columns (2) and (4) focus on agricultural and fishing jobs. Agriculture and fishing are distinct activities only in a few surveys, we grouped these activities together to maximize the number of observations.

Table B18: Comparing the effect size of ocean pH and conflict

Dependent variable:	**NMR (deaths per 1,000 births)**					
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.006	-1.014	-1.010	-1.603	-1.614	-1.612
	(0.629)	(0.632)	(0.629)	(0.799)	(0.796)	(0.799)
	[0.110]	[0.109]	[0.109]	[0.045]	[0.043]	[0.044]
At least 1 violent event (*in utero*)	1.702			1.715		
	(1.107)			(1.128)		
	[0.125]			[0.129]		
In-utero fatalities		1.591			1.616	
		(0.848)			(0.840)	
		[0.061]			[0.055]	
Mean (dep.var.)	27.657	27.657	27.657	27.657	27.657	27.657
Identifying observations	1,257,991	1,257,991	1,257,991	1,257,984	1,257,984	1,257,984
Singleton observations	82	82	0	89	89	0
Communities	31,284	31,284	31,284	31,284	31,284	31,284
Countries	36	36	36	36	36	36
Birth year range	1984–2018	1984–2018	1984–2018	1984–2018	1984–2018	1984–2018
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, and control variables (see Section 3). Controls for local seasonality are either country by birth month FEs or $5°\times5°$ cell by birth month FEs. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B19: Contemporaneous exposure and labor supply

Dependent variable:	**Respondent works in ...**		**Partner works in ...**	
	Any job	Agriculture/fishing	Any job	Agriculture/fishing
	(1)	(2)	(3)	(4)
pH in the nearest waters	-0.002	-0.003	0.002	0.004
	(0.003)	(0.003)	(0.008)	(0.007)
	[0.523]	[0.223]	[0.842]	[0.556]
Mean (dep.var.)	0.472	0.089	0.897	0.906
Identifying observations	621,284	599,315	42,285	34,138
Singleton observations	4	4	0	0
Grid cells	821	821	143	143
Communities	28,865	28,846	2,989	2,986
Countries	36	36	7	7
Interview year range	1990–2018	1990–2018	2015–2018	2015–2018

Note. Estimates are based on equation (2). Dependent variables are indicator variables equal to 1 if the respondent reports being working in the corresponding job at the time of the interview, and 0 otherwise. *pH in the nearest waters* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the female respondent's community in the month of the interview. The sample is restricted to coastal areas (see Section 2). Columns (1)–(2) use the full sample of women, whereas columns (3)–(4) restrict the sample to women who are either the household head or their partner. All specifications include location FEs using grid cells at the $1°\times1°$ resolution, interview month FEs, interview year FEs, country by interview month FEs, country by interview year FEs, and control variables (see Section 3; weather controls correspond to the year of interview). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.8 Responses in food consumption

Table B20 shows estimates of the effect of ocean pH at the time of the interview on the probability of consuming different food items, considering macronutrients in columns (1)–(3), and micronutrients in column (4).

Table B20: Contemporaneous exposure and food consumption among women

Dependent variable:	Other proteins	Carbohydrates	Fats	Other iron-rich food
	(1)	(2)	(3)	(4)
pH in the nearest waters	0.011	-0.010	-0.021	0.005
	(0.013)	(0.006)	(0.014)	(0.008)
	[0.401]	[0.107]	[0.146]	[0.532]
Mean (dep.var.)	0.568	0.605	0.493	0.626
Identifying observations	49,052	49,159	47,151	49,203
Singleton observations	2	2	2	2
Grid cells	239	239	239	239
Communities	5,954	5,956	5,588	5,956
Countries	14	14	14	14
Interview year range	2005–2016	2005–2016	2005–2015	2005–2016

Note. Other proteins and *other iron-rich food* includes only food items other than seafood. Estimates are based on equation (2). *pH in the nearest waters* is the average pH (multiplied by a factor of 100) in the ocean grid cell closest to the female respondent's community in the month of the interview. The sample is restricted to coastal areas (see Section 2). All specifications include location FEs using grid cells at the $1° \times 1°$ resolution, interview month FEs, interview year FEs, country by interview month FEs, country by interview year FEs, and control variables (see Section 3; weather controls correspond to the year of interview). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.9 Robustness to assuming a shorter gestation period

Table B21 replicates Table 3 assuming a gestation period of 8 months.

Table B21: Table 3 – assuming shorter gestation period

Dependent variable:	NMR (deaths per 1,000 births)					
	(1)	(2)	(3)	(4)	(5)	(6)
A. Benchmark specification						
pH in the nearest waters (*in utero*)	-0.886	-0.845	-0.893	-1.794	-1.732	-1.742
	(0.539)	(0.551)	(0.531)	(0.610)	(0.627)	(0.611)
	[0.101]	[0.126]	[0.093]	[0.003]	[0.006]	[0.005]
Mean (dep.var.)	30.473	30.473	30.474	30.474	30.474	30.475
Identifying observations	1,583,706	1,583,706	1,581,815	1,583,703	1,583,703	1,581,812
Singleton observations	25	25	25	28	28	28
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
B. Within-sibling specification						
pH in the nearest waters (*in utero*)	-1.399	-1.373	-1.465	-2.124	-2.108	-2.257
	(0.654)	(0.668)	(0.654)	(0.827)	(0.826)	(0.821)
	[0.033]	[0.041]	[0.026]	[0.011]	[0.011]	[0.006]
Mean (dep.var.)	31.476	31.476	31.476	31.476	31.476	31.476
Identifying observations	1,474,945	1,474,945	1,474,945	1,474,941	1,474,941	1,474,941
Singleton observations	108,786	108,786	108,786	108,790	108,790	108,790
Communities	31,356	31,356	31,356	31,356	31,356	31,356
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3, but assuming a gestation period of 8 months instead of 9. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs. Seasonality is captured by either country by birth month FEs or $5° \times 5°$ cell by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.10 Early-life mortality rates

Table B22 presents estimates of the effect of ocean pH in the nearest waters (experienced *in utero*) on early-life mortality.

Table B22: The effect on early-life mortality rates

Dependent variables:	**Post-neonatal (PMR)**	**Child (CMR)**	**Infant (IMR)**	**Under-5 (U5MR)**
	(1)	(2)	(3)	(4)
pH in the nearest waters (*in utero*)	1.076	-0.044	-0.406	-0.434
	(0.490)	(0.330)	(0.666)	(0.795)
	[0.028]	[0.895]	[0.542]	[0.585]
Mean (dep.var.)	27.919	26.932	57.543	82.925
Identifying observations	1,533,608	1,490,789	1,581,815	1,581,815
Singleton observations	25	26	25	25
Communities	31,378	31,377	31,380	31,380
Countries	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs. The full list of controls is presented in Section 3 and refer to weather and demographic covariates. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.11 Supplementary results on inference

Clustering. Table B23 shows estimates of equation (2) for NMR using different assumptions for the clustering of standard errors (reported in column).

Table B23: Robustness to clustering assumptions about standard errors

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	Community
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.491	-1.491	-1.491	-1.491	-1.491	-1.491
	(0.664)	(0.625)	(0.359)	(0.667)	(0.645)	(0.610)
	[0.025]	[0.017]	[0.000]	[0.026]	[0.023]	[0.015]
Mean (dep.var.)	30.474	30.474	30.474	30.474	30.474	30.474
Identifying observations	1,581,815	1,581,815	1,581,815	1,581,815	1,581,815	1,581,815
Singleton observations	25	25	25	25	25	25
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to the coastal area (Section 2). All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Standard errors are reported in parenthesis, *p*-values are reported in brackets. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Permutation-based inference. Focusing on Table 3, we implement three different tests. In the *birth dates within communities* test, birth dates are randomly reassigned within each community. In the *birth dates within countries* test, birth dates are randomly reassigned within each country, independently from the community and the survey. In the *across communities* test, mothers (and their children) are randomly allocated to different communities, independently from the country and the survey. Figure B10 shows the distribution of estimates in each test and the empirical p-values.

Figure B10: The effect on neonatal mortality: permutation-based inference

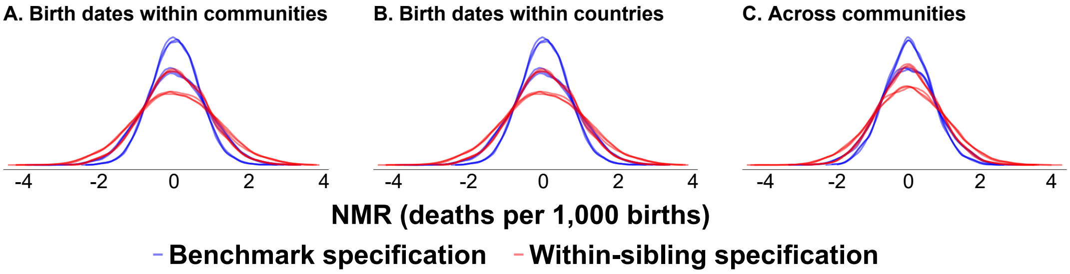


	Table 3 coefficients	Empirical p-values		
		A	B	C
Benchmark specification				
Specification 1	-1.417	0.012	0.012	0.014
Specification 2	-1.419	0.012	0.012	0.016
Specification 3	-1.491	0.009	0.009	0.010
Specification 4	-2.117	0.006	0.006	0.005
Specification 5	-2.094	0.008	0.008	0.006
Specification 6	-2.083	0.008	0.008	0.005
Within-sibling specification				
Specification 1	-2.065	0.007	0.007	0.005
Specification 2	-2.126	0.006	0.006	0.005
Specification 3	-2.232	0.005	0.005	0.005
Specification 4	-2.459	0.007	0.007	0.006
Specification 5	-2.502	0.009	0.009	0.007
Specification 6	-2.612	0.007	0.007	0.005

Note. Distributions of marginal effects of ocean pH in the nearest waters (*in utero*) on NMR when birth dates are randomly reassigned. Tests are described in Appendix B.11, and are based on 5,000 iterations. *pH in the nearest waters (in utero)* is defined in Section 3. Each graph depicts the empirical distribution of estimates using the specification in each of the columns in Table 3. In each iteration, marginal effects are estimated using equation (2). The sample is restricted to communities in the coastal area (see Section 2). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.12 Parental investments and adaptation

Table B24 shows estimates of shows estimates of the effect of *in-utero* exposure to the ocean pH on parental health investments and on health outcomes associated with poor contemporaneous nutrition. Figure B11 shows instead the effect of ocean pH on the probability of being underweight, distinguishing by the age of the child at the time of the measurement. The dependent variable is an indicator variable equal to 1 if the child has a weight-for-age z-score below negative 2 standard deviations, and 0 otherwise. Table B25 presents the same estimates presented in Table 4, but adding an interaction term between ocean pH and indicator variables capturing different dimensions. Panel

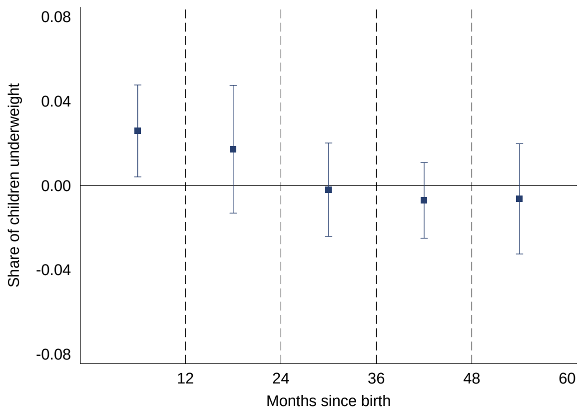
A focuses on whether the household is part of the richest half of the sample, panel B on whether the mother is married, and panel C on whether the mother has at least primary school education.

Table B24: Parental investments and postnatal nutritional outcomes

	Antenatal		**Delivery**		**Nutrition**	
Dependent variables:	Number of visits	w/ health profes-sional	In health center	w/ health profes-sional	Morbidity	Anæmia
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-0.001	0.004	0.003	-0.003	-0.002	0.002
	(0.009)	(0.002)	(0.002)	(0.003)	(0.004)	(0.006)
	[0.940]	[0.025]	[0.063]	[0.221]	[0.677]	[0.765]
Mean (dep.var.)	1.643	0.442	0.354	0.638	0.391	0.558
Identifying observations	263,819	494,305	491,838	267,900	339,407	114,370
Singleton observations	1,099	131	131	1,032	871	1,437
Communities	29,943	31,304	31,163	30,031	29,932	15,844
Countries	36	36	36	36	36	27
Birth year range	1985–2018	1972–2018	1972–2018	1985–2018	1985–2018	1995–2018

Note. Estimates are based on equation (2). The dependent variables are reported in the column's header. *Morbidity* is an indicator variable equal to 1 if the child has experienced fever, cough or diarrhea in the weeks previous to the interview, and 0 otherwise. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. For cross-survey comparability, the samples are restricted to the last birth, independently from the child being alive. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Figure B11: Effect on the probability of being underweight



Note. Marginal effect of *pH in the nearest waters (in utero)* on the probability of the child to be underweight. *pH in the nearest waters (in utero)* is defined in Section 3. The dependent variable is an indicator variable equal to 1 if the child has a weight-for-age z-score below negative 2 standard deviations, and 0 otherwise. Confidence intervals are computed at 90% level. Estimates are based on equation (2) including community FEs, birth month by birth year FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Standard errors are clustered at the ocean raster data point. Appendix A.1 provides further information on the variables and for the list of surveys included in the study.

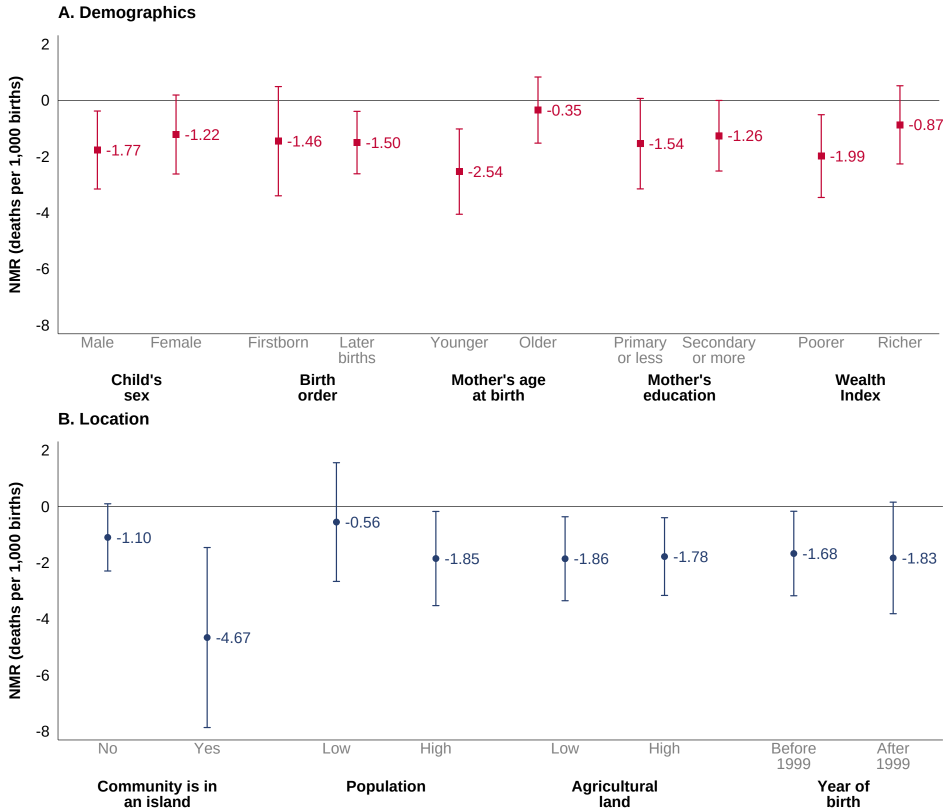
Table B25: Early-life exposure and parental adaptation – heterogeneity

Dependent variables:	Antenatal	Delivery	Postnatal		
			Healthcare	Breastfed	Vaccinated
	(1)	(2)	(3)	(4)	(5)
A. By socio-economic status					
pH in the nearest waters (*in utero*)	0.003	-0.005	0.005	0.001	-0.006
	(0.007)	(0.005)	(0.009)	(0.003)	(0.006)
	[0.661]	[0.295]	[0.615]	[0.681]	[0.282]
× Richer household	0.004	0.004	-0.002	-0.000	0.002
	(0.003)	(0.004)	(0.004)	(0.001)	(0.003)
	[0.201]	[0.246]	[0.599]	[0.745]	[0.480]
Richer household	0.023	0.072	0.014	-0.004	0.015
	(0.011)	(0.014)	(0.015)	(0.004)	(0.010)
	[0.040]	[0.000]	[0.336]	[0.345]	[0.110]
Mean (dep.var.)	1.747	1.348	0.441	0.969	0.295
Identifying observations	223,215	217,069	101,069	172,683	179,042
Singleton observations	973	1,046	3,077	2,077	1,965
Communities	25,759	25,669	18,445	24,039	24,198
Countries	36	36	34	36	36
Birth year range	1997–2018	1997–2018	2002–2018	1999–2018	1999–2018
B. By marital status					
pH in the nearest waters (*in utero*)	0.002	-0.003	0.005	0.001	-0.009
	(0.007)	(0.005)	(0.009)	(0.003)	(0.006)
	[0.791]	[0.573]	[0.576]	[0.790]	[0.139]
× Married	0.002	-0.001	-0.001	0.000	0.004
	(0.003)	(0.003)	(0.002)	(0.001)	(0.002)
	[0.581]	[0.639]	[0.708]	[0.539]	[0.106]
Married	0.050	0.027	-0.004	0.005	0.031
	(0.013)	(0.011)	(0.008)	(0.003)	(0.008)
	[0.000]	[0.011]	[0.671]	[0.040]	[0.000]
Mean (dep.var.)	1.698	1.299	0.441	0.972	0.293
Identifying observations	263,696	256,547	101,075	206,350	210,371
Singleton observations	1,100	1,191	3,078	2,336	2,212
Communities	29,942	29,822	18,445	28,029	27,964
Countries	36	36	34	36	36
Birth year range	1985–2018	1985–2018	2002–2018	1987–2018	1987–2018
C. By education					
pH in the nearest waters (*in utero*)	0.001	-0.005	0.004	0.000	-0.007
	(0.007)	(0.005)	(0.009)	(0.003)	(0.005)
	[0.849]	[0.369]	[0.673]	[0.939]	[0.231]
× At least primary schooling	0.003	0.001	0.000	0.001	0.002
	(0.004)	(0.004)	(0.003)	(0.001)	(0.002)
	[0.489]	[0.839]	[0.866]	[0.008]	[0.311]
At least primary schooling	0.037	0.055	0.030	0.001	0.020
	(0.014)	(0.016)	(0.010)	(0.003)	(0.007)
	[0.007]	[0.001]	[0.003]	[0.665]	[0.006]
Mean (dep.var.)	1.698	1.299	0.441	0.972	0.293
Identifying observations	263,697	256,548	101,075	206,350	210,372
Singleton observations	1,100	1,191	3,078	2,336	2,212
Communities	29,942	29,822	18,445	28,029	27,964
Countries	36	36	34	36	36
Birth year range	1985–2018	1985–2018	2002–2018	1987–2018	1987–2018

Note. Estimates are based on equation (2), adding an interaction term between ocean pH and different indicator variables. *Richer household* is an indicator variable equal for whether the household's wealth index is above the sample median. *Married* and *at least primary schooling* are indicator variables for whether the mother is married or has completed at least primary education, respectively. The dependent variables and sample restrictions are reported in Table 4. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures. Column (3) excludes the survey(s) for Indonesia and Morocco because information is not available in the corresponding surveys.

To test for the presence of adaptation, we introduce two additional checks related to the effect on neonatal mortality. First, to verify whether observable characteristics that could explain adaptation predict the effect on neonatal mortality, Figure B12 presents estimates of heterogeneous effects on neonatal mortality, distinguishing by children and mothers' demographics (panel A) and for location characteristics (panel B). Second, Table B26 re-estimates Table 3 interacting ocean pH while *in utero* with a location's initial conditions, namely the (standardised) average ocean pH from 1972–1975. Heterogeneous impacts by initial conditions would indicate adaptation because these communities would have had more time to adapt.

Figure B12: Ocean acidity and neonatal mortality – split sample heterogeneity



Note. Heterogeneous effects of *pH in the nearest waters (in utero)* on NMR by child and mother's demographics (panel A), and by location's characteristics (panel B). *pH in the nearest waters (in utero)* is defined in Section 3. Marginal effects are estimated using equation (2) restricting the sample to the corresponding group. For mother's age at birth, wealth index, agricultural land, population, we create an indicator 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. confidence intervals are computed at 90% level. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B26: Ocean acidity and neonatal mortality – heterogeneity by initial conditions

	Dependent variable: NMR (deaths per 1,000 births)					
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	-1.970	-2.017	-2.195	-2.273	-2.302	-2.329
	(0.717)	(0.697)	(0.685)	(0.783)	(0.785)	(0.771)
	[0.006]	[0.004]	[0.001]	[0.004]	[0.004]	[0.003]
× initial conditions	1.110	1.106	1.303	1.119	1.095	1.299
	(0.322)	(0.325)	(0.319)	(0.329)	(0.329)	(0.315)
	[0.001]	[0.001]	[0.000]	[0.001]	[0.001]	[0.000]
Mean (dep.var.)	30.473	30.473	30.474	30.474	30.474	30.475
Identifying observations	1,583,706	1,583,706	1,581,815	1,583,703	1,583,703	1,581,812
Singleton observations	25	25	25	28	28	28
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018	1972–2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Note. Estimates are based on equation (2). *pH in the nearest waters (in utero)* is defined in Section 3. *Initial conditions* refer to a location's (standardised) average between 1972–1975. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. All specifications include community FEs, birth year by birth month FEs, country by birth year FEs. Controls for local seasonality are either country by birth month FEs or 5°×5° cell by birth month FEs. The full list of controls is presented in Section 3. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

B.13 Physical development and adulthood outcomes

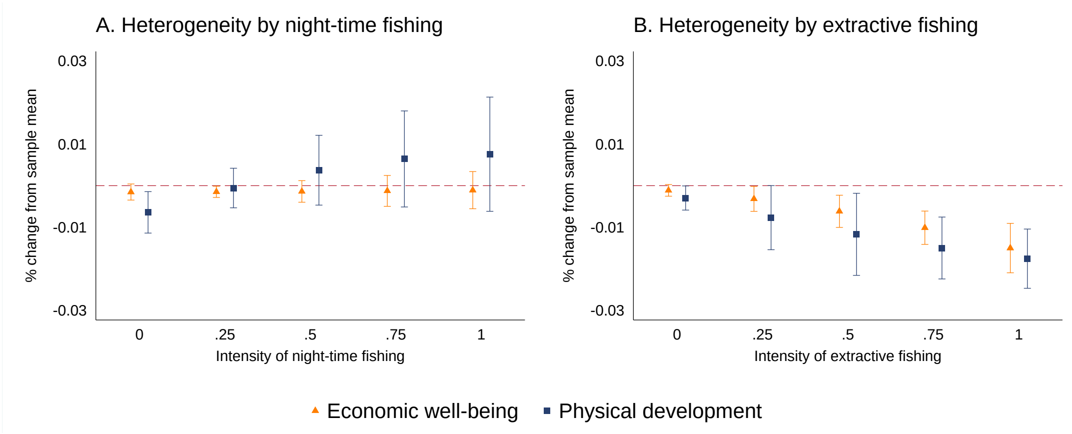
Tables B27 and B28 replicate Table 5, but providing estimates separately for boys and girls and trimming observations in which z-scores are smaller than the 1st or larger than the 99th percentiles of the z-score distribution. Table B29 replicates Table 5 using anthropometrics among adults. For adults older than 18 years old, z-scores refer to standard reference curves at age 18, when physical development is assumed to be complete. Table B30 shows estimates on economic well-being. In column (1), we proxy economic well-being with a measure of wealth, computed as an asset-based index. Columns (2)–(6) focus on correlates of well-being, such as fertility (number of births), years of schooling, cognitive skills (determined by the ability to read a sentence), and labor supply. To account for family structure and capture intra-household dynamics, columns (1) and (6) select only women that are either a household head or their partner, while columns (2)–(5) refer to the full sample of women aged 15–49. Economic outcomes measured at household level or influenced by intra-household dynamics are more likely to be observed in women that are married and leading a family. Figure B13 shows heterogeneity of the effects on physical development and economic well-being by the intensity and type of fishing.

Table B27: Table 5 – estimates by sex at birth

Dependent variables:	*z*-scores		Indicators	
	W/h	**H/a**	**Wasted**	**Stunted**
	(1)	(2)	(3)	(4)
A. Boys				
pH in the nearest waters (*in utero*)	-0.002	-0.032	0.009	0.011
	(0.018)	(0.020)	(0.006)	(0.007)
	[0.902]	[0.103]	[0.142]	[0.125]
Mean (dep.var.)	-0.338	-1.041	0.084	0.243
Identifying observations	115,472	115,528	115,472	115,528
Singleton observations	3,370	3,437	3,370	3,437
Communities	21,209	21,423	21,209	21,423
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018
B. Girls				
pH in the nearest waters (*in utero*)	-0.014	0.024	-0.004	-0.013
	(0.019)	(0.020)	(0.007)	(0.006)
	[0.446]	[0.227]	[0.595]	[0.037]
Mean (dep.var.)	-0.285	-0.942	0.076	0.227
Identifying observations	111,095	111,157	111,095	111,157
Singleton observations	3,508	3,577	3,508	3,577
Communities	20,843	21,052	20,843	21,052
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018

Note. Estimates are based on equation (2) estimated separately for boys (panel A) and girls (panel B). Dependent variables are reported in the column's header and defined in Appendix A.1. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. Specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures. All panels exclude the survey(s) for Indonesia, Pakistan, and the Philippines because information is not available in the correspondent surveys.

Figure B13: Acidity shocks and resource exploitation – effects on adults



Note. Estimated impacts of a one-standard-deviation increase in acidity on long-run indicators as a function of intensity of fishing. Intensities range between 0 (no presence) and 1 (high). Estimates are based on equation (2) introducing interaction terms between ocean pH and a quadratic polynomial in the corresponding intensity. *Economic well-being* is a household-level asset-based index which ranges from 1 (poorest) to 5 (richest). *Physical development* is the average *z*-score of available anthropometric measures. The sample is restricted to communities in the coastal area (see Section 2). We exclude surveys for Peru as information for the intensity of night-time fishing is not available (see Appendix A.1). All specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables (see Section 3). Standard errors are clustered at the ocean raster data point. Confidence intervals are computed at 90% level. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

Table B28: Table 5 – trimming z-scores

Dependent variables:	z-scores		Indicators	
	Weight-for-height	**Height-for-age**	**Wasted**	**Stunted**
	(1)	(2)	(3)	(4)
A. Overall effect				
pH in the nearest waters (*in utero*)	-0.027	0.009	0.007	0.002
	(0.016)	(0.014)	(0.003)	(0.004)
	[0.093]	[0.534]	[0.034]	[0.637]
Mean (dep.var.)	-0.321	-0.994	0.072	0.228
Identifying observations	227,589	227,849	227,589	227,849
Singleton observations	1,172	1,176	1,172	1,176
Communities	24,710	25,029	24,710	25,029
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018
B. Heterogeneity by sex				
pH in the nearest waters (*in utero*)	-0.019	0.003	0.011	0.006
	(0.017)	(0.019)	(0.006)	(0.007)
	[0.262]	[0.860]	[0.065]	[0.439]
× female	0.001	0.036	-0.012	-0.019
	(0.021)	(0.024)	(0.010)	(0.011)
	[0.974]	[0.138]	[0.263]	[0.068]
Mean (dep.var.)	-0.324	-1.003	0.072	0.230
Identifying observations	221,698	221,848	221,698	221,848
Singleton observations	7,063	7,177	7,063	7,177
Communities	23,843	24,148	23,843	24,148
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018

Note. Estimates are based on equation (2). The sample includes observations trimmed to exclude z-scores below the 1st percentile or above the 99th percentile of the distribution. Dependent variables are reported in the column's header and defined in Appendix A.1. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. Specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables. In panel B, FEs are sex specific. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures. All panels exclude the survey(s) for Indonesia, Pakistan, and the Philippines because information is not available in the correspondent surveys.

Table B29: Early-life exposure and physical development among adult women

Dependent variables:	z-scores		Indicators	
	W/h	**H/a**	**Wasted**	**Stunted**
	(1)	(2)	(3)	(4)
pH in the nearest waters (*in utero*)	0.011	0.010	0.000	-0.007
	(0.007)	(0.005)	(0.001)	(0.003)
	[0.133]	[0.069]	[0.988]	[0.022]
Mean (dep.var.)	-0.310	-1.386	0.082	0.301
Identifying observations	324,160	327,124	324,160	327,124
Singleton observations	554	683	554	683
Communities	22,635	22,848	22,635	22,848
Countries	32	32	32	32
Birth year range	1972–2003	1972–2003	1972–2003	1972–2003

Note. Estimates are based on equation (2). Dependent variables are reported in the column's header. *W/h* (weight-for-height) and *h/w* (height-for-age) are z-scores from a reference scale. *Wasted* is an indicator variable equal to 1 for an for an abnormally low weight-for-height. *Stunted* is an indicator variable equal to 1 for an abnormally low height-for-age, and 0 otherwise. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to communities in the coastal area (see Section 2). Standard errors (in parentheses) are clustered at the ocean raster data point, p-values are reported in brackets. In Panels A and B, specifications include community FEs, birth year by birth month FEs, country by birth year FEs, country by birth month FEs, and control variables. In panel C, specifications include community FEs, woman's birth year by woman's birth month FEs, country by woman's birth year FEs, country by mother's birth month FEs, and control variables (see Section 3). Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures. We exclude the survey(s) for Angola, Indonesia, Pakistan, and the Philippines because information is not available in the correspondent surveys.

Table B30: Early-life exposure and long-run economic well-being

Dependent variables:	Economic well-being	Fertility	Schooling	Cognitive skills	Labor supply	
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (*in utero*)	0.016	-0.008	0.030	0.000	0.006	0.014
	(0.009)	(0.004)	(0.034)	(0.002)	(0.004)	(0.007)
	[0.062]	[0.049]	[0.389]	[0.951]	[0.130]	[0.036]
Mean (dep.var.)	3.096	1.552	7.183	0.771	0.425	0.513
Identifying observations	212,741	497,982	433,480	414,000	429,173	190,665
Singleton observations	1,161	536	538	794	549	2,256
Communities	25,432	30,429	27,878	26,824	27,859	24,720
Countries	36	36	36	36	36	36
Birth year range	1972–2003	1972–2003	1972–2003	1972–2003	1972–2003	1972–2003
Sample:	Head/partner	All	All	All	All	Head/partner

Note. Estimates are based on equation (2). The dependent variables are reported in the column's header. *Economic well-being* is a household-level asset-based index which ranges from 1 (poorest) to 5 (richest). *Fertility* is the number of births per woman. *Schooling* is the number of completed years of education. *Cognitive skills* is an indicator variable equal to 1 if the respondent is able to read a whole sentence in her native language or has completed at least secondary schooling, and 0 otherwise. *Labor supply* is an indicator variable equal to 1 if the respondent is working at the time of the interview, and 0 otherwise. *pH in the nearest waters (in utero)* is defined in Section 3. The sample is restricted to coastal areas (see Section 2), and in columns (1)–(6) to women in the household that are household head or their partner. Standard errors (in parentheses) are clustered at the ocean raster data point, *p*-values are reported in brackets. All specifications include community FEs, woman's birth year by woman's birth month FEs, country by woman's birth year FEs, country by woman's birth month FEs, and control variables (see Section 3). Column (2)–(4) have a reduced number of observations because, for comparability of estimates, we include only the random sub-sample of women that completed both the education and the work modules. Appendix A.1 provides detailed information on variables, selected surveys, and weighting procedures.

C Projections of neonatal mortality

To compute these projections of deaths attributed to ocean acidification from 1975 to 2100, we need to calculate series of NMR and live births for the timeline under analysis. We decompose NMR in country k at time t into the following two elements:

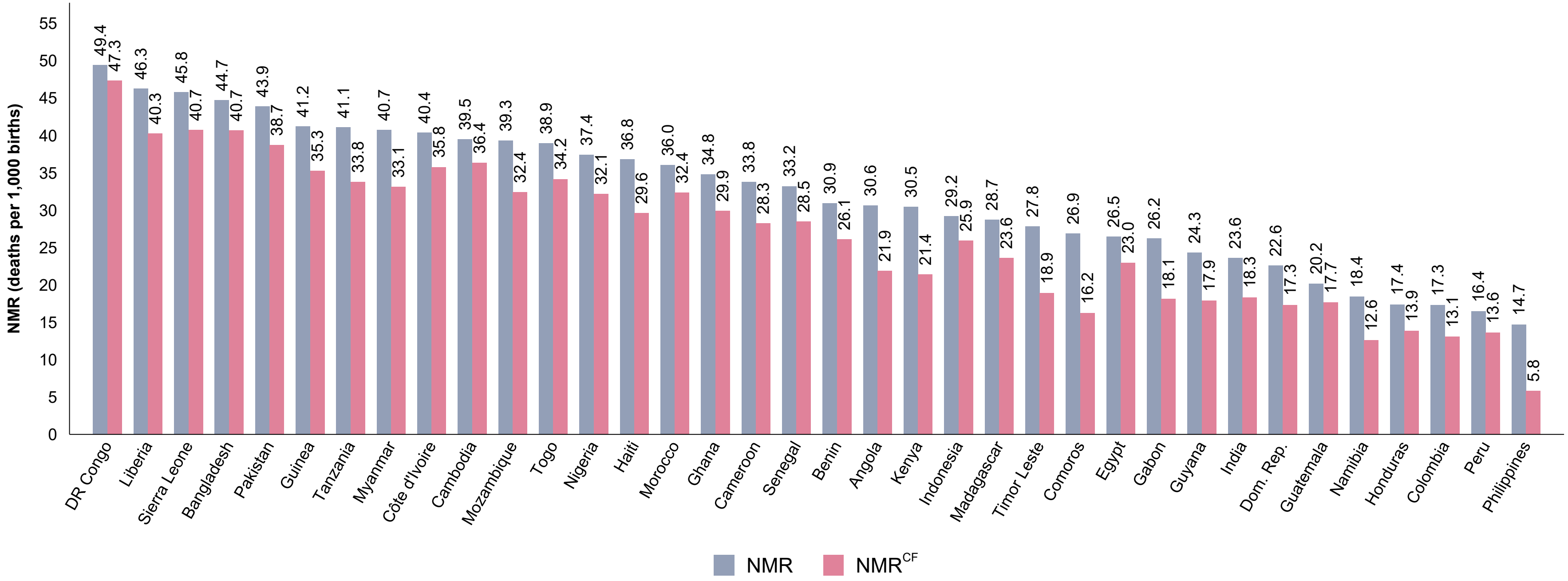
$$\text{NMR}_{k,t} = \text{NMR}_{k,t}^{CF} + \text{NMR}_{k,t}^{OA} \tag{4}$$

where $\text{NMR}_{k,t}^{CF}$ is the (counterfactual) NMR in the absence of ocean acidification, and $\text{NMR}_{k,t}^{OA}$ is the NMR that can be attributed to ocean acidification, capturing the mechanisms described in the paper.

We calculate $\text{NMR}_{k,t}^{CF}$ using birth-level NMR from DHS data to estimating equation (2). To increase predictive power, we allow the effect of *in-utero* exposure to ocean pH to vary flexibly on the distance from the shore, introducing interaction terms for distance, distance squared, and cubed distance. We obtain a prediction for child i born at time mt in community c, using estimates applied to actual data but holding *in-utero* exposure to ocean pH at its 1975 level (with within-year variation to capture seasonality). Averaging the prediction at the country k and year t levels, we obtain $\text{NMR}_{k,t}^{CF}$, which represents the NMR a country would have experienced at time t had ocean acidity in its coastal communities remained at 1975 levels. Using the same estimates, we predict a value that accounts for actual variation in pH and average the prediction at the country k and year t levels, obtaining an estimate for $\text{NMR}_{k,t}$.

Figure C1 summarizes descriptive statistics for the 1975-–2018 average of the estimated $\text{NMR}_{k,t}$ and $\text{NMR}_{k,t}^{CF}$ using the described procedure. We highlight considerable heterogeneity, finding that the overall NMR ranges from 49.4 for the coastal area of DR Congo to 14.7 for the Philippines. These numbers are in line with official statistics from UNICEF (2024), highlighting, e.g., an NMR in Sub-Saharan Africa equal to 46 in 1990, 40 in 2000 and 27 in 2022. The counterfactual NMR ranges instead from 47.3 of DR Congo to 5.8 for the Philippines. Comparing the two values, we find that in all countries the contribution of ocean acidification to NMR is positive and heterogeneous.

Figure C1: Estimates of $\text{NMR}_{k,t}$ and $\text{NMR}_{k,t}^{CF}$, 1975–2018 average



Note. The figure presents the 1975–2018 country-level average of NMR and of (counterfactual) NMR in absence of any ocean acidification from 1975. The sample is restricted to the countries used in the study and to their coastal area (see Appendix A.1). Details about the methodology followed to compute these statistics are presented in Appendix C.

This analysis provides insights into the period 1975–2018, but does not allow extrapolation to 2100. To create projections, we proceed as follows. First, we project $\text{NMR}_{k,t}^{CF}$ by extending the series built for 1975–2018, extrapolating NMR to 2100. To assure smooth projections, we use nonlinear least squares to fit an exponential decay curve, achieving an adjusted R^2 of 99.5%, and project values to 2100. For projections of $\text{NMR}_{k,t}^{OA}$, we consider ocean acidification projections based on global pH data from the IPCC Sixth Assessment Report (IPCC, 2022a), considering two scenarios for 2006–2100: a low-emissions scenario (RCP2.6) and a high-emissions (RCP8.5). For comparison with future projections, we use the historical simulation for 1975–2005.[2] We estimate NMR_t^{OA} using the following expression:

$$\text{NMR}_t^{OA} = \left[\frac{\mathrm{d}\,\text{NMR}}{\mathrm{d}\,\text{R}}\right]_t \times \frac{\Delta\text{pH}_{1975,t}}{0.01} \tag{5}$$

where $\left[{}^{\mathrm{d}\,\text{NMR}}/{}_{\mathrm{d}\,\text{R}}\right]_t$ is the time-t effect on NMR of *in-utero* exposure to varying degrees of ocean pH in nearby waters, as obtained from equation (2), $\Delta pH_{1975,t}$ is the change in pH from 1975 to time t (the denominator is due to the fact that, in our analysis, we rescale pH to consider changes of 0.01 in pH; see Section 2).

The remaining missing information is the number of live births in coastal areas for our selected group, which we compute from two sources. First, we use projections of country-level population and crude birth rates from the UN's medium-fertility scenario (United Nations, 2024). This scenario, which assumes a gradual decline in global fertility rates toward replacement levels, serves as the UN's baseline. Second, because our focus is on coastal areas, we assume a distribution of future populations between coastal and inland areas within each country. Factors such as trade, inequality, tourism, migration, and coastal management can influence population dynamics between coastal and inland areas. To address this, we draw on data from Merkens et al. (2016), which provides a gridded population dataset every five years from 2005 to 2100 for different scenarios. We consider the SSP1 scenario, which assumes a sustainable development path, and the SSP5 scenario, which anticipates rapid economic growth driven by fossil fuels. For each country and the world, we compute the coastal population share for

[2] These series reflect the global average pH, with coastal areas representing only a small portion of the oceans. We assume that coastal pH follows, on average, a similar trend.

each available year, applying these shares to project population and birth dynamics in coastal areas based on the UN's estimates. Between 2005 and 2020, the global coastal population is estimated to have grown from 2.54 billion to 3 billion. Under SSP1, it is projected to decrease slightly to 2.98 billion by 2100, while under SS5, it is expected to rise to 3.2 billion. Although RCPs and SSPs are not directly interchangeable, we assume RCP2.6 aligns with SSP1 and RCP8.5 with SSP5.

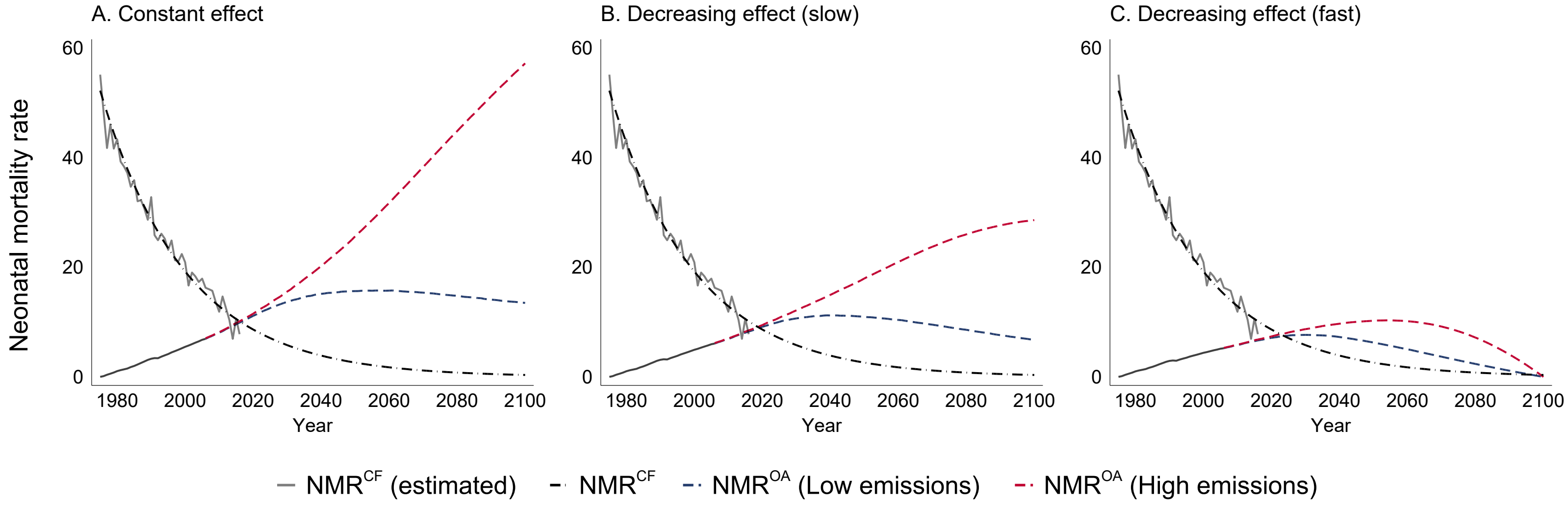
To compute neonatal deaths, we use of the two scenarios related to emissions (low- and high-emissions) and alternative assumptions about adaptation (see Section 5), and apply the estimates for $\text{NMR}^{CF}_{k,t}$ and NMR^{OA}_{t} to the number of live births in coastal areas for our selected group. Table C1 reports the total number of neonatal deaths attributable to ocean acidification from 1975 to 2100. Figure C2 shows instead how the estimates for NMR^{CF}_{t} (aggregated in the whole sample of countries and presented in both the estimated and fitted values) and NMR^{OA}_{t} change over time under the different emission scenarios and assumptions about adaptation. These statistics change when we alter the effect of ocean acidification, meaning that with *no adaptation*, *migration away from coast – high*, and *migration away from coast – low* we obtain the same values of NMR because the effect is assumed to be constant (panel A). Panel B and panel C show instead the estimates considering decreasing effects.

Table C1: Total neonatal deaths attributable to ocean acidification, 1975–2100

	Low-emissions scenario			**High-emissions scenario**			
	Estimate	90% CI bounds		Estimate	90% CI bounds		$\lvert\%\Delta_{\text{low-high}}\rvert$
		Lower	Upper		Lower	Upper	
Assumptions about adaptation	(1)	(2)	(3)	(4)	(5)	(6)	(7)
No adaptation	37.98	10.1	65.83	77.21	20.54	133.8	50.81
Migration away from coast (low)	34.48	9.17	59.75	67.83	18.04	117.55	49.17
Migration away from coast (high)	30.02	7.98	52.02	55.67	14.81	96.47	46.08
Decreasing effect (slow)	26.3	7.00	45.58	49.55	13.18	85.87	46.92
Decreasing effect (fast)	14.61	3.89	25.33	21.90	5.82	37.95	33.29
Optimistic adaptation	12.86	3.42	22.29	18.14	4.83	31.44	29.11

Note. Total number (in millions) of neonatal deaths attributable to ocean acidification from 1975 to 2100. Assumptions about adaptation are detailed in Section 5. The *low-emissions scenario* is the IPCC RCP2.6 scenario, targeting global warming limits of around 1.5°C–2°C by 2100 through strong mitigation efforts. The *high-emissions scenario* is the IPCC RCP8.5 scenario, a worst-case high-emissions scenario with rising emissions potentially increasing temperatures by 4°C–5°C or more by the end of the century. Assumptions and the methodology followed to compute these estimates are detailed in Appendix C. Column (7) reports the percent reduction in the estimate from the high-emissions to the low-emissions scenario. The evolution over time of the cumulative number of neonatal deaths attributable to ocean acidification is reported in Figure 6.

Figure C2: Counterfactual and ocean-acidification-induced NMR, 1975–2100



Note. The figure shows the evolution of NMR_t^{CF} and $\text{NMR}_{k,t}^{OA}$ over time. For NMR_t^{CF}, we show both the values estimated using DHS data and the fitted series. Section 5 details the assumptions. Panel A shows the values assuming the effect of ocean pH experienced while *in utero* on NMR is constant over time. In panel B, we assume the effect gradually diminishes linearly over time halving by 2100. In panel C, we assume the effect gradually diminishes linearly over time reaching 0 by 2100. The *low-emissions scenario* is the IPCC RCP2.6 scenario, targeting global warming limits of around 1.5°C–2°C by 2100 through strong mitigation efforts. The *high-emissions scenario* is the IPCC RCP8.5 scenario, a worst-case high-emissions scenario with rising emissions potentially increasing temperatures by 4°C–5°C or more by the end of the century. Assumptions and the methodology followed to compute these estimates are detailed in Appendix C.

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