Using Population Models to Compare Strategies for Slowing Population Growth in Countries with High Fertility

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Abstract

Countries in the developing world continue to feel the effects of rapid population growth despite slowing growth in some regions. Due to limited funding and costs of fieldwork however, programs working to slow population growth have been hesitant to spend money to compare different methods. My study used computer modeling to create control models for Haiti and Niger, two countries with the highest fertility in their respective regions. Control models were compared to experimental models that took into account improvements in either education or family planning programs. The models revealed that in Haiti, helping women with no education achieve primary education would be the most effective method of reducing growth, given that helping women achieve secondary education led to population decline. In Niger, achievement of secondary education for all women would be most effective. These results may suggest that more emphasis should be placed on education as a strategy for slowing population growth in developing countries.

List of Tables and Figures

Introduction

Despite the fact that human population growth has slowed in many regions, world population still increases by over 80 million people per year (Lutz and Qiang, 2002). In particular, countries in the developing world - often ravaged by poverty, famine, disease, health issues, and environmental ruin - feel the effects of rapid growth (Newbold, 2007). Of the world's total expansion, 98 % occurs in less-developed countries, where 81% of the human population resides (Newbold, 2007). In these areas, fertility rates, or average births per woman over a lifetime, are typically high (McNicoll, 1992).

The speed of global population expansion places an increasing burden on Earth's natural resources, including water, cropland, forests, and energy (Brown et al.., 1999). While the population has increased rapidly, grain production, croplands, and oceanic fisheries have not been able to keep up, and thus there is less of each resource available per person (Brown et al., 1999). Although technology has made significant contributions to human standards of living, it has been unable to improve food production to meet these rising demands (Pimentel and Pimentel, 1999). Additionally, water is a necessity both for human survival and for agriculture, and more people leads to greater strain on this integral resource (Pimentel and Pimentel, 1999). Finally, an increasing population requires more space and energy and produces more waste; this urbanization and expansion taxes forests and natural recreation areas (Brown et al., 1999).

Potential solutions to population growth can be grouped into three general categories: improvement of education, increase of socioeconomic status, and providing for family planning and healthy reproduction (Lutz and Qiang, 2002). Basic education can raise fertility consciousness and change social and cultural attitudes, raised socioeconomic status can lead to more women in the workforce and less need for laboring children, and increased family planning can help women limit their number of children if desired (Lutz and Qiang, 2002). However, programs in these areas are often lacking in funding (Newbold, 2007). Also, organizations conducting fieldwork are hesitant to spend money comparing effectiveness of approaches, as they would rather focus on those they support (Cohen, 1995).

Population modeling, which can be used to predict the size of a population in the future, is an alternative method that could be useful in comparing various growth slowing approaches to identify which would have the largest impact (Akcakaya et al., 1999). While an exponential growth model with an initial population and growth rate of R could be used to predict population size, this method rests on the false assumption that all individuals within a population are homogeneous (Akcakaya et al., 1999). Instead, human populations can be modeled more accurately using the cohort-component method which takes into account age and sex (Lutz and Qiang, 2002). The cohort-component method utilizes age or stage structure models, which require age or stage specific fertility and mortality rates as input data. Age distributed initial populations can be paired with these age specific rates in matrices to project populations over time (Leslie, 1945). Lutz et al. (2001) used this cohort-component method to create a median world population projection for 2100 concluding that world population growth may eventually end.

To serve as models for the present study, I chose the two countries with the highest fertility rates in their respective regions – Haiti (3.81 children/woman) in Latin America and Niger (7.75 children/woman) in Sub-Saharan Africa (CIA World Factbook, 2009). Haiti exhibits a class division between the few rich and the numerous poor

(Wingfield and Parenton, 1965), and 82% of the latter are eking out a rural, agricultural living (Allman, 1982). Family planning in Haiti – contraception for example – is not common, with only 5% of 15-49 year old women reporting steady contraceptive use (Chahnazarian, 1993). Of the males, 54.8% are literate, as are 51.2% of females (CIA World Factbook, 2009). Niger is characterized by rural villages and a farming economy (Faulkingham and Thorbahn, 1975). In Sub-Saharan Africa, women often have little control over their reproductive decisions, although contraceptive use increased from 19 to 29% in 15-49 year old married women between 1984 and 1988 (Kalipeni, 1995). Illiteracy rates are high, especially among women; 57.1% of the country's men are illiterate, as are 84.9% of its women (CIA World Factbook, 2009).

To compare future population growth in these two countries, I produced control models using age based modeling with current mortality and fertility rates. This method allowed me to take into account the differences in fertility and mortality between age classes. I used fertility data from health surveys and past attempts at slowing population growth to form experimental models comparing various forms of population control to control models. I hypothesized that, due to the low prevalence of contraceptives in Haiti, improvement of family planning programs would be the most effective solution there. Because of the high illiteracy rate in Niger, especially for women, I hypothesized that better education would lead to less population growth compared to controls. Therefore, I also hypothesized family planning programs would cause a greater percentage decline in population growth in Haiti as compared to Niger and that education would bring about a larger percentage decrease in growth in Niger as compared to Haiti.

Methods

Control Data

I acquired data to build control models of population growth for Haiti and Niger. For each country, I located current female age specific fertility rates (Haiti 2000: Demographic and Health Survey and Niger 1998: Demographic and Health Survey) and utilized population data to calculate age specific survivorships (U.S. Census Bureau International Database, 2009). Although data were organized in five year age class structures, I reorganized the data to 0-19, 20-24, 25-29, 30-34, 35-39, 40-44, and 45+ years of age for this study to create seven age classes for modeling purposes. The age specific population data is shown in Table 1. I calculated female age specific survivorships as the proportion of female individuals in an age group surviving to the next time step (Akcakaya et al., 1999). I averaged the survivorships for each age class less than 19 years of age to estimate the survivorship for my 0-19 age class and averaged the survivorships for each age class over 45 years of age to estimate the survivorship for my 45+ age class. The survivorships for my seven age classes are shown in Table 2.

The fertility data required some manipulation for use in the Leslie matrix necessary for modeling and so I could model only the female portion of the population. Fertility rates were presented in births per 1000 women, so I divided the data for each age class by 1000 to reach births per woman and multiplied these values by 0.5 to reach female births per woman. Finally, because each age class contained five years of reproduction, I multiplied each of these fertilities by five. I converted the fertility rates to fecundity – the average number of offspring per individual in an age group surviving from one time step to the next – by multiplying the fertility for each age class by the survivorship for that same age class (Akcakaya et al., 1999). The original fertility data and modified fecundity data are shown in Table 3. The fecundities for the control models (models NC and HC) are also found in comparison to experimental models in Table 4.

Experimental Data

Fertility rate was my independent variable of focus in the study. To create experimental growth models of the two countries to compare with the control models, I obtained fertility data that account for education and family planning programs already in place in each country. To create experimental models taking into account education, I used fertility data from the Demographic and Health Surveys conducted in Haiti in 2000 and Niger in 1998. A list of the experimental models and their abbreviations is found in Table 4.

To calculate experimental fecundities based on the effects of education, I first obtained known fertilities for a) all women – a baseline fertility b) women with no education c) women with primary education and d) women with secondary education (Haiti 2000: Demographic and Health Survey and Niger 1998: Demographic and Health Survey). I also obtained percentages of the female population by educational attainment (Haiti 2000: Demographic and Health Survey and Niger 1998: Demographic and Health Survey). For modeling purposes, women with primary education included women with preschool, some primary education, or all of primary education. Women with secondary education included all women who had either some or all of secondary education. For models NSE and HSE, which assume that all women with no education or primary education would achieve secondary education, I calculated the proportional difference between the baseline fertility and fertility for women with secondary education. Using the proportional difference from the aggregate data, I calculated the same proportional decrease in fecundity for each age class. For models NPE and HPE, which assume that all women with no education achieve primary education, I calculated the proportional difference between the baseline fertility and the average fertility of women with either primary or secondary education. Using the proportional difference from the aggregate data, I again calculated the same proportional decrease in fecundity for each age group (Table 4).

Experimental fecundities for increased family planning and contraceptive prevalence were estimated in a similar manner. I obtained a known fertility for all women in Haiti and Niger to serve as the baseline fertilities (Haiti 2000: Demographic and Health Survey and Niger 1998: Demographic and Health Survey). For models NFPW and HFP, I used data from Schultz (1994) which identified that in low income countries, increased family planning resulted in a 2.5 child decrease in total fertility. I calculated the proportional difference between the baseline fertility and a fertility decreased by 2.5. Using the proportional difference from the aggregate data, I calculated the same proportional decrease for each age group. For model NFPA, I utilized Africa specific data from Kirk & Pillet (1998) which found that in countries in Sub-Saharan Africa, those with increased family planning had a total fertility of 5.12 as compared to the 7.02 for countries with little family planning. I calculated the proportional difference between these fertilities, and using this proportional difference from the aggregate data, I again calculated the same proportional decrease for each age class (Table 4).

Modeling

I used RAMAS® Ecolab Software to simulate control and experimental populations. I utilized the Age and Stage Structure Program to project control and experimental models 50 years into the future. My methods were based loosely on exercises in Chapter 4: Age Structure of Akcakaya et al.'s *Applied Population Ecology: Principles and Computer Exercises using RAMAS® Ecolab* (1999). For the control models NC and HC, I added demographic stochasticity, allowed constraints to be in effect, and for simplicity, excluded density dependence. Each projection was replicated 50 times. The seven stages of the model were as the seven age classes specified above – weighting each as one – then specified initial abundances using current populations of each age class. Finally, I entered current age specific fecundities and survivorships into the matrix and ran each simulation.

Procedures for the experimental models were identical to those used for control models, except potential age specific fecundities were substituted for the known baseline fecundities. For each country, I generated models based on better education and increased family planning programs as identified in Table 4. I compared these experimental models with the control models for their respective countries as well as with each other by examining graphical trajectories, average population sizes at 25 years, average population sizes at 50 years, and percent decrease in growth as a result of each experimental model. Additionally, I statistically compared the models by calculating a confidence interval using Microsoft Excel and standard deviation data from RAMAS®. Due to software limitations, once populations reached a size of 2.1 billion the program no longer presented standard deviation. In such instances, I used the last known standard deviation before the population exceeded 2.1 billion. Using the confidence interval, I identified lower and upper limits for each model and examined the overlap between models.

Results

The modeling simulations yielded results in the form of both graphical and numerical data. Graphs of the population growth trajectories show changes in population numbers over the 50 year interval (Figures 1-9). A summary of the average population size and the standard deviation at both 25 years and 50 years are included in Table 5 for each model. From the average and standard deviation, I calculated a confidence interval and upper and lower confidence limits and compared the models for overlapping limits in Table 6 for Haiti and Table 7 for Niger. If the limits did not overlap, I concluded that the population sizes were different and if they did overlap I concluded that they were statistically the same. Finally, to compare Haiti with Niger, I located the percentages of decrease in growth due to the experimental models as shown in Table 8. The percentage decrease in growth compared the final population reached in each experimental model with the final population of the control model.

Discussion

My study attempted to identify effective methods for slowing population growth using population modeling as opposed to conducting fieldwork. In Haiti, all experimental models at both 25 years and 50 years were significantly different from the control and from each other, indicating that increases in family planning programs and improved education may have an impact on population growth. For models HSE and HFP, the Haitian population trajectory moved toward extinction and did so more quickly for secondary education. This reveals both that these solutions will not be effective unless accompanied by a decline in mortality rates and that secondary education may provide a more rapid method for fertility decline. Of the three experimental models, model HPE was the most effective in decreasing population growth without causing extinction. This does not support the hypothesis that increased access to contraceptives and family planning would have the most impact on Haitian population growth.

Findings that better education may be the most effective strategy for slowing population growth in Haiti reveal a different angle from past research. A national family planning program has been put in place in Haiti, and studies by James Allman (1982) have focused on the impact of these programs. By surveying women in Haiti, Allman concluded that there were high levels of knowledge about both modern and traditional methods of contraception and that many women wanted to limit their number of children, but traditional methods of contraception were most prevalent even though they can be inefficient. Allman and May (1979) concluded similarly that although contraceptives are available, family planning programs have had a small influence. However, another study directly distributed oral contraceptives in rural areas in Haiti and found that contraceptive use increased and pregnancy decreased (Bordes et al., 1982). In light of the results of the current study, it is possible that education is a necessary component in fertility decline beyond the availability of contraceptives. This conclusion is not at odds with the findings of Bordes et al., (1982) as the direct distribution methods included information on family planning, a form of educating women.

In Niger, most of the experimental models at 25 years and 50 years were significantly different from the control and each other. However, some models were statistically the same. Models NFPW and NSE were the same at both 25 and 50 years and like the control, models NFPA and NPE reached the software limit at 50 years. These results reflect the higher fertility rates and greater threat of population explosion in Niger as compared to Haiti. While models NFPW and NSE produced the same results, the differing results from model NFPA may indicate that modeling with regional data provides a more accurate picture of population growth. With this in mind, secondary education was the most effective method for reducing population growth, followed by increasing family planning programs, followed by helping women with no education achieve primary education. Assuming that achievement of secondary education for all women is feasible, this does support the hypothesis that better education would have the most impact on population growth in Niger.

Past studies regarding fertility in Niger reveal numerous contradictions and highlight the limitations and complicated nature of population studies. Caldwell et al. (1992) conclude that providing contraceptive services for women with the greatest need is the best way to facilitate fertility decline in Africa. As an example of past successes of contraception in Africa, South Africa, Botswana, and Zimbabwe have achieved fertility decline by instituting family planning programs (Lucas, 1992). In contrast to these results and paralleling the conclusions of my study, Kravdal (2002) finds that both educational levels of individual women and of communities as a whole lead to lower fertility levels. Kalipeni (1996) on the other hand, asserts that both contraceptive use and education are factors necessary for fertility decline.

When modeling populations, it is difficult to establish causality and tease apart tendencies. Analogous to trends in Haiti, the above contradictions bring to view the possibility that education may be an important component to contraceptive use. By surveying women in Zaire, Shapiro and Tambashe (1994) found that women with better education were more likely to use contraception. Another study in Sub-Saharan Africa also concluded that while contraception was the most important proximate determinate of fertility decline, it was influenced by higher educational status of women (Kirk and Pillet, 1998). It is probable that the multiple factors affecting fertility comprise a complex web of relationships impacting each other and human population growth as a whole.

Other limitations are evident in my study as well. No modeling study provides an exact simulation of reality, as population growth is an intricate process. For example, due to constraints such as food, space, and disease, a population will reach its carrying capacity as opposed to experiencing exponential growth as assumed in my models. Additionally, while it is possible to hypothesize how a particular variable will impact fertility rates, due to differences in cultural and societal norms it is impossible to articulate with certainty the effects in a specific country. Another important limitation involves the lack of age-specific experimental data. I applied an average decrease in fertility to multiple age classes, but it is possible that education or family planning could impact different age classes in unique ways. For example, Lutz and Goujon (2001) projected populations in multiple regions by creating more modeling stages taking into account both age and education. Finally, for models NSE and HSE, it is unlikely that every woman in the country would achieve secondary education and thus lowered fertility. However, considering that all of my models included the same simplifying assumptions, my comparisons between models that differ only in education and/or family planning suggest that these experimental factors do have an effect on population growth.

Comparing strategies for slowing population growth in Haiti and Niger, the hypothesis that different methods would be more effective in Latin America than Africa was not supported. For both countries secondary education resulted in the greatest percentage of decrease in population growth, even though the population in Haiti declined and that in Niger grew. The secondary education model was followed by family planning, with primary education the least effective of the three. This may indicate that improved education is a necessity for slowing population growth in developing countries worldwide as opposed to regionally. The countries did differ in the specific impact of the experimental models, as Niger more frequently reached the software population limit and Haiti more frequently moved towards extinction. This sheds light on the urgency of population growth issues in Niger as compared to Haiti.

Some studies contradict with my findings. For example, family planning programs played an integral role in reducing fertility rates in Bangladesh from 1980 to 1996 (Caldwell and Barat-e-Khuda, 2000). Other research corroborates my findings. Using regression analysis, Hadden and London (1996) concluded that education for females in developing countries leads to lower birth rates. Similarly, Schultz (1994) showed that women's education had a significant reduction effect on fertility rates while family planning did not. In a more specific instance, female education was identified as the most important factor in recent fertility reductions in India (Dreze and Murthi, 2001).

The complexity of population growth lends itself to further research on this topic. More countries with high fertility could be examined to better establish the widespread impact of education. Additionally, exact age-specific fertility rates for experimental models could provide a more accurate picture of population growth. The costs of education versus family planning could also be examined, as that could have an impact on whether one of the methods is more cost effective even if it is not the most effective method overall. Finally, more fieldwork could be conducted comparing strategies for slowing population growth and more data collected in general, as this could be helpful in establishing causality of fertility decline. Regardless, my results suggest that education is an effective tool in managing population growth.

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Tables and Figures

Table 1: Female Age Specific Population							
	0-19	20-24	25-29	30-34	35-39	40-44	45+
Haiti	2,236,164	461,655	381,705	307,926	257,567	226,302	770,232
Niger	4,701,620	644,341	536,705	444,711	358,531	296,216	949,215
Note: Data from U.S. Census Bureau International Database, 2009							

Table 2: Female Age Specific Survivorships							
	0-19	20-24	25-29	30-34	35-39	40-44	45+
Haiti	0.96	0.83	0.81	0.84	0.88	0.89	0.52
Niger	0.80	0.83	0.83	0.81	0.83	0.84	0.48

Table 3 – Age Specific Fertility Rates and Fecundities							
Fertility Rates (births per 1,000 women)							
	0-19	19-24	25-29	30-34	35-39	40-44	45+
Haiti	80	187	204	219	153	75	18
Niger	216	322	319	293	206	96	42
Fecundities							
	0-19	19-24	25-29	30-34	35-39	40-44	45+
Haiti	0.19	0.39	0.41	0.46	0.34	0.17	0.02
Niger	0.43	0.67	0.66	0.59	0.43	0.20	0.05
Note: Data from Haiti 2000: Demographic and Health Survey and Niger 1998: Demographic and Health Survey							

Table 4: Fecundities for Control and Experimental Models								
Model	**Description**	0-19	20-24	25-29	30-34	35-39	40-44	45+
NC	Niger Control	.42	.67	.66	.59	.43	.20	.05
NSE	Niger Secondary Education	.27	.43	.42	.38	.28	.13	.03
NPE	Niger Primary Education	.38	.59	.58	.52	.37	.18	.04
NFPW	Niger Family Planning with Worldwide Data	.28	.43	.43	.38	.28	.13	.03
NFPA	Niger Family Planning with Africa Specific Data	.31	.49	.48	.43	.31	.15	.04
HC	Haiti Control	.19	.39	.41	.46	.34	.17	.02
HSE	Haiti Secondary Education	.10	.21	.22	.24	.18	.09	.01
HPE	Haiti Primary Education	.18	.36	.38	.42	.30	.15	.02
HFP	Haiti Family Planning with Worldwide Data	.09	.18	.19	.21	.16	.08	.01

Table 5: Numerical Summary of Population Growth					
Model	**Type of Growth***	**Population Size at 25 Years**	**Standard Deviation at 25 Years**	**Population Size at 50 Years**	**Standard Deviation at 50 Years**
Niger Control	Limit – 21 years	2.1 billion	894,336	2.1 billion	894,336
Niger Secondary Education	Normal growth	94,724,392	72,840	1 billion	955,456
Niger Primary Education	Limit – 29 years	1,042,155,712	711,680	2.1 billion	1,475,456
Niger Family Planning Worldwide Data	Normal growth	94,724,392	72,840	1 billion	955,456
Niger Family Planning Africa Specific Data	Limit – 40 years	284,140,096	239,648	2.1 billion	1,343,488
Haiti Control	Limit – 50 years	101,339,968	101,512	2.1 billion	1,801,600
Haiti Secondary Education	Decline	896,316	2,777	125,297	954
Haiti Primary Education	Normal Growth	51,080,672	53,496	552,983,552	669,568
Haiti Family Planning Worldwide Data	Decline	1,012,582	2,728	180,664	1,121
**Limit* (with a year) identifies a model that reached the 2.1 billion limit of the software in a particular year. *Decline* identifies a model that experienced population decline as opposed to growth. *Normal* means that the population experienced growth but did not reach the limit.					

Table 6: Overlap of Limits for Haiti Models*

25 Years

	Haiti Family Planning	Haiti Primary Education	Haiti Secondary Education	Haiti Control
Haiti Control	No	No	No	
Haiti Secondary Education	No	No		
Haiti Primary Education	No			
Haiti Family Planning				

50 Years

	Haiti Family Planning	Haiti Primary Education	Haiti Secondary Education	Haiti Control
Haiti Control	No	No	No	
Haiti Secondary Education	No	No		
Haiti Primary Education	No			
Haiti Family Planning				

*Confidence intervals were calculated for each model using standard deviations. Upper and lower limits were calculated for each model using the confidence intervals. If the upper and lower limits of two models did not overlap, as identified by a "No" above, the models were considered to be significantly different. If the upper and lower limits did overlap, as identified by a "Yes" above, the models were considered to be the same.

Table 7: Overlap of Limits for Niger Models					
25 Years					
	Niger Family Planning Africa Specific	Niger Family Planning Worldwide	Niger Primary Education	Niger Secondary Education	Niger Control
Niger Control	No	No	No	No	
Niger Secondary Education	No	Yes	No		
Niger Primary Education	No	No			
Niger Family Planning Worldwide	No				
Niger Family Planning Africa Specific					
50 Years					
	Niger Family Planning Africa Specific	Niger Family Planning Worldwide	Niger Primary Education	Niger Secondary Education	Niger Control
Niger Control	Yes	No	Yes	No	
Niger Secondary Education	No	Yes	No		
Niger Primary Education	Yes	No			
Niger Family Planning Worldwide	No				
Niger Family Planning Africa Specific					
*Confidence intervals were calculated for each model using standard deviations. Upper and lower limits were calculated for each model using the confidence intervals. If the upper and lower limits of two models did not overlap, as identified by a "No" above, the models were considered to be significantly different. If the upper and lower limits did overlap, as identified by a "Yes" above, the models were considered to be the same.					

Table 8: Percent Decrease Population Growth from Control to Experimental Models*

Haiti

	Secondary Education	Primary Education	Family Planning
25 Years	99.1%	50.0%	99.0%
50 Years	100%	74.7%	100%

Niger

	Secondary Education	Primary Education	Family Planning Worldwide Data	Family Planning Africa Specific Data
25 Years	95.5%	50.4%	95.5%	86.4%
50 Years	52.4%	0%	52.4%	0%

*Percent decrease population growth refers to the percent decrease of growth incurred under each experimental model when compared to the control.

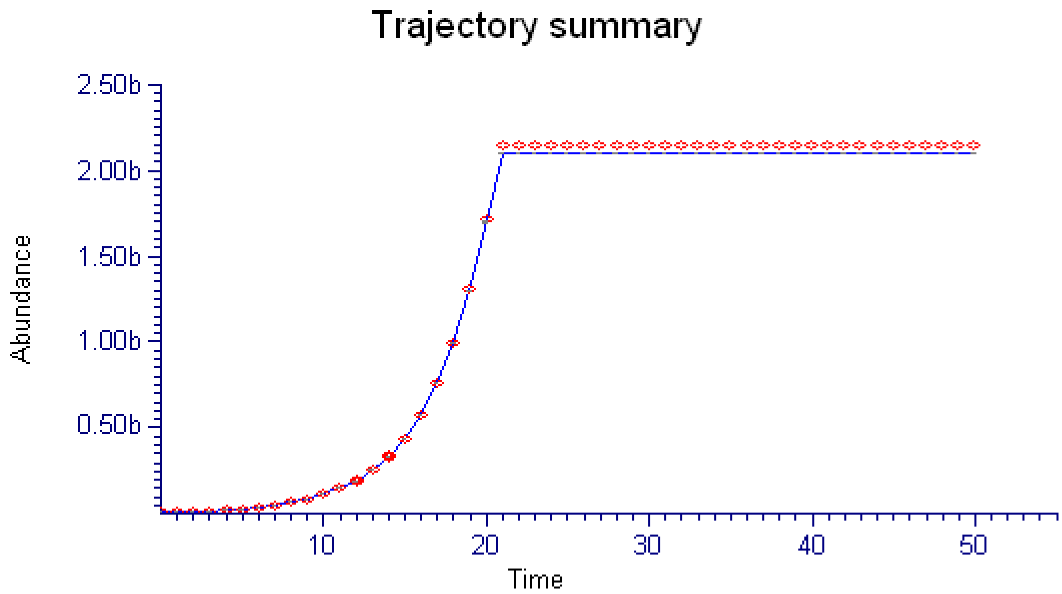

Figure 1. Niger Control Trajectory. Current age specific fecundities and survivorships were used to project the trajectory of population growth in Niger fifty years into the future.

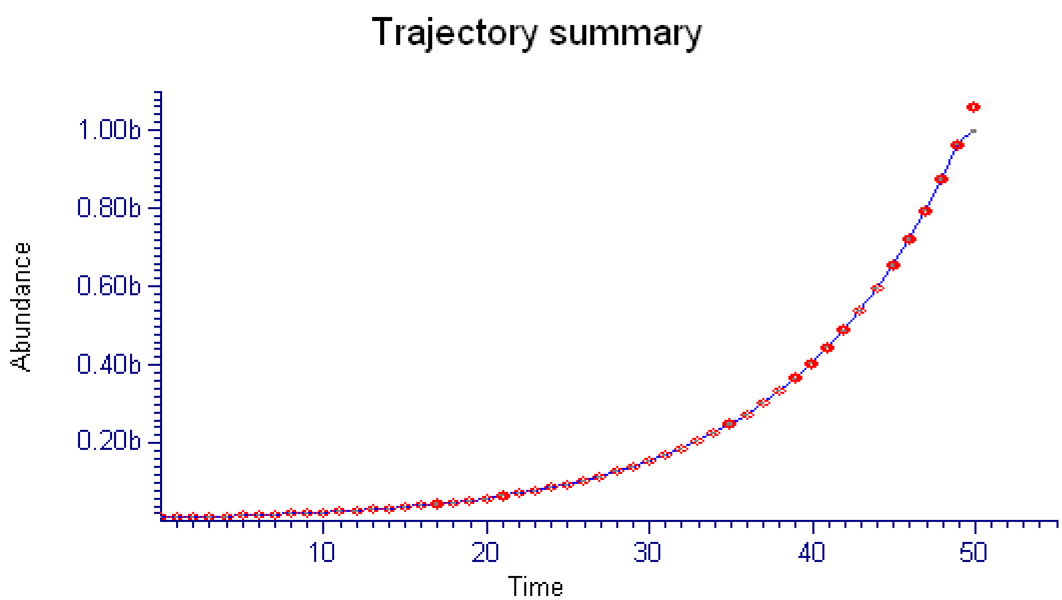

Figure 2. Niger Secondary Education Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Niger fifty years into the future.

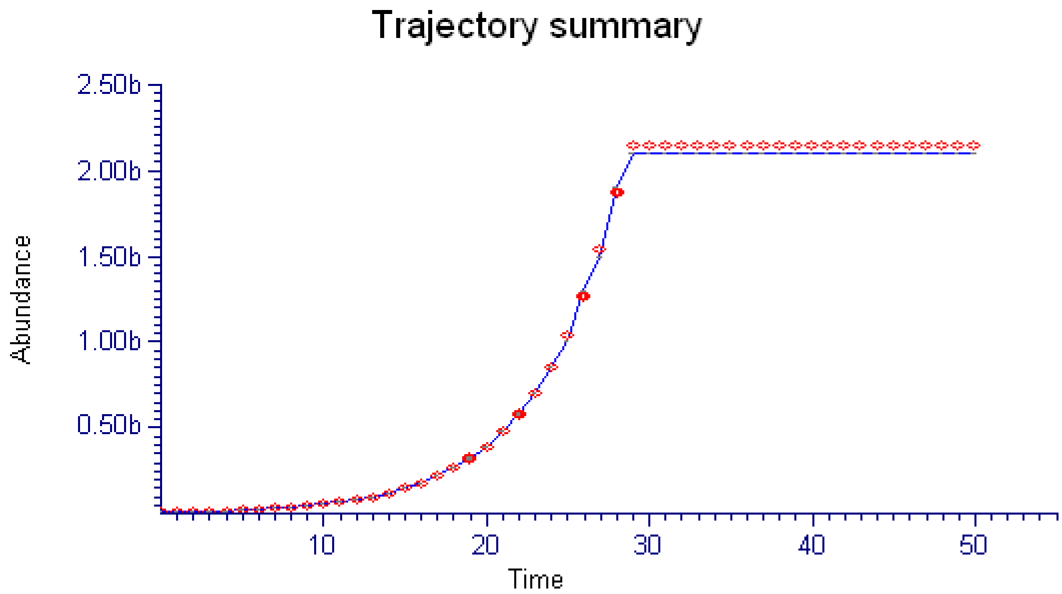

Figure 3. Niger Primary Education Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Niger fifty years into the future.

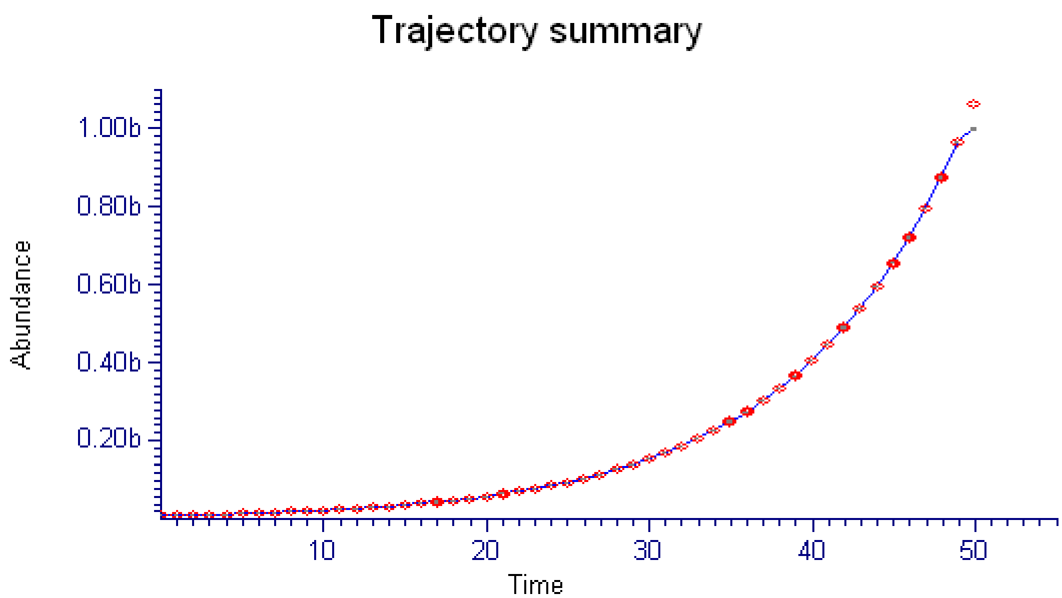

Figure 4. Niger Family Planning with Worldwide Data Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Niger fifty years into the future.

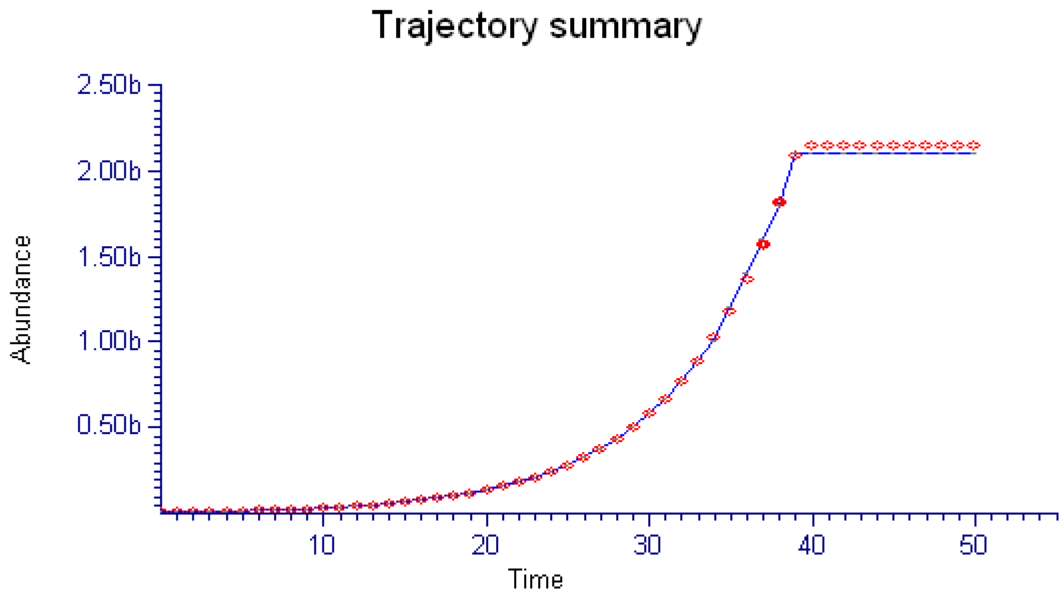

Figure 5. Niger Family Planning with Africa Specific Data Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Niger fifty years into the future.

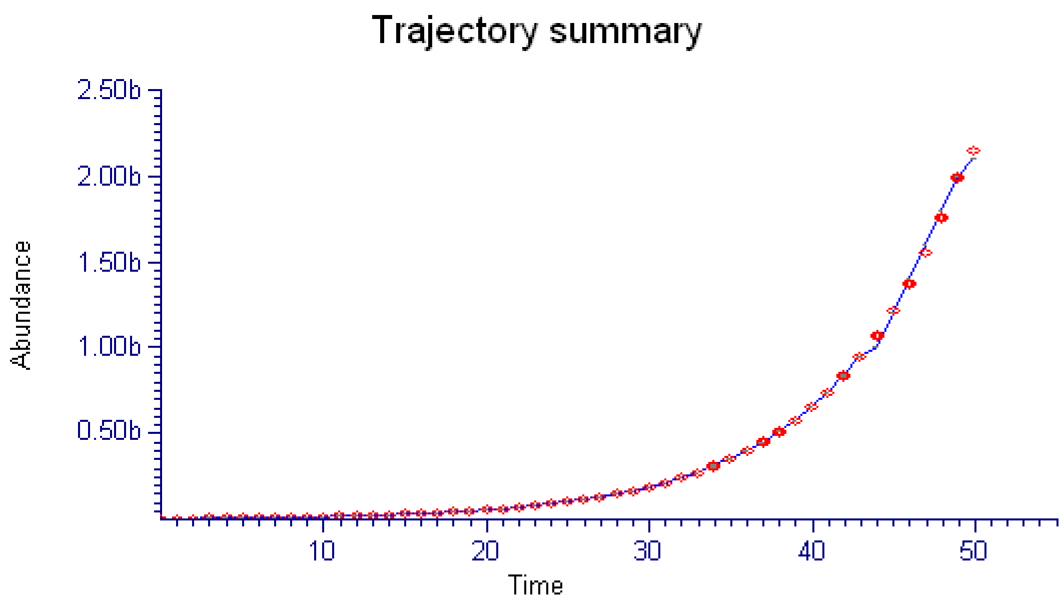

Figure 6. Haiti Control Trajectory. Current age specific fecundities and survivorships were used to project the trajectory of population growth in Haiti fifty years into the future.

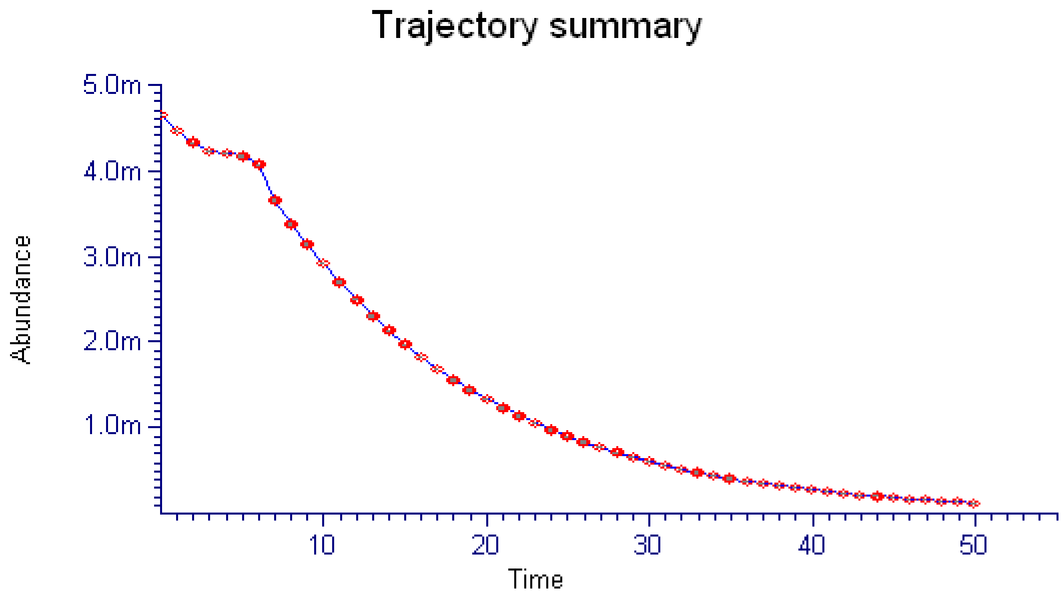

Figure 7. Haiti Secondary Education Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Haiti fifty years into the future.

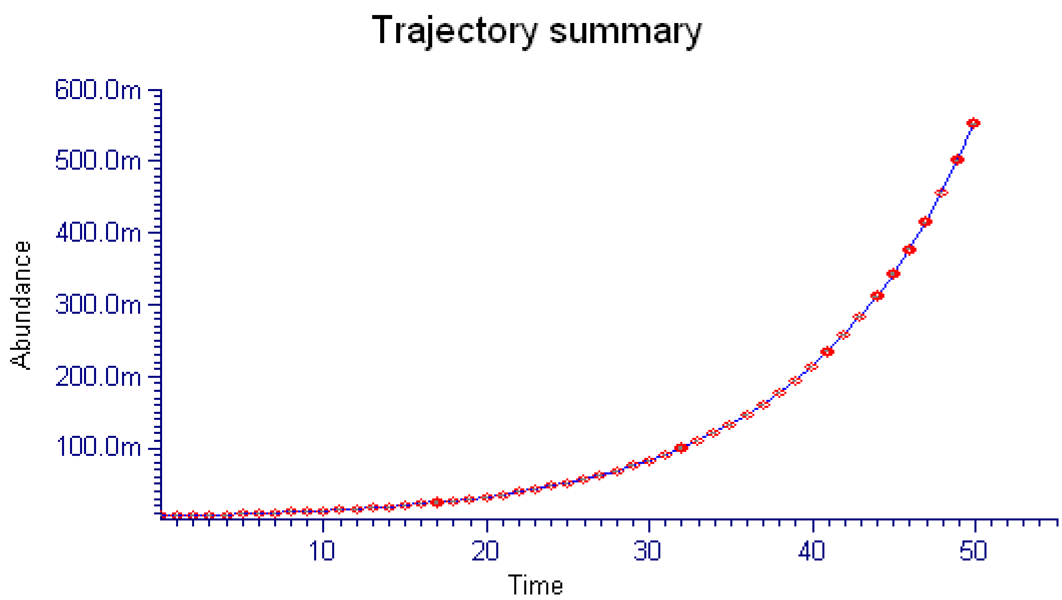

Figure 8. Haiti Primary Education Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Haiti fifty years into the future.

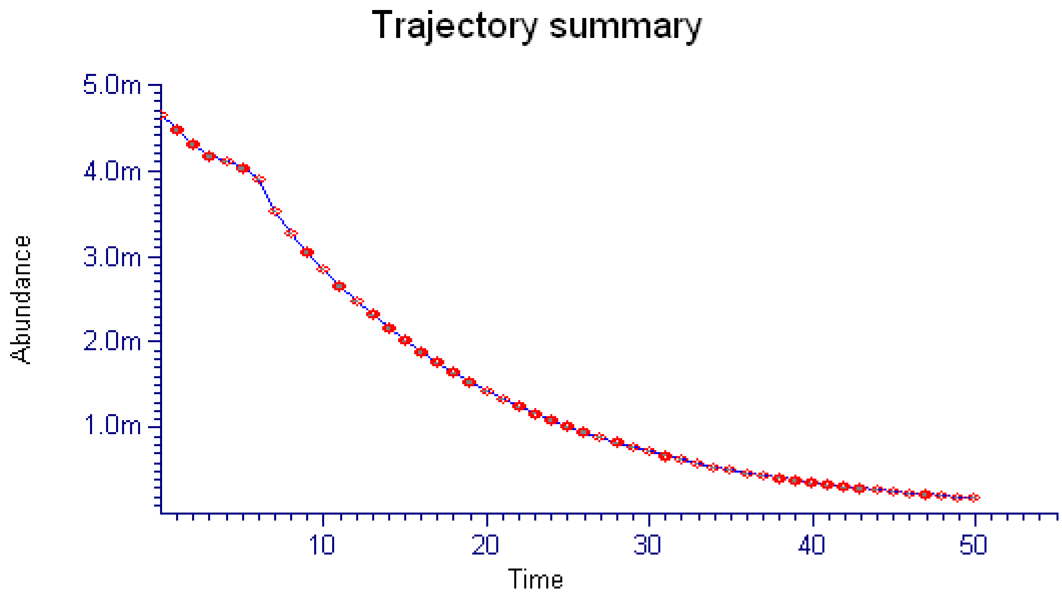

Figure 9. Haiti Family Planning with Worldwide Data Trajectory. Experimental age specific fecundities and survivorships were used to project the trajectory of population growth in Haiti fifty years into the future.