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El Niño adversely affected childhood stature and lean mass in northern Peru

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Abstract

Background: *El Niño* is responsible for natural disasters and infectious disease outbreaks worldwide. During the 1997–1998 *El Niño*, northern Peru endured extreme rainfall and flooding. Since short stature may occur as a result of undernutrition or repeated infections during childhood, both of which are highly prevalent during natural disasters, we sought to determine if the 1997–1998 *El Niño* had an adverse effect on stature and body composition a decade later. In 2008–2009, we measured height, weight, and bioimpedance in a random sample of 2,095 children born between 1991 and 2001 in Tumbes, Peru.

Results: Height-for-age increased by 0.09 SD/year of birth between 1991 and 1997 ($P < 0.001$), indicating overall improvements in health over time in the study area; however, this rate fell to 0.04 SD/year of birth during and shortly after *El Niño*, less than half the rate prior to *El Niño* ($P = 0.046$). Height shortfalls were even greater in children residing in households most likely to be flooded after *El Niño*. Any improvement over time was completely blunted and became negative in children living in households with flood likelihoods of ≥7% ($P = 0.001$). In the subset of 912 children with bioimpedance measurements, those born after the onset of *El Niño* had less lean mass ($P < 0.001$), whereas fat mass was unaffected ($P = 0.48$).

Conclusions: Children born during and after 1997–1998 *El Niño* were on average shorter and had less lean mass for their age and sex than expected had *El Niño* not occurred. The effects of *El Niño* on health are long lasting and, given its cyclical nature, may continue to negatively impact future generations.

Keywords: *El Niño*, Flood, Child growth, Height, Lean mass

Introduction

The *El Niño* phenomenon is an anomalous warming of sea surface temperatures (SST) in the equatorial Pacific that causes extreme weather variability every 2 to 7 years [1], leading to disaster and disease worldwide. During *El Niño* episodes, natural disasters such as severe drought and floods are estimated to affect 35 per 1,000 people, more than four times the rate affected by natural disasters during non-*El Niño* years [2]. *El Niño* episodes have been linked to increased incidences of malaria [3-6], dengue [7-10], cholera [11-10], and diarrhea [15,16], all of which are highly prevalent in the developing world. Even small increases in any of these diseases translate into hundreds of thousands of deaths and millions affected.

While many studies have evaluated the short-term effects of *El Niño* episodes such as an increase in the burden of infectious diseases, the long-term consequences on human health have not been studied. Due to the recurrent and global nature of *El Niño*, it is important that we gain a better understanding of possible long-term adverse effects on the health of affected human populations. One such measure of poor health is failure to grow adequately in height, also known as stunting. Small stature for a given age and sex is a surrogate measure of chronic malnutrition [17]. Stunting occurs in early childhood as a result of undernutrition, a high burden of infectious diseases, or both [18]. In developing countries, height deficits incurred early in life generally persist through childhood and even

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adulthood [19,20] and have been linked to other developmental problems including delayed motor [21] and locomotion skills [22], cognitive impairment [23], delayed school enrollment [24] and poor school performance [25], lower adult productivity [26], and higher risk pregnancies and deliveries.

El Niño impacts communities throughout the world; however, the northern coastline of Peru suffers the greatest effects of *El Niño* episodes through heavy rainfall and severe flooding. During the 1997–1998 *El Niño* episode, the most severe on record, the Peruvian government received an early forecast of its potential severity 6 months prior to the onset of heavy rains. The government developed a prevention strategy that centered on the preservation of infrastructure and construction and repair of irrigation and drainage systems [27]. Despite these efforts, overflowing riverbanks cut off access to bridges and roads and isolated many rural villages in northern Peru, some for months at a time. Food, clean water, and healthcare were largely inaccessible in these villages, and increased cases of malaria and diarrhea were reported throughout the region [5,28]. Severe damage to crops and livestock limited food reserves and severed an important source of income for most rural residents. Due to severe food shortages and increased incidence of infectious diseases during *El Niño*, we hypothesized that children born in northern Peru during and after the 1997–1998 *El Niño* may be shorter for their age and sex than children born in other years. In 2008–2009, we visited a random sample of children born between 1991 and 2001 in a cluster of rural villages in Tumbes, Peru, and measured their height, weight, and bioelectrical impedance. As secondary objectives, we also examined 1) whether children born after the onset of *El Niño* had differences in later body composition (lean mass (LM) and fat mass (FM)) and 2) whether birth and death rates in Tumbes changed significantly in 1997–1998, the period of *El Niño*, using data collected by the Peruvian National Institute of Statistics and Information between 1994 and 2002.

Methods

Study setting

The Department of Tumbes is located in the northern coast of Peru (9°S of the equator). Our study area consists of a group of communities with about 20,000 people over 80km^2 where the traditional agricultural landscape has become intermixed with rapid urbanization. Average ambient temperatures range 23°C–31°C during the rainy season (December to May) and 21°C–28°C during the dry season (June to November).

Study design

In November 2008 through December 2009, we conducted a cross-sectional study of children in 59 rural villages who were born between 1991 and 2001. We calculated that we would require 698 children per age strata (prior, during, and after the 1997–1998 *El Niño*) to detect a 0.15 SD difference (SD) in height-for-age (HAZ) due to the 1997–1998 *El Niño* episode with a variance of 1 SD for HAZ, 95% confidence, and 80% power. We excluded children who did not live in the study area since 1 year of age and limited enrollment to only one child per household. Using a recent local census conducted in early 2008, we randomly selected 2,456 children, based on year of birth, from 59 villages in Tumbes and who were born between January 1, 1991 and December 31, 2001. The majority of children who were not enrolled in the study had either moved between the census date and date of enrollment (54%) or could not be located for other reasons (22%). An additional 19% did not meet study inclusion criteria and 6% refused to participate. A total of 2,095 (84%) children met the eligibility criteria, agreed to participate, and were enrolled in the study. Following informed consent, the child's parent completed a survey that included information on household characteristics (e.g., construction materials, fuel used for cooking, source of drinking water, type of sanitation facility, ratio of bedrooms to household members), household assets (e.g., appliances and vehicles), parental occupation, parental education, and migration history of the child. We measured the child's height and weight as previously described [29]. In a subset of children, we measured bioelectrical impedance to estimate both LM) and FM. To account for seasonality, all nutritional measurements were conducted during the November and December months across 2 years (2008 and 2009). The Institutional Review Boards of A.B. PRISMA (Lima, Peru) and Johns Hopkins University (Baltimore, USA) approved this study. Participants aged ≥18 years provided written informed consent. Children aged <18 years provided assent, and parents provided written informed consent on their behalf.

Nutritional indicators

We calculated HAZ using the 2007 World Health Organization Reference for children 5 to 19 years of age [29]. We measured body composition in a subset of children using bioelectrical impedance, a simple field prediction method widely used in children and specifically calibrated for application in our sample. We measured total body water in children using a foot-to-foot impedance scale, the Tanita BF300 (Tanita Corporation, Tokyo, Japan). Bioelectrical impedance analysis requires calibration in each study population against a gold standard measurement of total body water obtained by isotope dilution [30,31], in which 70 children from our sample participated. We calculated lean mass (in kilograms) using age (in years), height (in centimeters), and impedance (in ohms) as previously described [32] with the following equation: $\ln(lean\ mass) = 0.206 + \left(0.829 \times \ln\frac{height^2}{impedance}\right) + \ (0.022 \times age)$. We estimated fat mass in kilograms as the difference between total weight and lean mass.

Calculation of flooding index

Disruptions and damages reported in Tumbes during the 1997–1998 *El Niño* were largely due to high precipitation and resulting flooding. Therefore, we hypothesized that flooding may be an independent risk factor for a lower achieved stature, and the degree of flooding may be linked to greater shortfalls in height during *El Niño* episodes. There were four *El Niño* episodes between 1991 and 2001 including weaker events in 1991–1992, 1992–1993, and 1994–1995. The strongest *El Niño* occurred in 1997–1998 during which annual rainfall in Tumbes was 2,500mm, 12 times greater of what is normally expected in any given year. We calculated a flood likelihood score which represents the likelihood that a child lives in a household that was prone to flooding between the period of 1991 and 2001. The flood likelihood score was computed using longitude and latitude coordinates for each child's household and percent soil saturation estimates at that location for the period of 1991–2001, which were generated from simulations with the Noah Land Surface Model [33,34] and meteorological data from the National Aeronautics and Space Administration Modern-Era Reanalysis for Research and Applications [35]. Specifically, flood likelihood scores were calculated for each child's household in two steps. First, we used a generalized linear mixed model with an identity link to estimate smoothed soil moisture estimates over time that accounted for repeated measures for each child's household. We estimated several time and space specifications to identify the best fit for this model, with model fit maximized with our final specification (village, month, year, and month by year interaction fixed effects; an autoregressive repeated measures covariance structure; and random effects for household location). We then calculated studentized residuals and defined flooding as a residual value greater than 2, which represents areas with a soil saturation greater than 97.5% of other areas. The second step involved taking the number of months since birth for each child (until 2001) that their household was defined as flooded and estimated the predicted probability that a child lived in a location prone to flooding using another generalized linear mixed model with a logit link. The calculated predicted probabilities were used as the flood likelihood score for our analyses.

Crude birth and death rates

We used local public registries to obtain data on all births and deaths that occurred in five out of seven districts in the Department of Tumbes during 1994 to 2002. Crude rates were calculated based on projected population totals in those five districts for the corresponding years (Peruvian National Institute of Statistics and Information).

Biostatistical methods

We used linear mixed models to assess the association between being born before or after the onset of the 1997–1998 *El Niño* and height in later childhood. Specifically, the model included two indicators of birth date to investigate the effect of being born before compared to being born after the onset of the *El Niño* episode on the distribution of HAZ. The first birth date indicator was the number of years between the each child's birth date and January 1991, modeled as a continuous variable. The second birth date indicator, also modeled as a continuous variable, was assigned the following values according to the date of onset of *El Niño* in July 1997: 1) the number of years between the child's birth date and the onset of *El Niño* for the each child born after the onset of *El Niño* and 2) 0 for children born before. Our choice of model was supported by exploratory analyses, in which we found a linear change in the slope of HAZ with birth date after the onset of *El Niño*. All regression models were adjusted for sex, socioeconomic status (SES) index, and likelihood of living in a flood-prone household, and accounted for clustering using a random intercept by village. All confounding variables were selected *a priori*. Principal components analysis was used to generate the SES index using a combination of variables for household characteristics, household assets, and maternal educational attainment (all variables included in the SES index are listed in Additional file 1: Table S1) [36,37]. We also tested for an interaction between flood likelihood and *El Niño* (the second birth date indicator variable). To investigate the differences in body composition, we used a bivariate linear mixed model to investigate the effect of the 1997–1998 *El Niño* episode on the joint distribution of lean mass and fat mass. We included the two indicators for birth date and adjusted for the same covariates as described above. We present a detailed description of our analysis in Additional file 1.

Annual birth and death totals from local public registries were used to generate crude birth and death rates. Poisson regression was used to examine the change in crude infant and child mortality rates and birth rates per year between 1994 and 2002. *El Niño* was represented in the model similarly to the previous models with two time-predictor variables, one representing time before *El Niño* and the second representing time after the onset of *El Niño*.

Statistical analyses were conducted in SAS 9.2 (SAS Institute, Cary, North Carolina, USA) and STATA version 11 (STATA Corp., College Station, Texas, USA).

Results

Baseline characteristics

The final sample of 2,095 children aged 7 to 18 years consisted of approximately equal proportions of children born in each year between 1991 and 2001 (Table 1), with the exception of those born in 1991, the oldest children in the sample, who were more difficult to locate. Slightly more than half the study participants were male. The largest deficits in height and the highest proportions of stunting were in those with the earliest birth dates. Children born in all years had a similar average SES index score, and each birth cohort had comparable distributions of living in a household prone to flooding between 1991 and 2001. Migration was uncommon in our cohort. Twenty-five children (1%) were born outside of Tumbes and all were 1 year of age or younger when they moved to Tumbes. Of the remaining 99% born in Tumbes, only 79 children (4%) were born in a village different from the one in which they were living at the time of enrollment in our study.

El Niño and extreme weather variability

Throughout 1991–2001, periods of high sea surface temperature were associated with periods of higher precipitation and higher minimum ambient temperature in Tumbes. The 1997–1998 *El Niño* episode was marked by a striking increase in sea surface temperature throughout 1997 and continuing to mid-1998 (Figure 1). During this period of high sea surface temperatures, precipitation increased dramatically more than any other time throughout 1991–2001. Furthermore, periods of low sea surface temperatures were associated with periods of lower precipitation. While sea surface temperatures were high during the winter months in 1997, minimum ambient temperature did not follow the usual winter periodic trough and remained at high levels comparable to summer months.

Precipitation, runoff, gauged discharge, and percent soil water content, all used as indicators of flood potential, were significantly higher in 1998 in comparison to all other years between 1995 and 2004 in Tumbes (Figure 2A). As soil moisture was maximized in Tumbes in 1998, rice and banana production, the chief crops of agriculture, simultaneously plummeted (Figure 2B), which is consistent with the reports of food shortages and economic distress in Tumbes during the disaster. To further understand the magnitude of flooding during this time, soil saturation estimates for the months of January through April in 1998 were compared to those in these same months between 1995 and 2004 (excluding 1998) which shows that Tumbes experienced significantly higher levels of saturation in 1998, with some areas experiencing root zone soil water saturation levels up to 2.5 times greater than in other years (Figure 3).

El Niño and height deficits

Children born in January 1991 were on average 1.4 standard deviations below the WHO reference for height, reflecting the poor nutritional status of children in Tumbes during this period. From this point through mid-July 1997, HAZ increased linearly with each subsequent year of birth, when children improved in height by approximately one-tenth of a standard deviation compared to children born in the previous year ($P < 0.001$; Table 2). Therefore, children born in later periods before *El Niño* had an improved stature for a given age and sex which reflects the steady improvement in overall nutritional status in this region before the 1997–1998 *El Niño*. However, those born during the start of *El Niño* (late July 1997) and shortly after exhibited a lower mean HAZ than what would be expected had *El Niño* not occurred. Specifically, children born during and after *El Niño* were only improving by 0.04 standard deviations with each year of birth

Table 1 Sample characteristics

Year of birth	Children, n (%)	Age in years, mean (SD)	Male, n (%)	Height-for-age *Z*-score, mean (SD)	Height-for-age *Z*-score < −2, n (%)	Socioeconomic status index, mean (SD)	Mean flood likelihood, % (SD)
1991	126 (6.0)	17.9 (0.6)	69 (54.8)	−1.17 (0.81)	18 (14.3)	0.36 (0.42)	1.4 (0.7)
1992	202 (9.6)	16.8 (0.5)	114 (56.4)	−1.19 (0.82)	33 (16.3)	0.38 (0.40)	1.3 (0.6)
1993	180 (8.6)	15.8 (0.6)	104 (52.2)	−1.04 (0.98)	27 (15.0)	0.40 (0.42)	1.2 (0.5)
1994	186 (8.9)	14.9 (0.6)	104 (55.9)	−1.02 (0.94)	29 (15.6)	0.35 (0.40)	1.3 (0.6)
1995	189 (9.0)	13.9 (0.5)	103 (54.5)	−0.96 (0.94)	31 (16.4)	0.34 (0.37)	1.2 (0.6)
1996	174 (8.3)	12.9 (0.5)	85 (48.9)	−0.69 (1.01)	17 (9.8)	0.37 (0.42)	1.3 (0.6)
1997	195 (9.3)	11.8 (0.6)	94 (48.2)	−0.66 (0.95)	15 (7.7)	0.38 (0.38)	1.3 (0.6)
1998	192 (9.2)	10.9 (0.6)	93 (48.4)	−0.71 (1.00)	16 (8.3)	0.35 (0.40)	1.3 (0.6)
1999	211 (10.1)	9.8 (0.6)	110 (52.1)	−0.67 (0.93)	16 (7.6)	0.28 (0.40)	1.2 (0.5)
2000	210 (10.0)	8.8 (0.6)	104 (49.5)	−0.54 (0.98)	13 (6.2)	0.34 (0.40)	1.3 (0.6)
2001	230 (11.0)	7.8 (0.5)	128 (55.7)	−0.53 (0.94)	18 (7.8)	0.40 (0.40)	1.2 (0.4)
Overall	2,095	12.5 (3.2)	1,098 (52.4)	−0.81 (0.97)	233 (11.1)	0.36 (0.40)	1.3 (0.6)

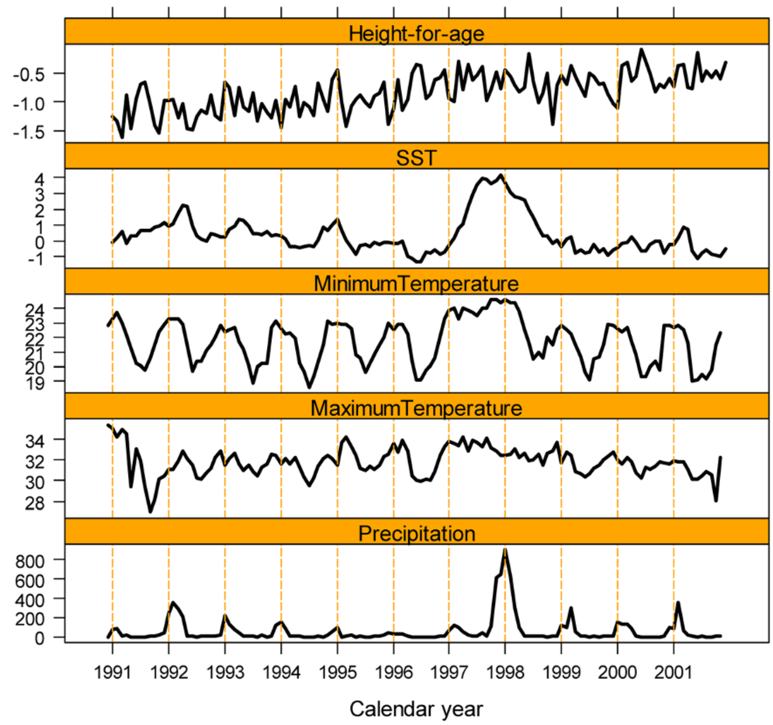

Figure 1 Climate and HAZ in Tumbes. Units for *y*-axis: height-for-age Z-score (HAZ), sea surface temperature (SST, degrees Celsius), minimum and maximum temperatures (degrees Celsius), and precipitation (mm). Precipitation and temperature data for Tumbes for 1991–2001 were obtained from the Peruvian National Weather Service (SENAMHI). SST data were obtained from the International Institute of Climate and Society (IRI).

compared to those born in the previous year, less than half the rate (44%) of the pre-*El Niño* group ($P = 0.046$) (Table 2).

There was a statistically significant interaction between the 1997–1998 *El Niño* and the likelihood of a child's home being in a location prone to flooding (Table 2), indicating that the direct impact of flooding during *El Niño* was largely responsible for the *El Niño*'s negative effect on long-term height in young children. Specifically, for every 10% increase in flooding likelihood of a child's home, the rate of improvement in HAZ with each year of birth declined by 0.13 standard deviations when compared with the rate of improvement in HAZ had *El Niño* not occurred ($P = 0.001$). Thus, a 50% increase in flooding likelihood would correspond to two-thirds of a standard deviation decline in the rate of improvement in HAZ with each year of birth. The effect of *El Niño* in areas with a flooding likelihood of 0% was negligible ($P = 0.14$).

El Niño affected lean mass but not fat mass

Fat mass and year of birth had a negative relationship, (Table 3) such that children had 0.89 kg less fat mass compared to children born in the previous year ($P < 0.001$), and this trend did not change with the occurrence of *El Niño* ($P = 0.48$). Similarly, lean mass decreased by 2.1 kg ($P < 0.001$) with each subsequent year of birth; however, lean mass declined more rapidly, by an additional 1.2 kg less ($P < 0.001$), for each year of birth for children born after the start of *El Niño*. In summary, older children in our sample (i.e., children born before *El Niño*) have a greater fat mass and lean mass compared to younger children; however, children born after the onset of *El Niño* have significantly less lean mass than what would be expected if *El Niño* had not occurred. There was no relationship between flood likelihood during the 1997–1998 *El Niño* and either fat mass or lean mass ($P = 0.47$ and $P = 0.54$, respectively).

Mortality unaffected by *El Niño*

The crude birth rate in Tumbes remained unchanged during 1994–2002 ($P = 0.77$) and therefore was unaffected by *El Niño*. During this same period, both crude infant mortality rates and child mortality rates decreased over time ($P = 0.006$ and $P < 0.001$, respectively); however, there were no significant deviations from these trends in 1998 ($P = 0.74$ and $P = 0.65$, respectively), the year of the heavy *El Niño* rainfall.

Discussion

Two important indicators used in public health to measure the well-being of children are mortality and nutritional status. This study demonstrates that *El Niño* may have

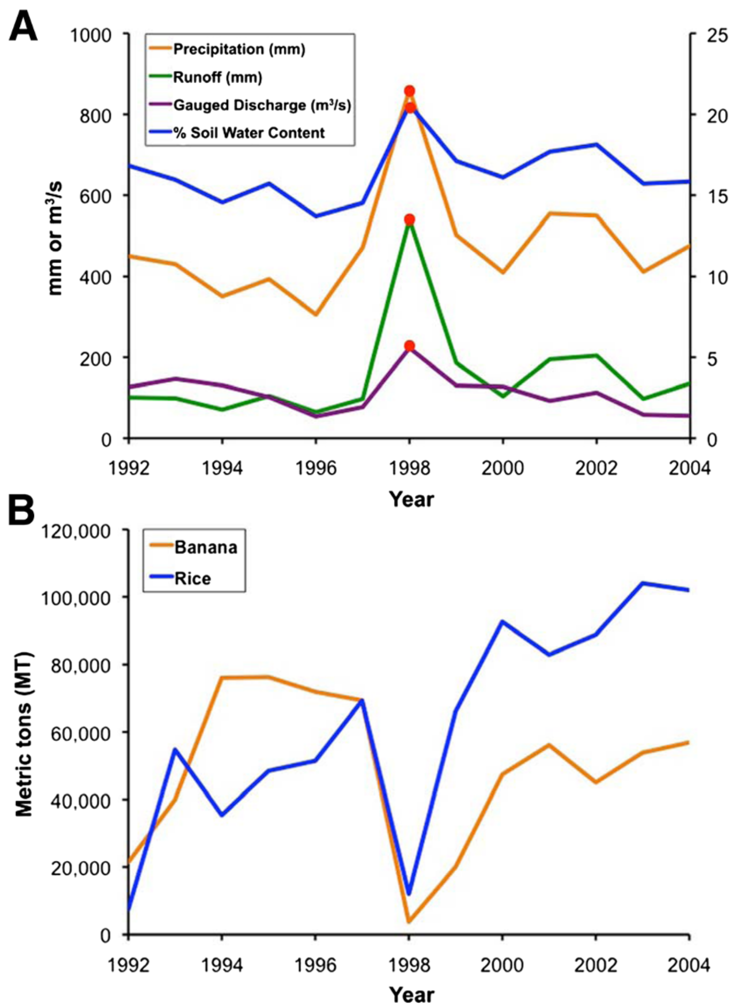

Figure 2 Moisture and subsequent agricultural impact in Tumbes. A. Annual precipitation from NASA's Modern-Era Reanalysis for Research and Applications, runoff (Noah Land Surface Model hydrological simulation), gauged discharge (Tigre gauging station), and percent soil water content (Noah Land Surface Model) for the Tumbes River basin for the 6 years preceding and following the 1997-1998 *El Niño* event. Values in 1998, indicated in red, are two standard deviations above the mean for all variables. **B**. Annual banana and rice production in Tumbes (Peruvian Ministry of Agriculture).

had a marked effect on the long-term nutritional status of children, yet the effect on mortality was negligible. Although the negative effect in height and lean mass was not prevented, if the major effort to intervene by the Peruvian government had not occurred, this disaster might have produced a severe impact on mortality which has been seen in other similar disaster situations such as the 1999 flood in Venezuela [38], the 2000 flood [38] and 2002–2003 droughts in Mozambique [39], and more recently, the 2009 flood in the Philippines [40] and the 2010 flood in Pakistan [41].

Our original hypothesis anticipated that the 1997–1998 *El Niño* would have a negative effect on the age- and sex-adjusted heights of children born during *El Niño*. These data support this hypothesis and further show that children born both during and after the 1997–1998 *El Niño* have a lower HAZ than would be expected if the *El Niño* had not occurred. That is, the trend of improvement in HAZ over time in children born in the post-*El Niño* years (1999–2001) failed to recover to pre-*El Niño* levels. Thus, the disruption and destruction left by *El Niño* may not have been resolved during this time, particularly in those regions with the heaviest flooding, having a protracted effect on the nutritional status of children born even 3 years after the initial disaster.

The abating height attainment of children born during and after the 1997–1998 *El Niño* event may be the result of an increased incidence of infectious illnesses during the period of the *El Niño* disaster as well as food unavailability. Previous studies conducted in Peru have shown that the incidence of infectious illnesses in children, particularly bouts of diarrhea, spiked during and

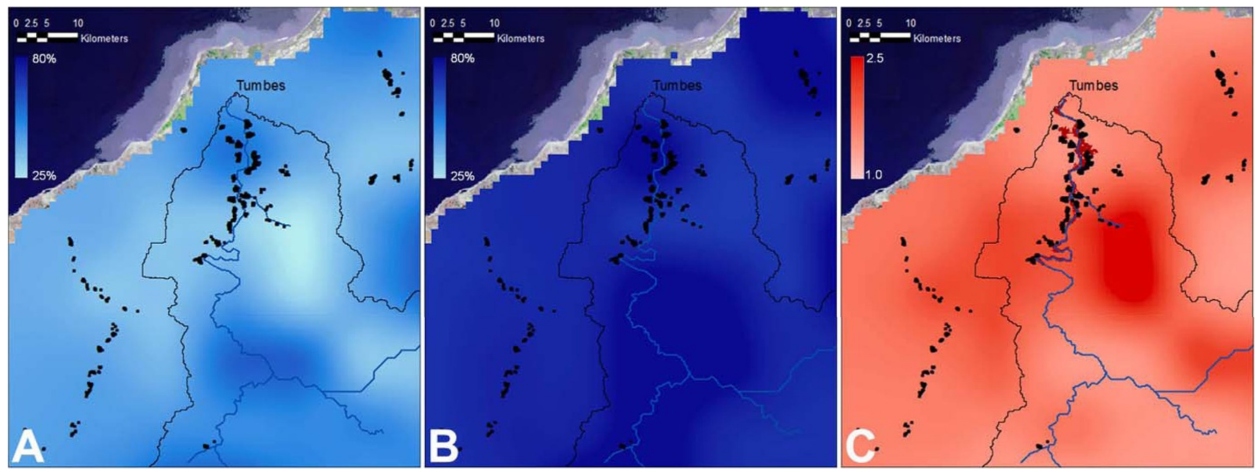

Figure 3 Hydrological impacts. Average degree of soil saturation for January to April in 1995–2004 excluding 1998 **(A)**, and 1998 **(B)**. **(C)** Ratio of degree of soil saturation in 1998 relative to the 1995–2004 average. All panels also show the locations of households surveyed in this study (black points), the course of Rio Tumbes (blue line), and the boundary of the Rio Tumbes watershed (black line).

after *El Niño* likely due to the warmer and wet conditions that accompany *El Niño* events [15,16]. In addition, *El Niño* has been linked to epidemics of malaria in northern Peru [5] and dengue in an Ecuadorian region neighboring Tumbes [5,42]. During focus groups conducted in a subsample of Tumbes villages (villages that are also included in our analysis), village members reported an increase in illness and prolonged food shortages, particularly of animal protein foods, during the *El Niño* period and after [43]. In addition, there was a substantial loss of the chief crops of banana and rice in this region as a result of *El Niño*, affecting food availability and prices as well as the economic livelihood of these communities, which largely rely on the export of these crops. In conclusion, it is possible that children born during the disaster as well as during its aftermath may have been more likely to have an infectious illness and less likely to have a diet adequate for optimal growth, which may explain the negative association of *El Niño* and height attainment in these children found in our results.

El Niño had an impact on lean mass but not fat mass regardless of the amount of flood exposure. It is not surprising that *El Niño* may have adversely affected only lean mass given that later body composition is strongly influenced by the nutritional environment experienced in early life, during both the prenatal and postnatal periods [44]. Previous studies from diverse populations have shown relatively consistent findings, in that birth weight is positively associated with later lean mass but not fat mass, indicating that reduction in fetal growth diminishes later lean mass [44]. Findings for infant weight gain differ between industrialized and developing countries; in the latter, based on studies from Brazil, Guatemala, and India, infant weight gain is again positively associated with later lean mass but not fat mass, indicating that poor infant growth would constrain later lean mass [44]. Lean mass is an important predictor of physical work capacity in later life [45,46], which may have important implications for productivity particularly in primarily agricultural and fishing communities such a

Table 2 Change in Height-for-age *Z*-score (HAZ) after onset of 1997–1998 *El Niño*

Variable	With interaction term		Without interaction term	
	β (95% CI)	*P* value	*β* (95% CI)	*P* value
Intercept	−1.443 (−1.579, −1.306)	<0.001	−1.445 (−1.584, −1.305)	<0.001
Year of birth				
HAZ slope before *El Niño*	0.093 (0.070, 0.117)	<0.001	0.095 (0.072, 0.118)	<0.001
Change in HAZ slope after *El Niño*	−0.052 (−0.104, −0.001)	0.05	−0.039 (−0.091, 0.013)	0.14
Female (male is reference)	−0.001 (−0.078, 0.076)	0.99	−0.002 (−0.079, 0.075)	0.96
Socioeconomic status index	0.449 (0.341, 0.557)	<0.001	0.446 (0.338, 0.554)	<0.001
Flood likelihood	−0.462 (−1.757, 0.832)	0.48	−0.020 (−1.341, 1.301)	0.98
Interaction flood likelihood × *El Niño*	-		−1.321 (−2.130, −0.512)	0.001

Table 3 Change in fat mass and lean mass after onset of 1997–1998 *El Niño*

Variable	With interaction term		Without interaction term	
	ß (95% CI)	*P* value	ß (95% CI)	*P* value
Fat mass (kilograms)				
Intercept	11.94 (10.62, 13.25)	<0.001	11.91 (10.59, 13.23)	<0.001
Year of birth				
HAZ slope before the 1997–1998 *El Niño*	-0.89 (-1.12, -0.65)	<0.001	-0.88 (-1.12, -0.64)	<0.001
Change in HAZ slope after *El Niño*	0.19 (-0.34, 0.72)	0.48	0.21 (-0.32, 0.75)	0.44
Female (male is reference)	4.03 (3.22, 4.83)	<0.001	4.02 (3.22, 4.83)	<0.001
Socioeconomic status index	2.49 (1.36, 3.61)	<0.001	2.48 (1.35, 3.60)	<0.001
Flood likelihood	3.02 (-6.74, 12.77)	0.54	4.03 (-6.26, 14.32)	0.44
Interaction flood likelihood?×?*El Niño*	–		-4.00 (-14.91, 6.90)	0.47
Lean mass (kilograms)				
Intercept	48.85 (47.71, 49.99)	<0.001	48.84 (47.70, 49.98)	<0.001
Year of birth				
HAZ slope before *El Niño*	-2.05 (-2.24, -1.16)	<0.001	-2.04 (-2.23, -1.85)	<0.001
Change in HAZ slope after *El Niño*	-1.16 (-1.58, -0.74)	<0.001	-1.14 (-1.56, -0.72)	<0.001
Female (male is reference)	-5.39 (-6.03, -4.76)	<0.001	-5.40 (-6.03, -4.77)	<0.001
Socioeconomic status index	1.75 (0.82, 2.68)	<0.001	1.74 (0.81, 2.67)	<0.001
Flood likelihood	-3.86 (-14.62, 6.89)	0.48	-3.72 (-14.54, 7.11)	0.50
Interaction flood likelihood?×?*El Niño*	-		-2.78 (-11.66, 6.11)	0.54

Tumbes. Similar to height, *El Niño*'s effect on decreasing lean mass may have been the result of the unavailability of nutrient- or energy-dense foods to those children born during the disaster and the aftermath. More research is needed to further understand the mechanisms by which the *El Niño* disaster affects growth in young children.

Just as rings act as indicators of natural disasters experienced by a tree throughout its life [47], exposure to severe adverse weather events *in utero* or early life can leave a long-lasting mark on growth and development in young children. In low- and middle-income countries, a child who undergoes inadequate growth early in life is unlikely to achieve complete catch-up growth later on [19]. Early shortfalls generally persist into adult life. As noted, stunting is a marker for decreased mental and physical capacity [21-23,27]. Early disruptions to lean mass appear to affect its constituent components unequally, protecting the brain at the expense of other organs and tissues such as the kidneys, liver, pancreas, and muscle mass [48,49]. These effects also vary as to whether they occur in fetal life or infancy. In later life, such constraints on early growth are predicted to reduce the capacity for homeostasis, and increase the risk of chronic degenerative diseases, as shown extensively elsewhere [26].

Our study has some potential limitations. First, due to the nature of the cross-sectional study design, nutritional measurements (height, weight, and body composition) were taken at only one time point for each child, and therefore, inferences cannot be made regarding the change in height across time at the individual level. In addition, we do not have earlier information such as birth weight or any illness history prior to or during the 1997–1998 *El Niño* episode. Despite this, our data include nutritional measurements for children across several birth cohorts and therefore allow for comparisons of the mean average change in height, lean mass, and fat mass between birth year cohorts. Second, we define exposure to *El Niño* in early life as having a birth year that coincides with the onset (or after) of *El Niño*. It is possible that the effects on height attainment and lean mass may be due to other events that may have occurred during the same period as the onset and aftermath of the *El Niño* disaster; however, in focus groups conducted in a subsample of villages in Tumbes, community members did not cite other events occurring during the same period as *El Niño* that had such a destructive impact on their lives [43]. Third, we may have been underpowered to detect a possible effect on lean mass in households with higher flood likelihood. Fourth, our study may be less representative of older children in our cohort, as many of them were either hard to reach because they were working and difficult to find or were married and had moved to another household or another village. Lastly, the variables used to generate the SES index were based on self-report. As with any self-reported information, these variables are subject to reporting bias; however, if bias were present in our data, the results would be biased towards the null making our estimates conservative and not changing our final conclusions.

Despite these limitations, our study has several strengths. First, both villages and children within each birth cohort were randomly selected. Therefore, we are confident that our sample is representative of the study population. Second, we used standardized and consistent methods to measure height, weight, and body composition across all children, and therefore the measurements are reliable and can also be compared with other populations. Third, only children who had lived in Tumbes since 1 year of age were eligible for enrollment eliminating a possible risk of bias from migration. Finally, as shown in our analyses, our results are not likely to be affected by migration or a mortality difference.

Conclusions

If adverse weather events affect a significant portion of young children of a country, then they have the potential to adversely affect the future of a community as a whole. Some investigators hypothesize that global warming will translate into more frequent *El Niño* episodes [50,51] heightening the urgency of the global health issues consequential to weather events accompanying *El Niño*. Because children and those in lower SES levels are most vulnerable to the health and economic impacts of disasters [52], including those induced by *El Niño*, it is imperative that we continue to explore the extent to which they are affected to design prevention strategies and target aid and relief during future *El Niño* episodes.

Additional file

Additional file 1: Supplementary information. This file contains figures and tables on study hypothesis, Department of Tumbes, SST, predicted HAZ, and household socioeconomic variables.

Abbreviations

HAZ: height-for-age *Z*-score; SES: socioeconomic status.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

HED, RHG, JCW, and WC made contributions to the design of the study. HED coordinated the fieldwork, and HED and WC wrote the first draft. RHG, JCW, WP, and BZ provided important revisions. HED, WP, BZ, and WC conducted data analysis. GG and MA provided essential field support. All authors read and approved the final manuscript.

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