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The Effect of Land Degradation on Fertility in West Africa: Disaggregating the Demographic Response

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The Effect of Land Degradation on Fertility in West Africa: Disaggregating the Demographic Response

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Dedication

This thesis is dedicated to my parents, for instilling me with curiosity and giving me the opportunity to pursue it. And to my wife, for willing to move across continents simply because I asked her to.

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Abstract

The Effect of Land Degradation on Fertility in West Africa: Disaggregating the Demographic Response

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Demographic responses to environmental stress have long been hypothesized in classic population theory, though empirical analyses remain scarce and traditionally focus on aggregate units of analysis. With the growing concern over environmental degradation it remains an empirical question as to how, to what extent and in which spatial and temporal scales populations, especially in developing countries, are directly and indirectly affected by their immediate natural surroundings. This paper examines the link between fertility related behavior of women at the individual level and several environmental determinants across eight sub-Saharan West African countries. Data is pooled from georeferenced Demographic and Health Surveys (conducted 2001-2005) combined with long term climatic data and a time series of remotely sensed vegetation index spanning 23 years. Results consistently show little to no effect of immediate natural resources or gross land degradation on fertility related behavior, but that effects tend to become more pronounced in larger geographic scales. Despite data limitations these results call for improved theoretical specificity. Questions that need to be addressed, both theoretically and empirically, are at which spatial and temporal scales environmental pressures induce certain types of demographic responses.

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Chapter 1: Introduction

Until recently, the influence of the natural environment on population dynamics was often neglected in demographic analyses, even though such influences lie at the core of classic demographic thought. The key processes of fertility, mortality and migration are implicitly assumed to be contained almost exclusively within the socio-economic realm in the modern era. However, it remains an empirical question how populations, especially in developing countries, are still directly and indirectly affected by their natural surroundings. The non-social context within which population dynamics occurs includes a variety of possible natural, geographic and spatial determinants: climate, topography, natural resource endowments, soil quality, availability of rainfall, surface and ground water, and proximity to shore, to name a few (Bilsborrow, 1992). These are further complicated when supplemented by interactions with the social world in the form of agricultural practices, land tenure and distribution, government policies, and of course the demographic processes themselves resulting in population growth and flows affecting their natural environment in return.

The relatively few studies that have tried to empirically question the responses of populations to environmental change were often limited to crude, macro level units of analysis such as regions, countries and sometimes entire continents (Bilsborrow & DeLargy, 1990; Bilsborrow, 1992; Tiffen & Mortimore, 2002) – mainly due to the scarcity of data at smaller scales. While some circumstantial evidence has been shown to support the link between population dynamics and the natural environment, it often suffers from an ecological fallacy, making it virtually impossible to link environmental determinants to individual behavior and outcomes (some recent exceptions are Balk, et al., 2004; and Hunter et al., working paper). With recent technological advancements making it possible to monitor the human and natural environment (e.g. remote sensing, GPS and GIS), as well as increasing availability of data from developing countries, it has become possible to better answer these long lasting questions with finer spatial and social resolution. This is especially important given the increased awareness of environmental problems, whether caused or amplified by collective human action.

Using the above mentioned resources, the key link that I propose to explore in this paper is the one between land degradation and fertility, focusing on sub-Saharan West Africa. More specifically, I evaluate the hypothesis that individuals in areas suffering from greater land degradation and fewer environmental resources will respond by reducing their fertility, either directly or through postponement. Granted, land degradation is only one form of environmental change. But it is one that is closely tied to many environmental and social factors, as will later be shown. Likewise, it is important to note that fertility reduction/postponement is also just one possible demographic response to land degradation. Others include internal and international labor and permanent migration – these may be the focus of future analyses using data pooled and analyzed in this paper.

I will start with a review of the theoretical frameworks linking land degradation and population dynamics, followed by the broader literature about land degradation and desertification: its causes (whether a natural or human induced problem), manifestation, issues regarding measurement and recent trends. I will then thoroughly discuss the data and methods used to assess the effect of land degradation on fertility and marriage at the *individual level* rather than some aggregate unit of analysis. These data include Demographic and Health Surveys conducted in 8 West African countries, spanning from 2001-2005 and including GPS coordinates of sampling clusters. As indicators of long term environmental resources and land degradation I use a set of pre-processed measures derived from a time-series of remotely sensed vegetation index spanning from 1981-2003. Several geographic and climatic control variables are also included. Results will then be shown and discussed, with emphasis on the scope, scale and limitations of the data presented, as well as theoretical implications for future research.

Chapter 2: Population dynamics and environmental degradation

The literature linking population dynamics and the environment can be broadly divided to 3 theoretical foci of arguably the same interrelated ontological phenomenon: (a) the effect of population pressure on the environment; (b) population responses to environmental pressure; and (c) a combination of the two, or feedback loops of population-environment dynamics. These can be further complicated by the level of theoretical specification with regard to social units of analysis – ranging from individuals and households to entire populations, however geographically (or otherwise) defined. While the emphasis of this paper is on demographic responses, specifically fertility, to environmental degradation, alternative causal directions should be considered. Additionally, even within the framework of demographic responses there exists a multitude of competing predictions as to the nature, direction and magnitude of possible responses. These are developed in the following discussion.

The effect of population pressure on the environment

Jolly (1994) identifies 4 major theoretical frameworks pertaining to the association between population growth and environmental degradation. First is the classical economic approach which views land degradation as a direct result of high population growth, leading to resource depletion. This approach dates back as early as Malthus (1798) and in principle anticipates rapid population growth, unmatched by a similar growth rate in food production, eventually resulting in major food shortage and increased mortality until equilibrium is achieved once again. This simplistic model follows an ecological logic of a limited (though variable through time and space) carrying capacity of the land. Sustained by Neo-Malthusians, this framework is identified as the dominant perspective in demographic literature (Hogan, 1992) – especially with regard to sub-Saharan Africa (Kalipeni, 1996).

The neo-classical economic approach, considered as the prominent challenge to the Malthusian theory and commonly attributed to Boserup (1965, 1981), contends that the effect of population pressure on the environment is mediated by market inefficiencies and technological advancements. In fact, increased population density can be seen as the driving force of technological progress – resulting in reduced stress on the environment and potential long term sustainability (Mortimore, 1993).

The third approach, associated with dependency theory, posits that both population growth and environmental degradation are the result of poverty and inequality, rather than directly linked to each other in a causal fashion. However, it remains unclear whether and under what circumstances poverty itself is an exogenous or endogenous factor of environmental degradation, degradation can be attributed to those in the upper or lower tail of the inequality distribution, and institutional or market failures play a role in this mechanism (see Duraiappah, 1994 for further discussion).

The fourth and last approach considers population growth only as an exacerbating proximate factor of environmental degradation, rather than the underlying cause (e.g. prevalence of polluting technologies, unfit policies etc.). Finally, Jolly suggests that these frameworks are not necessarily mutually exclusive (Kalipeni, 1996) and instead may depend on regional factors.

Demographic responses to environmental pressure

Regardless of the driving force underlying environmental degradation, once it manifests itself, it is theorized to impose stress on nearby populations. If the stress is long lasting (e.g. land degradation) rather than temporary (droughts, floods and other natural disasters), individual and population level demographic responses are likely to take place. As previously described, the Malthusian theory argues that equilibrium is to be re-established mainly through the reduction of population levels below the environment's carrying capacity – or in plain words – increased mortality. The theory's major fault, as now widely recognized, is in disregarding alternative means of economic and demographic responses.

One such example is through technological advancements increasing crop yield per area unit, postulated by the Danish economist Ester Boserup (1965, 1981) and referred to as land *intensification*. Once the pressure of population growth is felt in some limited agricultural land area, the production of food will be intensified by use of fertilizer, irrigation and other technological means (later additions include genetic engineering of crops for example). Another economic path of increasing food production is through *extensification* (Bilsborrow, 1992), in which additional agricultural land can be appropriated by deforestation and other means of land-use change.

Kalipeni (1996), however, argues that there has been too much emphasis in the literature on economic responses rather than demographic ones. A conceptual framework of purely demographic multi-phasic response was originally suggested by Davis (1963), albeit with the cases of modern Japan and West Europe in mind. An encompassing theory of economic and demographic responses, directed mainly at developing countries, is developed by Bilsborrow and Okoth-Ogendo (1992). Their multi-phasic response model links population adjustments to land-use pressure through several paths: (1) Tenurial – the redistribution of land ownership to accommodate growing population; (2) Extensification – the appropriation of additional land; (3) Technological – which can be identified with Boserup's intensification argument; (4) Demographic – incorporating fertility reduction through either postponement of marriage, reduction of marital fertility or both, and finally population redistribution through internal rural-rural, rural-urban and international migration.

As the pressure of food and resource shortage increases, and economic solutions are unmet, demographic responses may follow in the form of fertility reduction and voluntary or forced migration (for an interesting discussion about the boundaries and definitions of "environmental refugees" see Suhrke, 1994). While Bilsborrow (1992) postulates that families will tend to exhaust all other options before resorting to demographic adjustment, it is not inevitable to find all four phases manifesting concurrently (albeit at different rates and time scales) when external environmental pressures are high. Bilsborrow (1987) describes the socioeconomic and institutional contexts in which different responses, both economic and demographic, are likely to take place. The geographical scales at which demographic responses should occur, however, are absent from the theoretical literature and only implied in empirical studies by the units of analysis for which data are available.

The problem of unmet demands for food and resources, however, is twofold: not only is the availability of land outstripped by growing populations, it may actually be depreciating. This is a possible outcome under both classic and neo-classic approaches. Mortimore (1993) refers to the Malthusian outcome as the *degradational pathway*, resulting in reduced fertility of cultivated soils, declining crop yield and a systematic fall in total output which eventually translates to a starved community; The Boserupian outcome is referred to as the *conservation pathway*, allowing for increased productivity and sustainability. However, it is not at all clear that intensification is indeed sustainable. Whether we take a generalized deterministic view or a locally mediated one, it may just as well be true that intensification itself depreciates the fertility of the land in the long term.

Individual and household response mechanisms

The economic and demographic responses discussed so far are largely stated at the population level – and so are the theoretical and empirical predictions derived from them. In order to avoid an ecological fallacy we must also consider how environmental pressures and responses operate at the household and individual level. The main causal mechanism underlying both economic and demographic responses, practically in all theoretical approaches discussed to this point, relies on resource scarcity (be it crops, fuel-wood or otherwise). As such it makes sense to consider the competing incentives, rooted in and limited by a cultural setting, which operate at the micro level.

Population growth in developing countries induces two main effects: (1) increasing the demand for food, and thus the price of arable land; (2) increasing the number of family members per plot size through natural growth and subdivision among heirs (Bilsborrow, 1990). Smaller family farms are also often excluded from taking the intensification route, as their access to new technology and financial credit is limited (others may switch to cash crops or livestock, though ironically it may require and exhaust land resources even faster). As these family-owned plots can no longer sustain their growing number of inhabitants, yet the prices of plots increase, many families end up selling their lands and become landless which increases socioeconomic differentiation (Bilsborrow, 1990). On the other hand, following the same logic, larger farms grow in average size and introduce non-traditional crops and new farming techniques (i.e. intensification). As families find it more and more difficult to sustain themselves, young males may seek seasonal and permanent employment in adjacent rural or urban areas. In the past, sub-Saharan African women were less prone for labor migration as they were typically the ones working in the farms along with the children (Boserup, 1985). More recently, however, it has been shown that rural-urban female migration in sub-Saharan Africa is more likely for women who are unmarried, more educated, or have fewer children (Brockerhoff & Eu, 1993), which may imply a change in previously gendered migration patterns. Ultimately, as conditions increasingly worsen and once families become landless, they are likely to migrate as a whole to new agricultural lands (possibly cleared by deforestation, putting further strain on the environment) or to urban areas, while still contributing to land-use pressure indirectly.

When it comes to fertility behavior, however, predictions may differ between the population level and individual level theories. While fertility reduction is another appropriate demographic response to land pressure according to the multi-phasic model, a competing hypothesis postulates that in sub-Saharan Africa particularly there may be social and cultural incentives to *increase* fertility as means to improve eligibility for land tenure (Boserup, 1985). Women in particular may have additional incentives to bear more children under environmental stress, as they are often responsible for housework (including the collection of increasingly rare water and fuel-wood) and are typically assisted by their children (Joekes, 1994). Put more formally in economic terms (Aggarwal et al., 2001): under environmental stress children have both increasing consumption and production utilities, the balance of which determines the demand for additional children. In particular, Aggarwal and colleagues find – using an individual choice model – that scarcity of fuel-wood in South-Africa has a positive effect on fertility. Similarly, the direction of fertility change as a demographic response, both at the population and the individual levels, is the focus of this paper and remains to be tested in following sections.

Methodological implications

The conceptual frameworks presented so far allude to two main methodological concerns. The first, and the most crucial to the aim of this paper, is the causal direction between environmental degradation and fertility choices. While it is clear that human populations both affect their immediate environment and are affected by it in return, the distinction between these effects is not straightforward when using cross-sectional data (albeit degradation is measured as a dynamic process prior to fertility). On one hand, higher population density is linked to environmental degradation in a causal effect (though the ecological footprint of urban areas can be far reaching, as asserted by Lambin et al., 2001); on the other hand, fertility reduction is expected once the strain on the environment translates back to land-use pressure on the local population. Thus, observing varying levels of fertility in degraded lands at one time point should not necessarily follow a uniform direction. Early in the process we expect increasing population growth rates to increase land degradation, while later in the process we expect a reversal in this causal mechanism, with land degradation driving fertility downwards. The question then becomes whether the land is degraded *enough* to induce a certain response (i.e. fertility decline), and whether contextual circumstances favor certain economic or demographic responses over the others Bilsborrow (1987).

The second methodological complication lies in identifying and measuring land degradation, however it may be defined (I address this in the following section). Relating land-use change and degradation solely to agricultural practices encompasses only a limited subset of the actual phenomenon. Land degradation in the social sciences literature is often treated as a human-induced problem – the result of deforestation, urbanization, globalization, overconsumption of fuel-wood and so on. An additional set of causes exists in the geosciences literature, especially with regard to the arid and semi-arid zones of sub-Saharan Africa, incorporating natural (and to some extent cyclical) climatic variation consisting of short term droughts and long term desiccation (Darkoh, 1998). This makes it all the more difficult to differentiate long term human-induced degradation from the natural and reversible "background noise". It is also expected that populations in these arid and semi-arid zones, characterized by higher climatic variability than humid tropical zones, will be more resilient to ecosystem changes when institutional socio-economic factors allow (Olsson, 1993).

Previous findings and additional theoretical considerations

Previous empirical evidence is scarce and generally regarded as circumstantial (Bilsborrow and Okoth-Ogendo, 1992; Kalipeni, 1996). Bilsborrow and colleagues find evidence of intensification, extensification and demographic change at the continental and country level in a broad range of developing regions (Bilsborrow, 1987; Bilsborrow & DeLargy, 1990; Bilsborrow, 1992; Bilsborrow & Okoth-Ogendo, 1992). Kalipeni (1996) suggests that the onset of the fertility transition in Malawi and internal migration patterns in the 1970's and 80's are tied to population pressures on the environment, measured at the district level (though he does not have a direct measure of environmental pressure and instead uses population density as the main explanatory variable). The use of aggregate units of analysis, however, is prone to ecological fallacies as these scholars recognize. Since both fertility transition and environmental degradation are dynamic processes which operate over the course of years and decades, it is difficult to disentangle the web of intervening and mediating variables. For instance, economic development may affect both (e.g. fertility reduction and environmental degradation) over time, even when the two are causally unrelated. Furthermore, as previously shown, competing incentives may operate at the individual level and these do not necessarily complement the population level predictions of fertility response. An individual based choice model may produce contradictory results, as recently shown in the case of fuel-wood scarcity in South-Africa during the early 1990's (Aggarwal et al., 2001).

If we take the stance that the present is in many ways unique and exceptional in human history (the speed of recent and contemporary demographic change suggests that this is the case), we may also have to consider the possibility that what the future holds cannot be fully derived from past collective experiences. In other words, the pace and extent of environmental changes may not follow a linear and cumulative trend. The effect of environmental degradation (whether nature or human induced) on human populations could be aggravated under climate change (Meadows & Hoffman, 2003). Exacerbated political tensions and conflicts, presumed to accompany massive migration in developing countries, are all possible scenarios if such extreme climatic changes should occur (see Suhrke, 1993; Eswaran et al., 2001).

To conclude, I intend to examine the demographic *response* of sub-Saharan West African populations to land degradation rather than degradation itself as a population induced phenomenon. While the two processes are conceptually interrelated, degradation is treated as an exogenous variable in the empirical analysis presented in this paper. I take this to be a plausible assumption with respect to individuals' fertility choices, by which land degradation is experienced as a structural constraint, even when at the population level a reversed causal mechanism can be hypothesized. Specifically, I examine whether land degradation affects individual decisions regarding fertility and marriage among rural women in eight West African countries: Benin, Burkina Faso, Cameroon, Ghana, Guinea, Mali, Nigeria and Senegal. These countries span over a variety of climatic conditions ranging from humid to hyper-arid. Following the revisited multi-phasic model (Bilsborrow & Okoth Ogendo, 1992) I evaluate the hypothesis that the higher the level of degradation, the lower the number of children women will tend to have, and the higher the age of first marriage (and consequently first birth). The effect of long term ecosystem characteristics as well as environmental resource predictability will also be examined. We now turn to discuss in further depth the definition, causes, manifestation and measurement of land degradation in sub-Saharan West Africa and the Sahel region.

Chapter 3: Land degradation and desertification

The definition of land degradation is a very tricky one. Its scope depends, to some extent, on the disciplinary affiliation of the researcher as well as on the focus of the study. Consequently, the identification and measurement of degradation varies considerably across the literature with regard to scale – both in terms of space and time. For these reasons it is difficult to present a coherent picture of the causes of degradation or its cumulative effect over time in a specific geographic region. Here I review the main definitions and causes of degradation in the literature, their "evolution" through the recent decades and how the consensus (if there ever was one) regarding the topic has changed. From this discussion I will later derive the somewhat limited scope of the term as operationalized in this study.

In the early literature land degradation was often referred to as *desertification*, a term coined by the forester Aubreville in 1949 with regard to the consequences of deforestation (Darkoh, 1998). The use of the term became common practice in the early 1970's, often depicting a large scale encroachment of the desert (mainly relating to the Sahara desert and the Sahel region, which suffered from extreme drought during 1965-1973). Preliminary claims (Stebbing, 1938; Lamprey, 1975) stated that the Sahara desert was advancing southward at a rate of several km per year, though these results were later shown to be flawed for various reasons (Dodd, 1994; Thomas, 1997; Nicholson et al., 1998). Nonetheless, these claims were enough to encourage the first UN Conference on Desertification in Nairobi in 1977, which eventually adopted the following definition

(UNCOD, 1977): “Desertification is the diminution or destruction of the biological potential of the land, and can lead ultimately to desert-like conditions”. A later supplement to the definition was adopted by the UN Environmental Program (UNEP) in 1990, stating: “Desertification/land degradation, in the context of assessment, is land degradation in arid, semi-arid and dry sub-humid areas resulting from adverse human impact” (Hellden, 1991). Another definition by UNEP in 1992 referred to the process of desertification as “patches of increasingly unproductive land breaking out and spreading over hundreds of square kilometers”, and the UN International Convention to Combat Desertification (INCD) in 1994 described land degradation as the “reduction or loss of the biological or economic productivity and complexity of the land” (Darkoh, 1998). Finally, a recent addition adopted by the UN specifies the causes and scope of the problem: “land degradation in arid, semiarid and dry sub-humid areas result[s] from various factors, including climate variations and human activities” (Nicholson et al., 1998).

Other definitions of desertification/degradation abound. Yet, the main sources of ambiguity are captured in the above set of definitions and include the following: whether degradation/desertification manifests only in large scale arid, semi-arid and dry sub-humid zones tangent to desert borders, or in sporadic patches; whether it is induced by climatic variation, by adverse human activities, or both; and consequently, whether it is reversible.

It is now commonly understood that the image of encroaching sand dunes is a false one with regard to degradation/desertification (Eckholm, 1975; Nicholson et al., 1998; Symeonakis & Drake, 2004). The previously held assessments of vast amounts of land being degraded to desert-like conditions have been refuted. UNEP's early assessments included up to 35% of the earth's land surface under vulnerability to desertification (Hellden, 1991), and a "desertification-hazard map" presented at the 1977 UNCOD turned out to be no more than simply a map of the world's drylands (Thomas, 1997). Satellite imagery in the past 3 decades have shown that the "advancement and retraction" of the Sahara is largely the result of natural variation in rainfall, and that this natural occurrence is to a large extent reversible (Hellden, 1991; Tucker et al., 1991; Nicholson et al., 1998; Tucker & Nicholson, 1999). However, smaller scale and sporadic anthropogenic induced degradation may still occur, especially when interacting with droughts in arid and semi-arid regions.

The causes of degradation/desertification were historically highly contested, mainly surrounding the question whether it is an anthropogenic problem or a natural one. The natural path includes short and long term droughts resulting in reduction in vegetation cover and ultimately loss of nutrients and land fertility through soil erosion. The anthropogenic path is more diversified and includes ill-designed agricultural practices (pastoral overgrazing, reduced fallow, poor irrigation practices etc.), land-use change through deforestation and urbanization, and lastly fuel-wood cutting to supply energy demands in developing countries (Symeonakis & Drake, 2004). The outcome however is fairly similar in both routes: reduced surface vegetation, soil erosion and loss of nutrients rendering the land practically sterile.

Geist and Lambin (2004) use a meta-analytical research design to derive the causal patterns of desertification. They conclude that neither explanation pathway (i.e. human vs. nature) can fully capture the multifaceted problem of degradation. Instead, they propose a typology of proximate causes and underlying driving forces. The proximate causes operating at the local level include mainly immediate human activities as agricultural practices, infrastructure extension and wood extraction, as well as increased aridity through reduced rainfall. The underlying driving forces on the other hand include demographic factors (e.g. population growth and redistribution through natural increment or migration), economic factors, technological advancements, cultural practices, institutional policies, and again, climatic factors. Furthermore, they conclude that the combination of factors has the potential to vary greatly among different geographic regions across the globe.

An additional level of complexity is obtained when considering interrelations between anthropogenic and natural factors, as well as feedback mechanisms. Natural habitats in arid and semi-arid zones are believed to be highly resilient to rainfall change. It is human practices *after* long periods of droughts that may drive the land to reach its resilience threshold (Olsson, 1993; Darkoh, 1998). Interestingly, the causality does not necessarily have to occur in one direction. While populations are driven to overexploitation of the land in times of natural crises (i.e. droughts), they may just as well affect climatic variation themselves through reduction of surface vegetation cover. Exposure of bare land where vegetation previously existed is hypothesized to increase the albedo (the proportion of reflected incident solar radiation by a surface) and in turn reduce precipitation (Nicholson et al., 1998; Geist & Lambin, 2004). Large scale climatic changes can also be induced by global greenhouse gas emissions and aggravate the natural water stress in arid and semi-arid zones.

This leads to the third question of reversibility. As stated earlier, arid and semi-arid environments are believed to be highly resilient to rainfall variation. It is also evident that large scale permanent encroachment of the southern border of the Sahara has not occurred in recent decades (ever since vegetation cover has been monitored through remote sensing techniques). Interannual fluctuations in the Sahel region have been attributed to change in precipitation, and were also proved to be highly reversible when conditions improved (Nicholson et al., 1998). Thus, it is assumed that under the time frame covered in this study (1981-2003), any *long term* degradation that has not been linked to interannual rainfall variation is likely to be induced by adverse human actions *or* interactions with the immediate environment. Although human populations are likely to be affected by natural degradation just as well as by anthropogenic degradation, the latter is believed to be prevalent through longer periods of time relative to the life course of individuals, and thus be more likely to induce demographic responses rather than other forms of temporary adjustments (here these include change in fertility and marriage patterns rather than migration). Simply put, land degradation addressed in the following analysis will be considered anthropogenic and largely irreversible in the scope of 2.5 decades.

The final concern is that of measurement. Due to the substantive complexity and large geographic scale of the phenomenon it remains relatively difficult to measure the extent of land degradation. Thanks to remote sensing technology it has become possible to track changes in global surface vegetation cover through time, with some of the datasets extending back to the early 1980's. Remote sensing technology utilizes the unique "electromagnetic signature" of various objects, comprising of absorption and reflectance patterns at different wavelengths of electromagnetic radiation (usually originating from the sun, though not exclusively). A commonly used measure of surface vegetation is the Normalized Difference Vegetation Index (NDVI) which, as the name implies, utilizes the normalized difference in surface reflectance of solar radiation between two bands: the Visible Red and the Near Infra-Red. Green vegetation generally absorbs at visible red and reflects at near infra-red, so the difference/ratio between the two plays a key role in many vegetation indices. NDVI is used in many of the studies cited through this paper. It takes the form of:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

In General, the higher the contrast between the two bands the higher the amount and vigor of surface vegetation believed to be (Chuvieco & Huete, 2010). As the leaf loses its green color through senescence it reflects more radiation in the visible red spectrum, becoming less sensitive to vegetation indices (in practice the change in leaf color *is* the result of higher reflection of visible red). NDVI assumes values between -1 and 1, where values below 0 usually indicate water, snow or cloud cover; values close to zero indicate bare soil and value approaching 0.7 indicate dense vegetation. However, it is worth noting that NDVI (as well as other remotely sensed indices) is sensitive to multiple factors such as cloud cover, level of illumination, topography, location of the satellite, the sun and the observed object, and many others requiring geographic and radiometric corrections.

A vegetation index is, however, simply that – a measure of the amount of surface vegetation. It is highly correlated with the net primary production (NPP) of an ecosystem (Nicholson et al., 1998) and does not necessarily indicate long term land degradation, but rather captures the natural interannual fluctuations associated with rainfall. For that reason, another measure often used in combination with NDVI, especially in arid and semi-arid regions, is *rain-use efficiency* (RUE) – defined as the ratio between NPP and precipitation. In practice this measure is approximated by the ratio of NDVI to rainfall integrated over a yearly time step, making it robust to shorter-term fluctuations. Simply put, RUE is an indication of the actual primary productivity of an ecosystem compared to its natural potential productivity. In longer time periods, negative deviations from the conservative baseline RUE values have been shown to indicate degradation (Symeonakis & Drake, 2004). It is crucial to note that land degradation is ultimately a multifaceted phenomenon having more than a single indicator, and that the measures adopted in this paper and discussed so far were emphasized due to their frequent use in the literature, the ability to monitor long-term change in large-scale ecosystems, and ultimately the availability of large scale data. Important measures other than vegetation cover and rain-use efficiency include overland flow of water, soil erosion and combinations of these indicators (Symeonakis & Drake, 2004).

Chapter 4: Data and methods

Data description and preparation

The following analysis is based on a combination of DHS data and several spatial and climatic data sources. The DHS data was collected during 2001-2005 from eight West African countries: Benin, Burkina Faso, Cameroon, Ghana, Guinea, Mali, Nigeria and Senegal. The surveys were randomly sampled in a two-stage design where sampling clusters often, though not necessarily, coincide with census enumeration areas (for more details about the sampling scheme see Demographic and Health Surveys, 1996). The surveys were designed to be representative at the national level and usually at the 1st level administrative regions. Data from these 8 countries were pooled together to include 64,829 households and 78,068 eligible women aged 15-49. Of these, a maximum of 48,512 rural, *de-jure* resident women were included in the final analysis (further broken down by age, marital status and motherhood).

The sampling clusters were georeferenced as point data, representing the centered coordinates of the households surveyed within the cluster. The size and density of clusters can be highly variable, as they can potentially represent a village up to a dense neighborhood in a large city. A total of 434 cases, of the original 48,512 rural women, were excluded from most analyses since GPS coordinates were missing for 9 out of the 1781 rural clusters. In six of the eight countries referenced here the survey also included a section regarding HIV, and although not directly relevant to this study, it has implications on the spatial accuracy of the data: due to confidentiality issues the GPS coordinates of clusters were randomly offset by up to 2 km in urban areas and up to 5 km in rural areas.

Geographical and environmental data include: gridded population density in the year 2000, proximity of DHS sampling cluster to coastline, mean annual precipitation for 1950-2000, mean annual sum NDVI, mean annual change in NDVI coefficient of variance, and finally, a time-series derived assessment of NPP loss in degraded lands. A summary of the geographical and environmental variables, their sources and spatial resolutions are shown in table 1. These variables were imposed on individual and household data using cluster GPS coordinates. Gridded data were averaged and calculated within a radius of 8, 16 and 24 km from the cluster, excluding water-bodies but not spillovers across national boundaries. Though land degradation has been hypothesized to influence individual economic and demographic decisions, it is unclear at which geographic and temporal scales these operate. More so, the assumption that all individuals are affected by degradation at the same geographic scale is a dubious one. For lack of theoretical guidance multiple radii buffer zones were chosen somewhat arbitrarily and according to limitations imposed by data resolution. The spatial distributions of key environmental variables and the locations of DHS sampling clusters are shown in figures 1-3.

Table 1: Data sources and description of geographical and environmental variables

Variable	Data Source	Description/comments	Resolution
Population density	Gridded Population of the World, v. 3 (CIESIN)	Persons per square-km	2.5 minute
Proximity to coastline	VMAP continental coastline data (FAO)	Euclidian distance to nearest point on coastline (calculated for each sampling cluster)	1 : 1,000,000
Mean annual precipitation	WorldClim (Museum of Vertebrate Zoology, UC Berkeley)	Long term mean precipitation for 1950-2000, in mm	30 second
Mean annual sum NDVI	Global Assessment of Land Degradation and Improvement (LADA, ISRIC & FAO)	Based on the GIMMS AVHRR NDVI time series 1981-2003, range 0-12	0.0727 degree (approximately 8 km at the equator)
% change in annual NDVI CoV	Global Assessment of Land Degradation and Improvement (LADA, ISRIC & FAO)	Linear trend for 1981-2003, percentage change per year	0.0727 degree
NPP loss in degraded land	Global Assessment of Land Degradation and Improvement (LADA, ISRIC & FAO)	Mean annual loss of NPP in kgC/ha/year, 1981-2003	0.0727 degree
Country and regional boundaries	GADM 1.0	National and 1st level administrative regions, used for calculating aggregate measures	

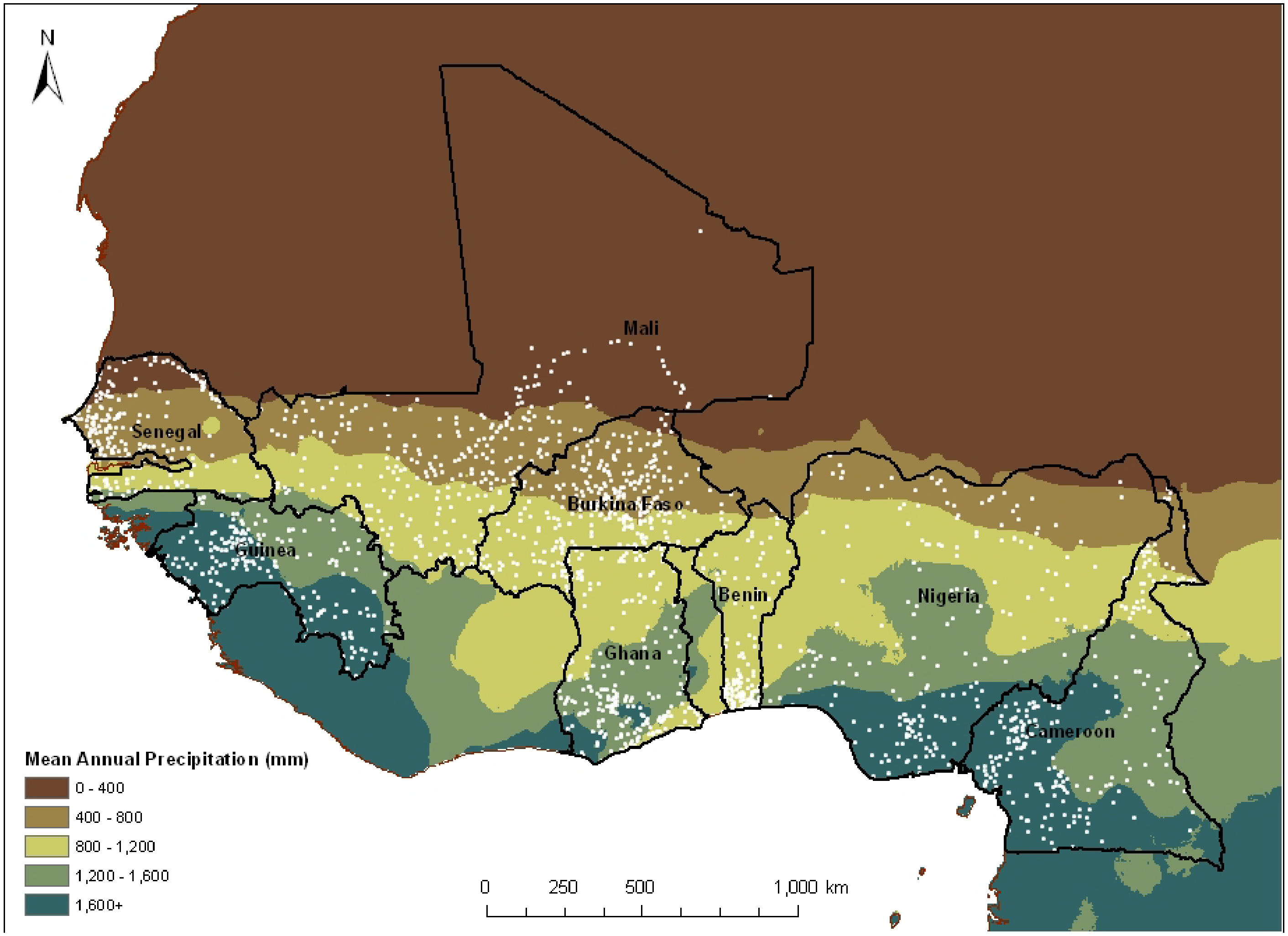

Figure 1: Mean annual precipitation, West Africa 1950-2000. White dots represent rural DHS sampling clusters.

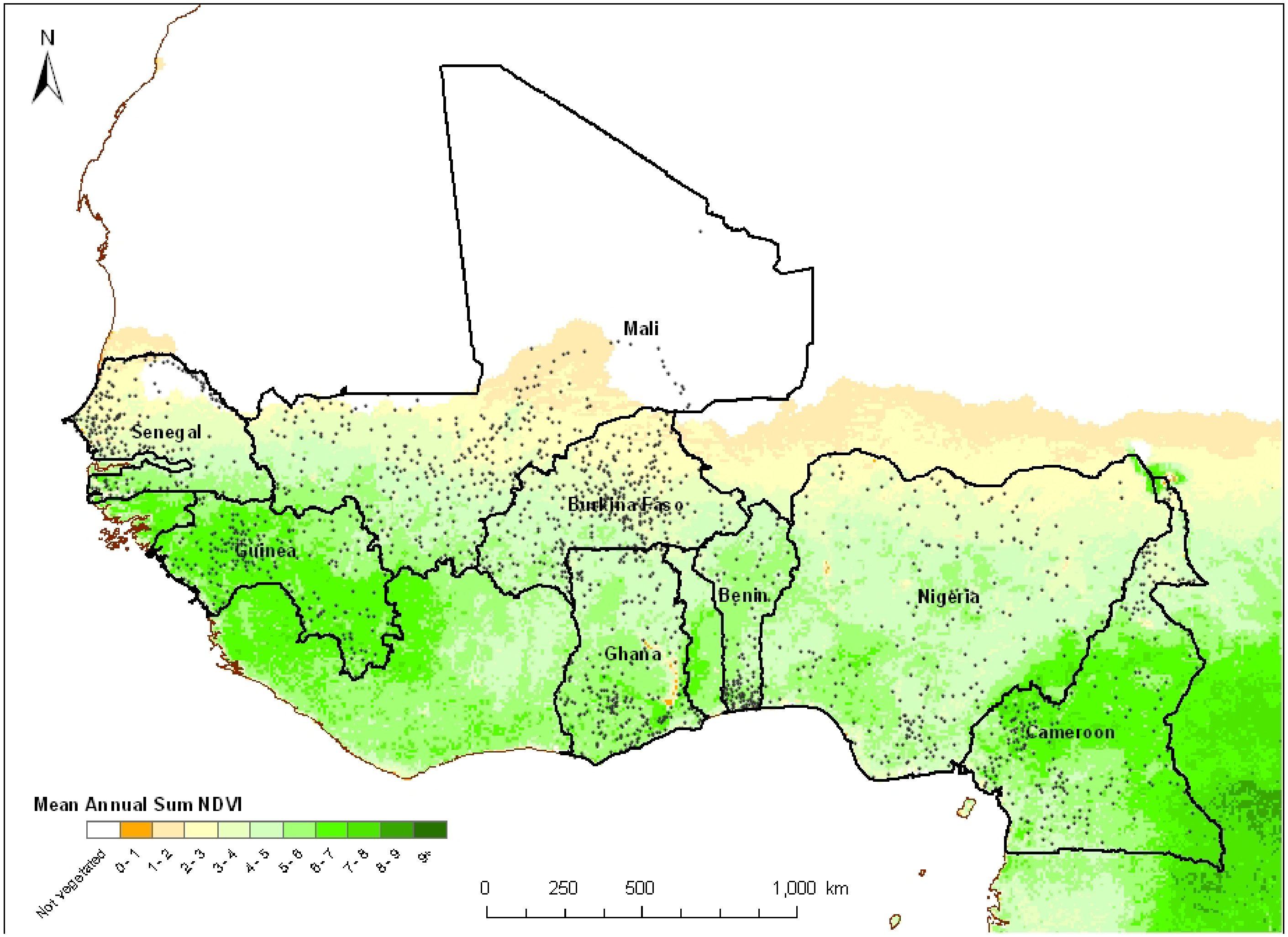

Figure 2: Mean annual sum NDVI, West Africa 1981-2003. Grey dots represent rural DHS sampling clusters.

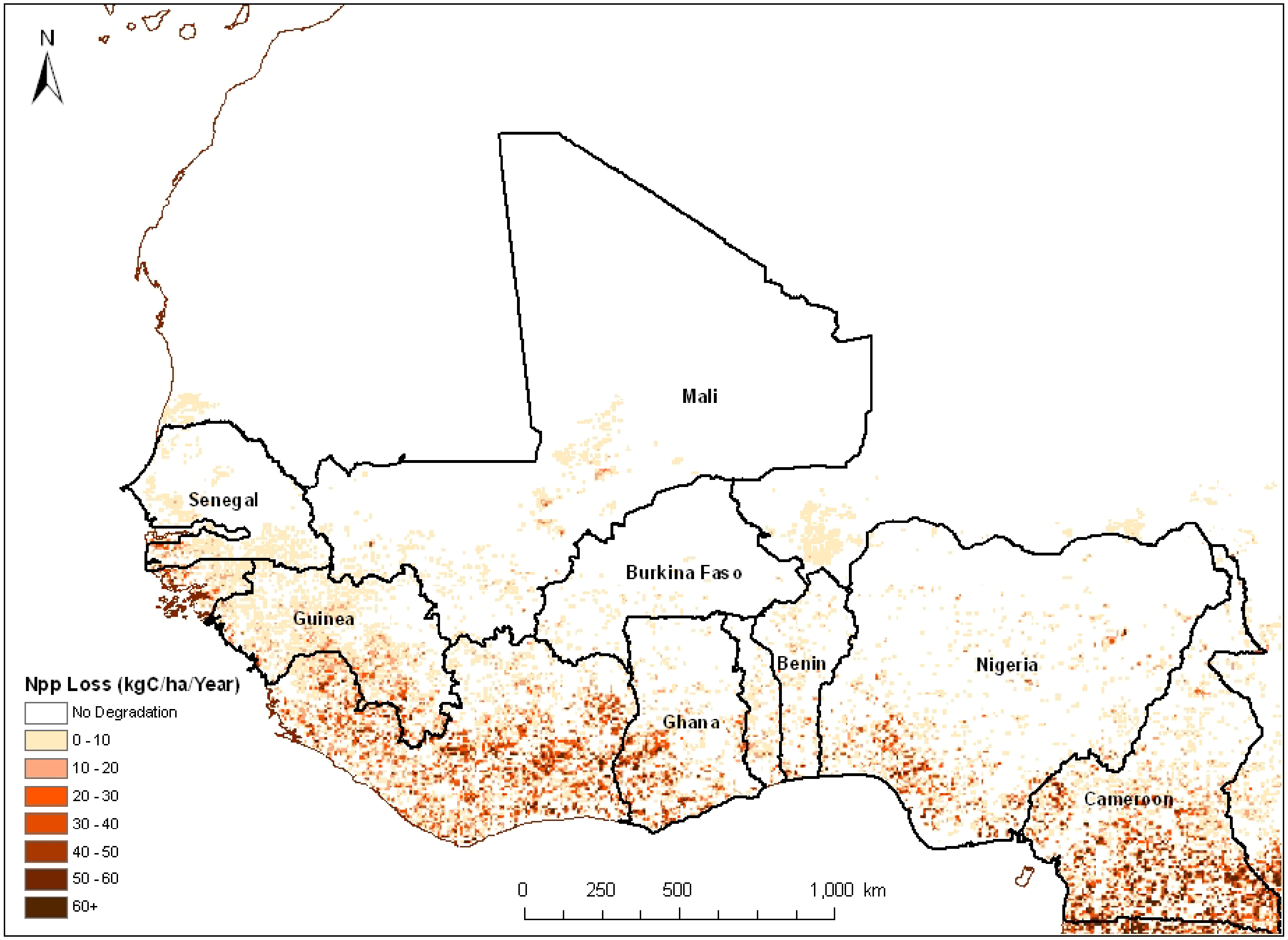

Figure 3: Mean annual NPP loss in degraded land, West Africa 1981-2003.

Since individual-level observations were pooled from eight separate surveys representing eight countries, sampling weights were adjusted proportionally to the country populations in 2005 (see table 2) while considering the differences in sample sizes (so that each sampled woman would represent a proportional number of women in her country). These weights were then multiplied by the original DHS individual sampling weights. The final weights were then normalized to have a mean of 1.

Table 2: Country populations in 2005, used for re-weighting

Country	Population Size	% of total pop.
Benin	7,867,626	3.35
Burkina Faso	13,747,182	5.86
Cameroon	17,823,352	7.60
Ghana	21,915,168	9.34
Guinea	9,220,768	3.93
Mali	11,832,846	5.04
Nigeria	140,878,575	60.06
Senegal	11,281,296	4.81
Total	234,566,813	100

Source: UN Data (data.un.org)

Environmental measures

The three main explanatory variables are: long term environmental resources measured by mean annual sum NDVI (theoretical range: 0-12); predictability of environmental resources measured by long term percentage change in annual NDVI coefficient of variation (CoV); and land degradation, measured by mean annual NPP loss (in kgC/ha/year). All measures are based on data released by GLADA[1], which itself is based on the GIMMS[2] NDVI time series covering 1981-2003.

Mean annual sum NDVI represents the long term annual level of "greenness" of a region. In other words, it captures the general characteristic of the ecosystem: values close to 0 are typical of extreme desert conditions while values approaching 8 and above are typical of tropical rainforests. Since different ecosystems are translated into potentially very different living conditions, these may affect fertility patterns. For example, water and fuel-wood are expected to be scarce in desert-like regions, yet local populations are expected to be resilient and accustomed to these long lasting conditions.

NDVI coefficient of variation is a measure of the annual variation in vegetation cover around the mean (regardless of the source of variation – whether natural or anthropogenic). The long term *percentage change* in annual CoV, however, measures the changing degree of dispersion about the mean. In other words, a negative change over time signifies a narrowing dispersion around the mean and a positive one signifies increasing dispersion – thus providing a measure of predictability (or unreliability) of environmental resources through the study period.

NPP loss, as a proxy for land degradation, is the most complex measure of the three. It is important to understand how this dataset was constructed in order to interpret

[1] Global Land Degradation Assessment in Drylands.

[2] The assessment is based on the GIMMS group 23-year bi-monthly maximum value NDVI composites (available at http://www.LandCover.org), a dataset designed to minimize cloud contamination, varying solar zenith angles and surface topography, and includes stratospheric aerosol corrections following the Mt. Pinatubo eruption in 1991 (documented in Anyamba & Tucker, 2005).

what it actually measures. The assumption underlying this estimate is that in areas where net primary productivity is reliant on precipitation, a declining trend in rain-use efficiency indicates land degradation. NDVI was integrated over each full-year period and translated to NPP using MODIS data (based on the years when data from the two sources overlap); urban areas and areas where declining productivity was attributed to reduction in rainfall were masked; for the remaining areas where RUE declined or where NDVI was negatively correlated with rainfall (i.e. areas believed to be irrigated) a trend was calculated for NDVI. Ultimately, a negative trend indicates land degradation *not* associated with rainfall decline. In the areas identified as degraded, NPP loss was estimated in kg carbon per hectare per year (further details are available in Bai et al., 2008). The main limitation of this dataset is the coarse resolution (approximately 8 km), making it difficult to ascertain smaller scale degradation effects surrounding DHS clusters.

While the first measure (mean annual sum NDVI) is a simple temporal aggregation of vegetation cover, the latter two (NDVI CoV and NPP loss) are derived from linear-trend models and as such should be considered with caution. Nonetheless, these measures combined offer a fairly novel and independent assessment of environmental resources and degradation compared to previous demographic literature.

Analysis

Multivariate linear and logistic models[3] were fitted to test the effects of long term environmental resources, reliability of resources over time, and land degradation on individual fertility and marital choices among rural women. Four dependent variables were examined: age at first marriage, age at first birth, and probability of giving birth at least once in the 12 and 60 months preceding the survey. Since degradation is measured as a cumulative process over 23 years but individuals were sampled *following* the period of degradation, women aged 27 and above were excluded from the analysis of age at first marriage and first birth (as they were likely to have married prior to experiencing significant degradation). Furthermore, as we are interested in the effects of *exposure* to environmental conditions on individual choices, analyses of these two outcome variables included only women who resided in the place in which they were surveyed at least one year prior to marriage or first birth (the majority of which have been born there themselves). The logistic models for probability of giving birth included all permanently residing women, aged 15-49, who were married at some point in their lives.

Control variables were grouped into 3 categories (or levels) and included interchangeably in the models: individual characteristics, household characteristics, and geographic characteristics at the cluster level. Individual characteristics included age (and age-squared when the full range of ages was included), years of education, and parity. Household level variables included a cumulative index of assets (electricity, radio,

[3] All models were analyzed adjusting for sampling design.

television, refrigerator and phone), the type of floor, water source, and type of toilet. Spatial and geographical variables included population density, mean annual precipitation[4], and proximity to coastline which was previously suggested as a proxy for economic development (Balk et al., 2004). See tables 3 and 4 for descriptive statistics and a correlation matrix of key variables.

All models, even when not shown in the tables, included dummy variables for countries (with Benin as the reference) to allow the intercepts to vary freely. Conceptually, these were included for two reasons: the means of outcome variables are expected to vary between countries; secondly, to accommodate the fact that surveys were not conducted at the exact same time for all countries. The models were then iterated using geographical and environmental data aggregated over 8, 16 and 24 km radii around the sampling cluster in order to examine scale effects (for the sake of parsimony only select results are shown in the next section). Finally, an aggregate level bivariate association between land degradation and total fertility rate was plotted for comparison.

[4] Precipitation was practically identical at all scales of aggregation (8, 16 and 24 km radii). This is partly due to the fact that the data was originally interpolated from an array of measurement stations (as well as aggregated temporally over 50 years), which has the effect of smoothing the data spatially. Conceptually, however, precipitation is unlikely to vary significantly at these geographic scales in any case.

Table 3: Descriptive statistics for rural women (aged 15–49), by country

Variable	Type	Benin	Burkina Faso	Cameroon	Ghana	Guinea	Mali	Nigeria	Senegal	All
Fertility outcomes										
Age at first marriage	Mean	17.71	17.16	16.53	18.39	15.97	16.24	16.02	16.8	16.41
Age at first birth	Mean	18.74	18.83	17.85	19.5	18.39	18.15	18	18.82	18.26
Gave birth in last 12 months	%	22.45	22.29	20.43	18.44	22.03	27.34	22.06	21.35	22
Gave birth in last 60 months	%	63.77	65.3	59.53	58.13	61.22	69.77	55.69	56.54	58.11
Individual controls										
Age	Mean	28.84	29.21	28.32	29.88	30.44	29.57	27.97	27.89	28.45
Education (in years)	Mean	0.99	0.45	3.53	4.32	0.58	0.45	3.84	0.96	3.08
Household controls										
Cumulative assets (0-5)	Mean	0.91	0.7	0.81	1.14	0.7	0.8	1.36	1.56	1.2
Floor type										
Natural	%	51.69	71.7	76.97	19.54	72.13	93.68	45.44	50.28	51.29
Finished	%	48.04	28.28	22.49	80.46	27.86	6.16	54.43	49.55	48.57
Other	%	0.27	0.02	0.54	0	0.01	0.16	0.13	0.17	0.14
Water source										
Piped water	%	30.81	4.04	11.94	10.86	3.37	18.01	8.46	44.37	10.9
Well	%	46.46	79.31	47.82	56.95	58.03	74.85	56.14	53.61	58.2
Surface water	%	14.93	16.35	39.71	31.29	38.57	6.9	29.36	1.72	26.71
Other	%	7.8	0.3	0.53	0.9	0.03	0.24	6.04	0.3	4.19
Toilet type										
Flush	%	0.36	0.5	0.83	2.11	0.62	3.4	6.82	16.61	5.4
Pit	%	15.75	16.5	85.88	62.96	60.74	69.03	61.59	49.94	58.15
None	%	83.1	82.88	12.8	34.92	38.63	27.39	31.46	33.21	36.3
Other	%	0.79	0.12	0.49	0.01	0.01	0.18	0.13	0.24	0.15

(Table 3 continued)

Spatial/geographic controls										
Population density (8 km)	Mean	249.98	65.1	82.11	157.67	47.38	40.07	400.81	115.67	289.52
Population density (16 km)	Mean	213.36	64.87	83.05	167.27	45.27	38.99	329.29	113.16	243.99
Population density (24 km)	Mean	206.92	62.88	80.11	164.03	44.26	39.43	298.55	103.21	223.43
Distance to coastline, km	Mean	196.43	780.67	487.7	223.92	227.25	822.1	475.33	101.97	465.23
Mean annual precipitation, mm	Mean	1100.45	761.72	1526.9	1278.39	2054.64	749.72	1368.96	607.43	1283.47
Environmental determinants (8 km radius)										
Mean annual sum NDVI (0-12)	Mean	4.91	3.58	5.18	5.19	6.06	3.57	3.95	2.94	4.14
% annual change in CoV NDVI	Mean	-0.79	0.34	-0.47	-0.91	-0.74	-0.08	-0.56	0.24	-0.48
NPP loss in degraded land, kgC/ha/year	Mean	1.91	0.11	4.21	6.56	3.5	0.45	1.67	0.97	2.06
Environmental determinants (16 km radius)										
Mean annual sum NDVI (0-12)	Mean	4.98	3.59	5.17	5.18	6.13	3.58	4	3	4.18
% annual change in CoV NDVI	Mean	-0.83	0.36	-0.51	-0.93	-0.73	-0.08	-0.55	0.19	-0.47
NPP loss in degraded land, kgC/ha/year	Mean	2.31	0.13	4.39	5.9	3.96	0.44	1.54	0.89	1.97
Environmental determinants (24 km radius)										
Mean annual sum NDVI (0-12)	Mean	5	3.6	5.18	5.18	6.12	3.6	4.03	3.03	4.21
% annual change in CoV NDVI	Mean	-0.83	0.35	-0.51	-0.93	-0.72	-0.09	-0.57	0.22	-0.49
NPP loss in degraded land, kgC/ha/year	Mean	2.29	0.13	4.44	5.8	3.95	0.4	1.52	0.9	1.94
Year of survey		2001	2003	2004	2003	2005	2001	2003	2005	2001-05
Number of clusters		129	310	222	238	195	273	196	218	1,781
Maximum sample size		3,735	9,308	5,020	3,267	5,465	9,189	4,457	8,071	48,512

Table 4: Correlation matrix of key variables for rural women (aged 15–49)

Variable		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Age at first marriage	**1**	1.00																				
Age at first birth	**2**	0.64	1.00																			
Gave birth last 12 months	**3**	0.03	0.02	1.00																		
Gave birth last 60 months	**4**	0.01	0.01	0.35	1.00																	
Age	**5**	0.12	0.18	-0.32	-0.54	1.00																
Education, years	**6**	0.30	0.18	0.02	0.02	-0.06	1.00															
Cumulative assets	**7**	0.14	0.09	0.02	-0.01	-0.02	0.40	1.00														
Distance to coastline	**8**	-0.31	-0.16	0.06	0.09	-0.12	-0.41	-0.21	1.00													
Population density (8 km)	**9**	0.09	0.06	-0.01	-0.03	0.02	0.21	0.26	-0.14	1.00												
Population density (16 km)	**10**	0.13	0.10	0.00	-0.03	0.03	0.25	0.27	-0.19	0.87	1.00											
Population density (24 km)	**11**	0.16	0.12	0.00	-0.04	0.05	0.28	0.27	-0.26	0.69	0.94	1.00										
Mean annual precipitation, mm	**12**	0.23	0.10	-0.06	-0.09	0.10	0.44	0.18	-0.74	0.12	0.15	0.22	1.00									
Mean annual sum NDVI (8 km)	**13**	0.17	0.09	-0.04	-0.04	0.09	0.17	-0.01	-0.48	-0.07	-0.06	-0.06	0.38	1.00								
Mean annual sum NDVI (16 km)	**14**	0.19	0.09	-0.05	-0.05	0.10	0.20	0.00	-0.55	-0.04	-0.04	-0.04	0.47	0.95	1.00							
Mean annual sum NDVI (24 km)	**15**	0.20	0.10	-0.05	-0.06	0.10	0.21	0.01	-0.57	-0.01	0.00	0.01	0.48	0.94	0.98	1.00						
% annual change in CoV NDVI (8 km)	**16**	-0.11	-0.04	0.03	0.05	-0.07	-0.21	-0.06	0.40	0.01	0.02	0.00	-0.36	-0.45	-0.48	-0.49	1.00					
% annual change in CoV NDVI (16 km)	**17**	-0.12	-0.05	0.02	0.04	-0.07	-0.22	-0.07	0.43	-0.02	-0.03	-0.05	-0.37	-0.51	-0.53	-0.54	0.90	1.00				
% annual change in CoV NDVI (24 km)	**18**	-0.13	-0.05	0.03	0.04	-0.07	-0.24	-0.08	0.46	-0.05	-0.06	-0.08	-0.41	-0.51	-0.55	-0.56	0.88	0.97	1.00			
NPP loss in degraded land (8 km)	**19**	0.15	0.09	-0.01	-0.04	0.06	0.22	0.06	-0.35	-0.02	0.02	0.04	0.36	0.29	0.28	0.25	-0.07	-0.12	-0.14	1.00		
NPP loss in degraded land (16 km)	**20**	0.18	0.10	-0.03	-0.05	0.07	0.26	0.05	-0.45	0.00	0.02	0.04	0.43	0.36	0.38	0.37	-0.14	-0.17	-0.21	0.85	1.00	
NPP loss in degraded land (24 km)	**21**	0.19	0.10	-0.04	-0.06	0.08	0.28	0.06	-0.49	0.04	0.05	0.08	0.45	0.37	0.41	0.41	-0.19	-0.20	-0.24	0.72	0.93	1.00

Chapter 5: Results

In most previous literature evidence of demographic responses to environmental conditions typically relies on aggregate units of analysis. For that reason it is best to start with a simple bivariate association between the main explanatory variable – land degradation measured by NPP loss – and an aggregate measure of fertility – total fertility rate (TFR) – measured at the regional level[5]. Since countries are expected to differ by their mean TFR and relative level of degradation for various reasons, these variables were standardized at the country level to produce figure 4. There is a clear negative association between the two variables as hypothesized by the multi-phasic response model: regions with higher level of degradation tend to have lower fertility rates (R = -0.351; in the unstandardized form R = -0.505). However, these tentative results are potentially confounded by various intervening mechanisms at several geographic (and temporal) scales, making causal inference through aggregate data highly problematic. It is not at all clear that lower fertility in degraded regions is directly driven by individual fertility choices as a response to land degradation (or long term resource unreliability). In order to avoid the ecological fallacy, individual level models of fertility choices are tested, including potential confounders operating at 3 scales: individual characteristics, household characteristics, and general geographic characteristics of the place of residence.

[5] Regional TFR scores were taken from the DHS final reports corresponding to the 8 surveys used in this study. These scores were based on births in the 3 years preceding each survey.

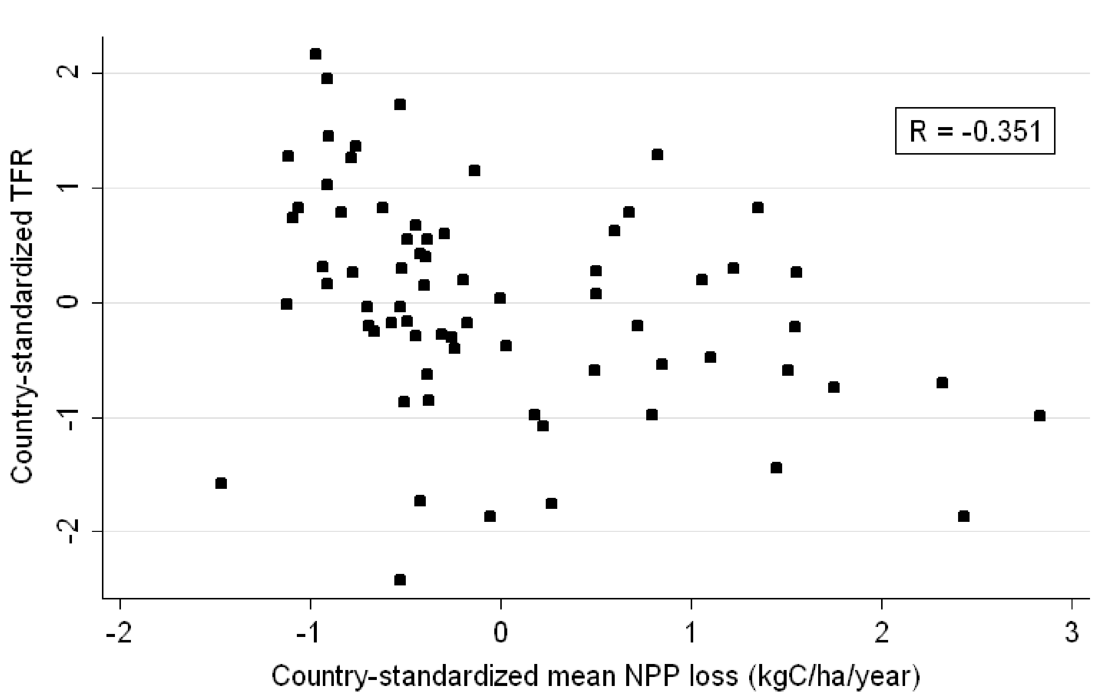

Figure 4: Regional TFR by land degradation. Administrative regions (N=70) from eight countries (excluding four capital or major cities in Burkina Faso, Cameroon and Mali). TFR and degradation standardized within each country.

The first set of linear models look into age at first marriage and first birth, controlling for potential confounders, with environmental and geographic determinants at varying scales around the cluster (since dummy variables for countries were included in all models, even when not shown, the baseline country effects for these two outcome variables are shown in table 5). Table 6 describes the effect of long term environmental resources (i.e. mean annual vegetation cover, a major ecosystem characteristic), within a 16 km radius, on age at first marriage for women aged 15-26 (inclusive). Model 1 in table 6 reflects the bivariate association (controlling for country), showing that environmental conditions have a substantial and significant positive association with age at first marriage. Model 2 shows that this association diminishes almost by half when controlling for individual characteristics (age, education), but remains unchanged in model 3, when including household characteristics: assets, floor type, water source and toilet type. Some of these household characteristics, however, reflect also on the general level of development in the place of residence (as they *may* depend on general infrastructure such as electricity, piped water etc.). Finally, model 4 introduces two geographic characteristics: distance to coastline and population density. In the study region vegetation tends to increase when moving away from the Sahara and approaching the coastline, and so does population density. These are believed to be proxies for economic development (indeed most capitals and large cities in these countries are located close the coastline) and seem to decrease the effect of vegetation cover on age at first marriage even further, though it remains highly statistically significant. Interestingly enough, the effect of population density is not statistically significant and nor is its interaction with mean annual NDVI (not shown in the table).

This sequence of additive models was repeated, with the same groupings of control variables, for the three main environmental determinants – mean annual sum NDVI, annual % change in NDVI CoV, and NPP loss – and for the 3 spatial scales (8, 16 and 24 km radii). Results for these key variables are summarized in table 7 (full models are not shown to save space). The effect of long term vegetation cover seems to show the same pattern, as seen in table 6, across all scales. It is also evident that the effect becomes stronger with scale, though this is not readily interpretable and may be an artifact of measurement error due to coarse data resolution (with 8 km being more prone for measurement error).

The effect of percentage change in NDVI CoV, a measure of environmental reliability, appears to have a negative effect on age at first marriage at all geographic scales (again, the effect slightly increases with scale). The interpretation of this finding is counter-intuitive – as the annual dispersion of vegetation around the mean increases, age at first marriage tends to be lower. In other words, counter to our predictions, women (embedded in communities) exposed to increasing unreliability of environmental conditions are likely to marry early rather than defer marriage. However, this negative effect is reduced by some 60-70% when controlling for individual and geographic characteristics (the inclusion of household characteristics has little impact on this effect).

At first glance, the degree of land degradation, measured by loss in net primary productivity, appears to have a positive effect on age at first marriage at all scales. This finding is consistent with the multi-phasic response hypothesis as well as the regional level finding apparent in figure 4. This association almost doubles when moving from 8 to 24 km radius, but quickly decreases when controlling for age, education, distance to coastline and population density – to the extent that it is no longer statistically significant. Simply put, although the association between land degradation and age of marriage shows the expected negative association, it is largely spurious or mediated by the level of development expressed in both individual and geographic characteristics. One possible interpretation of this is that areas experiencing development may exhaust their natural resources to the extent of degradation, but the resulting demographic change occurs through development and not due to environmental stress.

Table 5: OLS regression models for age at first marriage/birth by country

Variable	Age at first marriage		Age at first birth	
Benin	-		-	
Burkina Faso	-0.268 (-1.71)	†	0.159 (2.25)	*
Cameroon	-1.128 (-6.32)	***	0.116 (1.24)	
Ghana	0.574 (3.07)	**	0.614 (5.70)	***
Guinea	-1.479 (-9.56)	***	-0.038 (-0.39)	
Mali	-1.293 (-8.36)	***	0.283 (3.61)	***
Nigeria	-1.613 (-8.19)	***	0.394 (4.31)	***
Senegal	-0.762 (-4.64)	***	0.340 (3.98)	***
Age at first marriage			0.738 (39.09)	***
Constant	17.077 (130.93)	***	5.593 (17.25)	***
R^2	0.051		0.579	
N	8,656		9,170	

* Significant at 0.05 level
** Significant at 0.01 level
*** Significant at 0.001 level
† Significant at one-tailed 0.05 level
t-values in parentheses

Table 6: OLS regression model for age at first marriage, 16 km radius

Variable	Model 1	Model 2	Model 3	Model 4
Mean annual sum NDVI (0-12), 16 km radius	0.582 (5.48) ***	0.327 (4.39) ***	0.333 (4.78) ***	0.221 (3.53) ***
Individual controls				
Age		0.185 (10.60) ***	0.176 (9.84) ***	0.172 (9.74) ***
Education (in years)		0.225 (9.18) ***	0.177 (7.65) ***	0.147 (5.75) ***
Household controls				
Cumulative assets (0-5)			0.011 (0.10)	0.002 (0.02)
Floor type				
Natural			-	-
Finished			0.302 (1.79) †	0.252 (1.49)
Other			0.394 (0.18)	0.389 (0.18)
Water source				
Piped water			-	-
Well			-0.108 (-0.52)	-0.061 (-0.29)
Surface water			0.074 (0.28)	0.077 (0.28)
Other			0.567 (1.14)	0.594 (1.31)
Toilet type				
Flush			-	-
Pit			-2.565 (-4.73) ***	-2.333 (-3.95) ***
None			-2.195 (-3.90) ***	-2.039 (-3.41) **
Other			-2.775 (-2.71) **	-2.599 (-2.49) *
Spatial/geographic controls				
Distance to coastline, 100 km				-0.113 (-2.95) **
Logged population density (16 km radius)				0.069 (0.89)
Constant	14.186 (26.14) ***	11.244 (19.56) ***	13.537 (14.10) ***	14.021 (12.27) ***
R^2	0.091	0.225	0.247	0.254
N	8,584	8,582	8,468	8,468

* Significant at 0.05 level   ** Significant at 0.01 level   *** Significant at 0.001 level   † Significant at one-tailed 0.05 level

t-values in parentheses

Includes women aged 15-26, living in current residence at least 1 year prior to marriage.
All models include dummy variables for countries, though not shown.

Table 7: OLS regression models for age at first marriage, all models and geographic scales

	Mean annual sum NDVI (0-12)			% annual change in NDVI CoV			NPP loss in degraded land, kgC/ha/year		
	sig	R^2	N	sig	R^2	N	sig	R^2	N
8 km radius									
Model 1 - bivariate	0.493 (4.37) ***	0.085	8,577	-0.475 (-5.04) ***	0.070	8,577	0.362 (3.66) ***	0.067	8,584
Model 2 - individual controls	0.288 (4.02) ***	0.224	8,575	-0.289 (-3.52) ***	0.220	8,575	0.124 (2.30) *	0.215	8,582
Model 3 - household controls	0.302 (4.53) ***	0.247	8,461	-0.261 (-3.24) ***	0.241	8,461	0.104 (2.30) *	0.237	8,468
Model 4 - spatial/geographic controls	0.204 (3.68) ***	0.254	8,449	-0.140 (-1.76) †	0.251	8,449	0.002 (0.06)	0.250	8,456
16 km radius									
Model 1 - bivariate	0.582 (5.48) ***	0.091	8,584	-0.597 (-6.43) ***	0.076	8,584	0.545 (5.14) ***	0.081	8,584
Model 2 - individual controls	0.327 (4.39) ***	0.225	8,582	-0.389 (-4.96) ***	0.224	8,582	0.216 (3.31) **	0.212	8,582
Model 3 - household controls	0.333 (4.78) ***	0.247	8,468	-0.371 (-4.94) ***	0.245	8,468	0.191 (2.93) **	0.239	8,468
Model 4 - spatial/geographic controls	0.221 (3.53) ***	0.254	8,468	-0.244 (-3.21) **	0.253	8,468	0.034 (0.56)	0.250	8,468
24 km radius									
Model 1 - bivariate	0.637 (6.54) ***	0.095	8,584	-0.676 (-6.89) ***	0.080	8,584	0.652 (5.81) ***	0.090	8,584
Model 2 - individual controls	0.373 (5.15) ***	0.228	8,582	-0.429 (-5.44) ***	0.225	8,582	0.266 (3.71) ***	0.219	8,582
Model 3 - household controls	0.383 (5.70) ***	0.250	8,468	-0.399 (-4.86) ***	0.246	8,468	0.225 (2.66) **	0.240	8,468
Model 4 - spatial/geographic controls	0.277 (4.26) ***	0.255	8,468	-0.261 (-3.23) **	0.243	8,468	0.047 (0.63)	0.250	8,468

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level † Significant at one-tailed 0.05 level

t-values in parentheses

Includes women aged 15-26, living in current residence at least 1 year prior to marriage.
All models include dummy variables for countries.
NPP loss transformed using square-root to reduce positive skewness.

A similar set of models was used for the outcome variable of age at first birth, with the exception of including age at first marriage as an additional regressor. This allows estimating the effects of environmental determinants on age at first birth, unaccounted by deferral of marriage (already tested in the previous set of models). Table 8 describes select results at 16 km radius. Since the effect of long term vegetation cover is already non-significant (model 1) this path is not followed. Models 2 through 5 describe the usual additive sequence of control variables with land degradation being the primary explanatory variable. The effect of land degradation, controlling for age at first marriage, is surprisingly negative, stable and statistically significant in all models except when including geographic covariates. The direction of this association does not support the multi-phasic response hypothesis and model 4 suggests that the effect of land degradation is at least partially spurious or mediated by geographic location.

The models discussed thus far do not measure fertility directly, but rather factors related to fertility schedules which in turn may affect life-long fertility outcomes. In order to address the actual decision process of having a child logistic regression models were used to estimate the probability of giving birth at least once in the 12 and 60 months preceding the surveys (tables 9 and 10 respectively). In these analyses women at all ages (15-49) were included. Only models at 24 km radius are presented as these typically had the largest effects of environmental determinants on outcome variables.

Table 9 describes 4 models of the probability of giving birth in the course of one year preceding the survey. Model 1 includes the baseline covariates without environmental determinants: dummy variables for each country (Benin as reference), age, years of education, and parity. A quadratic term for age is also included since the full range of ages is analyzed – it is expected that age increases the probability of giving birth up to a certain peak, then the probability decreases going into older ages. Model 2 and 3 add to the baseline model mean annual NDVI and % change in NDVI CoV respectively. Model 4 adds NPP loss to the baseline model as well as two additional covariates: distance to coastline and long term mean annual precipitation. These are included as control variables in the 4th model since the study region typically becomes more arid when moving north from the coastline towards the Sahara, and the ideal is to compare the effect of degradation between similar climatic regions but varying degrees of degradation. In other words, there is no degradation north of the Sahel simply because it is already a desert. In all models the effects of environmental determinants are negative, but extremely small and non-significant[6].

The same analysis is repeated with the probability of giving birth at least once in the previous 5 years as the outcome variable (table 10). The effect of mean annual NDVI becomes slightly positive while the effects of percentage change in NDVI CoV and NPP loss are still negative. Although the effects of all three environmental variables seem larger than apparent in table 9, these results are still statistically insignificant.

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[6] Pseudo-R^2 is not reported for any of the logistic models presented here since in its generalized form R^2 is calculated using the likelihood ratio statistic, which is not valid under a clustered sampling design.

Table 8: OLS regression model for age at first birth, 16 km radius

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Age at first marriage	0.743 (38.03) ***	0.748 (39.67) ***	0.709 (31.49) ***	0.706 (30.03) ***	0.711 (30.85) ***
Mean annual sum NDVI (0-12)	-0.065 (-1.01)				
NPP loss in degraded land, kgC/ha/year		-0.153 (-3.19) **	-0.145 (-3.21) **	-0.145 (-3.24) **	-0.084 (-1.39)
Individual controls					
Age			0.135 (7.56) ***	0.137 (7.54) ***	0.138 (7.60) ***
Education (in years)			-0.006 (-0.38)	-0.015 (-0.91)	-0.001 (-0.07)
Household controls					
Cumulative assets (0-5)				0.004 (0.05)	-0.002 (-0.03)
Floor type					
Natural				-	-
Finished				0.022 (0.18)	0.053 (0.43)
Other				1.050 (1.34)	1.018 (1.21)
Water source					
Piped water				-	-
Well				-0.161 (-1.21)	-0.160 (-1.20)
Surface water				-0.053 (-0.35)	0.025 (0.17)
Other				0.084 (0.33)	0.080 (0.30)
Toilet type					
Flush				-	-
Pit				-0.436 (-2.15) *	-0.436 (-2.11) *
None				-0.597 (-2.61) **	-0.570 (-2.55) *
Other				-0.862 (-1.51)	-0.807 (-1.37)
Spatial/environmental controls					
Distance to coastline, 100 km					0.064 (2.22) *
Logged population density					0.038 (0.98)
Constant	5.577 (17.27) ***	5.595 (17.37) ***	3.216 (8.35) ***	3.880 (8.62) ***	3.328 (0.98)
R^2	0.580	0.582	0.603	0.603	0.605
N	9,096	9,096	9,094	8,981	8,981

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level † Significant at one-tailed 0.05 level

t-values in parentheses

Includes women aged 15-26, living in current residence at least 2 years prior to first birth.

All models include dummy variables countries, though not shown.

NPP loss transformed using square-root to reduce positive skewness.

Table 9: Logistic regression model for probability of giving birth in previous 12 months (women ever married, aged 15‑49), 24 km

Variable	Model 1	Model 2	Model 3	Model 4
Country				
Benin	-	-	-	-
Burkina Faso	1.020 (0.35)	1.018 (0.24)	1.028 (0.30)	0.929 (-0.67)
Cameroon	0.878 (-1.88) †	0.878 (-1.88) †	0.880 (-1.76) †	0.843 (-1.33)
Ghana	0.907 (-1.25)	0.907 (-1.24)	0.908 (-1.24)	0.888 (-1.35)
Guinea	1.014 (0.23)	1.013 (0.18)	1.012 (0.21)	1.066 (0.51)
Mali	1.22 (3.62) ***	1.219 (2.63) **	1.227 (2.94) **	1.107 (0.87)
Nigeria	1.096 (1.32)	1.095 (1.21)	1.100 (1.36)	1.033 (0.30)
Senegal	1.011 (0.20)	1.002 (0.03)	1.011 (0.14)	0.991 (-0.09)
Individual controls				
Age	1.309 (9.37) ***	1.309 (9.38) ***	1.309 (9.35) ***	1.313 (9.51) ***
Age^2	0.994 (-12.33) ***	0.994 (-12.32) ***	0.994 (-12.30) ***	0.994 (-12.34) ***
Education	0.994 (-0.50)	0.994 (-0.48)	0.994 (-0.52)	1.003 (0.26)
Number of children previously born	0.994 (-0.35)	0.994 (-0.34)	0.994 (-0.34)	0.992 (-0.44)
Geographic controls				
Distance to coastline, 100 km				1.013 (0.59)
Mean annual precipitation, 100 mm				0.994 (-0.50)
Environmental Determinants				
Mean annual sum NDVI (0-12)		0.999 (-0.03)		
% annual change in NDVI CoV			0.993 (-0.11)	
NPP loss in degraded land, kgC/ha/year				0.999 (-0.07)
Constant	0.021 (-9.07) ***	0.021 (-8.06) ***	0.021 (-8.98) ***	0.020 (-8.51) ***
N	41,321	40,948	40,948	40,948

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level † Significant at one-tailed 0.05 level
t-values in parentheses

Exponentiated coefficients.
Pseudo R^2 not reported due to sampling design (LR not valid in clustered sampling).

Table 10: Logistic regression model for probability of giving birth in previous 60 months (women ever married, aged 15–49), 24 km

Variable	Model 1	Model 2	Model 3	Model 4
Country				
Benin	-	-	-	-
Burkina Faso	1.204 (2.77) **	1.267 (2.83) **	1.272 (2.55) *	1.06 (0.43)
Cameroon	0.782 (-3.40) **	0.780 (-3.43) **	0.795 (-3.17) **	0.732 (-2.44) *
Ghana	1.054 (0.59)	1.054 (0.58)	1.053 (0.58)	1.059 (0.60)
Guinea	0.854 (-2.41) *	0.816 (-2.64) **	0.855 (-2.34) *	0.83 (-1.51)
Mali	1.064 (0.93)	1.119 (1.35)	1.100 (1.24)	0.934 (-0.47)
Nigeria	0.799 (-2.98) **	0.832 (-2.09) *	0.812 (-2.62) **	0.724 (-2.47) *
Senegal	0.791 (-3.62) ***	0.838 (-1.87) †	0.819 (-2.35) *	0.800 (-2.36) *
Individual controls				
Age	1.805 (19.59) ***	1.803 (19.55) ***	1.803 (19.55) ***	1.807 (19.60) ***
Age^2	0.989 (-24.24) ***	0.989 (-24.15) ***	0.989 (-24.18) ***	0.989 (-24.18) ***
Education	0.986 (-1.09)	0.984 (-1.26)	0.985 (-1.24)	0.994 (-0.51)
Number of children previously born	1.210 (8.78) ***	1.210 (8.75) ***	1.209 (8.78) ***	1.209 (8.63) ***
Geographic controls				
Distance to coastline, 100 km				1.020 (0.79)
Mean annual precipitation, 100 mm				1.004 (0.36)
Environmental Determinants				
Mean annual sum NDVI (0-12)		1.037 (1.04)		
% annual change in NDVI CoV			0.955 (-0.87)	
NPP loss in degraded land, kgC/ha/year				0.988 (-1.40)
Constant	0.002 (-13.27) ***	0.002 (-12.17) ***	0.002 (-13.17) ***	0.002 (-12.73) ***
N	41,321	40,948	40,948	40,948

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level † Significant at one-tailed 0.05 level

t-values in parentheses

Exponentiated coefficients.

Pseudo R^2 not reported due to sampling design (LR not valid in clustered sampling).

Chapter 6: Discussion

Environmental stress, whether in the form of long term ecosystem characteristics or in the form of a dynamic degradation processes, is hypothesized to induce economic and demographic adaptations and responses. These pressures are expected to be more pronounced and localized in developing countries than in developed ones, as the former typically suffer from limited material, political and social infrastructure needed for allocation and distribution of scarce resources. While individuals and communities are expected to be adapted and resilient to long term environmental conditions (Olsson, 1993), they may be largely affected by (relatively) irreversible negative changes to their immediate environments. Classic demographic theory anticipates that environmental pressures, expressed as resource scarcity (crops, fuel-wood, etc.), will decrease the carrying capacity of the land for human population. Once the carrying capacity is lower equilibrium may be achieved either by fertility reduction or increased mortality. More nuanced theories suggest that adaptation to environmental stress is not limited to fertility and mortality responses, but may include economic adaptations as well as voluntary and forced migration. Furthermore, fertility reduction itself may be achieved in several ways: change in exposure to marriage (e.g. postponement), contraceptive use, change in frequency of sexual intercourse (due to labor migration), or a combination of these factors and others. On the other hand, micro-economic theory suggests the existence of contradicting incentives for decreasing or increasing fertility under scarcity of environmental resources. These are further bounded by social norms and contexts related to gender equality, division of labor, land tenure practices and more.

This study in particular has focused on fertility responses to environmental conditions: (a) long term mean vegetation as an ecosystem characteristic; and (b) dynamic processes over a 23-years period. Dynamic processes have included the change in resource reliability measured by change in annual dispersion of vegetation around the annual mean (either naturally or anthropogenically induced), and land degradation believed to be largely anthropogenic (or some combination of natural and anthropogenic factors). Several aspects of fertility-related decisions are examined at the individual level: deferral of marriage or first birth, and likelihood of giving additional births under varying degrees of environmental pressures. The research method presented here is innovative within the related subset of demographic literature in two ways: (1) using external measures of environmental resources and land degradation based on remotely sensed data; (2) focusing on individual level data rather than on aggregate units of analysis in order to avoid ecological fallacy.

Findings consistently show that the effects of all three environmental determinants (long term vegetation, reliability over time, land degradation) on outcome variables are significantly diminished when accounting for individual and geographic characteristics, but not as much for household characteristics. While this method of "adding control variables until the main effects become statistically insignificant" is not in the least statistically conservative, it does reflect on the existence of confounding or intervening factors. This is in contrast to the relatively large negative association between total fertility rate and land degradation found in aggregate units of analysis such as regions. Simply put, demographic transitions occur through individual responses – and these are the units of analysis we should focus on, especially when modeling historically unique dynamic processes.

Looking at long term vegetation cover we see that the effect on outcome variables is not consistent. With regard to deferral of marriage it is positive and significant, but not so with regard to other outcome variables. This positive association does not necessarily reflect a causal relationship between environmental resources and age at first marriage (i.e. that women tend to postpone marriage when vegetation is abundant). It is more likely to be a result of historical events related to the spatial distribution of different populations whose characteristics were omitted from the models. Religious, ethnic and cultural characteristics, as well as colonial histories, are likely to influence many of the outcome and explanatory variables addressed here. These factors are not easily incorporated into a cross-national analysis.

The effect of decreasing environmental predictability is less consistent across outcome variables and is generally statistically insignificant. Interestingly enough, it tends to be negatively associated with outcome variables, suggesting that increasing environmental uncertainty may actually be associated with fertility increase rather than reduction (again, this finding is largely statistically insignificant).

Results regarding the effect of land degradation on nuptiality and fertility generally seem to lean towards the multi-phasic response model predictions (e.g. marital postponement, fertility reduction) and not towards those of micro-economic theory. However, these effects greatly diminish (to the extent of statistical non-significance) once individual characteristics – and more importantly geographic characteristics – are accounted for. Climate and proximity to coastline are highly correlated with degradation, the latter of which may have both environmental and social interrelations with degradation: it is both a predictor of climate and of economic development. Nonetheless, this suggests that at least part of the circumstantial evidence linking fertility transition to environmental pressures found in the literature may be spurious where development is leading both degradation and a demographic transition. Granted, the underlying conditions and mechanisms involved may be fundamentally different in other areas such as South-America and even in other parts of sub-Saharan Africa – among those are the extent and severity of degradation and the social context mediating economic and demographic responses.

Interestingly, scale effects are apparent throughout the analyses presented above. Generally, the larger the geographic scale within which environmental determinants are measured the larger the effect on fertility outcome. This may indicate that the geographical extent of environmental conditions is a strong factor in demographic responses – for example, where degradation is a wide spread phenomenon it becomes harder to utilize other economic and demographic responses such as extensification or migration. The theory is underdeveloped with regard to the geographic scales at which certain responses operate and others are inhibited. Alternatively, scale effects may potentially be attributed to measurement error due to the coarse spatial resolution of environmental data. Small scales include very few data points and are less centered about the sampling cluster (the coordinates of which include some component of random error by construction). Spatial aggregation over larger geographic scales utilizes more data points while at the same time smoothing their values, resulting in attenuation of extremely localized conditions[7].

Ultimately this study examines only responses related to fertility using limited measures of environmental degradation, albeit with greater detail than previously available. While it finds little evidence of change in fertility trends driven by environmental factors, other economic and demographic responses may be operating according to the multi-phasic response model – namely intensification, extensification and labor or permanent migration. As Bilsborrow (1992) postulates, these are likely to take precedence over fertility reduction. Since this paper focuses on women that have been residing within the same rural settlement for some years prior to the survey, it necessarily misses those rural women who have been recently displaced as well as those who migrated to urban areas. Both internal and international migration may play a key role here, yet migration data at the individual level is not as readily available as for fertility.

[7] Additional data limitations apply: the data used to measure degradation suffers from poor spatial resolution and is based on a temporal linear trend. These factors introduce measurement error that may cause further attenuation of coefficient estimates, underestimating the real effect of degradation on fertility.

Conclusion

Results in this paper consistently show little to no effect of environmental determinants, particularly long-term land degradation, on a set of fertility related outcomes in 8 countries in sub-Saharan West Africa. While the hypothesized negative association between fertility and land degradation is evident at the regional scale, this effect diminishes greatly when examined at smaller scales and after accounting for individual, climatic and geographic characteristics. Despite data limitations, this potential gap between individual level effects and circumstantial aggregate level results (often discussed in the literature) calls for a more nuanced theory. The complex relationship between environmental degradation and demographic transition is not necessarily straightforward and directly causal, but instead one that runs through development (which may or may not be sustainable in the long term). Questions that need to be addressed, both theoretically and empirically, are at which spatial and temporal scales environmental pressures induce certain types of demographic responses. Since individuals are also likely to utilize response paths other than fertility reduction according to the revisited multi-phasic response model (Bilsborrow & Okoth-Ogendo, 1992), aspects such as urbanization and internal and international migration should be examined as well with finer detail. Recent technological advancements such as remote sensing and GPS offer increasingly better ways to answer such questions without the pitfalls of ecological fallacy. Ultimately, if a gap in empirical findings between the micro and macro units of analysis indeed exists, the causal mechanisms in population-environment dynamics may require respecification as to the scales and modes of operation. Assumptions about the locality of environmental resources and their effects on individual behavior may need to be revisited accordingly.

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