Land Cover Change and Fertility in West-Central Africa: Rural Livelihoods and the Vicious Circle Model

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Abstract The vicious circle argument, rooted in a neo-Malthusian tradition, states that resource scarcity increases the demand for child labor and leads to higher fertility. The rural livelihood framework, on the other hand, contends that households employ multiple strategies, only one of which involves adjusting their fertility levels as a response to environmental pressures. This study provides a unique test of both theories by examining the relationship between land cover change and fertility across hundreds of rural communities in four West-Central African countries. The findings reveal a complex relationship between natural capital and fertility. In communities where natural capital was initially low, a further decline in that capital is associated with both higher fertility preferences and levels. However, we find that fertility preferences and behavior are often discordant, with notable within-community differences in response to decline in natural capital across levels of household wealth.

Keywords Fertility; Environment; Natural capital; Rural livelihood; Vicious circle; Sub-Saharan Africa

> In northern Somalia, Nimcaan Farah Abdi's 10 acres of corn, tomatoes and other vegetables were ruined as violent storms swept the Horn of Africa. . . "My farm has been washed away," Mr. Abdi said. It was the second year in a row of unusually heavy storms to have destroyed his livelihood, leaving him uncertain about how he will provide for his six children. "God knows," he added, "but I don't have anything to give now." (Myers and Kulish 2013)

Introduction

In this paper, we examine the relationship between environmental change and fertility in four West and Central African countries. First, we evaluate whether the relationship between land cover change and fertility is consistent with two theoretical frameworks. Specifically, we compare the *vicious circle model* (Dasgupta 1993) with the *rural livelihood approach* (de Sherbinin et al. 2008; Ellis 1998, 2000). Both frameworks are rooted in long-standing demographic traditions, with the former having neo-Malthusian origins (de Sherbinin et al. 2007) and the latter—although originating in human geography and development studies—showing many similarities to Davis' (1963) *multiphasic response theory*. In order to test the two frameworks at different levels of aggregation, we employ a multilevel design that places individuals in the context of their households, communities, and natural environment. Second, in order to elucidate the relationship between environmental change and fertility decision-making, we examine both fertility preferences and outcomes, which may or may not be concordant. We argue that this dual approach to fertility can resolve some of the conflicting findings found in prior literature.

Our model integrates standard measures of sociodemographic characteristics with a complex of community-level indicators. Of particular importance: our central indicator of environmental quality is a remotely sensed vegetation index, observed over the course of a decade to measure land cover change. And our indicators of community economic development use both aggregate household wealth and proxy measures of development based on geographic location.

Incorporating measures of environmental quality and change over time into analyses of fertility is important for two main reasons. The first is jointly theoretical and methodological, and related to the exploratory gap between micro- and macro-sociological frameworks on fertility. Writing in the 1990s, several demographers called for broadening research on the relationships between environmental constraints and demographic change, including fertility change (Hogan 1992; Stycos 1996; Pebley 1998). Although these calls gave rise to some theoretical and methodological advances, reviewed below, laments about inapposite data and incomplete conceptual frames continue (Hogan and Marandola 2012; Bilsborrow and Henry 2012). We argue that by focusing on individual-level fertility preferences and outcomes while retaining a population perspective (Duncan 2008), we come closer to resolving some of the outstanding difficulties in this area of research, including resolving inconsistent empirical claims associated with different parts of the literature. This is done by combining demographic and environmental data in a multilevel design, which is "necessary to establish the relationships across levels of analysis, such as the national level, the community level, the household level, or the individual level" (Axinn and Ghimire 2011:210).

The second reason that incorporating measures of environmental quality into analyses of fertility is important is more practical. In an era of anthropogenic climate change and global inequality (Roberts and Parks 2007)—not unrelated—it is important to understand how individuals and households respond to diminishing natural capital and increasing uncertainty. This is especially important for sub-Saharan Africa, which is the most vulnerable region to climate change (Challinor et al. 2007) and where fertility reflects deeply embedded cultural and ideational factors (Bongaarts and Casterline 2012; Casterline and El-Zeini 2014).

Overall, our analyses show that there is a strong yet complex relationship between natural capital and fertility preferences and outcomes. In communities where natural capital was initially low, a further decline in that capital is associated with both higher fertility preferences and levels. By contrast, in communities where natural capital was initially high, a decline in natural capital over time is associated with lower fertility levels but not preferences. Alongside this parallel, we find notable within-community differences, with significant differences across poor and wealthy households in terms of fertility preferences, but no differences between poor and wealthy households in fertility levels.

Taken together, these findings confirm the utility of using a multilevel approach and multiple types of data, specified in both absolute and relative ways. More substantively, our results lean more toward the vicious circle model, but in ways that articulate with an emerging body of scholarly literature on how uncertainty shapes fertility decision-making—perhaps deserving of greater attention in the rural livelihood framework.

Background

Some of the first formal statements about population-environment dynamics are found in Malthus's claims that limited natural resources will inevitably restrain population growth, whether through human volition or environmental catastrophe. The logic underlying this Malthusian "arithmetic" (Hogan 1992) animated much of the population movement from the 1950s through the late twentieth century (Hodgson and Watkins 1997) and continues to fuel scholarly debate (e.g. Becker 2013; Lam 2011)—as well as contemporary theories relating to population-environment dynamics. One such theory is the "vicious circle model" (VCM). Its proponents argue that in many underdeveloped rural areas, high fertility can serve as a strategy for meeting household or farm labor demands (Dasgupta 1993; Filmer and Pritchett 2002; Lutz and Scherbov 2000). Therefore, as certain types of natural resources become scarce (e.g. firewood, fodder, water), and efforts to collect them from communal lands increase, VCM predicts greater demand for child labor among the poorest households. As this cycle continues, it places an increasing burden on the environment, reduces per capita resources further, and inflates the demand for more child labor.

Nevertheless, the major fault of Malthus' argument is widely recognized. It failed to anticipate the technological breakthroughs that occurred shortly after the time of his writing, allowing for vast improvements in energy and food production (Lam 2011). Furthermore, scholars have since argued that human populations hold a variety of potential responses, both economic and demographic, to ward off such Malthusian catastrophe. These include the introduction of new agricultural technologies (intensification) and land appropriation through deforestation, land use change, and various modifications in patterns of land ownership (extensification) (Bilsborrow 1992; Boserup 1965, 1981; Carr et al. 2006; Pan and López-Carr 2016).

This range of responses—and suggested causal ordering—were first clarified in the "multiphasic response theory" (Bilsborrow 1987; Bilsborrow and Ogendo 1992; Davis 1963). The theory suggests that families engage in multiple strategies simultaneously, though they will tend to exhaust other options before resorting to significant demographic adjustment, such as postponement of marriage, decline in marital fertility, and migration (Bilsborrow 1987, 1992). Later theoretical additions to the multiphasic response theory include clarifying how patterns of landholding (Stokes and Schutjer 1984), distinct types of social relations (Curran 2002) or consumption (Curran and de Sherbinin 2004) can mitigate the effects of environmental pressures on demographic response. There have also been attempts to bridge discipline-specific debates about "vulnerability" (mainly geography) and "risk" (mainly economics) in order to provide a credible conceptual framework for cross-disciplinary work on the multiphasic response theory (Marandola and Hogan 2006).

Indeed, many similarities can be drawn between Davis' classic multiphasic response theory and contemporary "rural livelihood framework" (RLF) (Ellis 1998, 2000)—originating in geography and development studies—as intensification, extensification, and seasonal labor migration of several household members can all be viewed as strategies for diversifying risk in the face of uncertainty. Some of those strategies may directly and intentionally affect fertility, whereas others may do so indirectly and inadvertently (e.g. spousal seasonal labor migration reduces exposure to intercourse). The rural livelihood framework further emphasizes that households rely on multiple activities for sustenance including farming, fishing, gathering, and hunting from the commons, as well as occasional off-farm employment. These various activities allow those households to retain ownership over, or acquire, enough forms of capital (e.g. financial, human, social, natural) to ensure survival.

The rural livelihood framework also shifts the focus from individuals to households as the primary unit of production (and reproduction), decision making, strategizing, and risk diversification. Among the strategies households rely upon are some which directly involve demographic processes, such as accumulating social capital through marriage or financial capital through labor migration of certain household members (Hunter et al. 2013), yet it remains silent with respect to the so-called "calculus of conscious choice" of reproductive decision-making (Van de Walle 1992). However, given the continued centrality of agricultural activities as a source of income in African rural households (Davis et al. 2010)—even as non-farm activities are becoming increasingly important (Barrett et al. 2001; Reardon et al. 2007)—natural capital features prominently in these equations. By this, we refer to "the natural resource stock, or local environmental endowment (including water, wind, soil, forest resources)" (de Sherbinin et al. 2008:40). A sustained decline in natural capital requires adaption in livelihood strategies.

The empirical record on population-induced intensification and extensification—often in concert with population pressures—is relatively strong (Bilsborrow and DeLargy 1990; Bilsborrow and Ogendo 1992; May 1995; Carr et al. 2009). The empirical record on environmentally induced fertility change is not.[1] Research on prior historical periods and contemporary societies yields a relationship that is thin and ambiguous, and that provides inconsistent support for VCM. For example, both Doveri (2000), in a review of the historical literature on land, fertility, and family, and Alfani (2007), in a test of Malthusian vs. Boserupian arguments using sixteenth century data on baptisms in northern Italy, find no clear relationship. The complex of mitigating factors they identify is echoed in empirical studies of

[1] The same is true for environmentally induced migration, where the empirical record is scarce and conflicted (e.g. Gray and Bilsborrow 2013; Hunter et al. 2013; Nawrotzki et al. 2013; Nawrotzki et al. 2016).

contemporary demographic change: An ethnographic study in two highland communities in Guatemala concludes that remittances—from labor migrants "pushed" to urban areas by resource scarcity—stimulate consumption but not fertility reduction (though the authors argue that increasing consumption desires may stimulate fertility reduction in the long-term) (Davis and Lopez-Carr 2010); in high fertility areas in India, the relationship between landholding and fertility tends to be positive, but as fertility transition occurs, the relationship is mitigated by other factors (James 2000); in the Ecuadorian Amazon, women with legal land title had fewer children than those with less secure (or no) land tenure (Carr et al. 2006); in rural Nepal, women exposed to higher plant diversity and density were more likely to use contraception (Brauner-Otto 2014); and yet in Guatemala, no relationship was found between fertility and either size of farm or type land ownership (Sutherland et al. 2004). Finally, and more generally, a study of non-OECD countries over the second half of the twentieth century found no evidence of rising fertility when external pressures were alleviated (e.g. receiving food aid), suggesting that the relationship—even where it exists—only works in one direction (Neumayer 2006), at least in the era of long-term fertility decline.

Of course, if fertility regimes in sub-Saharan Africa are as distinct as some have argued (Caldwell and Caldwell 1987; Casterline and El-Zeini 2014; Van de Walle 1992), the threshold at which they would respond to environmental pressures may be quite different from those in other non-OECD countries—it presumably should be higher. Again, however, though scarce, the existing empirical record does not support the suggestion that Africa is intrinsically different. Kalipeni (1996) documented a relationship between the onset of the fertility transition in Malawi in the 1970s and 1980s and population density at the district level—which he interpreted as an indicator of pressure on the environment; in rural South Africa, fertility was negatively associated with private landholding (as opposed to communal), though it was positively associated with size of cultivated land (Mencarini 2000). In addition, and consistent with the VCM, fertility in South Africa was positively associated with scarcity of firewood (and to a lesser extent water) (Aggarwal et al. 2001).

In summary, a relationship between fertility and resource scarcity or environmental degradation is posited in both macro- and micro-oriented demographic theory, though there is substantial variability in the proposed mechanisms, direction of the hypothesized relationship, and empirical results. In general, scholars who emphasize the VCM focus on children's net production value and argue that resource scarcity is likely to increase fertility to meet rising labor demands, especially among the poorest households. By contrast, those who emphasize RLF do not appear to have a strong prediction that fertility should increase or decline because different livelihood strategies may have opposite effects on fertility, the net effect of which is unknown. Empirical support for both frameworks is thin, inconsistent, and unreliable. We argue below—in good scholarly company—that this may be a function of different levels of aggregation, inadequate specification of time lags and horizons, poor measurement of environmental effects, and lack of broader conceptualization that ignores important unobserved effects and confounds.

Whether or not that is the case, the present study complements the prior literature in three ways. First, our study region spans hundreds of communities across four countries and multiple ecozones, and ranges from arid to humid tropical. Whereas smaller scale studies were able to get a nuanced understanding of the forces at play, ours is able to generalize across a variety of social and environmental settings. Second, although we rely on cross-sectional survey data, we supplement it with land cover time-series data, allowing us to understand dynamic change over time. Third, we use a multilevel study design to understand what goes on at the household and community level, rather than the population average.

Conceptual Framework

The VCM is essentially a demand theory (Filmer and Pritchett 2002), and as such, it presumes that fertility preferences and outcomes are generally concordant. Introducing RLF to the conceptual framework, however, provides an added layer of nuance in which livelihood strategies may be in conflict with one another. For example, one livelihood strategy may involve increasing fertility to meet labor demands, consistent with VCM, whereas other strategies may reduce fertility indirectly via fertility's proximate determinants (e.g. reduced exposure to intercourse due to spousal migration). In this case, fertility preferences and outcomes may not align with one another. Investment in women's education—yet another livelihood strategy for diversifying risk—similarly delays childbearing over and above any normative effects of education that occur throughout the demographic transition (Axinn and Barber 2001). By contrast, fertility decline may stall if there is unmet demand for contraception, even when livelihood strategies facilitate such intentions. This appears to be the case in many areas of sub-Saharan Africa, where women's desire to limit fertility is often unrealized (Bongaarts and Casterline 2012; Casterline and Sinding 2000). Likewise, the downward effects of investments in education on fertility will be limited where households have insufficient capital to invest in education or where school-girls in particular have older boyfriends whose generosity is contingent on sex. This "sugar-daddy" phenomenon is well documented (Tawfik and Watkins 2007; Trinitapoli and Weinreb 2012) and parallels research on adaptation to impoverished household resources findings in other settings (Hunter et al. 2011).

Figure 1 summarizes our conceptual framework. The availability of natural capital shapes livelihood strategies at the household level, which in turn affects the proximate determinants of fertility, and finally determines fertility outcomes. The effect of livelihood strategies on fertility may be both intentional and unintentional. Importantly, two main confounders operate in the background. First, economic development constrains the availability of natural capital and livelihood strategies, and can affect fertility preferences directly (e.g. through mass education). Second, population density can induce additional strain on the natural environment as well as on livelihood strategies directly. Although population density is endogenous to fertility outcomes at the population level, it can be considered exogenous from an individual or household standpoint.

[Fig. 1 here]

The model in Fig. 1 clarifies the common conflation between micro- and macrolevels of explanations of population-environment dynamics. Although the two operate in a continuous feedback loop at the aggregate (i.e. P←→E), the same is not necessarily true for micro-demographic behavior. From an individual perspective, both population density and the biophysical environment are exogenous, although the same may not be true at higher levels of aggregation. Thus, while the choice between P→E and E→P is often artificial and arbitrary, depending on the researcher's locus of interest, it can nevertheless be disentangled by disaggregating the demographic response both spatially and temporally. We operationalize this framework using multilevel models, in which some variables are measured at the individual or household level, whereas others are measured at the community level. In other words, we observe variation in fertility outcomes and preferences across different environments as well as variation across individuals residing in those environments.

In summary, our conceptual framework emphasizes three important points: (1) Fertility-environment interrelations should be examined at the level in which fertility decisions are made—namely, individuals and households rather than aggregate units of analysis; (2) both fertility preferences and levels should be examined in order to disentangle the causal nexus of natural capital availability, livelihood strategies, and fertility; (3) macro-level factors should be incorporated into the analysis as potential confounders. Based on those criteria and the conceptual framework, we set out to test the following hypotheses:

H1: Fertility will be higher in communities where natural capital declined, as suggested by vicious circle model (VCM).

H2: Fertility will be higher among the poorest households *within the same impoverished community* (i.e. where natural capital declined). Note that this is a second and necessary condition for VCM to hold true.

H3: Poor households in communities where natural capital declined will use fertility as part of their livelihood strategies, but may or may not be able to actualize this strategy. In other words, unlike VCM, their fertility preferences and outcomes may be discordant.

The rural livelihood framework emphasizes that households rely on multiple, sometimes competing strategies for diversifying risk—and those strategies may have opposing effects on fertility outcomes. Therefore, it is imperative that we examine both fertility preferences and outcomes across a variety of environmental settings. By contrast, the VCM suggests that fertility preferences and outcomes are concordant and that the poorest households should be affected the most in communities where natural capital declined, because they generally rely on it for sustenance and have fewer resources to mitigate such decline.

Study Sites

To examine the relationship between land cover change and fertility across a range of climate conditions, this study focuses on four countries in West-Central Africa: Senegal, Burkina Faso, Nigeria, and Cameroon. The climate across the four ranges from arid to humid tropical. All four are located either within, or just to the south, of the Sahel, an ecozone that, since the 1980s, has had reductions in rainfall (Dai et al. 2004) and changes in land use (Mortimore and Adams 2001). The rainy season in the region is summer, peaking around August, but with significant variation in length across countries.

With respect to fertility, all four nations are still in early stages of the fertility transition (see Table 1). Burkina Faso, with a population of almost 16 million as of 2010, has seen only a modest decline in the total fertility rate (TFR) over the past two decades—from 6.9 births per woman in 1993 to 6.0 in 2010 (Institut National de la Statistique et de la Démographie 2012). Cameroon has seen a similar modest decline from 5.8 to 5.1 around the same period (Institut National de la Statistique 2012), whereas Nigeria, the most populous nation in Africa, shows practically no change with TFR standing at 5.7 (National Population Commission 2009). Senegal, on the other hand, experienced the largest decline in TFR, from 6.4 in the mid-1980s to 5.0 in 2011 (Agence Nationale de la Statistique et de la Démographie 2012). In all countries, there is a significant rural-urban differential in TFR, ranging from 1.6 in Nigeria to 2.8 in Burkina Faso.

Religion plays an important role both with respect to the population's spatial distribution and its fertility preferences and outcomes. All four countries are dominated by Christian and Muslim religious traditions. Senegal and Burkina Faso are predominantly Muslim (respectively, 95 and 71%), Cameroon is majority Christian (70%), and Nigeria almost equally split (about 53% Christian) (Agence Nationale de la Statistique et de la Démographie 2012; Institut National de la Statistique 2012; Institut National de la Statistique et de la Démographie 2012; National Population Commission 2009). This is relevant to our analysis since within each country, Christians are almost wholly in the southern zones of each country, and Muslims in the North.

Current use of modern contraception among women is generally low in the study region, varying from 9% in Senegal to 16% in Cameroon, but rates are significantly higher among sexually active, non-married women or when considering traditional methods too (Agence Nationale de la Statistique et de la Démographie 2012; Institut National de la Statistique 2012; Institut National de la Statistique et de la Démographie 2012; National Population Commission 2009). At the same time, there is significant unmet demand for contraception in those countries that has changed little over the past two decades (Bongaarts and Casterline 2012). This is why we emphasize the need to examine fertility preferences in addition to fertility outcomes when considering fertility-environment interrelations.

[Table 1 here]

Data, Measures, and Methods

Data

Our data on fertility and household characteristics are pooled from Demographic and Health Surveys (DHS) collected in the four sampled countries between 2008 and 2011. In each country, households were randomly selected using a stratified two-stage design where sampling clusters usually, though not always, overlap with census enumeration areas. Within each cluster, households were sampled with equal probability and all present women aged 15–49, whether permanent residents or visitors, were eligible for interview (Agence Nationale de la Statistique et de la Démographie 2012; Institut National de la Statistique 2012; Institut National de la Statistique et de la Démographie 2012; National Population Commission 2009). The surveys were designed to be representative at the national and first-level administrative areas, as well as of rural and urban populations.

Overall, our analytic sample includes all women aged at least 20, other than temporary visitors, with a total sample of 39,831 respondents from 1496 rural clusters. Each of the latter is georeferenced as point data, representing the centered coordinates of surveyed households within the cluster. The constraint here is that to ensure confidentiality, the DHS randomly perturbs cluster GPS coordinates up to 5 km in rural areas. This introduces some degree of measurement error to all spatial indicators and is likely to attenuate statistical associations at the community level.

We merged the DHS data with spatial and environmental variables from a number of other data sources, including Gridded Population of the World (CIESIN), Global Administrative Areas, Global Self-consistent Hierarchical High-Resolution Geography, Africa Infrastructure Country Diagnostic, and Normalized Difference Vegetation Index (NDVI) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite. Table 2 lists the various data sources and their spatial resolution or scale.

[Table 2 here]

Measures

Fertility. The main dependent variables are fertility outcomes and preferences. Outcomes are measured as the number of births during the 60 months preceding the DHS interview. Preferences are measured as the desire to have additional children in the future, recorded at the time of the interview. Women wanting another child within 2 years, after 2 years, or unsure about timing were recoded as "Yes," whereas women who want no more children are undecided, or have been sterilized (or their partner, if married) were recoded as "No."

Natural capital. The primary explanatory variables measure the quality and change over time in natural capital, derived from a time series of Normalized Difference Vegetation Index (NDVI)—a remotely sensed measure of vegetation cover. The original data were generated by MODIS, and, after correction for cloud and atmospheric contamination, disseminated as a time series of 10-day composites at 250 m resolution from January 2001 to December 2010 (Early Warning and Environmental Monitoring Program 2013). Remote sensing technology utilizes the unique "electromagnetic signature" of various objects, comprising of absorption and reflectance patterns at different wavelengths of electromagnetic spectrum. NDVI measures the amount and vigor of surface vegetation by utilizing the difference between the visible red spectrum (absorbed by green vegetation) and the near infra-red (reflected by vegetation) (Chuvieco and Huete 2010). It takes the form

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

In general, the higher the contrast between the two bands, the higher the amount surface vegetation. NDVI assumes values between −1 and 1, with values below 0 typically indicating water, snow, or cloud cover; values close to zero indicate bare soil, and values approaching 0.7 indicate dense vegetation. Vegetation indices are highly correlated with rainfall and net primary productivity of an ecosystem (Nicholson et al. 1998). It is important to note that short-term changes in vegetation cover do not necessarily indicate long-term land degradation but often capture natural fluctuations associated with rainfall or droughts.

In order to obtain local measures of natural capital around at each DHS sample cluster, buffer zones were created at 7.5 km (4.66 mi) radius from the center. This ensures that the buffer contains the true center of the cluster despite the DHS' intentional perturbation. It also reflects a reasonable distance for collecting resources on foot and is consistent with similar studies using DHS data (e.g. Balk et al.

2004; Hunter et al. 2011). Within each buffer, two summary measures of natural capital were constructed from the NDVI time series: (1) baseline natural capital and (2) linear change in natural capital over a 10-year period. To construct the two measures, annual sum NDVI was calculated around each cluster for each of the 10 years. Next, a random-effects linear regression model was used to estimate the intercept and slope of change in annual sum NDVI in each buffer. This method summarizes 360 data points in just two simple measurements per cluster, overcomes seasonal variation in vegetation cover, and measures long-term trends in vegetation cover. As a final step, the two variables were standardized.

Population density. This measure is derived from the CIESIN Gridded Population of the World dataset in 2000, providing a baseline measure of residents per square kilometers at 2.5 arcminute resolution. However, the underlying average resolution varies by country depending on the level and number of administrative units for which population estimates were available. Average resolution is highest in Burkina Faso (28 km) and lowest in Cameroon (97 km).

Economic development. In the absence of direct measures of economic development at the community level, we had to rely on mean household wealth in the sampling cluster (see details below) and two proxy indicators gathered from external data sources. The first proxy variable, coastal proximity, is a known correlate of economic development (Mellinger et al. 2000; Nordhaus 2006) and indicates better access to goods and trade opportunities on the global market. This was measured by the Euclidean distance from the GPS coordinates of the sampling cluster to the continental shoreline. The second proxy is the Euclidean distance to the nearest maintained road, classified under "Good" or "Very Good" condition by the Africa Infrastructure Knowledge Program (2013), suggesting that only minor or no road maintenance is required. Maintained roads not only establish opportunities for trade and mobility but also indicate domestic or international investments in the area. In both cases, distances were measured in 5 km increments.

Household wealth. In each country, the DHS constructed a single, continuous measure of household wealth. The household wealth index is derived from multiple indicators using principal component analysis and includes household assets (e.g. television, bicycle), access to drinking water, housing construction materials, sanitation facilities, and other country-specific indicators (Rutstein and Johnson 2004). We calculated the mean household wealth index in each sampling cluster; next, we created a relative measure of household wealth by subtracting from it the cluster mean wealth (both were standardized within each country). This approach not only helps us differentiate poor and wealthy communities but also provides a relative measure of deprivation *within* each community.

Additional controls. When appropriate, the analyses include a variety of sociodemographic control variables at the individual level. These include age and age-squared, educational attainment (no education, primary, secondary, or higher), marital status (married, never in union, or other), number of living children, religion (Christian, Muslim, or other), and whether the respondent is currently pregnant.

Methods

As noted above, the rural livelihood framework suggests that environmental pressures may induce fertility decline at the household level, which then accumulates to curb population growth. It follows that, net of appropriate controls, areas with falling NDVI should also have falling TFR. We can model these areas at high or low aggregations. In contrast, the vicious circle model (VCM) suggests that fertility should be higher in impacted communities due to higher demand for children. Furthermore, within those communities, the poorest households should have higher fertility than more affluent households. We test these competing claims using multilevel models, which have the particular advantage of allowing us to parse out the differences in fertility between and within clusters. These models can be generalized to include count or binary dependent variables. We use both.

The two-level Poisson model that we use takes the form

Level-1: $$log(\mu_{ij}) = \gamma_{0i} + \sum_p \gamma_{pi} Z_{pij}$$

Level-2: $$\gamma_{0i} = \beta_{00} + \sum_k \beta_{0k} X_{ki} + u_{0i}$$

where μ_{ij} is the number of births in the past 60 months for woman *j* in cluster *i*, γ_{0i} is the cluster-specific effect on number of births, γ_{pi} are fixed effects at the individual/household level, and Z_{pij} are individual/household covariates (e.g., educational attainment, household wealth). At level-2, β_{00} is a constant, β_{0k} are community-level fixed effects, X_{ki} are community-level covariates (e.g., population density), and u_{0i} are random effects. Notice that level-1 fixed effects are conditional on level-2 random effects. This mixed-effects design implies that individuals (and households) are compared to others within the same community (sampling cluster), hence "controlling" for unobserved factors at the community level. We use a similar approach to model fertility preferences using a hierarchical logit model.

Results

Descriptive statistics

Table 3 shows the unweighted descriptive statistics for each country and the entire sample. Overall, 69.5% of women in the sample desire more children in the future and have had, on average, 1.1 births in the 60 months preceding the interview. The average number of living children per women is 3.5, with 11.7% of women currently pregnant (both figures are about the same across all countries). The majority of women were married at the time of the interview (84.6%) and had no formal education (63.6%), although these figures vary dramatically by country (e.g. from 32.3% reporting no education in Cameroon to 90% in Burkina Faso). A little over half of the sample identified as Muslim (57.2%), with the remainder predominantly Christian (37.7%). Since religious categories were inconsistent across surveys, a further breakdown by Christian (or other) denomination was not possible.

[Table 3 here]

Population density around the sampling clusters varies from 63 persons per km2 in Burkina Faso to 254 in Nigeria, with an average density of 161 across all rural clusters. Average distance to maintained road was similar across countries, estimated at 20.7 km. By contrast, the average distance from the sampling cluster to the continental shoreline varied significantly by country and was smallest in Senegal (104 km) and largest in Burkina Faso (734 km). Natural capital measures and household wealth index were standardized to have a mean of zero and standard deviation of one, and are therefore not shown in the table. Figure 2 shows a single NDVI measurement across the study region, with NDVI values ranging from about zero in the Sahara to a maximum of 0.80–0.85 in the tropical forests of Cameroon (represented by darker shades of green). Points on the map represent DHS sampling clusters.

[Fig. 2 here]

Fertility outcomes

We estimated a series of multilevel Poisson regression models in order to test the effect of change in natural capital availability on recent fertility. The results are shown in Table 4. Model 1 tests the effects of NDVI baseline and slope, as well as their interaction, on the number of births in the preceding 60-month period net of individual, household, and community-level confounders.[2] Both baseline and change in vegetation cover are negatively associated with the number of births, yet their interaction is positive and statistically significant. The combination of main effects and their interaction term yields an interesting interpretation, illustrated in Fig. 3a. In communities where the level of this type of natural capital was initially low, a further decline over the 10-year period was associated with higher fertility, whereas an

[2] Since the associations between fertility and individual or household-level control variables are both predictable and not at the core of this analysis, we do not discuss them at length. Age has a nonlinear association with the number of recent births. On average, women with primary education had more births than those with no education, and women with secondary or higher education had fewer births. Non-married women had fewer births than married women, but religion had no significant effect. Finally, net of all other factors, women in wealthier households tend to have fewer births than those in less affluent households. Only one community-level factor was found to be statistically significant: mean household wealth was negatively associated with the number of recent births and desire for additional children. However, we kept other community-level indicators (population density, distance to nearest maintained road, and distance to the continental shoreline) in the model as control variables.

improvement was associated with lower fertility. The opposite is found in communities where natural capital was initially high—a decline in natural capital corresponds to low fertility, whereas further improvement corresponds to high fertility. Overall, these results appear to be consistent with H1 and VCM. The latter, however, requires an additional condition, which we test in Model 2.

[Table 4 and Fig. 3a here]

According to VCM, fertility should increase when environmental conditions worsen in order to meet labor demands on the farm. Environmental pressures, however, should be particularly felt among the poorest households in the community because they rely on natural capital for sustenance and lack alternative forms of capital. In order to test this hypothesis (H2), Model 2 introduces an interaction term between household wealth relative to the community and land cover change (NDVI) over time. The results show that the interaction is not statistically significant and the model offers no improvement relative to Model 1 (also evident in the nearly identical log-likelihood). In other words, although fertility tends to be higher in communities where environmental conditions worsen—particularly those where natural capital was already low—we find no difference between poor and wealthy households in the same community. In conclusion, we find evidence for H1 but not H2.

The rural livelihood framework, however, suggests that fertility preferences and outcomes may be discordant due to the complex causal nexus of various livelihood strategies. Therefore, we turn to evaluate the effect of land cover change on women's desire for additional children.

Fertility preferences

Fertility preferences were measured as a binary outcome indicating whether the respondent desired additional children at the time of the interview. Results from a series of multilevel logit models are shown in Table 5, which follows the same logic as Table 4 but introduces two new control variables: number of living children and current pregnancy.[3] Net of individual, household, and community characteristics, natural capital shows a similar pattern of association with fertility desires as with fertility outcomes. NDVI baseline and slope both show a negative main effect but a positive interaction, the combination of which is illustrated in Fig. 3b. In this case, however, the effect of change in natural capital is pronounced only in communities where it was already low at baseline. In those settings, declining natural capital is associated with higher desire for additional children, whereas increasing natural capital is associated with lower desire. In settings where baseline natural capital is high, we find no difference in fertility preferences by further change in vegetation cover.

[Table 5 here and Fig. 3b here]

In order to test H3, Model 2 introduces an interaction term between change in natural capital (NDVI slope) and relative household wealth in the community. The interaction is positive and statistically significant but difficult to interpret on its own. Figure 4 illustrates the predicted probability of desiring additional children among poor and wealthy households *in the same community* by change in natural capital. In communities where natural capital is declining, women in poor households have a greater probability of desiring an additional child relative to women in poor households in communities where natural capital is increasing. Among wealthy households in the community, change in natural capital does not appear to affect the desire for additional children (the difference is not statistically significant). Therefore, H3 supported by the evidence. The findings reveal that women from poor households in communities where natural capital declined have a greater desire for children than women from poor households in communities where environmental conditions improved; women from wealthy households, on the other hand, exhibit no difference in fertility preference based on land cover change.

[Fig. 4 here]

[3] Both of which are negatively associated with desire for additional children and are statistically significant.

Discussion

This study set out to evaluate two key theoretical frameworks used to discuss environmental aspects of fertility decision-making and, if possible, to reconcile previous theoretical and empirical inconsistencies. One of those frameworks, the vicious circle model (Dasgupta 1993), has clear neo-Malthusian tones (de Sherbinin et al. 2007), since it dictates that fertility should increase in the face of worsening environmental conditions and resource scarcity. Rooted in ideas about the economic and cultural value of children (Becker 1960; Cain 1983; Caldwell 1982), this model suggests that poor households have incentives to increase fertility to meet labor demands on the farm or in collecting resources from the commons. Another set of ideas is associated with the rural livelihood framework (de Sherbinin et al. 2008; Ellis 1998, 2000). It shares many similarities with multiphasic response theory (Bilsborrow 1987; Davis 1963), but is less clear about the direction of the association between environmental change and fertility. This framework views the household as the primary decision-making unit, employing multiple livelihood strategies in the face of declining natural capital and rising uncertainty. While some livelihood strategies may involve direct behavioral change, such as fertility spacing or even increase to meet labor demand, as put forth by VCM, other strategies may affect fertility indirectly and unintentionally, such as spousal labor migration.

In this paper, rather than view these as two competing theories, we have attempted to test them in a single conceptual framework. Looking across nearly 1500 rural communities in four sub-Saharan African countries, we find a strong yet complex relationship between natural capital—which we index here using land cover change over the course of a decade—and fertility preferences and outcomes. In communities where natural capital was initially low, a further decline was associated with higher fertility; however, in communities where natural capital was initially high, a decline in natural capital over time was associated with lower fertility. Although this finding lends some support to the VCM, we find no difference between poor and wealthy households *in the same community* given further decline in natural capital. A similar pattern arises in fertility preferences, measured via the desire to have additional children at the time of interview. In this case, communities where natural capital was initially low, a further decline was linked to higher fertility, but no difference was found among communities where initial natural capital was high. Furthermore, poor households in communities where land cover conditions worsened over time had higher fertility than poor households where conditions improved; wealthy households, on the other hand, were not affected by change in natural capital.

Taken together, these findings offer greater, though partial, support to the vicious circle model. The conditions necessary to establish VCM are found only with respect to fertility preferences, but not fertility outcomes. Fertility was indeed higher in communities where natural capital declined—but only where natural capital was already low to begin with and not among the poorest households within those communities. Yet, the poorest households in those communities showed a preference for higher, not lower, fertility—rendering VCM incomplete. As these findings reveal, the vicious circle model remains a viable theory in explaining high fertility in rural sub-Saharan Africa. Yet, its main drawback lies in its inability to reconcile preferences and outcomes, which we show to be discordant—particularly among those for whom the theory should be most relevant. This is precisely where the rural livelihood framework becomes relevant.

Our findings show that poor households *desire* higher fertility when natural capital is declining—particularly when it was already low to begin with—but lack the means to realize that higher fertility. Whether it is part of their livelihood strategies, as suggested by the VCM, is yet unclear. A growing body of scholarly literature on fertility has documented how uncertainty shapes actions and decision-making. This literature refers both to uncertainty of goals and means to achieve them (Watkins 2000; Johnson-Hanks 2006) and uncertainty about how to express those goals (Morgan 1981, 1982; LeGrand et al. 2003; Hayford and Agadjanian 2011). Feeding into our conceptual framework, uncertainty regarding the availability of future resources shapes livelihood strategies at the household level.[4] Some of those strategies may involve increasing fertility to meet labor demands—particularly among poor households, as our findings suggest—but those strategies may not be realized due to various constraints or competing livelihood strategies which operate to lower fertility. Indeed, the most surprising finding in this study is that when environmental conditions worsen poor households *want* to increase fertility but lack the means to do so. In other words, both proponents and opponents of the neo-Malthusian tradition appear to have been correct, but each for the wrong reason. Additional research is needed to understand how specific livelihood strategies interact with one another to shape fertility outcomes at all levels of aggregation from the individual level to demographic rates.

This study is not without limitations. First, although natural capital is measured longitudinally, fertility preferences and outcomes are measured in cross section (and, in the latter case, retrospectively). Second, only a single form of natural capital is measured. Vegetation cover constitutes a crude measure of natural capital that is likely correlated with multiple resources including rainfall, firewood, and wild foods. It is impossible to disentangle those resources using remotely sensed measures. At the same time, only such measures allow a large, cross-national study that represents multiple ecosystems and climate zones. Third, since the DHS no longer inquires about migration history, it is impossible to ascertain how long respondents have been exposed to the environmental conditions in which they were surveyed. Fourth, only women's fertility preferences are examined, which may be different from their spouses' preferences and do not necessarily reflect how fertility-related decisions are made within the household. Fifth, although we considered the effect of land cover change on fertility as going in one direction, population-environment dynamics operate in feedback loops. We believe that this simplifying assumption

[4] We tested the effect of inter- and intra-annual variation in NDVI on fertility preferences and outcomes, net of baseline vegetation cover, and neither was significant. However, we are unable to tell from our data whether respondents' fertility preferences and behavior reflected uncertainty about future availability of natural capital in face of recent decline.

is justified from an individual/household standpoint (the unit of analysis) and given the temporal scale of this study (a single decade).

In spite of those limitations, this study contributes to the literature by uniquely evaluating competing fertility-environment models using a multilevel, cross-national study design. Moving away from mono-causal explanations of fertility responses to the natural environment, future research would do best to highlight how different livelihood strategies can lead to different fertility outcomes.

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Table 1 Study region characteristics

Country	Last population estimate (millions)	TFR	Rural-urban TFR differential	Modern contraceptive use (%)
Burkina Faso	15.7	6.0	2.8	14
Cameroon	17.5	5.1	2.4	16
Nigeria	140.4	5.7	1.6	15
Senegal	12.5	5.0	2.1	9

Sources: Agence Nationale de la Statistique et de la Démographie 2012; Institut National de la Statistique 2012; Institut National de la Statistique et de la Démographie 2012; National Population Commission 2009

Table 2 Data sources and description

Measure	Data Source	Description	Spatial Resolution/Scale
Country and regional boundaries	Global Administrative Areas, v2.0	National and 1st level administrative boundaries, used in calculating aggregate measures	-
Distance to nearest maintained road	Africa Infrastructure Country Diagnostic	Euclidean distance to nearest "Good" or "Very Good" road	-
Distance to shoreline	Global Self-consistent Hierarchical High-resolution Geography, v2.2.2	Euclidean distance to nearest point on shoreline (calculated for each sampling cluster)	1:100,000
Natural capital	Famine Early Warning Systems Network (MODIS Terra NDVI time series)	Used 360 ten-day composites to derive: (1) Baseline annual sum NDVI; (2) Linear change in annual sum NDVI over a 10-year period (2001-2010). Both measures were standardized	250 m
Population density	Gridded Population of the World, v3 (CIESIN)	Persons per km^2 in 2000	2.5 arcminutes

Table 3 Sample descriptive statistics (unweighted; standard deviations in parentheses)

Variable	Burkina Faso	Cameroon	Nigeria	Senegal	All Countries
Fertility					
Number of births in past 60 months	1.2 (0.8)	1.1 (1.0)	1.1 (0.9)	1.1 (0.9)	1.1 (0.9)
Desire for more children (%)	71.1	64.2	68	75.5	69.5
Individual characteristics					
Age	32.2 (8.2)	32.1 (8.5)	31.7 (8.4)	31.1 (8.1)	31.8 (8.3)
Currently pregnant (%)	11.9	11.9	11.9	10.7	11.7
Number of living children	3.7 (2.1)	3.6 (2.4)	3.3 (2.4)	3.4 (2.4)	3.5 (2.4)
Educational attainment (%)					
None	90.0	32.3	52.7	83.2	63.6
Primary	7.6	46.6	21.7	12.1	20.4
Secondary	2.4	21.1	25.6	4.8	16.1
Marital status (%)					
Married	93.6	67.7	84.1	88.3	84.6
Never in union	1.7	8.0	9.5	7.1	7.1
Other	4.7	24.3	6.4	4.6	8.3
Religion (%)					
Christian	27.2	69.3	46.7	2.8	37.7
Muslim	60.5	22.6	51.0	96.2	57.2
Other	12.3	8.1	2.3	0.9	5.1
Community (cluster) characteristics					
Population density (person/km^2)	63 (84)	75 (118)	254 (533)	115 (164)	161 (381)
Distance to maintained road (km)	15.7 (13.4)	18.8 (17.7)	25.2 (22.7)	17.2 (17.3)	20.7 (19.8)
Distance to shoreline (km)	734 (108)	414 (298)	436 (289)	104 (95)	440 (307)
Sample size					
Clusters	370	282	606	238	1,496
Respondents	8,915	5,694	18,126	7,096	39,831

Table 4 Multilevel Poisson regression of births in last 60 months (N = 39,678)

Variable	Model 1			Model 2		
Natural capital						
Baseline NDVI	0.974	(-2.59)	*	0.974	(-2.59)	*
NDVI slope	0.983	(-2.69)	**	0.983	(-2.68)	**
Baseline x slope	1.025	(4.28)	***	1.025	(4.28)	***
Individual/household characteristics						
Age	1.251	(38.19)	***	1.251	(38.19)	***
Age^2	0.996	(-44.68)	***	0.996	(-44.68)	***
Education (ref. = None)						
Primary	1.030	(2.04)	*	1.030	(2.04)	*
Secondary or higher	0.930	(-3.67)	***	0.930	(-3.67)	***
Marital status (ref. = Married)						
Never in union	0.180	(-41.95)	***	0.180	(-41.95)	***
Other	0.724	(-15.16)	***	0.724	(-15.15)	***
Religion (ref. = Christian)						
Muslim	1.016	(1.16)		1.016	(1.16)	
Other	0.984	(-0.67)		0.984	(-0.67)	
Relative household wealth	0.969	(-6.25)	***	0.969	(-6.14)	***
Household wealth x NDVI slope	-			1.000	(0.04)	
Community characteristics						
Population density	1.000	(0.68)		1.000	(0.68)	
Mean household wealth	0.941	(-9.52)	***	0.941	(-9.52)	***
Distance to maintained road	1.000	(-1.73)		1.000	(-1.73)	
Distance to shoreline	1.000	(-1.26)		1.000	(-1.26)	
Country (ref. = Burkina Faso)						
Cameroon	1.064	(3.14)	**	1.064	(3.14)	**
Nigeria	0.982	(-1.13)		0.982	(-1.13)	
Senegal	0.932	(-2.39)	*	0.932	(-2.39)	*
Constant	0.077	(-26.94)	***	0.077	(-26.94)	***
Log-likelihood	-46,721.9			-46,721.9		

Effects are reported as relative risks; Z-statistics are in parentheses

*p < .05; **p < .01; ***p < .001

Table 5 Multilevel logit regression of desire for additional children (N = 37,983)

Variable	Model 1			Model 2		
Natural capital						
Baseline NDVI	0.788	(-4.81)	***	0.787	(-4.82)	***
NDVI slope	0.878	(-4.28)	***	0.879	(-4.24)	***
Baseline x slope	1.097	(3.40)	**	1.095	(3.36)	**
Individual/household characteristics						
Age	1.137	(6.87)	***	1.137	(6.87)	***
Age^2	0.996	(-13.62)	***	0.996	(-13.62)	***
Number of living children	0.650	(-46.69)	***	0.650	(-46.70)	***
Currently pregnant	0.693	(-7.89)	***	0.693	(-7.88)	***
Education (ref. = None)						
Primary	1.052	(1.04)		1.050	(1.00)	
Secondary or higher	0.996	(-0.07)		1.003	(0.04)	
Marital status (ref. = Married)						
Never in union	0.296	(-16.81)	***	0.294	(-16.87)	***
Other	0.446	(-14.15)	***	0.444	(-14.24)	***
Religion (ref. = Christian)						
Muslim	1.363	(6.06)	***	1.363	(6.06)	***
Other	1.128	(1.52)		1.129	(1.52)	
Relative household wealth	1.031	(2.05)	*	1.025	(1.63)	
Household wealth x NDVI slope	-			1.048	(3.31)	**
Community characteristics						
Population density	1.000	(-1.80)		1.000	(-1.79)	
Mean household wealth	0.902	(-3.53)	***	0.902	(-3.53)	***
Distance to maintained road	0.998	(-1.19)		0.998	(-1.19)	
Distance to shoreline	1.000	(-0.66)		1.000	(-0.66)	
Country (ref. = Burkina Faso)						
Cameroon	0.971	(-0.31)		0.972	(-0.30)	
Nigeria	0.755	(-3.48)	**	0.754	(-3.49)	***
Senegal	1.048	(0.33)		1.048	(0.33)	
Constant	16.565	(8.43)	***	16.560	(8.43)	***
Log-likelihood	-15,963.5			-15,958.0		

Effects are reported as odds-ratios; Z-statistics are in parentheses

*p < .05; **p < .01; ***p < .001

Fig. 1 Conceptual framework linking natural capital, livelihood strategies, and fertility outcomes

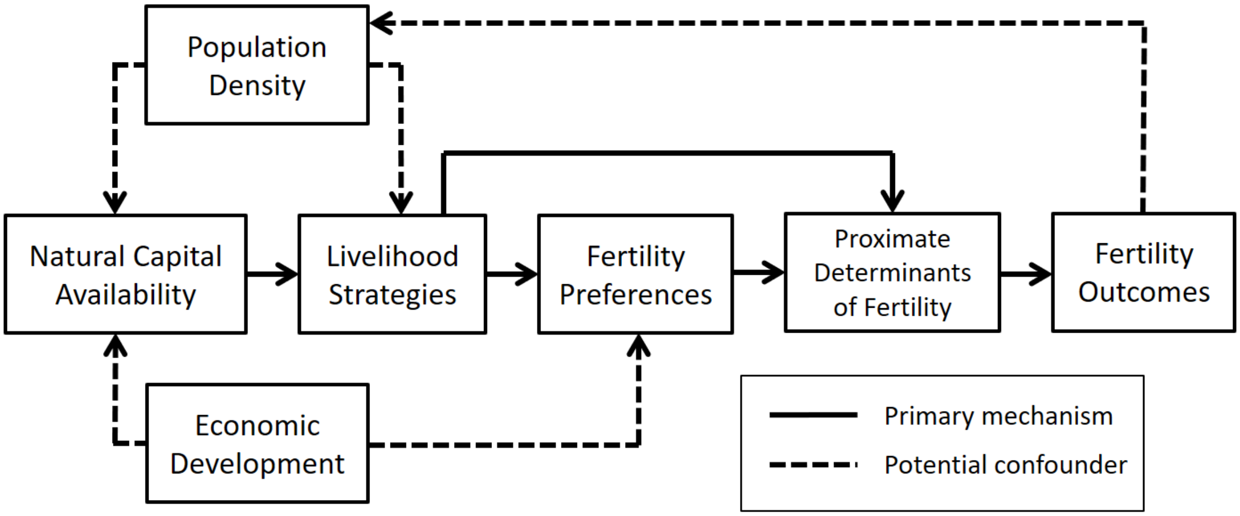

Fig. 2 Study region. Points represent DHS sampling clusters in Burkina Faso, Cameroon, Nigeria, and Senegal

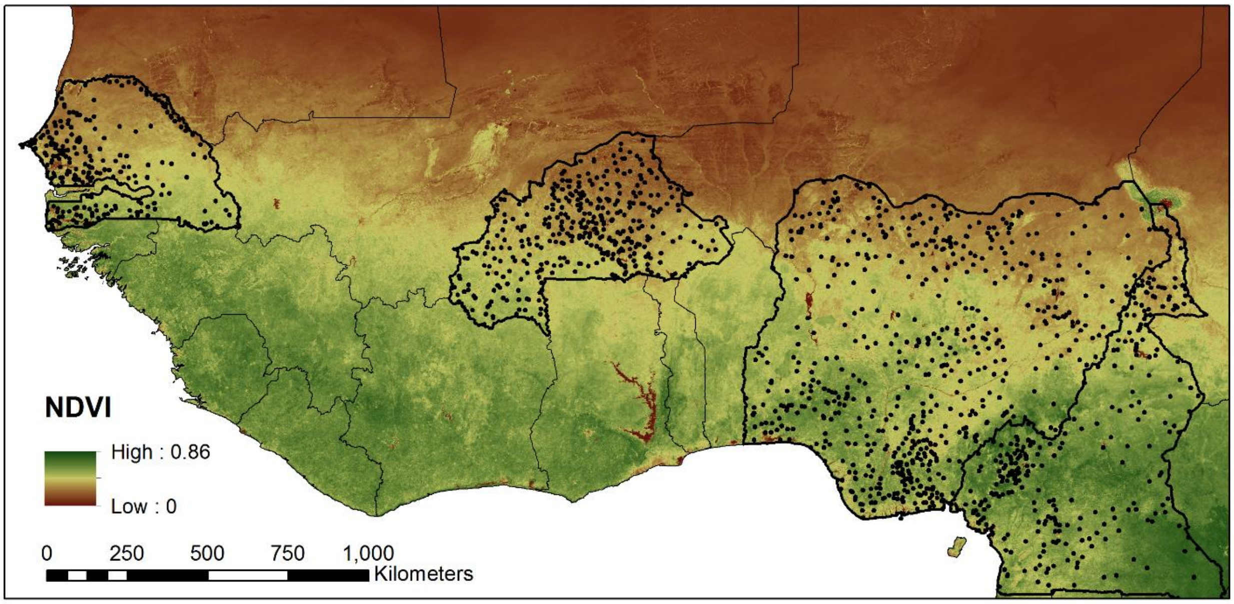

Fig. 3 a Number of births in past 60 months by natural capital. **b** Desire for additional children by natural capital. Low/high and declining/increasing natural capital correspond to ±1.5 SD in NDVI baseline and slope, respectively; Average marginal effects with random effects set to zero

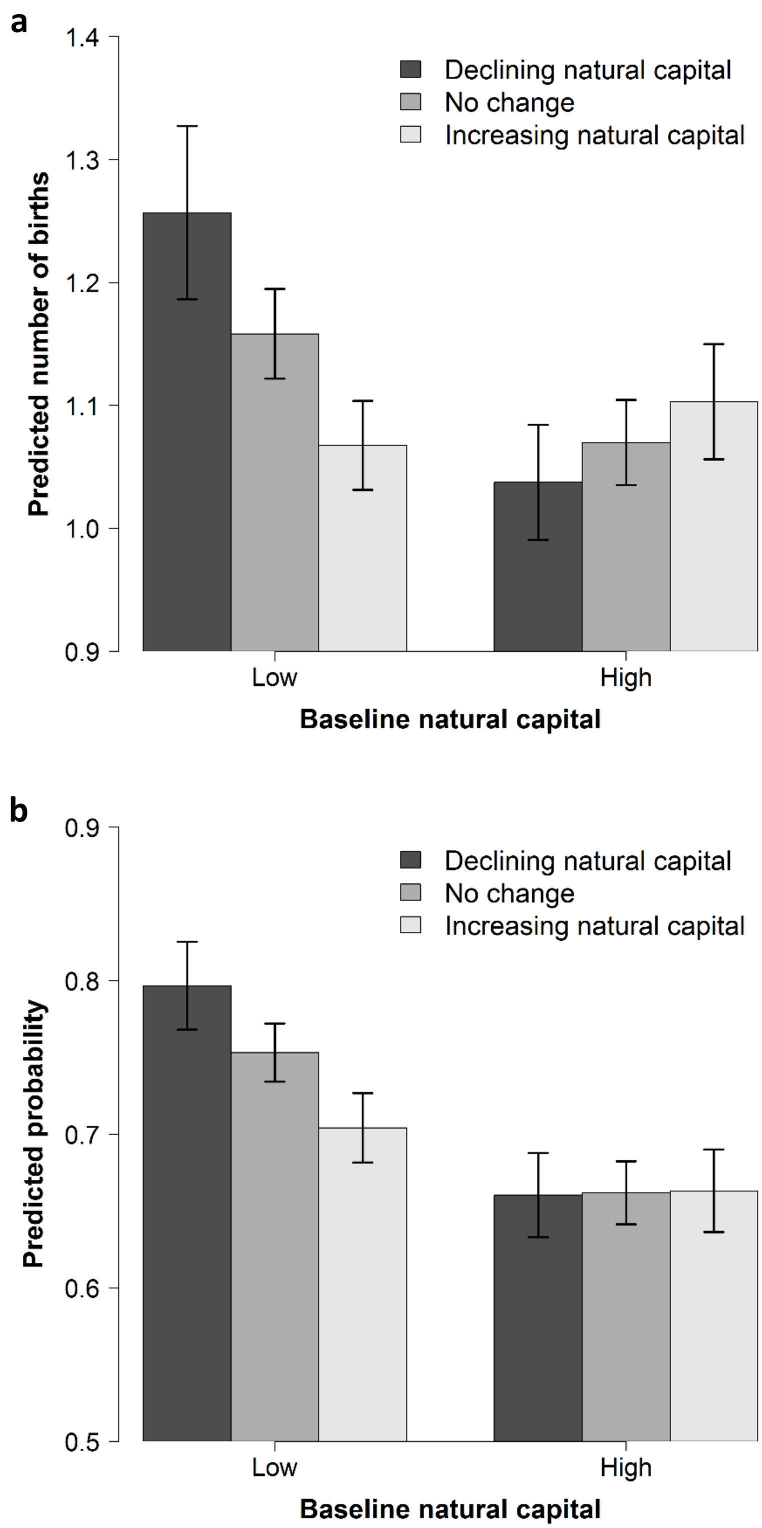

Fig. 4 Desire for additional children by relative household wealth and change in natural capital. Increase/decline in natural capital correspond to ±1.5 SD in NDVI slope where baseline NDVI is set to the country-specific mean. Poor/wealthy household corresponds to ±2 SD in relative household wealth. Average marginal effects with random effects set to zero