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Trends of child undernutrition in rural Ecuadorian communities with differential access to roads, 2004–2013

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Abstract

Road access can influence protective and risk factors associated with nutrition by affecting various social and biological processes. In northern coastal Ecuador, the construction of new roads created a remoteness gradient among villages, providing a unique opportunity to examine the impact of roads on child nutritional outcomes 10 years after the road was built. Anthropometric and haemoglobin measurements were collected from 2,350 children <5 years in Esmeraldas, Ecuador, from 2004 to 2013 across 28 villages with differing road access. Logistic generalized estimating equation models assessed the longitudinal association between village remoteness and prevalence of stunting, wasting, underweight, overweight, obesity, and anaemia. We examined the influence of socio-economic characteristics on the pathway between remoteness and nutrition by comparing model results with and without household-level socio-economic covariates. Remoteness was associated with stunting (OR = 0.43, 95% CI [0.30, 0.63]) and anaemia (OR = 0.56, 95% CI [0.44, 0.70]). Over time, the prevalence of stunting was generally decreasing but remained higher in villages closer to the road compared to those farther away. Obesity increased (0.5% to 3%) over time; wasting was high (6%) but stable during the study period. Wealth and education partially explained the better nutritional outcomes in remote vs. road villages more than a decade after some communities gained road access. Establishing the extent to which these patterns persist requires additional years of observation.

KEYWORDS

anthropometry, child malnutrition, child nutrition, distal determinant, global health, roads

1 | INTRODUCTION

Malnutrition among children under 5 years is a general indicator of ill health in a population (Onis, Frongillo, & Blössner, 2000). An estimated 45% of all deaths among children under 5 years are attributed to undernutrition (Black et al., 2013). The burden of undernutrition is amplified because frequent infections in children increase the risk of undernutrition, and undernutrition increases the risk of infection, creating a vicious circle in areas where access to food and healthcare is poor (Scrimshaw, 2003). On the other hand, overweight and obese children have many of the comorbidities plaguing overweight and obese adults, such as elevated blood pressure, dyslipidaemia, or other risk factors common to Type 2 diabetes (Deckelbaum & Williams, 2001). Increasingly, both undernutrition and overweight/obesity outcomes have been concurrently observed throughout low- and middle-income populations (Kennedy, Nantel, & Shetty, 2006; Varela-Silva et al., 2012).

Food systems, specifically food availability and consumption, which in turn affect population nutrition, are influenced by macrolevel factors, such as globalization (Popkin, 2006). In the context of our study, availability and consumption of food may be influenced by a critical component of globalization called differential road access, which creates a gradient of remoteness. We collected anthropometric data in children over a 10-year period in northern coastal Ecuador. We hypothesize that differential road access in this population is a key driver of sociodemographic changes that influence nutritional outcomes in children under 5 years. Specifically, we assessed four undernutrition outcomes: stunting, wasting, underweight, and anaemia; as well as overweight and obesity.

These childhood undernutrition outcomes have important distal sociodemographic determinants at the individual-level (e.g., age), at the household-level (e.g., household wealth, number of siblings, family employment, and education of the mother; Larrea & Kawachi, 2005; Victora, Vaughan, Kirkwood, Martines, & Barcelos, 1986), and at the community-level (e.g., differences in food security, access to healthcare, and organized sanitation between communities; Khan & Bhutta, 2010). These distal determinants can in turn be altered by road access. Roads promote easier movement of people, food, and services and may lead to regional economic improvement that would presumably improve nutritional outcomes through multidimensional pathways (Hine, Abedin, Stevens, Airey, & Anderson, 2014) including the normalization of marketplace exchanges (Hawkes, 2006). Living in an urban community has been shown to impact undernutrition through a decreased risk of stunting compared to living in rural communities (Kandala, Madungu, Emina, Nzita, & Cappuccio, 2011; Ortiz, Van Camp, Wijaya, Donoso, & Huybregts, 2014). However, roads can also potentially have negative consequences. For example, our studies have shown that less remote communities have a higher prevalence of diarrhoeal disease (Eisenberg et al., 2006). This finding may be due, in part, to the fewer social contacts among individuals living in less remote villages, who also have higher migration and movement rates (Trostle et al., 2008), and counter to generally accepted views, this lower social network density enhances their risk of diarrhoea (Bates, Trostle, Cevallos, Hubbard, & Eisenberg, 2007). In the context of infection transmission, network ties are thought to solely represent conduits of transmission; however, they can also represent levels of social cohesion (Entwisle, Faust, Rindfuss, & Kaneda, 2007). Network density, therefore, is also likely a marker of individual-level as well as collective community-level water, sanitation, and hygiene-related practices that mediate the relationship between remoteness and disease prevalence (Zelner et al., 2012). These dynamics influence the distal determinants of health in complex ways.

Here, we examine whether road access, in addition to influencing community-level interactions and infection, can also influence community-level outcomes of nutritional status. Identifying nutritional risk factors present in different environments over time may help elucidate how nutrition outcomes change within a population and can help to inform interventions to protect those vulnerable to poor nutrition. The construction of a road in a previously roadless region of northern coastal Ecuador provides a unique opportunity to study how a village's remoteness profile maps onto temporal trends in childhood nutrition.

In this study, we report village-level nutritional trends among children under 5 years of age in Esmeraldas Province to determine how these trends vary by time and place. Guided by a conceptual model akin to a neighbourhood-level analysis, we view road access as influencing nutrition through its effect on community-level measures (e.g., wealth, education, and family size) and analyse nutritional data gathered over 10 years across 9 time points and 28 villages of varying remoteness levels. Changes brought about by road construction may lead to improved nutrition; however, road access can also introduce processed food and poor sanitation to the region, increasing the long-term risk of both undernutrition and overweight and obesity outcomes. The purpose of this study is to determine the role of village remoteness on nutrition outcomes over time.

Key messages

- Within the context of changing epidemiologic, nutritional, and sociodemographic population transitions, this research examines the role of a distal determinant, road construction, on the nutritional profile of children in rural communities.
- Remoteness, marked by road construction, provides some protection against stunting; however, the influence of remoteness has tempered over time.
- Our results highlight the need for additional research examining pathways leading to child malnutrition in efforts to develop appropriate public health interventions to counter the complicated effects of large scale infrastructure development.

2 | METHODS

2.1 | Setting

The province of Esmeraldas, located along the northern coast of Ecuador, is home to a large Afro-Ecuadorian population. In 1996, a national road construction project to link Colombia and Ecuador began, and in 2001, a two-lane paved highway was completed in the Esmeraldas region (Eisenberg et al., 2006). The timber and oil palm industries built secondary and tertiary roads throughout the 1990s and into the 2000s to facilitate the transport of lumber and production and processing of palm oil within the region (Sierra, 1999); as a byproduct, connectivity between communities has increased (Eisenberg et al., 2006). The study population is located primarily in Eloy Alfaro, one of seven Esmeraldas cantones. The village of Borbón (~5,000 inhabitants), a major population centre of the region, serves as a regional outpost for the exchange of goods and services due to its location at the confluence of the Cayapas, Santiago, and Onzole rivers. In addition to Borbón, 31 smaller villages in Eloy Alfaro and San Lorenzo cantones were selected over time and enroled in the study using block randomization to ensure that there were communities in the study, which (a) resided on each of the three rivers basins as well along the newly constructed road and (b) on varying distances from the commercial centre, Borbón (Eisenberg et al., 2006). The main analyses presented include 28 of the 31 villages. Three villages populated primarily by an indigenous group, the Chachi, were excluded due to limited data over the study time period. Qualitative data collection also showed extensive dietary differences between the Chachi and the Afro-Ecuadorian and Mestizo peoples living in other villages (unpublished). For further details on enrolment, see Data S1.

2.2 | Data collection

This study uses secondary data from a natural experiment (Eisenberg et al., 2006) that examined the impact of new roads on diarrhoeal disease between 2003 and 2013 (Data S1 provides information on numbers of villages, households, and individuals included as well as the dates of when data were collected, referred to as study cycles). Consequently, proximal determinants of nutritional status, such as dietary intake or physical activity, were not available for analysis. Cycles 3–11 (2004–2013) are included in this study. During each study cycle, we took anthropometry and haemoglobin measurements for all children <5 who were enroled in the study (see Data S2 for methods for these measurements). Because nutrition was of secondary interest to the original study objectives, we began collecting the anthropometry and haemoglobin data the beginning of Cycle 3. Data on village-, family-, and individual-level sociodemographic data were also obtained. Data collection methods and study procedures were approved by the University of Michigan and the Trinity College Institutional Review Boards and the Universidad San Francisco de Quito Bioethics Committee.

2.3 | Definitions

The primary nutrition outcomes are prevalence of stunting, wasting, underweight, anaemia, overweight, and obesity among children aged 0–59 months. Anthropometric measurements were converted to *Z*-scores using the World Health Organization's ([WHO], 2006) Child Growth Standards and the igrowup Macro Version 3.2.2 for SAS, modified to reflect a recumbent length cutpoint of 12 months. Stunting, an index of chronic undernutrition, is measured as height-for-age *Z*-scores <−2 (WHO, 2006). Wasting, an index of acute undernutrition, is measured as weight-for-height *Z*-scores <−2 (WHO, 2006). Underweight, a composite measure of chronic and acute undernutrition, and overweight/obesity are general measures of nutrition and are measured using weight-for-age *Z*-score < −2 and body-mass-index-for-age *Z*-score >2 or 3, respectively (WHO, 2006). As described in Data S2, observations with extreme *Z*-scores as calculated by the macro were excluded. Anaemia was defined as haemoglobin concentrations less than 11.0 g/dl in children from 6 to 59 months and undefined for children <6 months (Peña-Rosas, & World Health Organization, 2011). Of note, this crude measure of anaemia does not distinguish between its different causes.

The primary exposure is remoteness, a static, continuous, village-level measure calculated from the cost and time it took to travel to Borbón by road or river in 2003. For each village, travel time and total cost of travel to Borbón were recorded by field staff members. For each village i, rank of remoteness, R_i, was then calculated by standardizing values of time, T_i, and cost, C_i, separately (i.e., dividing by the sum of all times and costs across the 28 villages, respectively) and then summing the two terms. Because the metric is the result of two values standardized to a [0,1] scale, the possible range of R_i is from 0 (the town Borbón itself) to 2 (the theoretical farthest community from Borbón). Categorical forms of the remoteness scale, previously developed (Eisenberg et al., 2006), were used for descriptive purposes only, whereas whenever remoteness was included as a predictor in a regression model, the continuous remoteness metric was used. This continuous measure was normalized to range from 0 to 1 so as to aid in interpretation of the model results (i.e., a one unit increase in remoteness score reflects comparing the least remote community to the most remote community). Comparing the extremes of this scale, all villages in the close remoteness category also had road access in 2013; likewise, with the exception of one community that remains isolated due to the cost and time of travel required to reach it, none of the villages in the far remoteness category had road access at the end of the study period. We suggest that this gradient of remoteness was maintained during the 10 years of data collection (Kraay, Trostle, Brouwer, Trujillo, & Eisenberg, in press). A more complete description of the remoteness metric and community characteristics is provided elsewhere (Eisenberg et al., 2006).

As described by both local individuals and reports from non-profits, decisions regarding where to build roads within the study site were independent of community characteristics. They were instead based on extracting valuable timber or gold or building extensive palm oil plantations (García Salazar, 2001; Jiménez et al., 2011). Additionally, government reports show that road development in the province (MTOP, 2011; SENPLADES, 2013) primarily focused on highway construction outside of the study region. This suggests that road locations, and thus the resulting remoteness measure, may be thought of as essentially randomly assigned to village and is therefore probabilistically unassociated with community characteristics in the preroad era. We assume a baseline (i.e., preroad) level of balance between villages on their community socio-economic status and therefore interpret postroad differences in socio-economic status across villages as driven by road access: The introduction of a road catalyses changes to community profiles, which in turn influence child nutritional status. That is, we interpret socio-economic status variables as mediators rather than confounders in this analysis. This logic is empirically supported by a prior study in the region showing that communities with road access indeed experienced greater monetary benefits after road construction (Sierra, 1999). Increased household wealth may change the types of foods a household will consume, affecting the nutritional status of children.

Three variables were selected for mediation analysis based on their significance in the literature and predicted trends by remoteness: wealth, education, and family size (Walker, Marini, Lucchetti, Waters, & Lastra, 2007). Household wealth was examined using a previously developed and validated score based on house and roof materials (Data S1; Arias & De Vos, 1996). A higher score is a proxy indicator for higher wealth. Education was defined as the highest level of education in years achieved by any individual within a household. Family size was measured by the number of nonworking children (under the age of 13) in each household. We present a village-level analysis; thus, individual-level covariates are not including within the modelling.

2.4 | Analysis plan

The relationship between remoteness and our binary nutrition outcomes was assessed using logistic generalized estimating equations (GEE) models to provide inference that is robust to the dependence between repeated measurements on individuals over time. We specified an autoregressive of order 1 (AR1) working correlation structure. The AR1 correlation structure assumes that the correlation between observations declines exponentially as a function of the distance in time. For example, an AR1 process with parameter 0.5 would correspond to correlations of 0.5, 0.25, and 0.125 between observations made 1, 2, and 3 time points apart, respectively. We argue that residual within-village dependencies are largely captured by remoteness and so are not explicitly modelled. Similarly, within-household dependencies would very likely result from the household-level measures included and so are not explicitly modelled.

The primary analyses were separate logistic GEE models for each nutritional outcome, with remoteness and cycle as the predictors. To compare early cycles (3–7) to later cycles (8–11), an additional stratified model was run to assess occurrence of temporal changes. Because the communities enroled in the study overtime changed at the study midpoint, as stated in Data S1, analysis was conducted on villages without two consecutive cycles of missing data. Comparing the covariates and remoteness category between excluded and included villages, the mean and standard deviation for each of the variables are similar, with the exception of Maximum Education (see Data S1 for a further discussion). Following the initial logistic regression modelling, additional explorations of an outcome variable were undertaken only if there was a significant association between remoteness and the nutritional outcome variable. For the reduced set of outcome variables, six covariates were individually added to the model: household-level covariates for wealth, education, and family size and the village-level mean value for these three household-level variables. This resulted in six unique models (for each outcome variable) that were each compared to the unadjusted model to assess for mediation via a change in the beta-coefficient for remoteness. Specifically, as an informal mediation analysis, we considered a >10% absolute reduction in the regression coefficient for remoteness post-adjustment to constitute evidence that the given covariate partially explains the remoteness-nutrition relationship. A separate analysis stratifying the prevalence of each nutritional outcome by ethnicity in Cycles 7–11 is included in Data S1. All analyses were performed using SAS Version 9.3 (SAS Institute, Cary NC).

3 | RESULTS

During the study period, 4030 weight measurements and 4029 height measurements were taken on 2,350 children; Data S1 presents the number of measurements excluded from the analysis for each nutritional outcome.

Characteristics of the final study population at time of enrolment are presented in Table 1. Of the household-level socio-economic covariates, there is little difference in the mean and standard deviation by remoteness category at time of enrolment, supporting our conceptual framework. Moreover, there is also little difference in the mean and frequency of and individual child characteristics across remoteness categories, providing evidence that further statistical models should not include these variables as covariates.

Of the estimated undernutrition outcomes, the aggregate prevalence of stunting and anaemia was 12% (95% CI [11%; 13%]) and 55% (95% CI [53%; 56%]), respectively, over the entire study period; whereas the prevalence of wasting and underweight during the study period was similar at 6% (95% CI for wasting [5.3%; 6.7%] and 95% CI underweight [5.4%; 6.9%]). The prevalence of overweight children was 5% whereas the prevalence of obesity was 1.6% throughout the entire study (see Data S1 for age-stratified estimates of all nutrition outcomes). The prevalence of each nutritional outcome over time is presented in Figure 1. As noted in the figure, the prevalence of stunting decreased over the study period, and although not statistically significant, child obesity increased. The outlying high prevalence of wasting for Cycle 3 and the outlying low prevalence of anaemia in Cycle 7 were likely due to wide variation in the number of villages included in the cycle. Further examination of the Cycle 3 peak in

TABLE 1 Characteristics of the total study population and of population stratified by remoteness category at enrolment into the study (N = 1,257 households and 2,350 individuals)

Covariate	Study population		Remoteness category: Borbón	Close	Medium	Far
Child characteristics		Number of children				
Age (months)	24 (17)	2,350	28 (16)	24 (16)	24 (17)	24 (17)
Male	49%	2,333	48%	48%	50%	49%
Afro-Ecuadorian[a]	80%	1,980	46%	79%	76%	89%
Total children	-	2,350	242	950	342	816
Household characteristics		Number of households				
Children per household	2.3 (1.5)	1,170	3.0 (1.5)	2.2 (1.4)	2.1 (1.3)	2.3 (1.6)
Maximum education (years)[b]	7.4 (3.9)	658	9.4 (3.9)	6.6 (3.8)	6.8 (3.5)	7.4 (3.7)
Wealth score	4.6 (1.1)	964	[c]	4.7 (1.1)	4.5 (1.1)	4.5 (1.1)
Total households	-	1,275	173	509	189	404

Note. Mean (*SD*) is reported for age, and frequency is reported for sex (% males) and ethnic group (% afro-Ecuadorian). Mean (*SD*) is reported for children per household, wealth score, and maximum education.

[a]Ethnic group missing for children enroled in Cycle 11 of data collection and includes 370 missing observations.

[b]Maximum Education missing for 617 households.

[c]Household construction data not collected Borbón.

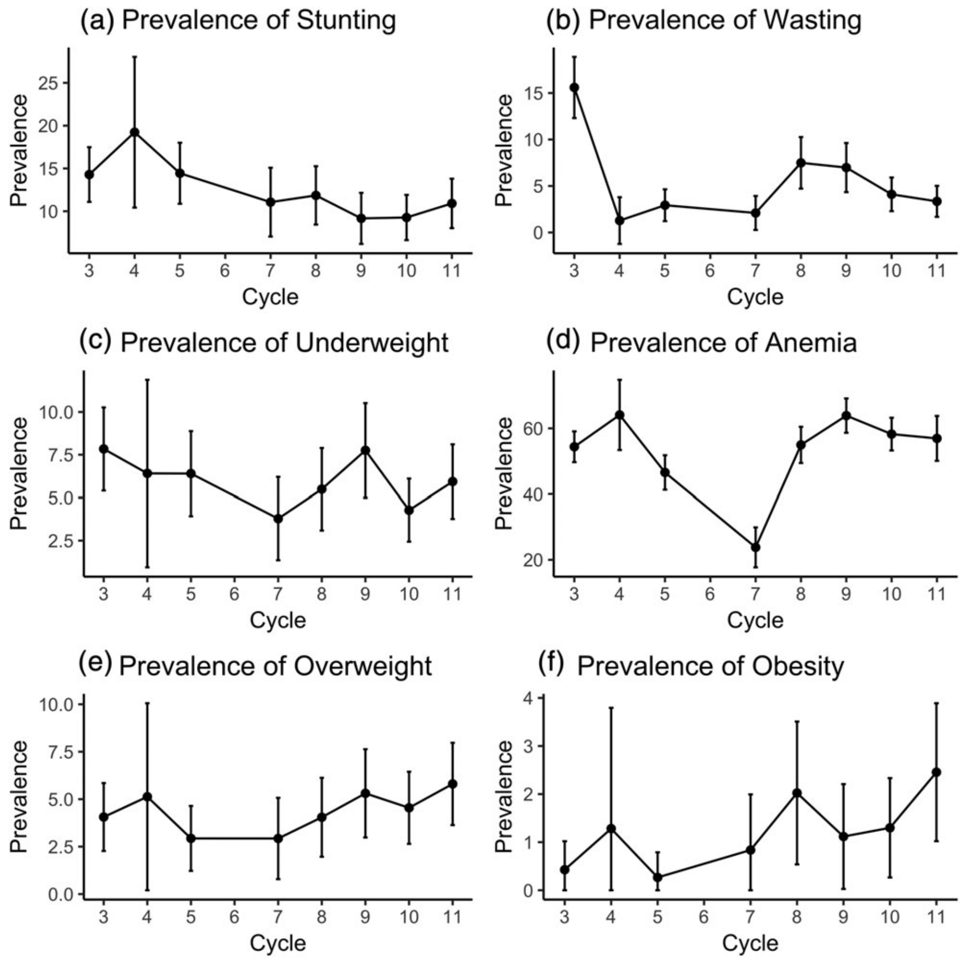

FIGURE 1 Prevalence of each nutritional outcome across time in 15 villages. Thirteen villages not included because they were missing data in >2 cycles or were missing two consecutive cycles. Data collected within cycles during (3) November 2004–June 2005, (4) August 2005–February 2006, (5) June 2006–December 2006, (7) September 2007–October 2008, (8) December 2008–November 2009, (9) January 2010–December 2010, (10) January 2011–May 2012, and (11) July 2012–July 2013. The prevalence of stunting and the prevalence of anaemia significantly decreased based on the generalized estimating equations model: outcome = $\beta_0 + \beta_1$(cycle). All other outcomes did not have statistically significant trends over time

wasting prevalence showed five communities driving the aggregate prevalence. Exploratory analyses of anthropometric measures within these outlying communities suggest that length/height measurements may have been subject to nonsystematic measurement error where height measurements in children were likely biased towards higher values in Cycle 3, exaggerating the aggregate wasting prevalence at this time point. Nevertheless, trends in the prevalence of wasting and anaemia were not significant as other cycles varied minimally across time.

Logistic GEE models adjusting for cycle, a proxy measure of time, showed that the odds of stunting decreased significantly as a function of remoteness (Table 2). This was also demonstrated in Figure 2, a graph comparing the change in prevalence of stunting in far and close villages over time, smoothed using predicted values from a generalized additive model with three knots (i.e., the number of sections that the data set have been divided into for the smoothing process). Similar to stunting, the odds of anaemia were lower in the more remote villages compared to the less remote villages, adjusted for cycle. There was no significant difference in the odds of the other four nutritional outcomes. Although there was a point estimate decrease, the odds ratio of stunting between more versus less remote villages did not vary significantly over time. The relationship between remoteness and odds of anaemia was also similar throughout the study.

Using a cutpoint of 10% change in estimate criterion, inclusion of the household wealth score in the stunting model showed minimal impact on the pathway from remoteness to stunting (Table 3), suggesting, paradoxically, that wealth score may not explain differences observed by remoteness. When maximum education level in the household is included in the model, the directionality of the 25% change in the beta-coefficient of remoteness suggests that educational attainment may play a role as a mediating factor in the pathway between remoteness and stunting. The influence of household family size, however, was null. Incorporation of community-level covariates within the models to account for within-village correlations did not meaningfully change the beta-coefficient of remoteness in the stunting model. An examination of the role of household-level variables as mediators in the relationship between remoteness and anaemia was not possible due to the large number of missing covariates and GEE assumptions that data should be missing at random.

TABLE 2 Odds ratio for each predictor in the model assessing the association between remoteness and nutritional outcome (outcome = β0 + β1[remoteness] + β_i[$cycle_i$])

	Stunting		Wasting		Underweight		Anaemia		Overweight		Obesity	
	OR [95% CI]	*p* value	*OR* [95% CI]	*p* value	*OR* [95% CI]	*p* value	*OR* [95% CI]	*p* value	*OR* [95% CI]	*p* value	*OR* [95% CI]	*p* value
Model results for entire study period												
Remoteness	0.43 [0.30, 0.63]	<0.0001	1.3 [0.84, 1.9]	0.26	0.81 [0.51, 1.3]	0.39	0.56 [0.44, 0.70]	<0.0001	1.1 [0.68, 1.7]	0.64	1.6 [0.68, 3.8]	0.28
Cycle 3	1.4 [1.0, 2.1]	0.06	5.4 [3.0, 9.6]	<0.0001	1.4 [0.85, 2.3]	0.19	0.86 [0.62, 1.2]	0.40	0.71 [0.39, 1.29]	0.26	0.17 [0.04, 0.74]	0.02
Cycle 4	2.5 [1.2, 3.8]	0.01	0.30- [0.3, 3.6]	0.34	1.1 [0.48, 2.5]	0.84	1.1 [0.66, 1.9]	0.67	0.85 [0.33, 2.19]	0.74	0.50 [0.07, 3.6]	0.49
Cycle 5	1.5 [1.0, 2.2]	0.06	0.93 [0.43, 2.0]	0.85	1.1 [0.65, 1.9]	0.69	0.64 [0.45, 0.90]	0.01	0.46 [0.22, 0.98]	0.04	0.10 [0.01, 0.81]	0.03
Cycle 7	0.97 [0.60, 1.6]	0.89	0.66 [0.25, 1.8]	0.41	0.69 [0.37, 1.3]	0.25	0.21 [0.13, 0.32]	<0.0001	0.45 [0.17, 1.2]	0.10	0.34 [0.07, 1.6]	0.18
Cycle 8	1.2 [0.75, 1.8]	0.52	2.3 [1.2, 4.4]	0.02	0.87 [0.49, 1.5]	0.62	0.88 [0.61, 1.2]	0.47	0.68 [0.35, 1.3]	0.26	0.82 [0.31, 2.2]	0.69
Cycle 9	0.85 [0.55, 1.3]	0.47	2.3 [1.2, 4.3]	0.01	1.4 [0.82, 2.2]	0.24	1.3 [0.89, 1.8]	0.19	0.84 [0.46, 1.6]	0.58	0.42 [0.13, 1.4]	0.16
Cycle 10	0.88 (0.59, 1.3)	0.52	1.2 [1.6, 2.4]	0.53	0.76 [0.46, 1.2]	0.29	0.93 [0.67, 1.3]	0.68	0.48 [0.51, 1.4]	0.50	0.52 [0.2, 1.4]	0.18
Cycle 11[a]	1	-	1	-	1	-	1	-	1	-	1	-
Stratified model at mid-point of data collection												
Remoteness	0.39 [0.23, 0.66]	0.001	1.5 [0.90, 2.7]	0.12	0.63 [0.32, 1.3]	0.19	0.56 [0.39, 0.79]	0.001	1.8 [0.69, 4.9]	0.22	10 [0.56, 185]	0.12
Cycle 3	1.5 [0.94, 2.5]	0.09	8.1 [3.2, 20]	<0.0001	2.3 [1.2, 4.4]	0.01	4.3 [2.9, 6.4]	<0.0001	1.3 [0.54, 3.2]	0.55	0.33 [0.06, 1.9]	0.21
Cycle 4	2.2 [1.1, 4.3]	0.02	0.55 [0.06, 4.7]	0.58	1.8 [0.76, 4.0]	0.19	6.0 [3.4, 11]	<0.0001	1.5 [0.47, 5.1]	0.48	0.89 [0.08, 9.5]	0.92
Cycle 5	1.5 [0.98, 2.4]	0.06	1.3 [0.43, 3.8]	0.65	1.8 [0.98, 3.2]	0.06	3.2 [2.2, 4.7]	<0.0001	0.85 [0.29, 2.5]	0.77	0.20 [0.02, 2.2]	0.19
Cycle 7[a]	1	-	1	-	1	-	1	-	1	-	1	-
Cycles 8–11												
Remoteness	0.49 [0.30, 0.80]	0.004	0.97 [0.53, 1.8]	0.92	1.0 [0.54, 1.9]	1.0	0.55 [0.40, 0.75]	0.0002	0.91 [0.50, 1.7]	0.77	1.2 [0.49, 3.1]	0.66
Cycle 8	1.2 [0.76, 1.8]	0.47	2.4 [1.2, 4.6]	0.01	0.92 [0.51, 1.6]	0.77	0.89 [0.62, 1.3]	0.51	0.71 [0.37, 1.4]	0.30	0.83 [0.32, 2.1]	0.71
Cycle 9	0.86 [0.59, 1.3]	0.49	2.3 [1.2, 4.4]	0.01	1.4 [0.82, 2.2]	0.24	1.3 [0.89, 1.8]	0.19	0.86 [0.46, 1.6]	0.62	0.43 [0.13, 1.5]	0.17
Cycle 10	0.87 [0.59, 1.3]	0.50	1.2 (0.65, 2.4)	0.51	0.75 [0.46, 1.2]	0.26	0.93 [0.66, 1.3]	0.68	0.85 [0.51, 1.4]	0.53	0.53 [0.21, 1.4]	0.20
Cycle 11[a]	1	-	1	-	1	-	1	-	1	-	1	-

Note. The *OR* for continuous remoteness, which ranges from 0 to 1 (as defined in the text), reflects a statistical comparison between the two extremes of all the remoteness values observed in the data set. Fifteen villages were included in the analysis, villages were excluded if they were missing >2 cycles of data or 2 consecutive cycles of data. *OR* = odds ratio.

[a]Referent group.

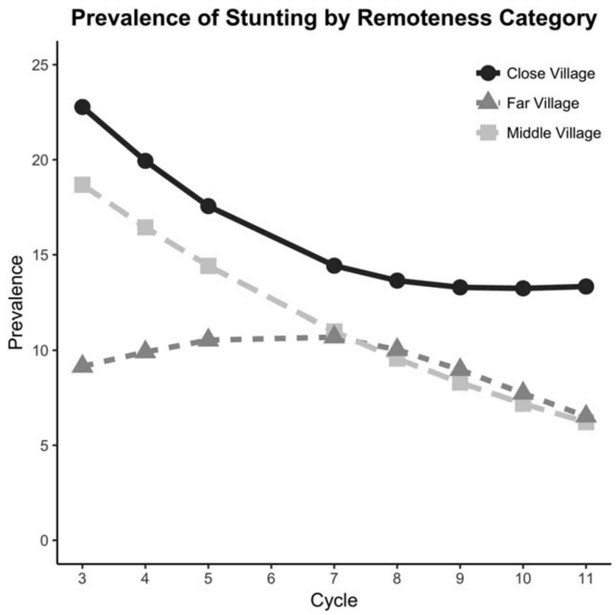

FIGURE 2 Prevalence of stunting, smoothed with a generalized additive model containing three knots, across time for remoteness categories of villages that were included in generalized estimating equations model

4 | DISCUSSION

The odds of stunting and the odds of anaemia were lower in more remote villages than in closer villages (*OR* = 0.43 and 0.56, respectively; Table 2). This result was not explained by household size and may be partially explained by wealth and education (Table 3). This observed spatial gradient was preserved throughout the study period (2003–2013; Figure 2) even though stunting decreased over time throughout the study region (from 14% to 11%; Figure 1). The fact that remoteness was related to both anaemia and stunting is not unexpected; the World Bank found an association between stunting and anaemia in Ecuadorian children, suggesting a likely shared aetiology (Walker et al., 2007). We hypothesize that if remoteness has an impact on either stunting or anaemia through a shared causal pathway, there will be an impact on both nutritional outcomes.

Roads can influence the nutritional status of child through numerous pathways. We frame our results here within a discussion of the pathways connecting roads to child stunting that are mediated by market access, wealth, and education. Demographic transitions, often marked by road construction, tend to distribute health services, wealth, and risk of disease unequally (Frenk et al., 1989) among villages in the area. Thus, comparing nutritional outcomes across remoteness categories provides insight into the macrolevel determinants influencing nutritional outcomes in rural Esmeraldas. Various studies have observed that closer proximity to roads and/or population centres with markets is associated with higher levels of diversity in diets, which likely contributes to more nutritionally adequate diets (Kumar, Harris, & Rawat, 2015; Sibhatu, Krishna, & Qaim, 2015). Yet the nutritional implications of greater road access will almost certainly vary based on the quality, diversity, and seasonality of food items available at newly accessible markets, regional price-to-wage ratios, and existing nutritional deficiencies or excesses (Jones, 2017). If markets do not provide access to affordable, healthy food options, their influence on nutrition outcomes may be negligible or even negative. Houck et al. (2013), in an 8-year study among children and adolescents in indigenous villages in the Northern Ecuadorian Amazon, found a higher prevalence of stunting among children and youth living in communities with increased market activity compared to another village with stable market activity. As a parallel, we suggest that the stable exposure to market activities likely experienced in close villages may partially explain the faster reduction in stunting among children living in villages close to a road. Whereas, the presence of a stable protein source from fish in the far villages can explain the lower stunting prevalence relative to the road villages; and a subsequent steady increased exposure to market activities over time can explain the observed slower reduction in stunting. Overall, these results highlight the important role of the differing pace of economic development within villages in our study, which in turn propagates changes to dietary patterns or income generation via exposure to market activities.

We hypothesize that road construction, a marker of economic development, may influence nutrition outcomes through changing resource availability. Specifically, we found evidence suggesting educational attainment acts as a mediator between road access and child health outcomes, a finding consistent with social epidemiologic literature framing parental education as a social determinant of health

TABLE 3 Mediation analysis of covariates within the remoteness-stunting pathway

	Wealth score	Maximum education	Children per household
Adjustment for household-level mediators	Beta	Beta	Beta
Remoteness estimate in unadjusted model	−0.83	−0.83	−0.83
Remoteness estimate in household-level adjusted model	−0.92	−0.63	−0.85
% Δ	10	−25	1.5
Adjustment for community-level mediators	Beta	Beta	Beta
Remoteness estimate in unadjusted model	−0.83	−0.83	−0.83
Remoteness estimate in community-level adjusted model	−0.86	−0.84	−0.85
% Δ	3.4	1.1	1.7

Note. Beta coefficient represents stunting between the most remote villages and the least remote villages, adjusted for time and select covariates. Percent change in beta upon addition of each covariate is displayed, where a positive Δ beta represents a shift away from the null and a negative Δ beta value represents a shift towards the null. Generalized estimating equations model is outcome = $\beta_0 + \beta_1$(remoteness) + β_2(cycle) + β_3(covariate).

(Li, Mattes, Stanley, McMurray, & Hertzman, 2009). Interestingly, the association between remoteness and stunting increased in magnitude when wealth was included in the models. This result suggests that perhaps unmeasured confounding between the household-level covariates and nutritional outcomes is obscuring the indirect mediation pathway (VanderWeele, 2010).

In addition to the impact of road access on nutritional status, we found that the prevalence of wasting is of medium severity for a population per the WHO recommendations (WHO, 2006), whereas more than half of children in the study site have a haemoglobin level less than 11 g/dl and are classified as having anaemia (6% and 55% prevalence, respectively). The prevalence estimates of underweight, overweight, obesity, and stunted children fall beneath the WHO cutpoint for population health concern. Nevertheless, the prevalence of stunting is 5 times higher than what would be expected based on the WHO recommended standards. Although the public health concern related to wasting, anaemia, and stunting among young children may be more pressing given the larger number of individuals affected, the prevalence of overweight children may also be of concern given its rising prevalence. The prevalence of child overweight in this population is 5%. This is slightly lower than, but near to, the global prevalence of child overweight that recently stood at approximately 7%. This prevalence of child overweight, and the increasing trend associated with it, has been highlighted as a key public health concern in low- and middle-income countries (Black et al., 2013). We also observed a more than threefold increase in the prevalence of obesity over time. Although the absolute levels are small, these data suggest that obesity within the region should be monitored. More data are need to assess whether the increasing trend of overweight translates to high levels of obesity in adults, which would suggest a dual burden of malnutrition in the population. Prior studies have observed a double burden of undernutrition and excess bodyweight at the population level in Ecuador (Freire, Silva-Jaramillo, Ramirez-Luzuriaga, Belmont, & Waters, 2014) as well as elsewhere in the region, namely, Brazil, Colombia, Guatemala, Mexico, and Uruguay (Rivera, Pedraza, Martorell, & Gil, 2014).

Most studies examining malnutrition among preschool age children in Latin America focus on nutritional outcomes and proximal determinates rather than distal, macrolevel determinants of child well-being. Our study is unique but has limitations. First, our conceptual model requires an assumption that locations were balanced in the preroad era in terms of village-level socio-economic status. In this way, we effectively view remoteness as a randomly assigned "treatment," whose effects are mediated through subsequent changes in village-level socio-economic status. This assumption is consistent with information indicating that areas were chosen for road construction without regard to their socio-economic status. However, as with any randomly assigned treatment, imbalances can arise purely through chance, and we are unable to rule out that possibility because we do not have preroad data. Prior literature has concluded that the introduction of a road does increase the socio-economic status characteristics of a village (Sierra, 1999), suggesting that the results found here are consistent with the hypothesized conceptual model. Additionally, there are also limitations inherent in using the odds ratio to assess common outcomes. Consequently, our models in Table 3 may overestimate the size of association in the mediation analysis and inhibit the comparison between indirect and direct effects due to issues of collapsibility (Greenland, Robins, & Pearl, 1999; Vanderweele & Vansteelandt, 2010; Zhang & Yu, 1998). Although future work is required to address and understand these limitations, our study is a first step in identifying the relationship between road access and child nutritional status.

This works presents the effects of an economic development project on child nutritional status over space and time. We found that road expansion influenced child stunting and anaemia in the Esmeraldas region of northern coastal Ecuador up to a decade after the main road was completed. These child malnutrition outcomes differ by road access, with children living in more remote communities experiencing a lower prevalence of malnutrition. Additional research is required to identify the dietary and lifestyle changes that took place during the study period. This study, however, is a first approach to identifying the distal determinants of nutritional change, which is necessary for developing appropriate interventions to counter the negative outcomes of road construction.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

VKL and CD equally analysed data, wrote the paper, had primary responsibility for final content, and are co-first authors of this manuscript. JT and NM designed research and conducted research, as well as contributed to data interpretation. PM and ADJ contributed to data interpretation. WC designed research and conducted research. JG analysed data and contributed to data interpretation. JNSE designed and conducted research, analysed data, and had primary responsibility for final content. All authors read, edited, and approved the final manuscript.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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