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Land use as a mediating factor of fertility in the Amazon

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Abstract

Despite implications for both humans and the environment, a scant body of research examines fertility in forest frontiers. This study examines the fertility–environment association using empirical data from Ecuadorian Amazon between 1980 and 1999. Fertility dramatically declined during this period, and our empirical models suggest that households' relationship to land partially explains this decline. Controlling for known fertility determinants such as age and education, women in households lacking land titles experienced a 27 % higher birth rate than did women in households with land titles. This suggests insecure land tenure was associated with higher fertility. Furthermore, each additional hectare of new pasture was associated with a 16 % higher birth rate, suggesting the potential role of a more stable and lucrative income source in supporting additional births. Findings from this research can help inform strategic policies to address sustainable development in frontier environments.

Keywords

Fertility; Environment; Land tenure; Amazon; Land use; Human–environment; Ecuador

Introduction

Does fertility theory apply to agricultural forest frontiers? The literature on human fertility is extensive. Yet explanations of fertility change have been devoted primarily to understanding how behavioral and biological proximate factors influence fertility (Bongaarts 1978; Davis and Blake 1956). As the world continues to urbanize, understanding distinctions between urban and rural fertility becomes more important. Yet even within rural regions, there may be substantial differences in the mechanisms mediating fertility (by mediation we mean the conditions or characteristics under which proximate determinants influence fertility).

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Differences in the difference in past 3-year pasture change (CPST3 = current pasture–pasture 3 years ago) are positive when more pasture is created (or less lost) for farms whose WBCA report a birth versus those that do not. Differences in the difference in future 3-year pasture change (FC_PST3 = current pasture–pasture 3 years from now) are positive when farms with WCBA reporting a birth gain less pasture (or remove pasture as a land use) than farms with WCBA not reporting a birth.

Differences in the difference in past 3-year agricultural change (CAGR3 = current agriculture–Agriculture 3 years ago) are interpreted similarly as pasture.

Perhaps, the regions most vulnerable to mischaracterization are forest (or agricultural) frontiers which encompass the world’s remaining large intact natural forest ecosystems. These regions are also the primary areas of interface between human agricultural development and the forest frontier.

In frontier contexts, such as the Amazon or Congo Basins, multiple factors influence land use and management and, therefore, livelihood decisions. Households have limited economic choice outside of farming or migration. All choices exist in a mixture of resource constraints: scarce labor yet abundant land; limited access to infrastructure, social services, and capital, but rapidly growing urban centers; and persistent cultural norms that put considerable pressure on women to pursue child-rearing as their primary activity rather than economic opportunities outside the home. While some of these characteristics are common globally in rural farming areas, scarce labor and excess land availability are more commonly found with frontier families.

Despite rich implications for human development and environmental conservation, surprisingly little research has been conducted on fertility determinants in forest frontiers. Understanding explicit determinants of fertility in agricultural forest frontiers is imperative. This is particularly true given recent evidence that fertility and population growth have been largely underestimated (Gerland et al. 2014). Relatively small populations account for a disproportionate amount of global environmental change (Lopez-Carr and Burgdorfer 2013; Rudel and Roper 1997) High fertility rates in these areas not only fuel regional population growth, but also enact direct sustained pressure on natural ecosystems. As our understandings of mechanisms underlying population, poverty, and environmental outcomes continue to evolve, it is undeniable that frontier regions report some of the highest fertility rates in the world, resulting in significant anthropogenic environmental impacts (Bremner et al. 2010; Carr et al. 2006). The relationship between land use and human fertility decisions is at the core of this narrative.

The primary goal of this paper was to better understand the relationship between factors associated with land-use/land-cover change (LUCC) and fertility in tropical environments. We focus on the Ecuadorian Amazon and test the importance of two dominant hypotheses in this debate: the land–labor demand hypothesis (abundant land but limited capital and labor increases fertility) and the land security hypothesis (land security lowers fertility through a relative shift from yield maximization to yield sustainability; see, e.g., Caldwell and Caldwell 1987; Carr et al. 2006; Carr 2007; Hawley 1955). The relevance of these hypotheses has been challenged (e.g., see Cleland 1993; Thomas 1991); however, we maintain that ostensible inconsistencies result largely from testing under distinct contexts (e.g., it may be inappropriate to apply determinants from a rural farming context to an agricultural frontier simply because they are both rural areas).

We contend that in agricultural forest frontiers, LUCC characteristics, such as changes in agricultural land area and tenure security, mediate the relationship between proximate determinants and fertility. More specifically, we argue that LUCC dynamics are inextricably linked to fertility rates in frontier contexts such as our research site in the Ecuadorian Amazon.

Context

Our hypotheses are tested using a longitudinal panel study of households and land plots in the northern Ecuadorian Amazon (NEA) between 1990 and 1999. From panel data, we reconstruct households. Research from these data include relevant articles on fertility, migration, and human health (Barbieri and Carr 2005; Barbieri et al. 2009; Bilsborrow et al. 2004; Carr et al. 2006; Pan et al. 2010).

Ecuador experienced a dramatic decline in the national total fertility rate (TFR) from over 8.0 in the 1980s to 3.6 in 1994; however, despite a 30 % increase in contraception prevalence between 1994 and 2004, TFR has remained stable and was most recently estimated to be 3.3 in 2004[1] (Ishida et al. 2009). Data from the Amazon suggest a sharp gradient between urban and (rural) frontier communities, with TFR 50–100 % higher in rural regions. Regional (mostly urban) TFR was estimated to be 4.2 in 2004 (CEPAR 2000); yet, data from colonist and indigenous surveys in the same region indicate TFRs of 6.3 and 8.9, respectively (Bremner et al. 2009; Pan et al. 2010). While this is not particularly surprising, the lack of a significant fertility decline despite improved access to family planning suggests differential fertility determinants.

Theoretical approach

Background

Explanations of fertility over the past century have evolved from classical approaches that associated fertility decline with the demographic transition (Davis 1945; Notestein 1945, 1983), to structural explanations which focus on society, culture, institutions or social organizations, and to explanations centered on the individual (e.g., age of marriage, fertility regulation, education). Regarding fertility in rural areas in general, several hypotheses emerge from these approaches. First, the child survival and replacement hypothesis proposes that couples with a high number of surviving children (low mortality) may respond by having fewer children and thus reduce fertility (van de Kaa 1996). Alternatively, the insurance births hypothesis postulates that women who perceive their risk of widowhood as high are motivated to have children quickly after marriage to reduce their risk of economic hardship (Dasgupta 2003; Marcoux 1999; van de Kaa 1996). These hypotheses have varying degrees of acceptance in the literature. They are largely based on the assumption that fertility choices are made in response to individual and societal perceptions of the level of mortality (e.g., see (Chesnais 1992; Chowdhury, Khan and Chen 1976; Taylor, Newman and Kelly 1976; van de Kaa 1996; van de Walle 1986).

A second set of hypotheses describes fertility in largely economic terms. Such theories conceptualize fertility as operating through household constraints, such as budget, technology access/use, and health care quality (Easterlin, Pollak and Wachter 1980; Schultz 1981), or via a household utility function that incorporates child quality, household consumption, and labor force participation in fertility decisions (Becker 1960; Nerlove

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[1] This period also reported a similarly slow decline in child mortality, from 82 deaths per 1000 in 1987 to 39 in 2000 and 35 in 2004 as reported in Pan et al. (2010) and Ishida et al. (2009). The slower declines in fertility and child mortality coincided with the economic crisis in Ecuador during the late 1990s that resulted in dollarization of the economy.

1974). A related class of approaches describes fertility behavior as a function of noneconomic factors, such as social conditions, family production modes (i.e., agriculture), and, most importantly, intergenerational wealth flows (Caldwell 1976; Okediji et al. 1976).

A third set of hypotheses suggests that the diffusion of fertility ideas, behaviors, and technologies along sociocultural networks (e.g., language, religion, geographic neighborhoods, ethnicity) induces changes in fertility (Casterline 2001; Kohler, Behrman and Watkins 2000; Montgomery and Casterline 1993; Rosero-Bixby and Casterline 1993; Tolnay 1995; Watkins 1987). Innovation–diffusion approaches are closely related to the belief that fertility is associated with cultural values or “ideational change” (Lesthaeghe 1983) as well as to Caldwell’s intergenerational wealth flow approach. These approaches have helped describe how institutional context and social structures regulate pathways involved in fertility decisions (Bilsborrow and Guilkey 1987; Bulatao 1983; Casterline and Casterline 1985).

Fertility theory in a frontier setting

A central question remains unresolved in the fertility literature: Are long-standing fertility theories applicable to agricultural forest frontiers (and if so, to what extent)? To begin addressing this question, we build on a proximate determinants model (Bongaarts 1978; Davis and Blake 1956; Henry 1953; Hobcraft and Little 1984; Reinis 1992) in which many factors influence fertility directly: exposure to intercourse (i.e., through marriage or consensual union); exposure to contraceptives (i.e., use, effectiveness, postpartum infecundability, sterility); and successful gestation. Although some factors shaping frontier fertility are consistent with this model, recent work on rural household livelihoods calls into question the connection between theories of livelihoods and proximate fertility determinants. For example, the land–labor demand hypothesis purports that abundant land but limited infrastructure, capital, and labor leads to low economic returns from land relative to labor. Hence, large desired family size is a unique feature of agricultural frontiers (Caldas et al. 2007; Caldwell and Caldwell 1987; Carr et al. 2006; Walker 2004). Using our study data (Carr et al. 2006; Pan et al. 2007; Pan et al. 2009; Thapa, Bilsborrow and Murphy 1996) in several settings, including Thailand (Van Landingham and Hirschman 1995), Brazil (Merrick 1978; Molyneaux 1986), Peru (Coomes and Grimard 2001), Guatemala (Sutherland, Carr and Curtis 2004), the US agricultural frontier during the nineteenth century (Anderton and Bean 1985; Easterlin 1971; Laidig, Schutjer and Stokes 1981), the Philippines (Schutjer, Stokes and Cornwell 1980), Egypt (Schutjer, Stokes and Poindexter 1983), and Ecuador, fertility has been observed to increase concurrently with increases in land plot size.

This relationship is embedded within core population–environment dynamics of land security/ownership, farm size/land and resource availability, and household demographics (Carr 2007, 2008; Doveri 2000). Population–environment dynamics are fluid in that households respond to external pressure in multiple ways, and these responses can occur simultaneously or not.

Theoretical approaches are often complimentary. For example, the vicious cycle and economic livelihood approaches have been proposed to explain how rural households make decisions under various asset constraints. The vicious cycle model (VCM) arises from a demographic approach. It draws upon the insurance births hypothesis to describe the situation in which high fertility persists despite declining quality of resources and rising poverty due to the lack of economic opportunities, land abundance, and labor demands (Dasgupta 1995; de Sherbinin et al. 2007, 2014; Guedes et al. 2012; Guedes et al. 2014; O'Neill, MacKellar and Lutz 2001). The economic livelihoods approach describes households as achieving basic needs through the mobilization of assets to engage in activities that help manage risk uncertainties (de Sherbinin et al. 2008; Frankenberger and McCaston 1998).

Empirical research has clarified some of the complexities of the land–fertility relationship. However, several shortcomings hamper our understanding of these processes. First, nearly all studies examining land use and fertility have been conducted in rural areas, not in frontier environments. Second, many of these studies have been cross-sectional, which limits inference and understanding intricacies of the land–fertility relationship. Third, the importance of (in- and out-) migration, a prerequisite for agricultural frontier colonization, has not been considered a factor in frontier fertility despite widespread literature that relates rural-to-urban or international migration to fertility of women in origin (those left behind) or destination locations (Burke 1995; Fennelly, Cornwell and Casper 1992; Gorwaney et al. 1991; Lee and Pol 1993; Lerman and Goldscheider 1992; Zeng 1996). While fertility, migration, and population size, in general, are recognized as important factors for land-use change (Bilsborrow 1987; Bilsborrow and Carr 2001; Bilsborrow et al. 2004; Carr 2004; Carr et al. 2009; Entwisle and Stern 2005; Ervin and López-Carr 2015; Geist and Lambin 2002; McCracken et al. 1999; Perz 2001; Vanwey et al. 2007), scant research exists on the repercussions of LUCC on components of population growth, particularly fertility.

Building upon the proximate determinants model, we frame our approach within a multiphasic response model. Davis (1963) proposed that individuals and households recognize the need to change demographic behavior to avoid declines in standards of living and to take advantage of economic opportunities. Novel to Davis' argument was the notion that households respond to external economic dynamics both sequentially and simultaneously, hence the term multiphasic. Davis' theory was corroborated by hosts of case studies, including the famous cases of marriage postponement in Ireland as a result of dwindling land availability and the proto-industrial French fertility decline. Missing from Davis' theory was the potential for non-demographic responses. Bilsborrow (1987) built on Davis' work by positing that responses are not limited to demographic decisions, but include both economic and economic-demographic responses as a more complete suite of options available to individuals and households. The former refers to adaptations such as changes in cultivation methods and technology adoption, the latter to out-migration and livelihood diversification. Davis and López-Carr (2010) expand on this approach. They suggest that remittances are an increasingly important income source in Latin America and should have a downward impact on fertility vis-a-vis investments in land intensification rather than labor. A multiphasic response suggests that fertility choices may precede, postdate, or occur simultaneously with a host of decisions, including changes in land ownership, plot size, and use.

We test three key hypotheses using longitudinal data to show that births are proportionately related to (1) size and/or changes in land holdings; (2) expanded agricultural land use (i.e., cleared land); and (3) less secure land ownership. These hypotheses will be tested after adjusting for proximate determinants in a multilevel model. Our approach can test whether land-use characteristics are modifiers of proximate determinants (e.g., the effect of marital status varies by levels of land use) or are mediators in which the effect of proximate factors disappears in the presence of land characteristics or that land has an indirect effect on fertility.

Data and methods

Survey data

Data for this study are from surveys conducted in the Northern Ecuadorian Amazon (NEA) in 1990 and 1999 on a representative sample of migrant colonist households. Details of the surveys and sample selection are described elsewhere (Bilsborrow et al. 2004; Pan and Bilsborrow 2005; Pichón 1997). Briefly, a two-stage sample of 480 land plots (*fincas*, approximately 50 ha) was selected in 1990 from which 405 had agricultural activity or human occupation and were successfully interviewed. Three hundred and ninety-five *fincas* were revisited in 1999. All households on the *fincas* were surveyed in both years with separate male and female household surveys (see http://www.cpc.unc.edu/projects/ecuador/sed/amazonian-colonist) resulting in 418 independent households in 1990 and 767 in 1999, as land subdivision divided plots.

Previous fertility studies using these data (Bilsborrow et al. 2004; Carr et al. 2006; Thapa and Bilsborrow 1995) were restricted to women of child-bearing age [WCBA] who were the responding female heads of household ($n = 291$ in 1990, 464 in 1999) or WCBA heads of household interviewed in both 1990 and 1999 ($n = 165$), thus studying mostly married, older women. Here, we include all WCBA in 1990 and 1999 (557 and 906, respectively) and reconstruct annual birth histories and household composition between 1980 and 1999 using data pertaining to children ever born, age, year of migration (to and from the household), and mortality. The larger sample size improves inferential power and fertility estimates. For example, Bilsborrow et al. (2004) estimated a total fertility rate (TFR) of 8.0 in 1990 and 5.0 in 1999, compared to a TFR of 7.0 and 6.2 in 1990 and 1999, respectively, using all WCBA.

Interpolation of land use

To estimate annual land-use/land-cover change (LUCC), we used a previously classified time series of LandSat satellite imagery (in 1972, 1986, 1989, 1996, 1999, and 2002) to interpolate annually for each *finca* (Messina and Walsh 2001). An average of 354 *fincas* provided land-cover data each year due to cloud cover on the image and missing GPS data for some *fincas*. These data were modeled using fractional polynomials for year (Cui et al. 2009; Royston and Altman 1994) and exogenous predictors, including road access; distances to the nearest primary community (Coca, Lago Agrio, Shushufindi, La Joya de los Sachas); population living on the *finca* three years prior and changes over three years (one- and five-year lags were also examined); settlement sector; and lagged national annual production and prices for coffee and cattle (one-, three-, and five-year priors were examined) that were obtained from the International Coffee Organization (ICO 2009) and FAOSTAT (FAO 2010). The fractional polynomials were fit using STATA 11, adjusting for both spatial and temporal correlations.

Annual land-cover data for each *finca* were obtained using a mixed effects model for each land-cover type with its corresponding fractional polynomials estimated above. This model is written:

$$y_{it} = \beta_0 + \beta_T T^* + \beta_4 x_{\mathrm{ACC},t} + \beta_5 I(\mathrm{comm}) + \beta_6 x_{d,i} + \beta_7 x_{\mathrm{POP}(t-3),it} + \beta_8 x_{\mathrm{POP}(\Delta t),it} \\ + \beta_9 I\ (\mathrm{sector}\ ) + Zu + e_{ij}$$

where y_{it} is land use on finca i during year t, β_0 is the intercept, $\boldsymbol{\beta}_{\mathbf{T}}$ and $\boldsymbol{T^*}$ are the parameter estimates and values for the fractional polynomials, $x_{\mathrm{Acc},t}$ is road access during year t, I(comm) is an indicator function for the nearest primary community and $x_{d,i}$ is distance to this community, $x_{\mathrm{POP}(t-3),it}$ and $x_{\mathrm{POP}(\Delta t),it}$ are values for the finca population in year (t–3) and change since year (t–3), I(sector) is an indicator function for the settlement sector in which the finca is located, and **Z** is a matrix of random effects with parameter vector **u**. The mean interpolated values for each land-cover type and observed means from satellite data are shown in Fig. 1. The models fit the data very well: Note that agricultural land cover increased from the 1980s to mid-1990s with a dip during the late 1990s, which may be related to the decline in coffee prices globally, poor economic conditions in Ecuador during the late-1990s, and/or dollarization of the Ecuadorian economy in 1999. Annual predicted land cover was used as an input to the fertility model.

Fertility model variable specification

Variables defined for each hypothesis as well as known predictors of fertility are shown in Table 1. Two primary variables are used to evaluate the land–fertility relationship. First, *LUCC* is defined by the annual estimates of forest, pasture, and agricultural (perennial and annual) crops from the interpolation model. One-, three-, and five-year lags of each are examined. Second, *land security* is measured as currently holding full title, certificate of possession, or nothing as well as years of holding full title. Note that the process of land titling changed in 1993 as Ecuador's titling agency (IERAC) was replaced by INDA. This change resulted in some challenges for colonists to obtain secure title as rapid farm subdivision occurred during the 1990s (i.e., dividing the original plot into independently owned farms), resulting in many new owners (mostly children of the original owner) holding informal *defacto* titles. This variable was defined such that if title (or certificate) was held for the original finca, all subdivisions were assigned the same security unless they reported having different documentation.

Two types of proximate determinants were examined: exposure to intercourse via marriage (married, consensual union, or single) and fertility control via postpartum infecundability. We were able to identify year of marriage with high accuracy for all but a small subset of women who lived in multi-generational households for whom the year of marriage was estimated to within 2 years. Postpartum infecundability, which results from lactational amenorrhea and abstinence, is directly adjusted for in the model by reducing the number of months at risk for childbirth following a birth by 6.5, which is the average time of postpartum abstinence (1.5 months) plus the lower range of waiting time for conception (5 months) (Bongaarts 1978). Assuming births are non-seasonal, this reduces months at risk to 7.5 months for the year of a birth and to 10 months the year after. Note that this approach precludes the ability to test for factors that may influence postpartum infecundability. Contraceptive use was considered. However, it was recorded only at the time of the survey (1990 and 1999) and only for one woman per household. Previous analysis on WCBA providing data from both surveys reported contraceptive use to be associated with *more* births (Carr et al. 2006), which is counterintuitive to findings in other studies. Contraceptive use was not included in this analysis, due to the inability to determine use annually.

Other important variables include *farm location and access*, which are measured using (1) road access; (2) walking distance to the road; (3) distance to the nearest major town (Coca, Shushufindi, Lago Agrio, La Joya de los Sachas); and (4) year of electricity access. Note that electricity can serve as a proxy for urbanization, better contraceptive access, and infrastructure development in other rural areas as well (Harbison and Robinson 1985; Sokari-george et al. 1991; Ullah and Chakraborty 1994).

Temporal, individual, and household variables that are known predictors of fertility were also included. *Temporal variables* are defined to capture the secular trend, which is believed to be curvilinear and monotonically decreasing. *Individual variables* for each WCBA include age, education (none, primary complete, secondary complete, or higher), and place of birth (*Oriente* or outside the Amazon). Age and education are considered to be time-varying. *Household variables* (excluding land use) were defined as annual household age–sex compositions (0–4, 5–9, 10–14, and 15+). The strata were subsequently collapsed to represent children (0–14) and adults by sex with one-, three-, and five-year lagged population values. We considered including a measure of socioeconomic status, but imputation of asset measures prior to 1980 and between 1990 and 1999 was not considered reasonable.

Statistical analysis

Data analysis focused on evaluating the key hypothesis that land use/management activities influence childbirth in rural agricultural frontiers. We conducted descriptive analyses to examine secular trends and univariate relationships. We employed multivariate models to test interactions with proximate determinants (marriage) and control for confounding and other known risk factors. Univariate relationships were evaluated by comparing trends across 5-year birth rates (1980–1984, 1985–1989, 1990–1994, 1995–1999). Both the secular trend and multivariate analysis used a log-linear Poisson model, with the outcome defined as the number of births reported by WCBA i, in sector j during year t (y_{ijt}). The model is generally specified as follows:

$$\log(y_{ijt}) = \log(N_{ijt}) + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots \beta_p x_p + u_j$$

where N_{ijt} is an offset term for months at risk for childbirth for each WCBA during year t and β_i coefficients are estimated for each predictor variable x_i, and u_j represents random variation by sector. This model is fit using generalized estimating equations to adjust for correlated observations over time and within settlement sectors (Zeger and Liang 1986).

The secular trend was estimated by defining the outcome as the number of births over two-year intervals (i.e., 1980–1981, 1982–1983) for each WCBA and by defining the denominator (an offset) as the number of months each woman contributed during each interval (a maximum of 12 months per year, adjusted for postpartum amenorrhea as described previously). To test the land–fertility relationships, a model of marital status and all significant non-land-use variables identified in univariate analyses was fit. Next, each of the three land factors (area owned, land-use change, land security) was fit separately. Lastly, interactions with marital status were included. Model selection criteria were implemented by removing all variables whose F test p value exceeded 0.3 and then individually testing them for reentry. Any variable not reentering was deemed unrelated to fertility. This approach allowed us to test whether land factors operate as mediators or moderators with marital status to predict fertility [see (Baron and Kenny 1986)]. Model fit was assessed using the quasi-likelihood information criterion statistic (QIC) and aggregates of residuals (Lin et al. 2002; Pan 2001). Data were analyzed using SAS 9.4.

Results

Trends over time

A total of 1444 WCBA were included in this study, contributing over 9400 person-years of observation. Overall, the birth rate (BR) declined by 38 % over the 20-year period, which is considerably lower than the nationally reported decline of almost 60 % (Fig. 2). Characteristics of women and households along with mean birth rates over time are reported in Tables 2 and 3 (note that p values reported in Table 3 are compared against the reference group for the specific interval, while the 95 % confidence intervals are meant to provide comparisons over time). The mean age of WCBA remained surprisingly consistent over time (28 years) with birth rates highest among 20–34 year olds. Notably, BRs generally declined for all age groups except the oldest and youngest who reported a slight increase. Education levels increased among WCBA over time, which is normally associated with reduced BR; yet, women with at least a secondary education reported higher rates over time. This may be a cohort effect as women achieving higher education tended to be younger.

Women with more social support, as measured by local family nearby and being born in the region, reported lower birth rates during the 1980s, but higher during the 1990s. The percentage of WCBA living near family did not change over time (~63 %), but the percentage born outside the NEA more than doubled. It is likely that a change in the social structural function of families and the community occurred from one in which lack of social support resulted in decisions to have larger families to one where social support was needed to support childbirth decisions. This contention is supported by the fact that average family sizes nearly doubled (from 4 to 7), but the number of WCBA per household remained relatively constant (~1.4). These findings correspond to increased housekeeping demands made of women and reduced time for child-rearing, unless social support is available. Road and electricity access, additional proxy measures for infrastructure, were associated with fewer births, but these differences decreased over time. Road access did not change significantly over time, but electricity access improved.

Land use and management varied considerably over time. The amount of land owned (titled or with certificate of possession) and the percentage of families who hold title increased, then decreased, over the 20-year period. Title ownership was the only variable that appears to have a consistent effect over time, with households of WCBA lacking title reporting about 50 % more births over the study period. Figure 3a–c demonstrates how land cover tends to change more following a birth than ahead of one.[2] The graphs illustrate the differences in the three-year land-use change for each year among women who report versus do not report a live birth. Black dots represent land-use changes prior to a particular year. Red triangles represent land-use changes following that year (larger dots and triangles represent significant differences between land-use changes among women on farms who report a birth and women on farms who do not). To interpret, in 1993, families who reported a birth had more forest cleared and created more pasture and agriculture in the 3 years following the birth than families who did not report a birth. All of the estimates for three-year changes in pasture prior to a birth are above zero, indicating that women were more likely to report a birth following larger increases (or smaller declines) in pasture. Similarly, most of the estimates for three-year changes in pasture following a birth are negative, indicating that pasture was created more often on farms where women reported a birth rather than on farms where women did not. Since the timing of fertility response to LUCC, and vice versa, is not known, we also examined one- and five-year changes. Prior land-use changes for both one- and five years were significantly associated with differences in birth reporting. However, one-year land-use changes subsequent to a birth were associated with differential reporting and not with five-year changes (analysis not shown). The findings provide evidence that the causal pathway between land use and childbirth is more likely unidirectional over short and long time periods, but bidirectional feedbacks are observed.

Model results

Parameters reported for Models 1–3 (Table 4) are log-incidence rate ratios and, when exponentiated, are interpreted as the percent change in birth rates for a one-unit change in the variable (or change in comparison with a reference group). For example, Model 1 reports an estimate of 0.196 for WCBA who do not have access to electricity during a particular year. This corresponds to a 22 % [exp(0.196) = 1.22] higher birth rate for WCBA without electricity compared to those with electricity. The model selection process involved removing all variables that did not significantly improve model fit (QIC) or whose F test p value was above 0.3, resulting in the following excluded variables: individual-level variables for place of birth, family network, and labor participation; household variables for the amount of land owned, household size, and number of adult women (excluding the WCBA); road access, distance to the road, and distances to the nearest town, market, and primary

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[2] From Fig. 3a, we take the difference in the difference in 3-year forest change (CFOR3 = Current forest cover–Forest cover 3 years ago) for WCBA on farms with a birth versus WCBA on farms not reporting a birth; therefore, positive values represent more forest gained (or clear less forest) on farms where WCBA report a birth than farms that do not report a birth. Similarly, differences in the difference in future change (FC_FOR3 = Current forest cover–Forest cover in 3 years) values are positive when more forest is cleared (or less gained) among farms whose WCBA report a birth versus those that do not report a birth.

community. Title holding in a particular year and years with title were strongly correlated. Thus, since title holding resulted in better model fit, only this factor was included in analysis. Land-use *values were centered (by year) to reduce* correlation with year and with other land uses. Parameter estimates across the four models do not vary considerably; thus, general results are discussed for Model 3a (interaction between title and marital status). Note that marital status was collapsed to married/union versus single as there was no statistically significant difference between these two categories.

Birth rates declined by 10 % from the 1980s to the 1990s. However, this secular trend never achieves significance ($p = 0.12$ for the F test in Model 3a), indicating that the univariate trend (Fig. 2) can be explained by model variables. Individual characteristics of WCBA (age, education) strongly influence birth rates. Women 20–24 or 25–29 years of age had the highest estimated birth rates (12.5 and 11.4 per 1000 WCBA), followed by women 15–19, 30–34, and 35–39 years old. Higher education was, as expected, inversely related with childbirth (higher education associated with lower rates of birth).

Household factors (electricity access and household composition) were also important predictors of childbirth. Lack of electricity, which is a measure of infrastructure access as homes closer to large communities tended to get electricity first, was associated with a 24 % increase in the birth rate. Spatial location was not significantly related to childbirth, though inclusion of the variable (nearest market town) did improve model fit. This indicates there is some (nonsignificant) spatial variation that exists, but electricity access likely is a better measure of infrastructure in this context. Another household factor is the number of adult males and children. After examining several different lags (1, 3, and 5 years), the three-year lag of children and one-year lag of adult males was the most predictive. The results indicate that each additional child living in the household 3 years prior was associated with a 1–2 % increase in the birth rate, while each additional adult male one-year prior was associated with a 5–6 % decline. These results correspond with the idea that younger households are demanding more children, possibly as laborers or as additional insurance births as described by theory, while WCBA in older households that already have male labor do not have pressure for additional children.

The effect of marital status, which is the key proximate determinant in the model, was significant across all models. WCBA who were married had a 3.2 times higher birth rate than women who were single, while WCBA who were widowed or separated had a 1.8 times higher rate. The inclusion of land-use covariates (title holding and pasture creation) attenuated these estimates slightly, indicating some partial mediation of this effect. Pasture and lack of title were both positively related to childbirth, with each hectare of pasture created being associated with a 16 % higher birth rate, while lack of title was associated with a 27 % higher rate. We estimated the indirect effect (mediation) of marital status through land-use covariates following methods of Baron and Kenny (Baron and Kenny 1986).[3] Moderation of marital status was evaluated through an interaction. For both title holding and pasture, the indirect effect of land use through these variables was miniscule (7 %

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[3] This approach requires fitting three equations, two of which were already fit using the approach described. The other model consists of the marital status being regressed on the title holding or pasture creation. Results of these models are not shown.

of the total effect for title and less than 2 % for pasture), but the effects were significant according to the Sobel test (Sobel 1982). Moderation of the proximate determinant by land characteristics was not found as the interaction effects (Models 3a and 3b) were not significant. However, the inclusion of title–marital status interaction did improve model fit. The differences primarily occur between married WCBA with and without title and single WCBA with and without title. These results demonstrate that although married women have much higher birth rates, lack of title in agricultural frontiers can push these rates even higher.

Conclusion and discussion

This study is one of the first to comprehensively test factors which influence fertility over time in a rural agricultural frontier. First and foremost, there is a clear relationship between land use and fertility behavior. Title holding and decisions about how land is managed are clear predictors of childbirth. Statistically speaking, these factors are *direct* such that they are shown to partially mediate the relationship between proximate determinants (marital status) and fertility but also have independent direct effects on fertility. However, since we cannot test all proximate determinants in this model, it is possible that land factors serve as mediators for other proximate determinants and the direct relationship observed here would be attenuated with the inclusion of variables such as contraceptive use and reported postpartum abstinence for each WCBA. For example, one could hypothesize that the decision to create additional pasture occurs in parallel with childbirth decisions since families may see the opportunity for family expansion with additional land in economic use or perceive more time for child-rearing as agricultural responsibilities shift to less time-consuming cattle ranching. Similar hypotheses could be conjectured for title holding.

A second important result was the consistency in age, education, electricity access, and household demographic characteristics relationships with childbirth, corroborating research in other regions. In particular, education and electricity access were recently promoted as key policy variables to address chronically high fertility rates in rural areas (Lutz 2014). WCBA have been identified as keys to population growth, poverty alleviation, and development, which our results support.

There are some shortcomings to our approach. It is unfortunate that we cannot include other proximate determinants in this analysis. It is also important to note that annual land cover is an estimate based on a time series modeling approach and not on actual observed land uses. This ontology has been addressed in several contexts (Messina and Pan 2013), including population–environment research (Liverman et al. 1998; Pan et al. 2004). Another important limitation of this study is the relevance of our estimates to contemporary fertility as our data are from 15 years prior. Unfortunately, Ecuador has not obtained any updated national or regional estimates of fertility to evaluate whether TFR remains stalled. However, findings from this study are relevant to other tropical frontier areas, including Peru, Bolivia, Colombia, Gabon, and the Congo where data from Demographic and Health Surveys indicate strong differentials between rural and urban TFR in the forested regions (Centre Nationale de la Statistique et des Etudes Economiques (CNSEE) and ICF International 2013; Coa, Ochoa, and Bolivia. Ministerio de Salud y Deportes. 2009; Direction Générale de la Statistique (DGS) and ICF International 2013; INEI 2011; Ojeda et al. 2011).

Fertility is declining, but, as is the case in several least developed nations, especially in sub-Saharan Africa, fertility is not declining at the rate reported by the national government. National estimates report almost 50 % declines in the Amazon over the 20-year period coinciding with this study, but our data suggest significantly slower declines, particularly in rural areas. Model-adjusted secular declines in fertility are even slower, with just a 10–15 % decline over the 20-year period. This underestimation of fertility has enormous implications for long-term population growth both in the Amazon and in other regions struggling to provide accurate estimates of rural fertility. The global impacts are beginning to be realized as population growth is now expected to exceed 11 billion by 2100. Disproportionate growth is coming from delayed rural fertility, especially in Africa where population may reach four billion before achieving stasis (Gerland et al. 2014). Our results underscore the important and often overlooked component of population when considering human–environment interactions, particularly in rural areas.

Fertility rates in rural agricultural frontiers are high, are underestimated, and are linked to unique land use and management characteristics of a rural agricultural frontier. While more research will inform when and why birth decisions occur concurrently with farm practices, this study identifies potential areas where policies can impact fertility choice, which can help alleviate demand for land consumption and global population growth. The geography, magnitude, and timing of the demographic transition among the world's poorest rural populations will largely predict how many people will live on the planet by 2100 and may also be a key predictor of how much forest we will have remaining in 2100 (Levy et al., 2012; López-Carr and López-Carr 2014). Understanding predictors of fertility decline in such environments is essential for our demographic and ecological futures.

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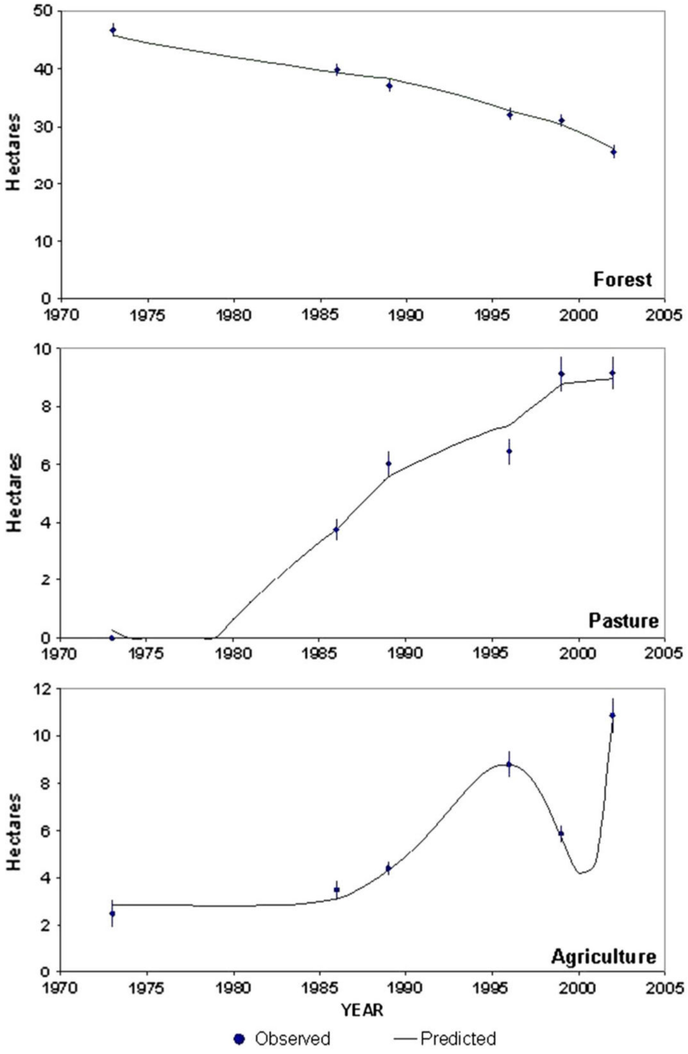

Fig. 1.

Observed and predicted land use, 1973–2003. This figure shows the model-predicted land-use values from 1973 to 2003 for (1) forest, (2) pasture, and (3) agriculture. The *solid lines* represent the smoothed, model-predicted land-use values, while the *point*-and-*whisker* points are the observed land-use values from classified satellite images. The predicted values for each land-use type were used in the model to estimate the impact of land use on fertility decisions

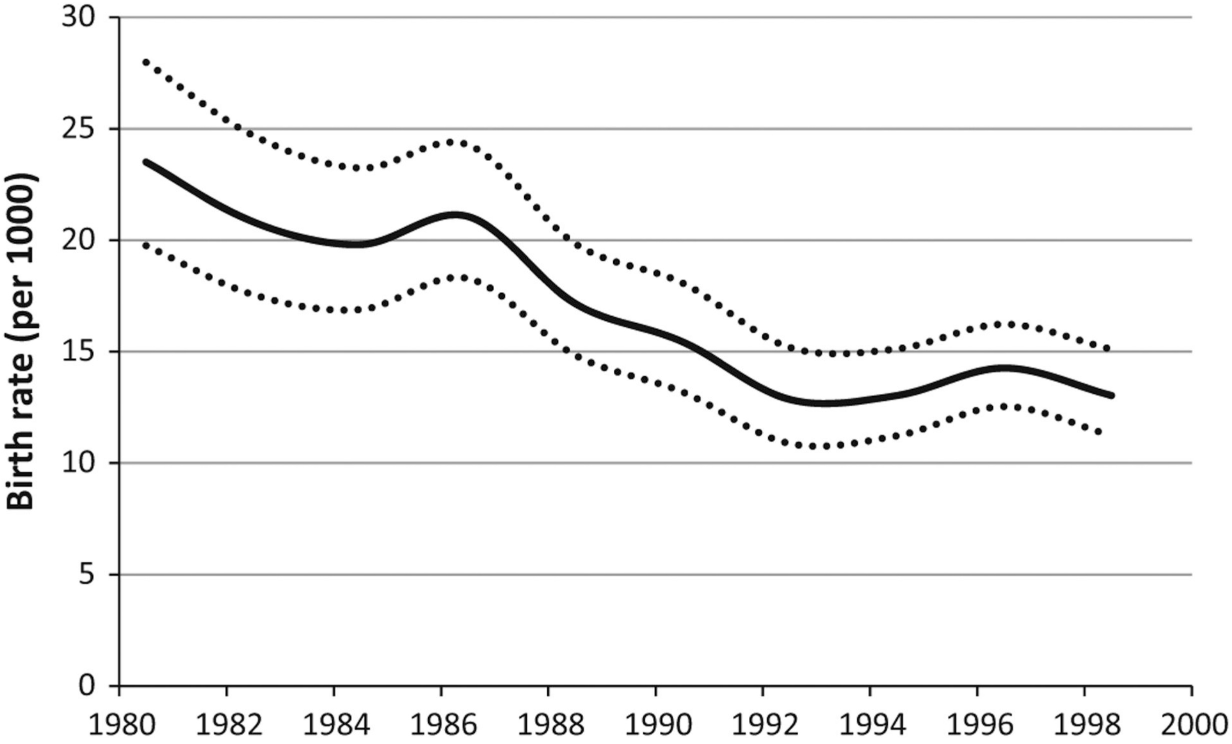

Fig. 2.

Birth rate per 1000 WCBA, 1980–1999, Northern Ecuadorian Amazon. *Solid line* is the mean birth rate for women of child-bearing age; *dotted lines* represent the 95 % confidence interval

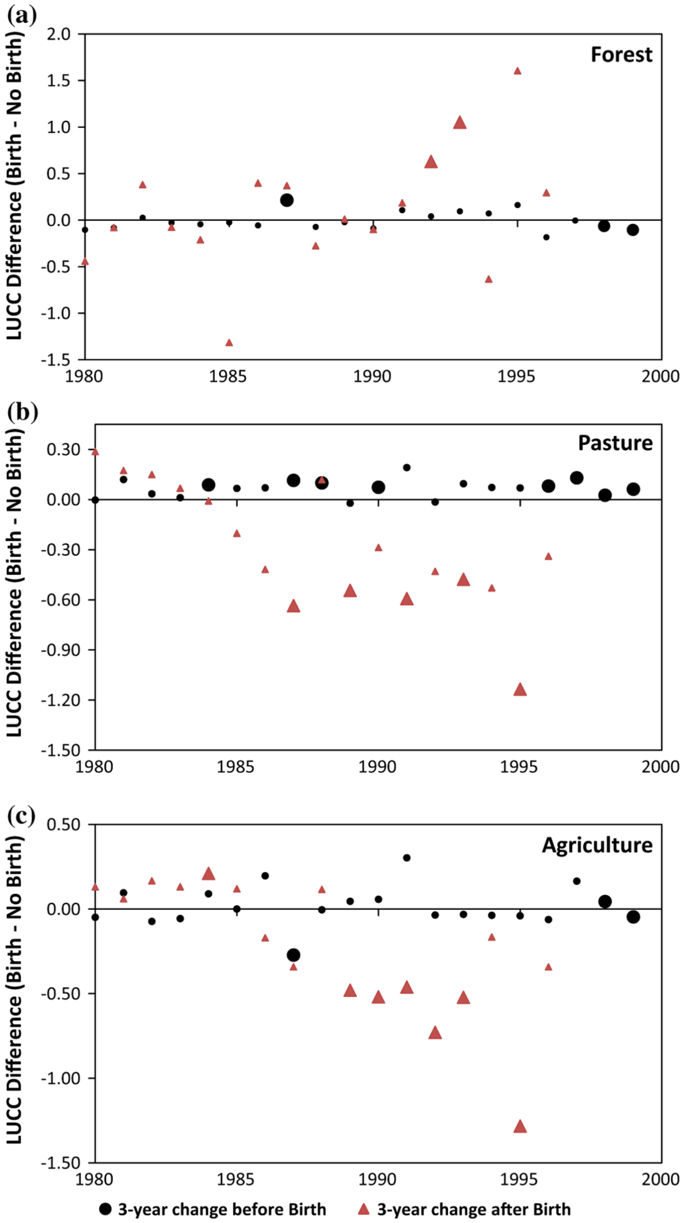

Fig. 3.

a–c Differences in three-year land-use change prior to and following birth. *Black dots* represent difference between the three-year change in land cover prior to a birth to the three-year change in forest cover if no birth was reported prior to a particular year. *Red triangles* represent the difference between the three-year change in land cover following a birth and the three-year change in land cover if no birth occurred that year. *Larger symbols* are years for which these differences are significant ($p < 0.05$)

Table 1

Fertility model variables

Variable	Description
Temporal variables	
Year	Specific year of interest (t = 1980, 1981, … 1999)
Farm year	Year of farm establishment: prior to 1980, 1980–1984, 1985–1989, 1990–1994, 1995–1999
WCBA variables	
Age (t)[a]	Age at year t
Marital status (t)[a]	Married/consensual union, divorced/separated, or single at year t
Education (t)[a]	None, incomplete primary, complete primary, incomplete secondary, complete secondary or higher
Place of birth[a]	In *Oriente* (Ecuadorian Amazon) or outside *Oriente*
Family network[a]	Family members live nearby
Household variables	
HH size (t)[b]	Population size of the household
Children (t)[b]	#Children in the household under age 15 in the previous year
Adult males (t)[b]	#Adult males in the household aged 15 and over in the previous year
Adult females (t)[b]	#Adult females in the household aged 15 and over, excluding the specified WCBA, previous year
Land use and management	
Forest (t)	Forest cover in year t, ($-t-3$), or ($t-5$) derived from land interpolation model
Crops (t)	Agricultural land cover in year t, ($-1-3$), or ($t-5$) derived from land interpolation model
Pasture (t)	Pasture in year t, $-$ ($-t-3$), or ($t-5$) derived from land interpolation model
Land owned (t)	Hectares of land owned
Title (t)	Land title holding: full title, certificate of possession; or nothing
Years with title	Years since full title had been acquired
Farm location	
Access (t)	Farm has road access (i.e., located next to road)
Road distance	Walking distance to road (km)
Health center	Distance to nearest town with a health center (km)
Primary town	Distance to nearest primary regional town (Lago Agrio, Coca, Shushufindi, La Joya de los Sachas)
Electricity (t)	Household access to electricity

[a] Refers to specific woman of child-bearing age

[b] Variables were also measured as change over 3 years

(t) Indicates a value during year t

Table 2

Characteristics of women of child-bearing age and their households, 1980–1999, Northern Ecuadorian Amazon

	1980	1985	1990[a]	1995	1999
WCBA (#)	240	370	557	631	906
Age (years)	28.4	28.6	28.2	28.3	28.4
Education (%)[b]					
None/incomplete primary	57	49	40	27	23
Primary/incomplete secondary	38	45	54	63	66
Secondary and higher	5	6	6	10	11
Marital status (%)[b]					
Married	66	62	49	49	45
Consensual union	17	21	21	19	24
Single	13	15	29	28	27
Separated/divorced/widowed	3	2	2	4	4
Born in the *Oriente* (%)	7.5	10.0	14.0	17.7	21.1
Family lives nearby (%)	61.4	64.0	64.4	63.4	63.9
# of Households	209	291	358	472	650
Household composition (mean)					
Under 15	1.6	1.9	1.6	2.1	3.1
WCBA	1.1	1.3	1.6	1.3	1.4
All females over 15	1.3	1.5	1.7	1.7	2.0
All males over 15	1.3	1.4	1.3	1.8	2.2
ALL	4.2	4.7	4.5	5.5	7.3
Land use (ha, %)[e]					
Forest	n/a	39.9	37.2	32.1	31.1
Pasture	n/a	3.8	5.9	6.5	9.1
Agricultural crops	n/a	3.4	4.4	8.8	5.8
Land owned (ha)[c]	31.1	39.3	53.2	25.8	35.8
Land title (%)[c]	5.8	15.1	53.1	36.6	36.4
Road access (%)[b]	51.4	49.5	47.5	50.8	45.4
Distance to road (km)[b]	2.3	2.5	2.7	1.1	1.2
Health center (km)[d]	22.6	24.0	25.3	19.2	18.8

[a] Data based on 1990 survey data

[b] Data were only collected for 1990 and 1999, and we assume that these values apply for the entire birth reconstruction

[c] Data are available by year between 1980–1990, but only for 1999 for the second household reconstruction

[d] Computed using GIS data taking into account when health centers were established and assuming the HH goes to the nearest center

[e] Land-use data determined from satellite imagery in 1986, 1989, 1996, and 1999

Table 3

Mean birth rates in five-year intervals (per 1000 WCBA)

	1980–84		1985–89		1990–94		1995–99	
	Mean	**(95 % Cl)**	**Mean**	**(95 % Cl)**	**Mean**	**(95 % Cl)**	**Mean**	**(95 % Cl)**
Age								
ALL WCBA	17.1	14.7–19.8	15.8	14.0–17.8	10.7	9.3–12.2	10.8	9.6–12.2
15–19 (ref)	7.4	4.5–12.1	9.0	6.5–12.4	8.4	6.4–10.9	10.4	8.6–12.7
20–24	22.9	18.1–29.0†††	23.2	18.8–28.7†††	18.9	15.0–23.7†††	20.0	16.6–24.0†††
25–29	30.3	24.1–38.2†††	26.3	21.4–32.3†††	17.8	13.9–22.9†††	15.4	11.8–19.9†
30–34	23.8	18.7–30.4†††	16.3	12.2–21.8††	13.6	10.1–18.2 †	15.6	12.1–20.3†
35–39	22.0	15.3–31.7††	19.9	15.1–26.3††	10.5	7.2–15.4	10.9	7.8–15.2
40–44	8.4	4.4–16.3	12.5	8.0–19.3	6.9	4.4–10.9	5.2	3.1–8.6†
45–49	1.8	0.5–6.5†	2.8	1.1 −7.2†	0.6	0.1–6.3†	1.6	0.5–4.8††
Civil status								
Married/union	21.7	19.0–24.7††	20.8–18.7	23.1†††	14.6	12.7–16.7†††	13.8	12.2–15.7†††
Widow/sep	11.9	4.3–32.9	10.2–5.1	20.5†	6.2	2.4–16.1	4.9	1.8–13.7
Single (ref)	4.6	1.8–11.7	3.9–2.2	7.1	4.5	3.1–6.6	5.6	4.2–7.5
Education								
>Secondary (ref)	3.2	0.3–29.7	6.4	3.1–13.3	8.1	5.1–12.8	10.3	7.3–14.6
Incomplete secondary	5.1	0.9–28.6	8.8	4.8–16.1	9.3	6.7–12.8	7.9	5.7–11.0
Complete primary	16.4	12.9–20.8	17.4	14.6–20.7††	12.4	10.2–15.0	12.5	10.6–14.7
Incomplete primary	22.2	18.5–26.5	19.3	16.4–22.7††	11.1	8.7–14.1	11.5	8.8–14.9
None	18.2	11.5–28.8	11.9	7.0–20.4	4.9	1.8–13.1	6.5	2.9–14.8
Family network								
Family not near	15.9	12.2–20.7	14.1	11.3–17.5	7.7	5.4–10.9	6.2	3.7–10.2
Family near (ref)	14.0	11.2–17.4	12.7	10.7–15.1	7.7	5.9–10.2	5.6	3.8–8.2
Place of birth								
Outside NEA	17.3	14.9–20.1	15.8	13.9–17.9	11.0	9.5–12.8	10.4	9.1–11.9
Inside NEA (ref)	14.5	7.1–29.3	15.6	11.1–21.8	8.8	6.3–12.3	12.4	9.6–16.1
Road access								
No road access	16.8	13.8–20.5	17.7	15.1–20.7	12.9	10.5–15.8	11.6	9.4–14.2
Road access (ref)	17.6	14.2–21.7	14.5	12.3–17.2	9.6	7.9–11.5†	10.6	9.1–12.3
Electricity								
None	17.8	15.4–20.7	17.2	15.3–19.5††	12.2	10.6–14.1††	11.5	9.7–13.7
Available (ref)	10.6	5.7–19.9	9.7	6.6–14.2	6.5	4.5–9.4	10.4	8.9–12.3
Title								
None	17.2	14.7–20.0	16.5	14.3–18.9	11.7	9.9–13.8†	13.5	11.8–15.4†††
Full title (ref)	11.7	6.1–22.6	13.4	10.7–16.7	8.7	6.7–11.2	6.4	4.9–8.3

[†††] $p < 0.0001$;

[††] $p < 0.01$;

[†] $p < 0.05$ for comparisons versus the reference group within each time interval

Table 4

Longitudinal Poisson model predicting birth rates for WCBA in the NEA

	Model 1	Model 2	Model 3.1	Model 3.2
Intercept	−7.52†††	−7.59†††	−7.79†††	−7.64†††
Year (ref = 1995–1999)				
80–84	0.06	0.00	0.04	0.04
85–89	0.09	0.08	0.10	0.10
90–94	−0.11	−0.10	−0.08	−0.08
Age of WCBA (ref = 45–49)				
15–19	2.42†††	2.36†††	2.35†††	2.34†††
20–24	2.94†††	2.87†††	2.86†††	2.86†††
25–29	2.83†††	2.77†††	2.76†††	2.76†††
30–34	2.49†††	2.44†††	2.43†††	2.43†††
35–39	2.30†††	2.28†††	2.26†††	2.27†††
40–44	1.64†††	1.64†††	1.63†††	1.63†††
Education (ref = none/incomplete primary)				
>Secondary	−0.60†††	−0.57†††	−0.58†††	−0.58†††
Incomplete secondary	−0.50†††	−0.45†††	− 0.44†††	−0.44†††
Complete primary	−0.19††	−0.16††	−0.16†	−0.16†
Marital status (ref = single)				
Married/union	1.15†††	1.12†††	1.31†††	1.13†††
Widow/sep	0.57†	0.61†	0.90†	0.60†
No electricity access in year *t*	0.21††	0.21††	0.21††	0.21††
Nearest city (ref = Lago Agrio)				
Coca	−0.06	−0.01	−0.02	−0.02
Joya de los Sachas	−0.18†	−0.16*	−0.16*	−0.16*
Shushufindi	−0.00	−0.02	−0.01	−0.01
Children, 3 years prior	0.02	0.01	0.01	0.01
Adult males, 1 year prior	−0.05†	−0.07††	−0.07††	−0.07††
No title or certificate in year *t*		0.24††	0.46†	0.23††
Change in pasture [t, t−5)		0.15†††	0.19†††	0.23†††
Interactions				
Marital status × title				
Married × no title			−0.25	
Widow/sep × no title			−0.43	
Marital status × pasture change				

	Model 1	Model 2	Model 3.1	Model 3.2
Married × pasture				−0.05
Widow/sep × pasture				0.33

[*] QIC statistics for Models 1–3 were, respectively, 6493.9, 6518.9; 6491.5; and 6514.2. The beta-estimates do not change significantly, and the model interpretation is the same. Only variables that significantly improved to model fit and whose *F* test was less than 0.3 remained in Model 1. *F* test *p* values for interactions in Models 3a and 3b were 0.43 and 0.46, respectively, indicating poor fit

[†††] $p < 0.0001$;

[††] $p < 0.01$;

[†] $p < 0.05$;

[*] $p < 0.1$