Chapter 9

RWANDA

Ngoga G. Tenge, Mutabazi Alphonse, and Timothy S. Thomas

Rwanda is located 2° south of the equator in central Africa and covers a surface area of 26,338 square kilometers. The country is primarily mountainous, with the average altitude ranging from 900 meters in the southeast to 4,500 meters in the regions of the Congo–Nile crest. The countryside is covered by grasslands. The eastern slopes are more moderate, with rolling hills extending across central uplands gradually reducing in altitudes to the plains, swamps, and lakes of the eastern border region. Due to the high altitude, the country experiences average annual temperatures ranging from 16° to 20°C (REMA 2009).

The Rwandan economy is primarily based on rainfed agriculture, with coffee and tea the major cash crops. Farms are small, fragmented, and semisubsistence oriented. The country has few natural resources to exploit and a small, uncompetitive industrial sector. In 2009 its gross domestic product (GDP) was estimated to be $5.1 billion. Agriculture accounted for 36 percent, industry 14.2 percent, and services 43.7 percent of GDP. The Government of Rwanda remains dedicated to a strong and enduring economic climate for the country, focusing on poverty reduction, infrastructure development, privatization of government-owned assets, expansion of the export base, and trade liberalization. Agricultural reforms have improved crop yields, the national food supply, and farming methods and have increased the use of fertilizers. In addition, the government is pursuing educational and healthcare programs that bode well for the long-term quality of Rwanda's human resource skills base (REMA 2009; USDoS 2011).

However, several challenges remain for Rwanda. The country relies heavily on foreign aid. Exports continue to lag far behind imports, affecting the health of the economy. The persistent lack of economic diversification beyond the production of tea, coffee, and minerals keeps the country vulnerable to market fluctuations. Expensive electricity and limited transportation impede private-sector development and raise the costs of imports and exports (USDoS 2011).

In addition, recent climate change patterns have also threatened ongoing economic improvements. Climate-related events like heavy rainfall or too little rainfall occur more frequently than in years past and are affecting human well-being. Droughts are often responsible for famine, food shortages, a reduction in plant and animal species, and displacement of people in search of food and pasture. At times these have led to conflicts over different land resources, as was the case for protected areas. In the past 10 years, these disasters have occurred throughout the country, exacerbated by poor farming practices, deforestation, and environmental degradation. These climatic events have affected health, water quality, transportation, and agriculture, leaving the country drained of its wealth and increasing the level of poverty. The poor are most vulnerable to climatic effects. Although the Rwandan government has drafted policies to address these disasters, assessing their impact is vital to the management, reduction, and mitigation of potential risks (REMA 2009, 2010; SEI 2009).

Review of the Current Situation and Trends

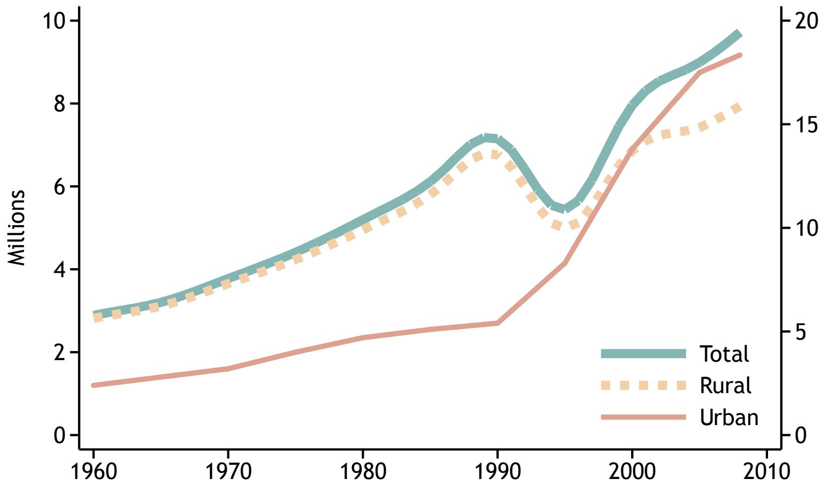
Economic and Demographic Indicators

Population

Figure 9.1 shows the total and rural population counts (left axis) and the share of the population that is urban (right axis). The Rwandan development indicators published by the National Institute of Statistics of Rwanda (2008) listed the total population of the country as an estimated 8.9 million in 2005. The figure shows a clear decline of the total and rural populations from about 1990 to 1995, which coincides with the war and genocide that led to mass migrations and deaths. The urban population as a percentage of the total began to increase rapidly during that time and has slowed only slightly since around 2005.

The increases in urban population resulted from the rural exodus, the return of refugees who lived in foreign countries after the 1994 genocide, and improvements in health and well-being. These events increased the percentage of the population in urban areas from 5.5 percent to 16.7 percent between 1991 and 2002. In its Vision 2020 plan, Rwanda recognizes the productive management of land and effective basic infrastructure as two of the pillars. The vision stipulates that Rwandan towns will have the tools to achieve sustainable urban management and planning and that the percentage of the population living in urban areas will grow to 30 percent by 2020. Furthermore, the country's Poverty Reduction Strategy Paper (Rwanda, Ministry of Finance and Economic Planning 2007) also advocates mainstreaming capacity building for the decentralized entities to improve urban and habitat management. In the

FIGURE 9.1 Population trends in Rwanda: Total population, rural population, and percent urban, 1960–2008



Source: *World Development Indicators* (World Bank 2009).

urban areas, a large percentage of the population lives below the poverty line, and more than 80 percent live in slums with no access to land.

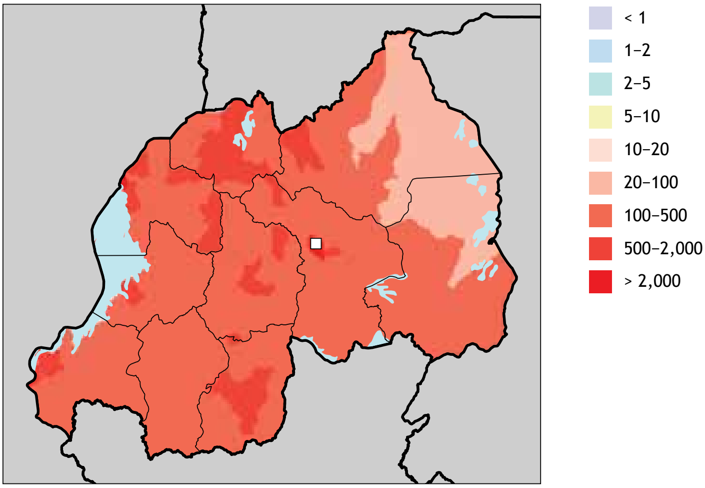
Table 9.1 provides additional information concerning rates of population growth between 1960 and 2008. The total population growth for the first three decades was 2.6, 3.2, and 3.7 percent, respectively; in the decade 1990–1999, in which the genocide was perpetrated, the growth rate was only –0.1 percent, and the growth rate during the first decade of the 21st century was 2.3 percent (through 2008). These trends in growth rates line up with the tendencies observed in Figure 9.1.

TABLE 9.1 Population growth rates in Rwanda, 1960–2008 (percent)

Decade	Total growth rate	Rural growth rate	Urban growth rate
1960–1969	2.6	2.5	5.5
1970–1979	3.2	3.0	7.1
1980–1989	3.7	3.7	5.2
1990–1999	–0.1	–0.9	9.4
2000–2008	2.3	1.6	5.9

Source: Authors' calculations based on *World Development Indicators* (World Bank 2009).

FIGURE 9.2 Population distribution in Rwanda, 2000 (persons per square kilometer)



Source: CIESIN et al. (2004).

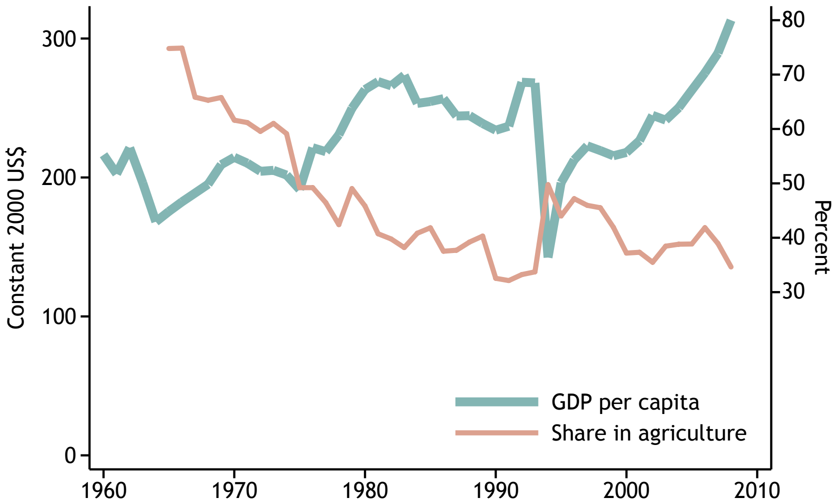
Figure 9.2 shows the geographic distribution of the population in Rwanda. Generally the country's recorded average population density of 321 persons per square kilometer is one of the highest of any country in the world, particularly one that relies on agriculture. The maps show that the country is densely populated except in places occupied by bodies of water located toward the borders with Democratic Republic of Congo and Tanzania.

Income

Figure 9.3 shows trends in GDP per capita and the proportion of GDP from agriculture in Rwanda. Recent information from the National Institute of Statistics of Rwanda (2008) shows that GDP per capita has increased considerably during the past five years, reaching US$465 (current US dollars, whereas the figure shows constant 2000 US dollars). Agriculture, forestry, and fishing activities contributed 39 percent of GDP, industry 14 percent, and services 41 percent.

Agriculture's contribution to the economy was nearly 80 percent of GDP at the beginning of the 1960s but is less than 40 percent today, which suggests the rising contribution of other sectors. Although the agricultural sector's proportion of GDP has declined, its importance in employment has changed little. The agricultural sector still employs 90 percent of the total labor population. The development of the agroindustry and appropriate post harvest technologies for each crop could increase employment in the industry and service sectors, thus enhancing the country's resilience to the threats of climate change.

FIGURE 9.3 Per capita GDP in Rwanda (constant 2000 US$) and share of GDP from agriculture (percent), 1960–2008



Source: *World Development Indicators* (World Bank 2009).
Note: GDP = gross domestic product; US$ = US dollars.

Vulnerability to Climate Change

Table 9.2 provides some data on additional indicators of vulnerability and resiliency to economic shocks: the education level of the population, the literacy rate, and the concentration of labor in poorer or less dynamic sectors. The high levels of primary education and adult literacy signify that much of the population has the potential to adapt to climate change through learning strategies, which would reduce their vulnerability to its adverse effects. However, the low levels of secondary education signify the low capacity of the population to take advantage of various employment opportunities. Hence, as observed in Table 9.2, most people remain engaged in agriculture—crop production, livestock rearing, fishing, and related services. Accordingly, many continue to be vulnerable to the impacts of climate change.

Figure 9.4 shows two noneconomic correlates of poverty, life expectancy and under-five mortality. Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.

Generally the graph shows very small improvements in under-five mortality and life expectancy trends in Rwanda. The sharp fall in life expectancy about 1991–1992 can be attributed to the genocide being carried out at that time. Life

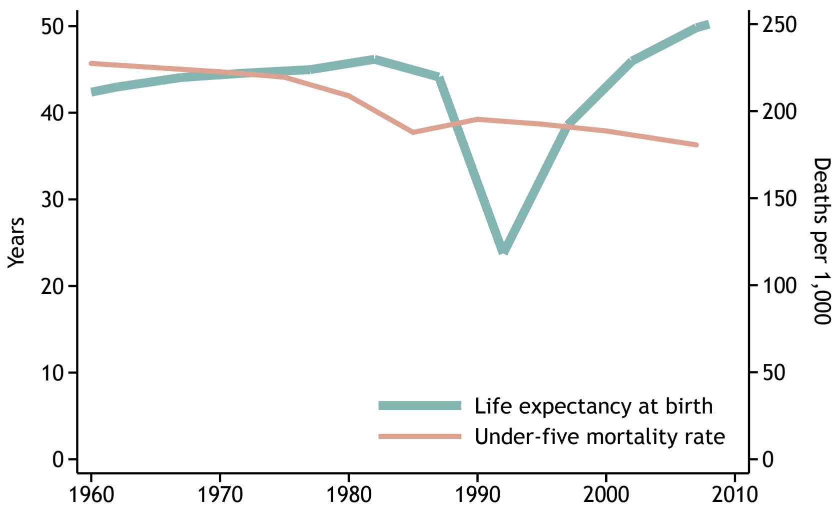
TABLE 9.2 Education and labor statistics for Rwanda, 1990s and 2000s

Indicator	Year	Percent
Primary school enrollment: Percent gross (three-year average)	2007	147.4
Secondary school enrollment: Percent gross (three-year average)	2007	18.1
Adult literacy rate	2000	64.9
Percent employed in agriculture	1989	90.1
Percent with vulnerable employment (in agriculture on own farm or as a day laborer)	1996	92.5
Under-five malnutrition (weight for age)	2005	18.0

Source: *World Development Indicators* (World Bank 2009).

expectancy and child mortality in Rwanda are affected by a wide range of factors such as malaria, diarrhea, injuries, and HIV/AIDS (WHO 2006). Several environmental conditions contribute to these factors, such as floods and droughts. Future advancements in these health indicators may be compromised by climate change, which often acts to alter these conditions. Climate change may cause droughts and flooding that will affect food security, eventually leading to malnutrition, morbidity, or death. Rwanda, for instance, has experienced four major floods in the past seven years—in 2006, 2007, 2008, and 2009—which resulted

FIGURE 9.4 Well-being indicators in Rwanda, 1960–2008



Source: *World Development Indicators* (World Bank 2009).

in fatalities, injuries, water contamination, and destruction of agriculture and infrastructure, among other damages. These effects have had economic consequences including increased direct medical costs, health protection costs, time lost at work, and welfare change. For example, the economic cost associated with the 2007 flood alone was about $22 million, of which the health economic costs were estimated to be between $1.6 million and $18.0 million. These events place a greater burden on the country's GDP, further increasing poverty (SEI 2009). Wood et al. (2010) report that in Rwanda, 85–95 percent of the people are living on less than $2 a day.

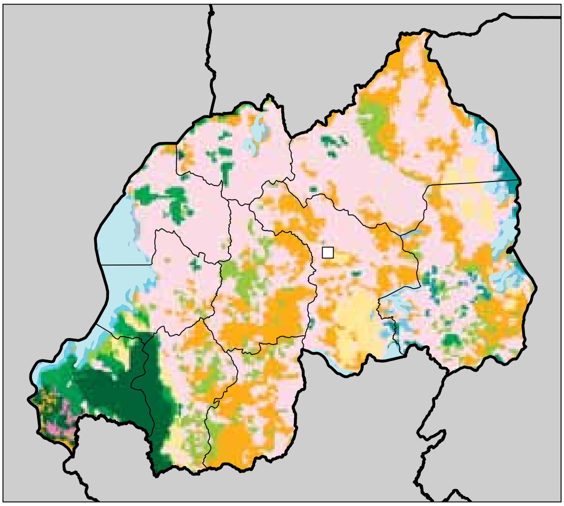
As a consequence of the traumatic upheaval of the genocide in the early 1990s, the baseline year for monitoring progress toward the Millennium Development Goal for poverty reduction in Rwanda was set to 2000. Progress in reducing poverty has been very slow in spite of strong economic growth. In 2006, 57 percent of the population lived below the national poverty line, and 37 percent of those people were regarded as extremely poor because they could not obtain the minimum calorie requirement on their income. Poverty declined most in urban areas in proportionate terms. In rural areas, poverty declined from 66.1 to 62.5 percent between 2000 and 2006. Improving rural incomes is critical to reducing poverty given that 90 percent of the population still lives in rural areas. A majority of rural income is generated through agriculture, which is affected by a number of input factors, including climatic patterns. Climate fluctuations will alter agricultural output directly and indirectly through change in input factors such as labor. With low incomes and little education, the rural poor are limited in their options for coping with the effects of climate change.

Review of Land Use, Potential, and Limitations

Land Use Overview

Figure 9.5 shows land cover and use in Rwanda as of 2000. Most of the country consists of cultivated and managed areas and shrub cover. The largest forested area is situated in the southwestern corner of the country, where Nyungwe National Park is located. Because agricultural land is taking more space over time as the forest cover diminishes, agroforestry is becoming a good option for poor households in the rural areas, providing not only forest products like firewood but also many other benefits, such as biomass for soil fertility, fodder for livestock, staking material for climbing beans, and erosion control. Agroforestry and agricultural intensification should be given more emphasis because agriculture puts a great amount of pressure on the land.

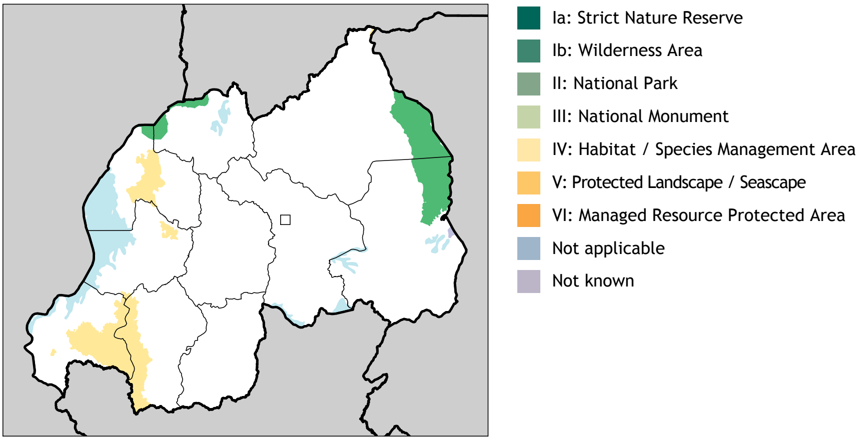
FIGURE 9.5 Land cover and land use in Rwanda, 2000



- Tree cover, broadleaved, evergreen
- Tree cover, broadleaved, deciduous, closed
- Tree cover, broadleaved, open
- Tree cover, broadleaved, needle-leaved, evergreen
- Tree cover, broadleaved, needle-leaved, deciduous
- Tree cover, broadleaved, mixed leaf type
- Tree cover, broadleaved, regularly flooded, fresh water
- Tree cover, broadleaved, regularly flooded, saline water
- Mosaic of tree cover/other natural vegetation
- Tree cover, burnt
- Shrub cover, closed-open, evergreen
- Shrub cover, closed-open, deciduous
- Herbaceous cover, closed-open
- Sparse herbaceous or sparse shrub cover
- Regularly flooded shrub or herbaceous cover
- Cultivated and managed areas
- Mosaic of cropland/tree cover/other natural vegetation
- Mosaic of cropland/shrub/grass cover
- Bare areas
- Water bodies
- Snow and ice
- Artificial surfaces and associated areas
- No data

Source: GLC2000 (Bartholome and Belward 2005).

FIGURE 9.6 Protected areas in Rwanda, 2009



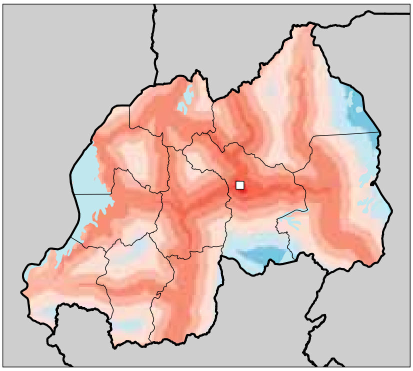
Sources: Protected areas are from the World Database on Protected Areas (UNEP and IUCN 2009). Water bodies are from the World Wildlife Fund's Global Lakes and Wetlands Database (Lehner and Döll 2004).

According to the *Rwanda State of Environment and Outlook Report* (REMA 2009), protected areas in Rwanda include national parks (Akagera, 108,500 hectares; Nyungwe, 101,900 hectares; and Volcanoes National Park, 16,000 hectares); forest reserves (Gishwati, 700 hectares; Iwawa Island and Mukura, 1,933 hectares); forests of cultural importance (Buhanga Forest); and wetlands of global importance (the Rugezi–Bulera–Ruhondo wetland complex).

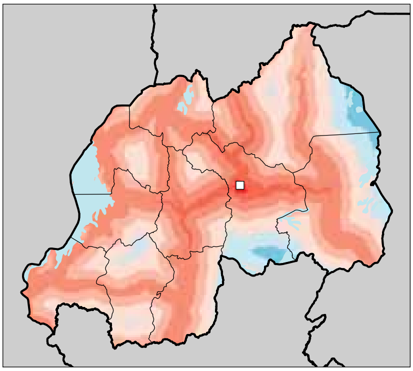
Figure 9.6 shows the locations of protected areas, including parks and reserves, that safeguard fragile environmental areas, conserve biodiversity, enhance water catchment and purification, mitigate climate change, and serve as sources of energy, construction materials, food, and health products. Protected areas (particularly forests) indirectly support ecological systems of agriculture. These areas are also important for the tourism industry and economic growth. The tourism sector has experienced considerably enhanced performance since 2002. In 2007, for example, gorilla tourism attracted 16,000 visits, generating $42 million, making it the largest foreign exchange earner in the country. In spite of their contributions, protected areas are threatened by several problems, including governance issues, an inadequate legal framework, and population pressures that have led to encroachment and deforestation. Protected forest areas were reduced by 64 percent between 1960 and 2007. The end result is increased vulnerability to the effects of climate change and soil degradation (REMA 2009).

Figure 9.7 shows travel times to cities and towns of various sizes in Rwanda. These maps help us better understand how far rural areas are from potential

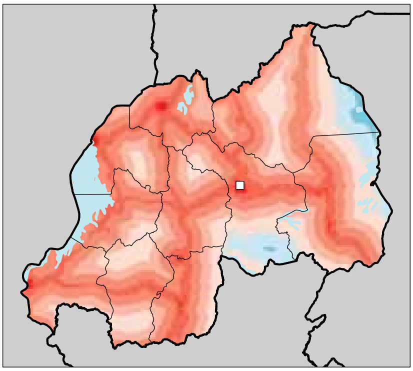
FIGURE 9.7 Travel time to urban areas of various sizes in Rwanda, circa 2000



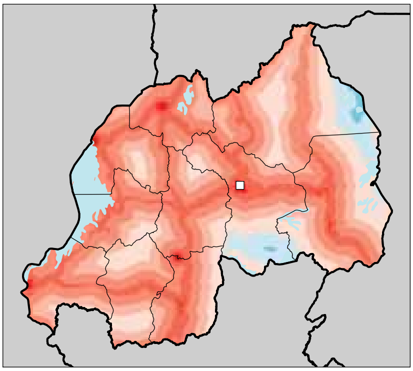
To cities of 500,000 or more people



To cities of 100,000 or more people



To towns and cities of 25,000 or more people



To towns and cities of 10,000 or more people

Source: Authors' calculations.

markets for agricultural products, as well as places for farmers to purchase inputs and consumer goods. Accessibility to markets in Rwandan cities is fairly easy. Rwanda is a small country with a relatively good road network that is continuously improved by the Ministry of Infrastructure in collaboration with local governments. The maps in Figure 9.7 show that most of the urban centers can be reached within 1–3 hours except when one is traveling from protected areas, which are more remote than other parts of the country.

Agriculture

Tables 9.3–9.5 show key agricultural commodities in terms of area harvested, value of the harvest, and consumption (ranked by weight). All values are based on three-year averages. Plantains and bananas appear to be the most important staple crops grown and consumed in the country. Rwanda's daily consumption of these crops, recorded at 250 grams per capita, is higher than anywhere else in the world (Mpawenimana 2005).

Figures 9.8–9.12 show the estimated yields and growing areas for key crops in Rwanda: bananas, beans, potatoes, sorghum, and cassava. The maps

TABLE 9.3 Harvest area of leading agricultural commodities in Rwanda, 2005–2007 (thousands of hectares)

Rank	Crop	Percent of total	Harvest area
	Total	100.0	1,692
1	Bananas and plantains	22.2	375
2	Beans	21.2	359
3	Sorghum	10.2	172
4	Potatoes	8.3	140
5	Sweet potatoes	8.2	139
6	Cassava	6.7	113
7	Maize	6.6	112
8	Pumpkins, squash, and gourds	2.5	43
9	Soybeans	2.5	43
10	Coffee	2.0	34

Source: FAOSTAT (FAO 2010).
Note: All values are based on the three-year average for 2005–2007.

TABLE 9.4 Value of production for leading agricultural commodities in Rwanda, 2005–2007 (millions of constant 2000 US$)

Rank	Crop	Percent of total	Value of production
	Total	100.0	603.4
1	Bananas and plantains	29.2	176.2
2	Potatoes	21.5	129.5
3	Beans	8.9	53.9
4	Cassava	7.4	44.9
5	Rice	5.4	32.7
6	Sorghum	5.0	30.1
7	Sweet potatoes	4.5	27.3
8	Tea	4.0	24.1
9	Taro cocoyams	3.4	20.3
10	Other fresh fruit	1.8	11.1

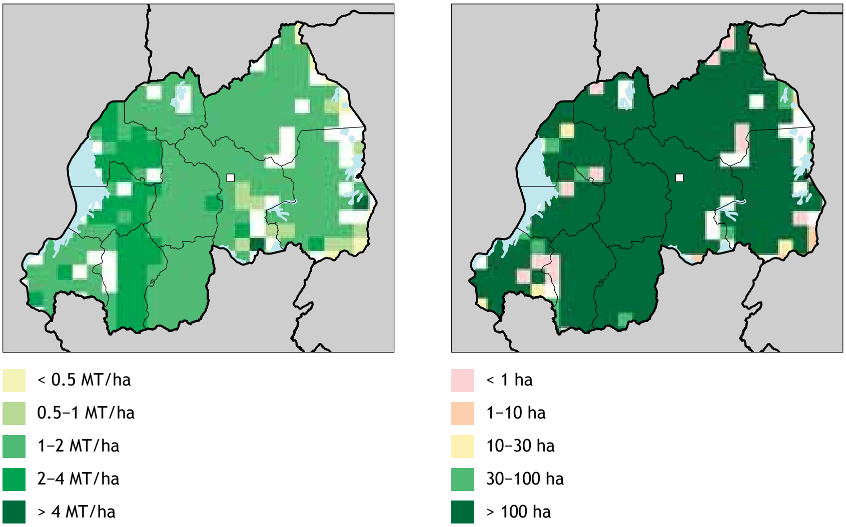
Source: FAOSTAT (FAO 2010).
Notes: All values are based on the three-year average for 2005–2007. US$ = US dollars.

TABLE 9.5 Consumption of leading food commodities in Rwanda, 2003–2005 (thousands of metric tons)

Rank	Crop	Percent of total	Food consumption
	Total	100.0	5,526
1	Bananas and plantains	22.5	1,245
2	Potatoes	18.7	1,033
3	Cassava	15.3	847
4	Sweet potatoes	15.1	834
5	Fermented beverages	7.3	406
6	Other vegetables	4.4	241
7	Beans	3.6	199
8	Sorghum	2.7	150
9	Other roots and tubers	2.2	124
10	Maize	1.9	106

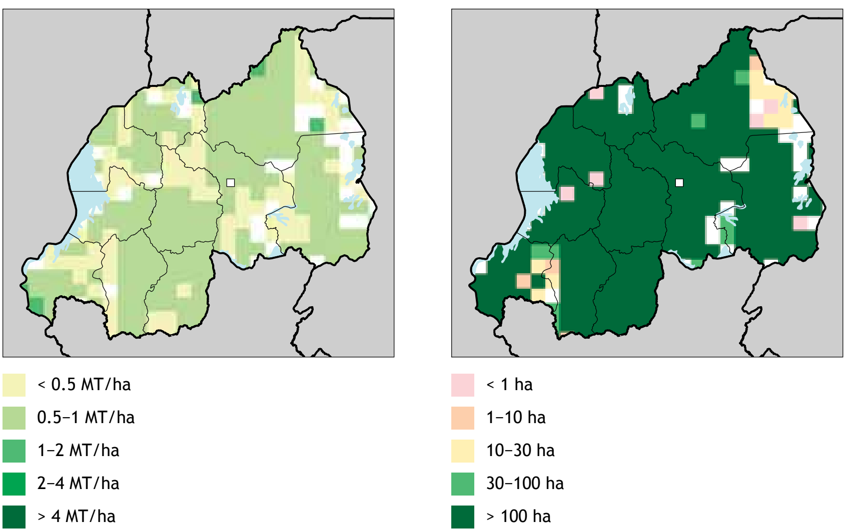
Source: FAOSTAT (FAO 2010).
Note: All values are based on the three-year average for 2003–2005.

FIGURE 9.8 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed plantains and bananas in Rwanda, 2000



Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

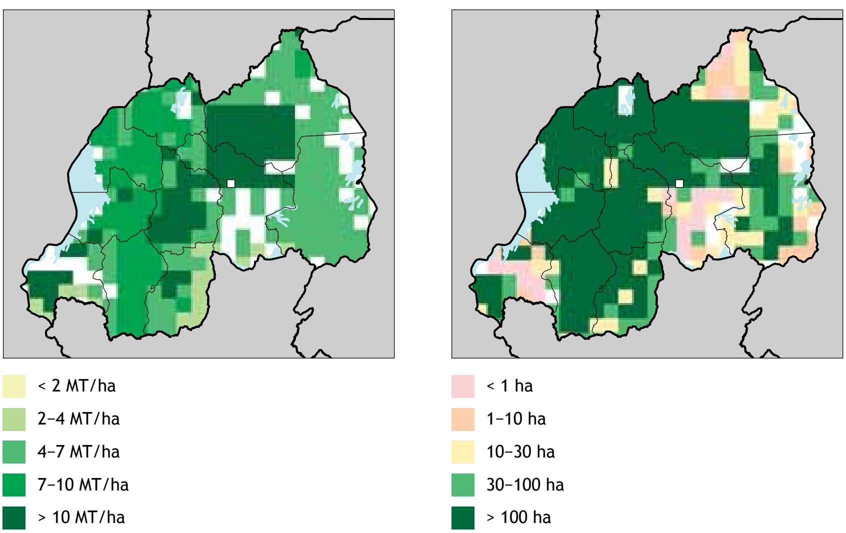
FIGURE 9.9 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed beans in Rwanda, 2000



Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

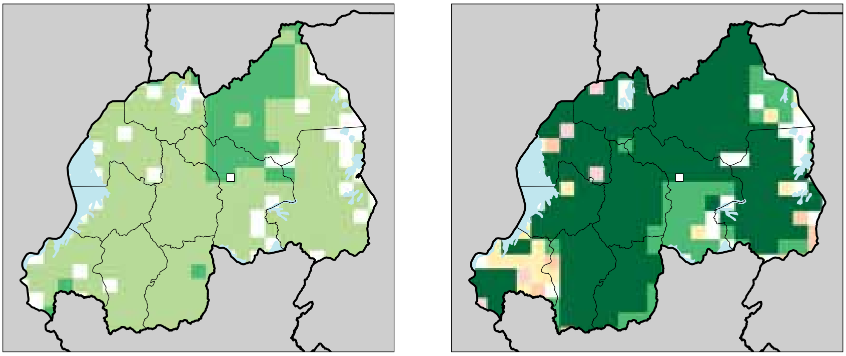
show that the crops are produced throughout the country. Banana production occupies 35 percent of the total cultivated land and is usually done by small-scale farmers. The crop is used mainly for food security and income generation, especially by peasant farmers. Bananas grow well in tropical temperatures of about 15°–30°C, rainfall of about 1,000–1,200 millimeters, and deep soils (Rwanda, Ministry of Agriculture and Animal Resources 2005). Like bananas, the other four crops are also grown for food and income and need similar conditions to grow. However, beans are grown at a much higher altitude of about 1,700 meters above sea level, where temperatures are cooler (14°–18°C). Bean production covers an estimated 22–30 percent of cultivated land and yields about 200,000–300,000 tons annually (Rwanda Agricultural Research Institute 2010). Other factors that may constrain crop yields are pests and diseases, lack of agricultural inputs, poor varieties, and weak extension systems. More effort is needed to make available improved seed varieties and proper integrated soil fertility management technologies to raise the yield for beans and sorghum to 4 tons per hectare and that for potatoes and cassava above 10 tons per hectare. More effort is also needed in the production and transformation of crops for value addition.

FIGURE 9.10 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed potatoes in Rwanda, 2000



Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

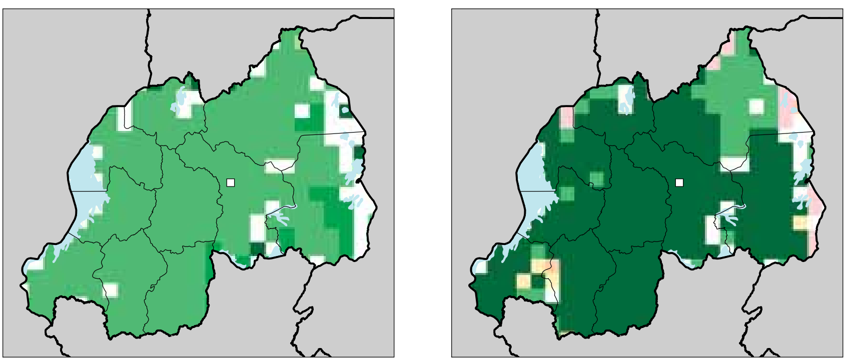
FIGURE 9.11 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed sorghum in Rwanda, 2000



< 0.5 MT/ha	< 1 ha
0.5–1 MT/ha	1–10 ha
1–2 MT/ha	10–30 ha
2–4 MT/ha	30–100 ha
> 4 MT/ha	> 100 ha

Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

FIGURE 9.12 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed cassava in Rwanda, 2000



< 2 MT/ha	< 1 ha
2–4 MT/ha	1–10 ha
4–7 MT/ha	10–30 ha
7–10 MT/ha	30–100 ha
> 10 MT/ha	> 100 ha

Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

Scenarios for the Future

Economic and Demographic Indicators

Population

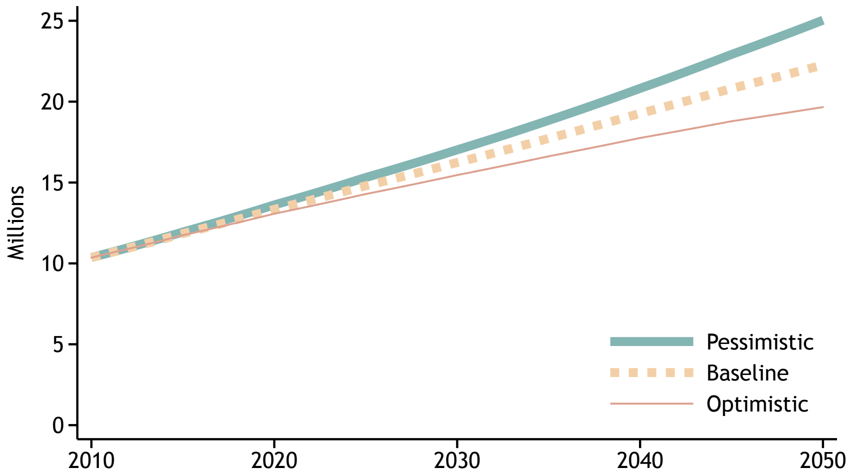
Figure 9.13 shows population projections by the UN Population Division through 2050. The low variant of the UN population projections (UNPOP 2009) estimates that the Rwandan population will almost double by 2050. The low variant is characterized by a declining fertility rate, which the country has been experiencing in the past decade (Indexmundi 2011). Attaining the low-variant projection would require appropriate education, family planning programs, and increased agricultural productivity to meet the food demands of the growing population. Given the already high population density in Rwanda, additional numbers of persons are likely to increase population pressure and land degradation. Therefore, emphasis should be placed on well-planned settlements in both rural and urban areas to reduce potential risks. The high-variant scenario is even worse, with the population in 2050 projected to be almost two and a half times that of 2010.

Income

Figure 9.14 shows the three scenarios for GDP per capita used for this study. These are the result of combining three GDP projections with the three population projections of Figure 9.14 from the United Nations Population Division. The optimistic scenario combines high GDP with low population. The baseline scenario combines the medium GDP projection with the medium population projection. Finally, the pessimistic scenario combines the low GDP projection with the high population projection.

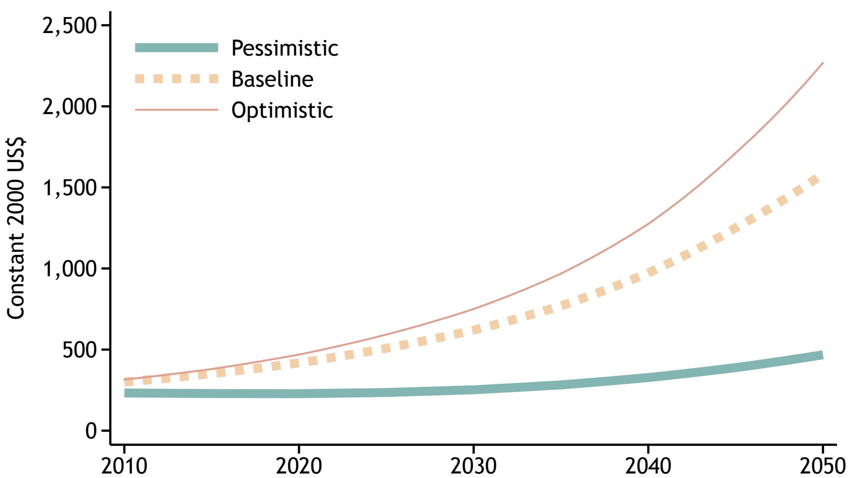
GDP per capita rose by 44 percent between 2000 and 2008 (World Bank 2009). If growth between 2010 and 2050 were to maintain that pace, we would find Rwanda's GDP per capita about midway between the baseline scenario and the optimistic scenario. In the optimistic scenario GDP per capita will reach just under $2,300 by 2050, while in the baseline scenario GDP per capita will be just under $1,600 by 2050. Attaining either of these levels would require improving agricultural productivity, which is a means of livelihood for 90 percent of the population. Adopting high-yielding and pest-resistant varieties and appropriate soil management techniques, improving markets and infrastructure, and providing extension services will be key to increasing productivity, rural incomes, and GDP. Agricultural development should be coupled with adequate measures for adaptation to climate change.

FIGURE 9.13 Population projections for Rwanda, 2010–2050



Source: UNPOP (2009).

FIGURE 9.14 Gross domestic product (GDP) per capita in Rwanda, future scenarios, 2010–2050



Sources: Computed from GDP data from the World Bank Economic Adaptation to Climate Change project (World Bank 2010), from the Millennium Ecosystem Assessment (2005) reports, and from population data from the United Nations (UNPOP 2009).

Note: US$ = US dollars.

Biophysical Analysis

Climate Models

Figure 9.15 shows projected precipitation changes under the four downscaled climate models (general circulation models or GCMs) used in this chapter with the A1B scenario.[1] The results from the CNRM-CM3 and ECHAM 5 GCMs predict neither an increase nor a decrease in rainfall in Rwanda.[2] But the CSIRO Mark 3 GCM indicates a drier future, and the MIROC 3.2 GCM indicates a wetter future. This kind of inconsistency is consistent with the type of information provided by climate models and tells us that any plans and policies made now would have to be sufficiently flexible either to benefit farmers under all three types of rainfall outcomes or to be changed quickly as the years go by and we are able to see what kind of climate is actually being experienced. One other study found that Rwanda is likely to have a wetter climate with more intense wet seasons and less severe droughts (Shongwe et al. 2010).

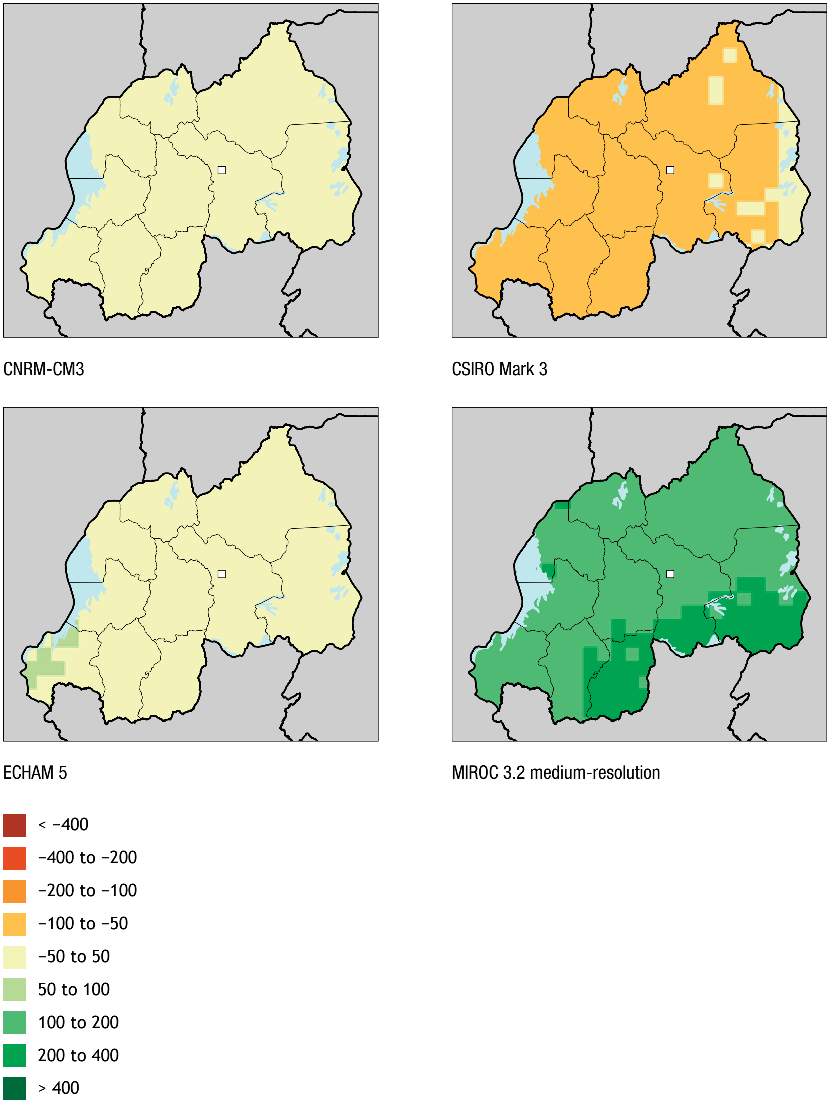
Figure 9.16 shows changes in normal mean daily maximum temperature for the month with the highest mean daily maximum temperature. All the models demonstrate a maximum temperature increase ranging from 1° to 2.5°C. There are some significant differences among the models. The CSIRO Mark 3 GCM has temperatures that range from 1° to 1.5°C, whereas the CNRM-CM3 model (and the only slightly cooler ECHAM 5 model) have temperatures that range mostly or entirely from 2° to 2.5°C. Higher temperatures are likely to affect crop yields, especially those of beans, which grow in cooler temperatures at high altitudes. Breeding for varieties adapted to relatively warmer temperatures is likely to keep the level of productivity high. High temperatures may also promote plant pest and disease multiplication as well as increased transmission of human diseases, particularly malaria. Rwandans can likely counter the effects of temperature increases by using appropriate pesticides and pest-resistant plant varieties and setting up appropriate health services.

---

1 The A1B scenario is a greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources.

2 CNRM-CM3 is National Meteorological Research Center–Climate Model 3. MIROC 3.2 is the Model for Interdisciplinary Research on Climate, developed at the University of Tokyo Center for Climate System Research. CSIRO Mark 3 is a climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation. ECHAM 5 is a fifth-generation climate model developed at the Max Planck Institute for Meteorology in Hamburg.

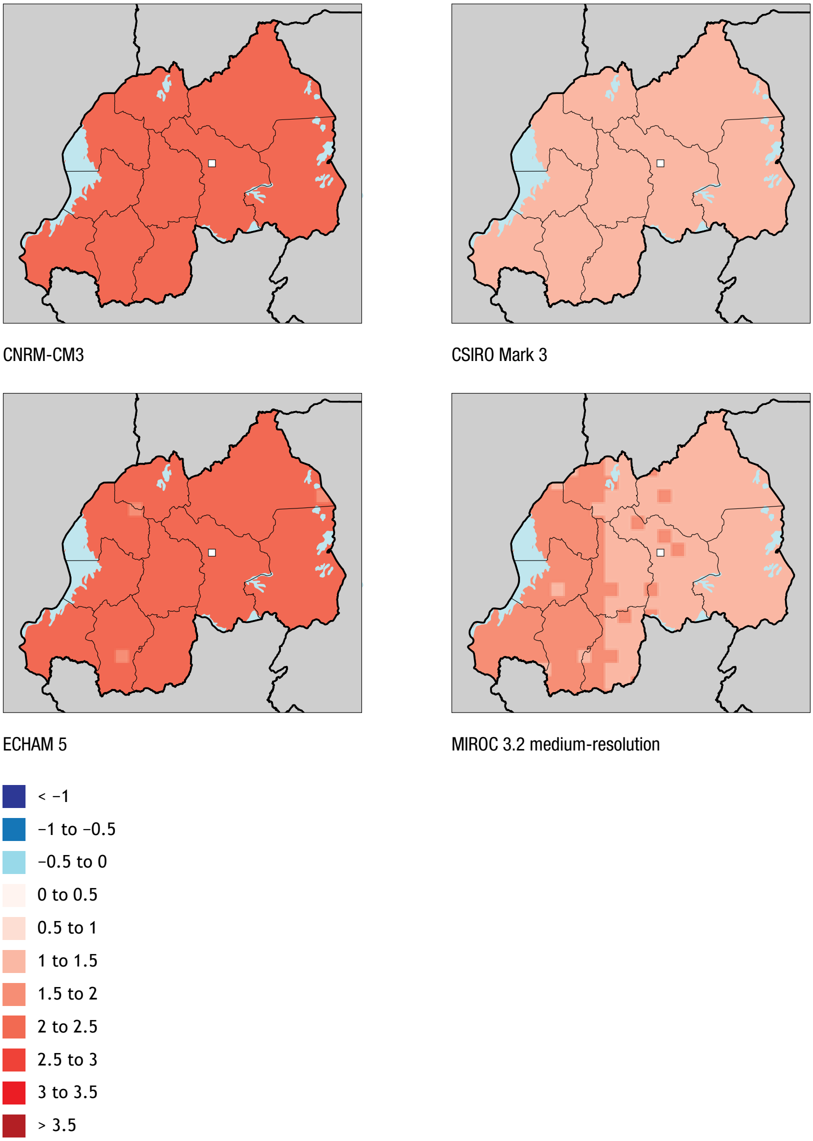
FIGURE 9.15 Changes in mean annual precipitation in Rwanda, 2000–2050, A1B scenario (millimeters)



Source: Authors' calculations based on Jones, Thornton, and Heinke (2009).

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

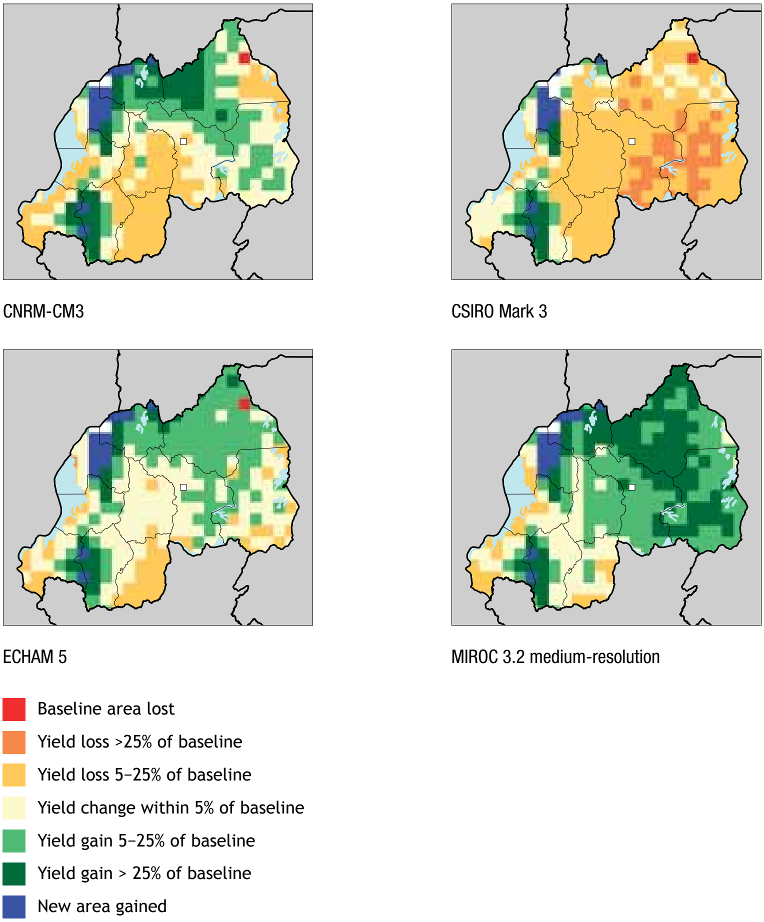
FIGURE 9.16 Changes in monthly mean maximum daily temperature in Rwanda for the warmest month, 2000–2050, A1B scenario (°C)



Source: Authors' calculations based on Jones, Thornton, and Heinke (2009).

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

FIGURE 9.17 Yield change under climate change: Rainfed sorghum in Rwanda, 2000–2050, A1B scenario



Source: Authors' calculations.

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

Crop Models

The Decision Support System for Agrotechnology Transfer software was used to compute baseline and future crop yields with current temperatures and precipitation. The results for sorghum are compared for the climate in the year 2000 and that of 2050 in Figure 9.17. There are significant differences among the climate models. The MIROC 3.2 model, for example, predicts possible gains of more than 25 percent in most of the eastern half of the country. The MIROC 3.2 model has only modest temperature increases and significant rainfall increases. The CSIRO Mark 3 model predicts losses for almost the entire country, though most of the losses range from 5 to 25 percent. The CSIRO Mark 3 model predicts modest temperature increases but lower rainfall. A consistent result across all maps is that some new areas in the western part of Rwanda will be able to cultivate sorghum that were previously unable to cultivate it. These happen to be higher-elevation areas that are currently too cold for sorghum but will become warm enough with climate change. Increasing sorghum production is important for improving the nutrition of mothers and children as well as generating incomes for families and reducing poverty. However, cultivating new lands may damage natural resources, especially because the land portions that will be better for sorghum appear to be protected areas displayed in Figure 9.6. Increasing productivity on the already cultivated land through applying appropriate agricultural technologies (for example, improved high-yielding plant varieties and good soil management techniques) will strike a balance between higher food production and conservation.

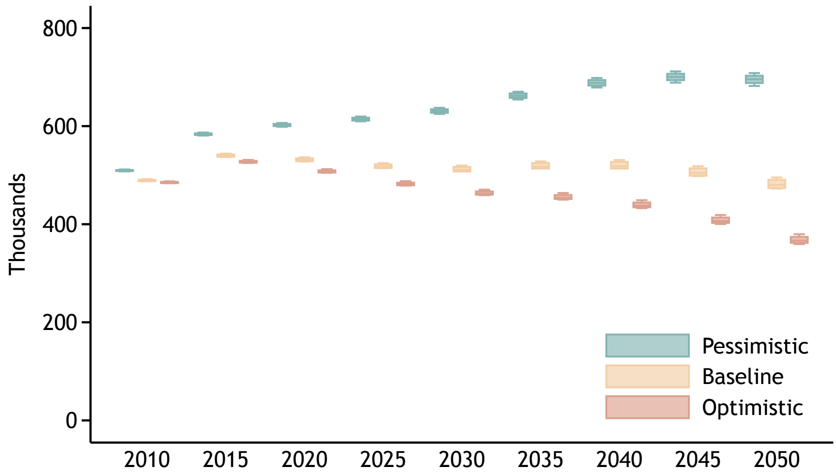
Vulnerability

Figure 9.18 shows the impact of future GDP and population scenarios on the number of malnourished children under age five in Rwanda. Figure 9.19 shows the share of children who are malnourished. In the baseline and optimistic scenarios, the number of children who are malnourished rises until 2015. Thereafter, they decrease over the next three and a half decades. However, the pessimistic scenario predicts a rise in the number of children who are malnourished throughout the next four decades. The malnutrition rate declines slightly during the same period.

In the optimistic scenario, greater per capita incomes will give families easier access to food (increasing caloric availability), education, and health services, consequently lowering malnutrition rates. This will lead to a decrease in the number of malnourished children under age five to fewer than 380,000 by 2050. It is important to note that changes in other factors may bring about a situation far from the optimistic scenario.

Figure 9.20 shows the kilocalories per capita available to each person in Rwanda. Even in the case of moderate increases in income represented by the baseline scenario, the number of kilocalories available per capita will increase

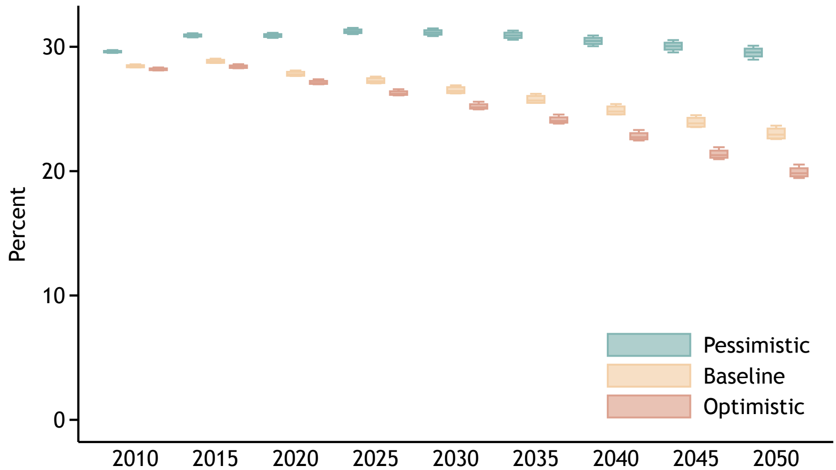
FIGURE 9.18 Number of malnourished children under five years of age in Rwanda in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

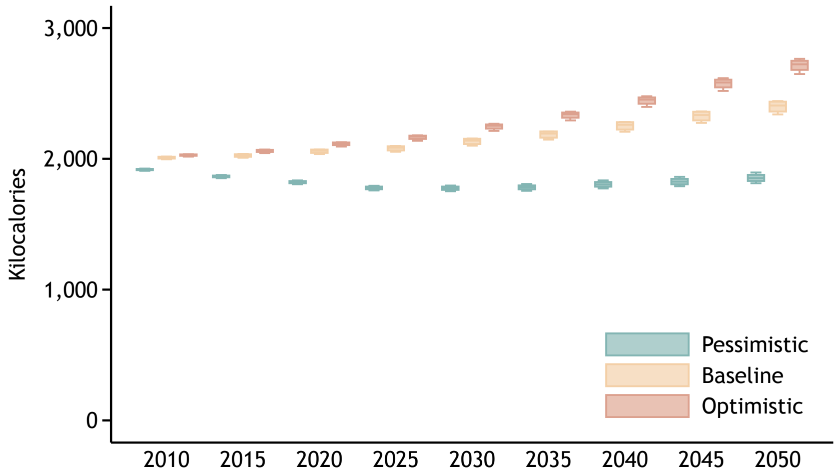
FIGURE 9.19 Share of malnourished children under five years of age in Rwanda in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

FIGURE 9.20 Kilocalories per capita in Rwanda in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

to as many as 2,400 by 2050 given an ideal climate (baseline scenario). Higher income will result in greater per capita kilocalorie availability—up to 2,700 by 2050 (optimistic scenario). However, a low rate of growth in income will result in the availability of a lower number of kilocalories per capita by 2050 (pessimistic scenario), reflecting how the price effects negate gains from the income effects.

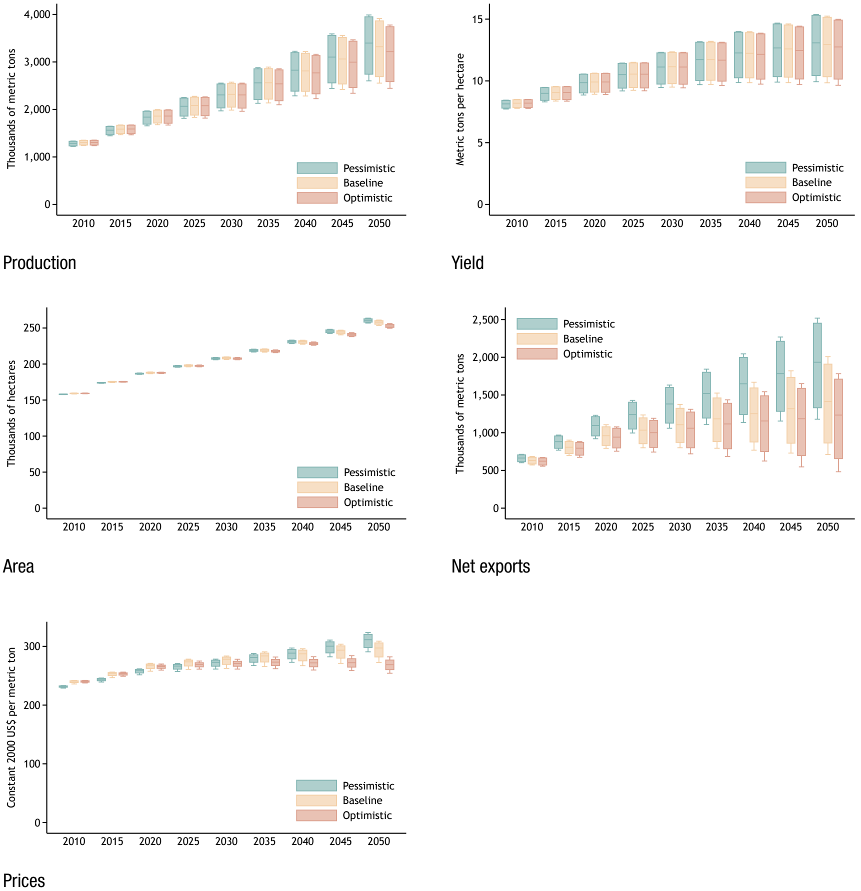
Agricultural Outcomes

Figures 9.21–9.23 show simulation results from the International Model for Policy Analysis of Agricultural Commodities and Trade associated with key agricultural crops in Rwanda. Each featured crop has five graphs, one each showing production, yield, harvested area, net exports, and world price.

The results in Figure 9.21 show an improved food security situation concerning potatoes given the expected changes in climate. All scenarios point to increased production, yield, harvested area, net exports, and price of potatoes by 2050. Increased net exports implies that by 2050 Rwanda will be able to meet all its domestic demand for potatoes and have supplies left to meet global demand.

Unlike in many other countries, the impact of climate on yield (and hence on production and net exports) will be quite large in Rwanda by 2050. That is,

FIGURE 9.21 Impact of changes in GDP and population on potatoes in Rwanda, 2010–2050



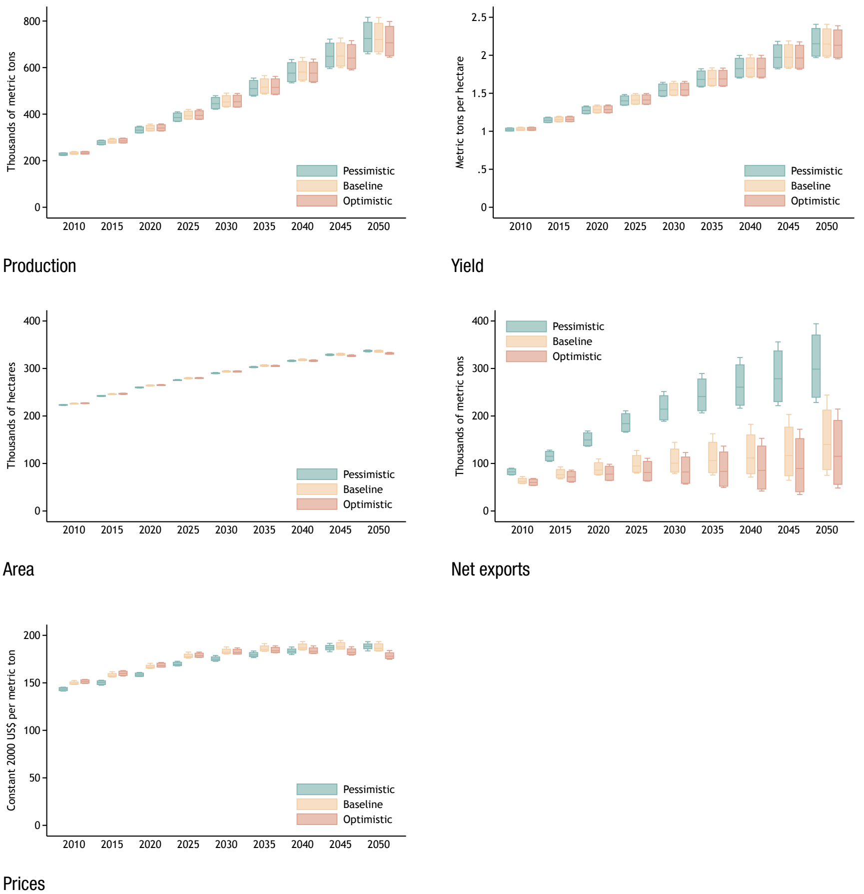
Source: Based on analysis conducted for Nelson et al. (2010).

Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

the difference for any scenario between the top whisker for 2050 and the bottom whisker for 2050 is quite large; most countries will have less than half of the range of Rwanda. This means that it is more difficult to generalize the results for Rwanda. The bottom whisker for the yield of potatoes indicates that there will be a gain in yield of only around 25 percent between 2010 and 2050, while the top whisker indicates that there will be a gain in yield of about 90 percent.

Figure 9.22 shows increased production, yield, and harvested areas of soghum, with yields doubling on average. Although the price for sorghum will

FIGURE 9.22 Impact of changes in GDP and population on sorghum in Rwanda, 2010–2050

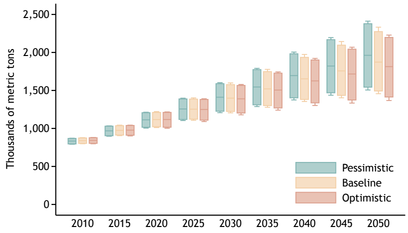


Source: Based on analysis conducted for Nelson et al. (2010).

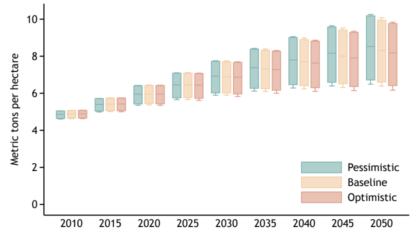
Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

be roughly 50 percent higher by 2050, even in the pessimistic scenario per capita income will have doubled, making higher food prices easier to bear. Net exports almost always show the greatest variance of the five graphs in each figure because they represent the difference between production and consumption, and both of these have their own variances. We generally observe that exports of sorghum will hold constant or grow, and in the few cases in which they will fall, the drop will be small.

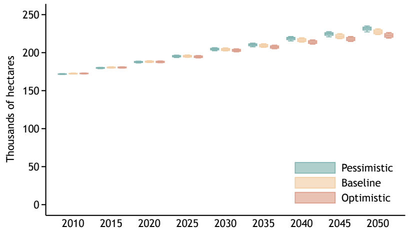
FIGURE 9.23 Impact of changes in GDP and population on cassava in Rwanda, 2010–2050



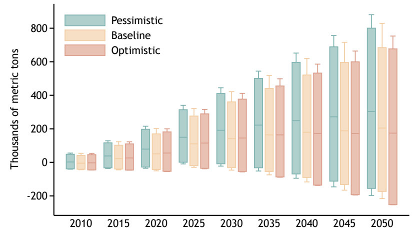
Production



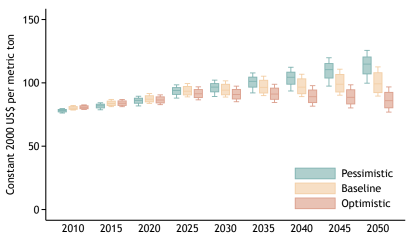
Yield



Area



Net exports



Prices

Source: Based on analysis conducted for Nelson et al. (2010).

Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

Figure 9.23 illustrates findings somewhat similar to those in Figure 9.22. The graphs show increased yield and area, which will naturally result in increased production. Prices will rise slightly except in the optimistic scenario, in which they will rise and then fall, with the price in 2050 almost the same as in 2010. There is a high variance on net exports. It is hard to generalize, but more scenarios show exports rather than imports increasing. However, it would be improper to conclude that either outcome is definitive.

Conclusions and Policy Recommendations

In this chapter we set out to assess the vulnerability of Rwanda to the impacts of climate change. This evaluation was based on several economic, demographic, health, and food security indicators, and we used crop models and a global partial equilibrium model to determine the impact of climate change across diverse projections by climate models.

For a country that already has a high population density, one of the most prominent projections that went into the partial equilibrium model is that in the best-case scenario, which is the low population projection, there should be a doubling in the population by 2050. This suggests that policies should be created to reduce fertility rates. To ensure sustainable development, country strategies should include development of a strong education system, increased use of family planning methods, planned settlements, and increased productivity to feed the growing population.

If Rwanda is to attain the higher growth rates of either the baseline or the optimistic scenario, strategies that improve its agricultural productivity will be critical given that they will increase incomes for a majority of the population. Strengthening the education system beyond the primary level will also enhance individuals' capacity to maneuver between alternative forms of employment. In addition, reinforcing the service sector will boost livelihoods in the country given its increasing contribution to the economy and employment.

The four GCMs we used differed on the direction of change in annual rainfall, with one showing a general increase, one showing a general decrease, and two showing rainfall remaining unchanged. Although the GCMs clearly predict that the country is likely to experience warmer temperatures over the next four decades, they disagree as to how much, with two essentially suggesting that the increases will be only 1°–1.5°C, while the other two suggest that the increases will be 2°–2.5°C. The risks associated with greater increases include an increased number of plant and human pests and diseases as well as reduced productivity for crops acclimated to cooler temperatures. Policies supporting a stronger health system, adoption of integrated pest management, and the breeding of crop varieties suitable for warm temperatures will counter such effects.

Higher temperatures will permit the growing of some crops in places that are currently too cold. Using improved technology to increase the productivity of already cultivated areas will be far more beneficial in increasing yields and regulating climate change.

The ability of farmers to produce more than consumers demand will increase for some key crops such as potatoes but is less certain for other crops, for which the models show great variance, so it is too difficult to determine whether production gains will outpace increases in consumer demand. Setting up and improving institutions and infrastructure to coordinate and allow movement of foodstuffs and production inputs will further mitigate the food shortages brought about by change climate.

References

Bartholome, E., and A. S. Belward. 2005. "GLC2000: A New Approach to Global Land Cover Mapping from Earth Observation Data." *International Journal of Remote Sensing* 26 (9–10): 1959–1977.

CIESIN (Center for International Earth Science Information Network), Columbia University, IFPRI (International Food Policy Research Institute), World Bank, and CIAT (Centro Internacional de Agricultura Tropical). 2004. *Global Rural–Urban Mapping Project (GRUMP), Alpha Version: Population Density Grids.* Palisades, NY, US: Socioeconomic Data and Applications Center (SEDAC), Columbia University. http://sedac.ciesin.columbia.edu/gpw.

FAO (Food and Agriculture Organization of the United Nations). 2010. FAOSTAT. Rome. http://faostat.fao.org.

Indexmundi. 2011. "Rwanda GDP-per capita (PPP)." Accessed December 14. www.indexmundi.com/rwanda/gdp_per_capita_(ppp).html.

Jones, P. G., P. K. Thornton, and J. Heinke. 2009. *Generating Characteristic Daily Weather Data Using Downscaled Climate Model Data from the IPCC's Fourth Assessment.* Project report for the International Livestock Research Institute. Geneva: International Panel on Climate Change.

Lehner, B., and P. Döll. 2004. "Development and Validation of a Global Database of Lakes, Reservoirs, and Wetlands." *Journal of Hydrology* 296 (1–4): 1–22.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Synthesis.* Washington, DC: Island Press. www.maweb.org/en/Global.aspx.

Mpawenimana, J. 2005. "Analysis of Socio-economic Factors Affecting the Production of Bananas in Rwanda: A Case Study of Kanama District." Accessed December 16, 2011. www.unipv.eu/on-line/en/Home/InternationalRelations/CICOPS/PublicationsandMaterials.html.

National Institute of Statistics of Rwanda. 2008. *Rwanda Development Indicators, 2006 Edition.* Kigali.

Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, et al. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options.* Washington, DC: International Food Policy Research Institute.

REMA (Rwanda Environment Management Authority). 2009. *Rwanda State of Environment and Outlook Report.* Kigali. www.rema.gov.rw/soe/full.pdf.

———. 2010. *Environment Sub-sector Strategic Plan, 2010–2015.* Kigali.

Rwanda, Ministry of Agriculture and Animal Resources. 2005. *Programme national pour le development de la banane.* Kigali.

Rwanda, Ministry of Finance and Economic Planning. 2007. *Economic Development and Poverty Reduction Strategy, 2008–2012.* Kigali.

Rwanda Agricultural Research Institute. 2010. "Banana Programme." Accessed August 15. www.isar.rw/spip.php?article45.

SEI (Stockholm Environmental Institute). 2009. "The Economics of Climate Change in Rwanda." Accessed August 31, 2011. www.rema.gov.rw/ccr/Final percent20report.pdf.

Shongwe, M. E., G. J. van Oldenborgh, B. van den Hurk, and M. van Aalst. 2010. "Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming, Part 2: East Africa." *Journal of Climate* 24 (14): 3718–3733.

UNEP (United Nations Environment Programme) and IUCN (International Union for the Conservation of Nature). 2009. World Database on Protected Areas (WDPA): Annual Release. No longer available online.

UNPOP (United Nations Secretariat, Department of Economic and Social Affairs, Population Division). 2009. *World Population Prospects: The 2008 Revision.* Accessed April 06, 2010. http://esa.un.org/unpp.

USDoS (United States Department of State). 2011. "Background Note: Rwanda Bureau of African Affairs." Accessed August 31. www.state.gov/r/pa/ei/bgn/2861.htm.

WHO (World Health Organization). 2006. *The World Health Report 2006: Working Together for Health.* Accessed October 19, 2010. http://whqlibdoc.who.int/publications/2006/9241563176_eng.pdf.

Wood, S., G. Hyman, U. Deichmann, E. Barona, R. Tenorio, Z. Guo, S. Castano, O. Rivera, E. Diaz, and J. Marin. 2010. "Sub-national Poverty Maps for the Developing World Using International Poverty Lines: Preliminary Data Release." Accessed May 6. http://povertymap.info.

World Bank. 2009. *World Development Indicators.* Accessed May 2011. http://data.worldbank.org/data-catalog/world-development-indicators.

———. 2010. *Economics of Adaptation to Climate Change: Synthesis Report.* Washington, DC. http://climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage.

You, L., and S. Wood. 2006. "An Entropy Approach to Spatial Disaggregation of Agricultural Production." *Agricultural Systems* 90 (1–3): 329–347.

You, L., S. Wood, and U. Wood-Sichra. 2006. "Generating Global Crop Distribution Maps: From Census to Grid." Paper presented at the International Association of Agricultural Economists Conference, Brisbane, Australia, August 11–18.

———. 2009. "Generating Plausible Crop Distribution and Performance Maps for Sub-Saharan Africa Using a Spatially Disaggregated Data Fusion and Optimization Approach." *Agricultural Systems* 99 (2–3): 126–140.