

**Variation by Geographic Scale in the Migration-Environment Association:  
Evidence from Rural South Africa**

Lori M. Hunter<sup>1,2</sup>, Stefan Leyk<sup>1</sup>, Galen J. Maclaurin<sup>1</sup>, Raphael Nawrotzki<sup>1</sup>,  
Wayne Twine<sup>3</sup>, Mark Collinson<sup>2,4,5</sup> and Barend F.N.Erasmus<sup>6</sup>

<sup>1</sup>University of Colorado Boulder, USA

<sup>2</sup>MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt), School of Public Health, University of Witwatersrand, South Africa

<sup>3</sup>School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa

<sup>4</sup>Umeå Centre for Global Health Research, Umeå University, Umeå, Sweden

<sup>5</sup>INDEPTH Network, Ghana

<sup>6</sup>Centre for African Ecology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa

Corresponding Author: Lori M. Hunter, [lorimaehunter@comcast.net](mailto:lorimaehunter@comcast.net)

Acknowledgements: Supported by NIH R03 HD061428, “Environmental Variability, Migration, and Rural Livelihoods.” The work has also benefited from the NICHD-funded University of Colorado Population Center (grant R21 HD51146) for research, administrative, and computing support. This work was also indirectly supported by the Wellcome Trust (grant 085477/Z/08/Z) through its support of the Agincourt Health and Demographic Surveillance System. The content is solely the responsibility of the authors and does not necessarily represent the official views of the CUPC, NIH, or NICHD.

**Variation by Geographic Scale in the Migration-Environment Association:  
Evidence from Rural South Africa**

Lori M. Hunter, Stefan Leyk, Galen J. Maclaurin, Raphael Nawrotzki,  
Wayne Twine, Mark Collinson and Barend F.N.Erasmus

**Abstract:** Scholarly understanding of human migration’s environmental dimensions has greatly advanced in the past several years, motivated in large part by public and policy dialogue around “climate migrants.” The research presented here advances current demographic scholarship both through its substantive interpretations and conclusions, as well as its methodological approach. We examine temporary rural South African outmigration as related to household-level availability of proximate natural resources. Such ‘natural capital’ is central to livelihoods in the region, both for sustenance and as materials for market-bound products. The results demonstrate the association between environmental factors and outmigration is, in general, positive: households with higher levels of proximate natural capital are more likely to engage in temporary migration. Yet, this association is highly localized, varying from strongly positive in some villages to strongly negative in others. We explore the socio-demographic factors underlying this “geographic scale sensitivity”. The cross-scale methodologies applied here offer nuance unavailable within more commonly used global regression models, although also introducing complexity that complicates story-telling and inhibits generalizability.

## **Variation by Geographic Scale in the Migration-Environment Association: Evidence from Rural South Africa**

Scholarly understanding of human migration's environmental dimensions has greatly advanced in the past several years, largely in response to public and policy dialogue about "climate refugees." As Gray and Bilborrow (2012) have noted, the more public, "conventional narrative" of millions of climate-driven international migrants misses the mark; most research places environmental drivers among a host of other forces shaping migration, with environmentally induced migration tending to cover shorter distances and remaining within national borders (e.g., Henry et al. 2004; Gray and Mueller 2012a, 2012b). In this way, migration can be seen as an adaptive livelihood strategy used historically by human populations responding to environmental shifts (e.g., Bardsley and Hugo 2010; McLeman and Hunter 2010).

The research presented here on the migration-environment connection offers both new interpretations and a geographically refined and nuanced analytical approach. We examine temporary outmigration in the Agincourt Health and Demographic Surveillance site in rural South Africa, as related to household-level availability of proximate natural resources and we contrast the results across regional and village geographic scales. "Natural capital" is central to livelihoods in the region, both for sustenance and as input for market-bound products (e.g., Shackleton and Shackleton 2011). The results demonstrate that the association between environmental factors and outmigration is highly localized, varying across neighboring rural villages in relation to resource availability or constraints in nearby communal landscapes. At the scale of the entire study site – the "global" model – natural resource availability is associated with higher levels of temporary migration. Yet, the association varies substantially when

considered for specific villages – we characterize this empirically as “geographic scale sensitivity” (GSS).

The methodological framework applied here offers nuance unavailable within approaches based solely on global regression models, although the complexity introduced also complicates interpretation and inhibits generalizability.

## **THE ENVIRONMENT’S PLACE IN MIGRATION SCHOLARSHIP**

Demographers have long explored the socioeconomic dimensions of migration, but the contemporary era of climate change has brought increasing research attention to migration’s environmental aspects (e.g., Adamo and Izazola 2010). A variety of empirical case studies have recently emerged offering important theoretical and methodological advancements (e.g., Gray and Bilsborrow 2012; Gray and Mueller 2012a, b; Nawrotzki, Riosmena, and Hunter 2013). The studies typically find that environmental factors affect migration, although in different ways across settings and through interactions with economic, political, and cultural forces (e.g., Black et al. 2011).

Migration’s environmental aspects may be especially important in regions where daily livelihoods are tied to the very local environment—where gathered reeds are used for market-bound baskets and wild spinaches are collected for the evening meal (e.g., Shackleton et al. 2008). In such resource-dependent communities, however, this dependence can also vary dramatically with the household’s demographic and economic characteristics, as well as its livelihood history (Hunter, Twine, and Johnson 2011).

### **Sustainable Rural Livelihoods: A Useful Theoretical Perspective**

The “Sustainable Rural Livelihoods” framework (Scoones 1998) has proven useful to migration-environment researchers in part because it explicitly includes “natural capital” (e.g., wild foods)

along with human (e.g., education), financial (e.g., savings), physical (e.g., automobiles), and social (e.g., networks) capitals among the factors that affect household decisions about livelihoods. This holistic approach is valuable since migration research has only recently begun to regularly consider natural resource availability or environmental conditions/shocks in general.

A large body of evidence documents the centrality of natural capital to rural livelihoods across the globe. In South Africa, for example, case studies in two rural villages demonstrate that 70% of households make use of non-timber forest products, such as fuelwood, wild fruit, and edible herbs, during times of shortage and crisis (Paumgarten and Shackleton 2011). Even in rural South African villages with readily available electricity, over 90% of households use fuelwood as a primary energy source owing to the cost of electricity and appliances (Twine et al. 2003). This trend has been observed in the Limpopo region generally (Madubansi and Shackleton 2007) as well as specifically in our Agincourt study site, where natural resources buffer shocks such as a breadwinner's death (Hunter, Twine, and Patterson 2007). Accordingly, local shifts in availability of natural resources likely trigger livelihood adaptations, including either temporary or permanent migration (Bilsborrow 2002).

### **Migration and Environment: Empirical Connections**

Empirical work on the migration-environment connection has blossomed over the past several years. Several generalizable findings are emerging from case studies examining the connections in Bangladesh (Gray and Mueller 2012a), Burkina Faso (Henry, Schoumaker, and Beauchemin 2004), Ecuador (Gray et al. 2008), Ethiopia (Gray and Mueller 2012b), Mexico (Nawrotzki, Riosmena, and Hunter 2013), Nepal (Massey, Axinn, and Ghimire 2010), Brazil (VanWey et al. 2007), Madagascar (Nawrotzki, Hunter, and Dickinson 2012), and Thailand (VanWey 2003), to name a few.

These quantitative studies have used a wide variety of environmental measures including rainfall patterns (Nawrotzki, Riosmena and Hunter 2013), vegetation coverage (Nawrotzki, Hunter and Dickinson 2012), land-use change (VanWey et al. 2007), and indicators of environmental extremes such as flooding (Gray and Mueller 2012a). In addition, qualitative case studies have examined the environmental dimensions of migration in “hotspots” across the globe including Egypt, Mozambique, and Vietnam (Warner 2011).

In all, several key findings are emerging. First, much environmentally associated migration is internal, short-term, and often cyclical. In Burkina Faso, for example, rain-fed agriculture is a dominant livelihood strategy, although a south-north rainfall gradient, combined with poor soils, limits the long-term viability of agricultural livelihoods, particularly in the nation’s north. Residents of relatively dry regions are generally more likely to migrate, but short-term rainfall deficits and harvest failures limit households’ ability to invest in long-distance moves. Rather, short-distance, cyclical migration is a common strategy in times of environmental stress (Henry et al. 2004).

Second, longer-distance migration, often across international borders, tends to be associated with heightened resource availability, likely reflecting the expense of such migration. This finding has been demonstrated in the Burkina Faso research reviewed above, as well as in rural Ecuador, where land provides capital that can facilitate migration (Gray 2010). In Bangladesh, long-distance mobility appears constrained by disasters such as floods and crop failure (Gray and Mueller 2012a).

Third, several studies have illustrated gendered distinctions in the migration-environment association. Of course migration, as a social process, is clearly a gendered phenomenon in general (Hunter and David 2011). In rural Ecuador, for instance, age and education tend to

predict male migration streams, but female streams are more likely to be associated with changes in family structure (i.e., marriage) (Barbieri and Carr 2005). Migration streams are also shaped by gendered norms regarding participation in agriculture, which is in turn linked to environmental factors. Again in rural Ecuador, access to agricultural land facilitates international migration for men, but not women—poor agricultural productivity tends to keep women at home (Gray 2010).

Fourth, as with migration in general, a key factor shaping migration-environment linkages is the existence of migrant social networks. In Mexico, for example, short-term rainfall deficits are associated with international migration from rural villages, but only in regions with long-standing Mexico-U.S. migration networks (Hunter, Murray, and Riosmena 2012). Finally, while environmental factors play a discernible role in migration, particularly from rural regions, there are also close interactions with political, economic, and cultural forces that need to be taken into account (Black et al. 2011, and references therein).

### **Gaps in Migration-Environment Methodologies and Understanding**

Although scholarly progress has been swift in the past few years (Black et al. 2011), gaps remain in knowledge of migration-environment connections as well as in understanding the implications of methodological choices. These gaps have motivated the present work.

Substantial methodological innovation characterizes this field. Examples include recent use of Agent-Based Modeling employing sociodemographic correlates of migration to simulate streams as far forward as 2045 (Kniveton, Smith, and Black 2012). Migration-environment researchers have also been quick to integrate advancements in multilevel modeling (e.g., Nawrotzki, Hunter, and Dickinson 2012). Even so, migration-environment research has not yet fully integrated spatial modeling techniques to “put people in place” (Entwisle 2007:687). And

since norms associated with social characteristics and processes vary widely across contexts, case studies have limited potential for generalizations about effects of environmental factors on migration, or about migration-environment interactions with age, gender, and other sociodemographic predictors.

Spatially refined analytical approaches are particularly relevant because, while political and economic forces clearly shape broader migration probabilities and directions, environmental influences and forces are likely even more strongly localized, especially in areas where the population is highly dependent on proximate resources. In our South African study setting, for example, villagers rely heavily on the productivity of bordering communal landscapes for fuelwood and sustenance. In such regions regressions reflecting average associations across the entire study setting may mask localized associations (e.g., Leyk et al. 2012).

This concern can be situated more generally in the dialogue regarding global and local modeling approaches (e.g. Fotheringham 1997; Fotheringham and Brundson 1999; Leyk et al. 2012). Our models reflecting all Agincourt households combined – the “global models” – seek to identify regularities across the setting. In contrast, village-scale estimates – the “local models” – demonstrate *differences* across space (Fotheringham 1997). The difference between global and local model results illustrate the impact of geographical scale sensitivity which refers to the boundaries used to define importance of the location, size and extent of the population studied.

The methodological concern demonstrated here is distinct from, but related to, both the ecological fallacy and the modifiable areal unit problem (MAUP); this distinction is briefly explained here. The ecological fallacy is well known among human ecology scholars, arising from making conclusions regarding individual or household-level processes based on the analysis of aggregate units (Robinson 1950; Waller and Gotway 2004). The interpretive leap is



problematic due both to potential confounding effects not represented at the aggregate scale, as well as aggregation bias where model associations could shift and thus provide a very different picture of the process of interest (e.g., Greeland and Morgenstern 1989). Similar to this, the more geographic perspective on ecological fallacy – called the modifiable areal unit problem (Openshaw, 1983) – also takes into consideration that analyzing aggregate data can yield differing conclusions depending on the level of this aggregation. More specifically, the MAUP entails two sub-problems: 1) the scale effect suggests that results will differ when analyzing the same data at different aggregation levels, and 2) the zoning effect suggest that the form or shape in which spatial analysis units are aggregated will produce different results (Wong 1995).

In the migration context, recent research on the MAUP effect examines the performance of different predictive variables in models of varying aggregation. This concept – termed operational scale sensitivity (OSS) -- provides a framework for examination of how model associations change with increasing levels of aggregation (when the analytical scale departs from the operational scale which is in the case of migration the household level) (Maclaurin et al. 2013).

Within the analyses presented here, the analytical focus remains at the household-level – the accurate operational scale given that migration represents a household-level decision in the rural South African setting. Yet we alter the geographic scale and thus the spatial extent or population size at which the models are estimated (Lam and Quattrochi 1992). Differences in household-level analysis results across different population sizes raise the issue of geographic scale sensitivity (GSS), where the explanatory power of certain variables depends on the spatial extent or population size for which statistical relationship of interest is estimated. It is our hope that this methodological exercise will both add nuance to substantive understanding of migration-

environment connections and also instill caution as to generalizations regarding this complex association.

## **RESEARCH OBJECTIVES**

For our rural South African study site, we aimed to (1) identify the overall “global” association between temporary migration and proximate natural resource availability; (2) explore variation in this association across “local” models (i.e., for individual villages); and (3) identify household characteristics that differentially shape the migration-environment association at each geographic scale.

## **RESEARCH SETTING**

The study site is in the far northeast of South Africa—the Agincourt Health and Demographic Surveillance Site (Agincourt HDSS) operated by the University of Witwatersrand School of Public Health (Wits) and South Africa’s Medical Research Council (MRC) (Figure 1). Today, the 400 sq. km. area encompasses 24 villages, including approximately 84,000 residents in 14,000 households. Since 1992, the Agincourt HDSS has conducted an annual census including the collection of migration information.

*(Figure 1 about here)*

A “homeland” area for black South Africans during the era of apartheid, the study site is characterized by high population densities (~170 persons per sq. km), high poverty, and a longstanding lack of development and access to state services. Two semi-paved roads, one north-south and the other east-west, provide access to nearby mid-sized cities. The study site’s eastern border is fenced by private game reserves that themselves border world-renowned Kruger National Park famous for wildlife tourism.

The Agincourt study site's settlement pattern is fairly typical of rural communities across South Africa, and socioeconomically it is characterized by a high reliance on remittances from the large proportion of adults who are migrant laborers on commercial farms and in towns and cities across the country. A substantial portion of households also depend heavily on the state pensions of elderly members (Collinson 2010).

The area is generally dry (annual rainfall of 550–700 mm), although an east-west rainfall gradient shapes locally varying resource availability. Household plots are typically too small to fully support subsistence agriculture; some households farm assigned plots in the surrounding communal lands. Residents are typically quite dependent on the natural environment for a range of uses, including grazing livestock and collecting fuelwood, wild foods, thatching grass, construction timber, and other domestic products both for household consumption and for generating income (Shackleton and Shackleton 2000).

## **DATA**

In many rural regions of developing areas, including the Agincourt study site, migration is predominantly a household-level livelihood decision instead of an individual one (Cohen 2004; Collinson et al. 2006; Taylor 1999). Therefore the household is our analytical unit, and all variables are aggregated to this level. In some cases we use information about the household head as representative of the larger household unit, since the household head will dominate decision-making about livelihood strategies. In the South-African context, a household can be loosely defined as “a group of people living on the same property who eat from the same pot of food” (Madhavan et al. 2009:39).

We use demographic data from the Agincourt Health and Demographic Surveillance Site (Agincourt HDSS) for the year 2007. For this year the sample comprised 9,625 households

located in 21 villages (see Figure 2).<sup>1</sup> The Agincourt HDSS dataset includes geo-referenced location information for each household, allowing information about the availability of natural resources to be appended through a Geographical Information System (GIS). Details are given below.

*(Figure 2 about here)*

### **Dependent Variable**

A measure of temporary migration represents our dependent variable. Temporary migration is a well-established phenomenon with a long tradition in Agincourt (see Tollman et al. 1999), with 60% of men and 14% of women, aged 30–49 years, recorded as migrants each year (Collinson et al. 2006). Temporary migration status is based on “resident months,” which record the amount of time each person is physically present in the household during the year preceding the census interview. In the Agincourt context a temporary migrant is defined as a household member who is away for more than 6 months in that year but retains a livelihood connection (e.g., through remittances) to the sending household (Agincourt HDSS 2011; Collinson 2010).<sup>2</sup>

We consider only migration of adults (age 15+), since we are interested in livelihood migration, which is predominantly labor-related. For modeling purposes, instead of dichotomizing the variable to represent migrant vs. nonmigrant households, we employ a count measure allowing for maximum use of details available within the data, a common strategy in migration research (Bohara and Krieg 1996; Leyk et al. 2012). Descriptive statistics can be found in Table 1, demonstrating that across Agincourt, households had on average 1.2 temporary migrants (range 0 to 12) in 2007.

---

<sup>1</sup> The Agincourt HDSS has expanded geographically and now includes 24 villages, although we make use only of 21 villages that have been included in the study site for much of its history.

<sup>2</sup> Agincourt HDSS employs a *de jure* household definition that retains links between temporary migrants and their rural household (Collinson 2010).

## **Independent Variables**

### *Primary Predictor*

The environmental data were derived from Moderate Resolution Imaging Spectroradiometer (MODIS) remote sensing imagery (<http://modis.gsfc.nasa.gov>) distributed by the National Aeronautics and Space Administration, and locally processed by the Institute for Soil, Climate and Water (ISCW) of South Africa's Agricultural Research Council (ARC). Our primary predictor reflects a satellite-derived index indicating availability, and recent change in availability, of proximate natural resources. The normalized difference vegetation index (NDVI) represents one among a set of commonly used indicators that make it possible to evaluate environmental change's impact on vegetation greenness (Roerink et al. 2003; Wang, Rich, and Price 2003; Zhou et al. 2003). Chlorophyll absorbs red light and the mesophyll tissues in plants scatter near infrared light; the NDVI is the difference between the values in the red and near-infrared spectral bands divided by the sum of these same values (Tucker 1979). This ratio has a theoretical range from -1 to 1, with negative values indicating senescent or dead vegetation. Positive values reflect actively growing green vegetation. NDVI values saturate at high biomass (Huete et al. 2002), but preliminary field work shows that Agincourt, which falls in a semiarid savanna region, does not contain areas with high enough biomass to approach this saturation point. Thus NDVI can be used as an effective proxy of vegetation cover in this region. Tree biomass (e.g., fuelwood) and non-timber productivity (e.g., seed production, stem growth) are also positively correlated with NDVI (Foody et al. 2001; Mutanga and Skidmore 2004a, 2004b; Wang et al. 2004). Therefore this greenness proxy effectively maps the availability of natural resources used directly by Agincourt residents (fuelwood, wild foods). NDVI has also been successfully employed in livelihood-focused studies of the environment-migration association

elsewhere in southern Africa (Nawrotzki, Hunter, and Dickinson 2012).

We created NDVI grids for the years 2005–2007 by calculating the annual NDVI mean of 16-day composites obtained from MODIS satellite imagery (250 meter resolution). To reflect more general patterns of resource availability during this time period, we take the average of these three grids at each pixel to produce one greenness grid. We then generated 2-kilometer buffers around each household, as this represents a maximum typical walking distance for natural resource collection in this region (cf. Fisher et al. 2011; Giannecchini, Twine, and Vogel 2007). We excluded productive areas within village boundaries, since these are typically private homestead gardens, not available for communal collection. To generate a single measure of available natural resources, we then calculated the sum of all pixels from the greenness grid outside the village boundaries and inside the 2-kilometer buffer for each household. The number of pixels representing communal land varies across households, thus the sum is calculated rather than the mean. Finally, the measure was scaled to the range of NDVI. The ‘NDVI mean’ variable represents the central measure of natural resource availability.

As noted above, a clear west-east rainfall gradient shapes spatial variation in natural capital. Villages in the northwest are surrounded by communal lands with the densest vegetation cover -- in Figure 2, see Xanthia and Agincourt (the village from which the study site took its name). However, the communal landscapes surrounding eastern villages receive less rainfall and therefore are less productive, while also experiencing higher collection pressures given the higher concentration of villages – see Ireagh as example...

*(Table 1 about here)*

### *Secondary Predictors (Control Variables)*

A host of sociodemographic variables that are known determinants of migration (White and Lindstrom 2006) represent a variety of livelihood capitals and serve as controls.<sup>3,4</sup> Beyond being controls, however, these sociodemographic variables also serve as secondary predictors of substantive interest. We use interaction terms in statistical models to shed light on the types of households most likely to demonstrate significant migration-environment connections at both global and local geographic scales. Additional detail is provided in the methods section below.

**Human capital.** Arguably the most important measure of human capital is educational attainment (Saenz and Morales 2006), which generally exhibits a positive association with migration. To capture overall household educational level, we include a per capita measure of years of schooling, considering only adult household members (age 15+).

A household's stage in the life cycle also shapes the likelihood of migration (Nivalainen 2004; White and Lindstrom 2006) as well as the level and patterns of natural capital use (De Sherbinin et al. 2008; VanWey et al. 2007). In line with previous research, we use the household head's age to capture differences in life-cycle stage (Edmeades 2008; Carr, Pan, and Bilborrow 2006). A third measure of human capital is elder dependency proportion: the percentage of adult

---

<sup>3</sup> Within the Agincourt HDSS, different modules are fielded annually, so that some information is collected only every second, third, or fourth year. Consequently we use some data collected before our study year as proxies. For example, educational data collected in 2006 were used in the 2007 models, as was labor status information from 2004.

<sup>4</sup> In preliminary analyses we included marital and Mozambican background in the estimations. They are not, however, included in the final presentation for the following reasons. Marital status was represented by a set of dummy variables (married 53%, divorced 12%, widowed 18% and missing 17%). Except for the missing category there was no evidence for differences in temporary migration based on marital status. On ethnicity, during the 1990s, Agincourt experienced a high influx of refugees from neighboring Mozambique as a result of the 1983–1992 Mozambique civil war (Hargreaves et al. 2004; Madhavan et al. 2009). In our sample, 27% of households are headed by individuals of Mozambican background. Although citizenship was made available to refugees in 1996, this remains a marginalized population, as social and cultural barriers prevent equal access to resources (Collinson 2010). However, owing to a high level of segregation (two villages are composed almost entirely of households of Mozambican background), this variable lacks the necessary variation to be included.

household members age 65 and above. Elder dependency may shape migration probabilities in two ways: (1) by decreasing household potential to engage in the labor force (Juelich 2011) and (2) by enhancing financial security through state-funded pensions, small but stable sources of income in South Africa (Collinson 2010).

Research also frequently finds substantial gender differences in the environment-migration association (Henry et al. 2004; Gray 2010; Gray and Mueller 2012b). In Agincourt, males have a tradition of labor migration and are more likely to be primary household breadwinners, but young women are increasingly migrating to pursue opportunities and gain freedom from traditional rural society (Collinson 2010). We incorporate two measures to examine gender effects: (1) a dichotomous measure for gender of household head (1=female) (in Agincourt, poorer female-headed households send migrants as a means of escaping poverty; see Collinson 2010), and (2) a masculinity proportion, which captures the overall gender composition of adult household members.

Finally, an important factor shaping household human capital and livelihood strategies in the study area is prime age adult mortality due to the HIV/AIDS pandemic (e.g., Hunter, Twine, and Johnson 2011). A dummy variable indicates whether or not the household experienced the death of an adult aged 15–49 in the past three years.

**Financial and physical capital.** Classic migration frameworks stress the importance of income differentials, relative deprivation, and living conditions as important migration motivators (Massey et al. 1993). In Agincourt, these aspects of socioeconomic status, encompassing both financial and physical livelihood capitals, are most usefully reflected through an asset index (Agincourt HDSS 2011; Mberu 2006). As in rural regions of many developing areas, income is challenging to measure because there is a significant informal economy and



much employment is seasonal (Montgomery et al. 2000). To measure socioeconomic status (SES) more generally, the Agincourt HDSS collects data on five categories of physical capital: modern assets (e.g., cell phone, refrigerator, television); livestock (e.g., cattle, goats, pigs); power supply (e.g., electricity, gas, fuelwood); water and sanitation (e.g., toilet type, private water supply); and dwelling structure (e.g., roof and floor material, number of rooms).<sup>5</sup> We anticipate a positive association between household temporary migration and SES, as has been shown in recent Agincourt-based scholarship (Collinson 2010). Better-off households can more likely afford the costs of migration and may have destination connections that facilitate relocation and/or employment. In turn, migrant remittances reinforce the higher socioeconomic status of migrant-sending households (Taylor et al. 1996).

Of course, socioeconomic status is clearly associated with employment status, so we include a measure of the proportion of adult household members employed in 2007. Agincourt residents tend to be employed locally, primarily in the public sector (teaching, clerical work, or police work) or in the informal sector (selling fruit, cooked food, and snacks) (Collinson 2010). However, residents may also seek employment outside the study area, predominantly in the tourist sector (Binns and Nel 2002), agricultural production, or mining (Wilson 2001). Some of these opportunities require temporary migration, while others do not.<sup>6</sup>

---

<sup>5</sup> To construct the asset index, each variable was coded such that increasing values correspond to higher SES and also effectively given equal weight through rescaling to comparable ranges. The asset values within a group were added and then rescaled to yield a group-specific value in the range 0 to 1. Finally, for each household, the five group-specific scaled values were summed to yield an overall asset score whose values could range from 0 to 5 (Agincourt HDSS 2011).

<sup>6</sup> As in most migration research, questions of endogeneity also arise because of potential correlation between outcome and predictor variables, although none of our predictors exceed a correlation of 0.21 with the household count of temporary outmigrants. Correlations with the count of temporary migrants that exceed 0.10 include those for asset index (0.19), average household education (0.21), and proportion male household members male (0.13), elderly, (-0.17), and in the labor force (0.10). Tests of the impact of specific predictors on the estimations suggest no substantial change in estimation results or errors.

**Natural capital, recent change.** Our central measure of natural capital, described above, reflects mean natural resource availability for the three years (2005–2007) before the migration outcome (2007). Since recent shifts in availability may confound the impact of this measure, we also include an indicator of recent *change* in natural resource availability. In general, the study site experienced a slight increase in “greenness” during 2005–2007. To account for spatial variation in this upward trend, we include a measure of “NDVI slope” as a control variable based on the same underlying greenness pixels used for calculating the average NDVI measure. For each pixel in the 2-km buffer, the slope was computed by simply fitting a regression line through the NDVI values of the three years.

## **METHODS**

The modeling process includes “global” estimates across the entire study site as well as “local” village-scale models, allowing to illustrate the contrast of estimated coefficients. We also focus on interaction terms, allowing the effect of all sociodemographic capital variables to vary by household’s mean NDVI, 2005–2007.

### **Global and Local Village-Scale Modeling**

We compute Poisson Generalized Linear Models (GLM) (McCullagh and Nelder 1989) of temporary household migration using the full set of predictive variables: the primary environmental predictor variable (natural capital: NDVI mean), livelihood capital secondary predictors/controls (human, physical, and financial capitals, and change in natural capital [slope]), and interactions between NDVI mean and the secondary predictors/controls.<sup>7</sup> The global model has the form

---

<sup>7</sup> Poisson models have been successfully applied in a variety of models with count-dependent variables (e.g., Boyle and Flowerdew 1993; Congdon 1993; Leyk et al. 2012).

$$\eta_i = \log_e(\mu_i / \varphi_i)$$

$$\eta_i = \beta_0 + \beta_1(X_{1i}) + \dots + \beta_J(X_{Ji})$$

where  $\log()$  represents the link function, the natural logarithm, to transform the outcome variable  $\eta_{ij}$  to linearity based on the set of secondary predictors,  $\mu_{ij}$  indicates the predicted counts of migrants in household  $i$ , and  $\beta_0$  constitutes the intercept (mean log migrant count), while  $\beta_{1-J}$  are the regression coefficients of the central predictor variable (NDVI mean), secondary predictors/control variables, and interactions between the environmental predictor and secondary predictors  $X_{1i}$  to  $X_{Ji}$ .

Since households vary in size, a measure of per-capita migrants is a more objective way of representing the outcome variable as compared to an absolute number. We therefore use household size  $\varphi_i$  as an offset to convert the number of migrants in household  $i$  to the rate of migrants per household member. To avoid overdispersion, we tested whether the variance equaled the mean of the values—a fundamental assumption for Poisson distributions.

We computed household-level Poisson GLMs for the study site as a whole -- the global model -- as well as for each village individually. At the local scale, we ran 21 village-scale models and Table 3 summarizes these village-scale results by simply indicating the number of positive and negative statistically significant coefficient estimates across the 21 villages for the NDVI mean measure and each secondary predictor/control. To present specific coefficient estimates at the local scale, we chose four illustrative villages for presentation of the GLM village-scale results as contrasted with the global model (Table 2). The villages chosen represent the west-east gradient of natural capital within communal lands. Finally, we mapped model coefficients (and their significance levels) at the village scale to represent both the coefficients for NDVI mean (Figure 3) and the most substantive and statistically significant interaction terms between NDVI and the secondary predictors (Figure 4).

## RESULTS

### Global Model Estimates

A key finding is that, considering the Agincourt study site as a whole, the level of natural resource availability (2005–2007) within a household's 2-km buffer is positively associated with temporary outmigration (2007). The estimated coefficient is statistically significant at the 0.01 level, net of the suite of secondary migration predictors within the models. The NDVI slope, 2005–2007, exhibits a positive association with temporary outmigration as well, suggesting that households with higher (and increasing) levels of natural capital are more likely to send temporary migrants.

*(Table 2 about here)*

Virtually all of the secondary predictors obtain statistical significance (with the exception of prime age mortality), no doubt partly due to the relatively large number of observations. In line with previous research, human capital and other forms of assets are important correlates of temporary migration. Households with relatively higher human capital in the form of overall higher education are more likely to have sent a temporary migrant, while such migration was less likely in households with lower levels of human capital in the form of more members of pension age. Temporary migration was also more common among households with more employed members, testifying to the importance of employment as a foundation for fueling migration as a further diversification strategy. Recall that the pairwise correlation between household temporary migration and proportion employed is 0.01, lessening concerns of endogeneity between migration and employment measures. In addition, the findings suggest that households with a larger proportion of male members and those with higher overall wealth levels/asset position are more likely to have sent a member elsewhere.

At the global geographic scale, interactions are explored to offer insights on the types of households potentially able to tap into natural capital to fuel temporary migration -- yet only two reach statistical significance. The positive estimated effect of NDVI mean on temporary outmigration is magnified for relatively older households as well as those with proportionately fewer men (likely because male members migrated). In this way, the results may suggest that natural capital enables migration by offering livelihood diversification strategies particularly for households with higher levels of human capital in the form of age and male members.

### **Village-Scale Model Estimates**

The Poisson GLM coefficient estimates by village suggest that the processes indicated by the global models operate quite differently at more local scales – which we call an issue of geographic scale sensitivity. Table 3 summarizes village-scale results illustrating that natural resource availability displays a range of effects, only some of which reach statistical significance. Figure 3 maps the substantively and statistically strongest effects of NDVI mean by village; Statistical significance is represented by hatching. In two villages (Kildare A #11 and Kildare B #13), consistent with the global estimates, the estimate reflect a positive, statistically significant association between temporary outmigration and natural resource availability, net of the control variables. Yet in two other villages, the opposite association emerges. In the villages of Agincourt (#2) and Newington (#4), a negative, temporary outmigration exhibits a negative, statistically significant association with natural resource availability. Interestingly, these latter villages (in which lower levels of natural capital constrains migration) tend to have relatively high levels of resource availability in general and are on the study site’s northern edge, proximate to packed dirt roads leading to slightly larger neighboring towns (e.g. Thulamahashe, ~11,000 residents). Here, the potential exists for households to make use of local natural

resources as livelihood strategies while also tapping into the market and/or employment potential of nearby communities without necessarily engaging in migration. On the other hand, the villages in which NDVI *facilitates* migration (Kildare A and B) tend to be in the study site's southeastern corner, more distant from larger neighboring towns and bounded by fenced game reserves. These villages have relatively low levels of resource availability in general while also being further from larger-scale markets and other employment opportunities. In this way, within these resource-poor contexts, households with relatively higher levels of proximate natural capital may be engaging those resources as well as temporary migration as livelihood strategies.

Yet in 17 of the 21 villages (81%), the influence of natural resource availability on temporary migration did not reach statistical significance net of the other included secondary predictors/controls (see Table 3) — a result quite different from the positive, statistically significant effect of NDVI at the global scale. Overall, a far less consistent migration-environment narrative emerges when using village boundaries to define study areas.

*(Table 3 about here)*

*(Figure 3 about here)*

On the secondary predictor/control variables, at the village scale the most consistent *positive* predictors of temporary outmigration include measures of human capital such as household proportion employed (significant in 18 villages), level of education (significant in 9 villages), and the proportion male (significant in 8 villages). On the other hand, households with relatively more elderly members are consistently *less* likely to send temporary outmigrants (significant in 6 villages). Household age composition, female headship, and mortality experience exhibit

virtually no association with migration at the village scale (not significant in at least 19 of the 21 villages).

Interaction terms at the village scale allow us to dive deeper into the mechanisms potentially underlying village-scale variation in the migration-environment association. Figure 4 maps the substantively and statistically strongest interactions with NDVI mean, by village. Statistical significance is again represented by hatching.

*(Figure 4 about here)*

The lack of predictive power among NDVI interactions at the village-scale is notable. Among the eight sociodemographic variables combined with NDVI to predict temporary outmigration across the 21 included villages ( $21 * 8 = 168$  interactions, not shown), only three (1.7%) reached statistical significance, and no distinct patterns emerged.

Households in Agincourt (Village #2) have relatively high access to natural resources and the probability of temporary outmigration exhibits a significant positive interaction with the asset index (see Table 2). On the other hand, households in Rholane (village #15) have relatively low access to natural resources and they exhibit the same pattern—a significant positive interaction between the asset index and NDVI as related to temporary outmigration (not shown). This interaction suggests that natural capital may fuel migration particularly for those households that already have diverse and stable livelihoods – even in natural resource-poor settings.

Interestingly, households in Justicia B (village #17) exhibit a strong negative interaction between proportion elderly household members (the dependency measure), natural capital and temporary outmigration. This village has particularly low levels of natural resources given its proximity to private, fenced game reserves. In this natural resource-poor village, monthly pensions, albeit low levels of income, may provide sufficient security to constrain temporary

migration. Another interpretation could relate to care-giving, as more elderly household members may suggest others have caregiving responsibilities, also constraining migration.

## **DISCUSSION, CONCLUSION, IMPLICATIONS**

Many empirical studies have been added to the migration-environment literature over the past several years, fueled in part by public and policy concern with the potential for climate change to spur migration as a result of increasing livelihood vulnerability. Such concern certainly warrants intensified scientific inquiry with the aim of ultimately generating conclusions about the connection between migration and environmental conditions/change. Even so, the research presented here yields a cautionary tale.

In general, we find that households with higher levels of local natural capital were more likely in 2007 to send a temporary migrant from our rural South African study site. This finding parallels prior work in Ecuador where migration was facilitated by more productive agricultural lands (Gray 2010). In rural South Africa, households rely heavily on natural resources for both daily sustenance as well as materials for products sold at market (e.g. Shackleton et al. 2008). In this way, access to natural capital may provide a safety net, of sorts, from which livelihoods may be further diversified – including through temporary migration. The safety net function of local resources has, indeed, been demonstrated in other research in the Agincourt HDSS setting focused on household coping strategies in the face of adult mortality (Hunter, Twine, and Patterson 2007).

Yet, the coefficient estimates yielded from analysis of all Agincourt HDSS households combined may not best reflect the optimal geographic scale to investigate the household-level process under study. In this setting, migration is typically a household-level decision (Collinson et al. 2006). Further, since 85.4% of Agincourt households do not own a car, it is likely that the



opportunities and constraints within the local village setting may particularly influence livelihood strategies. As such, we test differences in coefficient estimates across geographic scales to better understand how the migration-environment connection might differentially unfold if the study area is partitioned into individual administrative units.

And differences do unfold. At the village scale, the models identify two villages in which households exhibit a particularly strong positive association between local natural capital and temporary outmigration – where households with higher levels of natural resources within a 2km buffer of the homestead were more likely to have sent a temporary migrant within the past year. Even so, the models also identified two villages with the opposite association – where households with lower levels of natural resources were more likely to have sent a temporary migrant within the past year. Natural capital's negative association with temporary outmigration is intensified for households in resource-poor regions and with access to elderly pensions.

The incongruent results across models fit to different geographic scales (or geographic extents) leaves researchers with a puzzle; and although we raise the question of geographical scale sensitivity – we do not propose to yet have an answer. Unlike the ecological fallacy, the example presented here has retained the household as the analytical unit and it is, therefore, justifiable to interpret the coefficients as related to the household level. And unlike the modifiable area unit problem (MAUP), our models do not operate at aggregate units of different size and shape. Instead, we have simply shifted the boundaries of the study areas, focusing first on all Agincourt HDSS households together (global) and then on distinct clusters of households as defined by village borders.

Models fit to each individual village show high levels of predictive power (Leyk et al. 2012) and thus provide an objective picture of existing (or non-existing) relationships. The distinction

between scales results from variation in the statistical distributions of incorporated variables due to the different boundaries and, therefore, different study populations. The global model masks associations that are apparent when using statistical distributions as defined by village scale boundaries. Yet, the village scale analyses do not allow for identification of broader scale migration-environment associations that more generally characterize the entire Agincourt HDSS.

Given this high geographic scale sensitivity, the question remains: what represents a ‘meaningful’ geographic scale to model migration-environment associations? We argue that, in this case, the more localized, village scale models represent a more appropriate vantage point for two reasons: 1) the household-level decision-making process of relevance to our outcome variable (migration) is likely influenced by localized livelihood options (including availability of natural capital) particularly given low levels of vehicle ownership, and 2) examination of goodness-of-fit measures suggest the village-scale models offer better prediction of household-level migration (Leyk et al. 2012).

Migration has long been an adaptive livelihood strategy used by human populations responding to local environmental shifts (e.g., Bardsley and Hugo 2010; McLeman and Hunter 2011). The results presented here demonstrate this local connection. In particularly resource-poor villages, stability in the form of other income (such as pensions) may negate the migration-facilitating impact of natural capital. Yet in general, higher levels of nearby natural resources appear to support temporary migration as a livelihood diversification strategy. Of central importance in future research will be investigation of temporal variation in the migration-environment connection and, in particular, under conditions of more chronic and/or several environmental change.

## REFERENCES

- Adamo, S. and H. Izazola. 2010. "Human Migration and the Environment." *Population and Environment* 32:105–108.
- Agincourt HDSS. 2011. "Agincourt Health and Population Unit: Data Definitions." Johannesburg, South Africa: University of the Witwatersrand. Retrieved September 19, 2011 from <http://www.agincourt.co.za/DataSection/DataDocumentation.htm>.
- Anselin, L. 1995. "Local Indicators of Spatial Association LISA." *Geographical Analysis* 27(2):93–115.
- Barbieri, A. and D.L. Carr. 2005. "Gender-Specific Out-Migration, Deforestation and Urbanization in the Ecuadorian Amazon." *Global and Planetary Change* 47(2): 99–110.
- Bardsley, D.K. and G.J. Hugo. 2010. "Migration and Climate Change: Examining Thresholds of Change to Guide Effective Adaptation Decision-making." *Population and Environment* 32:238–62.
- Bilsborrow, R.E. 2002. "Migration, Population Change and the Rural Environment." *ECSP Report*. Woodrow Wilson International Center for Scholars, Environmental Change and Security Project. Issue 8:69–94.
- Binns, T. and E. Nel. 2002. "Tourism as a Local Development Strategy in South Africa." *Geographical Journal* 168:235–47.
- Black, R., W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D.S. Thomas. 2011. "The Effect of Environmental Change on Human Migration." *Global Environmental Change* 21:S3–S11.
- Bohara, A.K. and R.G. Krieg. 1996. "A Zero-Inflated Poisson Model of Migration Frequency." *International Regional Review* 19(3):211–22.

- Boyle, P.J. and R. Flowerdew. 1993. "Modelling sparse interaction matrices: interward migration in Hereford and Worcester, and the underdispersion problem." *Environment and Planning*. 25:1201-1209.
- Carr, D.L., W.K.Y. Pan, and R.E. Bilborrow. 2006. "Declining Fertility on the Frontier: The Ecuadorian Amazon." *Population and Environment* 28(1):17–39.
- Cohen, J.H. 2004. *The Culture of Migration in Southern Mexico*. Austin, TX: University of Texas Press.
- Collinson, M.A. 2010. "Striving Against Adversity: The Dynamics of Migration, Health and Poverty in Rural South Africa." *Global Health Action* 3. 5080 - DOI: 10.3402/gha.v3i0.5080.
- Collinson, M.A., S.M. Tollman, K. Kahn, S.J. Clark, and M. Garenne. 2006. "Highly Prevalent Circular Migration: Households, Mobility and Economic Status in Rural South Africa." Pp 194-216 in *Africans on the Move: Migration in Comparative Perspective*, edited by M. Tienda, S.E. Findley, S.M. Tollman, and E. Preston-Whyte. Johannesburg, South Africa: Wits University Press.
- Congdon, P. 1993. "Approaches to modelling overdispersion in the analysis of migration." *Environment and Planning*. 25:1481-1510.
- deSherbinin, A., L.K. VanWey, K. McSweeney, R. Aggarwal, A. Barbieri, S. Henry, L.M. Hunter, W. Twine, and R. Walker. 2008. "Rural Household Demographics, Livelihoods and the Environment." *Global Environmental Change* 18:38–53.
- Edmeades, J. 2008. "The Legacies of Context: Past and Present Influences on Contraceptive Choice in Nang Rong, Thailand." *Demography* 45(2):283–302.
- Entwisle, Barbara. 2007. "Putting People Into Place." *Demography* 44(4):687–703.

- Fisher, J.T., E.T.F. Witkowski, B.F.N. Erasmus, J. Van Aardt, G.P. Asner, K.J. Wessels, and R. Mathieu. 2011. "Human-Modified Landscapes: Patterns of Fine-Scale Woody Vegetation Structure in Communal Savannah Rangelands." *Environmental Conservation* 39(1):72–82.
- Foody, G.M., M.E. Cutler, J. McMorrow, D. Pelz, H. Tangki, D.S. Boyd, and I. Douglas. 2001. "Mapping the Biomass of Bornean Tropical Rain Forest From Remotely Sensed Data." *Global Ecology and Biogeography* 10(4):379–87.
- Fotheringham, A. S. 1997. "Trends in Quantitative Methods I: Stressing the Local." *Progress in Human Geography*. 21: 88-95.
- Fotheringham, A.S. and C. Brundson. 1999. "Local Forms of Spatial Analysis" *Geographical Analysis* 31(4):340-358.
- Giannecchini, M., W. Twine, and C. Vogel. 2007. "Land-Cover Change and Human-Environment Interactions in a Rural Cultural Landscape in South Africa." *Geographical Journal* 173:26–42.
- Gray, C.L. 2010. "Gender, Natural Capital, and Migration in the Southern Ecuadorian Andes." *Environment and Planning* 42:678–96.
- Gray, C. L. and R. Bilborrow. 2012, forthcoming. "Environmental Influences on Outmigration in Rural Ecuador." *Demography*.
- Gray, C. L. and V. Mueller. 2012a (early edition). "Natural Disasters and Population Mobility in Rural Bangladesh." *Proceedings of the National Academy of Sciences*. Retrieved July 2012 from <http://www.pnas.org/content/early/2012/03/28/1115944109.full.pdf>
- , 2012b. "Drought and Population Mobility in Rural Ethiopia." *World Development* 40(1):134–45.

- Gray, C.L., R.E. Bilborrow, J.L. Bremner, and F. Lu. 2008. "Indigenous Land Use in the Ecuadorian Amazon: A Cross-cultural and Multilevel Analysis." *Human Ecology* 36(1):97–109.
- Greenland, S. and H. Morgenstern. 1989. "Ecological Bias, Confounding, and Effect Modification." *International Journal of Epidemiology* 18:269-274.
- Hargreaves, J.R., M.A. Collinson, K. Kahn, S.J. Clark, and S.M. Tollman. 2004. "Childhood Mortality Among Former Mozambican Refugees and Their Hosts in Rural South Africa." *International Journal of Epidemiology* 33(6):1271–78.
- Henry, S., B. Schoumaker, and C. Beauchemin. 2004. "The Impact of Rainfall on the First Out-Migration: A Multi-Level Event-History Analysis in Burkina Faso." *Population & Environment* 25(5):423–60.
- Huete, A., K. Didan, T. Miura, E.P. Rodriguez, X. Gao, and L.G. Ferreira. 2002. "Overview of the Radiometric and Biophysical Performance of the MODIS Vegetation Indices." *Remote Sensing of Environment* 83:195–213.
- Hunter, L.M. and E. David. 2011. "Climate Change and Migration: Considering Gender Dimensions." Invited chapter in *Climate Change and Migration*. Etienne Piguet, Paul de Guchteneire and Antoine Pecoud (Eds). UNESCO Publishing and Cambridge University Press: Cambridge UK.
- Hunter, L.M., S. Murray, and F. Riosmena. 2012. "Rainfall Variation and U.S. Migration From Rural Mexico." CU Population Center Working Paper, University of Colorado Boulder.
- Hunter, L.M., W. Twine, and A. Johnson. 2011. "Adult Mortality and Natural Resource Use in Rural South Africa: Evidence From the Agincourt Health and Demographic Surveillance Site." *Society & Natural Resources* 24(3):256–75.

- Hunter, L.M., W. Twine, and L. Patterson. 2007. "“Locusts Are Now Our Beef”: Adult Mortality and Household Dietary Use of Local Environmental Resources.” *Scandinavian Journal of Public Health* 25 (Suppl. 69):165–74.
- Juelich, S. 2011. "Drought Triggered Temporary Migration in an East Indian Village." *International Migration* 49:189–99.
- Kniveton, D.R., C.D. Smith, and R. Black. 2012. "Emerging Migration Flows in a Changing Climate in Dryland Africa.” *Nature Climate Change* 2:444–47.
- Lam, N.S. and D.A. Quattrochi. 1992. "On the issues of scale, resolution, and fractal analysis in the mapping sciences.” *The Professional Geographer*, 44(1):88-98.
- Leyk, S., G.J. Maclaurin, L.M. Hunter, R. Nawrotzki, W. Twine, M. Collinson, and B. Erasmus. 2012. "Spatially and Temporally Varying Associations Between Temporary Outmigration and Natural Resource Availability in Resource-Dependent Rural Communities in South Africa: A Modeling Framework." *Applied Geography* 34:559–68.
- Maclaurin, G.J., S. Leyk, and L.M. Hunter. 2013. "Understanding the impacts of aggregation while accounting for spatial non-stationarity: The case of migration models.” CUPC Working Paper Series. University of Colorado Population Center.
- Madhavan, S., E. Schatz, and B. Clark. 2009. "Effect of HIV/AIDS-Related Mortality on Household Dependency Ratios in Rural South Africa, 2000–2005." *Population Studies* 63(1):37–51.
- Madubansi, M. and Shackleton, C.M. 2007. "Changes in fuelwood use and selection following electrification in the Bushbuckridge lowveld, South Africa.” *Journal of Environmental Management*. 83 (4): 416-426.

- Massey, D.S., J. Arango, G. Hugo, A. Kouaouci, A. Pellegrino, and J.E. Taylor. 1993. "Theories of International Migration—A Review and Appraisal." *Population and Development Review* 19(3):431–66.
- Massey, D.S., W.G. Axinn, and D.J. Ghimire. 2010. "Environmental Change and Out-Migration: Evidence From Nepal." *Population and Environment* 32(2–3):109–136.
- Mberu, B.U. 2006. "Internal Migration and Household Living Conditions in Ethiopia." *Demographic Research* 14:509–539.
- McCullagh, P. and J.A. Delder. 1989. *Generalized Linear Models*. Boca Raton, FL: CRC Press.
- McLeman, R. and L.M. Hunter. 2010. "Migration in the Context of Vulnerability and Adaptation to Climate Change: Insights from Analogues." *WIREs Clim Change* 2010, 1: 450-461. doi: 10.1002/wcc.51
- Montgomery, M.R., M. Gagnolati, K.A. Burke, and E. Paredes. 2000. "Measuring Living Standards With Proxy Variables." *Demography* 37(2):155–74.
- Moran, P.A.P. 1950. "Notes on Continuous Stochastic Phenomena." *Biometrika* 37:17–33.
- Mutanga, O. and A.K. Skidmore. 2004a. "Narrow Band Vegetation Indices Overcome the Saturation Problem in Biomass Estimation." *International Journal of Remote Sensing* 25(19):3999–4014.
- Mutanga, O. and A.K. Skidmore. 2004b. "Merging Double Sampling With Remote Sensing for a Rapid Estimation of Fuelwood." *Geocarto International* 19(4):49–55.
- Nawrotzki, R.J., L.M. Hunter, and T.W. Dickinson. 2012. "Rural Livelihoods and Access to Natural Capital: Differences Between Migrants and Non-Migrants in Madagascar." *Demographic Research* 26:661–99.



- Nawrotzki, R.J., F. Riosmena, and L.M. Hunter. 2013. "Do Rainfall Deficits Predict U.S.-Bound Migration From Rural Mexico? Evidence From the Mexican Census." *Population Research and Policy Review*. 32(1): 129-158.
- Nivalainen, S. 2004. "Determinants of Family Migration: Short Moves vs. Long Moves." *Journal of Population Economics* 17(1):157–75.
- Paumgarten, F. and C.M. Shackleton. 2011. "The Role of Non-Timber Forest Products in Household Coping Strategies in South Africa: The Influence of Household Wealth and Gender." *Population and Environment* 33:108–113.
- Robinson W. S. 1950. "Ecological correlations and the behavior of individuals." *American Sociological Review*. 15: 351-357.
- Roerink, G.J., M. Menenti, W. Soepboer, and Z. Su. 2003. "Assessment of Climate Impact on Vegetation Dynamics by Using Remote Sensing." *Physics and Chemistry of the Earth* 28(1–3):103–109.
- Saenz, R. and M.C. Morales. 2006. "Demography of Race and Ethnicity." Pp. 169–208 in *Handbook of Population*, edited by D.L. Poston and M. Micklin. New York: Springer.
- Scoones, I. 1998. "A Framework for Analysis." Working Paper, Institute of Development Studies. Retrieved Sept 2012 from <http://200.17.236.243/pevs/Agroecologia/Sustainable%20Rural%20Livelihoods-Scoones.pdf>
- Shackleton, S.E., Campbell, B., Lotz-Sisitka, H., Shackleton, C. 2008. "Links between the local trade in natural products, livelihoods and poverty alleviation in a Semi-arid region of South Africa." *World Development* 36:505-526.

- Shackleton, C.M. and S.E. Shackleton. 2000. "Direct Use Values of Savanna Resources Harvested From Communal Savannas in the Bushbuckridge Lowveld, South Africa." *Journal of Tropical Forest Products* 6(1):28–47.
- , 2011. "Exploring the Role of Wild Natural Resources in Poverty Alleviation." Pp. 209-234 in *Reforming Land and Resource Use in South Africa: Impact on Livelihoods*, edited by Paul Hebinck and Charlie Shackleton. New York, NY: Routledge.
- Taylor, J.E. 1999. "The New Economics of Labour Migration and the Role of Remittances in the Migration Process." *International Migration* 37(1):63–88.
- Taylor, J.E., J. Arango, G. Hugo, A. Kouaouci, D.S. Massey, and A. Pellegrino. 1996. "International Migration and Community Development." *Population Index* 62(3):397–418.
- Tollman, S.M., K. Herbst, M. Garenne, J.S.S. Gear, and K. Kahn. 1999. "The Agincourt Demographic and Health Study—Site Description, Baseline Findings and Implications." *South African Medical Journal* 89(8):858–64.
- Tucker, C.J. 1979. "Red and Photographic Infrared Linear Combinations for Monitoring Vegetation." *Remote Sensing of Environment* 8(2):127–50.
- Twine, W., D. Moshe., T. Netshiluvhi and M. Siphugu. 2003. "Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo province, South Africa." *South African Journal of Science*. 99: 467-473.
- VanWey, L. 2003. "Land Ownership as a Determinant of Temporary Migration in Nang Rong, Thailand." *European Journal of Population* 19(2):121–45.
- VanWey, L.K., A.O. D'Antona, and E.S. Bondizio. 2007. "Household Demographic Change and Land Use/Land Cover Change in the Brazilian Amazon." *Population and Environment* 28:163–85.

- Waller, L.A. and C.A. Gotway. 2004. *Applied Spatial Statistics for Public Health Data*. Hoboken, NJ: John Wiley & Sons.
- Wang, J., P.M. Rich, and K.P. Price. 2003. "Temporal Responses of NDVI to Precipitation and Temperature in the Central Great Plains, USA." *International Journal of Remote Sensing* 24(11):2345–64.
- Wang, J., P.M. Rich, K.P. Price, and W.D. Kettle. 2004. "Relations Between NDVI and Tree Productivity in the Central Great Plains." *International Journal of Remote Sensing* 25(16):3127–38.
- Warner, K. 2011. "Environmental change and migration: methodological considerations from ground-breaking global survey." *Population & Environment*. 33(1):3-27.
- White, M.J. and D.P. Lindstrom. 2006. "Internal Migration." Pp. 311–346 in *Handbook of Population*, edited by D. Poston and M. Micklin. New York: Kluwer Academic Publishers.
- Wilson, F. 2001. "Minerals and Migrants: How the Mining Industry Has Shaped South Africa." *Daedalus* 130(1):99–121.
- Wong, D. 1995. "Aggregation Effects in Geo-referenced Data." Pp. 83-106 In *Practical Handbook of Spatial Statistics*. (Arlinghaus, S. L., Ed). Boca Raton: CRC Press.
- Zhou, L., R.K. Kaufmann, Y. Tian, R.B. Myneni, and C.J. Tucker. 2003. "Relation Between Interannual Variations in Satellite Measures of Northern Forest Greenness and Climate Between 1982 and 1999." *Journal of Geophysical Research* 108(D1):3:2 – 3:11.

**Table 1.**  
**Descriptive Statistics and Group Mean Comparison (t-test) for**  
**Selected Variables for the Agincourt Study Site and Four Illustrative Villages, 2007**

	<i>Global</i>		<i>Xanthia</i>	<i>Agincourt Village</i>	<i>Ireagh</i>	<i>Justicia</i>
	Mean	(S.D)	Mean	Mean	Mean	Mean
<u>Outcome</u>						
# temporary migrants <sup>b</sup>	1.19	-1.36	1.38 ***	1.54 ***	1.4 ***	0.87 ***
<u>Primary predictor</u>						
NDVI mean	0.53	-0.08	0.63 ***	0.58 ***	0.52	0.42 ***
<u>Secondary predictors</u>						
NDVI slope	0.61	-0.16	0.56 ***	0.58 ***	0.85 ***	0.4 ***
Age of HH head	52.27	-15.09	53.83 **	54.61 ***	51.75	51.09 *
Female HH head	0.39	-0.49	0.43	0.38	0.41	0.44 **
Proportion Male	0.44	-0.25	0.45	0.45	0.46	0.43
Proportion Elderly	0.1	-0.21	0.11	0.11 *	0.09	0.1
Proportion Employed	0.29	-0.27	0.26 **	0.27 *	0.31	0.29
HH Educational Level	6.64	-3.26	7.05 **	7.57 ***	6.05 ***	6.4 *
SES	2.43	-0.44	2.46	2.53 ***	2.36 ***	2.4 *
Prime Age Mortality <sup>c</sup>	0.09	-0.29	0.12 *	0.09	0.1	0.11
N (households)	9625		587	969	490	740

Note: Villages are presented in order of decreasing mean NDVI. HH=Household.  
 Ordinary t-test performed to evaluate differences between individual village and collective group of remaining villages.

<sup>b</sup> Number refers to household unit.

<sup>c</sup> Deaths within the last three years.

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

Data Source: Agincourt Health and Demographic Surveillance Site (Agincourt HDSS), 2007.

**Table 2:**  
**GLM Models Predicting Temporary Outmigration, Household-Level, Agincourt Health and Demographic Surveillance Site, Mpumalanga Province, South Africa, 2007.**

	<i>Four Illustrative Villages</i>				
	<i>Global, Agincourt Study Site</i>	<i>Xanthia</i>	<i>Agincourt Village</i>	<i>Ireagh</i>	<i>Justicia</i>
<b><u>Primary predictor</u></b>					
NDVI mean	0.430 ***	0.072	-0.042 *	-0.052	-0.264
<b><u>Secondary predictors</u></b>					
NDVI slope	0.241 ***	-0.050	-0.010	-0.009	0.312
Age of HH head	0.004 ***	0.082 *	0.015	0.088 *	-0.012
Female HH head	0.052 *	0.041	0.016	-0.027	-0.004
Proportion Male	0.434 ***	0.018	0.055 **	0.013	0.161 **
Proportion Elderly	-0.702 ***	-0.150 *	-0.071	-0.190 **	-0.009
Proportion Employed	0.793 ***	0.176 ***	0.112 ***	0.129 ***	0.265 ***
HH Educational Level	0.042 ***	0.150 ***	0.126 ***	0.014	0.215 ***
SES	0.114 ***	-0.034	0.009	0.022	0.011
Prime Age Mortality	-0.019	0.019	0.003	0.052 *	0.012
<b><u>Interactions (each run individually)</u></b>					
NDVI*Age Head	0.160 **	0.020	0.103	0.021	0.021
NDVI*Female Head	0.080	-0.225	0.081	-0.012	0.168
NDVI*Proportion Male	-0.110 *	-0.169	-0.275	1.351	-0.247
NDVI*Proportion Elderly	-0.030	0.113	-0.087	-0.551	-0.166
NDVI*Proportion Employed	-0.020	0.436	-0.090	0.387	-0.487
NDVI*HH Educational Level	0.100	0.127	-0.150	0.155	-0.121
NDVI*SES	0.050	0.158	0.325 *	-0.001	0.232
NDVI*Prime Age Mortality	0.050	0.097	0.050	-0.047	-0.199
N (households)	9625	587	969	490	740

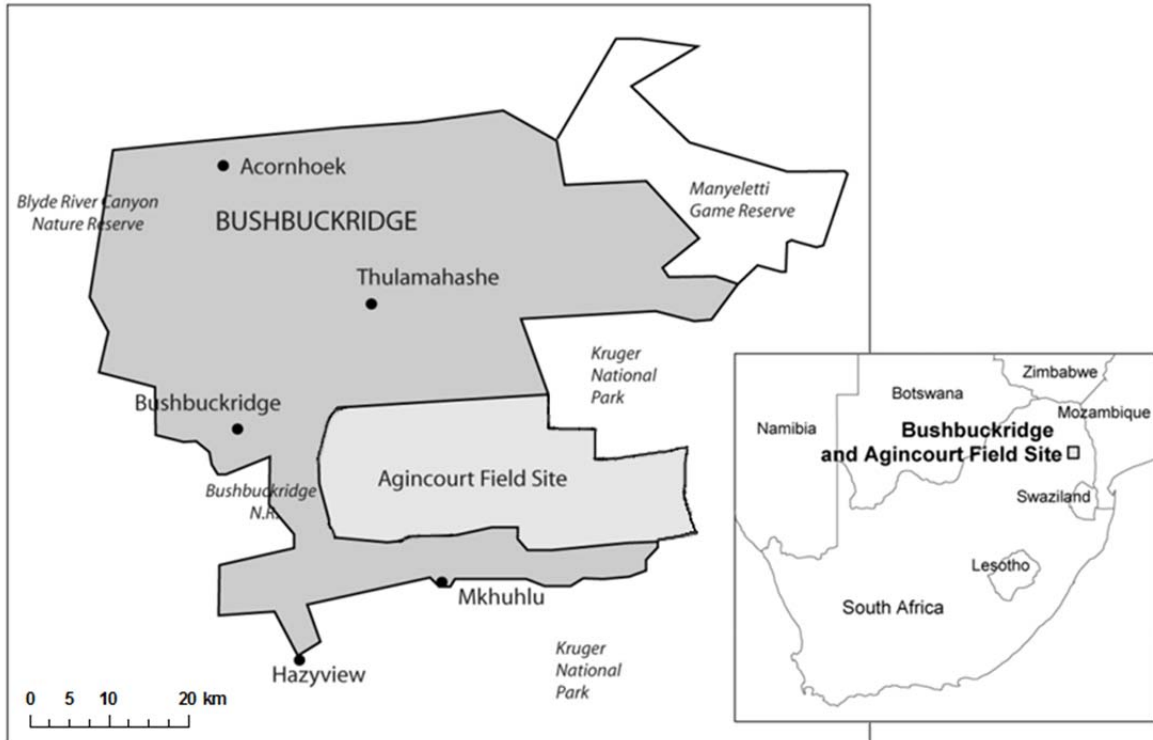
\*p<.05; \*\*p<.01; \*\*\*p<.001

Data Source: Agincourt Health and Demographic Surveillance Site (Agincourt HDSS), 2007.

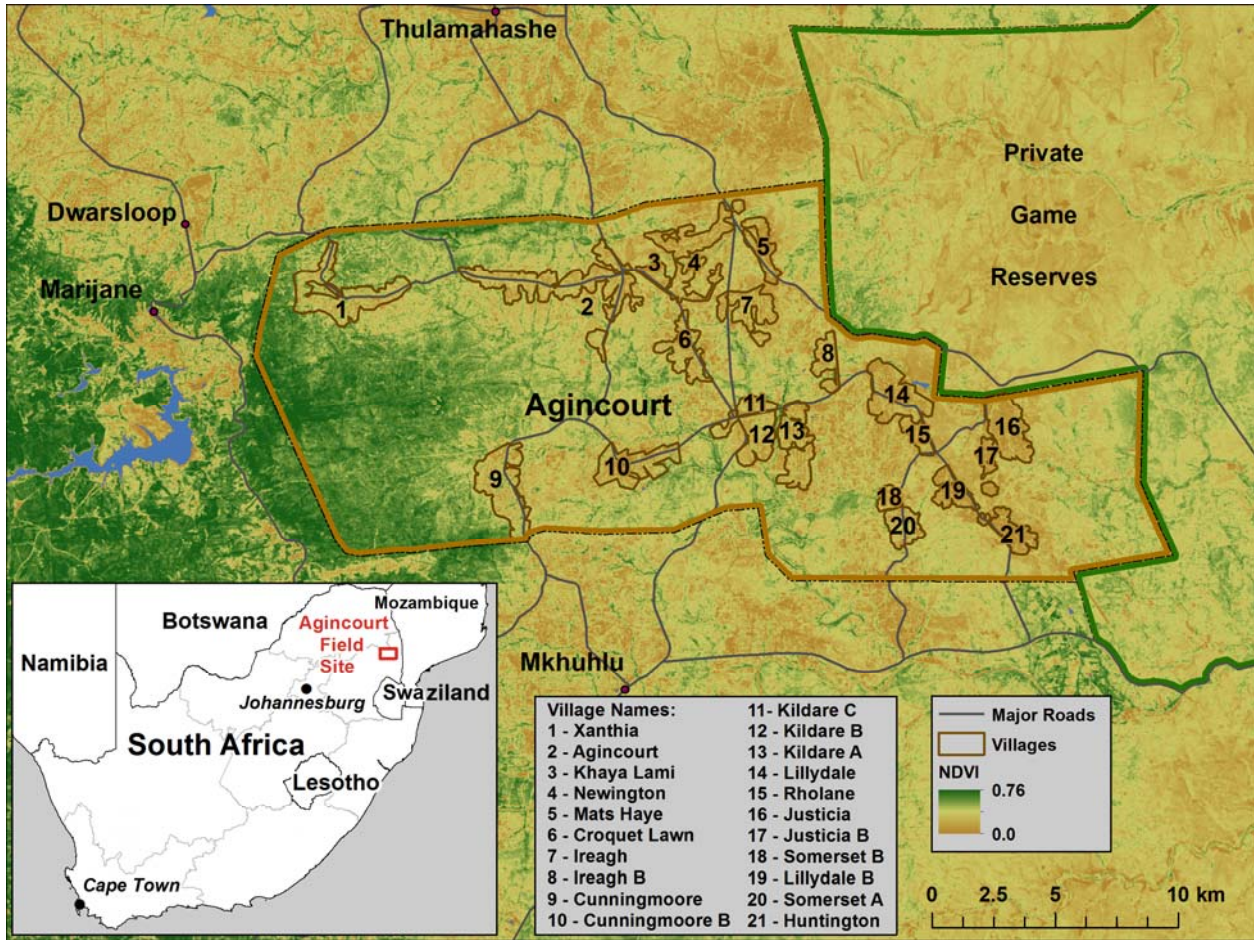
**Table 3: Summary of Village-Level Coefficients Predicting Temporary Outmigration at the Household-Level, Agincourt Health and Demographic Surveillance Site, Mpumalanga Province, South Africa, 2007.**

	Positive Sig.	Negative Sig.	Not sig.
<b><u>Primary Predictor</u></b>			
NDVI mean	2	2	17
<b><u>Secondary Predictors</u></b>			
NDVI slope	1	2	18
Age of HH head	2	0	19
Female HH head	0	0	21
Proportion Male	8	0	13
Proportion Elderly	0	6	15
Proportion Employed	18	0	3
HH Educational Level	9	0	12
SES	3	2	16
Prime age mortality	1	1	19

**Figure 1:**  
**Study Area, Agincourt Health and Demographic Surveillance Site,**  
**Mpumalanga Province, South Africa**

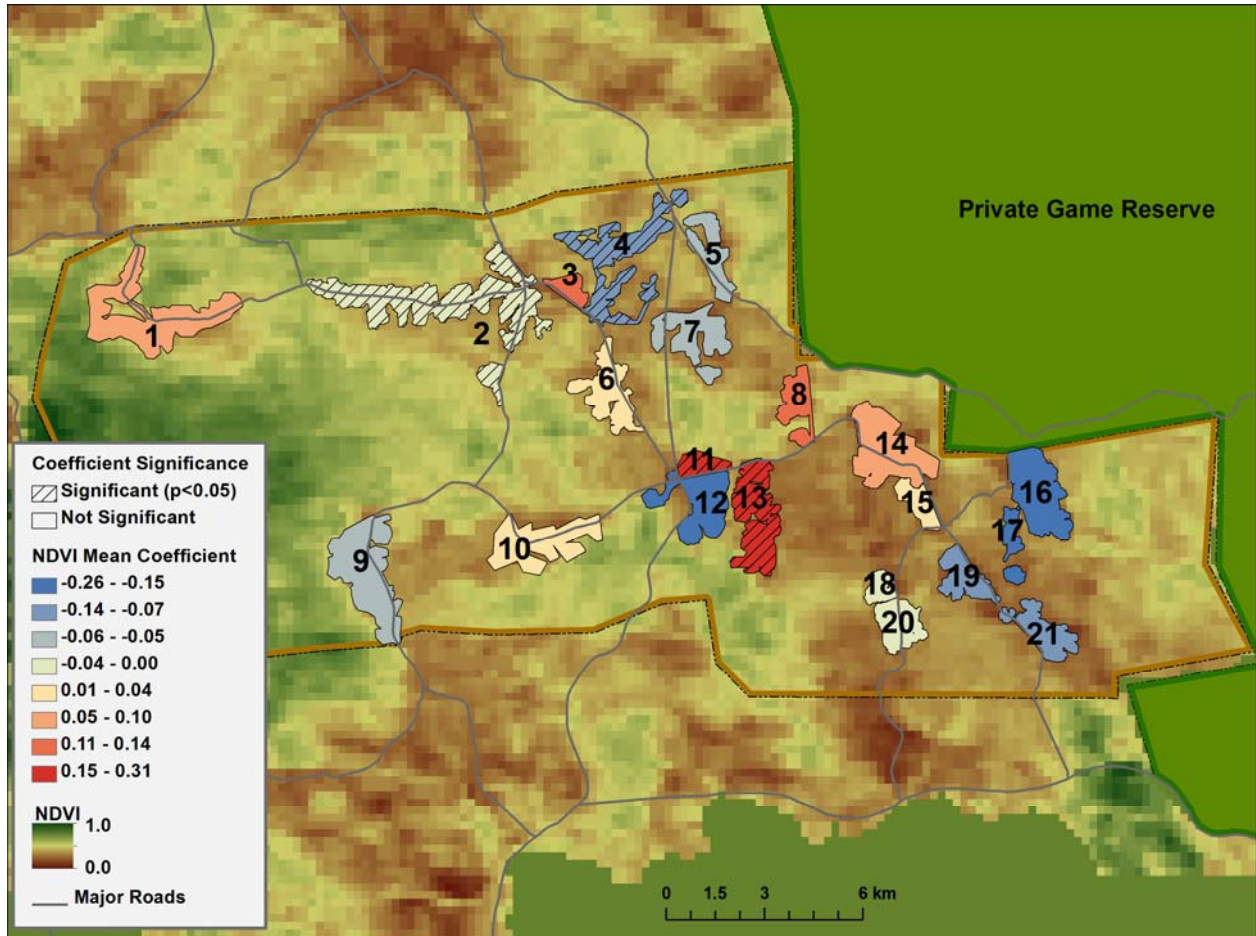


**Figure 2:**  
**Village Names and Identifying Numbers,**  
**Agincourt Health and Demographic Surveillance Site, Mpumalanga Province, South Africa**

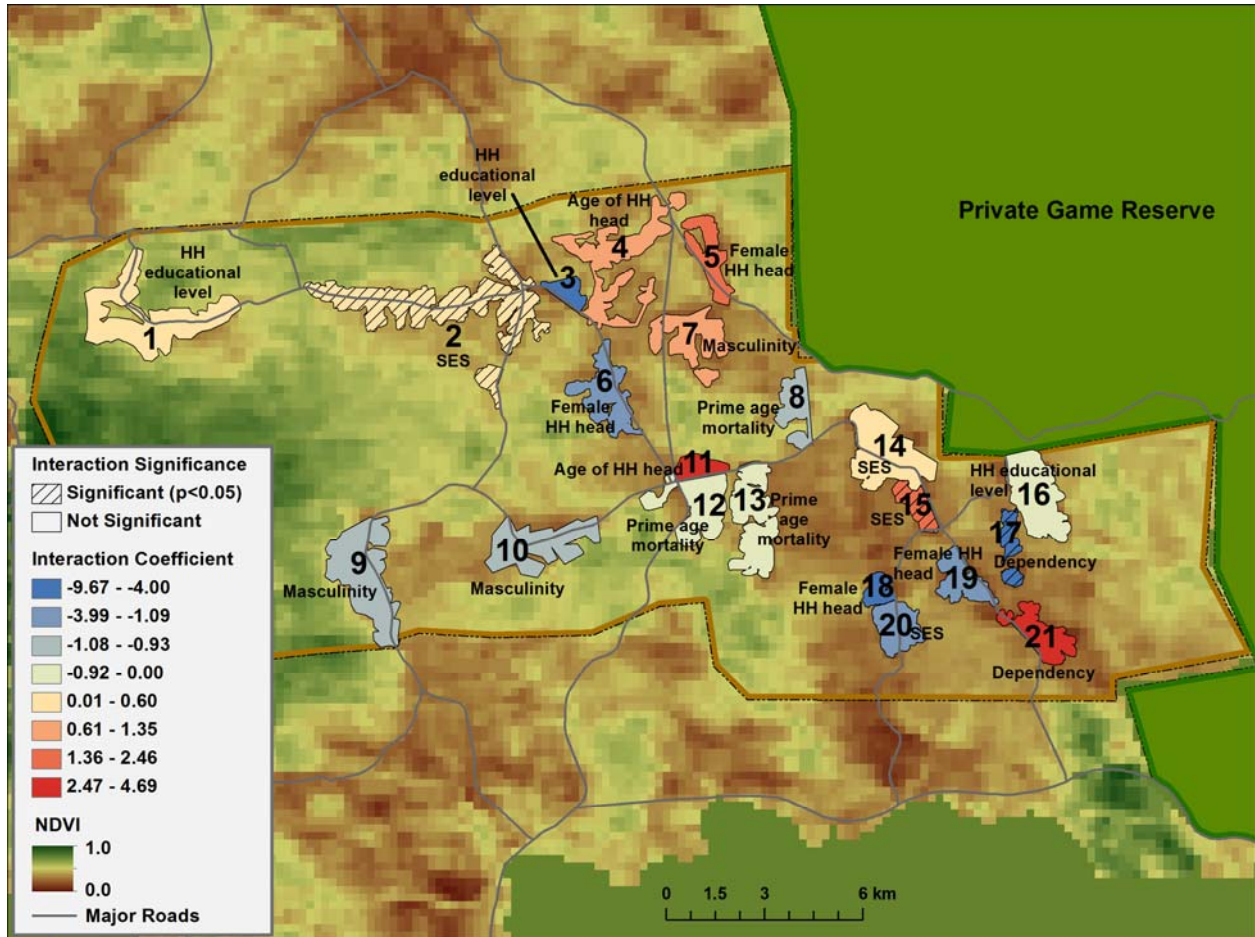




**Figure 3:**  
**NDVI coefficient estimates predicting temporary outmigration by household, village-level models,**  
**Agincourt Health and Demographic Surveillance Site, Mpumalanga Province, South Africa**



**Figure 4:**  
**Largest Standardized Coefficients for Interactions between NDVI and Secondary Predictors,**  
**Village-level Models, Agincourt Health and Demographic Surveillance Site,**  
**Mpumalanga Province, South Africa\***



\* "Dependency" = proportion elderly