USAID | GHANA
FROM THE AMERICAN PEOPLE

GHANA CLIMATE CHANGE VULNERABILITY AND ADAPTATION ASSESSMENT

June 2011
This report was produced for review by the United States Agency for International Development (USAID). It was prepared by the USDA Forest Service, International Programs.

COVER PHOTOS: Courtesy of USFS, IP

GHANA CLIMATE CHANGE VULNERABILITY AND ADAPTATION ASSESSMENT

Prepared by John A. Stanturf, Melvin L. Warren, Jr., Susan Charnley, Sophia C. Polasky, Scott L. Goodrick, Frederick Armah, and Yaw Atuahene Nyako

JUNE 2011

This page is intentionally left blank

TABLE OF CONTENTS

ACRONYMS

CAADP	Comprehensive African Agricultural Development Programme
CBO	community-based organizations
CC	Climate Change
CDCS	Country Development Cooperation Strategy
CEA	Country Environmental Analysis
CEPF	Critical Ecosystem Partnership Fund
CFM	Collaborative Forest Management
CI	Conservation International
CIDA	Canadian International Development Agency
CITES	Convention on International Trade of Endangered Species
CPUE	Catch Per Unit of Effort
CRC	Coastal Resources Center
CREMA	Community Resource Management Area
CRMU	Collaborative Resource Management Unit
CSIR	Council for Scientific and Industrial Research
CSO	Civil Society Organization
CSP	Country Strategic Plan
DA	District Assembly
DSD	dry semi-deciduous
SARI	Savanna Agricultural Research Institute
EPA	Environmental Protection Agency
ETOA	Environmental Threats and Opportunities Assessment
EU	European Union
FAO	Food and Agriculture Organization, UN
FAA	Foreign Assistance Act
FASDEP	Food and Ag. Sector Development Policy
FC	Forestry Commission
FDMP	Forestry Development Master Plan

FR	Forest Reserves
FSD	Forestry Services Division
FtF	Feed the Future (USAID multi-year strategy)
FY	fiscal year
GCMs	Global Circulation Models
GDP	Gross Domestic Product
GEF	Global Environment Facility
GFTN	Global Forest Trade Network
GoG	Government of Ghana
GPRS	Ghana Poverty Reduction Strategy
GSBA	Globally Significant Biodiversity Areas
HDI	Human Development Index
GWS	Ghana Wildlife Society
IBA	Important Bird Areas
IEE	Initial Environmental Examination
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
ITCZ	Intertropical Convergence Zone
IUCN	International Union for the Conservation of Nature
JICA	Japan international development agency
LME	Large Marine Ecosystem
ME	moist evergreen
METASIP	Medium Term Ag. Sector Investment Plan
MEST	Ministry of Env., Science and Technology
MEO	Mission Environmental Officer
MLNR	Ministry of Lands and Natural Resources
MOFA	Ministry of Food and Agriculture
MSD	moist semi-deciduous
NAP	National Action Programme
NEPAD	New Partnership for Africa's Development
NDPC	National Development Planning Commission

NGO	Non-Governmental Organization
NCRC	Nature Conservation Research Centre
NREG	Natural Resources and Environmental Governance program
NRM	natural resources management
NTFP	non-timber forest products
PA	protected area
PAMSCP	Protected Areas Management and Wildlife Conservation Project
PGRC	Plant Genetic Resources Centre
RAMSAR	Convention on Wet Lands, Ramsar Iran
REDD	Reduced Emissions from Deforestation and Degradation
REDD+	REDD including sustainable forest management, conservation, and enhancement of forest carbon stocks
SEA	Strategic Environmental Assessment
SEIA	Social Environmental Impact Assessment
SM	southern marginal
SNV	Netherlands development agency
SO	Strategic Objective
SOW	Scope of Work
TES	threatened and endangered species
UE	upland evergreen
UNCCC	United Nations Convention on Climate Change
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Program
USAID	U.S. Agency for International Development
VBA	Volta Basin Authority
VPA	Voluntary Partnership Agreement
WAPCA	West African Primate Conservation Action
WD	Wildlife Division
WE	wet evergreen
WRC	Water Resources Commission
WWF	World Wildlife Fund

This page is intentionally left blank

ACKNOWLEDGEMENTS

The team would like to acknowledge the support of the many individuals who contributed to this assessment. We would like to thank the USAID liaisons, Nino Nadiradze (Senior Environmental Officer) and Justice Odoi (Environmental Specialist) in Accra, Ghana for providing technical support to the team. Nino and Justice helped both in planning the report and in setting up interviews and contacts during the three-week in-country fact-finding phase of the project. More than 100 people, representing a variety of governmental organizations, non-governmental organizations, civil society, and industry were interviewed and/or contributed papers to this report. The full list of those interviewed is contained in Appendix 1. We are grateful to these individuals for their generous contributions of time.

The Climate Change Assessment was conducted simultaneously with another effort, an Environmental Threats and Opportunties Assessment (ETOA). The ETOA was conducted by Steven Brady and Joseph Krueger and we appreciated the time spent with them, conducting interviews and discussing what we learned. We were also supported by many in our home units and would like to acknowledge their valuable contributions. We thank Amy Carson-Commens, Anthony Rietl, and Elizabeth McQuire, all of the Center for Bottomland Hardwoods Research, Southern Research Station, for assistance with literature and graphics. Administrative support and travel logistics were provided by Cathy Jenkins, CBHR-SRS, and Janet Revell, Center for Forest Disturbance Science, Southern Research Station. David Banis and Ross Calhoun of Portland State University made our maps. Francis Kwabena Dwomoh, Forest Reseaerch Institute of Ghana and Visiting Scientist at the Center for Forest Disturbance Science, provided GIS support as well as cultural, political, and resource interpretations. We especially thank Zinede Minia, formerly of Ghana Meteorological Agency, who provided historical meteorological data.

Finally, we want to single out Matthew Edwardsen and Stephanie Otis of the US Forest Service International Programs for selecting us for this opportunity and for their indispensible assistance; without them, this would not have happened.

All photos were taken by the team.

This page is intentionally left blank

EXECUTIVE SUMMARY

Countries in Africa are among the most vulnerable globally to the effects of climate change because of the dependence of much of the population on agriculture, particularly rain-fed agriculture, and widespread poverty that renders them unable to withstand climate stress. Additional constraints (disease burden, debt burden, political instability, and conflict) reduce the adaptive capacity and increase the vulnerability of rural populations. Recurrent drought in many countries has demonstrated the effects of climate variability on food resources. Widespread poverty in many countries places many people facing food insecurity even in good times. Additionally, climate variability and change threaten other resources including water, forests, and fisheries. Communities in coastal areas will be impacted by projected rise in sea-level of up to 1 m in this century; some countries already experience coastal erosion and flooding.

The West African country of Ghana is located on the Gulf of Guinea and extends northward from a low-lying coastal zone through the Volta River basin to the savanna zone on the border with Burkina Faso. Ghana is bordered on the west by Côte d'Ivoire and the east by Togo. Ghana's economy relies on agriculture, which accounted for >25 percent of Gross Domestic Product (GDP) in 2008 and employed half of the economically active population. The main exports are cocoa, gold, timber, diamonds, bauxite, manganese, and hydropower. Ghana is designated a Low Income Country, making it one of only four West African countries that are not classified as Least Developed Countries. Among Ghana's advantages are its political and social stability as well as internal energy resources and natural resources in demand in world markets.

This Climate Change Assessment of Ghana was prepared by a team of US Forest Service scientists and Ghanaian counterparts, based in part on interviews with government officials, staff of non-governmental organizations (NGOs), and representatives of civil society organizations (CSOs) over a two-week period. In addition to interviews, the Team collected geospatial and demographic data from agencies and electronic public sources, as well as conducted an extensive literature review. The Assessment was focused at two levels, a national overview and a targeted assessment of the northern savanna zones, comprised of the three northern administrative regions in Ghana (Northern, Upper West, and Upper East). Additionally, the Team examined the coastal zone and the energy sector in light of recent development of oil and gas resources offshore in the Gulf of Guinea.

CLIMATE OVERVIEW

The climate of Ghana is dominated by the interaction of the Inter-Tropical Convergence Zone (ITCZ) and the West African Monsoon. The ITCZ, also known as the Equatorial Convergence Zone or Inter-Tropical Front, is a region of calm winds separating the northeasterly and southeasterly trade winds. The location of the ITCZ annually moves, reaching its northernmost extent during the northern hemisphere summer and its southernmost extent during the northern hemisphere winter. The principal feature of the climate of Ghana is the alternate wet and dry seasons caused by the movements of the ITCZ and West African Monsoon. In southern Ghana there are two distinct wet seasons, but Northern Ghana has only one.

Available temperature data indicates a warming climate in Ghana with the drier northern area warming more rapidly than southern Ghana. Since 1960 for Ghana as a whole, mean annual temperature rose by 1.0°C. The rate of increase generally was more rapid in the northern than southern regions. The frequency of "Hot" days and nights in Ghana increased from 1961 to 2003. A "Hot" day or night is defined by the temperature exceeded on 10 percent of days or nights in the current climate. Annual rainfall in Ghana is highly variable making identification of long-term trends difficult. In the 1960s, rainfall in Ghana was particularly high and decreased to particularly low levels in the late 1970s and early 1980s. There was no evidence that extreme rain events have either increased or decreased since 1960.

CLIMATE VARIABILITY AND CHANGE

The climate of West Africa is subject to considerable spatial and temporal variability. This variability is linked to variations in the movement and intensity of the ITCZ as well as variations in the timing and intensity of the West African Monsoon. The most documented cause of these variations on an inter-annual timescale is the El Niño Southern Oscillation (ENSO). The West African Monsoon is influenced either during the developing phase of ENSO or during the decay of some long-lasting La Niña events. In general, El Niño is connected to below normal rainfall in West Africa.

When assessing climate change, it is important to note that it will affect regions of Ghana differently. In addition, predictions from climate models can vary significantly. Information derived from any model must be used judiciously, being cognizant of the uncertainty inherent in these tools. Specifically for Ghana, although Global Circulation Models (GCMs) agree generally that mean temperatures will rise, little agreement exists on future precipitation amounts or seasonality; some GCMs project increased precipitation in the northern three regions and others project decreases.

All climate projections through the 21st century we examined, including our own analysis, indicated increasing temperatures across Ghana. For example, across most ecological zones of Ghana, dry season mean temperatures are projected to rise by about 1.5 to 2.0 ^{o}C to about 3 ^{o}C by 2080. Because of the complexity of correctly reproducing a number of key features of the atmospheric circulation patterns over West Africa, projections of rainfall by climate models are mixed and uncertain.. Our ensemble modeling projections of rainfall among seven representative meteorological stations also gave mixed and inconclusive results, lacking consistency and predicting decreases and increases in rainfall across stations. The results are summarized for each station as follows:

- **Accra (Coastal Savanna Zone):** Forecasted changes in precipitation ranged from 52 percent decreases to 44 percent increases in wet season rainfall by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Kumasi (Deciduous Forest Zone):** Forecasted changes in precipitation range from 48 percent decreases to 45 percent increases in wet season rainfall by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The A2 scenario, which generally shows the largest greenhouse gas (GHG) impact, predicts the weakest increase in wet season rainfall, 1.13 percent.

- **Tarkwa (Rain Forest Zone):** Forecasted changes in precipitation range from 45 percent decreases to 31 percent increases in wet season rainfall. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Techiman (Forest-Savanna Transition Zone):** Forecasted changes in precipitation range from 46 percent decreases to 36 percent increases in wet season rainfall. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The A2 scenario, which generally shows the largest GHG impact, predicts the largest decrease in wet season rainfall, -2.94 percent.

- **Tamale (Guinea Savanna Zone):** Forecasted changes in precipitation range from 36 percent decreases to 32 percent increases in wet season rainfall. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The Northern Region where Tamale is located is the southern-most region in Ghana to show a consistent trend toward decreased rainfall.

- **Walembelle (northern Guinea Savanna Zone):** Forecasted changes in precipitation range from 25 percent decreases to 24 percent increases in wet season rainfall. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Bawku (Sudan Savanna Zone):** Forecasted changes in precipitation range from 28 percent decreases to 30 percent increases in wet season rainfall. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

Projections also indicate sea-surface temperatures will increase in Ghana's waters with potential negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity. Associated in part with sea temperature increases is sea-level rise which is also projected to rise from 0.13-0.60 m by the late 21st century, depending on development scenarios modeled.

UNCERTAINTY OF CLIMATE PROJECTIONS

These results illustrate the uncertainty in climate change projections, especially for future precipitation. Climate science is an expanding field and more reliable projections of future climate should become available soon. Improved methods exist now in terms of more realistically modeling current climate at scales useful for decision-making, suggesting that improved projections of future climate are available. Even so, uncertainty remains because these dynamically down-scaled regional climate models begin with the boundary conditions set by the global circulation models. Government agencies, NGOs, and CSOs in Ghana seem to have little access to detailed climate projections and seemingly little understanding of the uncertainties surrounding projections. Tools to assess the impact of climate change on agriculture are critical components of poverty reduction programs.

Modeling is best tempered with observation and experience. Northern Ghana has the highest poverty levels in the country and is also where temperatures are hottest, rainfall is low and there is only one rainy season. The actual experience of people interviewed during our field visit to the north reported delays in the onset of the rainy season, heavier rains late in the rainy season, and increased flooding, causing crop damage. The experience of our interviewees is congruent with observed trends of decreasing rainfall and increasing temperatures in the last several decades. These factors combine to make the north the most vulnerable region of Ghana to adverse affects from climate change.

CLIMATE POLICY FRAMEWORK

Responsibility for developing, coordinating, and implementing Ghana's climate policy is understandably dispersed among several agencies. The Environment and Natural Resources Advisory Council (ENRAC) operates at the Cabinet level and is in place to coordinate among ministries. Within ministries with climate-related responsibilities, there are coordinating and consultative activities. For example, a Carbon Credit Policy Committee operates in the Ministry of Environment, Science and Technology (MEST) to clearly define rules and procedures affecting carbon credit generating activities, allocation of carbon rights, and participation in sub-national carbon activities. The Environmental Protection Agency within MEST is responsible for developing national climate change policy and integrating priorities into sectoral plans. The National Climate Change Coordinator is located within the Energy Resource and Climate Change Unit of the Environmental Protection Agency (EPA).

The MEST developed a list of 55 actions and policies the Government of Ghana (GoG) could take to reduce GHG emissions. These Nationally Appropriate Mitigation Actions (NAMAs) were appended to Ghana's submission to the Copenhagen Accord. Most NAMAs align with development priorities in the Ghana Shared Growth and Development Agenda 2010 (GSGDA), and most are energy-related but do not specifically mention biofuels, other than waste as renewable sources, and do not mention woodlots to meet community cooking needs. Eight of the 55 NAMAs address land use, land use change, and forestry, including sustainable forest management, REDD+, plantation development, and rehabilitation of degraded lands. The NAMAs are mostly broad statements without implementation details, cost estimates, likely funding sources or priorities.

Ghana is at the forefront of pilot efforts to implement REDD+ activities to mitigate climate change, with significant investments by The World Bank and other organizations. The greatest potential for REDD+ in Ghana is in carbon enhancement, which means better management of the remaining small amount of forest and restoration of degraded forests. The potential so far has been regarded as mostly within the High Forest Zone (HFZ), including shade-grown cocoa (cocoa culture is primarily carried out in the HFZ), although REDD+ could certainly be extended to the northern savanna woodlands. However, major obstacles remain to be addressed before REDD+ will be successful, including land and tree tenure issues, carbon rights, benefit sharing, illegal logging, cocoa production methods and carbon measurement, reporting, and verification (MRV) methods.

Ghana has done little to develop forest-based carbon offset projects through the Kyoto Protocol's Clean Development Mechanism (CDM) to help mitigate climate change. The Environmental Protection Agency is the designated national authority for CDM projects in Ghana. Ghana's CDM strategy focuses on integrating CDM into its plantation development program, targeted at 30,000 acres/year both on and off of forest reserves. To date, only one CDM project – a rubber plantation located in the Western Region – has been advanced, though another plantation project is under development in Brong-Ahafo Region inside a GoG forest reserve that is mainly grassland. Barriers to CDM projects include lack of financing to invest in plantation development, the rigor and high cost of verification and compliance, weak carbon markets, and uncertainty over CDM's future once the Kyoto Protocol expires in 2012. Even so, Ghana seems to be slowly moving to develop more CDM projects, though no plan is yet developed that identifies how money earned by selling certified emission reduction credits will be distributed.

Several gaps and various obstacles hamper mainstreaming climate change in the GoG. Within MEST, the Town and Country Planning Department has no specific climate responsibility although there is clearly a need to focus on low emissions development. National and regional level coastal development plans should include adaptation strategies for sea-level rise (e.g., relocation of transportation, housing, and business zones) and natural mitigation measures to slow coastal erosion (e.g., mangrove zones, sand-mining restrictions).

The National Disaster Management Organization (NADMO) within the Ministry of the Interior (MOI) is responsible for the management of disasters and similar emergencies. In addition, NADMO is charged with ensuring Ghana is prepared to prevent disasters and to manage them well when they occur. Currently, NADMO needs strengthening of capacity to respond to extreme weather events (e.g., floods and drought) and should disaggregate its national level planning to local development plans. Disaster planning and climate change adaptation are conceptually linked and should be explicitly coordinated within the GoG.

Wildfires and biomass burning are a significant component of Ghana's GHG emissions. The draft National Wildfire Policy (as of 2006) seeks to overcome past policy limitations (unclear authorities, lack of deterrents, disregard of traditional practices, and no involvement of traditional authorities in policy formulation or implementation). Nevertheless, the draft policy is overly focused on fire prevention and suppression, ignoring the role of fire as an ecological agent and a traditional management tool. The policy assigns key roles to the Ghana National Fire Service (Ministry of the Interior), including fire suppression and training programs throughout the country and developing a fire detection and monitoring system. Neither of these roles has been addressed, and the Fire Service is focused almost entirely on fighting structure fires.

Underlying all resource issues and agricultural development is the difficulty posed by the seemingly perverse incentives arising from the complexity of land rights (access to and tenure of land, tree tenure, and benefit sharing) associated with both customary and statutory systems. Though an issue in and of itself, land and resource tenure complicate the potential to use REDD+ incentives in reducing deforestation.

Infrastructure needs, shortages of technical expertise, and institutional barriers that limit data-sharing are general obstacles to mainstreaming climate policy within the GoG.

AGRICULTURE AND LIVELIHOODS

Agriculture dominates the Ghanaian economy (>25 percent of GDP in 2008) in terms of income, employment, food security, and export earnings. Performance of the sector, however, has lagged other segments of the economy at rates lower than growth in GDP. Positive growth rates within the agriculture sector come primarily from cocoa production and marketing. The livestock, fisheries, and food crops sub-sectors, on the other hand, have not shown appreciable improvements. Nevertheless, modernization of the agriculture sector is expected to be an important driver of growth in the medium-term on the basis of improved productivity; the growth goals cannot be met by simply expanding land under cultivation. The GoG considers agricultural modernization as a pre-condition for the structural transformation of the economy and sustainable reduction in the incidence of poverty. Central to this strategy are improvements in food crop production and expansion of cash crops with a heavy reliance on transforming smallholder farmers by increasing their market orientation. Commercialization and large-scale agriculture pose uncertainties with or without climate change interactions with regard to environmental effects and long-term sustainability, given likely increases in costs of oil, fuel, and petroleum-based agricultural chemicals.

Cropping systems in Ghana are highly diverse, reflecting dynamic adaptations to increasing population pressure, land insecurity, climate variability, and new trading opportunities or markets. Most smallholder farmers combine strategies to meet food security and cash flow needs; farming systems may combine sedentary and shifting cropping systems as well as intercropping and rotational cropping. Even cocoa farmers retain some of their land to grow food crops to meet their own needs. Traditional cropping systems in semi-arid West Africa, including the northern savanna zone in Ghana, are dominated by cereal-based systems, usually combining two or more crops in a field. Intercropping minimizes risk of crop failure from drought or flooding and spreads the need for labor over a longer period. With the risk spread over two crops, a smallholder can take advantage of a long growing season during a year of above-average precipitation. Maize is the most important food crop for smallholders, who obtain 20 percent of their caloric intake from maize. Because maize is also used to meet their cash needs, about half of the maize produced is marketed. Low soil organic matter and limited availability of plant nutrients, in particular phosphorus and nitrogen, are major bottlenecks to agricultural productivity in Ghana, which is further hampered in the northern savanna zones by substantial topsoil losses through wind and water erosion.

Ghana is one of the world's top producers and exporters of cocoa, and the sector has played a key role in the nation's economic development. Cocoa yields in Ghana are below international averages; the potential increase from higher productivity could more than double the yields in 2005. Recent increases in production have come from expansion of the land cropped to cocoa and higher inputs of family labor. Increasing land in cocoa production has been a driver of deforestation. Because cocoa was traditionally grown under shade, however, many valuable timber trees were retained in cocoa fields, augmented by planting of fruit and other useful trees. Thus shade-grown cocoa was an agroforestry practice with greater biodiversity value than slash and burn (bush fallow) agriculture. Research has demonstrated the technical advantages of fertilized, low shade or full sun hybrids, and current recommendations from the Cocoa Research Institute of Ghana call for fertilizing densely planted hybrid cocoa in full sun or light shade with phosphorus, potassium, and micronutrients. In practice, smallholders have been able to adopt only the low shade/full sun recommendation, as they lack resources to acquire hybrid seeds and fertilizer. Little research has been directed towards increasing productivity of traditional shade grown cocoa, although that alternative would avoid the negative effects of full sun hybrid cocoa on biodiversity.

Rice production accounts for 15 percent of agricultural GDP and 45 percent of the total area planted to cereal grains in Ghana. The main production systems are irrigated, rainfed lowland, and rainfed upland systems. Urban consumers prefer imported rice because the domestic rice is uneven in quality and often contains impurities. Thus, two challenges to commercialization of rice production are to increase productivity and improve quality of domestic rice. Optimal whole-farm production systems, including rice using traditional (grass fallow) methods, requires >9 ha of production land, which is about twice as much as the mean land holding for farmers in the north. Transforming existing smallholders into commercial operations will require increasing land holdings. Replacing traditional grass fallow with short-duration leguminous cover crop fallow would have to be accompanied by increasing mechanization to replace the labor needed to farm the larger acreages.

The agricultural sector has been a major driver of poverty reduction, almost exclusively dominating the livelihoods of rural households. Smallholder farmers, who cultivate 1-2 ha plots of land, produce 80 percent of the country's agricultural output. The two most important cash crops for smallholders are maize and cocoa. Additional, albeit less lucrative, foods grown by smallholders include cassava, yam, plantain, cocoyam, and various fruits and vegetables. The remaining 20 percent of agricultural production comes from larger scale industrial plantations that produce palm oil, cotton, rubber, sugar cane, and tobacco. Raising livestock is another important activity engaged in by >60 percent of households. Chicken is the most commonly reared animal (30 percent of households), along with goats (18 percent), sheep (11 percent), cattle (4 percent), and other poultry, including ducks, turkeys, and guinea fowl. A few households raise pigs, grasscutter (cane rats), and rabbits.

Fish provide 40-60 percent of the protein in the Ghanaian diet, and fisheries contribute about 4.5 percent to the national GDP. The fishing industry in Ghana is based primarily on a large marine fishery, and to a lesser but important extent, on inland or freshwater fisheries and aquaculture. The Volta Lake impoundment, other reservoirs, aquaculture, and coastal lagoons are the sources of inland or freshwater fish. Even without consideration of climate change, clear evidence is available of over-exploitation of the marine fishery and at least anecdotal evidence is available of declining fisheries in Lake Volta and Lake Botsumtwi. On the coast, overfishing of marine stocks is obvious and acknowledged by local fishers; however, the root causes are not clear. Foreign and reportedly domestic trawlers using illegal pair trawling and both inshore purse seiners and traditional canoe fishers using lights at night to attract fish deplete all sizes of fishes, and trawling is reportedly degrading the bottom habitat for fishes. Likewise, traditional fishers are unsustainably harvesting near shore stocks using unselective methods and evidence suggests they are fishing down existing stocks (e.g., depleting all but the smallest sizes and species). Traditional fishers report they are catching smaller, fewer fishes despite increased fishing effort and going farther out to sea to fish.

Continued expansion of the canoe fleet is also associated with fishery declines. The traditional fishers attempt to manage the fishery by limiting by traditional means the number of craft operating on a given day. The possible role of the loss or degradation of mangroves as breeding and rearing habitat should be investigated. Fisheries are under tremendous pressure, facing collapse, unless the government is ready to seriously monitor and regulate the resource. Any solution will involve a drastic cut in catch size and a reduction of the fishing season. This means individuals that depend on the fisheries will need to find employment elsewhere. Reduced domestic fish production seems to be likely, whether it is caused by collapse of the fisheries from overfishing, increased regulation in an attempt to avoid a collapse, climate change effects, or a combination of these factors. The unexplored question is how this critical protein source will be replaced in the Ghanaian diet and how will it impact nutrition and food security?

Although growth rates in agricultural production have slowed since the 1980s, they have been positive, but for most crops growth came from increases in the area harvested not from productivity gains. Rice and millet were exceptions. For maize, substantial differences exist in regions of the country, both in terms of average growth rates and the share of growth resulting from increasing the area under cultivation (extensification) versus improving yields per ha (intensification). Extensification has caused significant environmental damage (deforestation, desertification, and soil erosion) and is clearly unsustainable. Meeting the ambitious goals of the GoG for increased agricultural productivity will be challenging; intervention is needed to set agriculture on a different development trajectory.

Commercialization of maize and rice production requires increased land security in order to motivate farmers to invest in technology and inputs. Commercialization of maize production already has led to changes in the land tenure patterns and a tendency to preferentially allocate land to large-scale commercial farmers. Pressure on the available land resource has already intensified conflict in the northern savanna zone. For example, conflicts have arisen between farmers and herdsmen on the alluvial plains; in other areas, land fallowed by one family has been reallocated to another family. Transforming rice cropping in the northern savanna zone would include concentrating access to land in the hands of wealthy producers, while smallholders would lose their use rights.

Crops are vulnerable to climate variability as evidenced by obviously lower yields during drought periods and less dramatically by year-to-year variation in productivity. Variability can take many forms, such as less total annual precipitation, delayed onset of the rainy period, higher temperature or sub-optimum moisture during critical growth stages. Changes in average climate values in regions currently at the limit for growing some crops could reduce yields to non-viable levels, for example, causing a shift towards agropastoral systems. The complexity of crop growth requires climate data (short-term variability, frequency of extreme events) at spatial and temporal resolutions that are currently beyond the reach of climate change models. In addition to inadequate climate models, crop modeling research has favored the major global food crops and devoted less attention to crops important to Ghana, such as millet and yams. Additionally, crop models generally are specified for monocropping and rarely consider intercropping. Improvements in climate and crop models and the ability to model effects at scales from the farmer's field to the region and nation will be critical to formulating adaptation options for agriculture and mainstreaming climate change into development programs.

ECOLOGICAL VULNERABILITY

The African continent is among the most likely to suffer adverse impacts of climate change because of vulnerable social and natural systems, multiple interacting stresses, and low adaptive capacity. Ghana spans a range of climatic and edaphic zones from coastal mangroves and rainforests along the coast to savanna in the north. In much of sub-Saharan Africa, precipitation is inherently variable from year to year. This is often expressed as recurrent drought and periodic flooding. Between 1991 and 2008, Ghana experienced six major floods with >2 million people affected by the floods in 1991. The northern savanna zone is exposed to floods as well as drought. In 2007, floods followed a period of drought and affected >325,000 people. Because most agriculture is rain-fed and rural populations in many countries lack resources to moderate or adapt to drought, the agricultural sector is particularly vulnerable.

The major findings for Africa of the Fourth Assessment Report of the IPCC confirm earlier reports, including a warming trend since the 1960s. In West Africa, rainfall has declined 20 percent to 40 percent, although the decline in the tropical rainforest zone has been only 4 percent. Despite advances in our understanding of the complex mechanisms driving rainfall patterns, much uncertainty remains. Drought, a manifestation of extreme rainfall variability, has long been a feature of the continental West African climate with severe and long-lasting impacts on natural and social systems. The decline in rainfall from the 1970s to the 1990s, for example, caused a 25-35 km southward shift of the savanna zone (Sahelian, Sudanese, and Guinean savanna zones) with loss of grassland and woodland and displacement of human populations. Besides long-term climatic trends and extreme events, ecosystems in West Africa have been degraded by human activity which often interacts with climate. Major stressors (drivers of degradation) are deforestation, wildfire, and soil erosion in upland areas and overfishing in coastal areas. Here, we examine resource and social vulnerability.

Climate change in conjunction with other destructive land use practices could accelerate desertification in northern Ghana (north of about 10° N latitude). Rapid land use and land cover changes suggest the process is well underway. Even so, further rainfall declines, coupled with increasing temperatures, would make much of northern Ghana even more vulnerable to desertification. The vulnerabilities are simply magnified given a host of biophysical and human related issues in the region (e.g., erosive rainfall, soil qualities and fertility, recurring drought, low input decreased fallow period farming, deforestation, frequent hot bush fires, and overgrazing). Regardless of climate change effects being negative or positive, the continuance along the current human-natural resource trajectory of population growth, over-exploitation, and overall extensive land degradation in the desertification-prone zones of Ghana is clearly unsustainable. At best, the resilience and productivity of much of the northern savanna zone will be progressively weakened and at worst those same areas, particularly those in northern most Ghana, will succumb to desertification.

Estimates of forest cover in Ghana vary considerably and depend on how forest is defined and the assessment method. To date, no complete forest inventory of the country exists. Most estimates of forest in Ghana focus on the High Forest Zone covering about the southern third of the country. Until 1900, it was estimated that 33 percent of the country had forest cover. By the late 1980s, forest cover had declined 78 percent (to 1.8 million ha), and forest areas are now fragmented. Deforestation, albeit poorly measured, is clearly happening at unsustainable rates over the entire country. In 1972, >98 percent of the northern savanna zones were covered by savanna woodland (>25 trees/ha) or open, cultivated savanna (6-25 trees/ha), respectively. By 2000, 33.6 percent of the northern savanna zone had been degraded to widely open, cultivated savanna (<5 trees/ha). Under current trends, the degradation is projected to increase to 65.5 percent of the area by 2050, clearly increasing risk of desertification. Similar dramatic shifts occurred in the Forest-Savanna Transition Zone. In 1972, >90 percent was dominated by open forest (<60 percent canopy) and closed cultivated woodland (>25 trees/ha) but now 57 percent of the zone is widely open, cultivated savanna (<20 trees/ha). Projecting current trends, open forest will cover only about 1.2 percent of the area by 2050. In the High Forest Zone, 57.6 percent of the land cover was closed forest (>60 percent canopy) but that decreased to 34.2 percent by 2000. In contrast, the moderately dense bush forest (<15 trees/ha) increased from 35 to 60 percent of the land cover in the High Forest Zone from 1972 to 2000. About 24 percent of the zone is projected to be converted to open, cultivated woodland (<5 trees/ha) by 2050.

The productive marine ecosystem of Ghana has supported a massive increase in fishing yield since the 1970s, but strong biological and cultural signals indicate it is under increasing strain. For example, catch of prominent species in the fishery have declined – most notably those high in the food web, as is often the case in heavily exploited systems. The fishery has also seen simultaneous declines in multiple small pelagic species, the mainstay of the fishery, and sudden shifts in dominant species, all indicative of an overexploited fishery. The vulnerabilities of this system are multi-faceted with or without consideration of climate change. Fleet growth, gear improvement, and technological innovation and adaptation have acted in concert with a lack of research, management, and regulation to deplete the fishery. Climate change-induced sea temperature increases could exacerbate existing problems by disrupting the timing and intensity of the coastal upwelling which could in turn dramatically reduce productivity in all sectors of marine fishery.

Coloring all development issues is the apparent willingness of resource agencies to turn over all responsibility for addressing and enforcing environmental laws to the Environmental Protection Agency. Although multiple agencies provide permits for development, monitoring and enforcement is left to an understaffed and technically deficient Environmental Protection Agency.

SOCIAL VULNERABILITY

We assessed social vulnerability to climate change on a district level in Ghana using a vulnerability index based on 11 socioeconomic indicators. The Upper East, Upper West, and Northern administrative regions have the highest overall social vulnerability to climate change. The eastern portion of Brong-Ahafo Region and both the far northern and southern-most districts of Volta Region also exhibit high social vulnerability to climate change. Urban districts are less vulnerable than rural districts. The Upper East, Upper West, and Northern regions also have a much higher incidence of poverty than other regions of Ghana and doubled (Upper East, Upper West) or tripled (Northern) in population density between 1960 and 2000. These three regions lie in the Sudan and Guinea savanna ecological zones. The Forest-Savanna Transition Zone has the next highest social vulnerability to climate change in Ghana, following the northern savanna zones. These data indicate that Ghana's three northern regions deserve attention for investments that support climate change adaptation. Nevertheless, other parts of the country that are also highly vulnerable also warrant attention. A district-level approach to identifying the areas in greatest need of support for climate change adaptation will help to better target resources than a regional-scale approach.

Ghana's economy is dependent on agricultural production, as are livelihood – especially rural livelihoods where >90 percent of the population depends primarily on agricultural related work. As noted, most of Ghana's agricultural production takes place on 1-2 ha plots of land. A pervasive sense of insecurity and a lack of transparency pervade the current customary land tenure system practiced over most of Ghana. Without secure access to land, farmers are less likely to invest in or develop long-term innovative agricultural systems. Nor are they likely to invest in new technologies. Rather, without secure access to land, farmers are more likely to try to maximize short-term profits, often at the expense of the land's long-term health. This is unsustainable in the long run. Without secure access to land, farmers also have difficulty accessing credit or connecting with investors, reducing overall production. Finding ways to secure land assess, provide credit at a local level, and strengthen local value chains (connecting farmers with local purchasers, etc.) could help farmers overcome these barriers.

Women, migrants, and unconnected (socially) landless farmers are among the most vulnerable groups in Ghanaian society. Under normal circumstances these groups have difficulty accessing land and securing livelihoods. Land tenure reforms should not only focus on titling and registration but on ensuring that land is distributed equitably, affordably, and simply (meaning the process should be straightforward enough to be navigated by groups without much social or political capital.)

Commercialized or mechanized farming could increase production and strengthen food security. However, it could also create joblessness and contribute to increased poverty if done without full consideration of potential socioeconomic impacts. This is especially relevant given that most of the large-scale commercial agricultural operations likely will occur in portions of the country that are already marginalized. If reduced rainfall caused by climate change reduces the amount of arable land, increased competition for land will lead to even greater vulnerability of smallholders. Livestock rearing occurs primarily in the northern savanna zones, and could be a viable livelihood diversification strategy for farmers. However, grazing rights threaten to pose increasing conflicts, particularly if land ownership and rights are unclear.

ADAPTATION

Farmers are vulnerable to shocks (unexpected events such as flooding), seasonal variation, particularly timing and amount of rainfall, and long-term trends (e.g., increased mean temperature). Coping strategies commonly in place to reduce vulnerability to seasonal variation include planting mixtures of crops and cultivars adapted to different moisture conditions (reducing the risk of complete crop failure), using landraces resistant to climate stresses and mulching or water conservation. Multi-year droughts, however, will overpower these short-term coping strategies and may cause long-term impacts if capital assets are lost and no effective local or national support system is in place (Challinor, Wheeler et al. 2007). An alternative to rainfed agriculture for some farmers may be small-scale irrigation; this requires suitable land, access to water, and ideally, capital to invest in a pump. In the northern savanna zones, dry season vegetable crops are grown in floodplain fields that often are hand watered. Many irrigation options require infrastructure or cooperation among groups and are thus beyond the resources of a single farmer.

Given the uncertainty of climate change projections for precipitation, the prudent adaptation strategy is one of "no regrets." Reducing vulnerability to current climate stress may increase adaptive capacity and increase resilience to future climate change. Many options are available for adapting agriculture to climate variability and change. Some farmers may opt to leave agriculture by diversifying entirely into non-farm activity or migrate to urban areas. Farm households in the Northern Region already send some family members south to work and return remittances. With increasing populations, this option may be unavailable, forcing some households to remain in agriculture (Challinor, Wheeler et al. 2007). Diversification of livelihoods in the coastal region will be a necessity for fishing households. A promising industry is the emerging tourism sector on the coast and eco-tourism near attractions such as national parks. Investment in infrastructure would provide employment in short-term construction jobs as well as in the long-term. Infrastructure (especially restaurants, lodging, developed recreational activities) would also enable local communities to capture more benefits from tourism.

Farmers who depend on annual rains have already demonstrated considerable ability to adapt to uncertain climate at least within the range of historic variation. Their ability to adapt to future climates will depend in part on a supportive institutional and macroeconomic environment. Ghana is fortunate among West African nations in that it is politically stable, yet its governance structures are weak and its public sector underperforms, especially in the northern savanna zones. Clarification of land tenure, tree tenure, and carbon rights is necessary for smallholders to access capital and make long-term investments in conservation practices, agroforestry, and improved crop varieties and inputs. Access to knowledge and assistance from extension workers is needed for farmers to modify their cropping systems. Community-based approaches to identifying climate change adaptation strategies as well as strategies for enhancing food security have been implemented in the northern regions and appear to hold promise.

Focusing food security investments entirely on commercialization, mechanization, and large-scale agriculture will result in adverse social impacts unless the needs of small farmers are simultaneously addressed. A multi-scaled approach to agricultural development appropriate to the local socio-cultural context should be considered. Farming for profit will require concentrating agriculture on fewer larger farms to take advantage of economies of scale, mechanization efficiencies, and market access. Such commercialization or rationalization of agriculture may be desirable from a national development perspective. However, given the traditional land tenure system and the insecurity of many smallholders, development of large-scale farms by overseas investors may displace many smallholders. Moreover, the food insecurity of local populations could be worsened in bad crop years if they are priced out of the market for food. Given the likelihood that oil, fuel, and petroleum-based agricultural chemicals will increase in price in the future and most smallholders cannot afford such inputs without subsidies, questions of economic viability also arise. Commercialization and large-scale agriculture also pose uncertainties with or without climate change interactions with regard to environmental effects and long-term sustainability.

ENERGY SECTOR

Wood-based fuels (charcoal and firewood) are the dominant source of cooking fuel in Ghana with >90 percent of households in most districts using them as their main source. Charcoal use is greatest along the coast and in urban centers, though most households (>50 percent) in most districts use firewood as their main source of cooking fuel. Firewood dependency is greatest in the Guinea Savanna ecological zone (comprised of the Upper West, the Northern, and the northern portion of the Volta regions), where >80 percent of households in most districts use firewood for cooking. Although much of the firewood reportedly comes from dead wood on farm and fallow land, fuelwood harvest is about 7.5-8.5 times the estimated national volume of timber harvested for other purposes, a clear warning sign of the fuelwood pressure on Ghana's forests and the threat it poses for deforestation, forest degradation, and climate change. Although agroforestry and CDM projects may have potential for addressing the wood-based fuels issue through tree planting, emphasis should also be placed on reducing fuelwood consumption through the development and distribution of affordable, efficient cook stoves that are compatible with Ghanaian cooking practices and food tastes and by improving forest management to promote sustainable fuelwood harvesting and use.

Hydropower is an issue of some concern in the contexts of climate change, potential for regional conflict, and national energy strategies. Clearly, the issue of future hydropower production from Akosombo (and Kpong) dams is complex, is not simplistically related to potential climate change, and is replete with trans-boundary implications. First, the water development focus between the two major countries in the Volta River Basin is fundamentally different. Burkina Faso has and is concentrating effort in the Basin on improved use and increased retention of water for agriculture with demands in that country (as well as northern Ghana) expected to increase rapidly. In contrast, Ghana's primary objective is to keep Lake Volta at optimal levels for power production. Clearly, potential exists for major conflict. Second, past meteorological data and hydrological modeling indicate water levels in Lake Volta are highly sensitive to even small changes in rainfall. Rainfall projections of global climate models are mixed, adding to the uncertainty; however, trends from historical data indicate fairly dramatic decreases from long-term averages. Third, the design of Akosombo dam was premised on one of the wettest periods on record affecting optimal power production even during relatively short or modest dry periods in an inherently variable precipitation regime. Fourth, water allocation agreements are lacking among Ghana and the other riparian countries in the Lake Volta Basin. Finally, the future power production at Akosombo dam clearly will affect Ghanaian choices for alternate energy sources (i.e., fossil based or alternative) in an attempt to meet shortfalls and ever increasing demand.

In Ghana, the issue of gas flaring from the Jubilee Oil field has created concern and controversy in civil society and donor countries. Given the substantial production, the gas from the Jubilee Oil Field will need to be stored, transported, or flared. Further, the infrastructure to pipe gas ashore will not be ready as oil production is initiated and ramped up, and re-injection of gas after ramp-up may not be feasible as once thought. Long-term gas flaring at the Jubilee Field may be inevitable without accelerated development of infrastructure for storage, shipping, and processing of the gas.

Prolonged gas flaring of the Jubilee natural gas would produce about 1.5 million tons of CO_2 annually (7 percent of Ghana's total national emissions). If the gas is used in a power plant, >13,000 barrels of oil/day are saved and 0.9 million tons of CO_2 emissions are avoided. The total emissions reduction potential from using the gas for power production instead of flaring is 2.4 million tons CO_2 equivalent or 10 percent of national emissions. Unfortunately, if gas infrastructure development is projected to take four years to become reality and high re-injection capacities are not feasible, the life of this valuable gas field will be reduced by about 20 percent (16 versus 20 years), an estimated 152-228 billion standard cubic feet of gas will be lost for energy production, and some 6 million tons of CO_2 will be released.

Oil and gas development is in its infancy but pressure on land prices and housing availability onshore has already occurred. Planned development of a gas pipeline and onshore uses (e.g., electric power generation, fertilizer plant, liquefied petroleum gas) likely will occur without adequate planning or mitigation of impacts on local communities. The over-inflated expectations in the press of the wealth to be derived from oil and gas development could lead to social unrest in coastal communities, especially since the GoG has side-stepped an attempt to designate a fixed percentage of revenues to the region.

NORTHERN SAVANNA CASE STUDY

Some key vulnerabilities to climate change in Ghana's three northern regions include high rates of illiteracy (>73 percent in most districts), and relatively underdeveloped infrastructure compared with other parts of the country (water sources, road infrastructure). USAID is well positioned to address these vulnerabilities. Significant obstacles to increasing the food security of farm communities in the northern regions are uncontrolled annual bushfires, declining soil fertility causing reduced productivity, and lack of access to affordable operating capital. The attraction of quick cash from making and selling charcoal for sale in the south draws young people away from farming. Such harvesting appears to be unsustainable and will add to soil erosion problems, affect local climate, perhaps accelerate desertification, and will eventually produce an unemployed segment of the population lacking in marketable skills. Adding to these problems is a shortage of dry season grazing and water for livestock, free-ranging livestock, and an influx of migrant pastoralists from the north. These factors can and are interacting to produce a downward spiral for soils, forests, farming, and farmers. Climate variability contributes to current food insecurity, which will be exacerbated by a changing climate.

A number of adaptations to climate variability and climate change are documented in Ghana's three predominantly rural, agriculturally dependent northern regions. These adaptations include changing agricultural practices, diversifying livelihood strategies outside of the agricultural sector, and increasing migration to southern Ghana and urban areas. There are a number of opportunities to support climate change adaptation in northern Ghana through USAID's Feed the Future program because of its focus on increasing the livelihood security of households. It is important to take a community-based approach to developing and implementing specific interventions to support both food security and climate change adaptation to ensure that they are appropriate to the local context and will be beneficial. Such an approach calls for helping communities identify their own vulnerabilities and develop their own adaptation strategies.

Addressing food security by focusing on the entire value chain appears to be the most promising approach, although there is room for better alignment between needs and current activities. Community-based approaches to identifying climate change adaptation strategies (e.g., CARE) and strategies for enhancing food security (e.g., Canadian International Development Agency or CIDA) have been implemented in the northern regions and appear to hold promise. Activities include adopting agroforestry practices, crop diversification, planting drought-resistant and short-season varieties, practices to enhance soil moisture retention in fields, minimal tillage, composting for fertilizer, planting dry season vegetable gardens, developing surface wells, rearing small stock (chickens, guinea fowl, goats, sheep, and pigs), and actions to reduce burning of fields. Practices that are successful at the local level could potentially be scaled up.

MAINSTREAMING CLIMATE CHANGE

Incorporating or "mainstreaming" climate change, climate variability, vulnerability, and adaptation into USAID programming offers many opportunities for USAID to help the GoG prepare for the future. The suggestions summarized here are based on the analyses conducted by the Assessment Team. Many of the options are multi-level, in that the vulnerability addressed will have to be attacked at several levels within Ghanaian society. Underlying all the options is a need to address the disconnect between customary and statutory rights in land that precludes improvements in many aspects of food security and environmental management. Without secure rights to land, smallholders lack incentives to adopt new technologies, invest in agricultural improvements, and are unable to access the resources needed to increase crop productivity because they cannot obtain operating capital at less than usurious interest rates.

We categorize intervention options into five types of barriers to climate change adaptation and mitigation: Policy Environment, Governance and Tenure, Capacity and Infrastructure, Information and Analysis, and Awareness and Implementation. Under each barrier, we briefly indicate intervention options and parenthetically identify USAID programs as we understand them that could address that intervention (FtF=Feed the Future, Edu=Education, H&S=Health and Sanitation, Dem/Gov=Democracy and Governance, Gen=Gender). Options could have certainly been categorized differently, but the purpose is to communicate important information the Assessment Team gleaned regarding potential interventions.

The policy environment barrier exposes vulnerabilities in areas directly and indirectly relevant to climate change. Decided vulnerabilities arise from uncoordinated responses to climate change. Options for intervention include supporting the completion and implementation of the Ghana National Climate Change Strategy, focus in that strategy on adaptation responses and incorporation of climate change in urban planning efforts (FtF, Edu, H&S, Dem/Gov, Gen). A national energy policy is needed that includes climate change mitigation and low emission strategies (i.e., advanced biofuels development, capturing not flaring natural gas) (Dem/Gov, FtF). Integrated national and regional level coastal development adaptation planning is needed to address sea-level rise and coastal erosion (Dem/Gov, Edu, FtF). The FtF program focuses with justification on the northern regions, but other areas exhibit high social vulnerability to climate change, indicating need for a more targeted, district-based approach (i.e., expansion to Brong-Ahafo and Volta regions). Indirectly but most certainly related to climate change are uncoordinated policy responses to water allocation among riparian countries in the Volta Basin (FtF, Dem/Gov) and lack of integrated fire management and regionally adapted policies (including traditional practices) focused on managing environmentally destructive fires (FtF, Dem/Gov). Because farmers need stable and favorable crop prices to make commercial crop production profitable, a favorable policy environment is needed for cash crop production (FtF).

The governance/tenure barriers and the associated vulnerabilities to climate change adaptation and mitigation in Ghana were viewed by the Team as overarching, keystone issues not only in the climate change arena but in development generally and FtF specifically. Key interventions include advocating for examination of land tenure and property rights issues at the community level, capacity building with traditional land management authorities (e.g., chiefs, Tendanas) for transparency and equality in land use practices, and a national examination and correction of tree tenure issues that result in perverse, counterproductive incentives against carbon sequestration and maintenance and creation of forests (all FtF, Dem/Gov, Gen). Retention of carbon benefits at the national level without local benefits sharing creates yet another perverse incentive system affecting carbon sequestration. Advocacy is needed for legislation defining carbon rights to provide equity to smallholders (FtF, Dem/Gov, Gen).The land tenure system also imposes insecurity on tenants and increases their vulnerability to climate change by restricting access to credit and discouraging if not precluding long-term planning and investment by tenants and landowners. Local strategies are needed to provide affordable credit to landowners and tenant farmers (FtF). The extreme reliance on wood-based fuels in Ghana is a significant vulnerability that seems largely unaddressed by any sector at any level. The Team viewed the wood-based fuel situation as a critical issue from the perspectives of dramatically increasing social vulnerability to climate change, its clear unsustainability and environmental ramifications thereof, and for USAID, the ability of FtF to succeed. Addressing forest management and tenure challenges to sustainable firewood and charcoal production are sorely needed as are community-based approaches to managing wood-based fuels sustainably (Dem/Gov, FtF). The FtF program emphasizes agricultural development which could affect land access and allocation of water resources. Social impact assessments of agricultural development projects are needed to identify mitigation measures, to ensure people are not displaced or lose land access, and to ensure conditions for marginalized groups (i.e., women and migrants) are improved not worsened (FtF). Irrigation development will redistribute water resources and perhaps increase competition for water access. An equitable system of water allocation and management should be developed as an integral part of any irrigation development project (FtF).

Many vulnerabilities under the capacity and infrastructure barrier cascade directly from the policy and governance/tenure vulnerabilities. Several relate directly to carbon sequestration and forestry issues. FtF activities need to be melded with reforestation and afforestation projects to meet community and family needs for fuel and construction wood, to produce non-timber forest products (NTFPs), to protect riparian areas, and to sequester carbon (FtF). Further, partners need to be identified who can link FtF activity to carbon financing or payments for ecosystem services markets as part of carbon offset payments (FtF). Technical capacity is needed to develop more efficient wood-based stoves to reduce deforestation, carbon emissions, and smoke (FtF, H&S, Gen). Community fuelwood programs need to be developed with technical assistance in species selection, plantation establishment, and management and governance structures (FtF, Gen, H&S, Dem/Gov). Scarce fuelwood most impacts women, the traditional gatherers of wood for cooking. A national integrated fire management program, including traditional practices, is needed to manage destructive bush fires to protect soil quality, increase forage quantity and quality, increase rates of reforestation and afforestation, and mitigate trends toward desertification in vulnerable areas (e.g., northern Ghana).

Several interventions related to the agriculture sector (and thus FtF) fall under the capacity and infrastructure barrier. Transportation infrastructure limits access to markets with most households in most districts of northern Ghana traveling >30 minutes to reach a food market and in many districts <50 percent of households have year round road access to their homes. Agricultural development and crop marketing in northern Ghana should focus on carefully planned improvements to market access and transportation infrastructure (FtF). Similarly, in most districts of the Upper West and Northern regions, 15-50 percent of households travel ≥30 minutes to get drinking water with a high dependency on unimproved water sources (FtF, Gen, H&S). Well-planned development of water infrastructure will help improve human health, free up labor (especially for women), and increase household livelihood security (FtF, Gen, H&S). To adapt to climate change, people need to diversify economically, but options are limited. Investment is needed in local processing facilities to add value to agricultural and wild-harvested products, increase income, and create nonfarm jobs (FtF). Because climate variability creates food shortages, investment also needs to focus on developing improved grain storage methods and facilities so excess grains produced in good years can be stored to buffer against crop failures (FtF). Harvesting and handling losses could be lowered by developing community or cooperative drying and storage facilities (FtF). Illiteracy (15 years and older) in Ghana's northern regions is high (61.3 percent to 87.5 percent in most districts), limiting people's capacity to understand and adapt better agricultural practices and to negotiate climate change. Programs developing literacy should be emphasized (Edu, FtF).

Given a declining fishery and the threat climate change poses for that resource, the GoG should be strongly encouraging development of capacity and infrastructure to scientifically monitor, regulate, and manage all sectors of the marine and freshwater fisheries for long-term sustainability (FtF, H&S, Gen). Local monitoring authorities should be strengthened and connected with local, regional, and national partners and counterparts (FtF, H&S, Gen). Most coastal residents are fisheries-dependent, are vulnerable to disruptions in the resource, and have few employment alternatives. Tourism, while promising, lacks the infrastructure to provide substantial income. Investments in tourism infrastructure could provide coastal residents viable alternative livelihoods. Investments in education could broaden skill sets and widen employment opportunities for youth and young adults (Edu).

The energy sector is also hampered by significant capacity and infrastructure barriers. The GoG should be encouraged to develop as soon as possible natural gas processing capabilities to avoid prolonged (months to years) gas flaring and increased GHG emissions from the Jubilee Field and use that gas to supplement an already inadequate national power grid. The lack of electricity in rural areas impedes entrepreneurial activity, calling for exploration of alternative energy systems (e.g. solar, biofuels) to meet local community needs. Because of education, training, and skill deficits, local populations are disadvantaged for competing for jobs in the nascent oil and gas industry. The GoG should be encouraged to provide training to afford locals employment opportunities in that industry (Edu).

Several other interventions were identified under the capacity and infrastructure barrier. Mainstreaming climate change in GoG activities could be advanced by improving data sharing policies among agencies, especially for meteorology data (Dem/Gov) as well as partnering with institutions to supply climate adaptation information (FtF, H&S, Gen). Lack of technical capacity and infrastructure limits the ability to share large data files between agencies and could benefit from improved internet capabilities. Efforts to decentralize government are impeded in rural areas by lack of infrastructure. Cell phone texting features should be explored for use in online registrations, permit applications, etc. to avoid long distance travel to government offices and to increase participation. Likewise, development of a practical system of farmer credit banks in rural areas is needed to establish farmer accounts that can be used remotely to conduct financial transactions (FtF). As noted, this latter intervention needs to be superseded by addressing land tenure issues that constrain credit and by making credit affordable to smallholders.

Information and analysis represents a significant barrier to climate change adaptation and mitigation in Ghana. Data is lacking for critical decision making, planning, and forecasting. Climate change should be investigated at a sub-national level using appropriately scaled GCM models and within the context of desertification, sea-level rise and coastal erosion, marine and inland fishery sustainability, water supply in the Volta Basin, and hydropower production (FtF, Gen). Rates of coastal erosion should be investigaged nationally with an emphasis on identifying causes and on impacts to coastal infrastructure and natural resources (e.g., towns, ports, biodiversity hotspots, lagoonal and inshore fisheries) (FtF). Regional organizations (e.g., CILSS, AGRHYMET, CORAF, INSAH, FEWSNET) should be engaged in partnerships to ensure availability of and access to data (e.g., weather data, hydrological data, ground cover change, agricultural expansion, improved land productivity, fish populations) and projections (FtF).

Several items identified under the information and analysis barrier relate directly to agriculture and food security. Research and technology development programs are needed in climate prediction, to improve crop models, and to link process-based crop models to high resolution regional climate models (FtF). To help adapt to climate change, soil suitability analysis should be incorporated into agricultural development planning and updated with soil suitability analysis data on new crop varieties (FtF). The uncertainties of FtF commercial and large-scale agriculture sustainability needs to be investigated in light of increasing future costs of petroleum-based fuels and agricultural chemicals and a changing climate (FtF, Gen). Likewise, FtF irrigation projects should be analyzed in regard to impacts on surface and ground water quantity and quality and downstream effects (FtF). An evaluation of the temporal pace of vegetation change and soil degradation is needed to assess desertification in northern Ghana, especially in the context of projected population increases, food security, water demands, ecological services, and climate change.

Information and analysis needs for forestry-related items are also apparent. Land cover/land use inventories and forest inventories are needed to set baselines for deforestation, carbon pools under REDD+ and to meet MRV requirements. Investigation is needed in areas where carbon sequestration can complement FtF efforts, e.g., increasing mangroves, rangeland management, agro-forestry, farmer managed natural regeneration (FMNR), and riparian forest management (FtF). Optimized shade-grown cocoa management schemes are needed that provide high levels of return to farmers, reduce deforestation and degradation and also offer greater biodiversity benefits than sun-grown cocoa (FtF).

Many in Ghana lack the awareness and skills to use climate change, agricultural, natural resource management, or other information that would reduce their vulnerability. Partnerships with local implementers would build the climate change awareness of end users (e.g., farmers, fishermen, media, government) and enhance their ability to use information (FtF, Edu). Workshops should be organized on various topics (e.g., climate change, adaptation, carbon sequestration) for agriculture sector partners and FtF implementers. Cocoa producers lack the skills and knowledge to implement the whole technology package for sun-grown cocoa; cocoa productivity could be increased by intensification and access to inputs (FtF). Top-down approaches to fire management are unsuccessful in part because of a lack of awareness of traditional methods. GoG agencies and personnel should be educated on modern integrated fire management approaches and traditional approaches and the two integrated on the ground. Not all adaptation measures currently used are sustainable and many are erosive to future economic health and well-being at the household, community, and regional levels. Adaptations should be considered carefully so that unsustainable approaches are avoided (e.g., marine fuel pre-mix program). Short-term temporary and long-term coping mechanisms should be distinguished and the difference communicated to the public (FtF, Edu). Livestock production in the north offers a potential to diversify livelihoods in the north and hence decrease vulnerability to climate change. This potentiality should be communicated and promoted; and support should be given to schemes that help farmers adopt livestock keeping (FtF). Most crop yields in Ghana are below potential, requiring intensification to meet middle income country (MIC) goals. Agricultural productivity could be increased by improving distribution channels and access to technology and inputs (e.g., fertilizer) and by providing farmers access to operating capital and crop insurance to mitigate effects of climate variability. (FtF). Farmers lack information on consumer quality expectations and fail to meet market demand. Awareness of consumer expectations should be raised and quality assurance programs instituted for improved marketability (FtF).

NEW INTERVENTIONS FOR USAID PROGRAMMING

To mainstream climate change into USAID programming in Ghana, and indeed for the GoG and other donor partners to integrate climate change into their development efforts, the availability of meteorological data and interpretive information must be increased. To effectively use available climate information, the capacity within Ghana to use the information must also be enhanced. This need presents an opportunity for USAID Ghana to develop programs or partner with others to build capacity. The two sides of the issue are increasing available data and enhancing capacity to use the data and climate projections. Increasing data availability can be achieved by partnering with regional institutions and non-governmental partners to increase meteorological monitoring capacity by increasing the number of weather stations, especially in rural areas in the northern regions where the current monitoring network is sparse. Other initiatives could focus on building relationships among regional institutions such as FAMNET, AGRHYMET, and others to deliver data interpretation. Climate modeling at the scale of the Global Climate Models is already available over the internet, but the expertise necessary to interpret these data, state their uncertainties, and effectively use them to downscale to regional climate models is generally lacking in Ghana and elsewhere in sub-Saharan Africa, except possibly in South Africa. Thus, another opportunity for USAID is to develop interpretation and communication capacity within Ghana, either at a university, within the GoG, or in a jointly funded and maintained center.

Other options are more sectoral in nature. One need seems to be an integrated and realistic energy strategy for Ghana that depends on internal resources. There are few opportunities to expand hydropower; in fact, the current capacity will likely diminish over time as precipitation within the Volta basin declines, and neighboring countries expand their extractions for drinking water and irrigation. Ghana is developing oil and gas that will provide new energy sources, but they will have to be developed – for example, by capturing the natural gas from the Jubilee Field and using it to power an energy plant. Perhaps the greatest opportunity for Ghana is to develop advanced biofuels or at least to use advanced conversion technology along with comparative advantages in growing woody feedstocks. Such a policy should, however, be integrated with agricultural and other uses of land and is predicated upon raising the productivity of food crops to their full potential under intensification.

Woody biomass for bioenergy already provides a large share of the energy needs of the average Ghanaian, specifically fuelwood for cooking. Currently, this use is inefficient (open fires, inefficient charcoal production methods) and often damaging to the environment. In addition to programs to increase fuelwood availability, improve cookstove efficiency, and improve charcoal production, the entire forestry sector of Ghana needs to be transformed. One starting point would be the transformation of the Forestry Commission (FC) into a land management and stewardship agency. Thus, a transformed FC would no longer be focused simply on generating income from timber concessions and permitting fees. Rather, the FC would be responsible for conserving the remaining high forests, restoring degraded forest reserves and wetland forests, and providing technical assistance to communities in developing community forests and fuelwood plantations. In addition, the wood industry in Ghana needs to be rationalized to remove subsidies that maintain an inefficient export market, and to improve provision to meet domestic lumber needs. Improved forest management will also maximize opportunities to capture payments for carbon and other ecosystem services.

Ghana's mid-term development strategy and goal of obtaining MIC status by 2015 depends heavily upon improvements in the agricultural sector. Although we have suggested some interventions in the agricultural sector, one change that requires multiple and continuing interventions is the need to overhaul agricultural research and extension in Ghana. The GoG does not provide adequate support for applied agricultural research internally, which causes research scientists to seek funding from outside sources. This usually means that agricultural research focuses more on basic research than is needed in Ghana, leading to the charge that it is irrelevant. Extension is also underfunded and is removed from the needs of the smallholder. Without a strong applied research focus on issues that matter to the smallholder, delivered by extension agents in affordable technology packages, the existing agricultural research and extension infrastructure will not contribute to meeting the needs of the Ghanaian farmer.

Finally, climate change vulnerability and adaptation analyses need to be conducted at the community and household levels in the different regions. Because variability and changes in climate will be felt locally, and a myriad of possible adaptation responses exist, vulnerability analysis needs to be situated in a local spatial context. USAID Ghana, working with donor partners, GoG agencies, NGOs, and CSOs should develop vulnerability and adaptation analyses as part of the project planning and design phase and require that the results be used to modify projects before embarking on them.

1. INTRODUCTION

The West African country of Ghana is located on the Gulf of Guinea and extends northward from a low-lying coastal zone through the Volta River basin to the savanna zone on the border with Burkina Faso. Ghana is bordered on the west by Côte d'Ivoire and the east by Togo. The total area of Ghana is approximately 238,500 km^2. Ghana's economy relies on agriculture, which accounted for>25 percent of GDP in 2008 and employed half of the economically active population (World Bank, 2009). The main exports are cocoa, gold, timber, diamonds, bauxite, manganese, and hydropower. Ghana is designated a Low Income Country, making it one of only four West African countries that are not classified as Least Developed Countries.

Countries in Africa are among the most vulnerable globally to the effects of climate change because of the dependence of much of the population on agriculture, particularly rain-fed agriculture and widespread poverty that renders them unable to withstand climate stress. Recurrent drought in many countries has demonstrated the effects of climate variability on food resources. Many people face food insecurity, even in good times, due to widespread poverty in many countries (Dixon et al., 2003). Additionally, climate variability and change threaten other resources, including water, forests, and fisheries. Communities in coastal areas will be impacted by projected rise in sea-level of up to 1 m in this century. Some countries, including Ghana, already experience coastal erosion and flooding (Boko et al., 2007).

The team analyzed climate change vulnerability and adaptation challenges with respect to land, water and forest resources, agriculture, energy, human health, human settlements, biodiversity, and coastal zone resource management (including marine fisheries, and coastal land-based resources). The team also analyzed the country's climate change policies, strategies and programs, and the outcomes and lessons learned from past and ongoing climate change programs in Ghana. This included work supported by bilateral and multilateral agencies and donors.

The purpose of this document is to provide the US Agency for International Development Mission to Ghana (USAID-Ghana) with an overview of climate change projections for Ghana, an interpretation of the significance of climate variability and change in terms of effects on natural resources and human populations, and to suggest potential adaptation measures with a view towards future USAID-Ghana programming.

2. APPROACH

This Climate Change Assessment (hereafter, Assessment) of Ghana was prepared by a team of US Forest Service scientists and Ghanaian counterparts, based in part on interviews with government officials, staff of non-governmental organizations (NGOs), and representatives of civil society organizations (CSOs) over a two-week period. In addition to interviews, the team collected geospatial data from agencies and electronic public sources, as well as an extensive literature review. The Assessment was conducted at two levels, a national overview and a targeted assessment of the Savanna Zone, comprised of the three northern administrative regions in Ghana (Northern, Upper West, and Upper East).

In the Assessment, we first set the context by describing the general climate of Ghana and the projected changes to 2080. We discuss vulnerability to climate change at the national level, by ecological zone, and derive key issues affecting vulnerability. Mitigation and adaptation opportunities and challenges are presented from a national perspective. The level of analysis then shifts to an assessment of the savanna zone for which USAID-Ghana has targeted the Feed the Future (FtF) program for the next several years (USAID/Ghana, 2010), and the Coastal zone where significant new developments in the energy sector are anticipated. The report concludes with some options for future USAID/Ghana programming in terms of integration into existing programs and new interventions.

Our approach to climate change assessment follows a particular conceptual model, and some explanation is in order of how we use terms such as vulnerability, mitigation, and adaptation. Assessing vulnerability of natural and human systems has developed from two disciplinary approaches, disaster risk reduction (natural hazards) and climate change adaptation (Renaud and Perez 2010) leading to multiple definitions of terms common to both approaches. Reviews of these approaches and attempts to reconcile terminology abound (e.g., (Adger 1999, Kelly and Adger 2000, Turner, Kasperson et al. 2003, Smit and Wandel 2006, Fussel 2007, Birkmann and von Teichman 2010). The climate change literature that follows the definition of vulnerability given by the Intergovernmental Panel on Climate Change (IPCC) (Carter, Jones et al. 2007; Schneider, Semenov et al. 2007) uses a combined vulnerability that is a function of hazard, exposure and sensitivity (Brooks 2003) termed biophysical vulnerability. This approach focuses on human exposure to hazards with little consideration of how humans might cope with hazards that occur (Brooks, 2003).

Our approach instead views vulnerability as a condition (or state) of a coupled human-environment system. We draw upon the conceptual framework of Sarewitz et al. (2003) who separate the likelihood of an event occurring that will affect a system (*event risk*) from the condition or internal state of the system (*vulnerability*) that makes it susceptible to harm from an event. The risk of a particular outcome (*outcome risk*) integrates the probability of an event with the characteristics of the system that jointly results in an impact. Brooks (2003) explores how this framework can be applied to the different uses of vulnerability in the disaster risk reduction and climate change adaptation literature and O'Brien, Eriksen et al. (2004) examine the conflicting interpretations of vulnerability in climate change research.

Apparent equivalencies and dissimilarities of the two approaches are evident (Figure 2.1). Event risk is synonymous with hazard (as used in the disaster reduction literature) and with climatic event. Similarly, there is little difference in meaning among outcome risk, disaster, and risk (as used in the natural hazards literature).

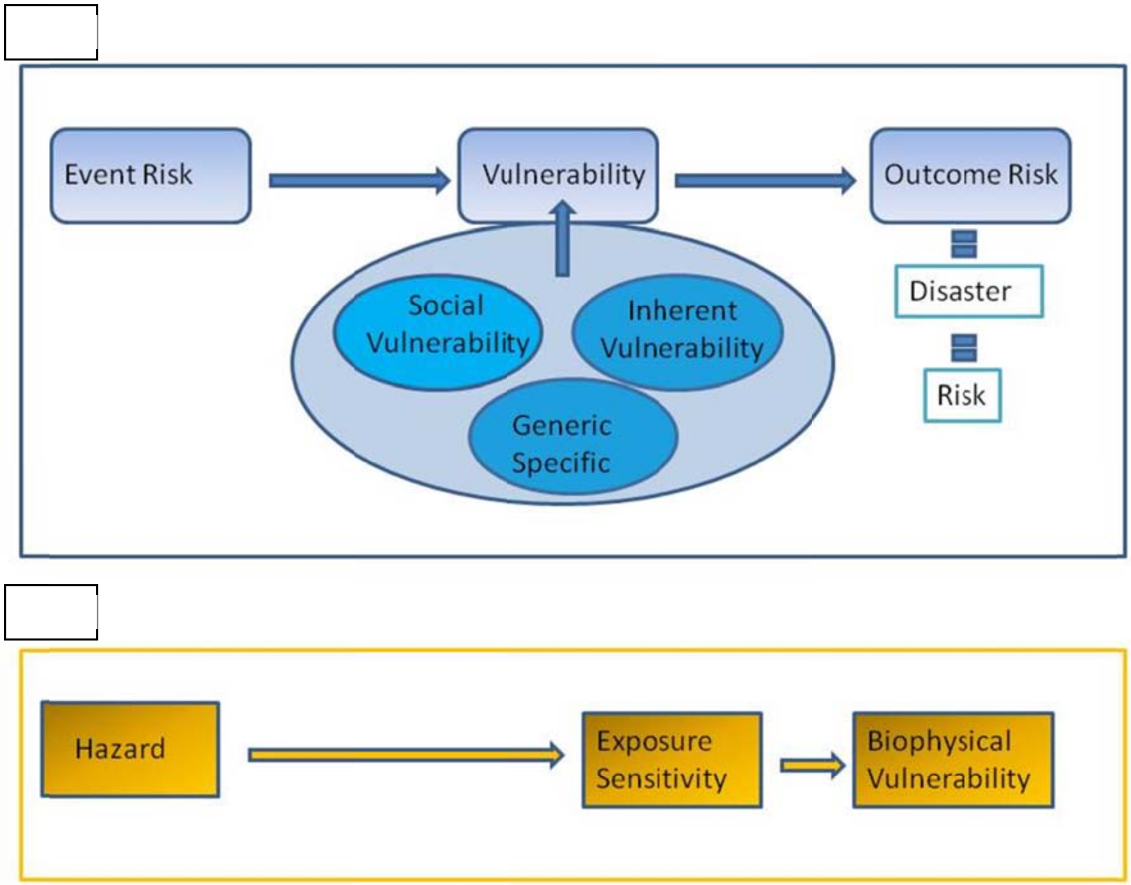


Figure 2.1 Two approaches to vulnerability analysis: (A) risk model of Sarewitz et al. (2003); (B) IPCC model

Figure 2.1 shows two approaches to assessing vulnerability to climate change. The first approach is based on a risk model described by Sarewitz et al., (2003) where vulnerability is a system condition, shown here as conditions of the natural and social sub-systems in a coupled model. In the second, vulnerability as defined by the IPCC views vulnerability as the effects of climate change on a biophysical system (Carter et al., 2007; Schneider et al., 2007). Similarities and distinctions are those suggested by Brooks (2003).

The use of vulnerability by Sarewitz et al. (2003) encompasses both the vulnerability of social systems and the inherent vulnerability of natural systems. Many aspects of social vulnerability are generic in that they are common across geographic scales; in contrast, aspects of inherent vulnerability are more location specific. As Brooks (2003) emphasizes, vulnerability only makes sense in the context of a specific system and range of hazards, that is, vulnerability is "place based" in that the scale of vulnerability assessment should match the scale of the decision-making (Schröter, Polsky et al. 2005).

Mitigation measures are directed toward reducing drivers of climate change; that is, reducing emissions of CO_2 and other green house gases (GHG) or enhancing CO_2 sequestration. We examine some mitigation policies (Reducing Emissions from Deforestation and Degradation plus biodiversity or REDD+; Clean Development Mechanism or CDM), strategies (conservation/low carbon agriculture, fire management, low carbon development), and practices (capturing and using natural gas instead of flaring, biofuels). One implication of our approach is that adaptation measures are directed toward reducing vulnerability, whether inherent, social, or both (Sarewitz, Pielke Jr et al. 2003). We examine vulnerability reduction for three resource sectors (agriculture, forestry, and fisheries) and locally sustainable adaptation measures for reducing social vulnerability.

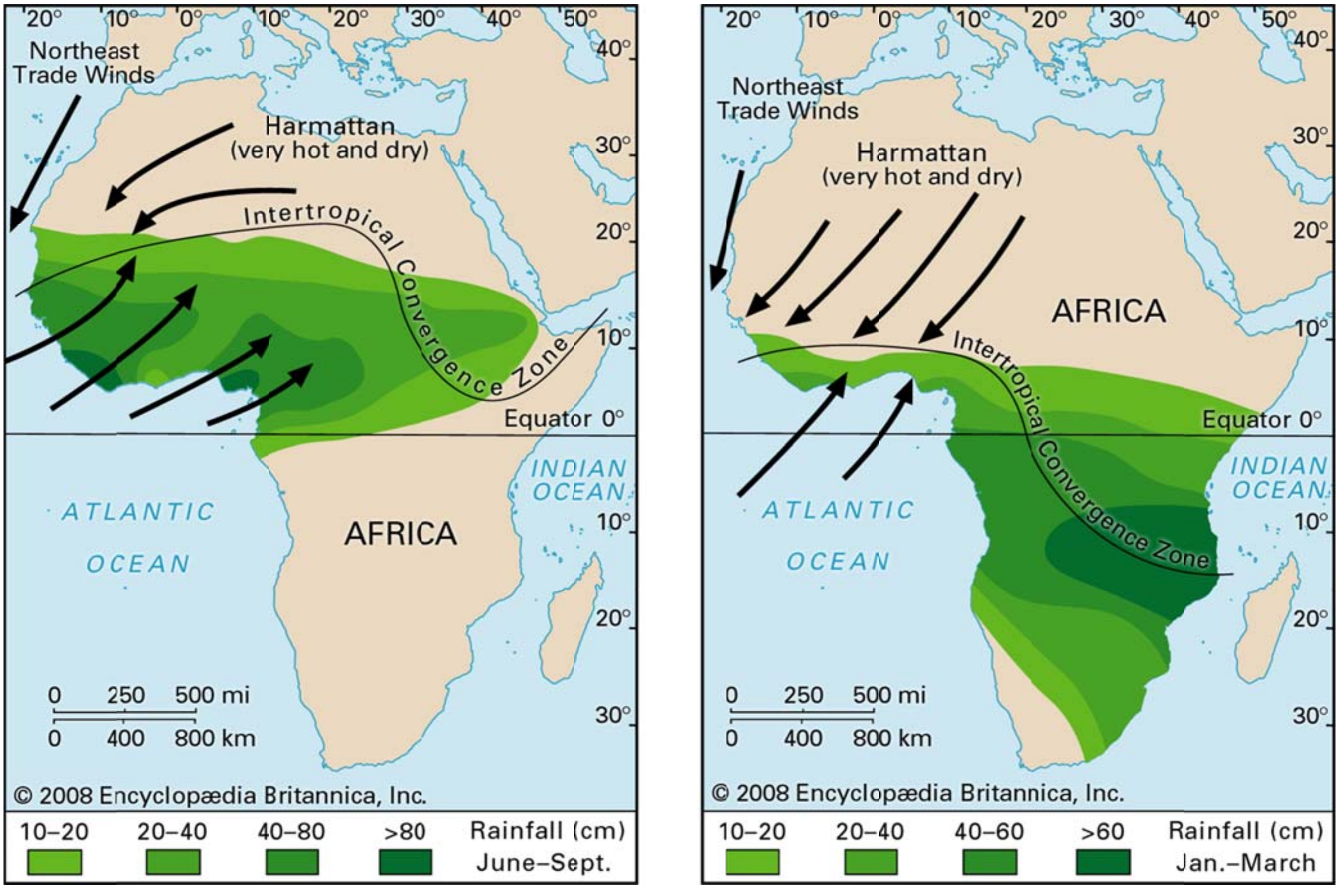
3. GHANA'S CLIMATE AND PROJECTED CHANGES

GENERAL CLIMATE

Ghana is located in West Africa along the Atlantic coast between the latitudes of 4-12°N. The climate is dominated by the interaction of the Inter-Tropical Convergence Zone (ITCZ) and the West African Monsoon. The ITCZ is a latitudinal band of convective activity that is a critical link in the Earth's global circulation pattern that redistributes solar energy from the tropics toward the poles. The ITCZ, also known as the Equatorial Convergence Zone or Inter-Tropical Front, is characterized as a region of calm winds (often referred to as the doldrums by sailors) separating the northeasterly and southeasterly trade winds. The location of the ITCZ oscillates on an annual basis, reaching its northern most extent during the northern hemisphere summer and its southern most extent during the northern hemisphere winter. The exact location of the ITCZ varies considerably as the ITCZ over land tends to venture farther north or south than the ITCZ over the oceans due to the variation in land temperatures. In Africa, the northern extent of the ITCZ is just south of the Sahel at about 10-15° N. During the winter, the ITCZ's southern progression is limited by the West African Monsoon (Figure 3.1).

The principal feature of the climate of Ghana is the alternate wet and dry seasons caused by the movements of the ITCZ and West African Monsoon. The rainfall seasons of Ghana are controlled by the movement of the ITCZ, which oscillates annually between the northern and southern tropics following the position of the sun with a lag of 1-2 months. The dominant wind direction in regions south of the ITCZ is southwesterly, blowing warm, moist air from the Atlantic Ocean onto the continent. North of the ITCZ, the prevailing winds (the Harmattan) come from the northeast, bringing dry, hot, and dusty air from the Sahara Desert. At the northern summer solstice, the ITCC lies near the Tropic of Cancer and wet maritime winds produce a rainy season north of the Equator. When the ITCZ moves south and the sun is over the Tropic of Capricorn, most of West Africa comes under the influence of the continental, hot, dry Harmattan. As the ITCZ migrates between its north and south positions over the course of the year, the regions between the northern and southernmost positions of the ITCZ experience a shift between the two opposing prevailing wind directions (i.e., the West African Monsoon) (Borrow and Demey, 2010; McSweeney et al., not dated a).

Major patterns of wet and dry seasons vary in Ghana from north to south roughly along a series of north to south eco-climatic belts or zones (Figs. 3.1-3.2). In northern Ghana (the Sudan and Guinea savanna zones), a single wet season extends from between May and November when the ITCZ is in its northern position and the prevailing wind is southwesterly, and a dry season occurs between December and March when the Harmattan wind blows northeasterly (Fig. 3.2). The northern and central regions of Ghana receive 150-250 mm/month of precipitation in the peak months of the wet season (July to September). Mean annual rainfall in these areas is about 900-1,300 mm (Fig. 3.1). The southern regions of Ghana (the Deciduous Forest, Rain Forest, and Coastal Savanna zones) experience two wet seasons corresponding to the northern and southern passages of the ITCZ across the region. One wet season occurs from March to July (with a peak in May-June), and a shorter wet season occurs in September to November, interspersed by a short relatively "dry season" in August and September, but rainfall occurs year round (Fig. 3.2). The southwest corner of Ghana (~Rain Forest Zone) is particularly hot and humid (mean annual rainfall >2,000 mm), but the southeast (Coastal Savanna Zone) is considerably drier (FIG. 3.1) (Minia, 2008; Borrow and Demey, 2010; McSweeney et al., 2011).

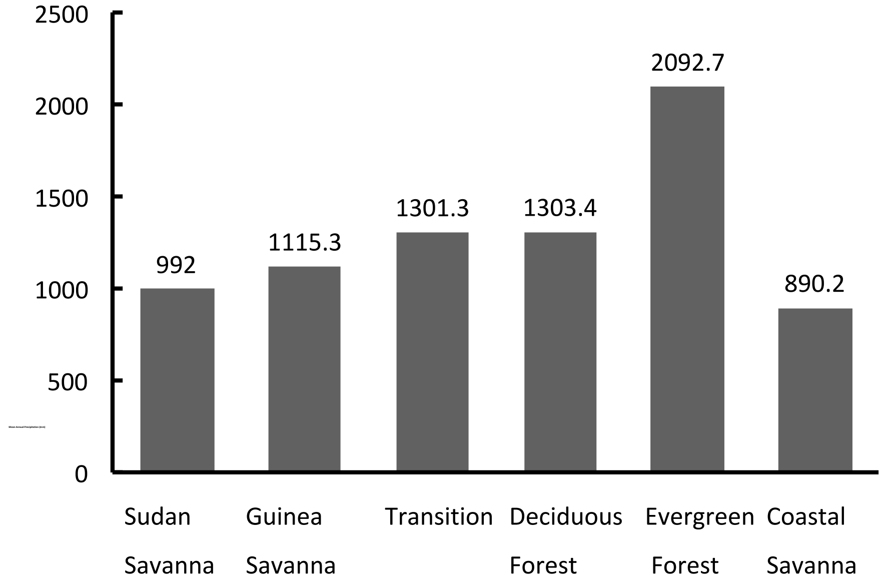


Source: Encyclopedia Britannica Online. Web. 19 Apr. 2011.

Figure 3.1 West African Monsoon

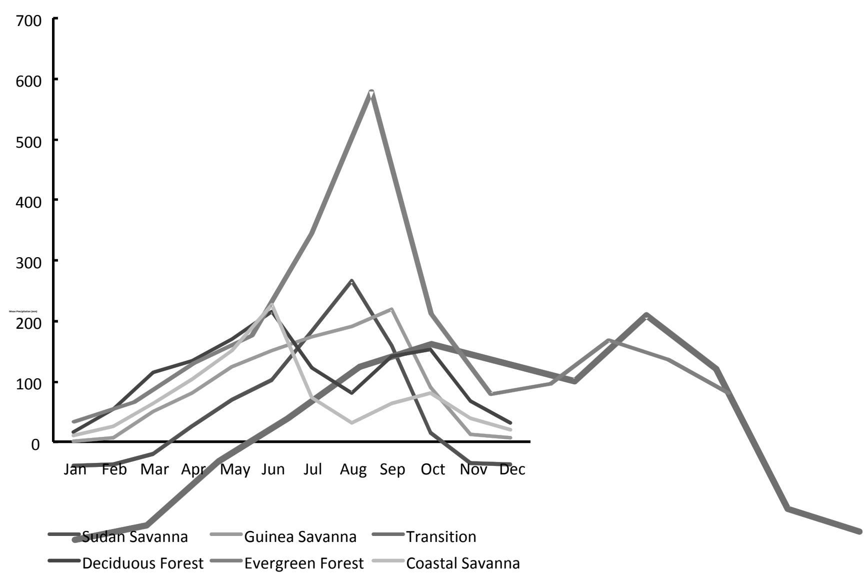
The onset and duration of the dry and rainy seasons and the annual rainfall in Ghana all show considerable inter-annual and inter-decadal variation and local topography also affects the weather (e.g., the Kwahu Plateau; Owusu and Waylen, 2009). This variation occurs in part because of variations in the movements and intensity of the ITCZ and variations in timing and intensity of the West African Monsoon. The best documented cause of these variations is the El Niño Southern Oscillation (ENSO). El Niño events are associated with drier than average conditions in West Africa (McSweeney et al., not dated a).

Seasonal variations in temperature in Ghana are greatest in the north Map 3.4) with highest temperatures in the hot, dry season (February to May) at 27-32°C, and lowest in July through September at 25-27°C (Fig.3.4). Farther south, temperatures reach 25-28°C in the warmest season (February through April) and 22-25°C at their lowest (July through September) (Minia 2008; McSweeney et al., not dated a).



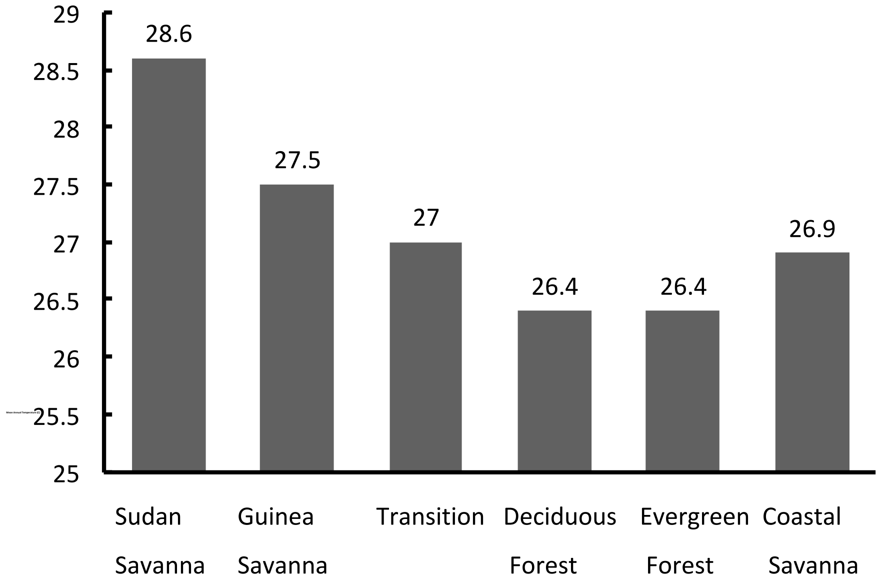
Source: Minia, 2008

Figure 3.2 Mean annual precipitation (mm) estimated from a baseline period from 1961-2000 for each of 6 eco-climatic zones in Ghana



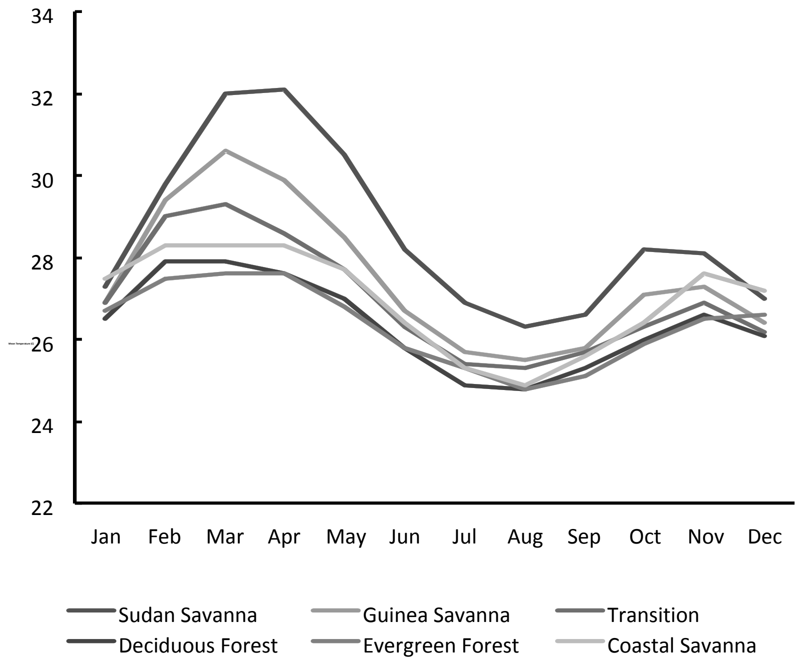
Source: Minia, 2008

Figure 3.3 Mean monthly precipitation (mm) estimated from a baseline period 1961-2000 for each of 6 eco-climatic zones in Ghana



Data from Minia, 2008

Figure 3.4 Mean annual temperatures (°C) estimated from a baseline period from 1961-2000 for each of 6 eco-climatic zones in Ghana



Source: Minia, 2008

Figure 3.5 Mean monthly temperatures (°C) estimated from a baseline period from 1961-2000 for each of 6 eco-climatic zones in Ghana

CLIMATE TRENDS AND MODELED CLIMATE CHANGE: SOURCES

We consulted two primary and several secondary sources that summarized recent climate trends and modeled climate change in order to provide context for our assessment. We also ran a series of atmosphere-ocean coupled global climate models (AOGCMs) based on data from seven meteorological stations (50 km projections) arrayed across different eco-climatic zones in Ghana. Global climate model output from the World Climate Research Programme's (WCRPs) Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007) were downscaled as described by Maurer et al. (2009) using the bias-correction/spatial downscaling method (Wood et al., 2004) to a 0.5° grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003).

First as a primary source, we used the country-level climate data summary report for Ghana (McSweeney et al., not dated a) prepared for the UNDP National Communication Support Programme (NSCP) and the UK Government Department for International Development (DFID). Second, we consulted climate data summaries and change scenarios developed for each of six eco-climatic zones (i.e., Sudan Savanna, Guinea Savanna, Transitional Zone, Deciduous Forest, Coastal Savanna, and Rain Forest) in Ghana by the Environmental Protection Agency (EPA) and Ghana Meteorological Agency (GMA) (Minia 2008, pers. comm.) under the Netherlands Climate Assistant Programme (NCAP) for use in an assessment of climate change impacts, vulnerability, and adaptation (Agyemang-Bonsu, 2008). We also used a peer-reviewed analysis of trends in rainfall in Ghana based on meteorological data from 1951-2000 from stations across the country (Owusu and Waylen, 2009). In that work, the country was divided into five meteorological zones, which corresponded approximately to eco-climatic zones of Minia (2008) as follows: Guinea and Sudan Savanna zones combined, the Transitional Zone, Deciduous Forest and Rain Forest zones combined, and a Coastal Savanna Zone.

The UNDP-NSCP country-level climate data summary for Ghana made use of existing climate data (1960-2003) to generate a series of climate observations and multi-model projections made available through the WCRP CMIP3 (McSweeney et al., not dated a, b). Specifically the report provides a set of maps and diagrams illustrating the observed and projected climate of Ghana. An area-average time series shows observed climate combined with model-simulated recent and future climate under three Special Report on Emissions Scenarios (SRES) emissions scenarios (A2, A1B, and B1; explained below). For the models, the series depicts the recent climate and future changes as a "plume" that encompasses the range of the 15-model ensemble under each scenario to demonstrate the degree of model uncertainty. A narrative summarizes the data in the figures and places it in the context of the country's general climate. In addition, maps depict projected changes for 10-year-average "time-slices" for the 2030s, 2060s, and 2090s under SRES emissions scenario A21 on a 2.5 x 2.5° grid demonstrating spatial variations in change across the country. The ensemble median change and the ensemble range are given for each grid box. The report also includes a summary table of observed trends and projected change, averaged over the whole country, 2030s, 2060s, and 2090s under SRES emissions scenarios A2, A1B, and B1. In addition, the report includes a section estimating sea level rise in Ghana. Finally, the report summarizes the data and places it in the context of the Ghana's general climate and known inadequacies in climate model performance affecting that region (McSweeney et al. not dated a, b).

The EPA-NCAP report for Ghana used existing climate data (1961-2000) to quantify observed trends and to generate a series of climate observations and scenarios of modeled future climate (air temperature and precipitation), mean sea level, and sea-surface temperatures using outputs of two global climate models (ECHAM4, CSIRO) and a simple climate model (MAGICC/SCENGEN; Minia 2008). The report provides a set of maps, diagrams, and tables illustrating the observed climate and projected climate under an A1FI emission scenario. Graphs of mean annual observed temperature and total observed annual rainfall were presented for each eco-climatic region for the 1961-2000 time period. Climate variable observed mean baselines and projections (mean monthly and annual temperatures and precipitation) were developed for six eco-climatic regions of Ghana and sea-level and sea-surface temperature projections were developed for Ghana's coast for comparison with base level conditions. Thirty-year climatological projections for these variables centered at 2020 (2006-2035), 2050 (2036-2065), and 2080 (2066-2095) were generated (10-year intervals, 2010-2080, for sea-level change with respect to 1990) (Minia, 2008). Many of the tables in Minia (2008) depicting the 2020, 2050, and 2080 medium and upper boundary projections for air temperature and rainfall appear to have been truncated during printing or are not clearly labeled; however we were able to obtain the complete appendices (Z. Minia, pers. comm.). In the GMA-NCAP report, we also consulted summarized trends of meteorological data from six coastal stations in Ghana, including mean annual air temperature, sea-surface temperature, precipitation, and salinity (Dontwi et al., 2008).

Our own projections of climate and rainfall were modeled from data at seven meteorological stations selected as representative of eco-climatic zones in Ghana. The projections were modeled from available meteorological data in Accra (Coastal Savanna Zone), Kumasi (Deciduous Forest Zone), Tarkwa (Rain Forest Zone), Techiman (Forest-Savanna Transition Zone), Tamale (Guinea Savanna Zone), Wallembelle (northern Guinea Savanna Zone), and Bawku (Sudan Savanna Zone). The models were run to project potential change in temperature and percentage change in rainfall for the dry (December-February) and wet seasons (June-August) at each station. The projections are for 2050 and 2080 and are based on an ensemble of 16 AOGCMs. Potential changes (mean, standard deviation, minimum, and maximum) were estimated for three emission scenarios (B1, A1B, A2). The B1 scenario represents the most conservative emissions scenario, the A1B an intermediate "balanced" scenario, and the A2 scenario, the most impact from greenhouse gases. As a summary, mean changes were estimated from the overall ensemble of 16 climate models across the three emission scenarios.

RECENT CLIMATE TRENDS

TEMPERATURE

Since 1960, for Ghana as a whole, mean annual temperature rose by 1.0°C, an average rate of 0.21°C/decade. The rate of increase was most rapid in April through June (about 0.27°C/decade) (McSweeney et al., no date a). The rate of increase generally has been more rapid in the northern than southern regions (Minia 2008; McSweeney et al., no date a). Five-year moving averages from 1961 to 2000 indicate about a 1°C increase in the Sudan Savanna and Guinea Savanna zones and <1°C in the Deciduous Forest (~0.8°C), Rain Forest (~0.4°C), and Coastal Savanna (~0.6°C) zones (interpolated from graphs in Minia, 2008; see also Idinoba et al. 2010). No obvious upward or downward trends in temperature were indicated in graphs from 1961 to 2000 for the Transitional Zone.

A significant linear increase in mean annual air temperature occurred between 1960 and 2001 along the coast of Ghana of about 0.9°C; the maximum and minimum temperatures increased by 2.5 and 2.2°C, respectively, during this time (Dontwi et al., 2008). Sea-surface temperatures showed a slight but non-significant increase during this period. Over the period of record, sea-surface temperatures were positively correlated (r=0.64) with air temperatures and less strongly so with precipitation (r=0.50). Salinity readings were too variable to establish trends.

The frequency of "Hot" days and nights in Ghana increased from 1961 to 2003. A "Hot" day or night is defined by the temperature exceeded on 10 percent of days or nights in the current climate of that region and season (McSweeney et al., no date a). Daily temperature data indicated that the frequency of "Hot" days increased significantly in all seasons except December through February, and the frequency of "Hot" nights increased significantly in all seasons. Between 1960 and 2003, the average number of "Hot" days/year in Ghana increased by 48 (an additional 13.2 percent of days). The rate of increase was strongest in September through November when the average number of 'Hot' days increased by 7.2 days/month (an additional 23.3 percent of days in September through November) over this period (McSweeney et al., no date a). In addition, between 1960 and 2003, the average number of "Hot" nights/year increased by 73 (an additional 20 percent of nights). The rate of increase is strongest in September to November when the average number of "Hot" nights increased by 8.9 days/month (an additional 28.8 percent of nights in September through November) over this period (McSweeney et al., no date a).

Similarly, since 1960, the frequency of "Cold" days and "Cold" nights in Ghana decreased significantly in some seasons. "Cold" days or nights are defined as the temperature below which 10 percent of days or nights are recorded in the current climate of that region or season (McSweeney et al., no date a). Between 1960 and 2003, the average number of "Cold" days/year decreased by 12 (3.3 percent of days). This rate of decrease is most rapid in summer (June through August) when the average number of "Cold" days in summer decreased by 2.1 days/month (6.8 percent of summer days) (McSweeney et al., 2011). The average number of "Cold" nights/year decreased by 18.5 (5.1 percent of days). This rate of decrease is most rapid in September through November when the average number of "Cold" nights decreased by 2.8 nights/month (9 percent of September through November nights) (McSweeney et al., no date a).

PRECIPITATION

Annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales, making identification of long-term trends difficult. In the 1960s, rainfall in Ghana was particularly high and decreased to particularly low levels in the late 1970s and early 1980s. This caused an overall country-wide decreasing trend in the period 1960 to 2006 of an average 2.3mm/month (2.4 percent)/decade (McSweeney et al., no date a). No evidence indicated a trend in the proportion of rainfall that falls in "Heavy" events since 1960. A "Heavy" event is defined as a daily rainfall total which exceeds the threshold that is exceeded on 5 percent of rainy days in the current climate of that region and season. Likewise, observed 1- and 5-day rainfall maxima did not indicate consistent trends (McSweeney et al., no date a).

For most eco-climatic zones, five-year moving averages also indicate a trend toward decreased total annual precipitation from 1961 to 2000 (Minia, 2008). Over this period, mean decreases occurred in the Guinea Savanna Zone (~120 mm decrease), Deciduous Forest Zone (~240 mm), and Rain Forest Zone (~750 mm) (interpolated from graphs in Minia, 2008). Inspection of graphs (Minia, 2008) did not indicate upward or downward trends in total annual precipitation for the Sudan Savanna or Transitional zones. Along the coast of Ghana, total annual precipitation showed a significant linear decrease from 1961 to 2000 (decrease about 1000 mm) with a marked cycling of high and low rainfall years with an apparent six-year lag (Dontwi et al., 2008).

Comparison of the mean annual rainfall differences between 1951-1970 and 1981-2000 at meteorological stations across Ghana also indicated less rainfall (Owusu and Waylen, 2009). Significantly less rainfall occurred in the latter period in the Deciduous Forest and Rain Forest zones (mean decreases ranged from 136.9 to 335.3 mm) and the coast (Accra station, mean decrease 260.5 mm). As a percentage of total annual rainfall, southwestern Ghana (i.e., ~Rain Forest Zone) experienced reductions in rainfall as high as 20 percent (300 mm), twice the proportion experienced in the savanna zones (Owusu and Waylen, 2009). Rainfall decreased, but not significantly so, for most stations in the Transitional Zone (mean decrease of 115.1-169.8 mm) and combined Sudan and Guinea savanna zones (77.3-93.3 mm) (Owusu and Waylen, 2009). Small sample size (number of stations) may have lowered statistical power and hence, the ability to detect statistical differences between the two time periods in those areas. Another analysis based on comparison of annual rainfall data between 1950-1970 and 1971-1990 showed significant decreases in rainfall in the Sudan and Guinea savanna zones (1.5 percent reduction at Tamale, 2.3 percent at Yendi, 7.2 percent at Navrongo, and 11.3 percent at Wa) (Gyau-Boakye and Tumbulto, 2000).

CLIMATE SCENARIOS

CLIMATE PROJECTIONS

In predicting future climatic conditions, assumptions must be made about how the human component of the climate system will evolve over the course of the forecast period. This is typically accomplished by developing different scenarios of anthropogenic influences, basically different rates of GHG emissions. These scenarios do not represent predictions, but are instead alternative views of how the future may unfold. The IPCC developed four different families of scenarios. This work will focus on three of those families described in various IPCC documents (IPCC 2007).

A2 - The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

A1B1 - The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.

B1 - The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The first set of projections of potential changes in temperature and precipitation presented are the result of averaging 16 atmosphere-ocean general circulation models (AOGCMs) that have been downscaled to a horizontal grid size of ~50 km following the statistical methodology described in Maurer et al. (2009). The use of an ensemble of models helps limit the influence of any bias present in any one model. Temperature and precipitation data are available from http://www.climatewizard.org .

It should be noted that most GCMs have difficulty correctly reproducing a number of key features of the atmospheric circulation patterns over West Africa which contribute to uncertainty in estimates of future rainfall (Douville et al., 2006; Joly et al., 2007; Caminade and Terray, 2009). Neither the Third nor Fourth Assessment Report of the IPCC reached a consensus regarding the sign or magnitude of predicted changes in precipitation over West Africa during this century (Hulme et al., 2001; Bernstein et al., 2007). The West African Monsoon is difficult for coarse resolution GCMs to describe considering the wide range of mechanisms for variability acting at various time and space scales from global teleconnection patterns related to the El Nĩno-Southern Oscillation ENSO (Caminade and Terray, 2010) or the Atlantic Multi-Decadal Oscillation (Shanahan et al., 2009) to the coupling of soil moisture to intra-seasonal variability (Lavender et al., 2010). Druyan (2010) provides a convincing argument for the need of more detailed (higher resolution) modeling to properly capture critical processes in this region. For this reason we focus on the changes predicted by an ensemble of climate models as this provides a means of examining not only the projected change in temperature and precipitation but also provides a measure of confidence in these projections.

TEMPERATURE PROJECTIONS

From country-wide projections for Ghana (McSweeney et al., no date a), the mean annual temperature is projected to increase by 1.0 to 3.0°C by the 2060s and 1.5 to 5.2°C by the 2090s. The range of projections by the 2090s under any one emission scenario used in the UNDP-NSCP work is about 1.5-2.5°C. The projected rate of warming is more rapid in the northern inland regions of Ghana than the coastal regions (McSweeney et al., no date a). All projections indicated substantial increases in the frequency of days and nights that are considered "Hot" in current climate, but the range of projections between different models was large. Annually, projections indicated that "Hot" days will occur on 18-59 percent of days by the 2060s and 25-90 percent of days by the 2090s. Days considered "Hot" by current climate standards for their season may increase most rapidly in July through September occurring on 34-99 percent of days of the season by the 2090s. Nights considered "Hot" for the annual climate of 1970-99 are projected to occur on 28-79 percent of nights by the 2060s and 39-90 percent of nights by the 2090s. Nights considered "Hot" for each season by 1970-99 standards are projected to increase most rapidly in July through September occurring on 52-99 percent of nights in every season by the 2090s. Most projections indicated decreases in the frequency of days and nights considered "Cold" in the current climate. "Cold" days and nights are projected to occur on <3 percent of days by the 2090s. Although the projected mean temperature increased more rapidly in the interior regions of Ghana than near the coast, the projected changes in the daily temperature extremes ("Hot" and "Cold" days and nights) in Ghana were largest in the coastal areas and smaller inland (McSweeney et al., no date a).

The eco-climatic zone projections of the EPA-NCAP work also indicated continued increases in temperature (Minia, 2008), but the projections do not appear to be scaled to the level of eco-climatic zone. An increase of 0.6, 2.0, and 3.9-4.0°C for 2020, 2050, and 2080, respectively, was uniformly applied to the mean annual baseline temperatures of each eco-climatic zone to produce the 30-year mid-range projections (upper boundary projected increases of 0.8, 2.5, and 5.4°C, for respective 30-year periods) (Minia, 2008, Appendix 1.1 and pers. comm., see Appendices V-X). For all but one zone (Sudan Savanna) the projected increases in monthly temperatures applied to each 30-year projection in each zone are identical and tended to be highest in February to- May. However, using this approach, the annual and monthly "projection" patterns follow the baseline mean annual (and monthly) temperature patterns and simply add a constant increase across most eco-climatic zones for each 30-year period. The usefulness of the projections at the scale of individual eco-climatic zones is questionable.

In the EPA-NCAP report, sea-surface temperatures were projected to rise from the annual base mean of 26.2 to median model estimates of 26.6, 27.6, and 28.9°C for the years 2020, 2050, and 2080. Upper boundary estimates were 26.8, 28.1, and 30.0°C for the respective 30-year periods (Minia 2008). Greatest monthly increases generally were projected to occur in June, July, and August. Attempts to use current trends to forecast sea-surface temperature to 2021 were inconclusive (Dontwi et al., 2008, but see section 6.B. "Fishery Resources and Overfishing").

Our projections of changes in temperature for meteorological stations across Ghana also indicated continued increases for 2050 and 2080. Notably, regardless of emission scenario the AOGCMs are consistent in predicting slightly warmer conditions with only minor differences between the wet and dry seasons (Tables 3.1-3.7).

Perhaps the best estimate of the impact of future climate conditions on temperature is provided by the overall ensemble of 16 climate models across the three emission scenarios which suggest the following increases in temperature.

- Accra (Coastal Savanna Zone): Wet Season,1.68 ± 0.38°C by 2050 and 2.54 ± 0.75°C by 2080; Dry Season, 1.74 ± 0.60°C by 2050 and 2.71 ± 0.91°C by 2080 during the dry season
- Kumasi (Deciduous Forest Zone): Wet Season, 1.71 ± 0.39°C by 2050 and 2.60 ± 0.77°C by 2080; Dry Season, 1.81 ± 0.68°C by 2050 and 2.83 ± 1.04°C by 2080
- Tarkwa (Rain Forest Zone): Wet Season, 1.69 ± 0.37°C by 2050 and 2.56 ± 0.75°C by 2080; Dry Season, 1.76 ± 0.67°C by 2050 and 2.76 ± 1.01°C by 2080
- Techiman (Forest-Savanna Transition Zone): Wet Season, 1.77 ± 0.43°C by 2050 and 2.71 ± 0.85°C by 2080; Dry Season, 1.95 ± 0.79°C by 2050 and 3.05 ± 1.20°C by 2080
- Tamale (Guinea Savanna Zone): Wet Season, 1.84 ± 0.46°C by 2050 and 2.83 ± 0.91°C by 2080; Dry Season 2.05 ± 0.75°C by 2050 and 3.18 ± 1.18°C by 2080
- Wallembelle (northernmost Guinea Savanna Zone): Wet Season, 1.92 ± 0.52°C by 2050 and 2.96 ± 0.98°C by 2080; Dry Season, 2.10 ± 0.71°C by 2050 and 3.27 ± 1.11°C by 2080
- Bawku (Sudan Savanna Zone): Wet Season, 1.92 ± 0.53°C by 2050 and 2.97 ± 0.98°C by 2080: Dry Season , 2.11 ± 0.68°C by 2050 and 3.25 ± 1.08°C by 2080

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Accra (Coastal Savanna Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.1 Potential change in temperature and % change in rainfall, Accra

Accra		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	**Mean**	**1.41**	**1.95**	**1.86**	**1.74**	**1.36**	**1.85**	**1.82**	**1.68**
	Std Dev	0.44	0.51	0.69	0.60	0.31	0.32	0.30	0.38
	Min	0.48	1.00	-0.17	-0.17	0.64	1.21	1.15	0.64
	Max	2.11	2.80	2.79	2.80	1.90	2.45	2.30	2.45
2080 Temperature	**Mean**	**1.95**	**2.91**	**3.27**	**2.71**	**1.82**	**2.67**	**3.13**	**2.54**
	Std Dev	0.52	0.60	1.00	0.91	0.43	0.53	0.59	0.75
	Min	1.28	2.01	0.54	0.54	0.86	1.55	1.82	0.86
	Max	2.88	3.91	4.93	4.93	2.69	3.87	4.29	4.29
2050 Precipitation	**Mean**	**3.69**	**3.13**	**2.75**	**3.19**	**2.00**	**1.75**	**4.19**	**2.65**
	Std Dev	13.40	18.31	17.36	16.14	14.63	14.53	13.47	13.96
	Min	-19.00	-25.00	-23.00	-25.00	-32.00	-33.00	-27.00	-33.00
	Max	36.00	42.00	49.00	49.00	34.00	29.00	30.00	34.00
2080 Precipitation	**Mean**	**6.75**	**8.38**	**10.69**	**8.60**	**4.81**	**4.50**	**2.31**	**3.88**
	Std Dev	17.51	27.78	26.84	24.02	17.23	22.47	19.36	19.41
	Min	-19.00	-40.00	-40.00	-40.00	-41.00	-52.00	-47.00	-52.00
	Max	50.00	68.00	58.00	68.00	29.00	44.00	36.00	44.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Kumasi (Deciduous Forest Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.2 Potential change in temperature and % change in precipitation, Kumasi

Kumasi		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.45**	**2.05**	**1.93**	**1.81**	**1.38**	**1.89**	**1.85**	**1.71**
	Std Dev	0.52	0.57	0.81	0.68	0.32	0.32	0.31	0.39
	Min	0.29	0.81	-0.42	-0.42	0.67	1.25	1.19	0.67
	Max	2.14	2.90	2.94	2.94	1.96	2.52	2.37	2.52
2080 Temperature	Mean	**2.01**	**3.04**	**3.43**	**2.83**	**1.85**	**2.74**	**3.21**	**2.60**
	Std Dev	0.61	0.70	1.17	1.04	0.44	0.55	0.61	0.77
	Min	1.25	1.87	0.16	0.16	0.88	1.59	1.85	0.88
	Max	3.06	4.12	5.20	5.20	2.78	4.00	4.40	4.40
2050 Precipitation	Mean	**4.56**	**6.56**	**5.81**	**5.65**	**0.25**	**1.63**	**3.31**	**1.73**
	Std Dev	15.02	20.89	23.54	19.72	12.78	14.93	13.14	13.42
	Min	-24.00	-21.00	-27.00	-27.00	-28.00	-29.00	-23.00	-29.00
	Max	31.00	50.00	75.00	75.00	29.00	35.00	29.00	35.00
2080 Precipitation	Mean	**8.81**	**10.13**	**11.38**	**10.10**	**4.31**	**4.13**	**1.13**	**3.19**
	Std Dev	16.71	27.04	28.69	24.21	16.33	22.40	18.79	18.98
	Min	-23.00	-39.00	-43.00	-43.00	-36.00	-48.00	-40.00	-48.00
	Max	44.00	70.00	57.00	70.00	32.00	45.00	32.00	45.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Tarkwa (Rain Forest Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.3 Potential change in temperature and % change in precipitation, Tarkwa

Tarkwa		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.41**	**1.99**	**1.88**	**1.76**	**1.36**	**1.86**	**1.83**	**1.69**
	Std Dev	0.51	0.55	0.79	0.67	0.30	0.30	0.30	0.37
	Min	0.27	0.77	-0.41	-0.41	0.68	1.25	1.19	0.68
	Max	2.15	2.84	2.90	2.90	1.86	2.40	2.27	2.40
2080 Temperature	Mean	**1.96**	**2.98**	**3.34**	**2.76**	**1.83**	**2.70**	**3.16**	**2.56**
	Std Dev	0.59	0.68	1.13	1.01	0.42	0.51	0.58	0.75
	Min	1.18	1.84	0.19	0.19	0.87	1.59	1.85	0.87
	Max	2.91	4.05	5.07	5.07	2.64	3.81	4.22	4.22
2050 Precipitation	Mean	**4.06**	**4.44**	**3.38**	**3.96**	**1.25**	**2.81**	**3.69**	**2.58**
	Std Dev	13.80	19.24	17.08	16.50	12.43	14.01	12.72	12.83
	Min	-16.00	-26.00	-21.00	-26.00	-27.00	-29.00	-24.00	-29.00
	Max	37.00	39.00	45.00	45.00	25.00	31.00	24.00	31.00
2080 Precipitation	Mean	**8.81**	**9.38**	**11.44**	**9.88**	**4.69**	**3.56**	**0.69**	**2.98**
	Std Dev	17.79	28.03	26.93	24.18	15.01	18.22	16.79	16.45
	Min	-21.00	-45.00	-41.00	-45.00	-38.00	-45.00	-42.00	-45.00
	Max	51.00	69.00	61.00	69.00	25.00	31.00	24.00	31.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Techiman (Forest-Savanna Transition Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.4 Potential change in temperature and % change in precipitation, Techiman

Techiman		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.56**	**2.22**	**2.07**	**1.95**	**1.42**	**1.97**	**1.92**	**1.77**
	Std Dev	0.60	0.66	0.94	0.79	0.36	0.37	0.35	0.43
	Min	0.25	0.76	-0.59	-0.59	0.67	1.28	1.23	0.67
	Max	2.47	3.17	3.43	3.43	2.15	2.78	2.59	2.78
2080 Temperature	Mean	**2.18**	**3.26**	**3.70**	**3.05**	**1.92**	**2.87**	**3.35**	**2.71**
	Std Dev	0.74	0.84	1.39	1.20	0.50	0.64	0.68	0.85
	Min	1.31	1.83	-0.10	-0.10	0.87	1.62	1.88	0.87
	Max	3.46	4.88	5.60	5.60	3.09	4.41	4.78	4.78
2050 Precipitation	Mean	**7.06**	**9.81**	**9.00**	**8.63**	**-2.31**	**-0.94**	**0.06**	**-1.06**
	Std Dev	17.30	24.55	27.33	22.97	13.22	15.36	14.92	14.25
	Min	-32.00	-26.00	-29.00	-32.00	-27.00	-24.00	-24.00	-27.00
	Max	34.00	63.00	83.00	83.00	27.00	31.00	25.00	31.00
2080 Precipitation	Mean	**14.00**	**20.31**	**20.19**	**18.17**	**0.31**	**0.13**	**-2.94**	**-0.83**
	Std Dev	21.20	34.38	38.91	31.82	16.79	22.46	20.60	19.71
	Min	-24.00	-36.00	-53.00	-53.00	-35.00	-46.00	-39.00	-46.00
	Max	57.00	98.00	96.00	98.00	31.00	36.00	29.00	36.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Tamale (Guinea Savanna Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.5 Potential change in temperature and % change in precipitation, Tamale

Tamale		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.65**	**2.32**	**2.17**	**2.05**	**1.49**	**2.06**	**1.99**	**1.84**
	Std Dev	0.56	0.63	0.88	0.75	0.39	0.40	0.39	0.46
	Min	0.47	0.97	-0.34	-0.34	0.68	1.30	1.23	0.68
	Max	2.43	3.16	3.46	3.46	2.31	2.92	2.74	2.92
2080 Temperature	Mean	**2.31**	**3.36**	**3.86**	**3.18**	**2.01**	**3.00**	**3.49**	**2.83**
	Std Dev	0.66	0.86	1.35	1.18	0.55	0.72	0.74	0.91
	Min	1.37	2.01	0.20	0.20	0.85	1.61	1.86	0.85
	Max	3.65	4.80	5.94	5.94	3.25	4.65	5.01	5.01
2050 Precipitation	Mean	**14.50**	**11.25**	**23.63**	**16.46**	**-1.88**	**-2.13**	**-0.38**	**-1.46**
	Std Dev	30.32	23.32	31.36	28.44	8.52	11.16	11.67	10.35
	Min	-47.00	-21.00	-26.00	-47.00	-20.00	-19.00	-19.00	-20.00
	Max	63.00	48.00	78.00	78.00	12.00	26.00	21.00	26.00
2080 Precipitation	Mean	**15.63**	**33.13**	**33.38**	**27.38**	**-1.44**	**-1.88**	**-3.25**	**-2.19**
	Std Dev	29.19	43.41	52.18	42.58	11.87	16.91	17.31	15.25
	Min	-28.00	-39.00	-53.00	-53.00	-28.00	-36.00	-31.00	-36.00
	Max	73.00	139.00	173.00	173.00	22.00	32.00	31.00	32.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Walembelle (northern Guinea Savanna Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.6 Potential change in temperature and % change in precipitation, Walembelle

Walembelle		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.67**	**2.37**	**2.26**	**2.10**	**1.55**	**2.17**	**2.04**	**1.92**
	Std Dev	0.51	0.61	0.81	0.71	0.43	0.47	0.45	0.52
	Min	0.50	0.92	-0.21	-0.21	0.72	1.17	1.12	0.72
	Max	2.22	3.27	3.05	3.27	2.39	3.01	2.84	3.01
2080 Temperature	Mean	**2.39**	**3.45**	**3.98**	**3.27**	**2.09**	**3.14**	**3.65**	**2.96**
	Std Dev	0.55	0.77	1.24	1.11	0.59	0.81	0.81	0.98
	Min	1.62	1.99	0.44	0.44	0.85	1.44	1.78	0.85
	Max	3.66	4.73	5.82	5.82	3.33	4.75	5.12	5.12
2050 Precipitation	Mean	**17.56**	**16.75**	**28.56**	**20.96**	**-0.56**	**-1.19**	**0.50**	**-0.42**
	Std Dev	35.68	31.82	42.37	36.50	6.90	10.26	9.78	8.93
	Min	-44.00	-34.00	-20.00	-44.00	-14.00	-18.00	-18.00	-18.00
	Max	68.00	82.00	139.00	139.00	11.00	21.00	15.00	21.00
2080 Precipitation	Mean	**14.50**	**35.69**	**43.56**	**31.25**	**-0.88**	**-1.00**	**-1.31**	**-1.06**
	Std Dev	39.49	50.80	73.38	56.51	8.92	13.13	13.55	11.79
	Min	-24.00	-33.00	-61.00	-61.00	-19.00	-24.00	-25.00	-25.00
	Max	141.00	153.00	235.00	235.00	16.00	24.00	23.00	24.00

Potential change in temperature (°C) and percentage change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Bawku (Sudan Savanna Zone) in 2050 and 2080 based on an ensemble of 16 atmosphere-ocean coupled global climate models across three emissions scenarios (B1, A1B, A2). For each season, values are given by emission scenario and an overall mean across emission scenarios. For each parameter (temperature and precipitation) the ensemble average, standard deviation (Std Dev), minimum (Min) and maximum (Max) values are presented.

Table 3.7 Potential change in temperature and % change in rainfall, Bawku

Bawku		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.69**	**2.36**	**2.27**	**2.11**	**1.54**	**2.18**	**2.05**	**1.92**
	Std Dev	0.49	0.58	0.77	0.68	0.44	0.49	0.46	0.53
	Min	0.73	1.20	0.02	0.02	0.68	1.13	1.08	0.68
	Max	2.27	3.30	3.07	3.30	2.37	3.07	2.78	3.07
2080 Temperature	Mean	**2.37**	**3.42**	**3.95**	**3.25**	**2.11**	**3.15**	**3.65**	**2.97**
	Std Dev	0.54	0.75	1.20	1.08	0.57	0.82	0.83	0.98
	Min	1.55	2.14	0.60	0.60	0.89	1.38	1.72	0.89
	Max	3.61	4.65	5.88	5.88	3.26	4.70	5.08	5.08
2050 Precipitation	Mean	**17.31**	**11.31**	**21.56**	**16.73**	**-0.13**	**-0.81**	**0.63**	**-0.10**
	Std Dev	32.37	28.69	36.81	32.37	7.33	10.89	10.81	9.63
	Min	-51.00	-28.00	-31.00	-51.00	-13.00	-20.00	-20.00	-20.00
	Max	73.00	72.00	107.00	107.00	14.00	23.00	19.00	23.00
2080 Precipitation	Mean	**18.19**	**35.13**	**34.19**	**29.17**	**-0.75**	**-0.56**	**-0.75**	**-0.69**
	Std Dev	33.94	55.97	64.68	52.57	9.43	14.42	15.11	12.94
	Min	-23.00	-41.00	-60.00	-60.00	-18.00	-25.00	-28.00	-28.00
	Max	105.00	166.00	193.00	193.00	19.00	30.00	29.00	30.00

PRECIPITATION PROJECTIONS

Projections of mean annual rainfall averaged over the country (UNDP report) from different models in the ensemble project a wide range of changes in precipitation for Ghana with about half the models projecting increases and half decreases (McSweeney et al., no date a). Seasonally, the projections tend towards decreases in January through June rainfall and increases in July through December rainfall. The proportion of total annual rainfall that falls in "Heavy" events tends towards increases in the ensemble projections. Seasonally, this varies between tendencies to decrease in January through April to increases in July through December, but the range of changes projected by the ensemble includes both increases and decreases in all seasons. Projected changes in 1- and 5-day rainfall maxima tend towards increases, but projections range between increases and decreases in all seasons.

At the eco-climatic level (Minia, 2008), rainfall is projected to decrease at 2020, 2050, and 2080 in all regions. Percentage decrease in rainfall at each projection period tend to increase from north to south from -1.1, -6.7, -12.8 percent in the Sudan Savanna Zone to -3.1, -12.3, -20.5 percent in the Coastal Savanna Zone for periods 2020, 2050, and 2080, respectively. Absolute change in rainfall is projected to be highest in the Deciduous Forest and Rain Forest Zones (243 and 423 mm decrease by 2080, respectively). Upper boundary projections indicate an annual decrease of 32.6 percent annual precipitation in the Sudan Savanna Zone and a 26.8 percent decrease in the remaining eco-climatic zones. Inspection of the projection tables (Minia 2008 and pers. comm., Appendix 1.2; see Appendices V-X) reveals the same monthly percentage changes in precipitation were applied to all but the Sudan Savanna Zone. Similar to the caveats about temperature projections for eco-climatic zones (see previous), scaling and suitability of the rainfall projections at the eco-climatic level is questionable.

Our AOGCM modeling projections of rainfall among seven representative meteorological stations gave mixed and inconclusive results (Tables 3.1-3.7). AOGCM predictions of precipitation lack any sense of consistency, predicting both decreases and increases in rainfall in at each station. The results are summarized for each station as follows:

- **Accra (Coastal Savanna Zone):** Forecasted changes in precipitation ranged from 52 percent decreases to 44 percent increases in wet season rainfall by 2080. The overall ensemble prediction across emission scenarios gives a slight increase in wet season rainfall of 2.65 ± 13.96 percent by 2050 and 3.88 ± 19.41 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Kumasi (Deciduous Forest Zone):** Forecasted changes in precipitation range from 48 percent decreases to 45 percent increases in wet season rainfall by 2080. The overall ensemble prediction across emission scenarios gives a slight increase in wet season rainfall of 1.73 ± 13.42 percent by 2050 and 3.19 ± 18.98 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The A2 scenario, which generally shows the largest greenhouse gas impact, predicts the weakest increase in wet season rainfall, 1.13 percent.

- **Tarkwa (Rain Forest Zone):** Forecasted changes in precipitation range from 45 percent decreases to 31 percent increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight increase in wet season rainfall of 2.58 ± 12.83 percent by 2050 and 2.98 ± 16.45 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Techiman (Forest-Savanna Transition Zone):** Forecasted changes in precipitation range from 46 percent decreases to 36 percent increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight decrease in wet season rainfall of -1.06 ± 14.25 percent by 2050 and -0.83 ± 19.71 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The A2 scenario, which generally shows the largest greenhouse gas impact, predicts the largest decrease in wet season rainfall, -2.94 percent.

- **Tamale (Guinea Savanna Zone):** Forecasted changes in precipitation range from 36 percent decreases to 32 percent increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a decrease in wet season rainfall of -1.46 ± 10.35 percent by 2050 and -2.19 ± 15.25 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region. The Northern Region where Tamale is located is the southern-most region in Ghana to show a consistent trend toward decreased rainfall.

- **Walembelle (northern Guinea Savanna Zone):** Forecasted changes in precipitation range from 25 percent decreases to 24 percent increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight decrease in wet season rainfall of -0.42 ± 8.93 percent by 2050 and 1.06 ± 11.79 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

- **Bawku (Sudan Savanna Zone):** Forecasted changes in precipitation range from 28 percent decreases to 30 percent increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight decrease in wet season rainfall of -0.10 ± 9.63 percent by 2050 and -0.69 ± 12.94 percent by 2080. The variability among the models' precipitation changes is not very different from the inter-annual variability currently experienced in the region.

SEA-LEVEL PROJECTIONS

The coastal regions of Ghana may be vulnerable to sea-level rise, and two different climate modeling efforts are in reasonably close agreement. By the 2090s, sea level is projected by the UNDP-NSCP climate models to rise by the following levels relative to the 1980-1999 sea level: 0.13-0.43 m under SRES B1; 0.16-0.53 m under SRES A1B; and 0.18-0.56 m under SRES A2 (McSweeney et al., no date a). With respect to the 1990 mean sea-level, the EPA-NCAP climate modeling (Minia 2008) also projected sea levels to increase. Those estimates range from 0.36 m (lower and upper boundaries of 0.16-0.60 cm) in 2010 to 0.35 m (0.16-0.58 m) in 2080 (under SRES A1F1).

CLIMATE VARIABILITY

The climate of West Africa is subject to considerable variability across a range of space and time scales (Lebel et al., 2000). This variability is linked to variations in the movement and intensity of the ITCZ as well as variations in the timing and intensity of the West African Monsoon. The most documented cause of these variations on an inter-annual timescale is the El Niño Southern Oscillation (ENSO). The West African Monsoon is influenced either during the developing phase of ENSO or during the decay of some long-lasting La Niña events (Joly and Voldoire, 2009). In general, El Niño (positive sea surface temperature anomalies in the equatorial Pacific Ocean) is connected to below normal rainfall in West Africa (Janicot et al., 1998). Other sources of variability at decadal, annual and intra-seasonal time scales include land-atmosphere feedbacks (Taylor et al., 1997; Grodsky and Carton, 2001; Douville, 2002) and large-scale circulation features (Matthews, 2004; Mournier et al., 2008; Lavender and Matthews, 2009). At intra-seasonal time scales, the West African Monsoon system also exhibits variability, specifically at frequencies of 15 days and 25-60 days (Janicot and Sultan, 2001). The longer of these periods is associated with the Madden-Julian Oscillation (a major source of intra-seasonal variability in the tropical atmosphere with a period of 30-90 days) and variability in the Asian summer monsoon (Matthews, 2004; Lavender and Matthews, 2009; Janicot et al., 2009).

4. CLIMATE CHANGE POLICY FRAMEWORK

CLIMATE CHANGE ACTIVITIES IN GHANA

Responsibility for developing, coordinating, and implementing Ghana's climate policy is understandably dispersed among several agencies. The Environment and Natural Resources Advisory Council (ENRAC) operates at the Cabinet level and is in place to coordinate among ministries. Within ministries with climate-related responsibilities, there are coordinating and consultative activities. For example, a Carbon Credit Policy Committee operates in the Ministry of Environment, Science and Technology (MEST) to clearly define rules and procedures effecting carbon credit generating activities, allocation of carbon rights, and participation in sub-national carbon activities.

The Environmental Protection Agency (EPA) within MEST is responsible for developing national climate change policy and integrating priorities into sectoral plans. The EPA is the main Country Implementing Institution (CII) for technical coordination of activities on climate change, the United Nations Framework Convention on Climate Change (UNFCCC) and some other environmental conventions ratified by Ghana. Within the Agency, a specialized unit on Energy Resources and Climate Change has been established to serve as the technical focal point on climate change and related issues in Ghana, including technical aspects for Clean Development Mechanism (CDM) projects. The National Climate Change Coordinator is located within the Energy Resource and Climate Change Unit of the EPA.

The Ministry of Lands and Natural Resources (MLNR) is the lead national entity responsible for overall oversight and direction on REDD+ activities in Ghana. The National REDD Steering Committee, established in 2009, provides support to MLNR. The Ministry is also represented at the National Climate Change Committee (NCCC). The REDD+ secretariat at the Forestry Commission in collaboration with the National REDD+ Steering Committee facilitated Forest Carbon Partnership Facility (FCPF) process with support from World Bank.

The Ministry of Finance and Economic Planning (MoFEP) is represented on the NCCC and has been nominated for accreditation as the National Operating Entity to the Adaptation Fund Board. This is to legally enable MoFEP to function as the fiduciary administrator of the Adaptation Fund in Ghana. MoFEP is also leading an inter-ministerial collaboration under the Forest Investment Programme (FIP) initiative by the World Bank to support REDD+ implementation in Ghana. The Natural Resource Governance desk at MoFEP centrally coordinates the budget support program under Natural Resource, Environmental Governance (NREG) program and the Forest Investment Programme Initiatives.

Climate change is being mainstreamed into Ghana's Shared Growth and Development Agenda and coordinated by the National Development Planning Commission (NDPC). Climate change was targeted for support by Donor Partners under the NREG program. The Ministry of Environment, Science and Technology is the lead institution for climate change and UNFCCC activities in the country and hosts the National Committee on Climate Change. Representatives from relevant ministries, universities, research institutions, the private sector, and NGOs serve on the committee. The NCCC is responsible for formulating a National Climate Change Policy for Ghana that includes mitigation and adaptation actions that are to be integrated into planning processes at national, regional, and district levels. Other duties of the NCCC are recommending areas of study to the MEST for comparing climate change adaptation strategies; identifying skills deficiencies and training needs; and developing harmonized climate change programs in the key sectors of finance and economic planning, forestry, agriculture, land and water, health, energy, and coastal zones management.

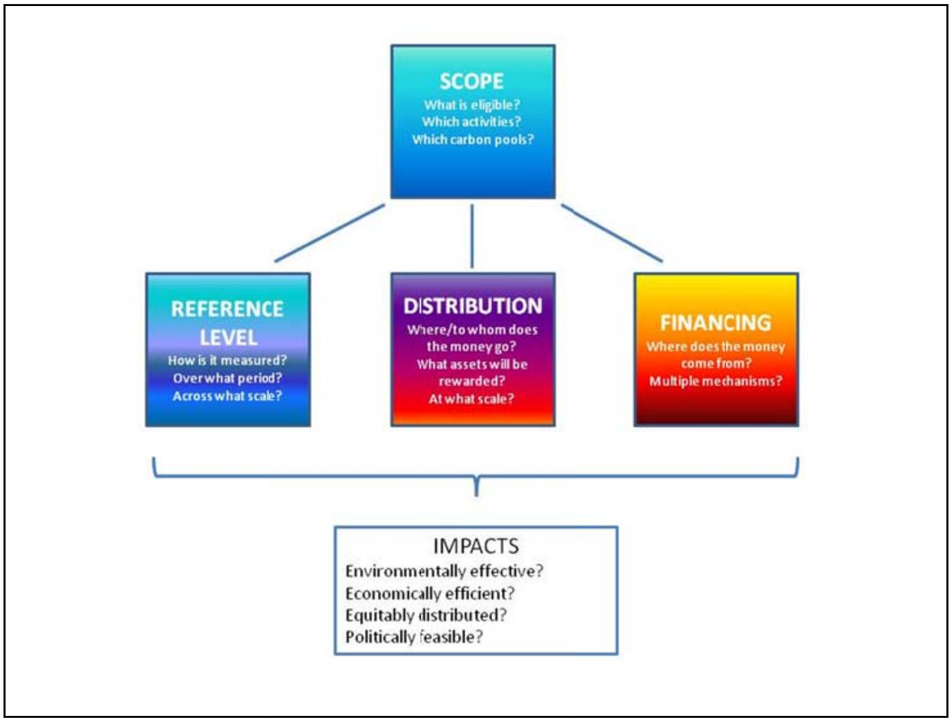
The MEST developed a list of 55 actions and policies the GoG could take to reduce GHG emissions. These Nationally Appropriate Mitigation Actions (NAMAs) were appended to Ghana's submission to the Copenhagen Accord. Most NAMAs align with development priorities in the Ghana Shared Growth and Development Agenda 2010 (GSGDA), and most are energy related but do not specifically mention biofuels, other than waste as renewable sources, and do not mention woodlots to meet community cooking needs. Eight of the 55 NAMAs address land use, land use change and forestry including sustainable forest management, REDD+, plantation development, and rehabilitation of degraded lands. The NAMAs are mostly broad statements without implementation details, cost estimates, likely funding sources or priorities.

REDD+ POLICY FRAMEWORK

INTRODUCTION

Reducing emissions from deforestation and degradation of tropical forests (REDD) is one means for mitigating the effects of increased CO_2 on global climate (UNFCC 2007). One strategy for reducing emissions from land conversion is to pay for maintaining and enhancing carbon stocks with the added benefit of halting deforestation (Kanninen, Murdiyarso et al. 2007). When the term REDD was formally recognized at the United Nations Framework Convention on Climate Change Conference of Parties meeting in Bali, Indonesia in 2007, the last clause of the decision document added the "plus" to the term. This recognized the role of conservation and sustainable forest management in enhancing carbon stocks (Mayers et al., 2010). The international community has invested heavily in preparing tropical countries to participate in an expected program to pay to maintain or enhance forest carbon stocks. Funding has been streamed through two mechanisms, the Forest Carbon Partnership Facility of the World Bank and the United Nations REDD (UN-REDD) program. Additionally, there are voluntary carbon markets and the Clean Development Mechanism/Afforestation and Reforestation mechanism (Westholm et al., 2009).

The UNFCC REDD concept has four components that set the boundaries for an eventual program (Figure 4.1): Scope, Reference Level, Distribution, and Financing. Because agreement on REDD+ has been illusive, most of the questions posed for these components have yet to be answered definitively. Thus, some details of a REDD+ program in Ghana must await international clarification. Although experience from the voluntary carbon markets and the CDM A/R provide some guidance, they essentially operated at the project-level. The national-scale envisioned for REDD presents new, more complex questions (Westholm et al., 2009). One issue is the necessity to monitor and verify that carbon stocks are being maintained; the Bali document featured measurement (monitoring), reporting, and verification (MRV) as a central focus (Westholm et al., 2009). Until Scope and Reference Level issues have been resolved, MRV components remain in flux. Another issue is whether REDD approaches should be strictly national, sub-national, or both and the related concerns about benefit-sharing among stakeholders. These and related issues for Ghana are discussed below.



Source: Little REDD Book, 2009

Figure 4.1 The Reduced Emissions from Deforestation and Degradation (REDD) framework under the UNFCC, showing the key questions to be answered

Because the details of REDD+ have not been finalized, necessary activities and components have yet to be specified. In the meantime, some have suggested that REDD+ provides a vehicle for a more comprehensive approach to carbon accounting and land use. The argument is that since in most of the tropics agricultural expansion is the main proximate cause of deforestation, it should be considered in programs to address deforestation. Others have pointed to the exclusion of some agroforestry practices from REDD+ consideration because they occur on land that is not designated forest. These other approaches, termed AFOLU (Agriculture, Forestry, Other Land Uses) and REALU (Reduced Emissions All Land Uses, includes trees not in forests), are opposed by those groups wishing to maintain the focus on forests. Alternatively, there has been discussion of using the REDD mechanism to develop payments for other ecosystem services, in addition to carbon sequestration (Karsenty, Guéneau et al. 2008).

Nevertheless, there is broad consensus on the key elements of a national REDD+ program: developing a reference scenario, transparency, and MRV (measurement [sometimes referred to as monitoring], reporting, and verification). A reference scenario involves defining what a forest is and setting a baseline for carbon emissions from deforestation or degradation. It is from this baseline that carbon accumulation or loss is to be evaluated. The choice of baseline rules can greatly affect the amount of emissions reductions claimed (Griscom, Shoch et al. 2009). Transparency requires adequate consultation with stakeholders and affected parties, including what constitutes adequate notification of farmers and others living in and around forests. Other aspects of transparency relate to forest law and governance, including forest management practices, policies and enforcement, illegal logging, etc. Indeed, REDD+ was attractive to many because of the potential to support (or require) governance reform (Hansen, Lund et al. 2009; Sandker, Nyame et al. 2010). Because REDD has been envisioned and approached as a national-level effort, concern for social responsibility and effects on local communities was not initially addressed. Social responsibility includes protecting the rights of indigenous people and more recently, sharing benefits from carbon payments equitably among government, land owners, and forest communities.

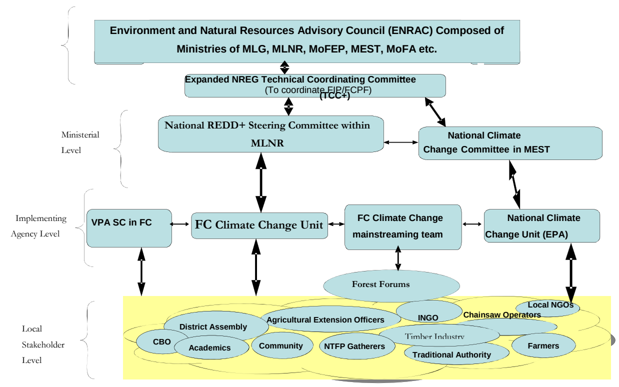
Once the structure of a REDD+ program has been established, MRV focuses on its operation (Herold and Johns 2007; Herold and Skutsch 2009). It is concerned with ongoing carbon accounting and related issues – for example, permanence and leakages. Reporting originally was envisioned as a national responsibility but sub-national carbon accounting seems reasonable as a way to jump-start REDD+ programs and to encourage private party participation it must somehow be accommodated within the national accounting structure (Angelsen and Institute 2009). Nevertheless, exclusively sub-national accounting has been ruled out because of concerns over leakage and permanence and the difficulty of verification.

REDD+ IN GHANA

The greatest potential for REDD+ in Ghana is in carbon enhancement, which means better management of the remaining small amount of forest and in restoring degraded forests. The potential so far has been regarded as mostly within the High Forest Zone (HFZ), including shade-grown cocoa (cocoa culture is primarily carried out in the HFZ) although there is no reason that REDD+ could not be extended to the savanna woodlands of northern Ghana.

The focal point for REDD+ in Ghana is the Climate Change Unit of the Forestry Commission; this unit serves as the secretariat for the National REDD+ Technical Working Group, a multi-stakeholder body within the Ministry of Lands and Natural Resources. This working group provides oversight (advice and guidance) on REDD+ processes. (The FC is within this ministry). The institutional framework for REDD+ in Ghana is shown in Figure 4.2.

At the Cabinet level is the Environment and Natural Resources Advisory Council, chaired by the Vice-President. This group provides oversight on national climate change issues, including REDD+, and coordinates cross-sectoral issues (i.e., settles disputes between ministries). This group was formed in May 2010. The NREG Technical Coordination Committee (TCC+) coordinates several forest-related initiatives within Ghana, including REDD+. NREG is a multi-donor sector budget program that is an effective government-donor-civil society mechanism that provides oversight and ensures cohesion in policy and coordination of REDD+ with other initiatives. A Carbon Credit Policy Committee has been set up in the Ministry of Environment, Science and Technology to clearly define rules and procedures for carrying out carbon credit generating activities, allocation of carbon rights, and participation in sub-national carbon activities.



Source: Forestry Commission 2010

Figure 4.2 REDD+ Management Arrangements

Technical Sub-Working Groups have been formed under the National REDD+ Technical Working Group to examine requirements in greater detail and recommend policies for implementing REDD+. The Sub-Working Group on Consultation and Participation is charged with developing a comprehensive Stakeholder Consultation and Participation Plan and Communication Strategy, outlining how local institutions and communities should be engaged in the REDD+ process. Another sub-working group on Policy, Legislation, and Governance will facilitate ongoing policy and legal reforms that seek to address drivers of deforestation and degradation. This group is to identify gaps and strategies in the reform efforts in the agriculture, mining, and forestry sectors.

Other key players in the REDD+ process are environmental non-governmental organization (ENGOs), such as Forest Trends, Rainforest Alliance, Nature Conservation Research Centre (NCRC) and others. A civil society contact group with Ghana Forest Watch as the hub was established in an earlier process (the Voluntary Partnership Agreement with the European Union; discussed below) and will be used in the consultation and participation processes.

PREPARATION, CONSULTATION AND IMPLEMENTATION FRAMEWORK

REDD+ in Ghana will proceed over a five-year period until fully implemented. The first phase consists of becoming REDD-Ready. A REDD Readiness Preparation Note (R-PIN) was submitted to the World Bank's Forest Carbon Partnership Facility, detailing how Ghana intended to prepare for REDD. The R-PIN was approved in July 2008. Subsequent to negotiations between the FCPF and the government of Ghana, a $200,000 Preparation Grant Agreement was signed in April 2009. This agreement provided the funding to underwrite the costs of preparing the REDD Readiness Preparation Proposal (R-PP). Following some limited consultation with stakeholders, the R-PP was submitted to the FCPF in December 2009 and simultaneously underwent external review. The R-PP was approved subject to revision by the FCPF in March 2010 and a revised R-PP was submitted to the FCPF in December 2010. At this time, a Readiness Grant is being finalized with the FCPF, including arrangements for fiduciary requi9rements to be met by dispersal of funds through a private body, further World Bank due diligence, and preparation of the R-PP Assessment Note. This Phase 1 of the REDD+ process should be completed by the end of 2011.

	2008	2009	2010	2011	2012	2013	2014-On
Phase 1 REDD Readiness							
Consultations begun with stakeholders to formulate R-PP							
R-PIN approved by World Bank, July							
FCPF Preparation Grant, April							
National validation workshop held, October							
The R-PP submitted to the FCPF, December							
RPP was approved subject to revision by the FCPF, March							
Revised R-PP submitted to the FCPF, December							
FCPF Readiness grant being finalized							
R-PP Assessment Note prepared							
Phase 2 Implementation of REDD+ strategy							
Implementation of the national plan, policies and measures							
Further capacity building, technology development and transfer							
Results-based demonstration activities or pilot projects							
Phase 3 (Implementation of Performance-Based Actions							
Results-based actions on-going							
Full implementation of MRV procedures							

Figure 4.3 Schedule for REDD activity in Ghana

Two further phases will follow: Phase 2, which runs from (2011 through 2012), will implement the REDD+ strategy. National plans, policies, and measures will have been finalized and implementation begun. Further capacity building, technology development, and transfer are needed to ensure that institutional capacity is sufficient to effectively proceed with a REDD+ plan. During this phase, results-based demonstration activities or pilot projects will be undertaken in order to develop and test the activities that will be included in the final program. The REDD+ Strategy will fall into two broad thematic areas – timber policy and supply and forest policy, including agroforestry, and other carbon conserving activities. To date, 14 candidate strategies have been identified in the R-PP. These will be subjected to social and environmental impact assessment during the consultation process and testing during the REDD+ piloting phase. A provision requiring a Strategic Environmental and Social Assessment was included in the R-PP. The SESA will promote due diligence, identify changes in institutional arrangements and governance needed for the implementation of REDD+, and identify the likely socio-economic and environmental risks associated with REDD strategies/policies. The SESA will also outline possible mitigation options, and assess potential additional benefits in terms of biodiversity conservation and poverty alleviation.

The REDD Secretariat has begun compiling a registry of companies, institutions, and individuals that are engaged in various REDD/REDD+ projects in Ghana. Unfortunately, registration must be done at the

Forestry Commission offices outside of Accra and a non-refundable processing fee of GH¢500 is required, thereby providing disincentives for small farmers to participate.

Phase 3 will run from 2012 to 2013 and will continue implementation of performance-based actions and fully implement the MRV procedures. An entity responsible for MRV will be established during this phase, along with setting of the Reference Emission Level. The carbon measurement, accounting, and MRV procedures will be tested. New legislation will be passed by this phase (2012-2013) to define carbon rights and address other legal requirements (GoG 2010).

OTHER EFFORTS AND INITIATIVES RELATED TO REDD+

The REDD+ program will not operate in a vacuum; there are several other initiatives and activities underway that should complement REDD+ and address some of the obstacles to realizing the full benefit of REDD+ in terms of halting deforestation and degradation.

Voluntary Partnership Agreement – A Voluntary Partnership Agreement (VPA) was signed between the Government of Ghana and the European Union (EU) on November 20, 2009. The VPA is meant to address sustainability, particularly illegal logging, by governing trade between Ghana and the EU; legally produced timber exported to the EU would be identified by a license issued in Ghana. Timber originating in Ghana without the license would be denied entry into the EU. As more than half of Ghana's annual commercial timber harvest is exported to the EU, the VPA should enable considerable progress in tackling illegal logging in the country. In the discussions leading up to the VPA, it was recognized that an agreement only about exports that did not include the sizeable domestic market largely served by illegal logging, would do little to address the underlying threats to the forests estate. A study by the International Institute for Environment and Development (Mayers et al. 2008) presented three scenarios: a baseline, business as usual scenario; a scenario with an effective timber regime that would meet the minimum requirements of a VPA; and a sector reform scenario that would reflect a transition toward improved forest governance and sustainability. The sector reform scenario would address important policy failures such as the highly protected processing industry (Mayers et al. 2008). They concluded that even with a legitimate timber regime, the forests will be substantially degraded. Nevertheless, many of the reform measures proposed in the Sector Reform scenario would be critical to the success of a REDD+ program.

Clean Development Mechanism – The Kyoto Protocol provided a Clean Development Mechanism that offered developed countries (so-called Annex 1 countries) with emission reduction targets a chance to offset some of their greenhouse gas emissions by funding renewable energy and forestry development projects in developing countries. The Kyoto Protocol itself makes no distinction between emission-avoiding and carbon sequestration or storage projects such as afforestation and reforestation. Some have questioned whether afforestation and reforestation should be part of REDD+ since these activities are included in CDM; the most compelling justification for inclusion in REDD+ is that the CDM A/R has been a failure. The role of CDM in Ghana is discussed in more detail below.

Forestry Investment Program – The Forestry Investment Program is part of the Strategic Climate Fund (a multi-donor Trust Fund within the Climate Investment Funds). The overall objective of FIP is to mobilize funds to reduce deforestation and forest degradation and to promote sustainable forest management. The main purpose of FIP is to support REDD-efforts by providing up-front bridge financing for readiness reforms and investments, taking into account opportunities to adapt to the impacts of climate change on forests, contribute conservation of biodiversity, and enhance rural livelihoods. Ghana is one of eight countries (one of three in Africa) selected to pilot the program. The Minister of Lands and Natural Resources is the FIP Focal Point and the expanded NREG Technical Coordination Committee provides overall guidance of the FIP. The Government of Ghana has received a Preparation Grant to develop an Investment Plan for the FIP, which is expected to be submitted in November 2011. A joint multilateral development bank (MDB) mission will visit the countries to develop an investment plan (this was tentatively scheduled for April of 2011). This plan will be approved by the FIP Sub-Committee (FIP-SC) and then specific projects and programs will be prepared and joint financing for these activities will be decided in more meetings of the FIP-

SC. A New National Plantation Development Program was launched in January 2010 by the Forestry Commission with an annual target of 30,000 ha. It is to be implemented nationwide, both within and outside forest reserves using paid/contract labor. The Forestry Commission expects to have a good portion of its targets met through financing from the FIP.

National Forest Forum – Civil society platforms such as Forest Forums are existing structures used for dissemination of REDD+ information to grassroots forest communities. In January 2005, the Forestry Commission partnered with the United Nations Food and Agriculture Organization (FAO) to address priority gaps in the implementation of Ghana's national forest program. A National Forest Program (NFP) has to be implemented by all stakeholders, not just the government acting alone. Thus the Forestry Commission established a National Forestry Forum (NFF) at the national, regional and district levels as a grassroots civil society organization to contribute to the development, implementation, and monitoring of key policies in the sector. The NFF was inaugurated at a meeting in November 2007 in Accra. The NFF is aimed at providing a national platform for forest stakeholders to discuss critical issues on forest governance, share information and interact with forest managers and policy makers on best practice resource management. In May 2002, the Forestry Commission, in conjunction with the donor-funded Forest Sector Development Project (FSDP) II and CARE, organized a workshop in Ghana together with NGOs and other civil society organizations in order to better understand the unresolved issues in Collaborative Forest Management. One of the recommendations from this workshop ("Akosombo 1") was the establishment of "Forest Forums" as "spaces" for district-level dialogue on forest issues. Forest Forums were a positive step, and one which continues today with 15 forums in districts around the country having regular meetings.

Modified Taungya Systems – In September 2001, the President of Ghana launched the National Forest Plantation Development Program with an ambitious annual planting target of 20,000 hectares using variety of approaches. One approach was the Modified Taungya System (MTS) whereby small-scale farmers could partner with the Forestry Commission to establish and manage tree plantations in degraded forest reserves and thus be entitled to a share in the monetary value of the tree crop. Legislation was passed to grant these rights but a farmer requires a certificate from the Forestry Commission to secure these benefits. Under the current phase of the National Forest Program partnership with FAO, a priority is accomplishing plantation development by consolidating the benefits due to farmers engaged in the Modified Taungya System. An estimated 100,000 hectares of MTS plantations have been established across the country through the involvement of over 100,000 rural farmers since its launching (Kalame 2009) but the signing of their benefit sharing agreement has become stalled due to inadequate resources and staff constraints within the Forestry Commission. To rectify the situation, the Forestry Commission is seeking proposals from qualified civil society groups (academic institutions, NGOs, CBOs and consulting firms) to complete the signing and registration of outstanding benefit sharing agreements. A project funded by USAID-West Africa under the STEWARD program has partnered with researchers at the Forest Research Institute of Ghana to pilot a community-based carbon monitoring method, working with three of these forest fringe communities that used the MTS to restore degraded forest reserves (Blay et al. 2008). The rationale was if the communities own timber rights, perhaps they could also obtain carbon rights.

Non-Legally Binding Instrument – In 2008, Ghana became the first country to systematically implement the Non-Legally Binding Instrument (NLBI) on All Types of forests with technical support from FAO and the German Agency for Technical Cooperation (GTZ) and funding from the German Federal Ministry for Economic Cooperation and Development (BMZ). Non-Legally Binding Instruments (NLBI) were developed at the sixth meeting of the United Nations Forum on Forests (UNFF-6) but negotiations for an NLBI on forests was put off until UNFF-7 (April 2007). The NLBI on Management, Conservation and Sustainable Development of All Types of Forests (the Forest Instrument) was adopted by the seventh session of UNFF and by the United Nations General Assembly in 2007. The Forest Instrument is to provide a comprehensive framework for national action and international cooperation for Sustainable Forest Management. The NLBI on Forests focuses on promoting horizontal and vertical communication, securing rights, including rights over resources, and clearly identify responsibilities, ensuring a transparent and participatory process of policy development and implementation, including providing early and adequate information. The NLBI on Forests provides for periodic review and promotes coordination of forest-related policies, strategies and programs. Because the NLBI is an over-arching effort, REDD+ strategies and programs should fit comfortably within the NLBI framework. Several of the efforts undertaken in implementation of the NLBI have been used in the REDD+ process or share similar goals. For example, stakeholder participation begun under NLBI and the VPA are used by the REDD+ process. (A/RES/62/98; available at http://www.un.org/esa/forests/nlbi-GA.html)

REDD+ IMPLEMENTATION ISSUES

Ghana is at the forefront of pilot efforts to implement REDD+ activities to mitigate climate change, with significant investments on the part of The World Bank and other organizations. However, major obstacles remain to be addressed before REDD+ will be successful, including land and tree tenure issues, carbon rights, benefit sharing, illegal logging, current methods of cocoa production, and carbon measurement, reporting, and verification methods. Three formidable technical issues arise when considering how Ghana will implement REDD+: setting a baseline (reference scenarios), carbon accounting, and MRV.

REFERENCE SCENARIO

To begin carbon accounting for REDD+ it is necessary to set a baseline for how much forest exists and how much has been lost. Ghana has a high deforestation rate, 1.9 percent per year based on national reporting to FAO –but this figure is unreliable (see the section on deforestation for a discussion). There is no regular monitoring or forest inventory system in place and until recently, remote sensing methods have been little used. Thus, the first step in setting the baseline is to determine how much forest cover remains and how much carbon it contains, which is a function of how degraded it may have become. Forest cover can be estimated from remotely sensed data; for Ghana, the most practical approach is data gathered from satellite. Frequent cloud cover is one difficulty in using remotely sensing approaches and the problem is greatest in the high forest zone. In conjunction with the satellite imagery, ground measurements are needed to estimate tree volumes. Where an on-going forest inventory and monitoring program is in place, this is a relatively easy step but, as noted already, no such inventory exists in Ghana. The conversion from inventory to biomass requires destructive sampling of a representative number of trees of various sizes and species. There are few biomass measurements available and the few data that exist are for relatively local areas. The conversion from biomass to carbon content is straightforward and largely a function of how dense a tree is or it can be estimated from generalized equations for tropical trees. Carbon estimates in Ghana have been based on a few regional forest inventories, from growing stock data and using generalized estimates from literature values.

Recently, a carbon baseline map has been produced as a collaborative effort between Forestry Commission, the Katoomba Group, Nature Conservation Research Centre, and Oxford University (Prof. Yadvinder Malhi). The ongoing carbon map project is supported by the Moore and Rockefeller Foundations. This map was not available for our examination although we did discuss the sampling methods with the field staff and it appears that the map is for the high forest zone only.

CARBON ACCOUNTING

Carbon accounting begins with the baseline and through monitoring, determines flows into and out of forest over reporting intervals. A country may gain carbon by normal stand development; as trees grow, they not only fix more carbon in their biomass but generally soil carbon increases. Carbon may also be gained by increasing the area of forest land through afforestation of farmland or restoration (rehabilitation) of degraded forest land. There are also fluxes associated with timber harvesting and regrowth. Carbon is lost by deforestation for agriculture, wildfire, and conversion to urban or insudtrial uses. In Ghana, the most likely losses (leakages in the carbon accounting terminology) will be from expansion of farming especially for cocoa, illegal logging, and wildfires.

Although the REDD+ framework envisions national-level accounting, the obstacles to implementing such a system in Ghana and many tropical countries are formidable, as we have described. Sub-national accounting, where smaller areas and projects are used to jump-start the REDD+ process, is put forward as a useful first step toward full REDD+ implementation. For sub-national accounting to be acceptable, methods will have to be developed that provide rigorous estimates of carbon are compatible with national-level accounting. Ghana is pursuing the sub-national carbon accounting approach as a first step to manage the national carbon accounting and actions related to crediting.

MONITORING, REPORTING, AND VALIDATION

Once a carbon accounting system has been developed it must be implemented as an ongoing function of some agency. Discussions by the MRV Sub-Working Group on how best to develop an effective MRV system are ongoing. The Remote Sensing & Forest Inventory Unit of the Forestry Commission and the Centre for Remote Sensing and Geographic Information Systems **(**CERSGIS) at the University of Ghana will be key collaborators in the design of the MRV and carbon accounting system. The challenges to effective MRV come from lack of infrastructure and limited human resources capacity. Internet speed is relatively low and bandwidth is narrow, constraining the ability to obtain data over the internet and to share data and interpretive maps among agencies. Historical LANDSAT and some SPOT data are available for Ghana and could form the basis for a regular forest cover change monitoring system. Because of the high cloud cover, however, additional radar data will be needed to provide full coverage of the country. A fire monitoing system is needed. At the present time, the state of the forest, trends, and functions are inadequate and must be revised to meet REDD+ standards. A true national continuous forest inventory must be established if carbon stock changes are to be monitored adequately. The forest area must be stratified into forest types; this effort should be extended to the savanna zone as well. A system of permanent measurement plots is needed that can be re-visited and re-measured regularly, to establish trends.

Technical capacity and expertise must be developed in both the remote sensing and field efforts. Technical expertise in optical and radar remote sensing acquisition, processing, and interpretation is required. Technical capacity is also needed to assess and validate the remote sensing interpretations using ground measurements. Technical capacity and expertise is needed for the field measurements and estimation of carbon stocks, including the research necessary to scale-up from individual tree diameter and height measurements to volumes, weight, and carbon contents. Research on all carbon pools, including soil carbon and deadwood, is needed for each forest type.

CARBON RIGHTS AND BENEFIT SHARING

The complex system of land and tree tenure varies in the different regions of Ghana (see next section for details). Even where smallholders have gained rights to share in benefits from planted trees (e.g., the modified taungya system) it is far from clear whether they have gained rights to share in carbon benefits. Without such incentive for local people to share carbon benefits, it is doubtful that deforestation and degradation can be avoided. The effectiveness of REDD+ schemes are not assured until tree tenure and carbon rights issues are addressed.

LAND TENURE IN GHANA

INTRODUCTION

Land tenure is generally understood as the mutually accepted terms and conditions under which land is held, used, and traded (Adams & Sibanda, 1999). Tenure can further be defined as the "social relations and institutions that govern access to and use of land and other natural resources" (Yaro & Zackaria, 2006, 25). It is important to note that land tenure is not a static system; it is a system and process that is continually evolving, and is influenced by factors such as the state of the economy, changing demographics, cultural interactions, political discourse, or a changing natural and physical environment. However, land tenure can, in turn, have an impact on these factors, which is why it should be considered in conversations concerning socioeconomic development and environmental change (Akoto et al., 1996). In the case of Ghana, land tenure is especially important. As a country with an agrarian-based economy, access to land and land use arrangements play an important role in determining economic productivity. Ghana aims to become a middle income country by the year 2020, and meeting this goal will involve making serious improvements to agricultural production (Akoto et al., 2006). The literature suggests that land tenure plays an important role in determining the ways in which land, labor, and other inputs can be organized and used to attain higher agricultural outputs within agrarian economies. This means issues relating to land tenure, including accessibility and security, will have to be addressed in development plans.

Many scholars purport that problems with land tenure in Ghana are most pronounced in urban areas close to the capital city of Accra (Yaro & Zackaria, 2006). However, land tenure is important throughout the country, and it would be remiss to ignore the impacts that existing land tenure systems play in rural agrarian areas. Many of the people we met with during our mission to Ghana raised land tenure as a barrier to climate change adaptation and mitigation.

In this section we address land tenure in rural Ghana, with a focus on the Western Region and the three northern regions (Northern, Upper East, and Upper West) where USAID/Ghana has a special interest. In the Western Region tenure issues are key, given the country's interest in developing REDD+ projects for climate change mitigation. The Western Region holds the majority of the country's remaining primary forest reserves and is experiencing a dramatic increase in cocoa farming (Osei-Owusu, 2011, Teal et al., 2006). The country's interest in increasing production means that further expansion of cocoa farms into the Western Region is likely. Land tenure will play an important role in developing successful REDD+ initiatives, promoting forest conservation, and managing the growth of the cocoa industry.

Northern Ghana contains roughly 41 percent of the country's land base, and 23 percent of the total population – nearly three-quarters of which is employed mainly in agriculture. Given this reliance on agricultural production, land is an important asset to households and local governments, being the base from which crops are grown, livestock are raised, animals are hunted, and natural resources are harvested (Yaro & Zackaria 2006). Making a living requires some form of access to land, without which many livelihoods would be non-existent. An ineffective tenure system could have serious implications for agricultural development in this region.

FORMS OF LAND TENURE CURRENTLY OBSERVED

All land in Ghana can be considered occupied, in the sense that it has been claimed, over centuries, by tribes and lineages. Throughout colonialism and into Ghana's statehood, some of this land was seized and claimed for private ownership, and eventually state ownership. As a result of both long-standing ancestral systems of land governance, and the need for state-managed lands, Ghana has developed two distinct forms of land governance: statutory tenure and customary tenure.

The statutory tenure system is based on formal, legally-defined Ghanaian law, and governs lands that are owned privately (registered with the state) or by the state. The state manages state lands on behalf of the people through its established agencies, and private ownership is managed through the Ghana Lands Commission's land registration project. Statutory tenure provides for tenure rights that are legally enforceable in a Ghanaian court of law, regulated, and well documented. Penalties apply should the agreement not be upheld (Yaro & Zackaria, 2006).

The customary system, by contrast, is largely undocumented, highly variable, and rights and leases granted through customary authorities are rarely legally enforceable in a court of law. Customary tenure laws govern lands belonging to tribes, lineages, and families – which constitute the majority of land in Ghana (Table 4.1). Ownership of these lands, in the form of the allodial title, is vested in chiefs and lineage heads. Although the lands are vested in chiefs and lineage heads, technically tribal land is ancestral property and therefore belongs to the people. Customary tenure forbids sale, but does allow for long-term leasing. Management of tribal lands occurs through sub-chiefs, elders, heads of lineages, or (in the North) Tendanas, all of which are individuals recognized through tradition as the true custodians of the land. These "headsmen" ensure that all members of the lineage, tribe, or clan have access to farmland by granting long-term leases to individual farmers. Ownership is never technically relinquished, although transitory forms of proprietorship are granted (Gildea, 1964).

Table 4.1 Land Ownership in Select Regions of Ghana (% of total land base)

Landowner	Western Region	Northern Region	Upper East Region	Upper West Region	Ghana
Communally held (allodial title vested in chief, lineage head, family head)	76.3	91.5	63.9	87.1	71
Chief/Queen	*16.6*	*63.3*	*8.7*	*28.7*	*21.5*
Clan/Lineage Head	*36.5*	*24.7*	*45.2*	*56.4*	*32.5*
Father/Family Inheritance	*14.9*	*2.8*	*7.0*	*0.0*	*9.8*
Other Family Relation	*8.3*	*0.7*	*3.0*	*2.0*	*7.2*
Individual	11.0	2.5	28.7	6.9	17.8
Government	0.6	0.0	0.0	2.0	2.9
Other/Undefined	12.2	6.0	7.0	4.0	8.1

In the Western Region (where the Akan ethnic group is dominant), land is vested in the chief, who is both the religious and political leader. However, land is controlled by the elders or heads of lineages, who ensure that all members of their lineage are granted access to land. Individuals gain access to land by applying to the headsman and documenting their relation to the land's original settler. "If one asks a farmer how he came to secure the right to farm where he does, he will relate that he established his right by tracing his descent in the matrilineal line to an ancestor known to have farmed there before him. This ancestor may have been one of the original land settlers or a person who was rewarded with land by a chief after a war. The right to use land is inherited from the original settler or done by maternal kinsmen; thus a whole lineage acquires the right of usufruct and can exercise such right in perpetuity, but cannot sell it." (Gildea, 1964). Typically, usufruct rights are granted free of charge, but as land becomes more valuable, some headsmen charge individuals in exchange for a lease. As land has become increasingly valuable and scarce in the Western Region (due primarily to cocoa farming), the state has intervened to modify customary tenure slightly, and allow for a greater degree of individual control. A husband who has been granted land rights by the headsman is now able to transfer a portion of his land to his wife and children upon death. This individualization was formalized by the passing of the Intestate Succession Law in 1985, which stipulated that upon death, one-third of the land be given to the surviving spouse, one-third to the surviving children, and one-third back to the matrilineal family (Otsuka et al., nd). Land that is left fallow (regardless of any death) reverts back to the lineage head for redistribution.

In Northern Ghana (Northern, Upper East, and Upper West Regions), tribal lands are also managed under a customary tenure system. Customary trustees hold the allodial title, from which all other rights are derived, on behalf of the community. In the Northern Region (within the more centralized cultural states, such as the Dagbong, Mamprugu, Nanumba, and Gonja), the allodial title is vested in the skins (chiefs) and managed by chiefs, sub-chiefs, and lineage heads, all of whom receive authority through the chief. In the Upper East and Upper West Regions, the title is vested in Tendanas, spiritual caretakers of the land, who are unaffiliated with the chiefs. (Tendanas are prevalent in less centralized states, such as the Tallensi, Kusai, Sissala, and Lobbi-Dagarba). In the Tendana systems, it is the Tendana himself who grants use of the land, either personally or through clansmen and recognized lineage heads. In Tendana systems, as land has become more valuable, chiefs have usurped the Tendana's role, which has created controversy among the population. Unlike in the South, individuals in the North trace their lineages through patrilineal descent when applying to a headsman for land rights. As in the South, traditionally long-term leases were granted free of charge, but increasingly the headsman (subchief) or even the Tendana will expect payment. (Yaro & Zackaria, 2006, Akoto et al., 2006).

When traditional methods of land acquisition are insufficient for providing family members with enough land to meet their needs, households typically seek additional acreage through renting agreements. These agreements might occur directly with a headsman, or they might occur with farmers who have been granted land, or they might occur with private landowners. If the sharecropper is a member of a landed family, use agreements are more fluid. Migrants who are not privy to an extended family networks are restricted to seeking tenancies under two forms of sharecropping arrangements: abunu (in which crops are shared equally between farmer and landowner), and abusa (in which the owner receives one-third of the harvest, the farmer two-thirds). The form of tenancy depends on which party cleared the land for farming (Kasanga & Kotey, 2001).

Overlying the traditional tenure regime throughout Ghana are other "tenurial niches" that include grazing rights, rights to fuelwood, fruit trees, and forest products (including edible and medicinal plants), and water rights (Yaro & Zackaria, 1996). Tree tenure in particular is relevant because of its role in potential climate change mitigation strategies.

TREE TENURE

Ghana's constitution vests all minerals and natural resources (including trees) in the President, regardless of whether or not the resource is on public or private land. Customary and statutory laws, while granting ownership of the land, do not grant ownership over naturally-occurring resources that the land holds (Osafo, 2010). There are some 279 forest reserves in Ghana, where forests are vested in the state and held in trust for communities (Owubah et al., 2001). Many of these reserves have been sites of extensive encroachment and resource conflict. Outside of forest reserves, harvesting and selling merchantable trees is illegal unless an individual has permission from the Forestry Commission, a tedious process. Protecting valuable, naturally-occurring trees is not generally in a farmer's interest, however, because loggers who come to harvest them often damage food and cash crops when harvesting such trees, and rarely compensate farmers for these losses, despite legal requirements to do so. This system creates an incentive for farmers to cut down merchantable trees before loggers can get to them, and potentially damage their fields, undermining sustainable forestry practices (Owubah et al., 2001). If a farmer plants trees on the land himself, he can seek a title for that tree, in which case he owns it outright, and can cut and sell it, keeping all profits. There is, however, a benefit-sharing system agreed upon, called the Modified Taungya System. The Modified Taungya System stipulates that revenues from a timber sale should be divided as follows: the farmer that cared for the tree and the Ghana Forestry Commission (tasked with managing all of Ghana's forest resources) each receive 40 percent, landowners (traditional authorities and tribal landowners) receive 15 percent (to be split if necessary), and the remaining 5 percent goes to the forest adjacent community – typically distributed through the district assembly (Ghana Forestry Commission, 2011; Agyeman et al., 2003). Other benefit-sharing systems exist for trees that occur on state owned forest reserves rather than communal lands.

CHALLENGES OF CUSTOMARY TENURE

Influenced by forces such as commercialization and urbanization, Ghana's customary tenure system has become unbalanced. "The efficacy of the traditional land tenure system is now being questioned, especially as most of the communal mechanisms – such as broader community consultation, social equity, and safety nets – that ensured easy access to land and transparency in land administration have been lost." (Akoto et al. 2006). Throughout Ghana, "High demand for land and its consequent translation into monetary value has generated conflicts between chiefs, clans, kinsmen, and family members." (Yaro & Zackaria 2006). A functioning customary landholding system should distinguish between individual, family, and communal rights, thereby supporting both sustainable development and land management. However, when these rights are not clearly defined, access to land may become restricted and individuals become more likely to depart from farm-based livelihoods, thereby reducing the agricultural potential of the economy (Kasanga 1994). Farmers in Ghana acknowledge that customary tenure has "in the past contributed to increased agricultural production, and therefore [improved] the economy of the country." However, the system as it is presently practiced tends to be riddled with problems in many places, frustrating rural residents and inciting conflict. Table 4.2 highlights the main problems associated with Ghana's current customary land tenure system. The data are based on a survey conducted by the Institute of Statistical, Social, and Economic Research at the University of Ghana.

Table 4.2 Problems Associated with Customary Land Tenure

Problem	Western Region n=554	Northern Region n=229	Upper East Region n=299	Upper West Region n=383	Country of Ghana n=3232
High price of land	41.3%	55.9%	38.1%	38.6%	48.1%
Disputes between tenants/users and land owners	17.8	4.8%	28.1%	13.1%	17.5%
Insecurity of tenure	20.1	14.8%	22.7%	18.5%	14.4%
Uncertainty about ownership of land	10.8	19.2%	7.4%	6.3%	10.7%
Sale of land without owners approval	1.1%	0.9%	1.7%	2.1%	1.8%
Disputes over family land	5.6%	3.1%	1.3%	12.5%	4.8%
Land is scarce	2.2%	0.4%	0.7%	6.0%	1.6%
Land taxes are too high	0.2%	0%	0%	2.1%	0.5%
Land is taken from you if you don't build on it	0.5%	0%	0.3%	0.2%	0.2%
Not enough funds to farm with	0.4%	0%	0%	0.3%	0.2%
Only administered by chief and Tendana	0%	0.4%	0%	0.3%	0.1%
Tribalism	0%	0.4%	0%	0%	0.1%
Death	0%	0%	0%	0%	0%

Source: ISSER, data

The most prominent issue facing respondents to the survey, from all four regions, was the high cost of land. The literature suggests that land prices have been inflated through the cultivation of cash crops (particularly in the Western Region, where cocoa farming has become lucrative) as well as processes like urbanization and commercialization. The result is that a greater variety of land users are now applying to headsmen for land rights, some of whom can afford to pay much more in exchange for a lease. Many headsmen simply lease rights to the highest bidder. In the South, this tends to mean that more land is put towards cocoa production (as opposed to subsistence use). Another implication of high land prices is that sharecropping arrangements tend to be less generous to the farmer, providing more benefit to the landowner (Kasanga & Kotey 2001, Otsuka et. nd). In the North, where cash crops do not grow as well, headsmen are granting more and more of the communal lands under their control towards commercial or urban residential uses, often at the expense of the greater community that depends on the land for farming. "There is fierce competition for even the lowest hierarchy of chieftaincy […] with the main motivation of [acquiring land to sell]" (Yaro and Zackaria 2006). Not all headsmen lease land for personal profit. But in many villages, anger arising from misdealings (the headsman collects fees from multiple users for the same plot of land, or demands increasingly high payments in exchange for a lease) has erupted into violence.

Following high land prices, the next set of problems facing respondents was the undocumented nature of their usufructory rights, and the lack of transparency surrounding tenure agreements. This confusion has resulted in frequent disputes over who has rights over what plot of land, often leading to conflict. "The current turbulence in land tenure arrangements in Ghana is reflected in the countless inter-tribal conflicts, inter-village conflicts, inter-household conflicts and contra-household confrontations over land ownership, use, and transfers. Problems of land tenure insecurity and the resulting conflicts do not only result in manifest loss of life and property, but also covertly form the basis of underdevelopment of productive forces in any society." (Yaro & Zackaria 2006).

The insecure nature of tenure does not just create conflict at the community level; it also creates a host of economic problems for Ghana. Undefined and undocumented agreements make it difficult to legally uphold tenure rights ownership in a court of law. Without established rights it is virtually impossible to obtain a line of credit or attract potential investors, reducing agricultural productivity. Furthermore, tentative and changing terms of tenure lead to uncertain, and therefore shorter, planning horizons. Short-term planning is less likely to entail large investments in productive assets or new technologies, as there is little opportunity for the tenant to capture any benefits from long-term investments. The same is true for investments in tree planting and sustainable forestry. Tenants are much more likely to maximize profits in the short term to ensure that they do not lose their investment. Thus, insecure tenure often leads to land degradation and is economically unsustainable in the long term (Place and Hazell 1993; Lopez 1995; Hayes et al. 1997; Place & Migot-Adholla 1998).

Land scarcity and disputes over family land were less common survey responses, but are likely to become larger problems in the future and may be locally important. For each successive generation available farmland is reduced, either through processes of commercialization and urbanization, or by the natural fragmentation and parcelization that occurs when land is split between family members. The resulting smaller and non-continuous plots will not provide for productive livelihoods unless more land is made available. This is already a problem in cocoa farming regions of the South. A study conducted in 1963 began suggesting that in many cases fragmentation and parcelization had occurred to the extent that remaining linear strips for farming were not economically viable (Hunter 1963). "With the depletion of virgin forest land in Ghana [as a result of the rapid expansion of cocoa cultivation] it [became] difficult for farmers to acquire more land for their children." (Benneh 1970: 206). This process is threatening to repeat itself in the Western Region as cocoa farming expands, and in the North.

SOCIALLY VULNERABLE GROUPS

Even in a well functioning customary system, access to land through inheritance or other means is based on power and social connections, which can limit access for certain groups or individuals based on their position in society. Acquiring a plot of land requires an abundance of social, political, and (most limiting) financial capital, assets not readily available to all members of society. In Ghana, "productive lands for growing commercial crops are denied to the less powerful in society such as widows, women, and migrants when they do not possess the backing of powerful men." (Yaro & Zackaria 1996, 6).

Women in particular have a difficult time accessing land. Ghanaian culture is arranged to allow for the economic productivity of men, while women are expected to be domestically productive. "Women are not supposed to be as economically productive as men are, and even if they are, men control their resources… This explains why Ghanaian society seems to invest more inheritance rights [to land] on men than women" (Gedzi, 2009: 2). Women are therefore considered to be a part of their husband's economic unit – a wife's claim to her husband's property is limited or nonexistent (Runger 2006). In the absence of a husband, a woman is left to rely on her father, her brother, or her son (if she is a widow).

Farmers that are not attached to a land owning family (farmers who cannot trace their lineage back to a plot of land) also experience difficulty obtaining land. Typically, they are forced to work as sharecroppers, or marry into a family with a lineage that provides access to land.

Often, the primary asset of socially marginalized groups is their relatively cheap and readily available labor, which is somewhat useless without land on which to turn that labor into a living. "In Ghana, whereas share contracts were a means by which land-poor but labor-rich households could gain access to a plot, those seeking sharecrop land must now put forward a significant fee in order to gain access." (Amanor 2001). Low-cost labor is not enough on its own to build a bridge out of poverty; it demands access to land in order to be transformed into useful capital. If trends in land tenure persist, and access to land is denied to the socially-marginalized and poverty-stricken members of society, the poverty cycle in Ghana will persist (Akoto et al. 2006).

TENURE CONSIDERATIONS IN LIGHT OF CLIMATE CHANGE AND FEED THE FUTURE

The current land tenure system in Ghana poses challenges for climate change mitigation efforts and implementing USAID's Feed the Future program. We outline below some of these challenges that should be taken into consideration in order to make progress with these programs.

Current customary land tenure practices have been impacted by processes of commercialization and urbanization, which drive up land prices. Commercial operators are better able to pay high fees in exchange for access to land, which makes headsmen less likely to grant land to subsistence farmers who cannot compete with commercial operators. If Feed the Future focuses primarily on commercialized forms of agriculture, this trend could be reinforced, and small-scale subsistence farmers could experience increased difficulty accessing land and securing a livelihood. Increased landlessness and unemployment will further strain food security and local economies.

Tree tenure, and complicated systems of benefit-sharing for revenues generated by trees, poses a threat to emerging climate change mitigation efforts. The confusing nature of tree ownership prompts many landowners to thwart the system entirely and illegally harvest trees. This creates problems for potential climate change mitigation efforts. Unless benefits can be shared equitably and transparently, or farmers are compensated for protecting trees, the risks of trees being illegally cut remains high.

Marginalized groups experience difficulty accessing land, particularly women and farmers that are not affiliated with a lineage that can establish a history of farming on a plot of land. Presently, these groups are forced to work as sharecroppers, or find other forms of employment. Women are dependent on men (husbands, fathers, brothers, and sons) to access farmland. If men are unable to access land for themselves, it is unlikely that they will be able to provide land for the women in their households. Therefore, interventions that reduce the amount of available land for farmers (by displacing them for large-scale farming schemes) could further marginalize these groups, as they are already the last to receive land in the present system. Some thought should be given about ways to incorporate these groups into commercial systems so they are not ignored.

One of Ghana's assets is a large pool of low cost labor. Commercialized and mechanized farming eliminate the need for this asset, utilizing inputs that are far more costly and potentially unsustainable in the long run without further inputs of foreign aid money (rising oil prices, fertilizers, tractors, etc.). An agricultural system that utilizes the available labor would not only provide jobs, it would eliminate the need for long-term inputs of capital.

Expected impacts of climate change are variable in nature, but point to changes in weather patterns that will impact farming, both in the short term, and in the long term. The threat of climate change is increasing climate variability. To cope with variable conditions, farmers will need longer planning horizons to work with when it comes to farming. The current tenure system does not allow much room for long-term planning.

The current tenure system encourages maximizing profits in the short term. Practices employed in profit maximizing farming schemes have a tendency to degrade the land, leaving it increasingly vulnerable to extreme weather events. (Poor soil quality as a result of over-farming leads to erosion, which is increased during flooding; the use of fire to clear land leads to bush fires, further spurred on by later rains or increased temperatures; etc.) Short-term and insecure tenure also contribute to deforestation. Finding ways to promote tenure security will help support sustainable forestry in Ghana.

5. PHYSIOGRAPHY, ECOLOGICAL ZONES, AND LIVELIHOODS

PHYSIOGRAPHIC ZONES

Like most of the West African mainland, Ghana is largely flat or gently undulating and >50 percent of the country is <150 m in elevation. A ridge and furrow topography is evident on Pre-Cambrian rocks reflecting the fold trends. The Volta River Basin occupies most of central Ghana and contains Lake Volta, the largest impoundment in Africa. The rim of the basin is comprised of plateaus with ridges and escarpments (i.e., Konkori Scarp to the west and Gambarga Escarpment in the northeast), whose altitudes may reach >450-600 m. The southwest part of the basin is bordered by the northwest to southwest trending Kwahu Plateau (an important climatic and drainage divide in Ghana), which forms a natural part of the Ashanti Uplands. The western part of the basin is bordered by the Akwapim-Togo ranges, which begin just north of Accra and stretch northeastward into Togo. The highest peak in Ghana, Mount Afadjato (885 m elevation) is situated in the Akwapim-Togo Range along the eastern border. The lowest lying areas in Ghana occur in the middle Volta Basin and in a broad belt along the coast (Dickson and Benneh, 1988; Owusu-Ansah, 1994; MSE, 2002; Borrow and Demey, 2010). From a geographic perspective, the country can be sub-divided into several distinct regions: Low Plains, Ashanti Uplands, the Volta Basin, and the High Plains (Owusu-Ansah, 1994).

LOW PLAINS

The Low Plains roughly parallel the coastline and can be divided into four subregions: the Coastal Savanna, the Accra-Ho-Keta Plains (including the Volta Delta), and the Akan Lowlands. A narrow strip of grassy and scrubby coast runs from a point near Takoradi in the west to the Volta River in the east. This coastal savanna, only about 8-km wide at its western end, stretches eastward of Accra through the Accra Plains, where it widens to >80 km and terminates at the southeastern corner of the country at the lower end of the Akwapim-Togo Ranges (Owusu-Ansah, 1994).

The Accra-Ho-Keta Plains begin near the southern terminus of the Akwapim-Togo Ranges near Accra and stretch north and eastward forming a large triangle in southeast of the country near the border with Togo. The Plains are almost flat and featureless and descend gradually from an inland height of about 150 m to the Gulf of Guinea. East of Accra the Plains are marked by a succession of ridges and spoon-shaped valleys and just west of Accra, the low plains contain wider valleys and rounded low hills with occasional rocky headlands. In general, however, the land is flat and covered with grass and scrub and classified as savanna. The Volta Delta (or Keta Plains), which extends into the Gulf of Guinea in the extreme southeast of Ghana, forms a rather distinct subregion of the Low Plains. The rock formation of the Delta, consisting of thick layers of sandstone, some limestone, and silt deposits, is flat, featureless, and relatively young. As the Delta fanned outward over time, sandbars developed across the mouths of the Volta and smaller rivers that empty into the Gulf in the same area, forming numerous, often large, lagoons (Owusu-Ansah, 1994).

The largest part of the Low Plains is the Akan Lowlands, which lie to the west and north of the Coastal Savanna and Accra Plains. Some classify this region as a subdivision of the Ashanti Uplands because of the many characteristics they share. Unlike the uplands, however, the height of the Akan Lowlands is generally sea level to 150 m. Some ranges and hills rise to about 300 m, but few are >600 m. The lowlands that lie to the south of the Ashanti Uplands receive several rivers that drain into the Gulf of Guinea (Densu, Pra, Ankobara, and Tano rivers) (Owusu-Ansah, 1994).

VOLTA BASIN

The Volta Basin, lying in the central part of Ghana, covers about 45 percent of the country's total land surface. The Basin's northern section, which lies above the upper part of Lake Volta, rises to a height of 150 to 215 m above sea level. The western rim along the Konkori Scarp and northern rim along the Gambaga Scarp reach elevations of 300 to 460 m. To the south and the southwest, the basin is <300 m in elevation. The Kwahu Plateau marks the southern end of the basin, although it forms a natural part of the Ashanti Uplands. The basin is delimited to the east by the Akwapim-Togo ranges. The basin is characterized by poor soil, generally of Voltaian sandstone. Annual rainfall averages between 1,000 and 1,140 mm. The most widespread vegetation type is savanna (Owusu-Ansah, 1994).

The Afram Plains, located in the southeastern corner of the basin, contrast with the rest of the Basin. The terrain in the Afram Plains is low (average 60-150 m in elevation), and annual rainfall is between 1,140 and about 1,400 mm. Near the Afram River, much of the surrounding countryside is flooded or swampy during the rainy seasons. With the construction of Lake Volta (8,515 ha in surface area) in the mid-1960s, much of the Afram Plains was submerged (Owusu-Ansah, 1994).

ASHANTI UPLANDS

The Ashanti Uplands consist of the Kwahu Plateau and Southern Ashanti Uplands and lie just north of the Akan Lowlands and stretch from the Côte d'Ivoire border in the west to the elevated edge of the Volta Basin in the east. Oriented from northwest-to-southeast, the Kwahu Plateau extends 193 km between Koforidua in the east and Wenchi in the northwest. The average elevation of the plateau is about 450 m, rising to a maximum of 762 meters. The Plateau forms one of the important physical and climatic divides in Ghana. From its northeastern slopes, the Afram and Pru rivers flow to the Volta River and on the opposite side, the Pra, Birim, Ofin, Tano, and other rivers flow south toward the Gulf (Owusu-Ansah, 1994). The Plateau has a significant impact on mean annual rainfall totals (Owusu and Waylen, 2009) and as a result, also marks the northernmost limit of the closed canopy forest zone (Hall and Swaine, 1976). The Southern Ashanti Uplands, extending from the foot of the Kwahu Plateau in the north to the Akan Lowlands in the south, slope from about 300 to 150 m elevation. The area also contains several hills and ranges (Owusu-Ansah, 1994).

HIGH PLAINS

The general terrain in the northern and northwestern part of Ghana outside the lower lying areas in the Volta Basin consists of a dissected plateau, which averages between 150 and 300 m elevation but in some places is higher. Rainfall averages between 1,000 and 1,150 mm annually, although in the northwest it is closer to 1,350 millimeters.

ECOLOGICAL ZONES

Tropical high forests (of various associations) and savannas are the two major biomes represented in Ghana (Figure 5.1). The southern half of the country, roughly south of the Kwahu Plateau, supports the closed forest and the northern half supports savanna and woodland vegetation. Within these major vegetation types there are many variants (e.g., swamp forests in the forest zone, gallery forests along rivers in the savanna) (MSE, 2002). These regions are largely influenced by the two main regimes of seasonal rainfall. The first is the double maximum rainfall regime occurring south of about latitude 8°30'N, affecting the closed forest region and coast. The two maximum periods generally occur from May to August and from September to October (Dickson and Benneh, 1988; Benneh and Agyepong, 1990). The single maximum regime occurs north of 8°30'N in the savanna biome where the single rainy season occurs from May to October followed by a long dry season from November to May. The forest zone extends over a major part of the southwest of Ghana and comprises the eastern end of the Upper Guinean forest block, one of Africa's two major lowland rainforest blocks. Much of the forested area in Ghana is now deforested and replaced by derived savanna, which is a mosaic of cultivation, farmbush, and secondary forest, all of which permit savanna species to extend into the forest zone. Of the remaining forest, most is now restricted to protected areas and little is primary forest, having been modified by humans (Owusu-Ansah, 1994).

Seven main forest types are recognized within the forest zone, based on environmental, physiognomonic, and geographical criteria (Hall and Swaine, 1981): wet evergreen, moist evergreen, upland evergreen, moist semi-deciduous, dry semi-deciduous, southern marginal, and southeast outlier forest. Three savanna types are generally recognized: a transitional zone, Guinea savanna, and Sudan savanna. The change from one type of forest or savanna to another is usually progressive. For purposes of addressing climate change, we delineated ecological zones in Ghana based primarily on annual total rainfall and major natural vegetation types (Hall and Swaine, 1976; MSE, 2002; Menczer and Quaye, 2006; Minia, 2008). We recognize six major zones: the Coastal Savanna Zone, Wet and Moist Evergreen Forest Zone, Deciduous Forest Zone, Transitional Zone, Guinea Savanna Zone, and Sudan Savanna Zone.

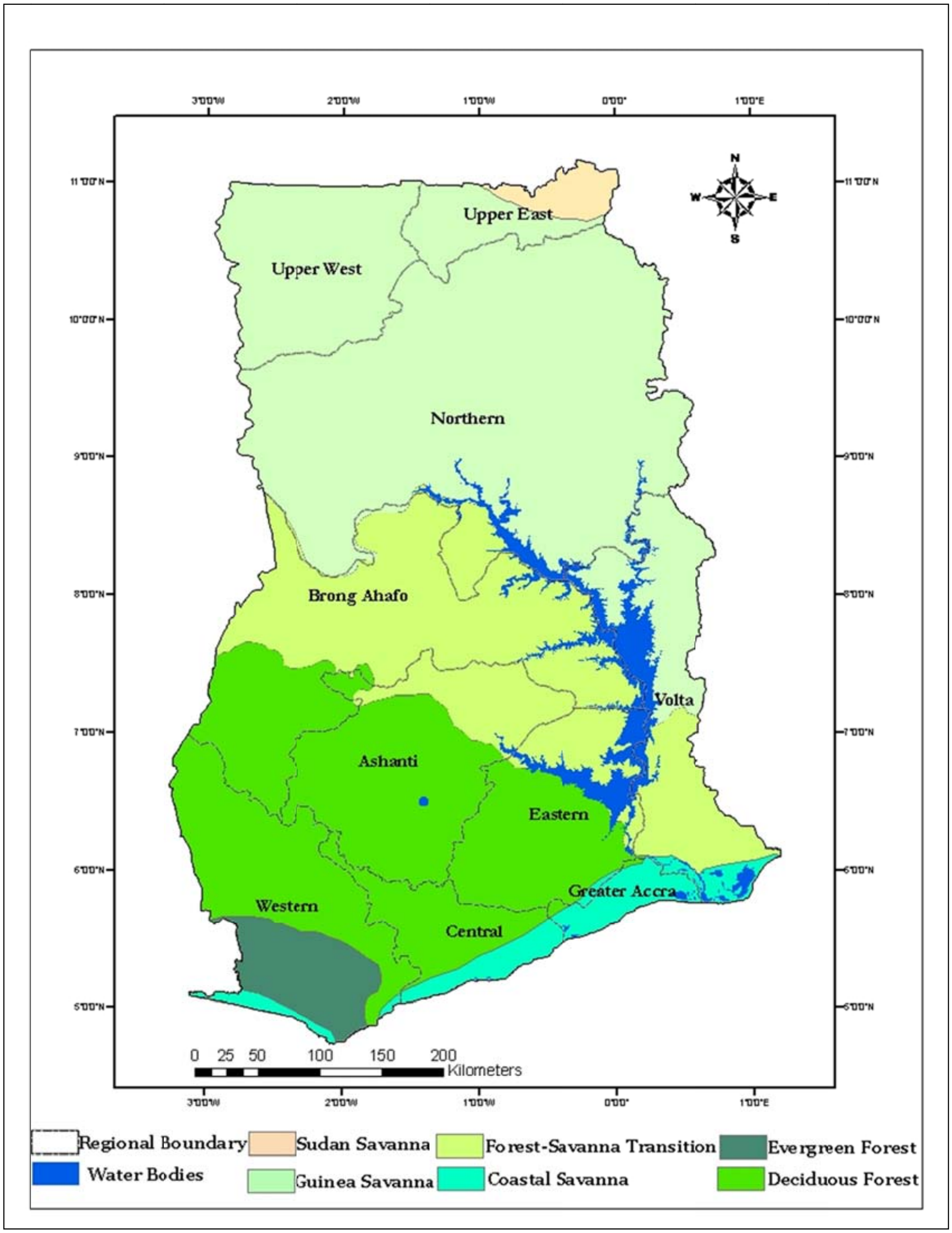


Figure 5.1 Ecological Zones of Ghana

COASTAL SAVANNA ZONE

The Coastal Savanna Zone is a narrow belt paralleling the coast (Jenik and Hall, 1976; Dickson and Benneh, 1988; Menczer and Quaye, 2006; Minia, 2008). Depending on exact boundary placement, estimates of the area covered by the zone ranges from 5,800 km² (Oppong-Anane, 2001) to 16,000 km² (Menczer and Quaye, 2006). Annual total rainfall averages 890 mm (range 600-1,150 mm, Menczer and Quaye, 2006; Minia, 2008) and occurs in two annual peaks, but rainfall in the southeastern part of the zone is the lowest in Ghana (ca.

600-800 mm per year, Jennik and Hall, 1976;. Dickson and Benneh, 1988; Menczer and Quaye, 2006). The major growing season is 100-110 days and the minor season 60 days (Oppong-Anane, 2001). From a tapered western point, the Coastal Savanna Zone widens to about 80 km inland and along its width includes southern parts of the Central, Greater Accra, and Volta regions. In southeastern Ghana, the region encompasses much of the Accra Plain and Keta Plain (Volta Delta) as well as the southern third of the Ho Plain (Jenik and Hall 1976, Oppong-Anane, 2001; Minia, 2008). The zone consists of a coastline strand of vegetation along the seashore, mangrove vegetation (mostly degraded) associated with lagoons and coastal estuaries, and inland vegetation primarily of scrub, grasses, and scattered trees with relatively poor soils. The major vegetation types are classified as southern marginal forest from about Accra westward, southern outlier forest in the Accra Plains, and savanna in the Ho Plains (Hall and Swaine, 1976; Menczer and Quaye, 2006). The southern marginal forest type occurs in a narrow strip from Cape Coast to Akosombo within the vegetation zone classified as coastal savanna. Because of population growth, southern marginal forests now are reduced to fragments and mosaics of forest mainly restricted to rocky hills (Menczer and Quaye, 2006).

EVERGREEN FOREST ZONE

The Evergreen (Rainforest) Forest Zone is located in the southwestern corner of Ghana in the Western Region. The zone covers about 7 percent of Ghana and about 20 percent of all high forest in the country (Menczer and Quaye, 2006). The forest types in the zone are wet evergreen and moist evergreen (Hall and Swaine, 1976). The wet evergreen forest type occurs in the southeastern-most corner of the country in an area of about 750,000 ha (SRID, 2010), where rainfall is highest at 1500-2100 mm/year (Menczer and Quaye, 2006), averages 2,092 mm/year, and occurs on average 143 days/year (Minia, 2008). The major growing season is 150-160 days and the minor season 100 days (Oppong-Anane, 2001). The moist evergreen forest type lies between the area of wet evergreen forest to the southwest and the moist semi-deciduous forest to the northeast; the area receives annual rainfall of 1500-1750 mm. Although somewhat less diverse floristically than the wet evergreen forest, the moist evergreen forest contains more species of commercial timber trees and as a result has been subjected to more logging.

DECIDUOUS FOREST ZONE

The Deciduous Forest Zone includes two primary forest types: moist semi-deciduous forest and dry semi-deciduous forest (Hall and Swaine, 1976). The northern boundary of the zone follows the Kwahu Plateau, and the southern edge blends into the moist evergreen forest type. The zone has a more clearly defined dry season than the evergreen forest types (MSE, 2002). Moist semi-deciduous forest occurs in a region receiving a total annual rainfall of 1,250-1,700 mm/year and abuts the moist evergreen forest type to the south. To the northeast along the Kwahu Plateau, the narrow belt of dry semi-deciduous forest type is in an area receiving annual rainfall of 1,250-1,500 mm. Here there is a pronounced dry season. The major growing season is 150-160 days and the minor season 90 days (Oppong-Anane, 2001). The dry semi-deciduous forest has two subtypes based mainly on amount of rainfall and occurrence of fire, a wetter inner zone, and a drier fire zone subject to frequent fires (Hall and Swaine, 1976). In the fire zone, the opening of the forest canopy for farming, the subsequent invasion of grass, and the effect of fire has destroyed the original high forest and allowed the invasion of savanna trees resulting in a mosaic of forest and savanna vegetation, referred to as derived savanna. This type is described as forests containing clearings of savanna or savanna with clumps of forest trees (MSE, 2002). The fire zone, along with the Guinea Savanna to the north, supplies much of Ghana's fuelwood and charcoal (Menczer and Quaye, 2006). The Deciduous Forest Zone includes areas in the Western, Ashanti, Central, Eastern, southern Brong Ahafo, and northern Volta regions.

FOREST-SAVANNA TRANSITIONAL ZONE

As the name implies, the Forest-Savanna Transitional Zone is an area largely of derived savanna between the Dry Semi-deciduous Forest Zone along the Kwahu Plateau and the Guinea Savanna to the north. The area is expanding along forest fringes with grassland replacing forest (Oppong-Anane, 2001) and is believed to have been derived from forest (Dickson and Benneh, 1988). The boundaries of this region are variously drawn. Menczer and Quaye (2006) indicated it occurs between about 120 and 275 m in elevation and receives a total annual rainfall of about 1450 mm. Oppong-Anane (2001) similarly placed the zone between about 7 and 8°

North latitude. Minia (2008) delineated a transitional eco-climatic zone as being farther north (about 7.5-8.5° North) with an average annual total rainfall of 1,301 mm with rain occurring an average of 101 days/year. SRID (2001) indicated the zone encompassed 6,630,000 ha of central Ghana. Rainfall occurs in one peak in some years and two peaks in others, although most years show two peaks (Oppong-Anane, 2001) with major and minor growing seasons of 200-220 and 60 days, respectively (SRID, 2010). Within this transitional area, most of the tree species are similar to those in the forest zone to the south (Dickson and Benneh, 1988), and occur in association with tall to medium tall grasses. The soils are fairly fertile and support a wide variety of crops.

GUINEA SAVANNA ZONE

The Guinea Savanna Zone (also called Tallgrass Savanna Zone or Interior Savanna Zone) lies to the north of the Forest-Savanna Transition Zone and is the largest zone, occupying the entire northern half of the country (northern Brong-Ahafo, Northern, Upper West, and Upper East regions, about 14,790,000 ha; SRID, 2010). The zone has an extension through the Akosombo gorge and into the Ho Plains in southwestern Ghana (southern Volta Region). The zone receives an average annual rainfall of about 1,115 mm allocated among an average of 99 days/year (Minia, 2008). The Guinea Savanna Zone has one distinct rainy season beginning in late April or early May, peaking in August-September and abruptly declining in October-November.The rainy season is followed by a long dry period (Dickson and Benneh, 1988; Oppong-Anane, 2001). The single growing season ranges from 180-200 days (SRID, 2010). Much of the eastern part of the zone lies in the relatively low-lying Volta River Basin, but the northern and western parts of the zone are situated on a dissected plateau (the High Plains of the Konkori and Gambarga escarpments) (Owusu-Ansah, 1994). Soils are generally poor but are most productive in floodplains and along river banks. The vegetation is that of wooded grassland, consisting of a ground cover of grasses of varying heights interspersed with fire-resistant, deciduous, mostly broad-leaved trees, some of which also occur in the dry semi-deciduous forest type to the south. The other dominant feature of the vegetation in the zone is the grasses that grow under and between the trees. Tree cover and tree height decrease from south to north along a decreasing rainfall gradient (Owusu-Ansah, 1994). In their most luxuriant state trees show varying completeness in canopy (Dickson and Benneh, 1988; Benneh and Agyepong, 1990). Likewise, the grasses in the Guinea Savanna Zone are not uniform but differ according to soil type and moisture regime (Oppong-Anane, 2001; MSE, 2002). The grasses tend be tall (2-3 m), dense perennial species which, with increased latitude, are replaced by smaller species, among which annuals become increasingly common (Owusu-Ansah, 1994). Bare, granitic inselbergs are a typical feature of the savanna landscape. In the dry season, fires, most of which are set by humans, rage through the region.

SUDAN SAVANNA

The Sudan Savanna (or Short-Grass Savanna) lies to the north of the Guinea Savanna and covers a greater part of Burkina Faso and Mali. Like the Forest-Savanna Transition zone, its boundaries are variously drawn. Some (Dickson and Benneh, 1988; MSE, 2002; Oppong-Anane, 2001; Menczer and Quaye, 2006) limit the zone to extreme northeastern Ghana in the Upper East Region in an area variously estimated as 1,900 (SRID, 2010), 7,200 (Benneh and Agyepond, 1990), and 10,540 km^2 (MSE, 2002). Minia (2008) delimited a much broader eco-climatic belt of Sudan Savanna across northern Ghana, corresponding roughly to the southern boundary of the Upper East Region and the northern half of the Upper West Region (about 10.5° N latitude). Given the rather high population pressure in the area, the former small patch in the Upper East Region may simply be the result of degradation by man rather than a climatic biome (Oppong-Anane 2001). Similarly, the broader belt (Minia, 2008) may likewise simply indicate degradation of Guinea Savanna by poor land use practices. The natural vegetation of the Sudan Savanna Zone is characterized by fire-swept short grasses interspersed with low-density woodland of short, low branching, thin-leaved, deciduous species that are drought and fire-resistant (Dickson and Benneh, 1988). Grass cover is sparse and in areas the land is bare and severely eroded (Menczer and Quaye, 2006).

AGRICULTURE

Agriculture dominates the Ghanaian economy in terms of income, employment, food security, and export earnings. Performance of the sector, however, has lagged other segments of the economy at rates lower than growth in GDP. Positive growth rates within the agriculture sector come primarily from cocoa production and marketing. The livestock, fisheries and food crops sub-sectors, on the other hand, have not shown any appreciable improvements. Nevertheless, modernization of the agriculture sector is expected to be an important driver of growth in the medium-term on the basis of improved productivity; the growth goals cannot be met by simply expanding land under cultivation (Breisinger, Diao et al. 2008). The Government of Ghana considers agricultural modernization as a pre-condition for the structural transformation of the economy and the sustainable reduction in the incidence of poverty. Central to this strategy are improvements in food crop production and expansion of cash crops with a heavy reliance on transforming smallholder farmers by increasing their market orientation (Chamberlin 2007).

The dominance of rain-fed agriculture in Africa makes its population vulnerable to climate change, particularly warmer temperatures and lowered rainfall, and some countries are more vulnerable than others (Kurukulasuriya, Mendelsohn et al. 2006; Dasgupta and Baschieri 2010). Additional constraints (disease burden, debt burden, political instability, and conflict) reduce the adaptive capacity and increase the vulnerability of rural populations (Challinor, Wheeler et al. 2007; Brown and Crawford 2008). Generally, however, African countries lag the rest of the world in adopting agricultural innovations, such as high-yielding crop varieties and capital intensive technologies such as irrigation (Evenson and Gollin 2003; Kurukulasuriya, Mendelsohn et al. 2006). Even as climate-neutral innovations could improve the lot of farmers currently and possibly increase their resilience in the face of future climate conditions, agricultural intensification could lead to other vulnerabilities. Intensification that led to higher incomes would likely attract migrants using less adapted methods that resulted in degradation, especially at climate zone margins (Geist, Lambin et al. 2006).

SMALLHOLDERS

The commonly held view of agriculture in Ghana is that smallholders predominate, with about 90 percent of farm holdings <2 ha in size (MOFA, 2006). Some of the characteristics associated with the smallholder classification include limited land, capital, and access to inputs; often smallholder is assumed to be synonymous with subsistence farming. Such generalizations obscure the diversity of conditions in Ghana at the household level among regions and ecological zones (Chamberlin, 2007). Even the statistics of landholding obscure the differences in secure access of land that result from the diverse traditional rights and tenure arrangements.

Chamberlin (2007) used the 2005/2006 Ghana Living Standards Survey and district-level production data to characterize Ghanaian smallholder agriculture. The national average landholding is 3.2 ha (defined as the land used by farmers for production, the sum of all plots sizes reported per household without regard to tenure arrangement). Landholding was on average larger in the Savanna zone (4.0 ha) and smaller in the Coastal and Forest zones (respectively 2.3 and 3.1 ha). More than 70 percent of farmers have the average landholding or less, whether at the national level or for their ecological zone. The larger landholding in the northern savanna zones is offset by the lower productivity of this lower rainfall area. Most farms grow multiple crops; the national average is about four but smaller farms grow fewer crops than larger farms. The less diverse smallholders thus may be more vulnerable to the risk of crop failure (Chamberlin, 2007). Maize and cassava are the most frequently grown crops regardless of farm size and geographic zone (Table 5.1) and they are particularly important for the smallest landholdings (>2 ha).

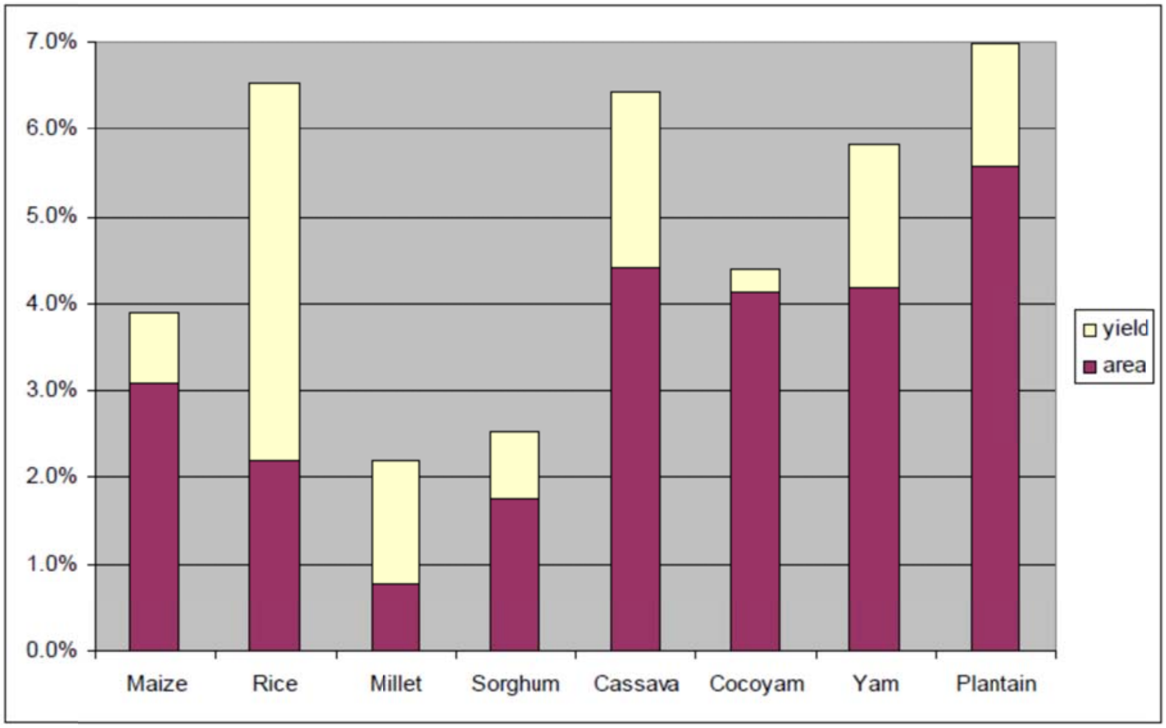
Table 5.1 Percentage of producer households that grow maize and cassava, by farm size and ecological zone, 2005/2006

	Maize			Cassava		
Farm size (ha)	Coast	Forest	Savanna	Coast	Forest	Savanna
<0.5	66	63	41	85	83	37
0.5-1.0	70	68	44	89	80	22
1-2	74	68	47	92	82	22
2-3	76	66	64	90	82	24
3-4	68	66	72	87	86	35
4-5	65	65	78	91	81	25
>5	63	67	86	85	81	35
Average	70	66	61	88	82	27

Source: Chamberlin, 2007

Somewhat surprisingly, a significant share of smallholders sells some portion of their production although the proportion is greater for larger landholders. Thus, even smallholders have multiple objectives of food security and generating cash to purchase clothing and other needs (Yiridoe, Langyintuo et al. 2006). With the exception of rice; the Savanna zone has the lowest rates of market participation. Nationally, groundnuts are the most commercialized crop and millet the least.

Although growth rates in agricultural production have slowed since the 1980s, they have been positive; annual growth over the period 1991-2000 was 3.97 percent (Chamberlin, 2007). Most of the growth, however, came from increases in the area harvested, not from productivity gains; rice and millet were exceptions. There are substantial differences in regions of the country, both in terms of average growth rates for maize and the share of growth resulting from extensification versus intensification (Figure 5.2). The strategy of extensification (increasing the area under cultivation) has led to significant environmental damage (deforestation, desertification and soil erosion) and is clearly unsustainable (FAO, 2003). Meeting the ambitious goals set by the government for increased agricultural productivity will be challenging; intervention is needed to set agriculture on a different development trajectory (Breisinger, Diao et al. 2008).



Source: Chamberlin, 2007

Figure 5.2 Average annual growth rates due to increased harvest area and yield (productivity gain), 1994-2003

CROPPING AND FARMING SYSTEMS

Cropping systems in Ghana are highly diverse, reflecting dynamic adaptations to increasing population pressure, land insecurity, climate variability, and new trading opportunities or markets (Challinor, Wheeler et al. 2007). A generalized scheme (Table 5.2) differentiates cropping systems on the basis of permanence, ranging from episodic to permanent cropping. Episodic cropping systems are further differentiated by the length of the fallow interval; traditional shifting cultivation, with fallow periods of ≤25 years, were common, especially in the wetter south before population pressure caused shortening of the fallow period. Some references distinguish between bush and grass fallow; both have six to 10 year fallow periods. It is unclear, however, if bush fallow refers only to more humid regions and grass fallow to the drier regions. Alternatively, the distinction could be that grass fallow refers to conditions where the fallow interval is too short or precipitation is too low for woody plants to re-grow. Short fallow of 1 to 2 years duration may be combined with a cover crop such as a nitrogen-fixing legume. Of course, continuous cropping has no fallow period. Fallow length is important for soil fertility recovery and also for weed control; also soil physical properties are sensitive to fallow length, requiring ≥10 years to recover structural stability, which can be less with cover crops (Valentin, Rajot et al. 2004).

Most smallholder farmers combine strategies to meet their food security and cash flow needs; farming systems may combine sedentary and shifting cropping systems as well as intercropping and rotational cropping. Even cocoa farmers retain some of their land to grow food crops to meet their own needs (Sandker, Nyame et al. 2010). Traditional cropping systems in semi-arid West Africa, including the northern savanna zones in Ghana, are dominated by cereal-based systems, usually combining two or more crops in a field. Intercropping minimizes risk of crop failure from drought or flooding and spreads the need for labor over a longer period. With the risk spread over two crops, a smallholder can take advantage of a long growing season during a year of above average precipitation. In the savanna zones, farming systems have been modified from shifting cultivation to a combination of compound and bush fallow systems. Compound cropping involves intensively cropping fields around the compound house with vegetables, millet, guinea corn, maize, cowpea, tobacco, and melons. These fields are kept fertile with household compost and livestock manure. The next zone of short-fallow fields are rarely fertilized and grow millet, guinea corn, and groundnuts (EPA 2008). The surrounding area may have upland or lowland bush fallow fields for growing yams and other staples or communal land for grazing. Crop residues from the bush fallow are the main source of livestock feed in the dry season (Bationo and Ntare 2000).

Table 5.2 Cropping Systems in Ghana

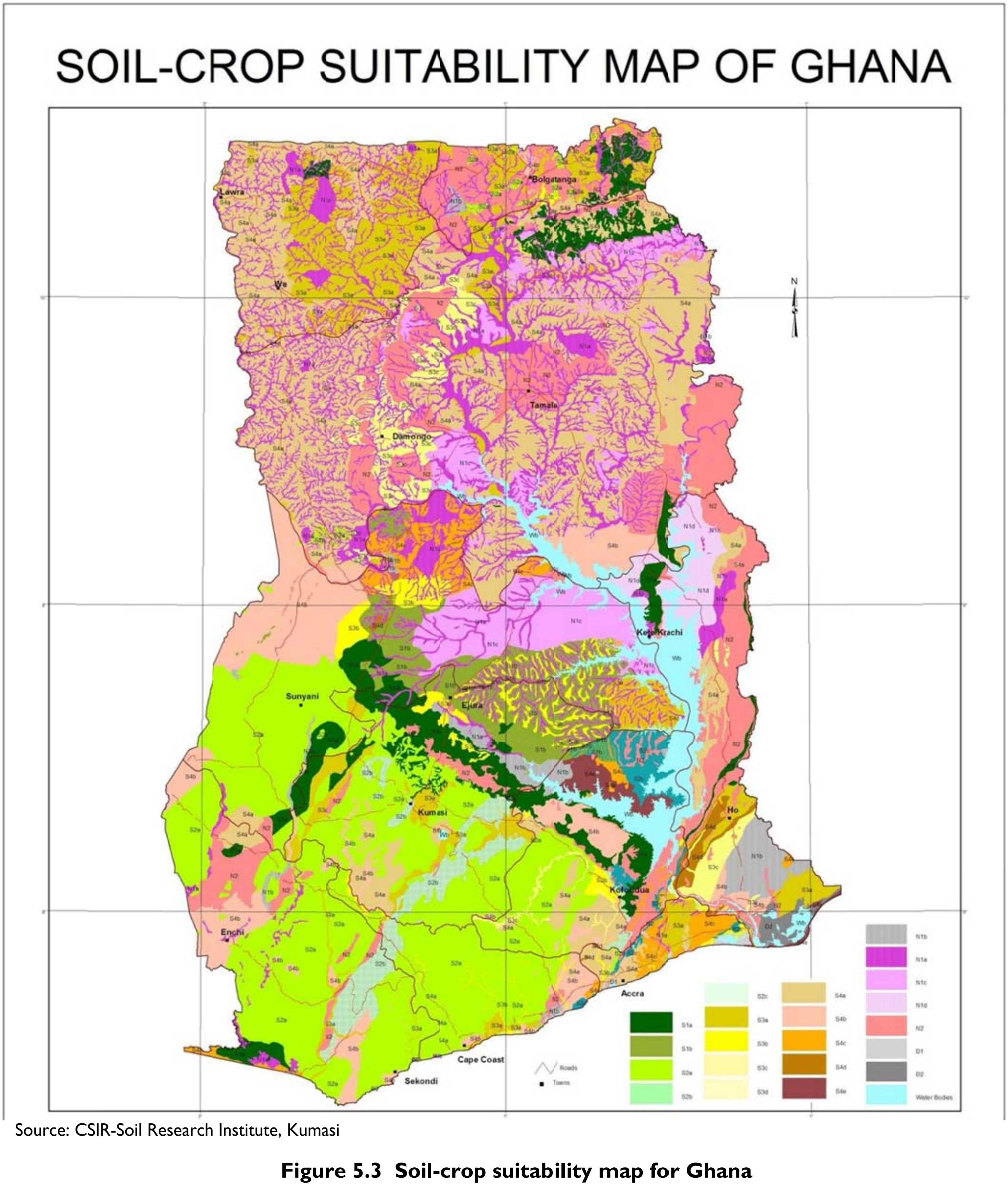
Cropping System	Ecological Zone	Crops	Negatives	Positives
Shifting Cultivation/Bush Fallow/Grass Fallow (clear vegetation, burn; fallow period to restore soil fertility)	Dominant farming system throughout Ghana	Depends on zone	Soil exposed to erosion; fire alters microbial communities and can reduce long-term soil quality; nitrogen is volatilized; deforestation; escaped agricultural fires degrade the rural landscape	Long fallow can restore soil physical and chemical conditions; correct mixture of crops (for example, cereals, and legumes) can augment soil fertility, promote water retention, and prevent flooding. Within a field during the cropping period, farmer may rotate crops (shallow vs. deep rooted, nutrient demand)
Permanent Tree Crop (permanent tree crops usually a monocrop; cocoa is the most extensive)	Rainforest, semi-deciduous forest and transition zones; cocoa cultivation has moved across Ghana, now mostly in the rainforest (west)	Cocoa, citrus, oil palm, avocado, rubber, coffee, mango	Deforestation; increasingly sun-grown cocoa varieties mean no tree cover cover (i.e., tree removal)	Soil erosion prevention or restoration, groundwater recharge, watershed protection, air quality improvement through carbon sequestration, beautification of the rural landscape
Mixed (integrates bush fallow system with permanent tree crops; intercropping of food crops temporary until trees grow and becomes too shaded)	Rain forest and semi-deciduous forest zones	Cocoa with food crops or oil palm with food crops; taungya to restore forest trees is a variant	Soil exposed to erosion and associated nutrient and water loss	Carbon sequestration, forest restoration
Compound (farms are cultivated within close vicinity of villages and commonly combined with animal husbandry; includes upland and lowland bush fallow and sometimes fadama)	Nothern savanna zones	Cashew and cassava intercrops and food crops such as yam, maize and cassava. tomato, okro, pepper and garden eggs	Soil erosion, leaching and eutrophication are prevalent in this zone;	Permanent agriculture with soil fertility often maintained in the compound fields
Irrigated, Floodplain, Fadama (swamp rice cultivation, irrigated farming, naturally moist valleys and depressions; fadama is a Hausa word for irrigable land)	Nothern savanna zones	Rice, dry season vegetables	Deforestation of riparian or gallery forests	
Special Horticultural Crops (mostly grown for export)	Southern Ghana	pineapples, pawpaw, and exotic vegetables	Soil erosion, Eutrophication, depletion of nutrients from sandy soils.	

LAND SUITABILITY

The CSIR-Soil Research Institute has used an agro-ecological zoning method with a GIS to assess the suitability of regions within Ghana for different crops and farming systems (Boateng 2005). The rationale for the method is that crops require a specific range of soil and climate conditions for best growth and some soil and terrain characteristics constrain cropping systems. A crop's climate and soil requirements are defined based on knowledge and empirical research. Soil and terrain factors such as soil type, texture, drainage, depth to impermeable layer, pH, salinity, and slope might be considered along with length of the growing season, temperature, and microclimatic factors during critical growth stages (Boateng 2005). Once the critical factors are defined, the range of values can be classified as to suitability. Geo-referenced soil, climate, and terrain variables are then interpreted in terms of the suitability classes and map layers produced for each factor; the factor layers were standardized to a grid cell (pixel) size for further analysis. Combining climate, soil, and terrain feature suitability sequentially by limiting factors results in an interpretive map of soil-crop suitability (Map 5.2).

Areas on the map in shades of green (S1a, S1b, S2a, S2b, and S2c) are suitable for extensive cultivation of export and food crops (soil descriptions are given in Table 5). The S1 soils are highly suitable for mechanized cropping (suitable crops are shown in Table 5.3) and the S2 soils are suitable for mechanized cropping with some limitations. The S3 soils (olive, yellow, and light tan colors on the suitability map) are not suitable for mechanized cropping but are still fairly suitable for cultivating a variety of crops. The S4 soils are less suitable (fairly or marginal) for agriculture, forestry, and improved pasture. The N1 soils are unsuitable for arable agriculture, tree crops or grazing due to heavy texture and poor drainage; N2 soils are very unsuitable for crop or livestock production. The D soils developed in lagoons and their high salinity makes them unsuitable for crop or livestock production.

Soil suitability for cropping is not the only consideration in agricultural development but is certainly a major factor in sustainability. Although this map provides sufficient guidance for large-scale planning, more detailed soils information is needed for project planning. A further limitation is that interpretations were made on currently available crop varieties under current climatic conditions; breeding programs may produce varieties that overcome some limitations and climate change may alter agro-climatic zones.



Source: CSIR-Soil Research Institute, Kumasi

Figure 5.3 Soil-crop suitability map for Ghana

Table 5.3 Crop Suitability by Soil Units

Soil Class	Major Crops	Mechanized	Soil Description	Limitations
S1a	Export – cocoa, coffee, black pepper, sweet berry, ginger, mango, cashew, avocado, nutmeg, sunflower, oil palm, jatropha, citronella grass; Food – maize, cassava, soybeans, cocoyam, plantain, banana	Yes	Deep red to yellowish red, well-drained loams, pale-colored lower slope and valley bottom soils, silty clay loam to silty clay upland drift soils	None; summits, upper and middle slopes
S1b	Export – cashew, sunflower, mango, jatropha, citronella grass, soybeans; Food – pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes	Yes	Very deep to deep, non-gravelly, red to brownish or yellowish red humus of fine sandy loam or clay loams; non-gravelly, imperfectly to well-drained, moderately shallow, red to brownish or pinkish gray sands, sandy loams pr clay loams or deep, imperfectly to well-drained, red to pale-colored clays or loams	None; upper and middle slopes; upper to almost flat valley bottoms
S2a	Export – cashew, sunflower, mango, jatropha, citronella grass, soybeans; Food – pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes; lowland soils suitable for rice, sugarcane, vegetables	Limited	Gritty, red, yellowish brown, grayish yellow or gray alluvial coarse or loamy sand, well to poorly-drained, and are concretionary and gravelly in the upper soil or brown to gray brown clay loam, well-drained; brown, well to moderately well-drained concretionary silty clay loams; poorly drained alluvial clays in valley bottoms	Upland soils cultivable but gravelly subsoil and slopes limit mechanical cultivation; erosive
S2b	Valley inclusions only are suitable for cashew, sunflower, mango, jatropha, citronella grass, soybeans, pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes, avocado, pears, oil palm, jatropha, citronella grass, citrus	No	Very shallow, well-drained, red soils on moderate slopes and hills, excessively drained, brown, brashy soils or red concretionary clays on summits and clay loams on middle slopes; valley soils yellow brown and gray brown alluvial sands and sandy clays; middle and steep slopes red to dark brown, well-drained humus loams	Shallow and skeletal soils suitable for forestry only; lowland soils suitable for cultivation
S2c	Export – cocoa, coffee, black pepper, sweet berry, ginger, mango, cashew, avocado, nutmeg, sunflower, oil palm, jatropha, citronella grass; Food – maize, cassava, soybeans, cocoyam, plantain, banana	Yes	Similar to S2a but with considerable inclusions of very deep, red or dark reddish brown, well-drained sandy clay loam to non-gravelly medium textured soils on summits, upper and middle slopes; lower slopes and valley bottoms are deep, yellowish brown to grayish brown, poorly to imperfectly drained hill wash sandy loam, sandy clay loam or alluvial loamy sands	
S3a	Maize, guinea corn, millet, citronella grass, vegetables, livestock	No	Brown, calcareous clay loams	Rainfall limited
S3b	Export – cashew, sunflower, mango, jatropha, citronella grass, soybeans; Food – pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes; lowland soils suitable for rice, sugarcane, vegetables	No	Brown, calcareous clay loams, gravelly	Slope, erosive
S3c	Sugarcane, citronella grass, maize, pepper, tomatoes, onions, garden eggs	No	Deep brown to grayish brown, moderately to imperfectly drained, non-gravelly and medium-textured	Levees and terraces along major rivers
S3d	Cashew, sunflower, mango, jatropha, citronella grass, soybeans, pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes; inclusions only suitable for hand cultivation of cassava and pepper	No	Upland soils red, well-drained concretionary clays, slopewash materials, deep red, well-drained loams with seasonally or perennially, ill-drained sandy or clayey, pale-colored lower-slope and bottoms	Inclusions of gravelly, shallow soils limit mechanical cultivation

S4a	Cashew, sunflower, mango, jatropha, citronella grass, soybeans; Food – pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes; lowland soils suitable for rice, sugarcane, vegetables	No		Erosive
S4b	Forestry, watershed protection	No	Summits of limited areas of gravelly soils, moderately to very shallow to parent rock	Shallow but associated with extensive areas of S1a soils
S4c	Forestry, watershed protection	No	Summits of limited areas of shallow to very shallow gravelly soils	Shallow but associated with extensive areas of S1b soils
S4d	A mix of soils; some are suitable for mechanized, irrigated cultivation of crops such as maize guinea corn, millet, tomatoes, peppers, onions, okro; some only for pasture; valley bottoms suitable for rice, sugarcane, and vegetables	Limited	Deep, brown to gray brown, moderately well-drained sands to sandy loams; limited areas of gray, hard claypan soils and gray clay loam to clays in valley bottoms	Inclusions of hardpan soils limit mechanical cultivation
S4e	Cashew, sunflower, mango, jatropha, citronella grass, soybeans, pineapple, maize, guinea corn, millet, yams, groundnuts, tomatoes can be grown with mechanization but major inclusions of poorly drained soils only suitable for swamp rice or pasture	Limited	Uplands of deep to very deep, red, well-drained non-gravelly medium textured soils with inclusions on the flat lowlands of shallow, gray mottled brown, imperfectly to poorly drained, gravelly sandy loams underlain by seepage iron pans	Limited by inclusions
N1a	Rice, sugarcane, vegetables	No	Deep, gray brown, imperfectly to very poorly drained sandy loams to clay loams on levees and valley bottoms	Poor drainage
N1b	Swamp rice, pasture	No	Groundwater laterites: gray sandy loams overlying gray mottled brown gravelly clays underlain by iron pans	Waterlogged in wet season
N1c	Rice, sugarcane, vegetables	No	Deep, heavy plastic clays on poorly drained lowlands	Poor drainage
N1d	Grass pasture, early crops	No	Humus-stained upper layer over yellowish brown sandy loam underlain by weakly developed sub-angular blocky structure, frequent to abundant ironstone concretions, imperfectly drained	Shallow, erosive, boulder-strewn surface
N2	Watershed protection	No	Shallow, gravelly soils over parent rock on steep slopes	Iron pan boulders on rocky, steep slopes
D1	Salt mining	No	Lagoon-derived alluvial soils, heavy plastic clays	Seasonally flooded with brackish water

(Source: CSIR-Soil Research Institute, Kumasi)

MAJOR CROPS

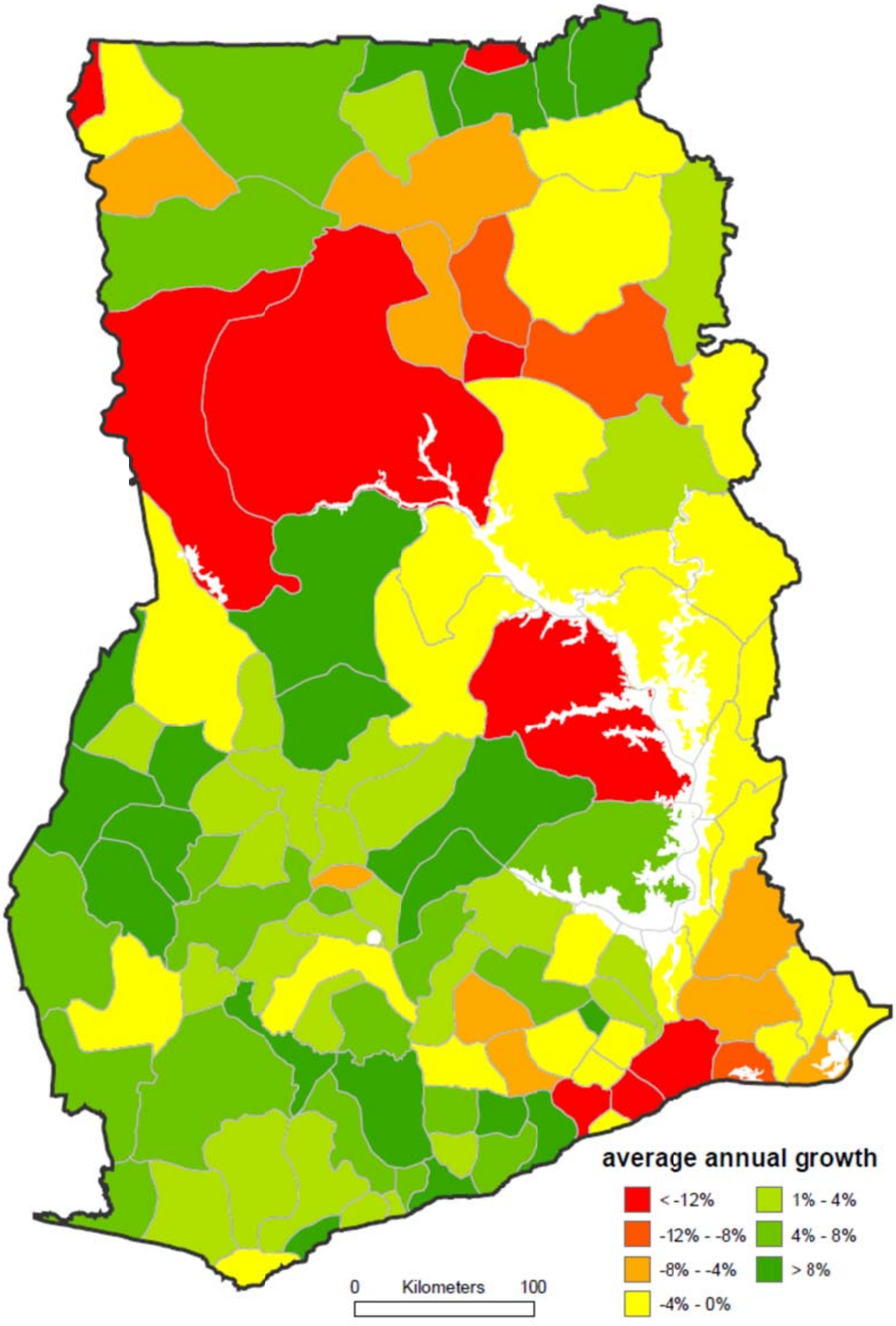
MAIZE

Maize is the most important food crop for smallholders, who obtain 20 percent of their caloric intake from maize. Because maize also is used to meet their cash needs, about half of maize produced is marketed (Braimoh and Vlek 2006). The Northern Region once was Ghana's leading producer of maize but yields have declined from an average yield in 1996 of >1200 kg/ha to less than 900 kg/ha in 2000 (Braimoh and Vlek 2006). Soil quality is the most important factor in maize yields in northern Ghana; cropping systems are needed that conserve soil organic matter (SOM) and minimize cultivation.

Low soil organic matter and limited availability of plant nutrients, in particular phosphorus and nitrogen, are major bottlenecks to agricultural productivity in Ghana, which is further hampered in the Savanna Zone by substantial topsoil losses through wind and water erosion (Schlecht, Buerkert et al. 2006). Low soil organic matter levels are due in part to "cut and carry" removals for livestock feed in the dry season. Residue burning to prepare fields for planting is another factor in low N inputs (Braimoh and Vlek 2006) and escaped agricultural fires are a problem throughout Ghana and is practically an annual event in parts of the savanna zones.

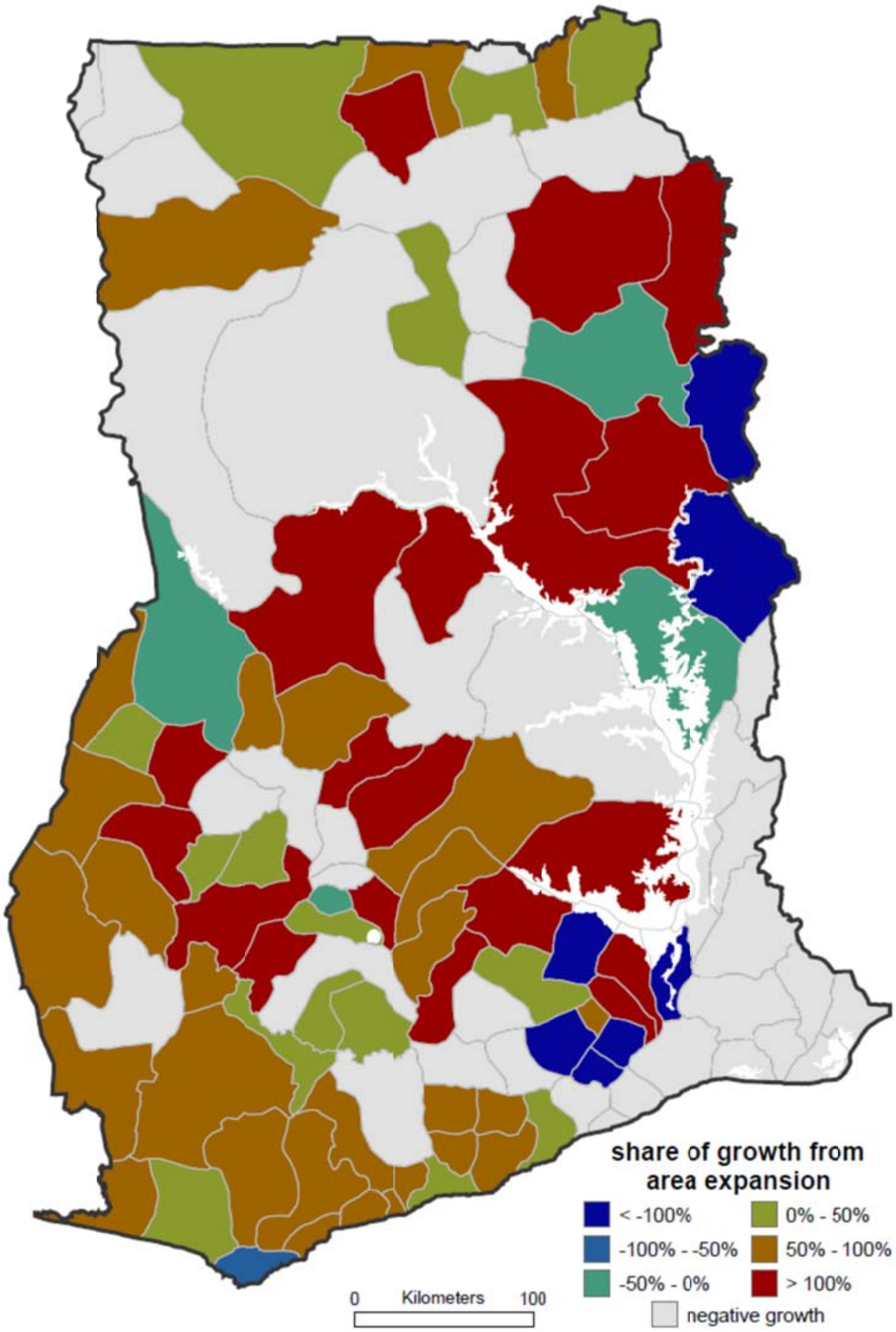
Braimoh and Vlek (2006) found that maize productivity in the Northern Region was limited by soil organic carbon, low clay content (which affected moisture holding capacity), and low potential for chemical activity (ECEC, exchangeable cation exchange capacity). The average level of nitrogen additions was 8.3 kg/ha/yr, well below the optimum level of 100 kg/ha/yr; fertilizer additions decreased as costs rose relative to prices for maize. Fertilizer use was a major policy strategy in the 1960s and 1970s with the government providing subsidies. After subsidies were removed in the structural adjustments of the 1980s, mineral fertilizer use by smallholders declined rapidly (FAO 2003). In addition to price constraints, the lack of access to credit, poor marketing, and distribution of fertilizer affect farmers' decisions (Braimoh and Vlek 2006).

Planted legume fallows have been tested that improve soil fertility and crop yields but cover crops are not attractive to farmers unless there is an additional benefit, e.g., livestock feed. Even with these organic systems, added fertilizer phosphorus and possibly potassium additions are required to sustain or maximize yields (Braimoh and Vlek 2004). For example, legumes that fix atmospheric nitrogen need phosphorus inputs for optimum production (Braimoh and Vlek 2006).



Source: Chamberlin, 2007, Figure 12

Figure 5.4 Average annual district growth rates for maize, 1994-2003



Source: Chamberlin, 2007, Figure 13

Figure 5.5 Share of district maize growth from area expansion, 1994-2003

RICE

Overall rice yields in sub-Saharan Africa are low; recent upward trends in rice production were mainly due to the expansion of rice production into marginal areas in West Africa where rice is grown more for subsistence than as a cash crop. Rice production accounts for 15 percent of agricultural GDP and 45 percent of the total area planted to cereal grains in Ghana (Yiridoe, Langyintuo et al. 2006). The main production systems are irrigated, rainfed lowland, and rainfed upland systems (Table 5.4). Urban consumers prefer imported rice because the domestic rice is of inferior quality; it is uneven in quality, with impurities. Thus two challenges to commercialization of rice production in Ghana are to increase productivity and improve quality of domestic rice.

Higher-yielding rice varieties have been developed by the West African Rice Development Association (WARDA). These 'New Rice for Africa' (NERICA) varieties are based on crossings between African rice (Oryza glaberrima Steud.) and Asian rice (O. sativa L.). The NERICA varieties have high yield potential and short growth cycle. Other desirable traits are early vigor during the vegetative growth phase (which may be useful for competing with weeds), and some varieties are resistant to African pests and diseases, such as the devastating blast, as well as rice stemborers and termites. They also have higher protein content and amino acid balance than most of the imported rice varieties.

RAINFED UPLAND

Yields in upland systems average about 1 t ha-1. Factors responsible for low yields include weed competition, drought, blast disease, soil acidity and low fertility (especially P). Traditionally, a long period of bush fallow was used to control weeds and maintain soil fertility but fallow periods have decreased. The increased weed competition increases labor needs during the main cropping season, which is already a problem in some areas, such as the northern savanna zones.

RAINFED LOWLAND

Adequate water control is the key to higher yields in rainfed lowland rice grown on flood plains and in valley bottoms; typical yields vary from 1 to 3 t ha-1. Although these systems have a high potential for intensification, development faces socio-economic constraints from access to resources to increase inputs, production risk, farmer knowledge of appropriate management practices, land insecurity, and human health problems, such as malaria (Tanser, Sharp et al. 2003; Haines, Kovats et al. 2006). Smallholder production in the northern savanna zones is on lowland fields (i.e., river alluvial plains); there is little upland rice grown in the northern savanna zones.

IRRIGATED RICE

Irrigated rice is mainly in the northern savanna zones and yield potential is much higher than in rainfed systems, 10 t ha-1. Major challenges of irrigated rice production are adequate water control and maintaining the irrigation system. Irrigated systems account for 25 percent of national production with access to irrigation systems dominated by political elites and economic power groups. The few irrigated rice projects in the Northern Region are controlled by the Ghana Irrigation Development Authority (Yiridoe, Langyintuo et al. 2006).

Table 5.4 Rice cropping systems in Ghana

Total area (ha)	Mangrove swamp	Deep water	Irrigated lowland	Rainfed lowland	Rainfed upland
81,000	0	0	12,150	12,150	56,700

Rice production in the northern savanna zones is constrained by nutrient limitations, especially nitrogen (Yiridoe, Langyintuo et al. 2006) but financial constraints and production risks (drought and flooding) limit chemical inputs (Langyintuo, Yiridoe et al. 2005). Although improved fallow (leguminous cover crops) would increase yields, optimal yields would only be possible with increased nutrient inputs (Langyintuo, Yiridoe et al. 2005), which is also the case with upland rice elsewhere in West Africa (Becker and Johnson 2001). Optimal whole-farm production systems, including rice using traditional (grass fallow) methods, requires more than 9 ha of production land, which is about twice as much as the mean land holding for Northern Ghana (Yiridoe, Langyintuo et al. 2006; Chamberlin 2007). Yiridoe et al. (2006) concluded from their modeling results that that transforming existing smallholders into commercial operations will require increasing land holdings. Replacing traditional grass fallow with short-duration leguminous cover crop fallow would be accompanied by increasing mechanization to replace the labor needed to farm the larger acreages.

Boateng (2005) used the agro-ecology zone method to estimate the amount of land in Ghana suitable for rain-fed rice agriculture. Three rice cultivars of differing maturation periods were used in the suitability evaluation. He found that 48 percent of the total land area of Ghana could potentially support growth of the very early-maturing variety that required < 100 days to mature, amounting to about 11 million ha. Of course, the same land areas are also suitable for a variety of other crops, including maize; therefore, his estimates should be regarded as optimistic. The amount of land suitable for the medium maturing cultivar (120-140 days) dropped to 5 million ha (26 percent of the land area). If only the areas judged very suitable for rainfed rice production were targeted for development as these should be the areas with the highest yield potential, then the suitable land would be 9 percent (about 2 million ha). Although Boateng (2005) used a GIS to map the suitability for rainfed rice cultivation, the poor quality of the publication available online does not permit us to comment on the location of suitable soils.

Commercialization of maize and rice production in the northern savanna zones requires increased land security in order to motivate farmers to invest in technology and inputs. Commercialization of maize production already has led to changes in the land tenure patterns and a tendency to preferentially allocate land to large-scale commercial farmers (Braimoh and Vlek 2006). Pressure on the available land resource has already intensified conflict between farmers and herdsmen on the alluvial plains and among smallholders where land fallowed by one family has been reallocated to another family (Braimoh and Vlek 2006). Transforming rice cropping in the northern savanna zones would include concentrating access to land in the hands of wealthy producers, while smallholders would lose their use rights (Yiridoe, Langyintuo et al. 2006). Because the optimal rice farming system integrates livestock with crop production, the current system of open grazing on communal lands would not be compatible and would likely mean a transition toward forage-based feeding systems and year-round confinement (Yiridoe, Langyintuo et al. 2006). Forage-based feeding and livestock confinement begs the question of how the forage be raised (e.g., inputs, processing, storage) and how smallholders would confine livestock on already small land holdings

COCOA

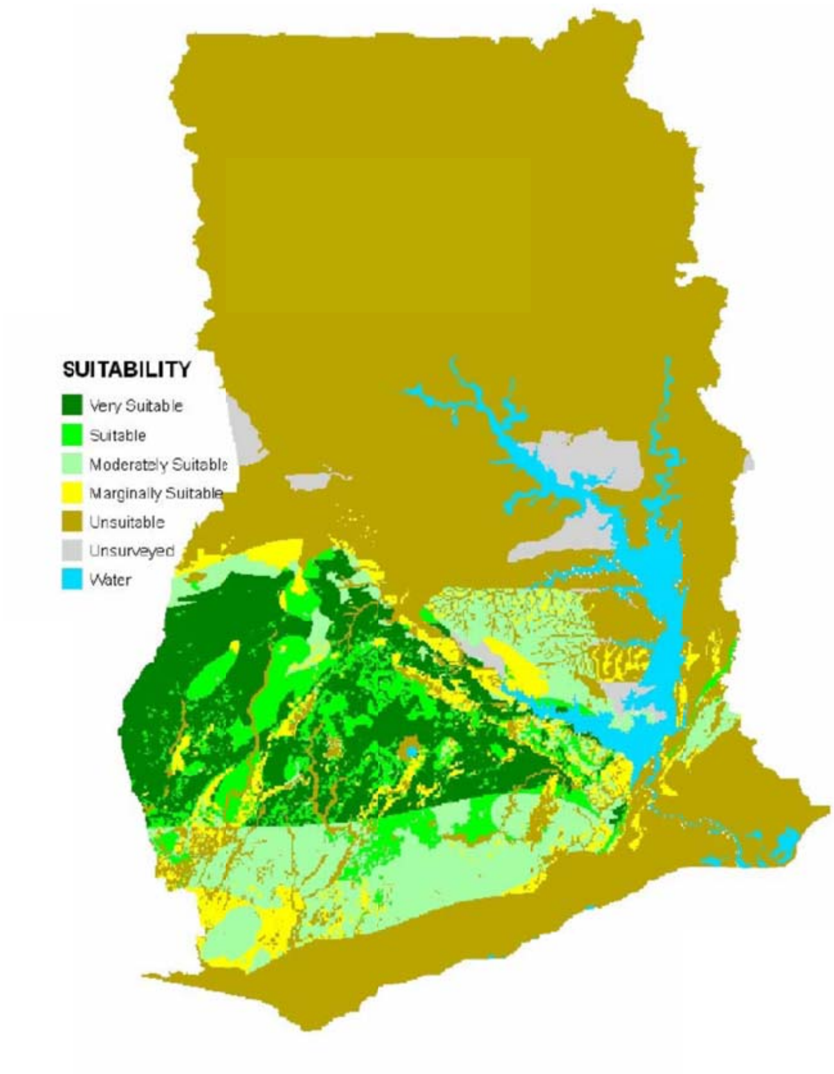
Ghana is one of the world's top producers and exporters of cocoa and the sector has played a key role in the nation's economic development (Breisinger, Diao et al. 2008). Recent increases in production have come from expansion of the land cropped to cocoa and higher inputs of family labor. Suitable cocoa land is limited to the Rainforest Zone (Figure 5.6) and production has moved across Ghana from east (Volta Region) to west, the so-called cocoa frontier. In 2006, fully 25 percent of cultivated land in Ghana was devoted to cocoa (Breisinger, Diao et al. 2008) and little additional suitable land is available (Chamberlin 2007). Increasing land in cocoa production has been a driver of deforestation. Because cocoa was traditionally grown under shade, however, many valuable timber trees were retained in cocoa fields, augmented by planting of fruit and other useful trees; thus, shade-grown cocoa was an agroforestry practice with greater biodiversity value than slash and burn agriculture (Duguma, Gockowski et al. 2001) and full sun cocoa farming.

Cocoa yields in Ghana are below international averages; the potential increase from higher productivity could be more than double the yields in 2005 (FAO 2005; Breisinger, Diao et al. 2008). Increases could come from new varieties and increased use of fertilizer. Newer varieties have been shown to increase yields by at least 42 percent and fertilizer use was associated with 19 percent higher cocoa yield per 50 kg bag of fertilizer (Edwin and Masters 2005). Research has demonstrated the technical advantages of fertilized, low shade or full sun hybrids and current recommendations from the Cocoa Research Institute of Ghana call for additions of phosphorus, potassium, and micronutrient fertilizer, densely planted hybrid cocoa (1,111 trees ha^{-1}), while retaining at most 12-15 shade trees ha^{-1} (Gockowski and Sonwa). In practice, smallholders have been able to adopt only the low shade/full sun recommendation as they lack resources to acquire hybrid seeds and fertilizer. Little research has been directed towards increasing productivity of traditional shade grown cocoa (Gockowski and Sonwa ; Breisinger, Diao et al. 2008) although that is an alternative that would avoid the negative effects of full sun hybrid cocoa on biodiversity (Belsky and Siebert 2003; Franzen and Borgerhoff Mulder 2007).

EFFECTS OF CLIMATE CHANGE ON AGRICULTURE

Crops are vulnerable to climate variability as evidenced most obviously by lowered yields during drought periods, less dramatically by year-to-year variation in productivity. Variability can take many forms; for example less total annual precipitation, delayed onset of the rainy period, higher temperature or sub-optimum moisture during critical growth stages (too moist during establishment might favor diseases, such as damping off; too dry during grain-filling might lower yield). Changes in average climate values in regions currently at the limit for growing some crops could reduce yields to non-viable levels, for example, causing a shift towards agropastoral systems. The complexity of crop growth requires climate data (short-term variability, frequency of extreme events) at spatial and temporal resolutions that are currently beyond the reach of climate change models (Challinor, Wheeler et al. 2007). In addition to inadequate climate models, crop modeling research has favored the major global food crops and devoted less attention to crops important to Ghana, such as millet and yams. Additionally, crop models generally are specified for monocropping and rarely consider intercropping. Improvements in both climate and crop models and the ability to model effects at scales from the farmer's field to the region and nation will be critical to formulating adaptation options for agriculture and mainstreaming climate change into development programs (Challinor, Wheeler et al. 2007).

Several assessments have been made of the potential effect of climate change on crop yields in Africa (Challinor, Wheeler et al. 2007). They are not readily compared because they use different global circulation models, IPCC emission scenarios, and crop models, but they generally indicate negative effects for maize, rice, millet and cereals in general; effects range from +16 percent to -98 percent change in annual yields (Challinor, Wheeler et al. 2007). Linking five climate models and five emissions scenarios with a spatially explicit agro-ecosystem model and a global food system (trade) model provided an integrated system to examine not only climate change effects on agriculture but the effects of limited agronomic adaptation (Fischer, Shah et al. 2005). Effects of climate change on agricultural production were relatively minor globally but significant regionally. Ghana was projected to gain cereal-production potential by 2080, depending upon emission scenario (Fischer, Shah et al. 2005) but generally, semi-arid zones within sub-Saharan Africa (such as the northern savanna zones in Ghana) would experience reductions in cereal-crop production (Fischer, Shah et al. 2005; Zhang and Cai 2011).



Source: Chamberlin, 2007

Figure 5.6 Land areas in Ghana suitable for cocoa farming

Higher resolution approaches to climate modeling may use statistical methods to downscale output from a GCM to the regional level to model effects at the smallholder level. Limitations of the approach are several, including that statistical downscaling relies on a dense grid of meteorological stations to establish historical relationships among weather variables; such grids are generally lacking over sufficiently long time periods (minimally 30 years); and empirical relationships based on historic data may not be relevant under changed future climates. Nevertheless, these downscaled data may have the temporal resolution to drive process-based crop models. Using this approach, Jones and Thornton (2003) simulated growth and yield of maize crops in Africa and Latin America until 2055. Maize is a C_4 plant, thus tolerant of high temperatures but still sensitive to lowered precipitation. Although the effects of climate change were small in aggregate (Jones and Thornton 2003), even the modest 10 percent decline in yield predicted for northern Ghana by Jones and Thornton (2003) would adversely affect smallholders. Improvements in climate modeling (both in the ability of GCMs to better project precipitation and the use of physically-based dynamic downscaling using regional climate models) and better understanding and modeling of crop responses to climatic variables (Tubiello, Soussana et al. 2007; Challinor, Ewert et al. 2009; Soussana, Graux et al. 2010) are needed to effectively guide choice among adaptation options.

Cocoa is highly susceptible to drought and the pattern of cropping of cocoa is related to rainfall distribution. Climate change could affect vigor of the cocoa plant as well as alter stages and rates of development of cocoa pests and pathogens. Using drought-tolerant varieties and irrigation are possible adaptations to climate change but farmers are conservative and unlikely to adopt new technology unless there is a support system, such as effective technical assistance (i.e., extension agents) and credit systems to assist in financing new technology. Another adaptation is alternative; there is some evidence from the Volta region that this has occurred when cocoa farming becomes marginal. Alternative crops to cocoa include other plantation crops (e.g., oil palm and oranges) or food crops, such as maize and cassava (Anim-Kwapong and Frimpong). If the cocoa sector is to realize its potential and contribute to Ghana achieving MIC status by 2015, yield increases through some form of intensification are critical (Breisinger, Diao et al. 2008).

ADAPTATION OPTIONS

Adaptation to climate variability and change occurs (or not) at multiple levels, from the smallholder to the national and even global level (Challinor, Wheeler et al. 2007). Farmers are vulnerable from shocks (unexpected events such as flooding from extreme weather), seasonal variation, particularly in timing and amount of rainfall, and long-term trends (such as increased mean temperature). Coping strategies commonly are in place to reduce vulnerability to seasonal variation including planting mixtures of crops and cultivars adapted to different moisture conditions (reducing the risk of complete crop failure); using landraces resistant to climate stresses; and mulching or water conservation (Challinor, Wheeler et al. 2007). Farmers may plant starvation reserve crops such as cassava that has 14 local varieties and three improved varieties with different maturation periods and flexibility in how soon it must be harvested. For example, cassava acreage increased sharply in 1984 because households with cassava farms during the drought in 1983 had food to eat after crop failure in the drought year (Sagoe 2006). Multi-year droughts, however, will overpower these short-term coping strategies and may cause long-term impacts if capital assets are lost (e.g., draft animals, seed stocks, savings, or social capital) and there is no effective local or national support system (Challinor, Wheeler et al. 2007). An alternative to rainfed agriculture for some farmers may be small-scale irrigation; this requires suitable land, access to water, and ideally, capital to invest in a pump. A simple treadle pump is in use in Ghana, mostly in the Volta and Ashanti regions (Adeoti, Barry et al. 2007). In the northern savanna zones, dry season vegetable crops are grown in floodplain fields that often are hand-watered. Many irrigation options require infrastructure or cooperation among groups and are thus beyond the resources of a single farmer; some examples for Northern Ghana are given in Table 5.5.

Many options are available for adapting agriculture to climate variability and change (Kurukulasuriya and Rosenthal 2003); some of them are gathered in Table 5.6. Some farmers may opt to leave agriculture by diversifying entirely into non-farm activity or migrate to urban areas (many farm households in the Northern Region already send some family members south to work and return remittances). With increasing populations, this option may not be available, forcing some households to remain in agriculture (Challinor, Wheeler et al. 2007). Rather than diversifying, intensifying agriculture is another adaptation. Farming for profit, however, will require concentrating agriculture on fewer larger farms to take advantage of economies of scale, mechanization efficiencies, and market access (Kurukulasuriya and Rosenthal 2003; Challinor, Wheeler et al. 2007). Such commercialization or rationalization of agriculture may be desirable from a national development perspective, but given the traditional land tenure system and the insecurity of many smallholders, development of large-scale farms by overseas investors may not only displace many smallholders (Robertson and Pinstrup-Andersen 2010; Daniel 2011) but also increase the food insecurity of local populations in bad crop years if they are priced out of the market for food. Given the likelihood that oil, fuel, and petroleum-based agricultural chemicals will increase in price in the future and most smallholders cannot afford such inputs without subsidies, questions of economic viability arise. Commercialization and large-scale agriculture also pose uncertainties with or without climate change interactions with regard to environmental effects and long-term sustainability.

Farmers who depend on annual rains have already demonstrated considerable ability to adapt to uncertain climate, at least to the historic range of variation. Their ability to adapt to future climates will depend in part on a supportive institutional and macroeconomic environment (Kurukulasuriya, Mendelsohn et al. 2006; Challinor, Wheeler et al. 2007). As noted by Challinor et al. (2007), coping with climate stresses will depend on "Good governance, political will, and positive economic development." Ghana is fortunate among West African nations in that is politically stable yet its governance structures are weak and its public sector underperforms, especially in the northern savanna zones (Blench and Dendo 2007). Clarification of land tenure, tree tenure, and carbon rights is necessary for smallholders to access capital and make long-term investments in conservation practices, agroforestry, and improved crop varieties and inputs. Access to knowledge and assistance from extension workers is needed for farmers to modify their cropping systems (Kurukulasuriya and Rosenthal 2003; Blench and Dendo 2007; Challinor, Wheeler et al. 2007; Breisinger, Diao et al. 2008). Community-based approaches to identifying climate change adaptation strategies (e.g., CARE) and strategies for enhancing food security (e.g., Canadian International Development Agency or CIDA) have been implemented in the northern regions and appear to hold promise. Reducing vulnerability to current climate stress may increase adaptive capacity and increase resilience to future climate change (Adger, Hughes et al. 2005; Challinor, Wheeler et al. 2007).

Identifying climate risks and preparing for and mitigating climate disasters is a central role for government but capability is poor or non-existent in Africa (Challinor, Wheeler et al. 2007). Weather monitoring and forecasting capability is necessary for effective disaster planning as well as for providing information for improving crop and climate modeling. Government agencies, NGOs, and CSOs in Ghana seem to have little access to detailed climate projections and seemingly little understanding of the uncertainties surrounding projections. Tools to assess the impact of climate change on agriculture are critical components of poverty reduction programs (Challinor, Wheeler et al. 2007).

Table 5.5 Water development options in Northern Ghana

Options	Status
Small scale dams	Extensively inserted by government, donor projects, and NGOs throughout the North. Generally successful, but cost is high and maintenance pathways (for larger repairs) not well established. Poor mitigation of health and environmental impacts.
Dugouts	Extensively inserted by government, donor projects, and NGOs throughout the north. Generally successful, but poor mitigation of health and environmental impacts. Rises in numbers of migrant cattle could make these sites sources of friction.
Culverts/bridges for water retention as add-on for feeder roads	This technology works well with high maintenance and extensive supervision (as in the AFD project). However, post-project community maintenance is extremely poor and this technology will not work unless much greater training investments are made.
Pumping from rivers	This is being tried informally on some river systems in Northern Ghana and undoubtedly produces the best return (in terms of land cultivated per dollar) of any of these technologies. Although collective pumps theoretically have economic advantages, in practice households prefer small individual pumps because a) they control refueling and maintenance, and b) they can easily be moved by bicycle. One of the objections to pumps is that they introduce inequity, but experience from other West African countries suggests that individuals will cycle long distances in order to make use of their productive advantages.
Natural flood-plain irrigation	This technology is not established anywhere in Ghana, although it works well in some neighboring countries (Mali, Nigeria) and has potential along the White Volta. Advantages are that it makes maximum use of natural fish production and is environmentally beneficial (limited standing water and river-bank protection). Disadvantage is that it requires significant initial investment in earthworks, community training, and cooperation (does not work for an individual household).
Wind pumps	Just two wind-ups have been installed on an experimental basis in Northern Ghana and it appears that neither pump is being properly maintained, nor are the gardens being irrigated to maximum efficiency. Should be treated with caution until proven to work
Drip technology	Although potential is great on existing dams, drip irrigation is only now being implanted on an experimental basis by ICRISAT. Given the high maintenance and the short training time envisaged by ICRISAT, the viability of this technology is doubtful at best.

Source: Blench and Dendo 2007

Table 5.6 Matrix of climate change adaptation options for agriculture

Adaptation Options in Agriculture to Climate Change and Variability				
Adaptation Option	**Purpose**	**Necessary supporting policies**	**Other prerequisites**	**Limitations**
Short-term				
Crop Insurance				
Private/public programs	Enabling improved risk coverage	Improving access	Synergies between government and private sector in bearing risks	Risk averse communities/insufficient collateral
Formal/informal schemes		Risk management through risk reduction and risk sharing	Minimizing information asymmetries	High opportunity costs of public funds
		Improving supervisory capacity	Establishing enforcement mechanisms	High monitoring costs (institutional limitations)
		Revising pricing incentives	Introducing measures for the correct estimation of premiums	Adverse selection/moral hazard
		Improving affordability/availability of coverage for catastrophes	Innovative schemes should be pursued (e.g., tradeable financial assets; catastrophic bonds; weather markets)	Need to establish well-functioning producer
Portfolio (Crop/Livestock) Diversification				
Replacement of plant types, cultivars, hybrids and animal breeds with new varieties	Risk-spreading/ promoting farm-level risk management	Availability of extension services	Tenure reform to ensure property rights are established	Traditions, lack of awareness, and other limitations (high opportunity costs) may dampen willingness to diversify
Alternative production techniques (adjustment of capital and labor inputs)	Increasing productivity	Financial support/ alternatives should be provided by private and public sector	Land-use regulations need to be reviewed to enable diversification	Over-dependence on government support mechanisms needs to be reduced
Multi-cropping	Defending against disease, pest	Enable mobility of activities	Education/training/ extension services need to be provided	Need alternatives that maintain quantity and income from production
Mixed farming systems of crops and livestock		Remove subsidies on certain crops/livestock production not conducive to changed climatic and resource conditions		
Adjusting Timing of Farm Operations				
Adjusting cropping sequence	Reducing risks of crop damage/ maximizing output in light of new conditions	Extension services/training are necessary	Mechanisms for the dissemination of agronomic and climate information	Investment in collection of climate data and disseminating information required

Adjusting timing of irrigation		Pricing policies must be reviewed	Institutional support must be strengthened	Limitations of existing infrastructure
Changing Cropping Intensity				
Adjusting fertilizer and other inputs	Improving moisture and nutrient retention	Extension services must be improved	Location-specific solutions should be sought	Availability of cultivable land; availability of alternative lands
Changing land use practices	Reducing soil erosion	Pricing policy adjustments for incentives to make adjustments		Socioeconomic (financial)
Changing location of crop/livestock production	Adjusting to changing length of growing season			Conflicts with other farm operations at other times of the year
Rotating or shifting production between crops and livestock	Increasing plant protection			Traditions, lack of awareness, and other limitations (high opportunity costs) may dampen willingness to diversify
Abandonment of land				Concerns regarding maintaining similar production levels
Changing the timing of activities (of sowing, planting, spraying and harvesting)				
Changing the timing of irrigation				
Livestock Management				
Change in biological diversity, species	Spreading risks; increasing productivity	Provision of extension services	Promoting investment in livestock management	Traditions, lack of awareness and other limitations (high opportunity costs) may dampen willingness to diversify
Altering the breeding management program (i.e., changing composition, or species distribution)	Adjusting to new climate conditions		Institutional support	
Change in grazing management (timing, duration, and location)				
Changing the location of watering points				
Changes in rangeland management practices				
Modifying operation				

production strategies				
Changing market strategies				
Implementing feed conservation techniques/ varying supplemental feeding				
Changes in Tillage Practices (Conservation Tillage)				
Land contouring and terracing	Conserving soil moisture and organic carbon contents decreases soil erosion and maintains soil fertility (nutrient management)	Extension services need to support activities	Investment	
Maintaining crop residues	Maintaining soil quality/provide protection against wind erosion	Pricing incentives to promote conservation	Land tenure reform	
Fallow and tillage practices	Increasing production per unit of evapotranspiration (water use efficiency)		Indigenous knowledge	
Planting of hedges	Reducing water runoff/ improving water uptake			
Alternative drainage methods	Recharging water supply			
Construction of diversions and reservoirs and water storage	Reducing runoff and erosion			
Irrigation	Nutrient restocking			
Reducing water use in land preparation	Conserving water			
Temporary Migration	Risk diversification strategy to withstand climate shocks and seasonal effects	Employment training/opportunities	Institutional support	Availability of employment opportunities in urban areas; growth elsewhere in economy
				Skills and earnings potential
				High population density in cities
Short-Term Forecasts	Improve preparation for medium-term climatic impacts	Institutional support for collection and dissemination, information dissemination	Infrastructure for monitoring	Financial constraints
Food Reserves and Storage	Temporary relief		Delivery mechanisms	Expensive/complacency

				Transportation network
Changing Crop Mix				
Adopting new crops	Spreading risk of damage	Revising pricing; food importation policy	Promoting investment	Institutional failures
Planting in different part of farm	Move away from unstable cash crop systems	Tenure; extension; pricing incentives	Institutional support to administer	Acceptance of change gradual
Converting land use		Improving access and affordability	Agricultural marketing policies	Economic failures (maintaining incomes)
		Need viable alternatives (incomes)	Review of agricultural credit schemes	Knowledge
Irrigation	Increase productivity; withstand precipitation shortages or timing	Investment by public and private sectors	Clear water management policy	Institutional support and enforcement mechanisms
Modernization of Farm Operations				
	Increase productivity	Promoting the adoption of technological innovations	Establishment of intellectual property rights	Conflicts between national/private objectives
Research and development (biological and mechanical options)	Withstanding climate effects		Role of private multinationals	Maintaining similar production levels
Adoption of technology (e.g., use of sprinklers)				Subsidization programs may create perverse incentives
Permanent Migration				
	Diversify income-earning opportunities	Education and training for alternative opportunities	Institutional support (property rights)	Impacts on resource base
	To overcome long lasting climate impacts	Retraining		Land pressure
Defining Landuse and Tenure Rights				
	Incentives to make necessary investments in agricultural land to withstand climatic	Legal reform and enforcement		

	impacts			
Efficient Water Use				
Improving water distribution	Water conservation	Pricing reforms for water	Sustainable water projects	
Promoting irrigation efficiency	Avoid salinization increase moisture; retention	Clearly defined property rights	Diffusion of technological advances in water management	Cost
Changing crop and irrigation schedules	Water storage and flood control	Develop open markets	Institutional reforms	Competing demands
Water recycling and the conjunctive use of groundwater		Strengthening farm level managerial capacity		Financial crises
Rehabilitation and modernization				Low-cost recovery of the investment in the water system
				Political economy issues
Both short and long-term				
Investment Promotion				
	Overcome financial limitations to adapt	Property rights; designing innovating financial tools		Social constraints against capital accumulation
		Injection of initial capital		Reluctance of agricultural traders to offer inputs on credit
Develop Market Efficiency				
Pricing reform	Promote more efficient use of resources	Remove barriers	Institutional support	
Develop open markets		Property rights; pricing policy	The establishment of regional consultation centers	Poor transport infrastructure
Reform of agricultural markets		Adjustment of agriculture input subsidies that constrain adaptation	Impart knowledge on adaptation alternatives	
		Land use regulations	Legislative reform	
Adoption of Technological and Other Adaptation Measures				
	Increasing agricultural yields	Pricing incentives/ tax reform	Community management and cooperation programs	Natural constraints-if land is available
	Reducing average fixed costs	Extension services for training		Socioeconomic capacity to adapt
	Reducing variable costs	Finance schemes		Complete removal of government support
				Lower producer prices

				Lower world food prices
				Attitudes towards risk
				Level of uncertainty of the future
				Availability of funds for investment
				Access to assets, capital, and credit
				High tariffs in export markets
Promoting Trade	Promoting economic growth			
	Strengthening long-term food supply and reducing production limitations	Pricing and exchange rate reform and stabilization	Social policy	Subsidies in developed markets
	Reducing risks of food shortages	Adjustment of agricultural subsidies and tariffs		
Developing Extension Services				
	Improve agricultural productivity	Role of private, non- governmental and cooperative agencies	Ensure agents are productive through adequate incentives	
	Improve awareness and knowledge of adaptation measures	Ensuring sufficient agents per farmer/region	Limit/remove management failures	
			Public organization, resources, and institutional support	
			Utilize indigenous knowledge	
Improving Forecasting Mechanisms				
	Assist planning	Extension	Information needs to be distributed across all sectors	Financial
	Strengthen ability of farmers to cope	Institutional support (e.g. establishment of farmer cooperatives to spread knowledge)	Horizontal and vertical exchanges of information	Conflicts with traditional practices/ social conventions
			Ensure information is in a usable form	Skepticism
Institutional Strengthening and Decision-making Structures				
	To support long-term planning	Reform existing institutions that support agricultural sector	Participation of key stakeholders	
	Reduce vulnerability	Pricing incentives; improving	Requires integrated	Planning agencies formed by

		regulations and technology standards	management practices; need to fit specific institutional settings	administrative resolution as opposed to being mandatory
	Provide information on the changing socioeconomic structure, demographics, technology, and public preferences	Legal infrastructure (reform) for stimulating domestic and international investment	Comprehensive multi- sectoral management plans	
	Improving organizational capacity, responsibility and operational effectiveness	Changes in international and domestic competition	Resilience; flexibility; public education program	
		Social policies	Remove bureaucratic inefficiencies	
		Upgrading of current physical planning laws and regulations	Equally well functioning institutions in other sectors	
			Improve coordination between central and local government	

Source: Kurukulasuriya and Rosenthal 2003

POPULATION AND ECONOMY

Ghana contains 10 administrative regions that are divided into 170 districts.[1] As of 2010, Ghana's population was estimated at 24,233,431, a 28 percent increase over 2000 population levels (GoG, 2011). Between 2000 and 2010, the country had an estimated 2.5 percent average annual population growth rate (Table 5.7). The population is unevenly distributed across the country, with the southern regions generally having much higher population densities than the northern regions (Table 5.C.1, Map 5.C.1).

Table 5.7 Population Growth Rate by Region

	Total Population					*Annual inter-censal growth rate (%)*			
Region	**1960**	**1970**	**1984**	**2000**	**2010**	**1960-1970**	**1970-1984**	**1984-2000**	**2000-2010**
Western	626,155	770,097	1,157,807	1,924,577	2,325,597	2.1	3.0	3.2	1.9
Central	751,392	890,135	1,142,335	1,593,823	2,107,209	1.7	1.8	2.1	2.8
Greater Accra	541,933	903,447	1,431,099	2,905,726	3,909,764	5.2	3.3	4.5	3.0
Volta	777,285	947,268	1,211,907	1,635,421	2,099,876	2.2	1.8	1.9	2.5
Eastern	1,044,090	1,209,828	1,680,890	2,106,696	2,596,013	1.5	2.4	1.4	2.1
Ashanti	1,109,133	1,481,698	2,090,100	3,612,950	4,725,046	2.9	2.5	3.5	2.7
Brong-Ahafo	587,920	766,509	1,206,608	1,815,408	2,282,128	2.7	3.3	2.5	2.3
Northern	531,573	727,618	1,164,583	1,820,806	2,468,577	3.2	3.4	2.8	3.1
Upper East	468,638	542,858	772,744	920,089	1,031,478	1.5	2.8	1.1	1.1
Upper West	288,706	319,865	438,008	576,583	677,763	1.0	2.3	1.7	1.6
Ghana	6,276,815	8,669,313	12,296,081	18,912,079	24,223,431	2.4	2.6	2.7	2.5

Sources: Ghana Statistical Service, 2000 Population and Housing Census; 2010 Population and Housing Census Provisional Results

The most densely populated administrative regions are Greater Accra, Central, and Ashanti, corresponding to the Coastal Savanna and Deciduous Forest ecological zones. The high population densities found in the Greater Accra Region and districts containing regional capitals reflect the fact that 43.8 percent of Ghana's total population lived in urban areas in 2000 (a locality having a population greater than 5,000 people, GSS, 2005). The Akan ethnic group is the largest ethnic group in Ghana, and includes the Ashanti (whose power is centered in Kumasi, in the Ashanti Region) and Fante (whose power is centered in Cape Coast, in the Central Region). Other major ethnic groups are the Dabomba of the north, the Ewe of the east, the Ga and Adangbe of the south, and the Guan of the northeast.

[1] In the late 1980s, Ghana's districts were reorganized into 110 districts. By 2006, 28 more districts had been created by splitting some of the original districts, for a total of 138. In 2008, new districts were again created, bringing the total to 170, where it stands currently (Wikipedia, Ghana Districts). Because most of the socioeconomic data contained in this report date from before 2006, they are presented for the 110 districts.

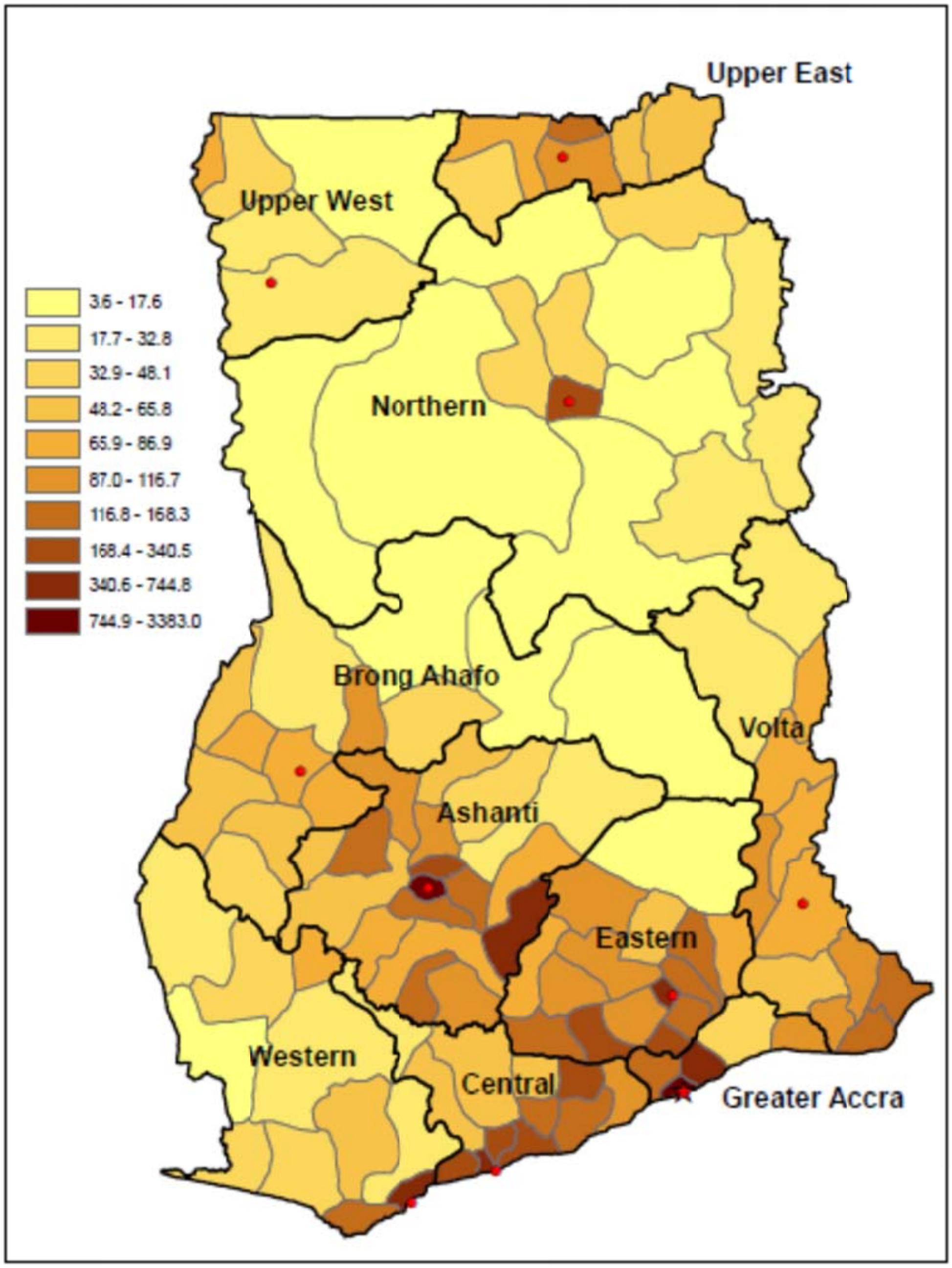


Figure 5.7 Ghana Population Density by District (persons/km²)

Source : Ghana 2000 Population and Housing Census

Note: Dots indicate regional capital cities.

At a national level, Ghana's economy is comprised of three primary sectors: agriculture accounts for roughly 30 percent of Ghana's gross domestic product, industry accounts for roughly 20 percent, and service accounts for roughly 50 percent (GSS, 2010a). There are three sectors that account for 80 percent of Ghana's total employment. The majority (55 percent) of the working population is formally employed in agricultural activities, followed by 15 percent in trading, and 10 percent in manufacturing (GSS, 2008b). The agricultural sector in

Ghana is comprised of crop and livestock production, which constitute 65 percent of all agricultural production; cocoa production and marketing, which make up 12 percent; forestry and logging, comprising 10 percent; and inland and marine fishing, constituting 13 percent (GSS, 2008a). The agricultural sector has been a major driver of poverty reduction, and dominates the livelihoods of rural households; 85 percent of rural households engage in agricultural activities. By comparison, 28 percent of urban households report being engaged in agriculture (GSS, 2008b).

The official unit of currency in Ghana is the Ghana Cedi (Gh¢). One Ghana Cedi was equivalent to 0.66 U.S. dollars in early 2011 (according to www.exchange-rates.org). The Ghana Cedi was introduced in July of 2007, and was essentially a redenomination of the old currency. The former currency was the Cedi (as opposed to the new Ghana Cedi); 10,000 (old) Cedis are equivalent to 1 (new) Ghana Cedi.

Below we provide a general characterization of the Ghanaian economy – with a focus on the agricultural sector – in the coastal, forest, and savanna ecological zones.

CROP PRODUCTION

Smallholder farmers, who cultivate 1-2 ha plots of land, account for 80 percent of the country's agricultural crop production (USAID, 2011). The two most important crops to smallholder farmers in terms of sales are maize, which brings in an estimated 412.29 million Ghana cedis in annual sales, and cocoa, which brings in 361.13 million Ghana cedis. Additional, albeit less lucrative, food staples grown by smallholder farmers include cassava, yam, plantain, cocoyam, and various fruits and vegetables (Table 5.8) (GSS, 2008b). The remaining 20 percent of the agricultural crop production is comprised of larger scale industrial plantations that produce palm oil, cotton, rubber, sugar cane, and tobacco. With the exception of oil palms, Ghana's plantation industries have suffered as a result of the country's economic difficulties (Clark, 1994).

LIVESTOCK REARING

In Ghana, 60.5 percent of households are engaged in raising livestock. According to the Fifth Round Ghana Living Standards Survey, chicken is the most commonly reared animal; 30 percent of households reported that they kept chickens. Eighteen percent raise goats, 11 percent raise sheep, 4 percent raise cattle, and 4 percent of households keep other poultry including duck, turkey, and guinea fowl. Much smaller numbers of households raise pigs, grasscutter rats, and rabbits (GSS, 2008b).

Table 5.8 Estimated annual crop value by value of sales

Crop	Annual value of sales (thousand Ghana cedis*) Coastal	Forest	Savanna	Ghana
Maize	276,525	82,121	53,629	412,274
Cocoa	8,081	313,381	39,670	361,132
Groundnut	3,445	5,880	66,856	76,180
Rice	2,273	3,904	23,661	29,839
Cotton			20,742	20,742
Beans/peas	408	2,444	12,726	15,578
Sorghum	3		11,844	11,847
Millet		14	11,633	11,647
Coconut	8,275	390	31	8,696
Tobacco	57		7472	7,529
Cashew nut	54	165	3315	3,534
Sugar cane	2,106	781		2,887

Source: Ghana Statistical Service, Ghana Living Standards Survey 5

*1 Ghana Cedi is equivalent to 0.66 U.S. Dollars.

FISHERIES

In Ghana, the fisheries sector, dominated by males, employs roughly 3 percent of the population (GSS, 2008a). The sector supplies about 60 percent of all animal protein for human consumption nationwide, and contributes about 4.5 percent to the national GDP (GSS, 2008a; USAID, 2011). Ghana's fishing industry is predominantly a marine fishery; the Ghana Statistical Service (2008a) reports that in 2007, more than 75 percent of all fish catches in Ghana were produced through marine fishing, while the remaining 25 percent occurred inland. The marine fleet can be further broken down into three fleets: small-scale artisanal operators fishing out of wooden canoes, semi-industrial inshore operators fishing out of planked, wooden vessels equipped with inboard engines, and industrial offshore operators fishing out of steel-hulled foreign-built trawlers. In the 2001 census there were 9,981 artisanal canoes (currently estimated at 13,500), 169 in-shore semi-industrial vessels (339 in 2008), and 88 industrial offshore vessels (Finegold et al., 2010; UN FAO, 2011). It is estimated that more than 150,000 individuals are engaged in marine capture fisheries (Mensah et al., 2003), and that an additional 1.5 – 2 million people rely on or provide support to the industry.[2]

NON-FARM RELATED ENTERPRISES

Despite the large size of the agricultural sector, a diverse array of industry groups can be found in Ghana (Table 5.9). After agriculture, the next two sectors with high employment include trade, which employs roughly 15 percent of the population, and manufacturing, which employs 11 percent (GSS, 2008b). Roughly 46 percent of all households in Ghana operate non-farm related enterprises. Half of these businesses involve trade; the rest are involved with some form of manufacturing. The main source of capital for non-farm related enterprises are household savings and assistance from relatives or friends (GSS, 2008b). Although sectors such as tourism, mining, forestry, and others make notable contributions to Ghana's overall GDP (Table 5.10), the impact of these industries on employment is minimal at a national level.

Table 5.9 Distribution of employed population age 15-64 years, by industry group (%)

Industry	Ghana	Urban	Rural
Agriculture	55.8	18.6	75.3
Fishing	1.4	0.7	1.7
Mining	0.7	0.9	0.6
Manufacturing	10.9	16.6	7.9
Electricity	0.2	0.5	0
Construction	1.8	3.5	0.9
Trade	15.2	30.4	7.2
Hotel and restaurants	1.9	3.1	1.3
Transport and communication	2.8	5.7	1.2
Financial services	0.3	0.8	0
Real estate	0.8	2.1	0.2
Public administration	1.4	3.7	0.2
Education	2.9	5.6	1.5
Health and social work	0.8	1.7	0.4
Other community services	2.7	5.3	1.4
Activities of private households	0.3	0.7	0.1
Extra territorial organizations	0	0.1	0
All	100	100	100

Source: GSS, 2008b; Ghana Living Standards Survey 5

2 Estimates in Chapter 1 of FAO (2002) on the size of the labor force vary somewhat from this estimate.

URBAN VERSES RURAL LIVELIHOODS[3]

Livelihood strategies in Ghana's urban areas differ considerably from those in rural areas. Urban livelihoods are important, given that 38 percent of Ghana's population (43 percent of total households) was urban in 2005/2006 (GSS 2008b). Urban areas can be further broken down into the Accra metro area, and other urban areas outside of Accra (Ghana's capital city). Accra contains 11.7 percent of the population, and 26.13 percent of the population lives in an urban area outside of Accra.

Urban households have a mean size of 3.5, which is slightly lower than the national mean household size of 4.0. Annual per capita income in urban areas is roughly 517 Ghana cedis, 120 Ghana cedis higher than the national average, and 212 Ghana cedis higher than in rural areas. Income in urban areas comes primarily from employment wages, which constitute 42.7 percent of an average household's income. After employment wages, non-agricultural forms of self employment constitute 30.7 percent of household income.

Table 5.10 Contributions of economic sectors to National GDP

Sector/subsector	% of national GDP	% of sector
Agriculture	**37.58%**	
Crops and livestock	24.83%	66.07%
Cocoa production and marketing	4.34%	11.55%
Forestry and logging	3.62%	9.63%
Fishing	4.78%	12.72%
Industry	**28.42%**	
Mining and quarrying	6.74%	23.71%
Manufacturing	8.83%	31.06%
Electricity and water	2.71%	9.52%
Construction	10.16%	35.77%
Services	**34.00%**	
Transport, storage, and communication	5.69%	16.75%
Wholesale & retail trade, restaurants, and hotels	8.31%	24.45%
Finance, insurance, real estate, and business services	5.35%	15.75%
Producers of private non-profit services	0.88%	2.60%
Government services	11.83%	34.79%
Community, social, and personal services	1.97%	5.80%

Source: GSS 2008a; Ghana in Figures

Household agricultural income constitutes 12.3 percent, and remittances constitute 10.7 percent. Within Accra these numbers change slightly; much more income comes from wages, and little income can be attributed to household agriculture. Outside of Accra less income comes from wage jobs, and more income comes from non-agricultural forms of self employment, making these two sources equal in terms of overall contributions to total household income. About 1/3 of urban households have savings to fall back on in the case of economic difficulty, which is significantly higher than the roughly 20 percent of households in rural areas who have savings (GSS, 2008b).

[3] The information in this section is based on the Ghana Living Standards Survey, Fifth Round, from 2005/2006 (GSS 2008b). Note that the statistics we provide from this source sometimes differ from those provided elsewhere in this section and this report that come from other sources (e.g., the 2000 Population and Housing Census).

In terms of employment, three major industry groups dominate: 30.4 percent of the working population is in trade, 18.6 percent in agriculture, and 16.6 percent in manufacturing. Minor industries such as construction, hotel and restaurants, transport and communication, public administration, education, and community services play a much larger role in urban than in rural areas (Table 5.9). Although only 18.6 percent of the urban population claims to be employed through agriculture, outside of Accra informal agriculture still plays a notable role in urban households – 40.6 percent of urban households outside of Accra reported owning or operating a farm or raising livestock. Given land restrictions, livestock rearing tends to dominate urban agriculture. Eight percent of the country's draught animals, 9 percent of cattle, 12 percent of sheep, 13 percent of goats, 6 percent of pigs, 20 percent of rabbits, and 13 percent of chickens are raised in urban areas (GSS, 2008b).

Rural livelihoods vary much more by locality than do urban livelihoods. When discussing rural livelihoods, it is therefore best to subdivide them into coastal, forest, and savanna livelihoods, comparable to the broad ecological regions of Ghana described in the previous section.

RURAL LIVELIHOODS ON THE COAST

The coastal ecological region is defined as the southernmost portion of the Western, Central, Greater Accra, and Volta administrative regions. Ghana's rural coast supports roughly 10.81 percent of the country's total population, and 12.19 percent of total households. Household size is on average 3.6, which is slightly lower than the national average of 4.0. Annual per capita income across the rural coast is roughly 368 Ghana cedis, close to the national average; however, households lying far from metro areas, particularly west of Sekondi-Takoradi, do experience more difficulty procuring income. Household income along the rural coast comes primarily from agriculture, which constitutes 48 percent, the largest share, of household income.[4] Wages from employment constitute 23 percent, and non-farm related enterprises constitute 20 percent. Only 25 percent of households have savings to fall back on in the case of economic difficulty. Although a significant amount of Ghana's tourism revenue is generated along the coast, the impact of that revenue on household income is relatively small and restricted to urban areas, where benefits are captured through secondary businesses (GSS, 2008b).

The predominant occupation of coastal inhabitants is marine fishing (Owusu-Ansah, 1994). As stated in the national overview, the 2001 census recorded 9,981 artisanal canoes (now projected at 13,500), 339 in-shore semi-industrial vessels, and 88 industrial off-shore vessels operating along the coast (Finegold et al. 2010, UN FAO 2011). These three fleets are estimated to support over 150,000 individuals directly and 1.5 – 2 million people indirectly.

Along the rural coast, 73 percent of households claim to engage in household agriculture. Only a small percentage of the country's livestock is raised by coastal households: 6 percent cattle, 5 percent sheep, 6 percent goats, 9 percent pigs, 1 percent rabbits, and 9 percent chickens. The silty Keta Plain east of Accra, with its abundance of water, supports shallot, corn, and cassava cultivation. The sandy soils of the river deltas also give rise to the copra (coconut oil) industry. Salt-making from the dried beds of coastal lagoons provides additional employment (Owusu-Ansah, 1994), however this practice is threatened in some areas by coastal recessions. Maize is the largest cash crop grown. Roughly 9 percent of households grow maize, bringing in 276,525,000 Ghana cedis in annual sales. The remaining agricultural production -- primarily cocoa, coconut, groundnuts, rice, and sugar cane – bring in 25,211,000 Ghana cedis annually (GSS, 2008b).

RURAL LIVELIHOODS IN THE FOREST

Ghana's rural forest areas, comprising portions of the Western, Central, Greater Accra, Eastern, Volta, Ashanti, and Brong-Ahafo administrative regions, support roughly 28 percent of the country's total population. Household size is on average 4.1, roughly the same as the national average of 4.0. Annual per capita income across the rural forest is roughly 323 Ghana cedis, 74 Ghana cedis below the national average. Household income within rural forested areas comes primarily from agriculture, which constitutes 51 percent, the largest share, of household

[4] The Ghana Living Standards Survey classification "agriculture" includes fishing.

income; non-farm related enterprises constitute 23 percent, and wages from employment constitute 17 percent. Only 27 percent of households have savings to fall back on in the case of economic difficulty (GSS, 2008b).

Cash crops bring in a total of 416,828,000 Ghana cedis in annual sales. Cocoa farming is the most valuable crop to farmers in this eco-region, responsible for 313,381,000 Ghana cedis annually; however, only 12 percent of households in the area farm cocoa. Twenty-two percent of households produce maize, which yields 82,121,000 Ghana cedis in annual sales. Other cash crops in the area include groundnuts, beans, coconuts, rice, sugar, ginger, coffee, cashew, kenat, timber from wood lots, and rubber. As evidenced by their lower value, these are grown at a much smaller scale. Most farmers also cultivate food crops; the forest eco-region produces the bulk of the nation's cassava, cocoyam, garden eggs, leafy vegetables, oil palm, plantains, tomatoes, yams, and fruits (GSS, 2008b). A fair number of households engage in livestock rearing, and a significant portion of the country's livestock are raised by households in this eco-region: 1 percent of cattle, 22 percent of sheep, 21 percent of goats, 11 percent of pigs, 45 percent of rabbits, and 32 percent of chickens (GSS, 2008b).

Aside from agricultural production, the forest is rich in mineral deposits, such as gold, diamonds, manganese, and bauxite. At a national level, mining officially employs only 1 percent of the population, and tends to occur in areas close to urban centers; however, a large informal and illegal mining industry also flourishes, employing individuals in primary and secondary forms of occupation. Most of this artisanal mining occurs in the forested areas, as well as in the north (GSS, 2008b).

In the Wet and Moist Evergreen Forest Eco-Region, soils are not highly fertile and are generally not suitable for continuous cultivation under mechanization. However, this eco-region does still support some cocoa production, the farming of starches like cassava, plantain, and cocoyam, and also tree crops such as rubber, coconut, and oil palm (Menczer and Quaye, 2006). However, it is the Deciduous Forest Eco-Region, which forms about 80 percent of the country's forested area that supports most of the food crop and cocoa cultivation, and provides most of the timber for local use and export in Ghana. The deciduous forest, as a result, is generally highly fragmented. The deciduous forest is also rich in minerals, and mining is another major land use (Menczer and Quaye, 2006). In the Forest-Savanna Transitional Eco-Region, soils are fairly fertile, and support a wide variety of crops. Maize, yam, and tobacco are important crops grown here; staples such as cassava and plantains are also found; and large-scale commercial farming is widespread. This is largely a peri-urban area, and the high population density in this eco-region exerts significant pressure on remaining natural resources (Menczer and Quaye, 2006).

RURAL LIVELIHOODS IN THE SAVANNA

Ghana's rural savanna areas (covering portions of Brong-Ahafo, and the entirety of the Northern, Upper West, and Upper East administrative regions) support roughly 23 percent of the country's total population, and 18 percent of households. Household size is on average 5.4, higher than the national average. Annual per capita income across the rural savanna is roughly 232 Ghana cedis, 165 Ghana cedis below the national average. However, people in the northernmost reaches of the savanna have much lower per capita incomes. The Upper West Region has an annual per capita average of 106 Ghana cedis, and the Upper East Region has an annual per capita average of 124 Ghana cedis. Income in the savanna comes primarily from agriculture, which constitutes 75 percent, the largest share, of household income; non-farm related enterprises constitute 12 percent, and wages from employment constitute 6 percent. Only 15 percent of households have savings to fall back on in the case of economic difficulty (GSS 2008b).

Cash crops bring in a total of 259,232,000 Ghana cedis in annual sales throughout the savanna. Groundnuts are the most valuable cash crop to farmers in the savanna eco-region, responsible for 66,856,000 Ghana cedis in annual sales; however, only 12 percent of households in the area are farming groundnuts. Fifteen percent of households produce maize, which yields 53,629,000 Ghana cedis in annual sales; 16 percent produce guinea corn, sorghum, or millet, which yield a combined 23,4770,00 Ghana cedis in annual sales. Other cash crops in the area include rice (23,661,000 Ghana cedis), cotton (20,742,000 Ghana cedis), beans (12,726,000 Ghana cedis), tobacco (7,472,000 Ghana cedis), cashew (3,315,000 Ghana cedis), sheanut (1,592,000 Ghana cedis), and mango (335,000 Ghana cedis). Farmers also cultivate food crops, though with the exception of okra, production is dwarfed by the high yields enjoyed in the south of the country (GSS, 2008b). Many farmers produce charcoal and firewood as a secondary source of income, which is often more profitable. However, charcoal and firewood production is a highly unregulated, often illegal occupation, and statistics are not available to characterize the size and extent of the industry.

The virtual absence of tsetse flies (which plague the forested and coastal areas, causing human sleeping sickness and animal trypanosomiasis) has led to a much larger livestock rearing industry across the savanna (Owusu-Ansah, 1994). Ninety-two percent of the country's draught animals, 84 percent of cattle, 60 percent of sheep, 73 percent of pigs, 34 percent of rabbits, and 46 percent of chickens are raised in the savanna (GSS, 2008b).

The savanna can be further classified as Guinea Savanna and Sudan Savanna, although some discrepancy exists regarding the delineation between the two. In the Guinea Savanna, soils are generally poor and are most productive in floodplains and along river banks (Menczer and Quaye, 2006). Moving north from the Guinea Savanna, grass cover becomes sparse, and erosion becomes more pronounced. Agricultural production begins to diminish, and livestock production plays a more important role in local livelihoods. In the Upper West and Upper East administrative regions families begin to depend more on nonfarm forms of self-employment and wage jobs for income (GSS, 2008b). Small-scale tourism operations have begun to pop up; however, the impact of the tourism industry on overall employment remains minimal.

6. VULNERABILITY TO CLIMATE CHANGE

The African continent is considered to be among the most likely to suffer adverse impacts of climate change because of vulnerable social and natural systems (Dixon, Smith et al. 2003), multiple interacting stresses, and low adaptive capacity (Boko, Niang et al. 2007). Ghana spans a range of climatic and edaphic zones from coastal mangroves and rainforests along the coast to savanna in the north.The previous section described this variability in natural systems and livelihood strategies. The following discussion of vulnerability of natural and social systems builds on this framework. In much of sub-Saharan Africa, precipitation is inherently variable from year to year. This is often expressed as recurrent drought and periodic flooding. Between 1991 and 2008 Ghana experienced six major floods with >2 million people affected by the floods in 1991 (GFDRR, undated). The northern savanna zone is exposed to floods as well as drought. In 2007, floods followed a period of drought and affected >325,000 people. In most of Africa, climate is a key driver of food security (Gregory, Ingram et al. 2005; Müller, Cramer et al. 2011). Because most agriculture is rain-fed and rural populations in many countries lack resources to moderate or adapt to drought (Dixon et al. 2003), the agricultural sector is particularly vulnerable (Haile 2005).

The major findings for Africa of the Fourth Assessment Report of the IPCC confirm earlier reports, including a warming trend since the 1960s (Boko, Niang et al. 2007). In West Africa, rainfall has declined 20 percent to 40 percent (average of 1968-1990 as compared to 1931-1960), although the decline in the tropical rainforest zone has been only 4 percent (Malhi and Wright 2004). Despite advances in our understanding of the complex mechanisms driving rainfall patterns, much uncertainty remains. Drought, a manifestation of extreme rainfall variability, has long been a feature of the continental West African climate with severe and long-lasting impacts on natural and social systems. The decline in rainfall from the 1970s to the 1990s, for example, caused a 25-35 km southward shift of the savanna zone (Sahelian, Sudanese, and Guinean savanna zones) with loss of grassland and woodland and displacement of human populations (Gonzalez 2001). Besides long-term climatic trends and extreme events, ecosystems in West Africa have been degraded by human activity, which often interacts with climate. Major stressors (drivers of degradation) are deforestation, wildfire, and soil erosion in upland areas and overfishing in coastal areas. In this chapter, we examine resource and social vulnerability.

NATURAL SYSTEMS VULNERABILITY

Most natural resources are climate-sensitive; plant and animal species are sensitive to weather extremes and communities are broadly distributed along climatic gradients. Soil resources are less sensitive to climate extremes but develop over time within a climatic regime characterized by mean values. Thus, climate variability and change potentially could affect these resources and the human communities that depend upon them. Here, we examine resource vulnerability at the national level in terms of climate hazards, stressors, resource systems, and outcome. We further categorize hazards as continuous or discrete; discrete hazards are further divided between those that are recurrent or singular. Brooks (2003) provides the rationale for approaching hazards in this fashion, noting that climate hazards operate over different timescales that may require different adaptation responses. Continuous hazards relate to changes in mean climate over many years or decades, such as the decreased rainfall in the savanna zones. Discrete recurrent hazards are transient, often extreme weather events such as storms, drought, or extreme rainfall events that lead to flooding. Discrete singular hazards are sudden shifts in climatic conditions that prevail for centuries or millennia – for example, the onset of Ice Ages (Brooks, 2003). Contemporary examples would be the melting of the Greenland or west Antarctic ice sheets (Schneider, Semenov et al. 2007). In our treatment, we regard sea-level rise as such a singular event because it is best regarded as exceeding a threshold level.

For our purposes, we examine how climate hazards stress natural systems, realizing that there is often an anthropogenic component to the stress mechanism. We list both the current stressors that increase vulnerability or future stressors induced by climate change; many stressors do both. These stressors are water or heat stress, wildfire, desertification, deforestation, soil health (erosion, low fertility, salinization), flooding, coastal erosion, overfishing, and saltwater intrusion (Table 6.1). Many of these stressors manifest throughout the country (e.g., heat stress) but some, such as coastal erosion, are limited to one region. Similarly, some resource systems are impacted by most stressors but in different ways depending on the resource subsystem, such as agriculture (e.g., small holder versus commercial operator). Following this overview, we detail how some current stressors increase vulnerability in specific resource sectors and ecological zones.

Table 6.1 Natural Systems Vulnerability

Hazard category[1]	Hazard	Stressor	Resource System	Rationale (Potential Outcome)	References	Ecological Zone
Discrete Recurrent	Drought	Water stress	Agriculture Small holder rainfed	Reduced yields or loss		
			Agriculture Livestock/mixed systems	Reduced yields or loss		
		Wildfire	Agriculture Small holder rainfed	Reduced yields or loss		
			Agriculture Livestock/mixed systems	Reduced yields or loss		
		Desertification	Agriculture Small holder rainfed	Reduced yields or loss		
			Agriculture Livestock/mixed systems	Reduced yields or loss		
	Extreme rainfall	Flooding	Agriculture Small holder irrigated	Crop loss		
	Extreme heat	Heat stress	Agriculture Small holder rainfed	Reduced yields or loss		
	Intense storms					
Continuous	Increased temperature mean					
	Increased rainfall mean					
	Decreased rainfall mean	Water stress	Agriculture Small holder rainfed	Reduced yields or loss		
	Increased wind	Soil erosion	Agriculture Small holder rainfed	Reduced yields or loss		
Discrete singular	Sea-level rise					

[1] After Brooks (2003); discrete recurrent are transient phenomena; continuous occur over many years or decades; discrete singular are abrupt shifts or possibly continuous events that reach a threshold value (e.g., sea-level rise). According to Brooks, these general hazard types relate to the likelihood of adaptation.

DESERTIFICATION

"Desertification" as defined by the United Nations Convention to Combat Desertification means land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, 1994; 2002). Land degradation, which in drylands can lead to desertification, is one of the consequences of mismanagement of land and results frequently from a mismatch between land quality and land use (Beinroth et al., 1994). Activities that can degrade drylands include high population densities, uncontrolled urbanization, land over-exploitation (e.g., excessive use of marginal lands, short bush fallow periods), misplanning of large agricultural projects, mechanized farming, overgrazing, bad irrigation practices, mismanagement of land input and neglect of land improvement, inappropriate land use systems and policies, bush and forest fires, deforestation, and mining and prospecting. Along with these human-caused factors, a range of natural factors appear to influence the process of land degradation (e.g., soil types, year-round aridity, high variability or energy in rainfall, recurrent drought) (Virmani et al., 1994; Reich et al., 2001; UNCCD, 2002; EPA, 2003).

When land degradation causes desertification, soil productivity diminishes, food production decreases, and vegetative cover is lost. Desertification can even negatively impact areas not directly affected by its symptoms, for example by causing floods, increasing soil salinization, decreasing water quality and quantity, and increasing sedimentation of natural waters and reservoirs (EPA, 2003; Andah and Gichuki, 2005).

VULNERABILITY AND RISK OF DESERTIFICATION IN GHANA

Three ecological zones in Ghana are classified as drylands based on the aridity index (ratio of mean annual precipitation to mean annual potential evapotranspiration, UNEP, 1997). These are the Sudan, Guinea, and Coastal savanna zones with aridity indices of 0.60, 0.60, and 0.54, respectively (EPA, 2003), which place the zones in the dry sub-humid category of drylands (UNEP, 1997). The administrative regions within these zones are the Upper East, Upper West, Northern, Greater Accra, Central, and Volta (EPA, 2003). Rainfall is unimodal in the Guinea and Sudan savanna zones and is concentrated into about four to six months of the year, with the remaining period being dry. During the long dry season, bush and forest fires are frequent because of the dryness of the atmosphere (i.e., low humidity, high evapotranspiration) and availability of combustible materials. The fires, overgrazing, and other poor land use practices (Table 6.3) leave much of the landscape essentially barren. The period of excessive, highly erosive rainfall occurring just after the prolonged dry period predisposes these areas, which have erodible and low infiltration soils, to a high risk of land degradation, particularly from erosion. In the Coastal Savanna and the Forest-Savanna Transition zones, rainfall is bimodal, but the minor wet season is unreliable. In these areas considerable variation exists between successive rainy seasons in time of onset, duration, spatial distribution, amount of rainfall, and number of rainy days. These conditions contribute to reductions in vegetative cover, crop yield, and food security in the affected areas (EPA, 2003).

Table 6.2 Values of aridity index, rainfall, evapotranspiration, and water deficit for three meteorological stations representative of four ecological zones in Ghana: Sudan, Guinea, Forest-Savanna Transition, and Coastal savanna zones

Meteorological Site (Ecological Zone)	Mean aridity index	Mean annual total rainfall (mm)	Mean annual effective rainfall (mm)	Total annual potential evapotranspiration (mm)	Mean annual water deficit
Navrongo (Sudan Savanna Zone)	0.54	885	782	1662	86%
Tamale (Guinea Savanna Zone)	0.60	1250	964	1720	66.4%
Wenchi (Forest-Savanna Transition Zone)	0.87	1250	964	1430	12.6%
Accra (Coastal Savanna Zone)	0.54	810	659	1504	46.1%

Source: EPA, 2003

Three independent sources categorized the risk or vulnerability of drylands in Ghana to land degradation and desertification, and all three show general spatial agreement of where the highest vulnerability exists. A global soil degradation assessment using expert opinion and (semi-)qualitative criteria identified three areas with the most severe degradation (GLASOD, Global Assessment of Soil Degradation, survey, Oldeman et al., 1990; FAO, 2005). That assessment placed the northeastern corner of Ghana (essentially the Sudan Savanna) and southeastern corner (the Ho-Keta plains area) in the "very severe" soil degradation class (FAO, 2005). The degradation in this area is long standing and a result primarily of poor land use, such as prolonged intense grazing, frequent widespread burning, cultivation to the point of near exhaustion of soil fertility, and historically high population densities and associated pressures on the landscape (Figure 6.2) (Dickson and Benneh, 1988). A strip along the Togo-Ghana border in the Volta Region was placed in the "severe" soil degradation class, and most of the Guinea Savanna and Forest-Savanna Transition zone were regarded as having "moderate" levels of soil degradation.

A quantified, large-scale (1:30 x 10^6) spatially explicit assessment of vulnerability to desertification based on soil types and qualities and rainfall variability was conducted for all of Africa (Reich et al., 2001). Reich et al. (2001) classified about 36,000 km^2 (16 percent of total land area) in Ghana as having a "high" or "very high" vulnerability to desertification. The largest area encompasses most of northern Ghana north of about 10°N latitude (all or parts of Upper East, Upper West, and northern Northern regions), including the Sudan Savanna Zone and northern Guinea Savanna Zone, and another smaller area was identified in the southeastern corner of Ghana (Ho-Keta plains area) (Figure 6.1). Notably, another 112,000 km^2 (about 49 percent of total land area of Ghana) was identified as "moderately" vulnerable to desertification (Reich et al., 2001). This includes the remaining Guinea Savanna Zone south of the 10°N latitude belt, the Forest-Savanna Transition Zone, and the Coastal Savanna Zone.

Because accelerated land degradation is associated with increased population density, Reich et al. (2001) spatially overlaid the desertification vulnerability classification with population densities to produce a map of the risk of human-induced desertification for Africa (Figure 6.2). In that analysis, most (about two-thirds by inspection) of northern Ghana, inclusive of the Guinea Savanna and Forest-Savanna Transition zones, were in the "high" to "very high" risk categories for human-caused desertification. Close inspection of that map highlights the "very high" risk for desertification of many of the urban centers and adjacent hinterlands within these zones (e.g., Wa, Tamale). The remaining third of land in these regions was classified at "moderate" risk of human-caused desertification. Also in the "very high" risk category was a band along the coast corresponding roughly to the Coastal Savanna Zone and the southeastern section of the Forest-Savanna Transition Zone (Accra-Ho plains region; Reich et al., 2001), areas with the lowest rainfall in Ghana (Minia, 2008).

In the National Action Plan to Combat Desertification, EPA (2003) indicated that about 35 percent (83,489 km^2) of Ghana's land area is prone to desertification. Assessments were apparently based on in-country expertise, not quantitative analysis. The savanna zones were acknowledged as prone to desertification. Particular high risk areas (hazard areas) in the Sudan and Guinea savanna zones were delineated in the northwestern corner of the Upper West Region, the entire Upper East Region, and eastern part of the Northern Region, enclosing an area bordered roughly by Damongo to the west, Kete Krachi in the south, Burkina Faso to the north, and Togo to the east (78,718 km^2). The Coastal Savanna Zone was also identified as a hazard zone.

Notably, none of these vulnerability-risk assessments were conducted in the context of global climate change but used current conditions as a basis for judgment (e.g., rainfall, soil types and qualities, land use, population density, or other features). In addition, two of these methods (Reich et al., 2001; FAO, 2005) were large-scale assessments (continental to global scale), and should be interpreted with caution when applied to a smaller area like Ghana. Further, two of the three are not based on empirical data (EPA, 2003; FAO, 2005), but relied on expert opinion or qualitative information to identify degraded areas or areas at risk of desertification. Clearly, a quantified evaluation of the temporal pace of vegetation change and soil degradation is urgently needed given the possible consequences to evaluate rates and extent of desertification in Ghana with or without climate change. Even so, a large number of pressing key issues can be linked directly to desertification in areas of Ghana identified as drylands at risk or vulnerable to desertification (Table 6.3). Even given these considerations and caveats, only tentative inferences can be put forward concerning the interaction of desertification and climate change in Ghana.

Table 6.3 Key Biophysical and human-related issues affecting vulnerability to desertification of the dryland zones (Sudan, Guinea, and Coastal savanna zones) of Ghana

Key issue	Issue/Cause-Effects/Vulnerable Zone(s)
Biophysical	
Rainfall erosivity	High energy rainfall increases erosion on sparsely vegetated or bare areas; Sudan and Guinea savanna especially vulnerable to sheet and gully erosion.
Salt intrusion	Salt intrusion into soils causes crop failure; affecting much of the soil in the Coastal Savanna Zone (Asiamah, 1995; Asiamah et al., 2000)
Soil properties	Predominantly sand textured surface horizons; rockiness common causing poor water retention, dryness, poor structure; underlain by hard pan, limits infiltration and enhances runoff; limited root growth volume; Sudan and Guinea savanna zones.
Soil fertility	Inherently low N and P, low organic matter, low buffering capacity and cation exchange; low fertility exacerbated by regular, intense bush fires and use of organic matter for fuel, animal feed, or building, and erosive rainfall; Sudan and Guinea savanna zones.
Water logging	Causes flooding and crop failures; exacerbated by soil compaction by livestock, raindrop compaction, shallow upland soils; exacerbates silting of rivers causing greater flooding; experienced every rainy season in Sudan and Guinea savanna zones, periodic in Coastal Savanna Zone.
Drought	Droughts of 1968-73, 1982-85, 1990-92 adversely affected soil quality, water supplies; each drought cycle may exacerbate the vulnerability to desertification.
Groundwater resources	Limited over much of region because of lack of geological porosity, low direct recharge via precipitation, variable but generally low borehole yields, and low hydraulic transmissivity (horizontal flow of aquifers). Characteristic of White and Black Volta River and Oti River basins, Sudan and Guinea savanna zone.
Human-related	
Population	Rapidly increasing population of people (and livestock) results in overexploitation of and intensified stress on natural resources; Sudan and Guinea savanna zones.
Cultivation	Low input-output farming may result in: nutrient mining; decreased fallow periods; farming of marginal lands, hill slopes, and fragile river margins; forest and woodland removal or degradation; exposure of plinthite to permanently harden into ironpan over extensive areas of Sudan and Guinea savanna (Asiamah and Dedzoe, 1999). Because of soil textures and clay pans, inappropriate mechanized plowing has resulted in topsoil loss, subsoil compaction, and exposure of clay subsoil in Sudan and Guinea Savanna (e.g., 1970s rice farming in northern Ghana).

Key issue	Issue/Cause-Effects/Vulnerable Zone(s)
Deforestation	Increasing demand for fuelwood, charcoal production, and building materials as well as losses to bush fires and bush-fallow farming. Especially high demand in Guinea and Sudan savanna zones where over one third of the landscape has been degraded from 55.6% savanna woodland (>25 trees/ha) and 44.0% cultivated savanna (6-25 trees/ac) to widely open, cultivated savanna (<5trees/ha) since 1972 (Idinoba et al. 2010). Natural savanna climax vegetation adapted to overland flow on slopes, removal/deforestation/bush fires exposes soil to high energy erosive rainfall. Wood use in Sudan and Guinea savannas appears unsustainable at present.
Bushfires	Whether for land clearing or from uncontrolled causes: decreases soil organic matter; induces rapid soil nutrient leaching; increases soil acidity to limit crop types and produces unpalatable forage. Prevalent in Guinea and Sudan savanna zones.
Overgrazing	Removes vegetation (leaves land bare in dry season); exposes and compacts soil, especially in watering areas; increases runoff and erosion exacerbating flooding and silting of waters. High numbers and density of livestock occur in Sudan and Guinea savanna zones.
Indirect and off-site effects	Increased downstream flooding; reduced water quality; silting of waterways, reservoirs, dugouts, and ponds; dust storms.
Water scarcity	Projected water demand in Ghana for irrigation for 2020 over 2000 in the Volta Basin is 538% (and high in every riparian country); stems from growing precariousness and unreliable nature of rain-fed agriculture in the basin; current water demands not being met in Basin; in upper Basin rivers and boreholes go dry.

Sources: EPA, 2003; Andah and Gichuki, 2005; Andah et al., 2005, and references therein

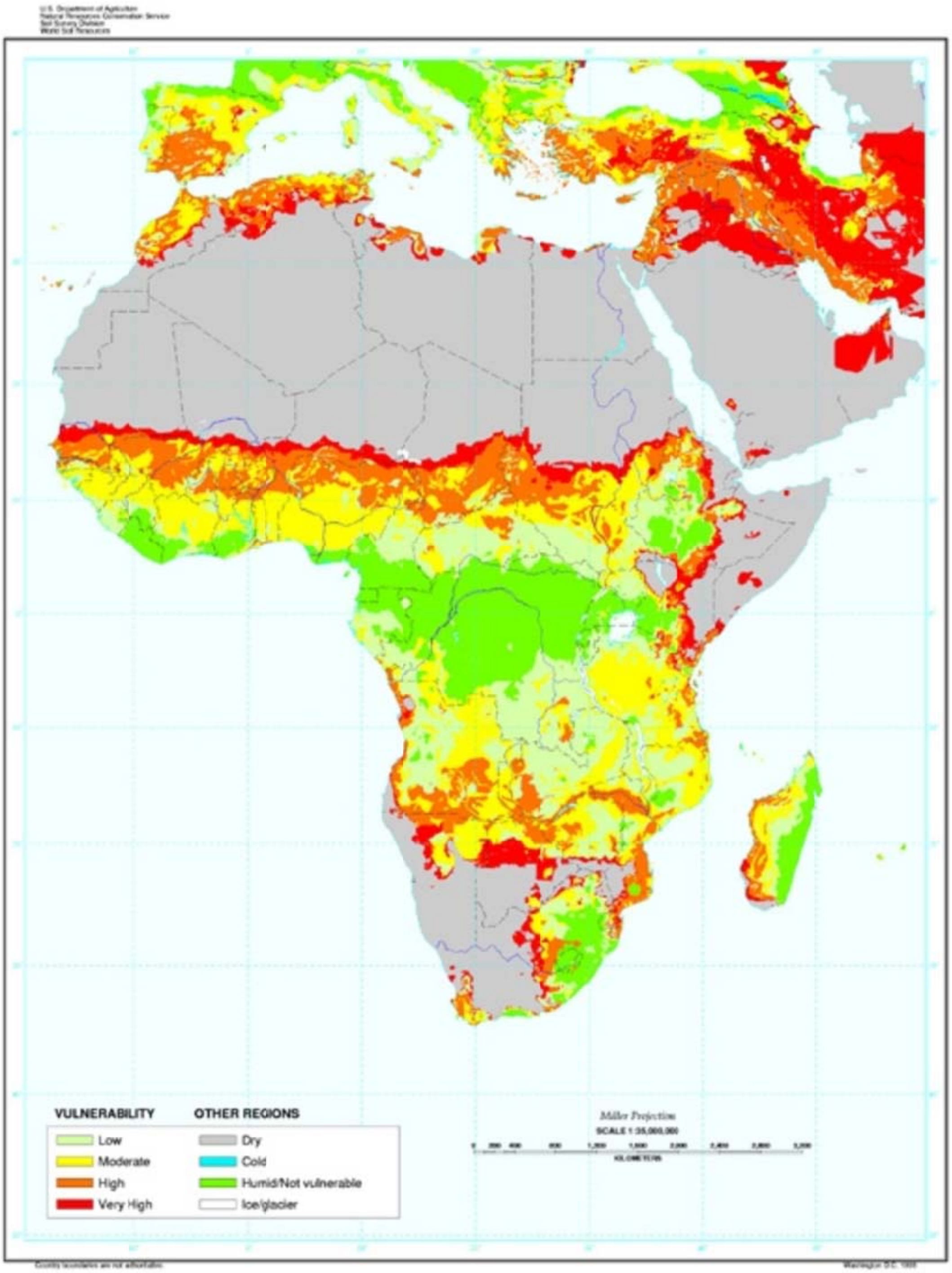
INTERACTION OF DESERTIFICATION AND CLIMATE CHANGE

Climate trends and climate projections suggest the future possibility of hotter temperatures, and if current trends hold, drier conditions in areas of Ghana already at risk of or undergoing desertification (i.e., Sudan, northern Guinea, and Coastal savanna zones). Climate trend data over the last four decades indicated increasing temperatures across Ghana and decreasing rainfall in most ecoregions (McSweeney et al., no date a) including the Sudan, Guinea, and Coastal savanna zones (Gyau-Boakye and Tumbulto, 2000; Jung, 2006; Minia, 2008; Dontwi et al., 2008; Idinoba et al. 2010; see Climate Section). The rate of temperature increase generally was more rapid in northern (Sudan and Guinea savanna zones) than southern regions (McSweeney et al., no date a). Further, the frequency of "Hot" nights increased across the country with increases being strongest during the transition in the Guinea and Sudan savanna zones from rainy to dry season (about September to November). In contrast, the frequency of "Cold" days decreased, most rapidly so in summer (June, July, and August), near the rainy season peak in the northern zones, as did the frequency of "Cold" nights, particularly during the rainy to dry season transition (McSweeney et al., no date a).

For rainfall, the Sudan and Guinea savanna zones experienced an overall decrease in total annual rainfall over the past 40 years (Minia, 2008). Meteorological and hydrological trend data from the Volta Basin also show a decline in rainfall amounts and duration of the length of the rainy season (Jung, 2006; Kasei, 2009). The frequency of rainfall deficiency has increased since the early 1970s, and moderate to severe drought years show reccurrence intervals of about 9-10 years. Notable years of drought extending to ≥50 percent of the basin area or more are 1961, 1970, 1983, 1992, and 2001 (Kasei, 2009). From the early 1980s to 2006 frequency of dry years increased with a probability of 0.7. Notably the large White Volta and Oti river basins, draining much of the Guinea and Sudan savanna zones, showed significant reduction in mean annual flows of 23.1 percent and 32.5 percent, respectively, when the periods 1953/54-1970 and 1971-1990/91 were compared. Peak September flows were reduced by 27.1 percent and 26.4 percent and October flows, those occurring in the transition between rainy and dry seasons were reduced as much as 44.2 percent and 54.4 percent, respectively. Rainfall from selected stations showed a decreasing trend from 1.5 percent to 11.3 percent between the two periods with the highest decreases north of 10°N latitude in Wa and Navarongo (Gyau-Boakye and Tumbulto, 2000). The reduction in river flow was attributed mostly to increased aridity (e.g., prolonged Sahel drought) in the watersheds outside Ghana but also to increased temperature over this period which increased evaporation and perhaps increased water withdrawal from boreholes. Emphasizing these trends, the volume of water behind Okosombo dam had not significantly recovered by the late 1990s to fill the dam for optimal operating hydropower generation since the droughts of the early 1980s (Kasei, 2009).

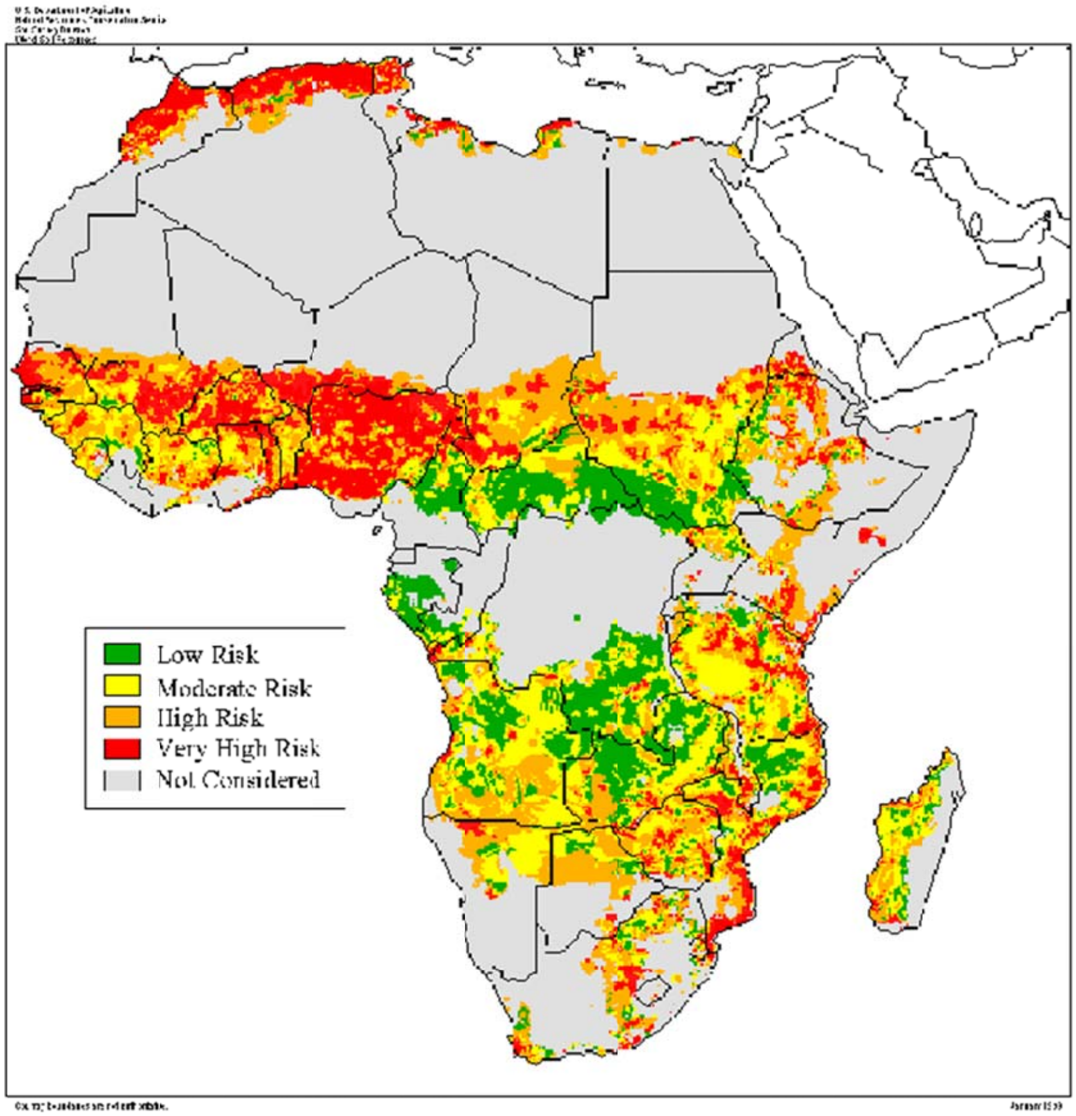
Projections from climate modeling also predict increases in temperature and increased frequency of "Hot" days and nights, producing higher peak rainy season temperatures (McSweeney et al., no data a; Kunstmann and Jung, 2005). Projected temperatures from modeling increased most rapidly in the interior of Ghana but were largest along the coast (McSweeney et al., no data a; Dontwi et al., 2008). Results from projected rainfall changes countrywide or in the Volta Basin are mixed with various models and SRES scenarios trending upward, downward, or showing little to no future change (McSweeney et al., no data a; Andah et al., 2005; Lehner, 2005; Kunstmann and Jung, 2005; Jung, 2006; Minia, 2008). Increased temperatures might also increase evapotranspiration rates in the Volta Basin although again climate projections are mixed (see model details in Kunstmann and Jung, 2005; Jung, 2006; Kasei, 2009). In sum, climate trend data and to some extent GCM projections indicate lower rainfall, higher temperature, and perhaps increased evapotranspiration rates, all conditions that exacerbate desertification in those areas already affected and increase risk to vulnerable but now only moderately affected areas.

Regardless of climate change effects being negative or positive, the continuance along the current human-natural resource trajectory of population growth, over-exploitation, and overall extensive land degradation in the desertification-prone zones of Ghana (e.g., Idinoba et al. 2010) is clearly unsustainable over the long term. At best, the resilience and productivity of much of the Sudan and Guinea savanna zones will be progressively weakened and at worst those same areas, particularly those in northern Ghana, will succumb to complete desertification.



Source: P.F. Reich, S.T. Numbem, R.A. Almaraz and H. Eswaran et al., 2001

Figure 6.1 Vulnerability to Desertification based on soil qualities and rainfall variability



Source: Reich et al., 2001

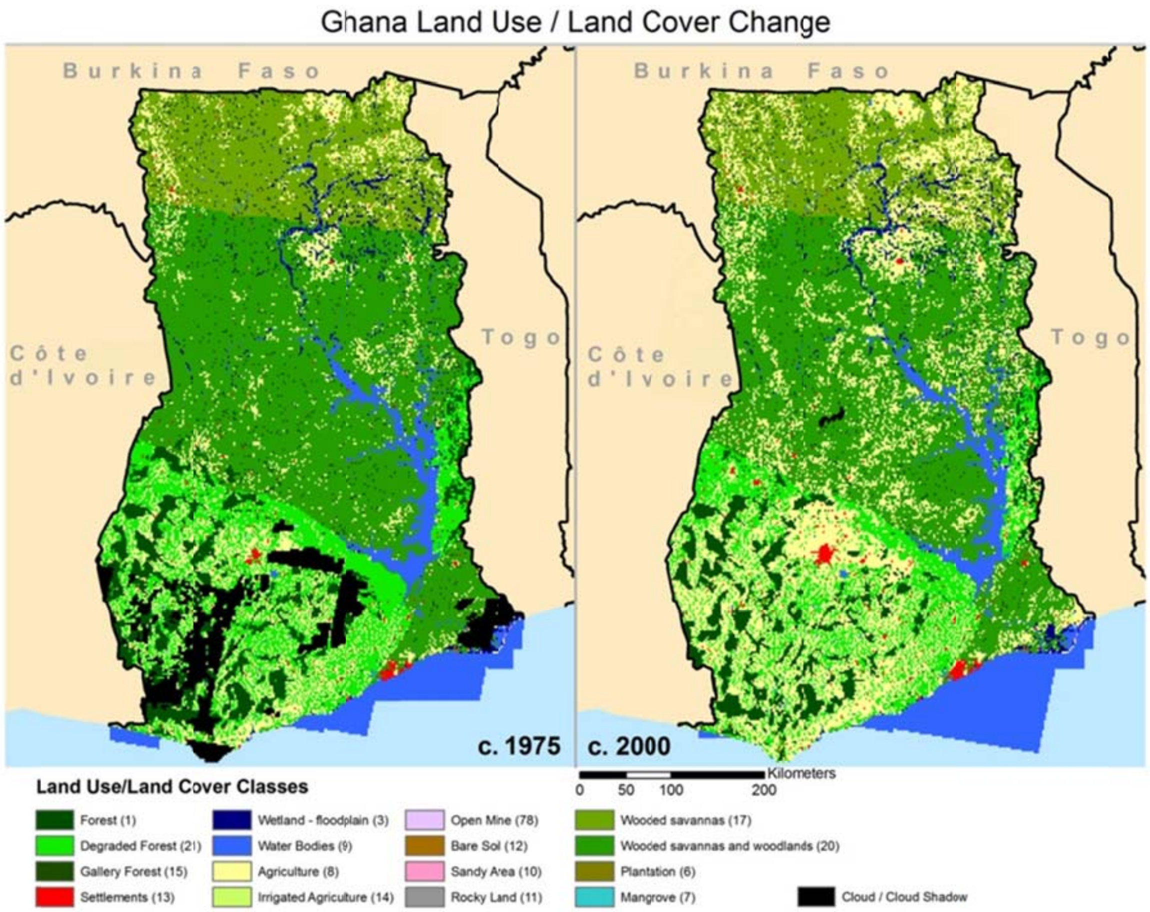
Figure 6.2 Risk of Human- Induced Desertification across Africa

DEFORESTATION AND DEGRADATION

Estimates of forest cover in Ghana vary considerably and depend on how forest is defined and the method of assessment. To date, no complete forest inventory of the country exists. Most estimates of forest in Ghana focus on the high forest zone, about the southern third of the country (the Rain Forest and Deciduous Forest zones, Figure 5.1). Until 1900, it was estimated that 33 percent of the country had forest cover (Wagner and Cobbinah 1993). By the late 1980s, forest cover had declined 78 percent (to 1.8 million ha) and forest areas are now fragmented. Estimates of deforestation rates for Ghana vary from 1.3 percent-3 percent/yr (Appiah, Blay et al. 2009). The Forestry Commission estimates the amount of high forest in Ghana in 1900 was about 8.2-8.8 million ha, consistent with estimates of the HFZ as 8.5 million ha (Hansen, Lund et al. 2009). Official statistics of forest cover, on which estimates of deforestation are based, seem to pertain only to the HFZ. Nevertheless, considerable forest cover exists outside of the HFZ (Wardell, Reenberg et al. 2003) and figures for land in forest reserves include areas in the Forest-Savanna transition and Guinea and Sudan savanna zones. Hansen et al. (2009) argue that definitions of forest have been applied inconsistently and that substantial areas outside forest reserves remain classified as forest but have been in agriculture for some time and should be classified as "other land with tree cover." The practical implication of these difficulties is that current deforestation in the HFZ may be over-estimated, which has implications for estimating the baseline under REDD+ and the potential reductions in carbon emissions (Hansen et al., 2009). A further consideration is that degradation probably contributes more to carbon depletion than deforestation (Hansen et al., 2009).

Regardless of actual deforestation rates, forest habitat is clearly increasingly fragmented in all zones in Ghana (Figure 6.3). Nearly all of the forests of West Africa have sustained some form of logging or commercial timber utilization (Wagner and Cobbinah 1993), and it is important to distinguish between logging and deforestation. We view deforestation as the removal of forest cover and the conversion into another land use such as agriculture. Slash and burn agriculture, often cited as a primary cause of deforestation, lies somewhere in between degradation and deforestation. At low levels of intensity with a relatively long interval or fallow period between slashing, this common form of smallholder agriculture could be called forest degradation where primary forest is converted into secondary forests with depletion of some species. As the fallow period becomes shortened and land is cropped almost annually, true deforestation occurs. But even this definitional distinction is too simplistic a view of deforestation in Ghana, which is a complex phenomenon with historical as well as contemporary threads (Wagner and Cobbinah 1993; Wardell, Reenberg et al. 2003; Asante 2005; Hansen, Lund et al. 2009).

A land-use land cover analysis emphasizes the loss of land cover types, especially classes of forest, and associated extent of land degradation in Ghana (Idinoba et al. 2010). In 1972 55.6 percent and 44.0 percent of the northern savanna zones were covered by savanna woodland (>25 trees/ha) and open, cultivated savanna (6-25 trees/ha), respectively. By 2000, 33.6 percent of the northern savanna zones had been degraded to widely open, cultivated savanna (<5 trees/ha). Under current trends, the degradation is projected to increase to 65.5 percent of the area by 2050, clearly increasing risk of desertification. Similar dramatic shifts were revealed in the Forest-Savanna Transition Zone. In 1972 it was dominated by open forest (32.3 percent, <60 percent canopy) and closed cultivated woodland (59.4 percent, >25 trees/ha) but now 57 percent of the zone is widely open, cultivated savanna (<20 trees/ha). Projecting current trends, open forest will cover only about 1.2 percent of the area by 2050. In the HFZ, 57.6 percent of the land cover was closed forest (>60 percent canopy) but that decreased to 34.2 percent by 2000. In contrast, the moderately dense bush forest (<15 trees/ha) increased from 35 to 60 percent of the land cover in the HFZ from 1972 to 2000. About 24 percent of the zone is projected to be converted to open, cultivated woodland (<5 trees/ha) by 2050 (Idinoba et al. 2010).



Source: US Geological Survey, (http://lca.usgs.gov/lca/africalulc/images/ghana_lulc_change_pair_factsheet_map_1280.jpg

Figure 6.3 Increasing Fragmentation of Forest Cover in Ghana 1975 -2000

Deforestation drivers are proximate or underlying (Geist and Lambin 2002; Kanninen, Murdiyarso et al. 2007). In the HFZ, proximate factors are agricultural expansion and intensification, wood extraction, and infrastructure expansion (Hansen, Lund et al. 2009). Although these activities can be traced back centuries before European contact in Ghana, inter-tribal warfare localized their effects (Asante 2005). Large-scale deforestation began with commercial timber exploitation and expansion of cocoa export in the late 1800s (Asante 2005). By the 1930s, slash and burn agriculture, bushfires, and grazing were seen as causes of forest degradation throughout the country (Wardell, Reenberg et al. 2003). Customary ownership of land, vested with the tribal chiefs (Stools in the south, Skins in the north), was seen as incompatible with rational forest management and areas were set aside as gazetted forest reserves by the colonial administrations, regulating use of these lands, a process completed by the 1950s in the whole country (Wardell, Reenberg et al. 2003; Asante 2005; Hansen, Lund et al. 2009). The system of forest reserves has been maintained by the post-colonial governments and currently resides with the Forestry Commission; Wardell et al. (2003) argue that pre-colonial land use patterns and colonial forestry interventions continue to influence current land use and natural resource management.

In the HFZ, forest clearance for cocoa production began in the east and has been spreading westward. Most canopy trees were removed although some were left to provide shade for the coca seedlings. Large areas were cleared by local farmers but also by migrants from the north who gained cultivation rights from the Stool chiefs (Hansen, Lund et al. 2009). The boundaries of the Forest Reserves were by and large respected and the clearance of the off-reserve land was largely completed by the 1970s (Hansen, Lund et al. 2009). An inventory from 1996 shows the area of off-reserve lands in various land use/land cover classes (Table 6.4).

Table 6.4 Off-reserve land use/land cover in the high forest zone, southern Ghana from a 1996 inventory

Land Use/Land Cover Class	Area (ha)	Percentage of total area
Natural forest	664,104	12
Secondary forest	183,906	3
Fallow	1,440,594	26
Newly cleared farms	439,330	8
Cocoa farms	1,001,264	18
Food crops	1,236,255	22
Grass lands	439,330	8
Other	102,170	2
Total	5,506,953	100

Source: Hansen et al., 2009

According to Asante (2005), Ghana's forests have always been regarded as a source of income regardless of policies and legislation to protect and conserve the forest. During the early phases of land clearing in the HFZ, wood had little commercial value; domestic timber demand was limited and export demand was minimal until after World War II (Hansen and Treue 2008) when it rose rapidly. By the 1960s, off-reserve resources were insufficient to meet demand and the on-reserve share of exports rose. Harvest peaked at 2 million m^3 annually in the 1960s, dropped during the economic crisis in the late 1970s-early 1980s, rebounded to pre-crisis levels but stabilized at around 0.9 million m^3 in 1995 (Hansen and Treue 2008). Generally, commercial demand was for a limited number of species and many areas were selectively logged, effectively contributing to forest degradation. An estimated 32 percent of forest reserves (exclusive of timber production and protection areas) in the HFZ were classified as degraded (Donkor and Vlosky, 2003). Over-exploitation of a number of species led to an export ban on 14 commercial species in 1979 that was expanded with an additional four species in 1987 (Abugre and Kazaare, 2010). These figures under-estimate actual removals; the current actual harvest is estimated to be >3 times the official tally at about 3.3 million m^3 yr^{-1} (Hansen and Treue 2008) because of under-reporting and illegal logging.

Illegal logging is widespread in Ghana and most (75 percent) is conducted by the informal sector who produce for the domestic market, variously called chainsaw operators or pit-sawyers (Hansen and Treue 2008; Marfo, Halladay et al. 2010). Chainsaw milling for commercial purposes is illegal in Ghana but provides jobs for about 130,000 people and livelihood support for 650,000 people (Marfo, Halladay et al. 2010). Additionally, chainsaw milling supplies 84 percent of domestic lumber supply at prices 12-74 percent lower than conventional sawmill lumber (Marfo, Halladay et al. 2010). Hansen and Treue (2008) estimated that much of the illegal timber is taken from forest reserves, $\leq$1.5 million m^3 yr^{-1}, which is clearly unsustainable. Commercial species are favored by the illegal loggers, who selectively harvest the higher-value species (Hansen and Treue 2008; Abugre and Kazaare 2010; Marfo, Halladay et al. 2010).

Fuelwood accounts for two-thirds of the energy consumption of Ghana; 84 percent of households use firewood and 13 percent use charcoal (Hansen, Lund et al. 2009). Even though much of the firewood comes from deadwood from farm and fallow land, fuelwood is estimated to consume 25-28 million m^3 yr^{-1} of raw wood (Hansen, Lund et al. 2009), which is about 7.5 to 8.5 times the estimated national volume of harvested timber. Charcoal is produced primarily in the transition and savanna zones but due to dwindling resources, more wood is coming from the HFZ within reserves (Hansen, Lund et al. 2009). Our observations in the Northern Region were that much of the locally produced charcoal was being transported to the south, and that younger farmers were abandoning growing crops for the more lucrative charcoal production. Because of the low value of the on-reserve timber in the savanna zones, the reserves have been degraded by charcoal harvests (Wardell and Lund 2006).

Two other proximate causes of deforestation and degradation are mineral mining and wildfires (see subsequent). Artisanal gold mining has occurred for >500 years and indeed gave Ghana its colonial-era name of the Gold Coast. This pit mining, locally termed Galamsey mining, has contributed mostly to forest degradation. Industrial mining for gold and other minerals began in the late 1800s. Although mining within forest reserves is hotly debated in Ghana and was briefly banned in 1997, anecdotal evidence is that some forest reserves have been severely degraded by Galamsey mining and would be open to industrial mining that has shifted from underground to surface mining (Hansen, Lund et al. 2009).

Underlying causes of deforestation and degradation include macroeconomic, technological, demographic, and governance factors (Kanninen, Murdiyarso et al. 2007). Macroeconomic factors include the global demand for primary resources; for Ghana this has been cocoa, timber, and minerals (Asante 2005; Hansen, Lund et al. 2009). Various governmental policies, incentives, and tax exemptions have at one time or another favored these industries. Technological developments in these industries have also contributed to deforestation and degradation. New "sun-tolerant" cocoa varieties requiring less shade than the traditional varieties have prompted clearing of trees on farms, especially in the cocoa-expanding western region of the HFZ (Hansen, Lund et al. 2009). As noted above, the industrial mining industry has adopted new technologies for surface mining, thereby increasing the amount of forest removed in their operations.

Ghana's population has grown at a fast rate and is becoming increasingly urban through migration from rural to urban areas. The growing urban population has increased domestic demand for construction wood, charcoal, and agricultural products; this demand is met chiefly by increasing the area of productive land rather than increasing the productivity of already cleared land. As noted above, most of the domestic demand for construction material comes from illegal harvesting (Hansen and Treue 2008; Marfo, Halladay et al. 2010). Migration from the poorer savanna zones to the south has long been a reality in rural Ghana, dating from colonial days and before (Wardell, Reenberg et al. 2003). Over time, this seasonal and permanent labor migration has included the slave trade (international, regional, and national), regional trade in kola nuts and salt, export of mahogany, expansion of cocoa, wild rubber, and public works construction. More recently there has been an exodus of young women to cities in the south to work in menial and domestic jobs. Another factor in the savanna zones has been vectors of human and livestock diseases that have caused cycles of depopulation and repopulation that influence deforestation and natural regeneration of savanna woodlands and floodplain gallery forests (Wardell, Reenberg et al. 2003).

Governance factors in Ghana are complex with customary or traditional rights overlain by often counteracting colonial and post-independence impositions by the central government. Customary rights affect not only land tenure but also tree tenure. Historically, much deforestation was driven by customary rules that granted usufruct or use rights to land by clearing virgin forest; this custom is common throughout West Africa. The customary chiefs (Stool, Skin, and lesser chiefs) managed the granting of these usufruct rights, including rights to certain tree species such as mango and shea nut. As noted above, the colonial administration alienated the rights of about 20 percent of the forest land into gazetted reserves. The 1962 Concessions Act section 16 went further and vested all natural forests and trees, on- and off-reserves, in the President in trust for the Stools and Skins. Management of this trust has devolved to the Forestry Commission (Wardell, Reenberg et al. 2003; Asante 2005; Hansen, Lund et al. 2009).

Tree tenure and access to trees in Ghana is complex and the right that a person has for use or sale of a tree depends on whether it is planted or naturally regenerated; occurs on communal/family land or rented land; and how much of the tree is needed (branches or fruit versus whole tree) and whether it is meant for commercial or domestic use (Marfo, Halladay et al. 2010). This means that a tree growing in a farmer's field belongs to the farmer if he/she planted it and can prove so with a certificate obtained from the Forestry Commission, but harvesting of that tree still requires a permit from the Commission. On the other hand, if that tree occurred naturally and the land is within a timber concession granted to a company by the Forestry Commission, the company can harvest that tree even if it means damaging the farmer's crops, usually without any compensation to the farmer because of low enforcement of rules by the Commission (Hansen, Lund et al. 2009; Hansen 2011). Community members can generally use parts of trees on communal lands for domestic needs but cannot harvest the products for commercial use (Marfo, Halladay et al. 2010). In practice, these rules and their selective or low enforcement encourage farmers to remove trees to avoid damage or by sale to chainsaw operators to gain some financial return (Hansen and Treue 2008; Hansen, Lund et al. 2009). Discussion of other issues such as benefit sharing that provides perverse incentives to forest management by farmers and forest fringe communities are deferred to the section on REDD+.

The foregoing discussion of deforestation and degradation of Ghana's forest estate begs the question of why does it continue and who benefits from the status quo? The answer from several authors who have studied these matters in greater depth suggests that we look at the political economy of timber in Ghana (Asante 2005; Hansen and Treue 2008; Appiah, Blay et al. 2009; Hansen, Lund et al. 2009; Hansen 2011). The encapsulatation of these analyses (Hansen et al. 2009; Figure 6.4) suggested that it begins with the failure of policies to protect and conserve the forests, the dominance of executive and bureaucratic actors who pursue revenue generation from the forest estate, and external factors such as global demand for the products of resource extraction and service of national debt (Asante 2005). This constellation of underlying drivers provides the context for urban elites who finance the illegal loggers and an industrial timber industry focused on export who maintain pressure for supporting a forest regime that effectively subsidizes log prices (Hansen, Lund et al. 2009). Because of a biased benefit-sharing arrangement, the small portion of forest fees that are channeled back to local government and customary authorities are used for recurring expenses or semi-private purposes (Hansen, Lund et al. 2009; Hansen 2011).

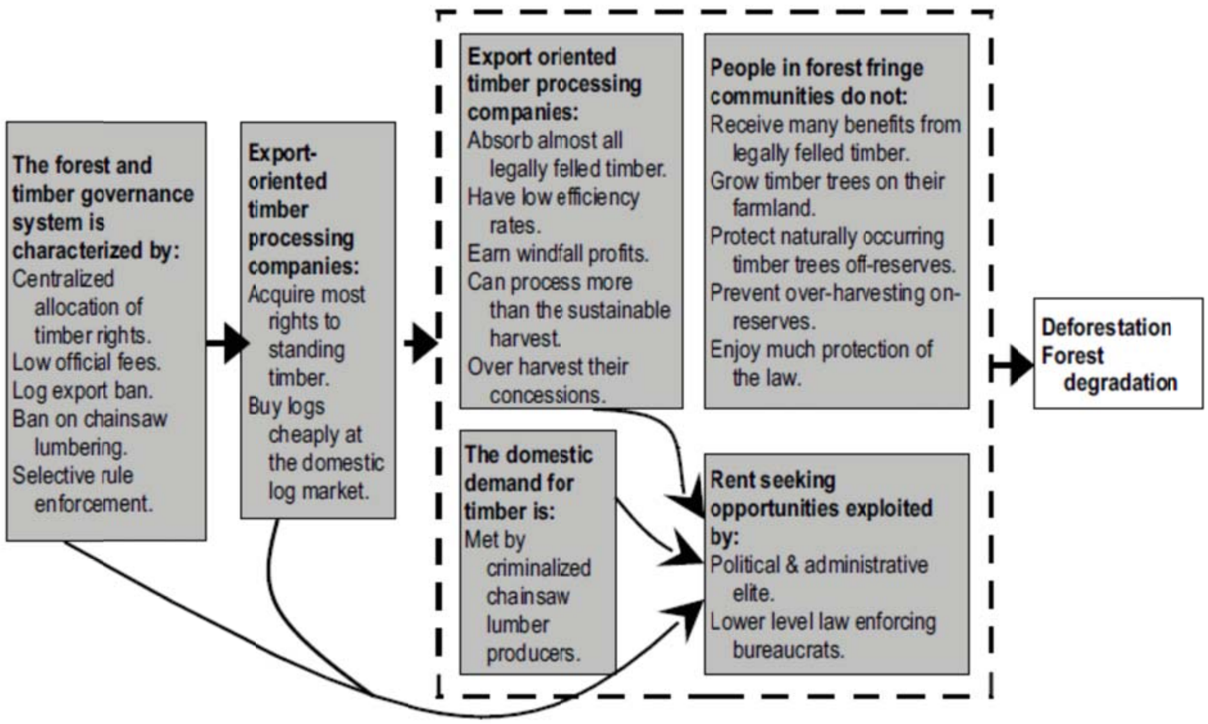


Figure 6.4 The political timber economy of Ghana

Horizontal straight arrows signify the sequence of governance effects that lead to deforestation and forest degradation while curved arrows signify associated, unofficial cash flows. Source: (Hansen, Lund et al. 2009)

WILDFIRE

The complex role that wildfire plays in shaping ecosystems can be described in terms of four vegetation responses: fire-dependent, fire-sensitive, fire-independent, and fire-influenced. Fire is largely absent from fire-independent ecosystems such as the evergreen rainforest in Ghana where conditions are wet burn. At the other extreme, fire is essential in fire-dependent ecosystems where species have evolved to withstand burning and to facilitate fire spread. The northern Savanna Zone in is such an ecosystem. Fire-sensitive ecosystems have evolved without fire as a significant process but humans have made them vulnerable to wildfire. Many of the deciduous forests would be fire-sensitive. Fire-influenced ecosystems generally are adjacent to fire-dependent vegetation where wildfires originate and spread; this type characterizes much of the forest-savanna transition. The response to fire in fire-influenced ecosystems is variable and often subtle. Government policy since the colonial era has been to reduce the occurrence of wildfire as much as possible by restricting its use and limited attempts to suppress wildfires (Laris and Wardell 2006). Such policies ignore the ecological role of fire as well as the traditional use of fire by agriculturalists, pastoralists, and hunters. There are few data on fire occurrence in Ghana but anecdotal evidence suggests that fires are common in the Northern Savanna zone, almost annual events. Wildfires are not as widespread in the forests regions, yet there may be a wildfire every year in many districts (Appiah, Damnyag et al. 2010) where the most common ignitions were caused by slash and burn land preparation followed by fires set by hunters.

Wildfires and biomass burning are a significant component of Ghana's GHG emissions. The draft National Wildfire Policy (as of 2006) seeks to overcome past policy limitations (unclear authorities, lack of deterrents, disregard of traditional practices and no involvement of traditional authorities in policy formulation or implementation). Nevertheless, the draft policy is overly focused on fire prevention and suppression, ignoring the role of fire as an ecological agent and a traditional management tool.

FISHERY RESOURCES AND OVERFISHING

The fishing industry in Ghana is based primarily on a large, marine fishery, and to a lesser but important extent, on inland or freshwater fisheries and aquaculture. Fish make up about 40-60 percent of the protein in the Ghanaian diet (Finegold et al., 2010). Much (about 42 percent) of the population lives <100 km from the coast, and a majority (65 percent) live <200 km from the coast (Perry and Sumaila, 2007). The Volta Lake impoundment, other reservoirs, aquaculture, and coastal lagoons are the sources of inland or freshwater fish. Lake Volta is the main source of inland fish landings, contributing >90 percent of inland fish landings annually. Lake Bosumtwi, a natural crater lake in the Ashanti Region, also provides a freshwater fishery, but for this fishery, the inland river fishery, and lagoonal fisheries little to no quantitative information exists (Dontwi et al., 2008; Finegold et al., 2010). Even so, even without consideration of climate change, clear evidence is available of over-exploitation of the marine fishery and at least anecdotal evidence is available of declining fisheries in Lake Volta and Lake Botsumtwi (Koranteng and Pauly, 2004; Andah and Gichuki, 2005; Dontwi et al., 2008; Finegold et al., 2010).

MARINE FISHERY

The coastline of Ghana is about 528 km long, and the associated continental shelf covers about 23,700 km^2 (DoF, 2003; Perry and Sumaila, 2007). The continental shelf varies in width from about 20 km at Cape St. Paul to about 100 km between Takoradi and Cape Coast (Bannerman and Cowx, 2002). Ghana's Exclusive Economic Zone is 218,100 km^2 in area (Finegold et al., 2010). There are 310 beach landing sites, 189 coastal fishing villages, and major ports where fish are landed (DoF, 2003).

A coastal upwelling system, known as the Central West African Upwelling, supports the productivity of the marine system of Ghana (Cury, 2004). Upwelling systems seasonally bring cool, nutrient-rich water to the surface, resulting in high productivity, and sustaining a high biomass of organisms relative to most of the open ocean. Four distinct and predictable hydrographic seasons occur in the Gulf of Guinea: a short "cold" season (minor upwelling, December–January); a long "warm" or "low" season (thermocline 1, February-June); a long "cold" season (major upwelling, July–September); and a short 'warm" season (thermocline 2, October-November). The upwellings are interspersed with periods of stratification (the warm periods or low periods of pelagic fish catch), typically with a thermocline 30-40 m below the surface (Koranteng and McGlade, 2001; Wiafe et al., 2008). Upwelling systems are directly linked with atmospheric and ocean circulation, and hence, the productivity associated with upwelling varies greatly seasonally and interannually. Peaks in production of zooplankton, a primary pelagic fish food source, are tied closely to the strength of the upwelling (Wiafe et al., 2008). The inherent unpredictability of marine productivity along the Ghanaian coast (Perry and Sumaila, 2007; Wiafe et al., 2008) is one of its natural characteristics. On evolutionary time-scales this instability within and between years is favorable to small plankton-eating fish with high fecundity and rapid generation times that can exploit unpredictable periods of exceptional high productivity and persist through periods of exceptionally low productivity.

The high biomass of these, mostly schooling, water-column dwelling species, collectively termed "small pelagics," are the foundation and mainstay of the fishery of Ghana. Their life cycles, adapted to exploit times of high productivity, can be resilient to even high fishing pressure and can sometimes recover rapidly from overexploitation (Bakun, 1998). Additionally, the small pelagics, because of their richness in oils and micronutrients, provide quality nutrition (e.g., Lokko et al., 2004). Small pelagic species dominate the catch, but in the sea, they are preyed upon by a high diversity of high-value, large pelagic species in Ghana's fishery (e.g., tunas, billfish, and marlin). The productivity supported by the upwelling system also increases productivity on the sea floor, supporting a rich fauna of demersal, or bottom-dwelling, fish on the continental shelf of Ghana. About 90 lagoons along Ghana's coast are also among the available habitats for marine resources, and provide vital seasonal income and subsistence fish and crustacean catches for nearby communities (Finegold et al., 2010).

The productive marine ecosystem of Ghana has supported a massive increase in fishing yield since the 1970s, but strong signals indicate it is under increasing strain (Koranteng and Pauly, 2004; Finegold et al., 2010). Catch of prominent species in the fishery have declined; most notably those high in the food web as is often the case in heavily exploited systems (Pauly et al., 1998; Koranteng and Pauly, 2004), but also more recently the small prey species (Bannerman and Cowx, 2002; Koranteng, 2004; Finegold et al., 2010). Striking, sudden system shifts (disappearance and appearance of fish species, e.g., round sardinella *Sardinella aurita*; sudden proliferation of otherwise uncommon species) can at least in part be attributed to high fishing pressure (Koranteng and Pauly, 2004). These observed changes indicate the future of the services provided by marine and coastal habitats are by no means assured (Finegold et al., 2010). The vulnerabilities of this system are multi-faceted with or without consideration of climate change.

MARINE FISHING FLEET

One of the most notable changes in recent decades is the tremendous growth in fleet size in nearly every category (Table 18), one, but only one indication of the increasing pressure being put on the marine fishery resource. The fleet today can be divided into 5 primary categories; the canoe fleet, the inshore fleet, the industrial fleet, the tuna fleet, and an extremely data poor segment, the coastal lagoon fisheries (Table 18, Ferraris and Korangeng, 2004; Dontwi et al., 2008; Finegold et al., 2010). A host of other biological symptoms of decline coupled with changes in fishing practices also emphasizes the increasing vulnerability of the marine fishery resource without any consideration of climate change (Table 19; see also State of the marine fishery).

Canoe Fleet: The canoe fishery is the most numerous and diverse fleet segment in Ghana, harvesting fishes from all resource sectors: large pelagic fish (tuna, billfish, sharks) by drift gillnets and hook and line gear; small pelagic fish via purse and beach seines; and demersal species with set nets and beach seines. Ghanaian canoe fishers are adaptable using >20 identifiable gear types (Doyi and Neequaye, 1990; Marquette et al., 2002) in the fishery to increase catch efficiency. The canoe fleet can be further subdivided by size, which also reflects the types of gear employed (Finegold et al., 2010).

Small or "one man canoes," typically 4-5m long and powered by paddle or sail, are used inshore for line fishing, small gill nets, and cast nets (especially in lagoons). During the last canoe census (2004), small canoes comprised only 5 percent of the surveyed canoe fleet. Subsistence fishing, particularly in lagoons, is not captured in landing statistics (Finegold et al., 2010).

Mid-sized canoes are 6-11 m long, typically crewed by 2-11 fishers, propelled by sail, paddle, or 8-40 hp motors (depending on length), and are used primarily for bottom-set, floating, or drifting gill nets and line fishing. Some are also used with smaller beach seine nets (Finegold et al., 2010).

Large canoes are 11-17 m long, crewed by 10-25 fishers, and propelled primarily by 40 hp motors. The large canoe category can be subdivided into the larger Ali/Poli/Watsa (APW) canoes and the large beach-seine canoes (Finegold et al., 2010). The former are named after the type of traditional fishing gear once used: "ali" nets were gill nets constructed from traditional fibres; poli and watsa nets are types of purse seine. Gear types have evolved considerably over the last century. Large canoes also employ large drift nets (e.g., the "nifa-nifa" net). Large beach-seine canoes make up the second sub-category; these usually have high planking at the bow to prevent large waves coming on board when operating in the surf (Finegold et al., 2010).

Without registration requirements and no limits on access to the fishery, the number of active canoes in Ghana has continually increased from 7,000 in 1980 to an estimated current fleet size of 13,500 (projected from last canoe survey in 2004, Finegold et al., 2010). From 1970 to 1980, about 85 percent of all canoes were reported to be motorized; now the figure has fallen to a fairly consistent 55 percent. Substantial growth occurred in motorized canoes, canoes, and canoe fishers in all coastal administrative regions from 1995-2004, but growth was notably strong in the Western Region which now represents about 36 percent of the canoe fleet of Ghana (Finegold et al., 2011).

Semi-industrial or inshore fleet: The semi-industrial or inshore fleet consists of mostly locally-built, planked wooden-hulled vessels (8-30 m long) with inboard diesel engines (90-400 hp) (Bannerman and Cowx, 2002; DoF, 2003; Nunoo et al., 2009). These vessels use trawling gear to catch demersal fish and purse seines to capture small pelagic fish during the major and minor upwelling periods. Smaller vessels in this class are generally underpowered for trawling and with the adoption of light fishing in the minor or low seasons, they have tended to specialize in purse seining. Most purse seine nets are 400-800 m long and 40-70 m deep with a mesh size of 25-40 mm; nets >2 km long are used by the large vessels. First deployed in Ghana in 1948, the numbers of these vessels quickly peaked in the early 1970s. Following steep decline from the early 1990s to early 2000s, vessel numbers rose sharply again through early 2000s, an impending warning sign of significantly increasing effort and perhaps stock overexploitation. The rapid and continued increase in this fleet likely relates to the adoption of light fishing, and the associated year-round access to the small pelagic resource (Finegold et al., 2010).

Industrial fleet: The industrial fleet consists of large, steel hulled foreign-built vessels that are further distinguished from the inshore fleet by their ability to freeze fish at sea, and hence, their ability to stay at sea for long periods of time (Finegold et al., 2010). Apart from the tuna fleet (see subsequent), the industrial fleet largely engages in demersal trawling. A sub-fleet targeting shrimp operated in the 1990s (22 operational vessels maximum); however, since 2002 only two operational shrimpers were reported. Another sub-fleet consists of ships practicing pair trawling, in which two industrial vessels pull a trawl net between them. Pair trawling was introduced in 2000, and the fleet grew to 20 vessels before the practice was banned in 2008. Though pair trawlers were supposed to be re-fitted as single trawlers following the ban, some may still be operating in pairs, leaving port separately and meeting up at sea. Fishermen in the Western Region continue to report observing pair trawlers operating off the coast (Finegold et al., 2011).

The industrial fleet has steadily expanded with a sharp increase over the last three decades when government policy targeted this fleet to promote fishery development and improved incomes from the sector. A problematic gap in the Ghanaian sampling system is that industrial vessels provide information on their own catches (self report), and no method is in place to verify the information provided. Extremely low catch and effort are reported by this fleet, so low it is inconceivable they could make a profit, providing strong indications that vessels substantially under-report catches (Finegold et al., 2010). Given the catch potential of these large vessels and their ability to stay at sea for long periods and transship catch to places other than Ghana, better data on this fleet segment is urgently required. The industrial fleet also supports another emergent but illegal "fishery"; one where so called "trash fish" (low value, small or damaged fish) are transferred at sea from trawlers to canoes specially modified to transport large volumes of fish (Nunoo et al., 2009). These fish then enter the normal beach-based market chain as accessed by canoe fishers. If this trade continues, Ghana's long-standing traditional fishing vocation, which is ranked among the best in West Africa (Atta-Mills et al., 2004) may be lost. Also, the increase in discards on the market tends to encourage offshore vessels to fish much closer to shore and also to use small, illegal mesh sizes. The continuation of trash fish trade puts more pressure on Ghana's depleting fish stocks, yet another situation that may push the already overfished stocks towards collapse. In addition, a government subsidy on fuel for artisanal fisheries, which is supposed to be used for legal fishing activities, is channeled into trans-shipment of catch at sea (Nunoo et al., 2009).

Tuna fleet: The tuna fleet is commonly considered to be part of the industrial fleet. The tuna should be considered as a separate entity because it is subject to a different governance system, regulated to some degree by international conventions (under the International Commission for the Conservation of Atlantic Tuna – ICCAT), targets a different resource with different gear types, and often fishes much further from shore than the other fleets (Finegold et al., 2010). The fishery was initially exploited by foreign-flagged vessels, peaking at some 80 active vessels in 1970. The first Ghanaian-flagged vessel went to sea in 1973; the last foreign vessels left in 1984. Since this time the number of active tuna vessels has numbered 35 to 40 (Finegold et al., 2010).

Lagoon-based subsistence/commercial fisheries: As the smallest fishery segment in Ghana, lagoon fisheries are the least known from scientific or national fishery authority perspectives (Finegold et al., 2010). Given the 90 lagoon systems along the coast, they are significant in terms of subsistence and seasonal commercial fishing for many communities (Koranteng et al., 2000). Gear types used in lagoons is for the most part not recorded in gear surveys, but along with nets operated from small canoes, cast nets, line fishing and various types of traps are commonly employed. Catch data are practically non-existent outside of a few studies in the scientific literature. In many ways, lagoon fisheries stand apart from marine fisheries. Their degree of exposure to external environmental drivers (up-stream effects, competition for water resources, erosion, and extreme pollution) is more akin to inland fisheries resources than their marine counterparts. The strong traditional belief systems around lagoons and the de-facto property right due to proximity of villages exploiting the resource present an entirely different set of incentives for governance to those seen in coastal and offshore fisheries (Finegold et al., 2010).

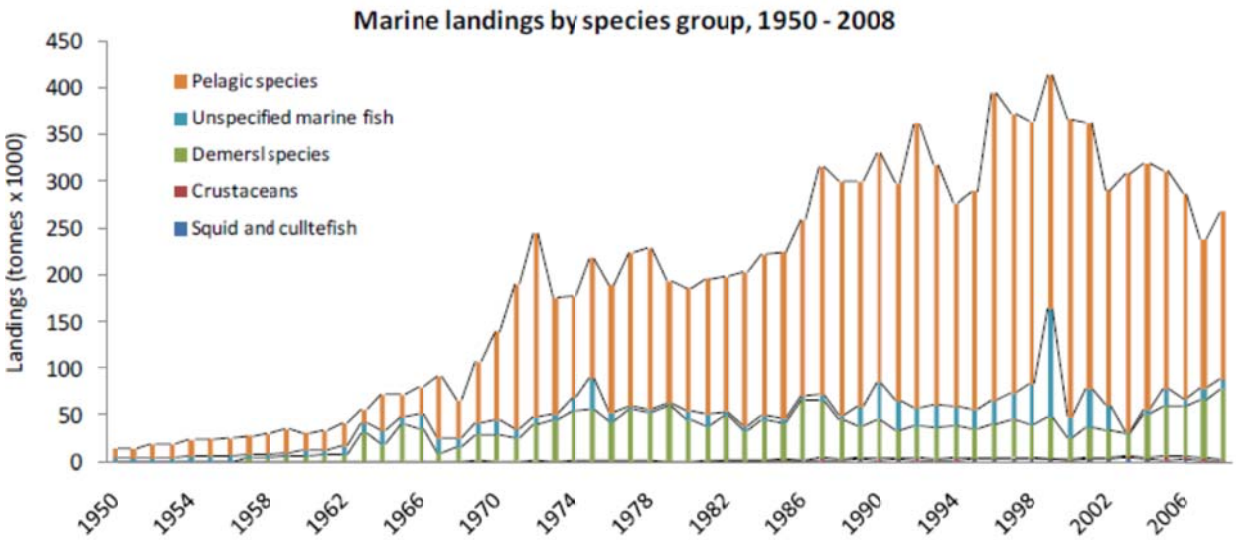
Table 6.5 Characteristics of fishing fleets in Ghana

Fleet	Crew	Length (m)	Power	Gear types	Estimated fleet growth
Canoe fleet					About 7,000 (1980) to 13,000 (2010)
Small Canoe	1	4-5	Paddle or sail	Lagoonal/near coast line fishing, small gill nets, drag nets, cast nets, traps (esp. in lagoons)	
Mid-size Canoe	2-11	6-11	Sail, paddle, 8-40 hp gasoline motor	Inshore bottom set, floating, drifting gill nets or line fishing; also small beach seines	
Large Canoes	10-25	11-17	Primarily 40 hp gasoline motors	Inshore gill nets, purse seines, drift nets, large beach seines; also light fishing	
Semi-industrial or inshore fleet		8-30	90-400 hp diesel motors	Inshore, trawls and purse seines, light fishing	About 154 (1990) to 339 (2008)
Industrial fleet		Large, steel hulled seagoing vessels, >35 m, stay at sea long period	Large diesel motors	Demersal trawling; pair trawling	About 32 (1970) to 73 (2008)
Tuna fleet		Large, steel hulled seagoing vessels >30 m, stay at seas long periods	Large diesel motors	Line fishing, Long lines, purse seine, fish aggregation devices	Stable at 35-40

Source: Marquette et al., 2002; Koranteng and Pauly, 2004; Dontwi et al., 2008, Feingold et al., 2010)

STATE OF THE MARINE FISHERY

Although catch data from Ghana's coastal fisheries go back to 1950 (Figure 6.5), methodological changes dictate caution in comparing reported catches before and after 1972 (Finegold et al., 2010). Even so, a broad overview indicates slow development up to the early 1970s is followed by a fairly consistent increase in catch until the late 1990s. The variability between 1970 and 1990 likely reflects environmental drivers (e.g., sea temperature, upwelling strength) involved in regulating pelagic productivity (Koranteng, 2004; Koranteng and McGlade, 2004; Perry and Sumaila, 2007). Notably the sizeable dip in pelagic catches from 1972 to the mid 1980s coincides with a near-complete crash and subsequent slow recovery of the round sardinella (*Sardinella aurita*) (Koranteng, 2004), a primary target and mainstay of the pelagic fishery. Since 2000, total catches showed a continuing declining trend, driven largely by a marked decrease in several species in the pelagic fish catch, which is offset somewhat by a rise in catch of demersal species.



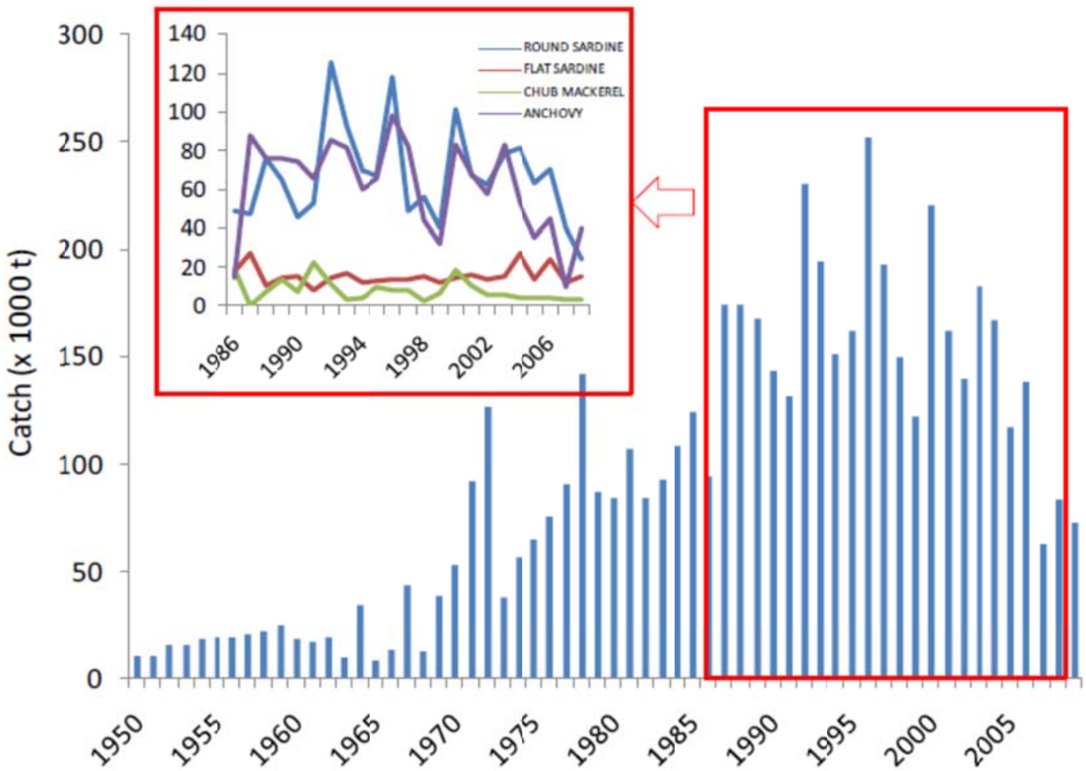
Source: FAO FishStat Plus, compiled by Finegold et al., 2010

Figure 6.5 Total reported catches by major group from Ghana's marine fisheries

Pelagic stocks: Because they are not associated with seafloor habitats, but rely totally on oceanic productivity, the dynamics and therefore management of pelagic fish resources is complex. Pelagic species tend to be fast swimming, schooling species which migrate widely, often crossing national boundaries. Effective management must be applied at a broad spatial scale, encompassing neighboring regions, districts, and countries sharing the resource. This represents an added level of vulnerability to pelagic resource sustainability.

All fleet segments exploit the pelagic fishery resource in Ghana although catches by industrial trawlers are largely incidental. Small, schooling species (sardinellas, anchovies, mackerel) make up the vast majority of this catch, but the small pelagic catch is currently at its lowest level since the 1970s (Figure 6.5). Given the inherent, environmentally driven variability of the small pelagic resource (e.g., Wiafe et al. 2008), the current decline cannot with certainty be assigned to a fishery-driven stock collapse that will have lasting effect. However, the most sustained period of decline is currently occurring in this resource since heavy exploitation began. The decline coincides directly with the uptake of light fishing (discussed below), which massively increased the pressure on this resource.

Decline in catch of small pelagic species since the mid-1980s (Figure 6.6) is not caused by the crash of one dominant species (as in the 1970s case with round sardinella), but rather of simultaneous decline of three (of four) main small pelagic species. Interviews with fishers in the Western Region (Finegold et al., 2010) and Central Region (pers. obs.) indicate this trend continued in 2010-2011.



Sources: FISHSTAT, FAO, and Marine Fisheries Research Division, Tema, compiled by Finegold et al., 2010

Figure 6.6 Data on changes in catch of the small pelagic resource

Demersal stocks: Demersal fish (bottom associated) are less mobile than pelagic species and as such depend to varying degrees on the integrity of seafloor habitat. Even though the transboundary migration issues associated with pelagic stocks are less of a problem, the habitat association and the sedentary nature of this group make them highly susceptible to overfishing and habitat damage. The resource in Ghana is exploited in inshore waters and on the continental shelf to a depth of about 75-m. Demersal fishes are targeted by all three prominent fishing fleets: line fishing in the canoe fleet; bottom-set gill nets, beach seines, and low ("warm") season trawling by the semi-industrial fleet; and trawling by the industrial fleet.

Several lines of evidence suggest demersal stocks are overexploited in the Ghana fishery. By the early 1970s, the heavily exploited status of demersal stocks in this region was apparent (Gulland et al., 1973). Recent reviews of demersal stocks in Ghana (e.g., Koranteng and Pauly, 2004) report clear trends in the reduction of biomass of longer lived and predatory fishes (e.g., snappers, groupers, seabreams, and Atlantic bigeye), suggesting overexploitation of the fishery. These results come from national catch statistics, but also from fishery-independent sources (research trawl surveys between 1963 and 2000). The independent surveys showed a marked decline in the abundance of demersal fishes in the 0-30 m depth zone, clear indication of overfishing (Karenteng and Pauly, 2004). The reason deeper water does not show a decline is twofold: methodological changes in the survey would mask recent declines and that much of the deeper waters are rocky and hard for trawlers to exploit (Karenteng and Pauly, 2004).

Ghana's demersal fishery is exhibiting symptoms of an unstable ecosystem. Some notable examples indicative of instability are the repeated collapse and recovery of a shrimp fishery operating around the Volta estuary (Koranteng, 1998; Koranteng and Pauly, 2004) and the massive proliferation in trigger fish (*Balistes carolinensis*) in 1973 followed by near-total collapse in the early 1980s, a near total recovery in the late 1980s, and a sustained and perhaps permanent collapse in 1989 (Ansa-Emmim, 1979; Koranteng, 1984; Caverivière, 1991; Aggery-Fynn, 2007). The latter species had not previously been reported in the area prior to 1970s, yet it rapidly came to almost completely dominate trawl catches before it collapsed. Its appearance is likely related to the availability of newly created "niche space" because of the wholesale removal of other demersal species by trawl fisheries. Other examples of symptoms of instability include the decline and subsequent recovery of round sardinella, *Sardinella aurita*, populations (Pezennec 1995), and the increase in abundance of cuttlefish, *Sepia officinalis* and globefish, *Lagocephalus laevigatus* (Ramos et al., 1990; Koranteng, 1998).

Multivariate analysis of demersal catch composition in Ghana from 1972 until 2008 is also informative (Finegold et al., 2010). The most significant shift occurred between 1988 and 1989. This coincides with the crash of the trigger fish fishery and an increase in burrito catch. The increase in burrito catch might reflect fishers targeting burrito as a replacement for trigger fish. The second shift in catch composition occurred between 1997 and 1998 and is driven by a decline in burrito catch and an increase in cassava fish catch. The continuing change in catch composition to 2008 (last sample analyzed) is driven by the increasing dominance of cassava fish in the catch. Although these community shifts cannot with total certainty attributed directly to fishing pressure, demersal communities typically are more stable than pelagic communities. Shifts in community structure caused by environmental factors (e.g., upwelling strength) are unlikely to lead to the permanent changes seen here. Similar analysis conducted on pelagic catches in Ghana showed no long-term consistent changes in composition (Finegold et al., 2010). The shifts apparently coincide with the removal of species dominant in catches, and as such, suggest fishing pressure as a principal cause of compositional changes (Finegold et al., 2010).

FISHING EFFORT AND TECHNOLOGY CHANGES

One of the significant shortfalls of fishery regulation and management in Ghana is a failure to document fishing effort among fleets. However, at the coarsest level, fleet size provides a measure of fishing effort. Increased numbers of active fishing vessels will likely lead to greater fishing pressure on resources. In Ghana, all fleets have expanded, some substantially so, since the 1990s, but the expansion is not reflected in total landings. To the contrary, as fleet size increased, catch has dropped. This coarse level of measurement is not the whole story, but it is a warning sign regarding the state of resources (Finegold et al., 2010).

Another indicator of fishing effort is time spent fishing or catch per unit effort (CPUE). If vessel numbers increase, but the time spent fishing by each vessel decreases, then vessel numbers viewed in isolation may represent an overestimate of the change in fishing effort. Data suggest a severe decline in CPUE for the inshore fleet, but no particular trends for the canoe or industrial fleet (Finegold et al., 2010). Although an improvement beyond simple measures of fleet size, measuring effort only as the number of fishing trips, which is how Ghanaian fisheries authorities measure effort, can be misleading in comparing across decades. Changes in technology and fishing practices can have a dramatic impact on effective fishing effort with no associated change in number of fishing trips (Finegold et al., 2010).

Fishers in Ghana have adopted a number of changes to their fishing practices that could substantially increase the effective fishing effort of a single trip. In the canoe and inshore fleets in particular, continued innovation and change have massively increased fishing power, even in the last decade. Among these are the use of outboard motors, changes in net type, net construction, or net size, and light fishing (Finegold et al., 2010).

Outboard motors and increased travel: Outboard motors allow fishers to travel great distances and track and exploit schools of small pelagic fishes as they move seasonally (Finegold et al., 2010). Similarly, gill netters or line fishers using outboard motors can target the relatively sedentary demersal stocks and maintain catches despite dwindling fish stocks. In Ghana, as shallow water stocks declined, outboard motors allowed canoe fishers to go farther along the coast and offshore to find new fishing grounds as others are depleted, a process termed serial depletion of a fishery. Over the last 10 years in the Western Region, interviews with fishers revealed that today on average they travel 2.7 times longer to get to fishing grounds than they did only 10 years ago (Fig. 6.7, Finegold et al., 2010). Given the increase in engine power over the past three decades, the increase in distance which they must travel to find fish would be even higher. Serial depletion masks fish stock declines until no fishers cannot locate productive fishing grounds, at which point CPUE will decline abruptly and severely. The shift to higher power, more efficient engines (i.e., 23-30 hp in 1981 to 40 hp engines, today) and improved propellers likely represents a doubling of effective engine power over the past three decades (Finegold et al., 2010). Similarly, small canoes are now often equipped with small (generally 8 hp) engines, again increasing effective range.

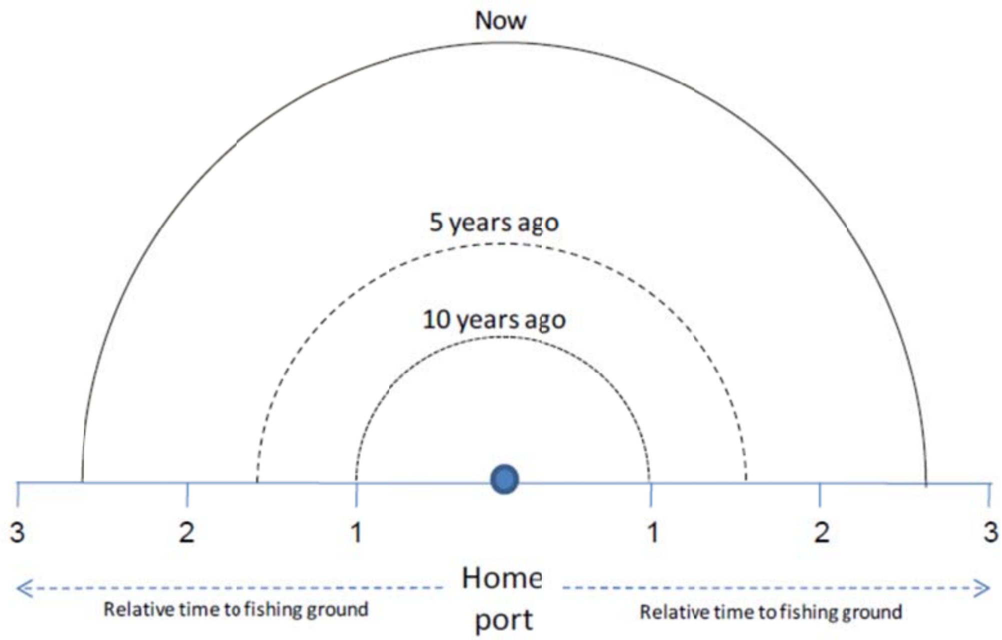


Figure 6.7 Relative time taken for fishers to reach their fishing grounds

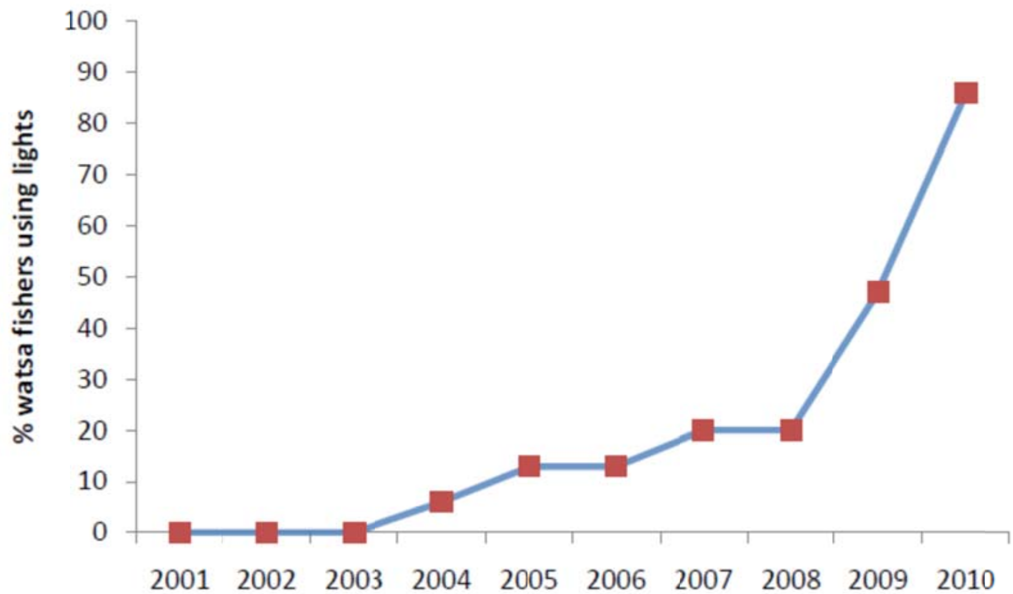
Change in net systems: Effort measured in terms of fishing trips does not account for changes in net type, net construction, or net size, all of which enormously impact fishing power. Detailed data on gear changes over time in Ghana are unavailable; however, field observations, interviews with fishers, and a few reports point to significant changes (Finegold et al., 2010).

To effectively double fishing effort, a fisher could double the length of net deployed. Data on changes in net length are unavailable for Ghana, but are available for a Côte d'Ivoire canoe fishery for large pelagic species (targeting billfish, sharks, and tuna; Bard and Goran, 2001). Between 1984 and 2000, the average length of gill nets doubled and the fishery data system reported an increase in fishing trips from low levels in 1984 (<500 trips) to around 7,000 trips in 2000. Standardizing the information based on the average net length deployed rather than simply the number of trips, results in a 30-fold increase in effective fishing effort rather than a trip-based 14-fold increase. The situation is likely similar in Ghana. In recent Ghana surveys among fishers using multi-panel gill nets (such as tenga and karadwee), an almost invariably a progression occurs from an initial purchase of a small number of net "bundles," perhaps purchasing 12 "bundles" initially, and over time adding ≥2 per year (Finegold et al., 2010).

Substantial changes in the materials used to construct nets over the years have had a marked impact on catch efficiency (Finegold et al., 2010). Early nets were constructed by fishers from natural fibers, which tended to rot, required frequent repairs, and required frequent replacement, all reducing time fished. Easy access to synthetic fibers substantially improved net efficiency and longevity, and allowed soak times (time in water) to increase. Monofilament gill nets, which have increased massively in use by fishers over the past 10 years, catch fish far more efficiently than synthetic multifilament nets. With the switch to monofilament, mesh sizes have continued to decrease, also increasing catch rates but potentially fishing down the stock. During interviews, a number of fishers in the Western Region noted that they do not travel as far to fish as they used to, because their catches have increased substantially due to using smaller mesh monofilament gill nets. Mesh sizes used in the construction of purse seine nets and drift nets may also have decreased in recent years (Finegold et al., 2010).

Light fishing: The technique of light fishing, as the name implies, involves using lights at night to attract large aggregations of small pelagic fish, increasing their catchability. Over the past two decades, light fishing rapidly became the technological innovation with the greatest impact on Ghanaian fishing (Finegold et al.. 2010). The technique was initially introduced by the Marine Fisheries Research Division (MFRD) as a means of alleviating poverty and increasing food availability. Canoe fishers found it difficult to make a living fishing outside of the major upwelling season (the "*maura*" season) because their main target species, the small pelagics (i.e., herrings, sardinella, and anchovies), were inaccessible. Early trials conducted initially in 1962 and showed promise (Bannerman and Quartey, undated cited in Finegold, et al. 2010), but the equipment was too expensive for most fishers and the potential benefits were not fully understood. In the early 1990s, the incentives for light fishing changed when the inshore fleet adopted the technology, and canoe fishers soon followed. The inshore fleet benefited considerably. The inshore vessels were originally designed to operate purse seines during the upwelling season, and then convert to trawling in the low season, but most were underpowered for trawling. Light fishing provided the option of continuing purse seine operations even in the low season. In interviews, fishers indicated catch in the low season was 3-8 times higher when using lights (Finegold et al., 2010). Many fishers suggested that with the current level of fish stocks, fish catch would be low to nonexistent in the low season without lights.

Purse seiners (predominantly "watsa" gear) from the large canoes and the inshore fleet now use light fishing. Small generators power high wattage incandescent lights that are lowered into the sea on long cables (Finegold et al., 2010). The technique has essentially extended the targeted small pelagic fishery from a three-month to a year-round fishery. For many canoe fishers, prior to their use of light fishing, fishing activities in the low season were largely for subsistence purposes, rarely were enough fish caught to sell for profit. With the use of lights, despite a decline in fish stocks, the chance of a profitable catch in the low season has substantially increased. Fishers who once changed to line or drift net fishing in the low season now purse seinet year-round. Since lights are not effective near the period of the full moon, many fishers only fish for two weeks a month, one week on either side of the new moon. In effect, this may act to decrease fishing effort as measured in number of trips. Yet once the uptake of light fishing is considered, the overall increase in fishing pressure is still considerable, once again confounding CPUE estimates from the fisheries information system. Light fishing activities were addressed in interviews of fishermen in the Western Region. Although the inshore fleet was first to use the technique, since 2000 increasing numbers of canoe purse-seiners are light fishing (Figure 10). Coupled with the large increase in the canoe and inshore fleets, this likely has produced in the last 10 years a massive increase in the fishing pressure on the small pelagic resource (Finegold et al., 2010).



Source: Finegold et al., 2010

Figure 6.8 Percentage of interviewed purse-seine (wasta) fishers in Western Region Using light fishing

Table 6.6 Symptoms of decline, sensitivities, and vulnerabilities of the marine fishery resources and associated changes in fishing effort and technology posing increasing risk to the resource

Category	Symptoms, sensitivities, and vulnerabilities
Pelagic Fishery	Inherently variable in productivity because of environmental drivers (e.g., sea-surface temperature, upwelling strength and duration), but species tend up to a point to be resilient and adapted to boom-and-bust cycles.
	Currently, experiencing most sustained period of catch decline across multiple important fishes (i.e., anchovies, sardinellas) (lowest level since the 1970s, when all fleets were much smaller) (Fig. 6.6).
	Decline coincides with initiation of light fishing which allows near year- round exploitation, primarily by canoe and semi-industrial fleets.
	Nearly all fleet categories exploit pelagic fishes, so pressure is from multiple zones on the continental shelf, depths, and gear types.
Demersal Fishery	Inherently more stable and less susceptible to environmental variability than pelagic fishery, but less resilient to over exploitation.
	Biomass of longer-lived, predatory fishes reduced.
	Decline in abundance of demersal fishes at 0-30 m depths.
	Other symptoms of inherent instability include: shifts in catch composition coinciding with apparent sequential over exploitation of dominant species; repeated collapses and recovery of stocks across multiple disparate species sudden appearance, dominance, and disappearance of species new to the fishery rapid population growth of formerly uncommon or moderately abundant species
	Targeted by the canoe, semi-industrial, and industrial fleets which have shown rapid growth in the last several decades suggesting increasing fishing pressure in multiple continental shelf zones, depths, and gear types.

Category	Symptoms, sensitivities, and vulnerabilities
Fishing effort and technology changes	Key catch statistics are lacking to quantify effort expended (e.g., effort among fleets, time spent fishing, net size and mesh differences and other gear differences, catch and effort often underreported, fabricated).
	Rapid sustained expansion in last few decades of canoe, semi-industrial (inshore), and industrial fleets coincide with drops in catch (Fig. 6.5).
	Semi-industrial fleet experiencing declines in catch per unit effort.
	Fishing effort and fishing pressure expanded enormously due to: • no registration or limits to access (canoe fleet) • extremely low self-reporting of industrial fleet of catch and effort provides strong indication of substantial under-reporting of catches • outboard motors (continued increase in power and expanded adoption allow canoe fishers to move farther along shore and offshore which combined with fisher reports of having to make longer trips to catch fish, suggests serial depletion of fisheries) (Fig. 6.5). • light fishing (opened up pelagic fish exploitation near year round) and rapidly adopted by semi-industrial and more recently canoe fleet (Fig. 6.8). • low maintenance, longer lasting netting allows more time fishing, increasing pressure per fisher • longer nets, more nets, and smaller mesh size per fisher increase fishing effort and pressure tremendously, but the effects on and trends in catch remain unquantified • pair trawling (illegal but apparently still commonly practiced) • transshipment and trade of by-catch (so called 'trash fish', small, low valued or damaged fishes) from industrial trawlers to canoe fishers encouraging near shore trawling and use of small mesh size, both increasing pressure on already highly pressured fisheries. • use of poisons and explosives as a non-selective fishing technique

Sources: compiled from Koranteng and McGlade, 2001; Koranteng and Pauly, 2004; Perry and Suamaila, 2007; Wiafe et al., 2008; Finegold et al., 2010 and references therein.

LAKE VOLTA FISHERY

The Volta River is one of West Africa's largest rivers, draining an area of 390,000 km² (Petr 1986). It is fed by the Black Volta, the White Volta, the Red Volta, and the Oti rivers. The Volta Basin covers parts of six countries: small portions are in Mali (4.8 percent), Cote d'Ivoire (3.2 percent), Togo (6.4 percent), and Benin (3.6 percent), and the majority of the basin lies in Burkina Faso (42 percent) and Ghana (40.2 percent) (Taylor et al., 2006).

Lake Volta, an impoundment on the Volta River covering 8,700 km² at maximum pool, extends some 400 km inland from Okosombo dam in the southern Eastern Region. The reservoir extends from the dam north into the Volta, Brong Ashafo, and Northern Regions. Not surprisingly, this large impoundment provides a large freshwater fishery. This lake reportedly produces about 98 percent of the inland freshwater fish in Ghana (Braimah, 2001; Andah and Gichuki, 2005; Lemoalle and Condappa, 2009), but apparently little to no accounting is made for fishes harvested from flowing rivers and streams in most of Ghana. In tonnage, Volta Lake reportedly produced about 87,500 tonnes of fish in 2000, but annual catch statistics are contradictory ranging from 40,000 to 250,000 tonnes/year depending on the author (Lemoalle and Condappa, 2009). An estimated 1,232 fishing villages and 79,900 fishers were estimated in 1998 to be scattered along the 4,300 km shoreline. Fishers used at least 11 gear types to fish, ranging from widespread use of nets (especially gill nets, cast nets, and beach seines) to traps, hook and line, and to a small extent spears. Fishing vessels consisted of an estimated 24,035 plank canoes most of which are open and non-motorized but a small percentage (<5 percent) are open motorized, decked non-motorized, or decked and motorized (Braimah, 2001; Dontwi et al., 2008). This fishery is reportedly already experiencing overexploitation, but the data or analyses on which these are based are unclear. Some indicate if the current practices (illegal nets, such as beach seines and purse seines and small mesh sizes) are not regulated, the fishery could collapse in the near future (Andah and Gichuki, 2005). The construction of the Akosombo Dam for hydropower, which drastically altered the annual flooding downstream, also resulted in the loss of several lagoons and creeks in the estuary which served as important fishing grounds. Associated with the shift in the estuarine salt wedge was the loss of the clam and prawn fisheries in the main channel that were a major source of livelihood (Andah et al., 2005; Lemoalle and Condappa, 2009).

The potential impacts of increased temperatures or changes in rainfall as a result of climate change are at this point unpredictable for Lake Volta or any other inland fisheries in Ghana. Little up-to-date, quantitative data is apparently available for this important fishery although as noted, some sources indicate the fishery is declining or at risk of decline under current fishing pressure. Continued warming as predicted by current trends and climate model projections could, for example, affect primary and secondary productivity in feeder rivers and the reservoir, changing the seasonality, quality, and quantity of the food source of fishes in unknown ways. Warming would likely also affect rates of egg development, fish metabolism and growth, and ultimately recruitment, and perhaps even the timing of reproduction of Lake Volta fishes. Similarly, future climate scenarios resulting in dramatically decreased or increased river flows (Kasei, 2009, see Desertification section) would also likely affect the fishery but in less easily conceptualized ways. For example, in the case of reduced flow, lower water levels in Lake Volta and tributaries would reduce the area of shallow, shoreline habitat. In turn, loss of the vegetated shoreline-lake interface would affect fishes using such habitats for feeding, spawning, or nursery areas. Depending on timing and variability, higher flows could change seasonal turbidity (and perhaps primary and secondary productivity) and dilute food resources, resulting in largely unpredictable changes on larvae, juveniles, and adult fishes. Clearly, the current state of the inland fishery resource in Ghana deserves further scientific attention as does the potential impacts climate change might have on this resource.

CLIMATE CHANGE AND THE MARINE FISHERY

The most prominent effect of climate change on marine productivity and ultimately the fishery could be increased sea temperatures, even though the primary proximate driver of productivity, the upwelling system, is admittedly complex and certainly not totally understood (Wiafe et al., 2008). Changes in sea temperature could affect primary (phytoplankton) and secondary (zooplankton) production which in turn could dramatically increase or decrease the abundance of pelagic fishes and their predators.

Historical trend analyses of sea temperature in the Gulf of Guinea tend to show increasing trends in sea-surface temperatures for the period of record in the late 20th century. Simple regression of annual mean data from about 1960-2001 indicated generally low interannual variability and an increased trend, albeit non-significant, in sea-surface temperature (Dontwi et al., 2008). Another more detailed analysis (covering through 1992) showed: an overall increase in offshore sea-surface temperature from 1946-1990 with some evidence of short-lived, cyclical, decadal decreases; consistently increasing temperatures during the second warm (or low) season between 1975-1992, generally increasing sub-surface temperature (100 m depth) from 1969-1992, increasing sea-surface and sub-surface temperatures during the second warm or low season, generally reduced temperatures during the minor upwelling period (i.e., the upwelling was intensified), and slight increases in temperatures during the main warm or low season (i.e., intensification of warming).

The period 1963-1992 could be divided into three distinct periods: an unsettled period from 1963-1974; a "cold" period from 1975-1980; and a "warm" period from 1981-1992. These periods apparently influenced the dynamics of the pelagic fishery resources with significant changes in the distribution and abundance of species coinciding with climatic periods (Koranteng and McGlade, 2001). Notably, another detailed analysis of seasonal trends over a 24-year period (1968-1992) showed the annual cyclical nature of temperature and zooplankton productivity but also revealed gradual increases in sea-surface temperature for the major upwelling and second warm or low season (second thermocline) periods (Waife et al., 2008). Notably, these upward trends in sea-surface temperature were associated with significant decreasing trends in zooplankton biomass. Although other factors certainly influenced biomass of zooplankton (e.g., biomass of and predation by sardinella larvae), increased sea-surface temperatures accounted for >50 percent of the variation in zooplankton biomass (Waife et al., 2008). Notably, future projections of sea-surface temperature from Global Climate Models estimate a 0.4, 1.4, and 2.7°C increase in sea-surface temperature in coastal waters of Ghana by 2020, 2050, and 2080, respectively (Minia, 2008).

The most abundant pelagic species in the upwelling region of the Gulf of Guinea all are zooplankton dependent at early life stages and some are zooplankton dependent as adults (i.e., round sardinella, *Sardinella aurita*; Madeiran sardinella, *S. maderensis*; European anchovy' (*Engraulis encrasicolus*; in some years, chub mackerel, *Scomber japonicas*; Mensah and Koranteng, 1988; Koranteng, 1995). Plankton abundance, providing forage for juvenile or adult fish, may be more important for sustaining stock biomass of some species than spawning success and larval survival

(Binet, 1995). Even if the declining zooplankton biomass is adequate for survival of the main fishery stocks (Mensah, 1995), a month's lag exists between the peaks of sardinella larval abundance and total zooplankton biomass, suggesting, not surprisingly, a temporal matching between predators and peak larval food. As such, a potential exists for climate change to cause a mismatch between larval pelagic fish abundance and their food, which could compromise recruitment. Significant decline in zooplankton biomass occurred from the late 1960s to the early 1990s, a decline attributed to the trend in global warming (Wiafe et al., 2008). Although biological (top–down) control was also important, no long-term trend in the abundance of the predatory fish larvae was detected. The zooplankton time-series analysis at the biomass level combined with the knowledge of the biology and distribution of the dominant species during the major upwelling (i.e., the copepod, *Calanoides carinatus*) indicated the current trend in warming of the ocean, especially during the major upwelling, could shift zooplankton community abundance and structure and impact fishery resources (Wiafe et al., 2008).

7. SOCIAL VULNERABILITY TO CLIMATE CHANGE IN GHANA

DEFINING AND ASSESSING SOCIAL VULNERABILITY TO CLIMATE CHANGE

New definitions of climate change vulnerability are constantly evolving (Kelly and Adger, 2000; O'Brien et al., 2004). In the context of climate change, definitions of vulnerability typically fall into two camps. The more traditional definitions assess vulnerability from what Kelly and Adger (2000) deem "the *end point* of a sequence of analyses." An end point analysis would determine the level of vulnerability by summarizing the net impact of problems associated with climate change. The second school considers vulnerability as "a starting point for analyses… Here, vulnerability is considered a characteristic of social and ecological systems that is generated by multiple factors and processes." (O'Brien et al., 2004a). Kelly and Adger (2000) take this definition further, defining vulnerability "in terms of the ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well being." Critical to the starting-point definition of vulnerability is the understanding that it is dynamic and in a continuous state of flux, as the biophysical and social processes that shape people's ability to cope with external stress change over time and across space (O'Brien et al., 2004a).

For purposes of this assessment, we adopt a "starting point" definition of social vulnerability to climate change, adhering to the Kelly and Adger (2000) definition of social vulnerability. We treat vulnerability as a measurable characteristic present within a population, and influenced by multiple socioeconomic and biophysical factors. Our assessment approach includes four main steps. First, we identified variables that contribute to social vulnerability to climate change, on the basis of the academic literature. Second, we selected socioeconomic indicators that served as proxies for evaluating these variables at the district level in Ghana. Third, we scaled the index values and combined them into an index to measure overall social vulnerability to climate change at the district level. Finally, using GIS we mapped the values generated by the index (high values correspond with high vulnerability) across districts. (Please see the methods section for a more detailed explanation of this process.) The scaled, mapped index values can be used to compare social vulnerability to climate change across districts in Ghana, and to facilitate analysis of social vulnerability in relation to ecological zone, climate, and natural resource vulnerability to climate change.

Social vulnerability varies by spatial scale: among members of a household, between households in a community, from community to community, and between districts and administrative regions. Given the need to provide a nationwide assessment, our objective was to characterize vulnerability at the smallest scale practicable using existing data sets. Thus, the purpose of this assessment is to help identify vulnerability "hot spots" within Ghana that may deserve attention when making decisions about where and how to implement development interventions (such as improving food security) to help people and communities build their adaptive capacity and increase their resilience to climate change and its impacts. These are places where more fine-scaled analysis is called for to reveal actual vulnerabilities and strategies to address them. It is important to note that vulnerability is a relative term. The districts ranking lower on our vulnerability scale are not necessarily invulnerable to climate change; and some individuals, households, and communities within these less vulnerable districts may be as vulnerable to climate change as those in the high vulnerability districts.

METHODS

As described above, to assess social vulnerability to climate change in Ghana, we developed a vulnerability index based on socioeconomic variables that were identified through a review of the climate change social vulnerability literature. We then selected indicators capable of serving as proxies for those variables for which we could obtain district-level data from existing sources. Our decision to focus on the administrative district limited our choice of indicators. The 11 indicators we used to construct the index are presented in Table 7.1, along with our rationale for choosing them and the sources from which we obtained the data.

To construct the social vulnerability index we first compiled data for the 11 indicators selected to serve as proxy measurements of social vulnerability to climate change. We then analyzed the data for each individual indicator using a variety of methods in ArcGIS, and chose the "natural breaks" classification method. Natural breaks (Jenks method) is a classification method that uses a statistical approach to group values into a pre-determined number of classes in a manner that minimizes variance within each class, and maximizes variance between classes, resulting in "natural breaks" in the dataset that are based on the data's distribution. We chose to create 10 classes for our data in order to examine differences between districts at a more refined level than fewer classes would allow, but that would still be visually discernable when mapped. (Note, due to the natural breaks approach, each class does not have an equal number of districts, nor is the range of values within each class set at consistent intervals, as indicated in the map legends.) After sorting the data for an indicator into 10 classes, we assigned each district a score for that indicator (from 1 to 10), depending on which class it fell into. One signified the lowest vulnerability class, and 10, the highest. Because we used 11 indicators in our vulnerability index, each district ultimately received 11 different scores, one for each indicator.

To combine the individual indicator values for purposes of creating one vulnerability index value for each district, we summed the 11 indicator scores for each district. Indicators were equally weighted because there is no evidence in the literature to suggest that any one indicator is more or less significant than another in influencing social vulnerability to climate change. Thus, the highest possible vulnerability score a district could receive was 110, and the lowest, 11. Finally, the index values were mapped, using ArcGIS software, into five vulnerability categories and 10 vulnerability categories, for comparison, based on their total scores and using the natural breaks method. The actual overall district vulnerability scores ranged from 25 to 93.

A number of factors limit our assessment. First, we used data from only one time period – the most recent for which data were available – rather than looking at temporal trends in the indicators. The lack of long-term, historical data at the district level for Ghana, combined with widespread changes in district boundaries over time, necessitated this approach. Second, the data we used are not recent; many of them come from Ghana's 2000 Population and Housing Census. Although Ghana conducted another population and housing census in 2010, initial results will not be released at the district level until 2012 (GoG, 2011). Because of this, our data pertain to the 110 districts that existed prior to 2006. Today, Ghana has 170 districts; we have not attempted to overlay current district boundaries on the 110 for which we have data because maps depicting newly created districts are not readily available. Another limitation was our inability to capture some components of social vulnerability to climate change with a proxy measure that best suited that component, or with any measure at all. For example, the literature suggests that health as a vulnerability indicator is best measured through life expectancy. However, life expectancy data were not easily accessible at a district level in Ghana; instead, we used childhood malnutrition. Moreover, we were unable to obtain any proxy measures for variables such as political involvement, social networks, and governance – all of which can play an important role in determining vulnerability to climate change. Despite these limitations, we believe that our index is useful for drawing attention to districts of Ghana that are likely to have high social vulnerability in the context of climate change.

Table 7.1 Social Vulnerability Indicators Included in the Index

Indicator	Description	Data source and year	Impact on vulnerability	Relevance for climate change social vulnerability	Other studies using this (or something similar) as an indicator of climate change social vulnerability
Ability to survive crisis	The percentage of total households within a district that felt either "somewhat" or "very" insecure about their ability to withstand any crisis	Ghana 2003 Core Welfare Indicators Questionnaire Survey Report: Statistical Abstract, Ghana Statistical Service (hereafter, CWIQ II)	High percentage increases vulnerability	Households that already feel insecure about their ability to withstand even a short-term crisis are likely to be equally unable to weather long-term threats to their livelihoods, or have enough extra capital to invest in necessary adaptation measures.	Brooks et al., 2005 Eriksen et al., 2007
Agricultural employment	The percentage of the district's total population > 15 years of age that is engaged in agriculture-related employment (including hunting and forestry related activities).	2000 Population and Housing Census, Analysis of District Data and Implications for Planning, Ghana Statistical Service (hereafter 2000 Census)	High percentage increases vulnerability	Agriculture is an especially climate-sensitive economic activity. Agricultural employment is likely to underestimate the extent to which a district depends on agriculture. However the higher the agricultural employment, the more a district will be impacted by disruptions in production due to changing environmental conditions. Reduced production will cause a similar reduction in disposable income. High agricultural employment also suggests a lack of other employment options, and therefore few opportunities for failing farmers to earn additional income through other economic pursuits (O'Brien et al., 2004b). People are more likely to fail to secure their needs in a time of crisis when they are restricted to a single sector for employment (Eriksen et al., 2007).	Social Vulnerability for Environmental Hazards, 2000 (USC) Brooks et al., 2005 O'Brien et al., 2004a Eriksen et al., 2007 Adger et al., 2004
Dependent population	The percentage of a district's total population that is < 15 and > 65 years of age	CWIQ II	High percentage increases vulnerability	Individuals <15 and >65 years of age depend on family members or social services for financial support. A district with a higher dependent population is forced to stretch resources further; households must juggle work responsibilities with care for dependents, threatening the household's ability to withstand disaster. Individuals who depend on social services for survival are often elderly, economically and socially marginalized, and require additional support in a post- disaster period (USC, 2000).	Social Vulnerability for Environmental Hazards, 2000 (USC) Brooks et al., 2005 Eriksen et al., 2007

Indicator	**Description**	**Data source and year**	**Impact on vulnerability**	**Relevance for climate change social vulnerability**	**Other studies using this (or something similar) as an indicator of climate change social vulnerability**
Distance from drinking water	The percentage of total households within a district that travel ≥30 minutes for drinking water	CWIQ II	High percentage increases vulnerability	The non-availability of clean water is indicative of poor overall physical infrastructure and poor sanitation (Adger et al., 2004). Additionally, households forced to travel ≥30 minutes to fetch water are also severely constrained by the time commitment and less likely to have extra time to put towards adaptation activities that might strengthen their well being in times of crisis. Climate-induced change in water availability may cause households to travel even farther for drinking water, increasing household stress.	Global Environmental Risk, 2001 Brooks et al., 2005 Haan et al., 2001 Adger et al., 2004
Distance from food market	The percentage of total households within a district that travel ≥30 minutes to reach a food market	CWIQ II	High percentage increases vulnerability	Households that must travel ≥30 minutes to reach a food market are much more isolated and likely more vulnerable. Limited access to commercial infrastructure limits opportunities to sell excess produce or livestock or engage in other entrepreneurial activities in times of crisis (Adger et al., 2004). Isolation also makes it difficult for aid distribution programs to provide relief in response to disasters like droughts, floods or famines. Less connection to outside villages indicates a smaller domestic social support network for families to fall back on in times of need.	Global Environmental Risk, 2001 Brooks et al., 2005 Haan et al., 2001 Eriksen et al., 2007 Adger et al., 2004
Female-headed households	The percentage of total households within a district that are headed by a female	CWIQ II	High percentage increases vulnerability	Households headed by females often have a more difficult time recovering from environmental disasters due to employment limitations, lower wages, and family care responsibilities (USC, 2000; Eriksen et al., 2007). In Ghana, women depend more on agricultural work and have limited access to capital and property, making it increasingly difficult for female headed households to diversify in the face of needed adaptation or otherwise compete for resources.	Social Vulnerability for Environmental Hazards, 2000 (USC) Global Environmental Risk, 2001 Brooks et al., 2005 Haan et al., 2001 Eriksen et al., 2007
Illiteracy	The percentage of the district's total population > 15 years of age that is illiterate. Illiteracy is defined as the inability to	2000 Census	High percentage increases vulnerability	Education is associated with poverty and marginalization – the least educated and lower skilled members of a society are likely to be the most vulnerable to climate hazards in terms of livelihoods and geographical location, depending	Social Vulnerability for Environmental Hazards, 2000 (USC) HIS

Indicator	Description	Data source and year	Impact on vulnerability	Relevance for climate change social vulnerability	Other studies using this (or something similar) as an indicator of climate change social vulnerability
	read or write in English, any Ghanaian language, or any foreign language.			more on climate-sensitive forms of employment (like agriculture and fishing). They are also less likely to have a political voice and their welfare may be a low priority on a national level (Adger et al., 2004) Illiteracy serves as a barrier to facilitating understanding of the complex nature of hazards and appropriate responses to them (Brooks et al., 2005).	Brooks et al., 2005 Haan et al., 2001 O'Brien et al., 2005 Eriksen et al., 2007
Malnourished children	The percentage of all 0-59 month old children, within a district, that are considered underweight for their age. Children are considered underweight if their weight is more than two standard deviations below the United States National Center for Health Statistics' standard weight for age.	CWIQ II	High percentage increases vulnerability	People in poor health, and those who are undernourished, will be more vulnerable to the immediate and secondary impacts of extreme events, whether this takes the form of direct physical injury or a more complex impact such as food shortage or famine. A population in poor general health is less likely to be prepared for a disaster, and less likely to be able to cope with the impacts of a disaster in the short term. Families caring for sick or malnourished members have less time, money, and energy to invest in activities that might mitigate the impacts of external hazards, recover from hazard events, or prepare for the future (Adger et al., 2004).	Brooks et al., 2005 Eriksen et al., 2007 Haan et al., 2001 Adger et al., 2004
Poverty Perception	The percentage of total households within a district that self identified as either "poor" or "very poor"	CWIQ II	High percentage increases vulnerability	Poor people often lack the education, skills, financial resources, and networks that are increasingly necessary to procure income or diversify away from a failing livelihood (Eriksen et al., 2007). Poor communities often face greater levels of risk than more affluent populations (United Nations, 2001). Poor people are more likely to live in hazard-prone locations, but will be less likely to invest in adaptation measures as they have more immediate priorities (Adger et al., 2004).	Global Environmental Risk, 2001 Brooks et al., 2005 Eriksen et al., 2007 Brooks 2003 Adger et al., 2004
Road Accessibility	The percentage of households within a district that can access their homes by road throughout the year	CWIQ II	High percentage decreases vulnerability	The existence of a reliable transportation network, year round, increases the ability of rural populations to access markets to sell excess produce or livestock or engage in other entrepreneurial activities in times of crisis (Adger et al.,2004). A well-developed transportation system also enables a more efficient system of aid delivery and increases	Global Environmental Risk, 2001 Brooks et al. 2005 Haan et al., 2001 Eriksen et al. 2007 Adger et al. 2004

Indicator	Description	Data source and year	Impact on vulnerability	Relevance for climate change social vulnerability	Other studies using this (or something similar) as an indicator of climate change social vulnerability
				the ability of communities to participate in policy. Lack of access at any time during the year increases vulnerability by further isolating remote settlements and limiting the extent to which social networks and structures can make a meaningful difference in terms of contributing to adaptation and reducing vulnerability.	
Unimproved drinking water source	The percentage of total households within a district that depend on unimproved sources for their drinking water. Unimproved sources include rainwater, rivers, lakes, ponds, and unprotected wells.	CWIQ II	High percentage increases vulnerability	Districts with better infrastructure are expected to have a higher capacity to adapt to climate fluctuations and other economic shocks (O'Brien et al., 2004). Households that rely on rainfall or water bodies for drinking water have fewer adaptation options if those sources are negatively impacted by climate change. Further, unimproved water sources present greater health risks.	Global Environmental Risk, 2001 Brooks et al. 2005 Haan et al., 2001 O'Brien et al. 2004

RESULTS AND DISCUSSION

The final section of this social vulnerability analysis contains a reference map and tables that can be used to identify individual Ghana districts. It also contains a map for each of the 11 indicators used in the social vulnerability index that shows data pertaining to that indicator for each district.

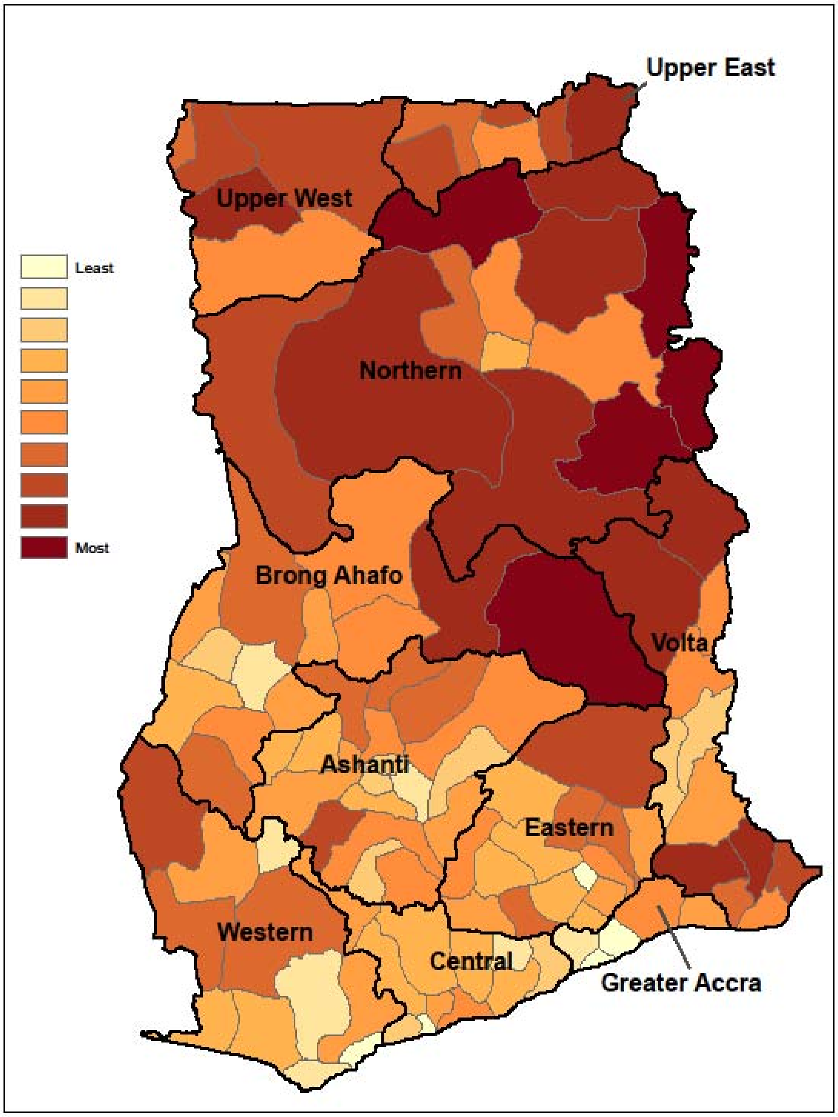


Figure 7.1 Social Vulnerability to Climate Change in Ghana, by District

(Based on the 110 district boundaries in place prior to 2006)

The districts of Ghana that have the highest overall social vulnerability to climate change are concentrated in the Upper West, Upper East, and Northern Regions (Figure 7.1). Within these three regions, the districts having the lowest vulnerability scores are those containing the regional capitals, making them the more urban districts: Wa, Bolgatanga, and Tamale, respectively. Tamale District has the lowest vulnerability of any district in the three northern regions, which is not surprising, considering that Tamale is the largest city in northern Ghana. Nevertheless, this district exhibits medium vulnerability relative to the rest of the country. Other districts exhibiting high social vulnerability to climate change are located in northern Volta Region and eastern Brong-Ahafo, most of them bordering the Northern Region. The southern-most part of Volta Region also has high social vulnerability to climate change. As a whole, Volta Region had the fourth highest overall social vulnerability to climate change. The vast majority of Ghana districts having high social vulnerability to climate change lie in the Sudan and Guinea Savanna ecological zones, with the remainder clustered in the Forest-Savanna Transition zone.

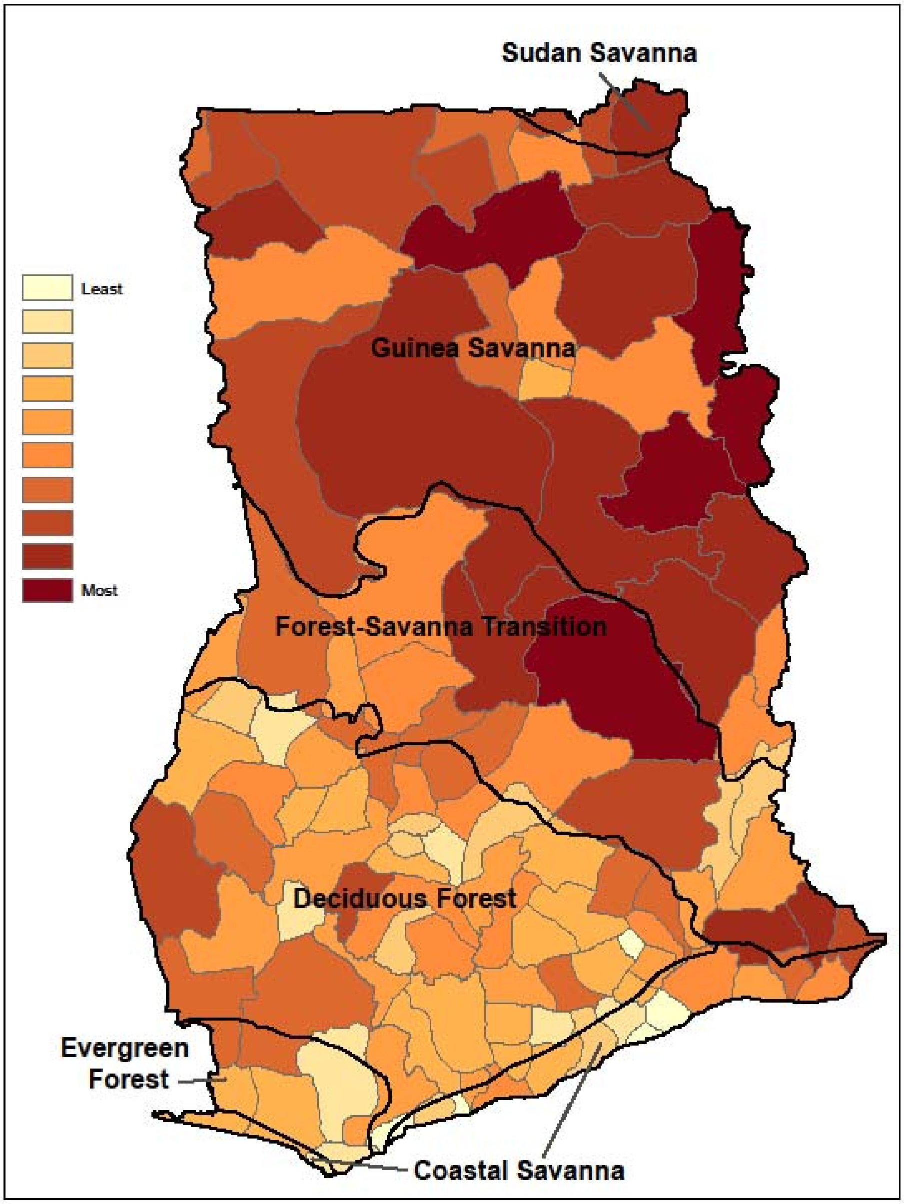


Figure 7.2 Social Vulnerability to Climate Change in Ghana, by Ecological Zone

Examination of the average district scores for each indicator in the index sheds light on why the Northern, Upper East, and Upper West Regions scored highest in overall social vulnerability (Table 7.2). Infrastructure-related indicators (road access, distance from drinking water, and distance from a food market) stand out as influential. Extremely high rates of illiteracy are also found in these regions. And, they exhibit the highest dependency on agricultural employment. Finally, perceived poverty is substantially higher in the northern regions. Interestingly, these three regions exhibit the lowest percentages of female-headed households in Ghana, making them less vulnerable to climate change from this standpoint.

Two other socioeconomic indicators that are important in considering social vulnerability to climate change are population growth and poverty. Population growth increases pressure on natural resources, exacerbating the negative effects of climate change. Poverty makes households more vulnerable to climate change because poor households generally have fewer options and less capacity for adaptation. We were unable to obtain data for these variables at the district level for purposes of this analysis. However, regional-level data make it possible to examine population growth and poverty in the regions most socially vulnerable to climate change.

Population growth rates for each region were provided in Chapter 5, Section C (Population and Economy). Here we focus on changes in regional population density (Table 7.3). Population density in the Upper East and Upper West regions of Ghana more than doubled between 1960 and 2010, and more than quadrupled in the Northern Region. Although the increase in population density in Upper East and Upper West was below the national average for this same time period, population density in the Upper East Region in 2010 (117 persons/km^2) was above the national average (102 persons/km^2), and more than three times higher than in the other two northern regions. This is surprising, considering the Upper East Region lies in the Sudan Savanna, which is drier and more marginal for agriculture than the Guinea Savanna. High population density in the Upper East Region may be a partial reflection of immigration by migrant herders from the north during the 20th century, but also reflects other more complex historical factors (e.g., military strength and stability, lack of slave raids, hosting refugees from neighboring tribes [Dickson and Benneh, 1988]). Annual population growth in the Northern Region between 2000 and 2010 was 3.1 percent, well above the national average of 2.5 percent. Nevertheless, this region had the lowest population density of any in Ghana in 2010. Population growth rates in Upper East and Upper West were 1.1 percent and 1.6 percent, respectively, suggesting out-migration to regions farther south. These findings indicate that all three northern regions are experiencing increases in population pressure – particularly the Northern Region – an additional challenge for climate change adaptation in these regions that have a high dependence on agricultural employment.

Regarding poverty, over the past two decades, rural areas in the Guinea and Sudan savanna ecological zones in northern Ghana have consistently exhibited the highest incidence of poverty in the country (Table 7.4). The most recent data (2005-06) show that poverty incidence in the rural savanna is more than double that of any other ecological zone; 60.1 percent of all households were living below the poverty line. At the scale of administrative regions, the Upper West Region has the highest poverty, with 88 percent of households living below the national poverty line in 2005-06 – three times the national average (Table 7.5). It was closely followed by Upper East, at 70 percent. The Northern Region exhibits the next highest poverty incidence in Ghana, at 52 percent. Although overall poverty in Ghana has steadily declined since the early 1990s, this was not the case in the Upper West or Upper East Regions.

Table 7.2 Social Vulnerability Index and Individual Indicator Scores, by Region, Based on District Averages

	Index Value	Dependent population	Distance from drinking water	Distance from food market	Female-headed households	Unimproved drinking water source	Malnourished children	Poverty Perception	Ability to survive crisis	Illiteracy	Agricultural employment	Road Access
	regional average											
	range of district level scores											
Ashanti	**55**	**6.7**	**2.2**	**4.1**	**6.8**	**4**	**6.9**	**5.2**	**4.4**	**4.2**	**5.9**	**4.6**
	33-75	*2-10*	*1-4*	*1-10*	*4-10*	*1-8*	*1-10*	*1-9*	*1-9*	*1-7*	*1-10*	*2-9*
Brong Ahafo	**61.0**	**5.8**	**4.8**	**5.1**	**6.8**	**5.5**	**4.3**	**5.7**	**5.3**	**4.8**	**6.7**	**6.2**
	36-87	*2-10*	*2-9*	*1-10*	*2-10*	*1-9*	*1-9*	*1-9*	*1-9*	*2-8*	*3-9*	*2-10*
Central	**48.1**	**5.8**	**2.8**	**2.8**	**7.4**	**3.0**	**5.1**	**4.4**	**4.4**	**4.7**	**4.4**	**3.3**
	29-62	*2-10*	*1-6*	*1-7*	*4-10*	*1-5*	*1-8*	*1-7*	*1-8*	*1-7*	*1-7*	*1-7*
Eastern	**56.5**	**5.6**	**4.1**	**4.6**	**6.5**	**5.2**	**5.5**	**5.3**	**7.1**	**3.3**	**4.5**	**4.8**
	25-75	*2-9*	*1-8*	*1-10*	*3-9*	*2-9*	*1-10*	*1-9*	*4-10*	*1-7*	*1-8*	*1-9*
Greater Accra	**41.8**	**1.8**	**3.6**	**5.0**	**6.4**	**2.2**	**6.8**	**3.8**	**4.2**	**3.0**	**1.6**	**3.4**
	29-61	*1-3*	*1-7*	*1-10*	*5-8*	*1-4*	*3-10*	*2-7*	*2-6*	*1-6*	*1-3*	*2-6*
Northern	**76.6**	**7.4**	**7.6**	**8.4**	**1.1**	**7.7**	**6.9**	**7.7**	**5.5**	**9.5**	**8.2**	**6.7**
	52-93	*2-10*	*3-10*	*6-10*	*1-2*	*4-10*	*1-9*	*4-10*	*1-10*	*7-10*	*2-10*	*2-9*
Upper East	**71.8**	**5.5**	**5.8**	**9.5**	**2.8**	**4.2**	**4.5**	**8.7**	**7.0**	**8.7**	**7.2**	**8.0**
	61-81	*3-9*	*3-8*	*8-10*	*1-7*	*3-6*	*2-7*	*8-10*	*3-10*	*8-10*	*4-10*	*5-10*
Upper West	**70.4**	**7.6**	**6.8**	**9.0**	**3.0**	**2.2**	**6.0**	**9.0**	**4.2**	**8.6**	**7.8**	**6.2**
	61-77	*6-10*	*3-8*	*8-10*	*2-5*	*1-3*	*1-9*	*8-10*	*2-6*	*8-9*	*6-10*	*3-10*
Volta	**65.6**	**5.6**	**6.0**	**6.3**	**6.8**	**7.5**	**5.3**	**6.0**	**6.8**	**4.5**	**4.8**	**5.9**
	39-83	*2-10*	*3-8*	*3-9*	*2-10*	*4-10*	*2-9*	*2-10*	*1-10*	*1-8*	*2-9*	*1-9*
Western	**51.1**	**3.6**	**2.9**	**4.6**	**4.7**	**5.8**	**5.1**	**3.7**	**3.7**	**4.9**	**6.0**	**5.9**
	31-71	*2-6*	*1-6*	*1-9*	*3-7*	*2-9*	*1-9*	*2-7*	*1-7*	*2-7*	*1-10*	*1-10*

Table 7.3 Population Density, 1960-2010, by Region

Region	Area *(km²)*	Population *(2010)*	*Population density (per km²)* 1960	1970	1984	2000	2010
Western	23,921	2,325,597	26	32	48	81	97
Central	9,826	2,107,209	76	91	116	162	214
Greater Accra	3,245	2,909,764	167	278	441	896	1,205
Volta	20,572	2,099,876	35	46	59	80	102
Eastern	19,324	2,596,013	54	63	87	109	134
Ashanti	24,390	4,725,046	45	61	86	148	194
Brong-Ahafo	39,557	2,282,128	15	19	31	46	58
Northern	70,383	2,468,557	8	10	17	26	35
Upper East	8,842	1,031,478	53	61	87	104	117
Upper West	18,477	677,763	16	17	24	31	37
Ghana	238,537	24,223,431	28	36	52	79	102

Source: Adeku and Kwafo 2005; Ghana 2010 Population and Housing Census Provisional Results

Table 7.4 Incidence of Poverty (Percentage) by Ecological Zone[a]

Ecological Zone	1991/92	1998/99	2005/06
Accra (GAMA[b])	23.1	4.4	10.6
Urban Coastal	28.3	31.0	5.5
Urban Forest	25.8	18.2	6.9
Urban Savanna	37.8	43.0	27.6
Rural Coastal	52.5	45.6	24.0
Rural Forest	61.6	38.0	27.7
Rural Savanna	73.0	70.0	60.1
Urban	*27.7*	*19.4*	*10.8*
Rural	*63.6*	*49.5*	*39.2*

Source: Ghana Statistical Service, 2007

[a] Incidence of poverty is given as a percentage of households within the given ecological zone living on <3,708,900 cedis/yr. The Ghana Statistical Service uses two levels of poverty: the upper line of poverty is set at the above figure, the lower line of poverty is set at 2,884,700 cedis (survey conducted prior to Ghana's currency adjustment). The US equivalent is about $245 for the upper level and $191 for the lower, based on spring 2011 exchange rates.

[b] Greater Accra Metropolitan Area

Table 7.5 Incidence of poverty (percentage) by Administrative Region, 1991/92 to 2005/06

Administrative Region	1991/92	1998/99	2005/06
Western	60	27	18
Central	44	48	20
Greater Accra	26	5	12
Volta	57	38	31
Eastern	48	44	15
Ashanti	41	28	20
Brong-Ahafo	65	36	29
Northern	63	69	52
Upper East	67	88	70
Upper West	88	84	88
Ghana	*52*	*40*	*29*

(See footnote to Table 6.C.4 for definition of poverty levels)

Source: Ghana Statistical Service, 2007

Ghana increases its social vulnerability to climate change, and will pose additional challenges for climate change adaptation.

CONCLUSIONS

Based on the measures used in this analysis of social vulnerability to climate change in Ghana, we find that the Upper East, Upper West, and Northern administrative regions have the highest overall social vulnerability to climate change. The eastern portion of Brong Ahafo Region and the far northern and southern-most districts of Volta Region, also exhibit high social vulnerability to climate change. Urban districts appear to be less vulnerable than rural districts, probably because of the relatively well-developed infrastructure and opportunities for economic diversification. The Upper East, Upper West, and Northern regions also have a much higher incidence of poverty than other regions of Ghana; and more than doubled (Upper East, Upper West) or quadrupled (Northern) in population density between 1960 and 2010. These three regions lie in the Sudan and Guinea Savanna ecological zones. The Forest-Savanna Transition Zone has the next highest social vulnerability to climate change in Ghana, following the savanna zones. Notably, the social vulnerability index, which contains no direct meteorological information, describes a general north-to-south decreasing vulnerability gradient which is congruent with a north-to-south decreasing gradient in rainfall. The congruent pattern of the two data sets, social vulnerability to climate change and rainfall patterns, is not likely a coincidence. Should climate change bring decreased rainfall, higher temperatures, or both, concomittant increased social vulnerability along this gradient is a logical expectation (see Chapter 3, Ghana's Climate and Projected Changes). These data emphasize that Ghana's three northern regions deserve attention for investments that support climate change adaptation. Nevertheless, other parts of the country that are highly vulnerable, such as eastern Brong-Ahafo Region and northern Volta Region, also warrant assistance. In addition, this vulnerability assessment is relative; less vulnerable districts are nevertheless still vulnerable to climate change. Finally, this assessment focuses at a fairly broad geographic scale. As the following chapter on climate change adaptation indicates, it is also important to assess climate change vulnerability and adaptation at the local level.

REFERENCE AND INDICATOR MAPS[5]

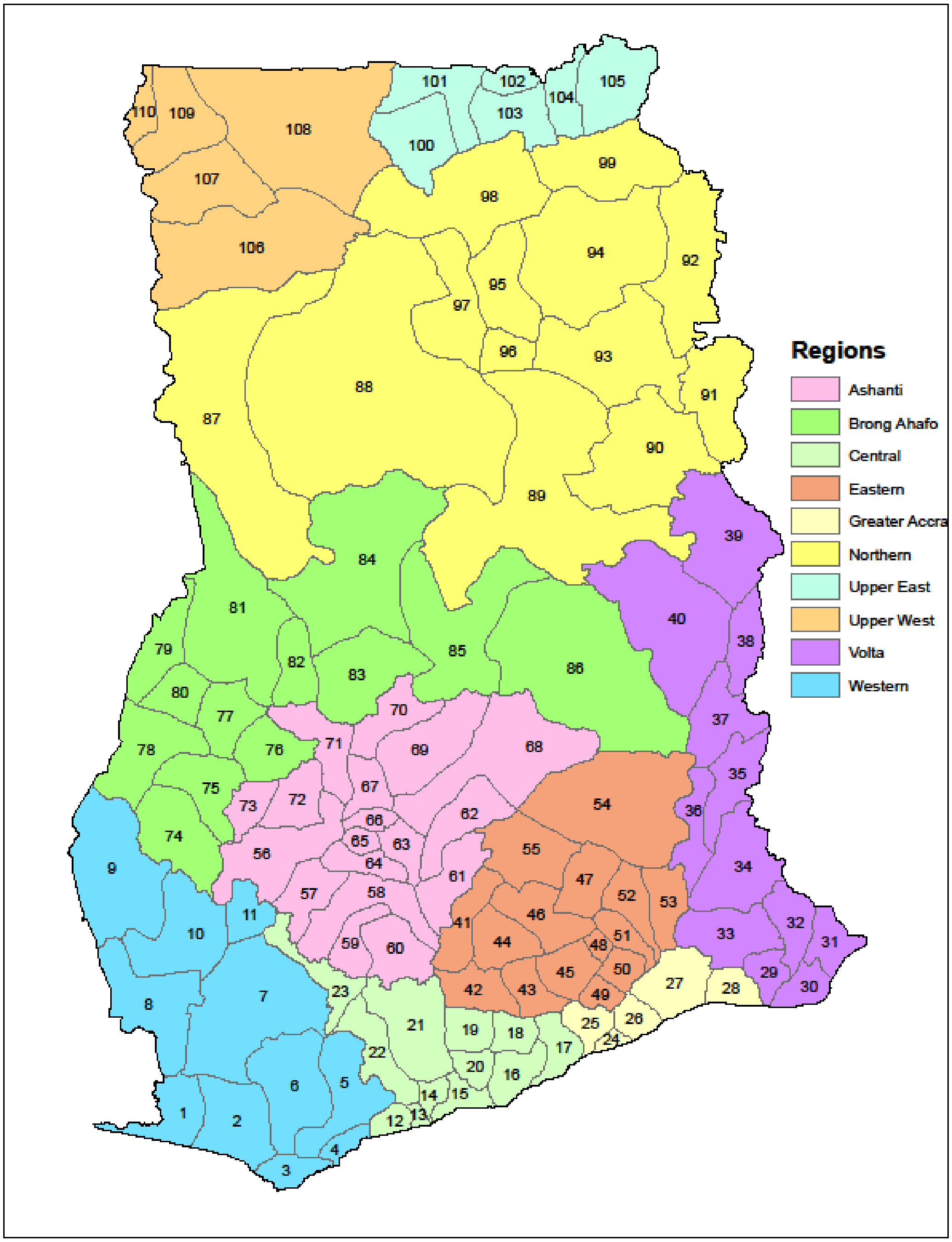


Figure 7.3 Reference Map for Identifying Ghana Districts.

(see Tables 7.6 and 7.7 that follow)

5 The legend values on the indicator maps represent actual percentages of the population or of households, based on survey data; they do not signify the district vulnerability score (assigned on a scale of 1-10) for a given indicator.

Table 7.6 Ghana District Names, Referenced by Map Number

Nos.	**District**	Nos.	**District**	Nos.	**District**
1	Jomoro	**42**	Birim South	**83**	Nkoranza
2	Nzema East	**43**	West Akim	**84**	Kintampo
3	Ahanta West	**44**	Kwaebibirem	**85**	Atebubu
4	Shama Ahanta East Metropolis	**45**	Suhum-Kraboa-Coaltar	**86**	Sene
5	Mpohor-Wassa East	**46**	East Akim	**87**	Bole
6	Wassa West	**47**	Fanteakwa	**88**	West Gonja
7	Wasa Amenfi	**48**	New Juaben Municipality	**89**	East Gonja
8	Aowin-Suaman	**49**	Akuapim South	**90**	Nanumba
9	Juabeso-Bia	**50**	Akuapim North	**91**	Zabzugu-Tatale
10	Sefwi-Wiawso	**51**	Yilo Krobo	**92**	Saboba-Chereponi
11	Bibiani-Anhwiaso-Bekwai	**52**	Manya Krobo	**93**	Yendi
12	Komenda-Edina-Eguafo-Abirem	**53**	Asuogyaman	**94**	Gushiegu-Karaga
13	Cape Coast Municipality	**54**	Afram Plains	**95**	Savelugu-Nanton
14	Abura-Asebu-Kwamankese	**55**	Kwahu South	**96**	Tamale
15	Mfantsiman	**56**	Atwima	**97**	Tolon
16	Gomoa	**57**	Amansie West	**98**	West Mamprusi
17	Awutu-Effutu-Senya	**58**	Amansie East	**99**	East Mamprusi
18	Agona	**59**	Adansi West (North)	**100**	Builsa
19	Asikuma-Odoben-Brakwa	**60**	Adansi East (South)	**101**	Kassena Nankana
20	Ajumako-Enyan-Essiam	**61**	Asante Akim South	**102**	Bongo
21	Assin	**62**	Asante Akim North	**103**	Bolgatanga
22	Twifo-Heman-Lower Denkyira	**63**	Ejisu-Juaben	**104**	Bawku West
23	Upper Denkyira	**64**	Botsomtwe-Atwima Kwanwoma	**105**	Bawku East
24	Accra Metropolis	**65**	Kumasi Metropolis	**106**	Wa
25	Ga	**66**	Afigya-Kwabre	**107**	Nadowli
26	Tema Municipality	**67**	Afigya Sekyere	**108**	Sissala
27	Dangme West	**68**	Sekyere East	**109**	Jirapa Lambussie
28	Dangme East	**69**	Sekyere West	**110**	Lawra
29	South Tongu	**70**	Ejura-Sekyedumasi		
30	Keta	**71**	Offinso		
31	Ketu	**72**	Ahafo Ano South		
32	Akatsi	**73**	Ahafo Ano North		
33	North Tongu	**74**	Asunafo		
34	Ho	**75**	Asutifi		
35	Hohoe	**76**	Tano		
36	Kpando	**77**	Sunyani		
37	Jasikan	**78**	Dormaa		
38	Kadjebi	**79**	Jaman		
39	Nkwanta	**80**	Berekum		
40	Krachi	**81**	Wenchi		
41	Birim North	**82**	Techiman		

Table 7.7 Ghana District Names, Alphabetical, and Associated Map Number

District	Nos.		Nos.	District	Nos.
Abura-Asebu-Kwamankese	14	Dangme East	28	North Tongu	33
Accra Metropolis	24	Dangme West	27	Nzema East	2
Adansi East (South)	60	Dormaa	78	Offinso	71
Adansi West (North)	59	East Akim	46	Saboba-Chereponi	92
Afigya Sekyere	67	East Gonja	89	Savelugu-Nanton	95
Afigya-Kwabre	66	East Mamprusi	99	Sefwi-Wiawso	10
Afram Plains	54	Ejisu-Juaben	63	Sekyere East	68
Agona	18	Ejura-Sekyedumasi	70	Sekyere West	69
Ahafo Ano North	73	Fanteakwa	47	Sene	86
Ahafo Ano South	72	Ga	25	Shama Ahanta East Metropolis	4
Ahanta West	3	Gomoa	16	Sissala	108
Ajumako-Enyan-Essiam	20	Gushiegu-Karaga	94	South Tongu	29
Akatsi	32	Ho	34	Suhum-Kraboa-Coaltar	45
Akuapim North	50	Hohoe	35	Sunyani	77
Akuapim South	49	Jaman	79	Tamale	96
Amansie East	58	Jasikan	37	Tano	76
Amansie West	57	Jirapa Lambussie	109	Techiman	82
Aowin-Suaman	8	Jomoro	1	Tema Municipality	26
Asante Akim North	62	Juabeso-Bia	9	Tolon	97
Asante Akim South	61	Kadjebi	38	Twifo-Heman-Lower Denkyira	22
Asikuma-Odoben-Brakwa	19	Kassena Nankana	101	Upper Denkyira	23
Assin	21	Keta	30	Wa	106
Asunafo	74	Ketu	31	Wasa Amenfi	7
Asuogyaman	53	Kintampo	84	Wassa West	6
Asutifi	75	Komenda-Edina-Eguafo-Abirem	12	Wenchi	81
Atebubu	85	Kpando	36	West Akim	43
Atwima	56	Krachi	40	West Gonja	88
Awutu-Effutu-Senya	17	Kumasi Metropolis	65	West Mamprusi	98
Bawku East	105	Kwaebibirem	44	Yendi	93
Bawku West	104	Kwahu South	55	Yilo Krobo	51
Berekum	80	Lawra	110	Zabzugu-Tatale	91
Bibiani-Anhwiaso-Bekwai	11	Manya Krobo	52		
Birim North	41	Mfantsiman	15		
Birim South	42	Mpohor-Wassa East	5		
Bole	87	Nadowli	107		
Bolgatanga	103	Nanumba	90		
Bongo	102	New Juaben Municipality	48		
Botsomtwe-Atwima Kwanwoma	64	Nkoranza	83		
Builsa	100	Nkwanta	39		
Cape Coast Municipality	13				

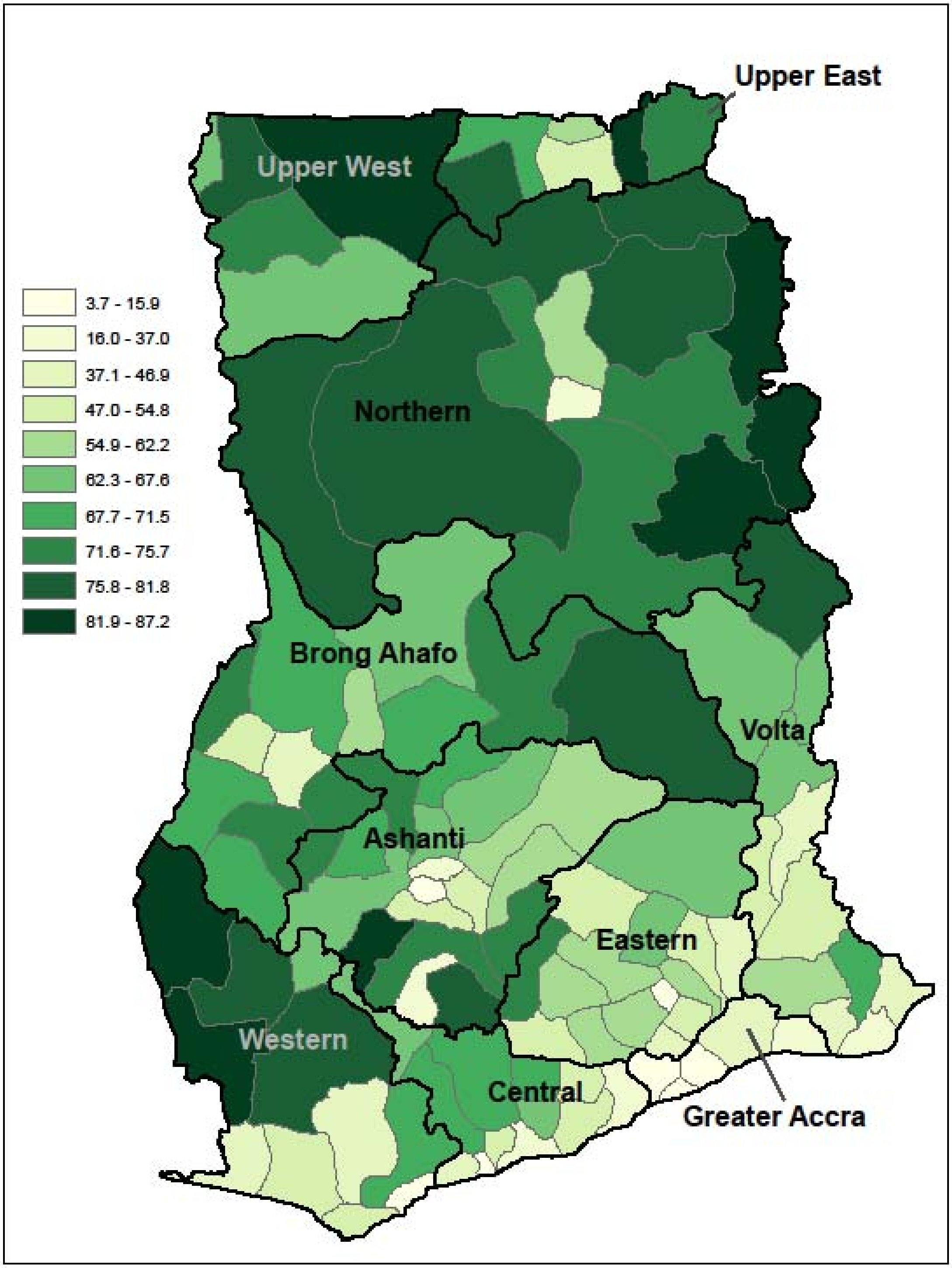


Figure 7.4 Percentage of district population >15 years old engaged in agriculture-related employment (including hunting and forestry)

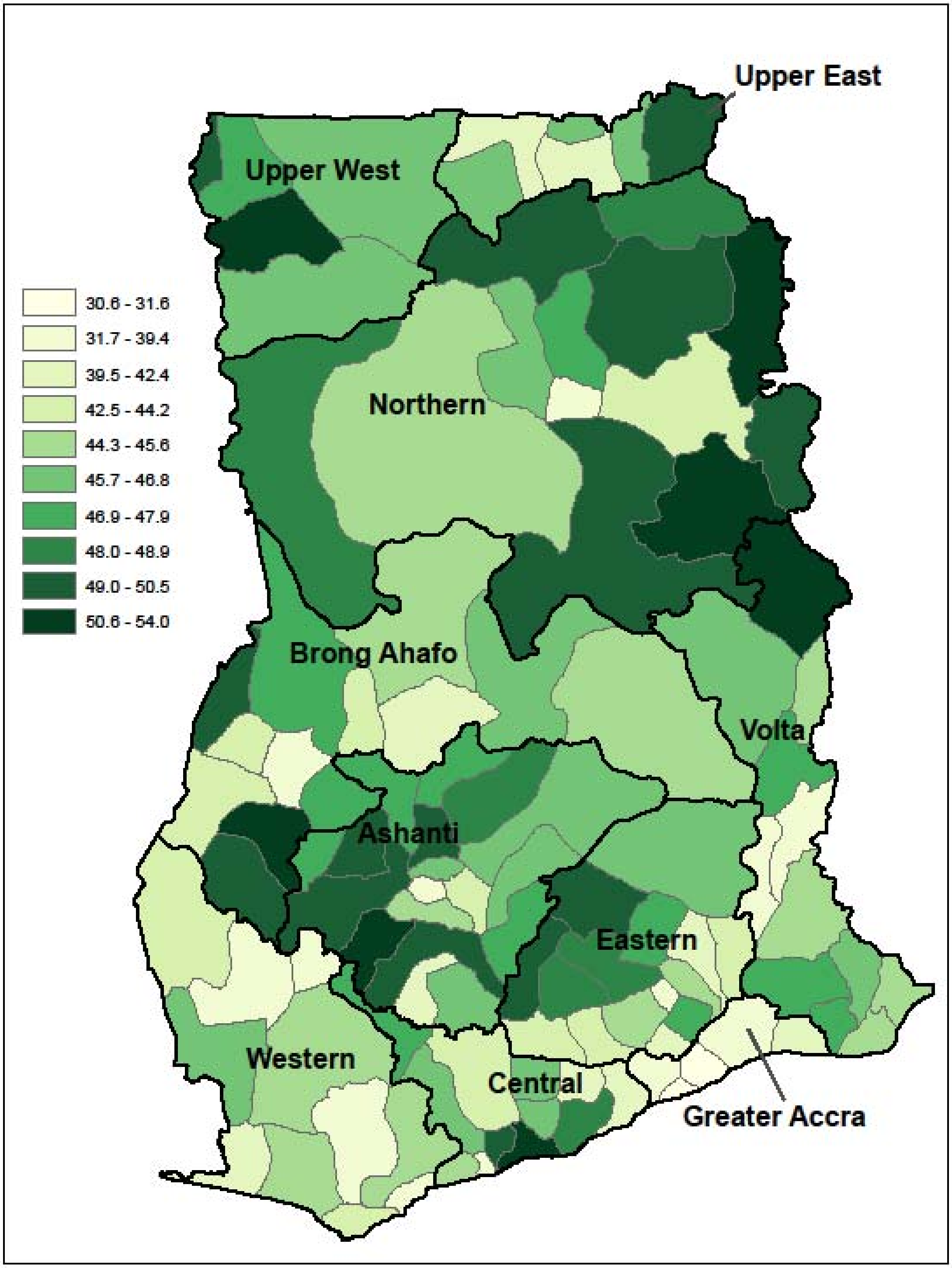


Figure 7.5 Percent of district population <15 and >65 (Dependent Population)

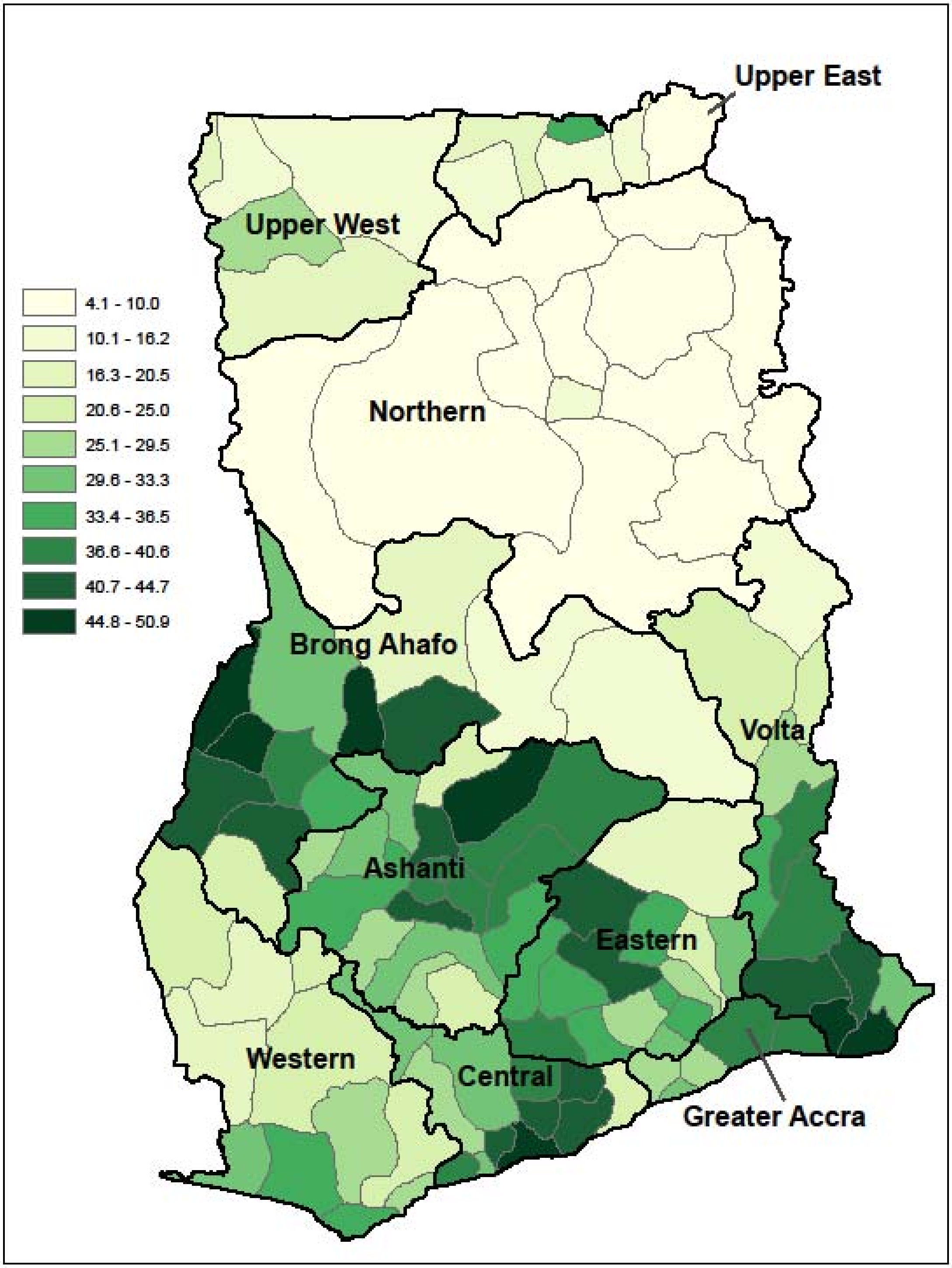


Figure 7.6 Percentage of female-headed District households

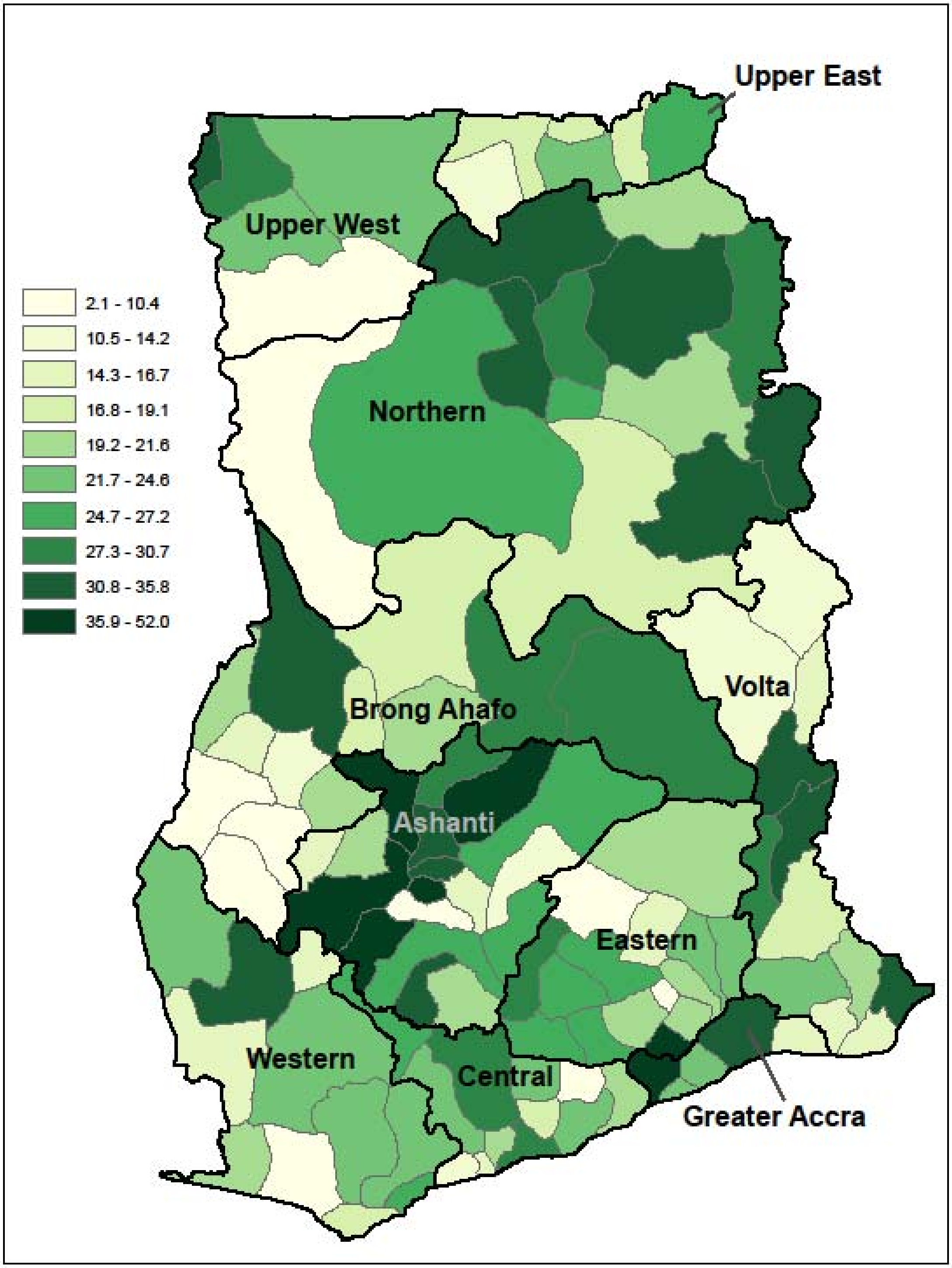


Figure 7.7 Percentage of children 0-59 months old who are underweight for their age

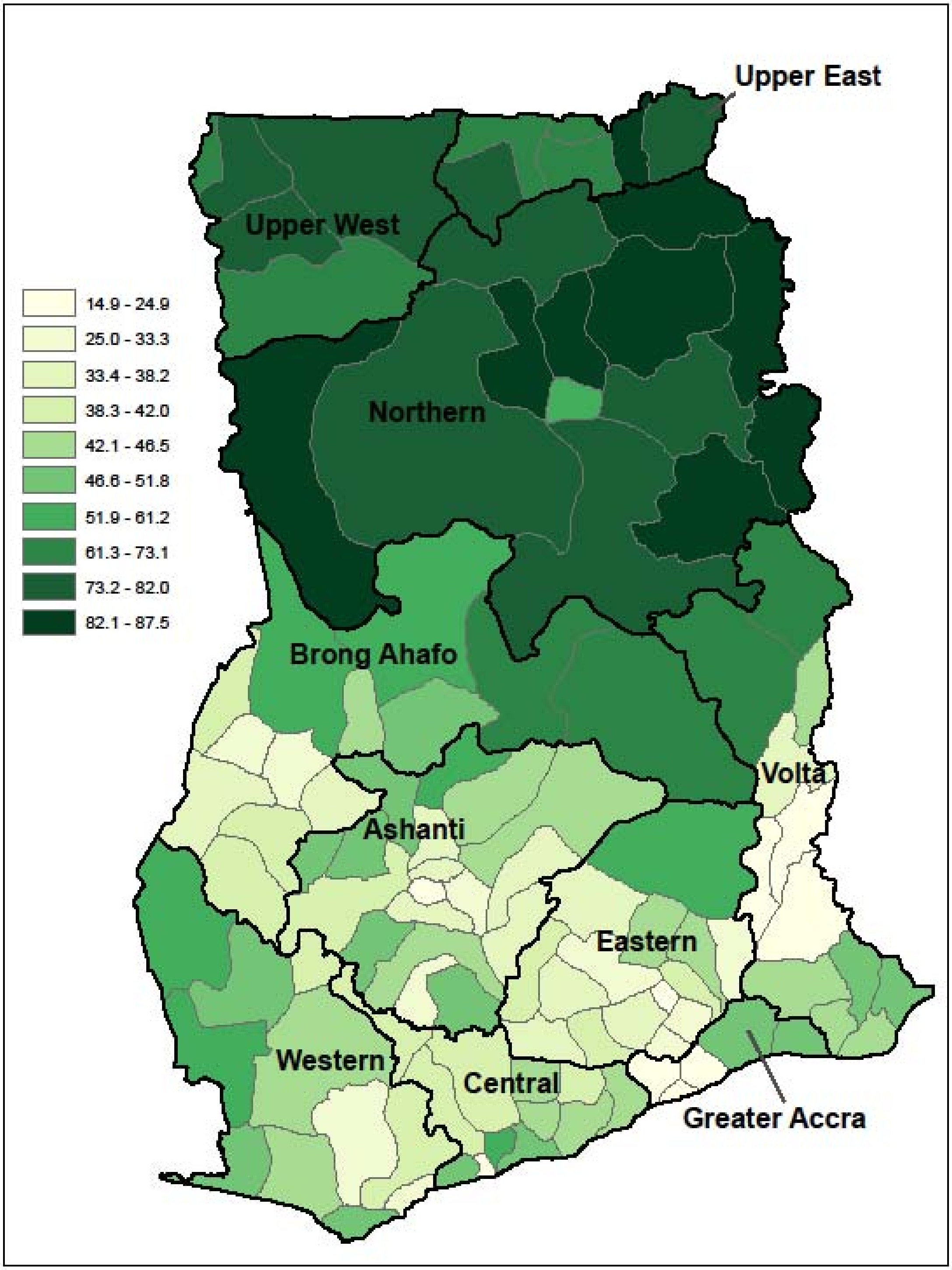


Figure 7.8 Percentage of the District population >15 years old that is Illiterate

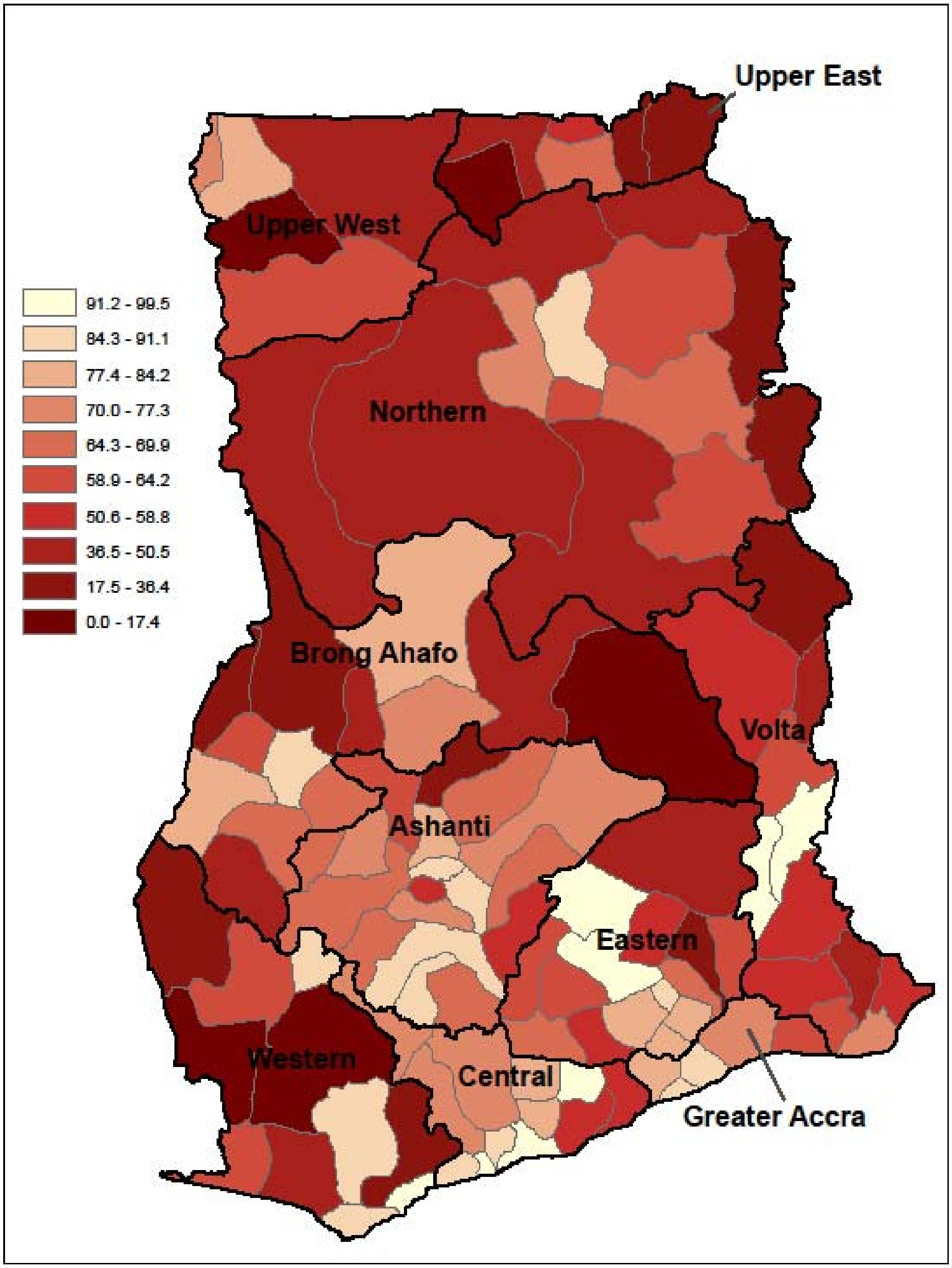


Figure 7.9 Percentage of District households that can access their homes by road year-round

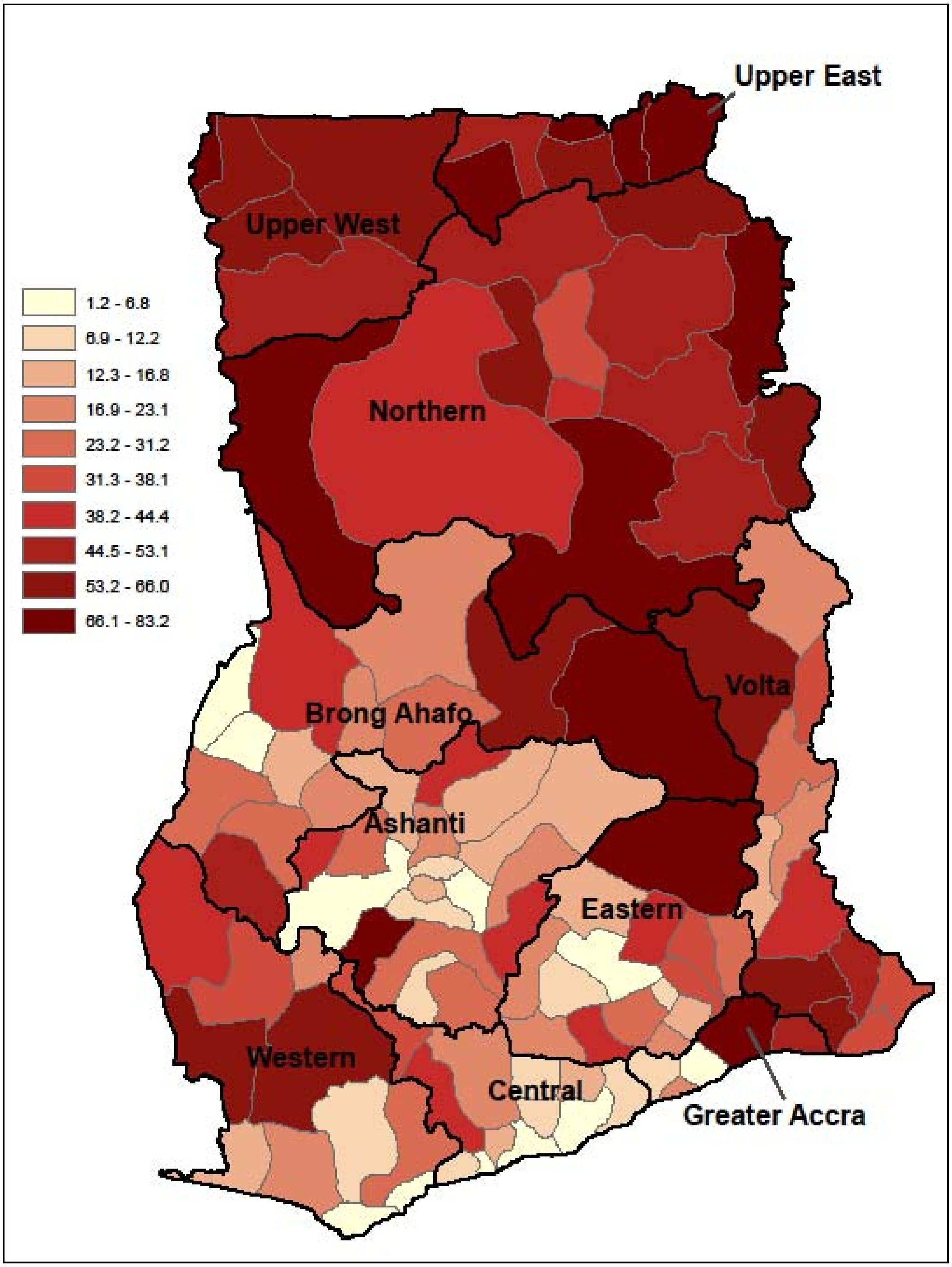


Figure 7.10 Percentage of District households that travel ≥30 minutes to reach a food market

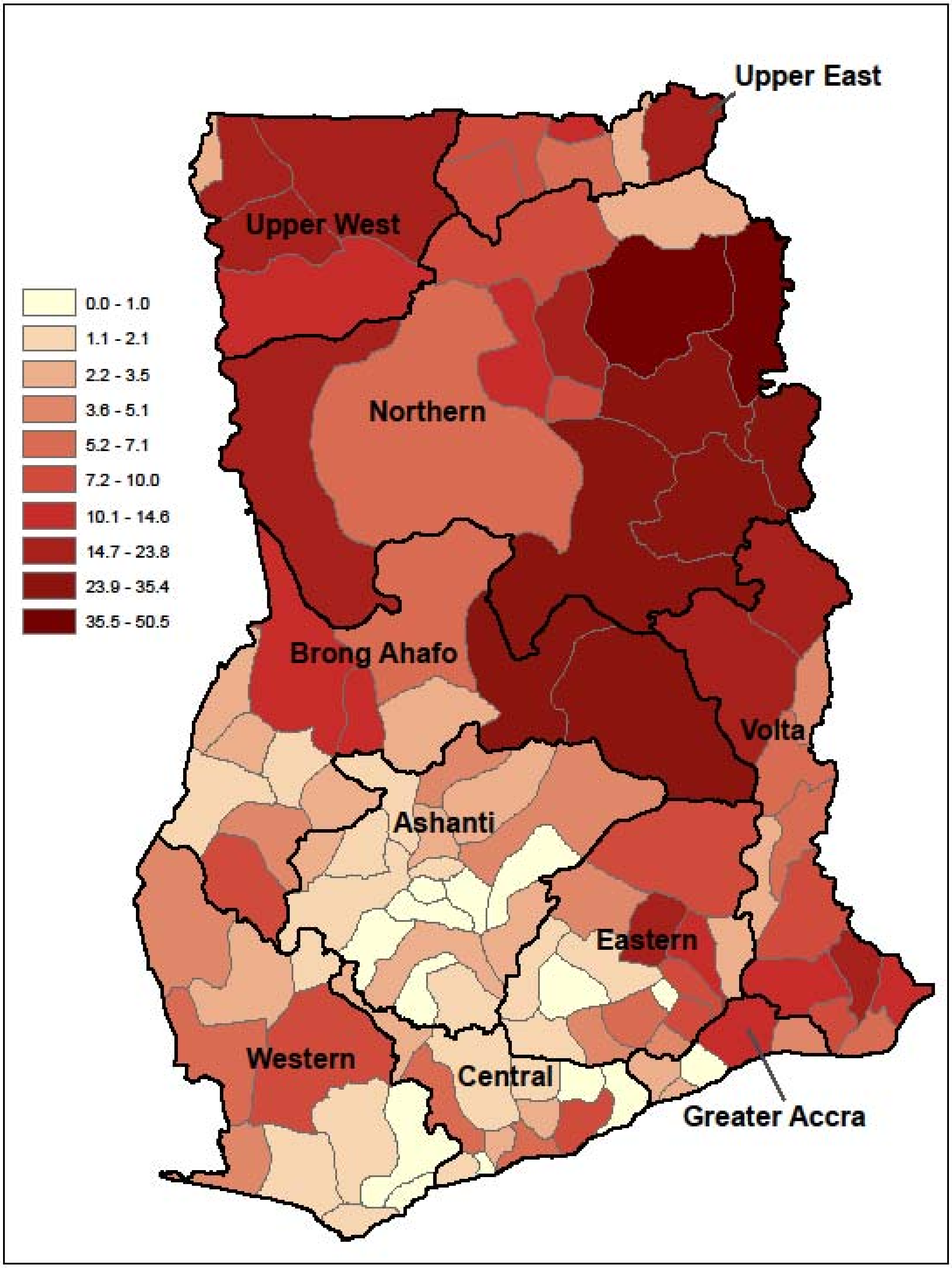


Figure 7.11 Percentage of District households that travel ≥30 minutes for drinking water

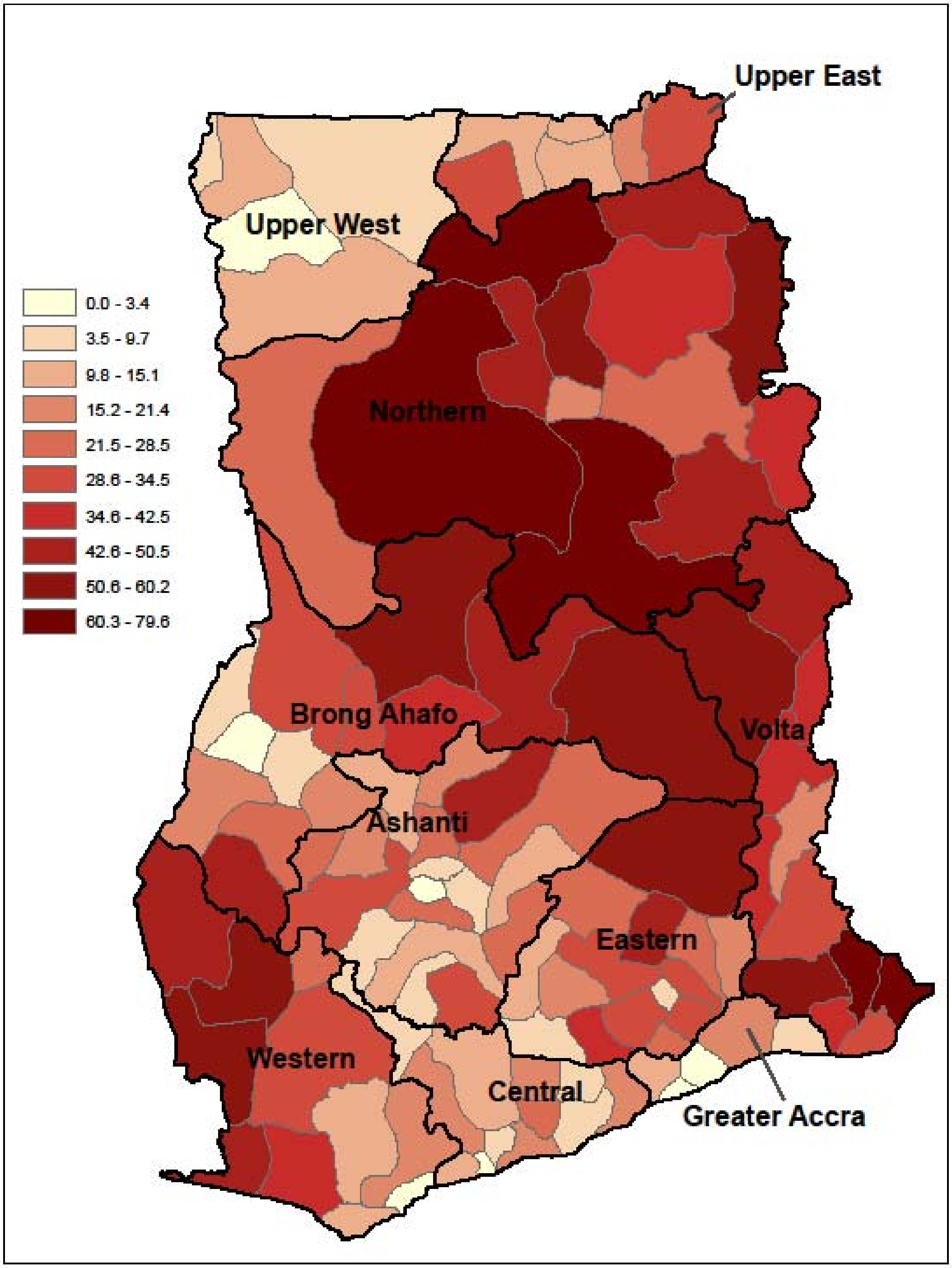


Figure 7.12 Percentage of District households that depend on unimproved drinking water sources (rainwater, rivers, lakes, ponds, and unprotected wells)

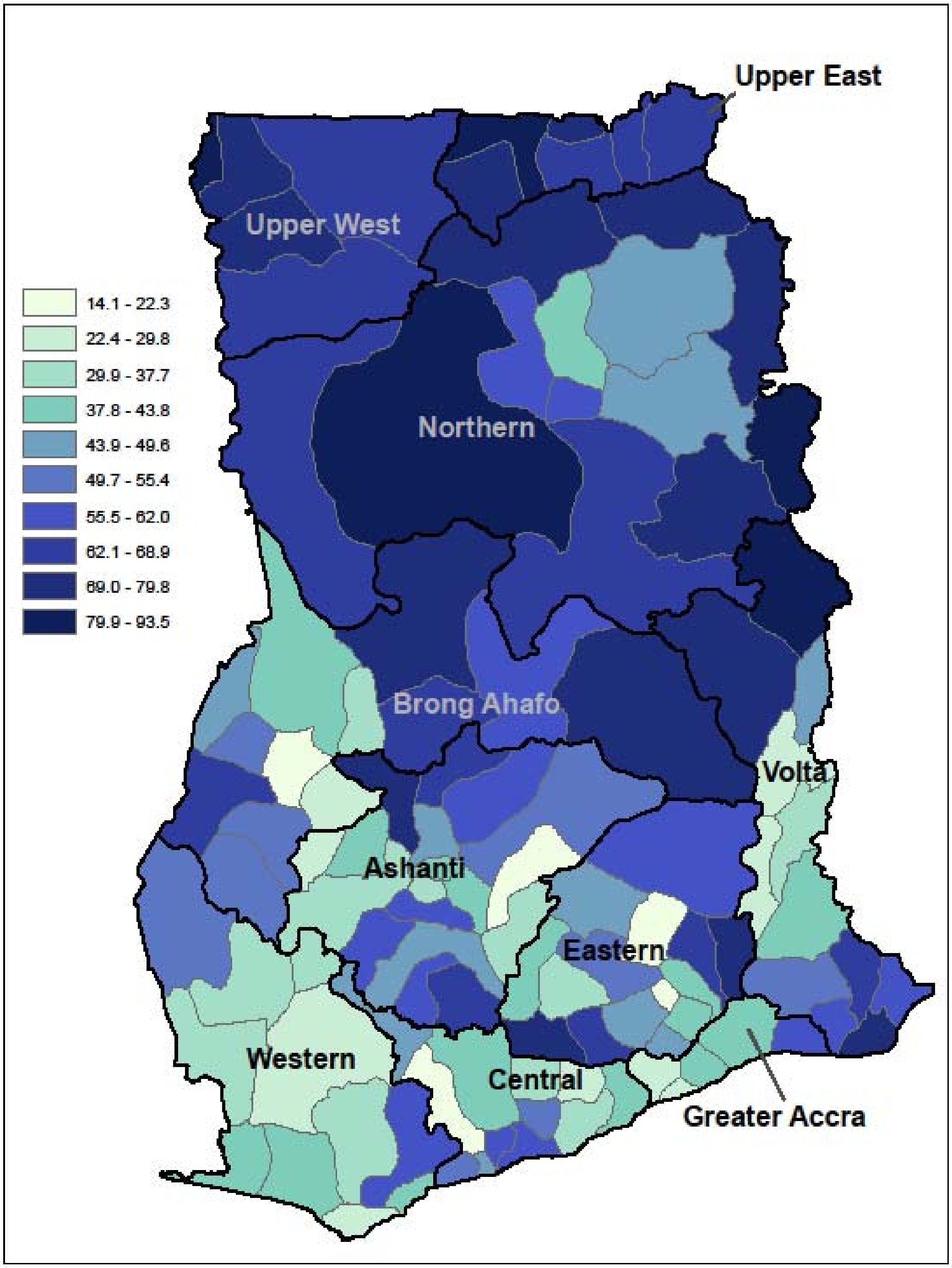


Figure 7.13 Percentage of District Households that self-identify as being "Poor" or "Very Poor"

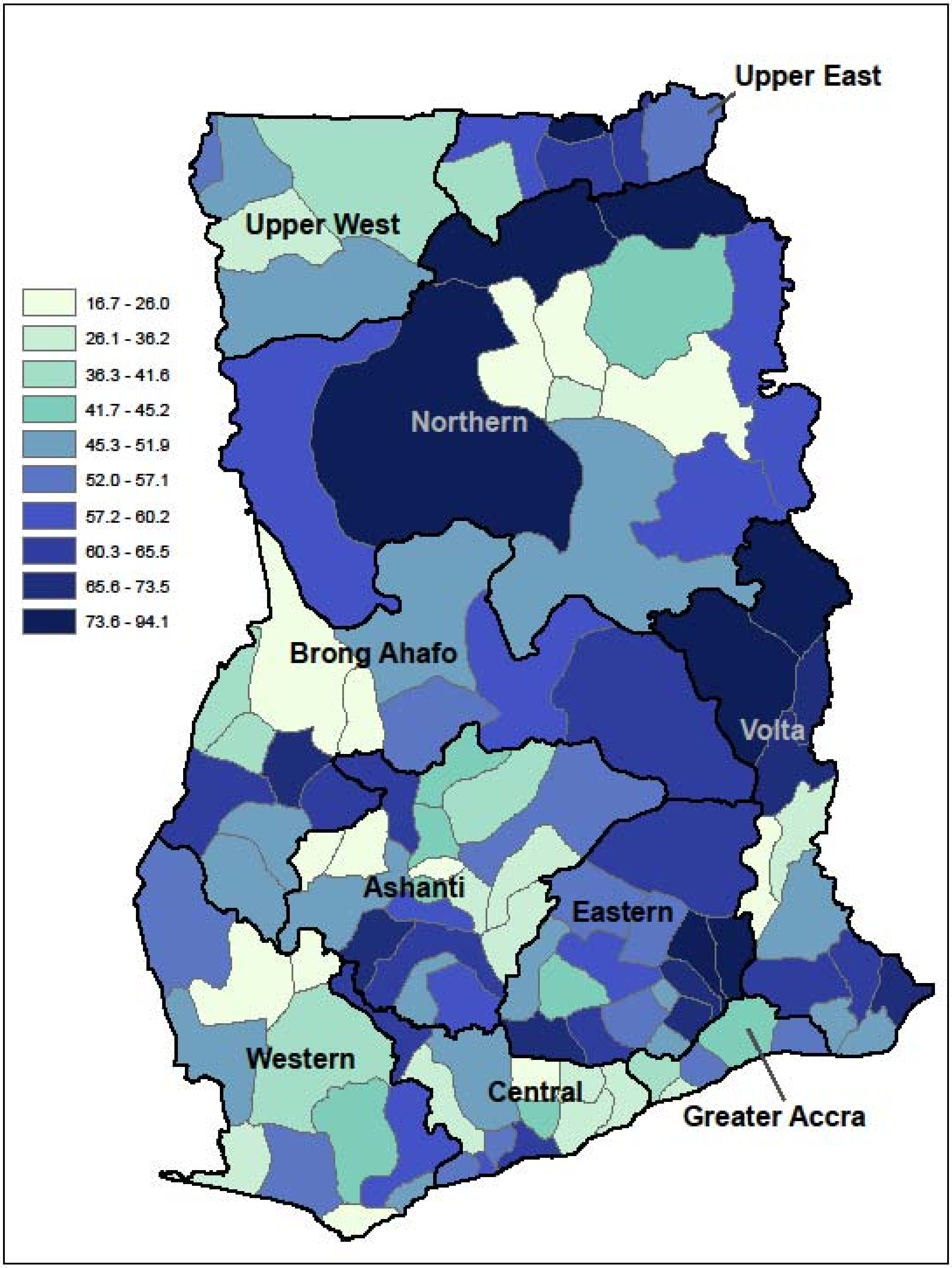


Figure 7.14 Percentage of total District households that feel "Somewhat" or "Very" insecure about their ability to withstand a crisis

8. ADAPTING TO CLIMATE CHANGE IN GHANA: CASE STUDIES FROM THE COASTAL AND NORTHERN SAVANNA REGIONS

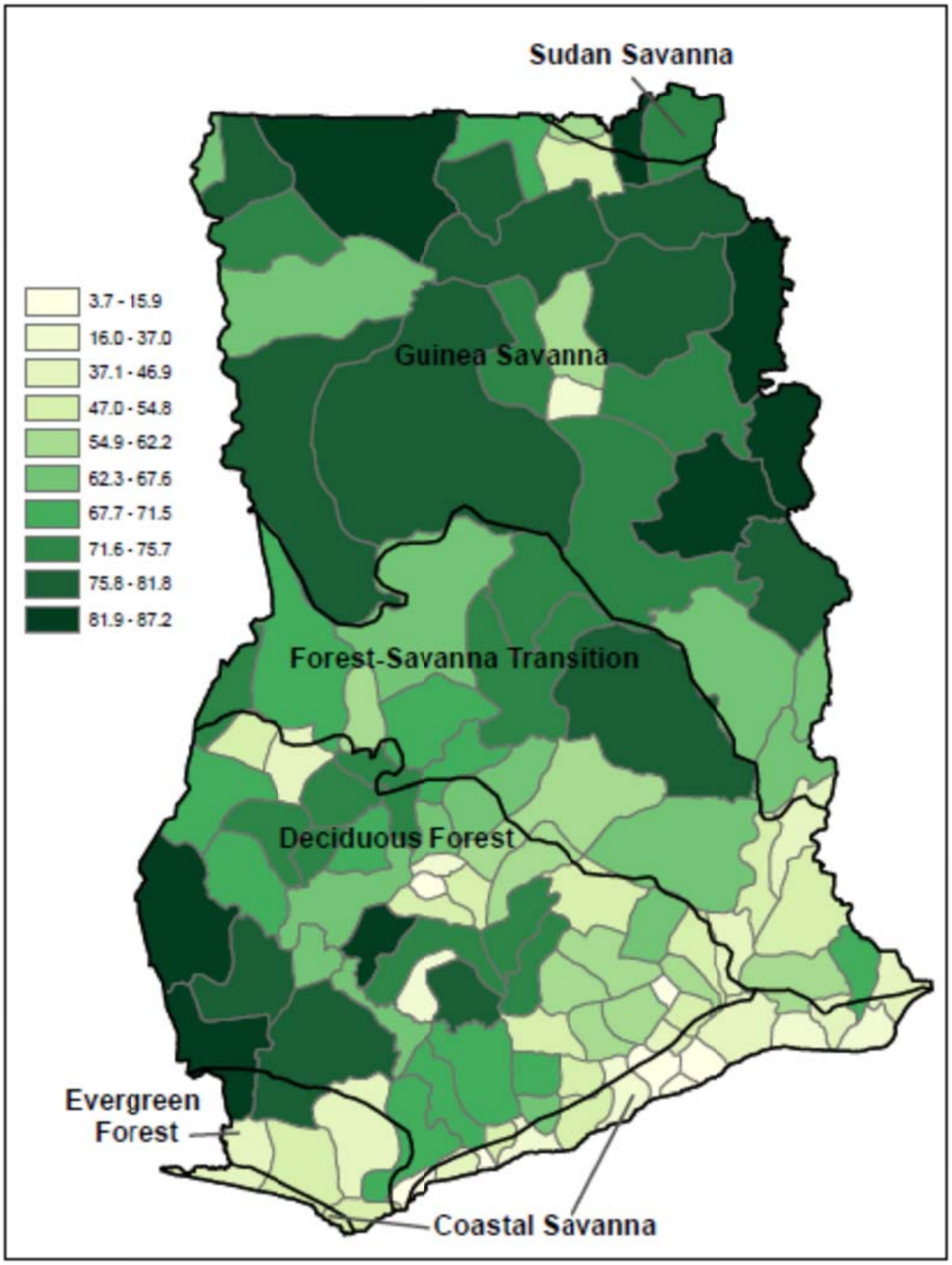
INTRODUCTION

Adaptation to climate change in Ghana calls for measures that reduce the vulnerability of natural resources and people to its impacts, increase people's ability to adapt to the long-term challenges posed by climate change (their adaptive capacity), and strengthen people's ability to absorb, cope with, and recover from unexpected changes that result (resilience) (following Ensor and Berger, 2009). To promote climate change adaptation, it is necessary to: 1) understand what the biophysical effects of climate change have been and are expected to be in specific places (e.g., increased drought, unreliable rainfall, rising sea levels, flooding); and 2) understand the nature of social and environmental vulnerability in a given place, including how and why people may be susceptible to the adverse effects of climate change. Thus, adaptation strategies are most likely to be effective if they are developed using a community-based approach that takes into account the local circumstances of specific communities.

Two case studies of climate change adaptation are presented in this chapter: one from coastal Ghana, and one from the northern Guinea and Sudan savanna ecological zones, which include the Upper East, Upper West, and Northern administrative regions. The adaptation strategies described in these case studies are not meant to be prescriptive; instead, they provide examples of how climate change is being experienced in parts of Ghana that USAID has expressed a particular interest in, and of approaches to adaptation that are currently underway in some communities or that could potentially be pursued.

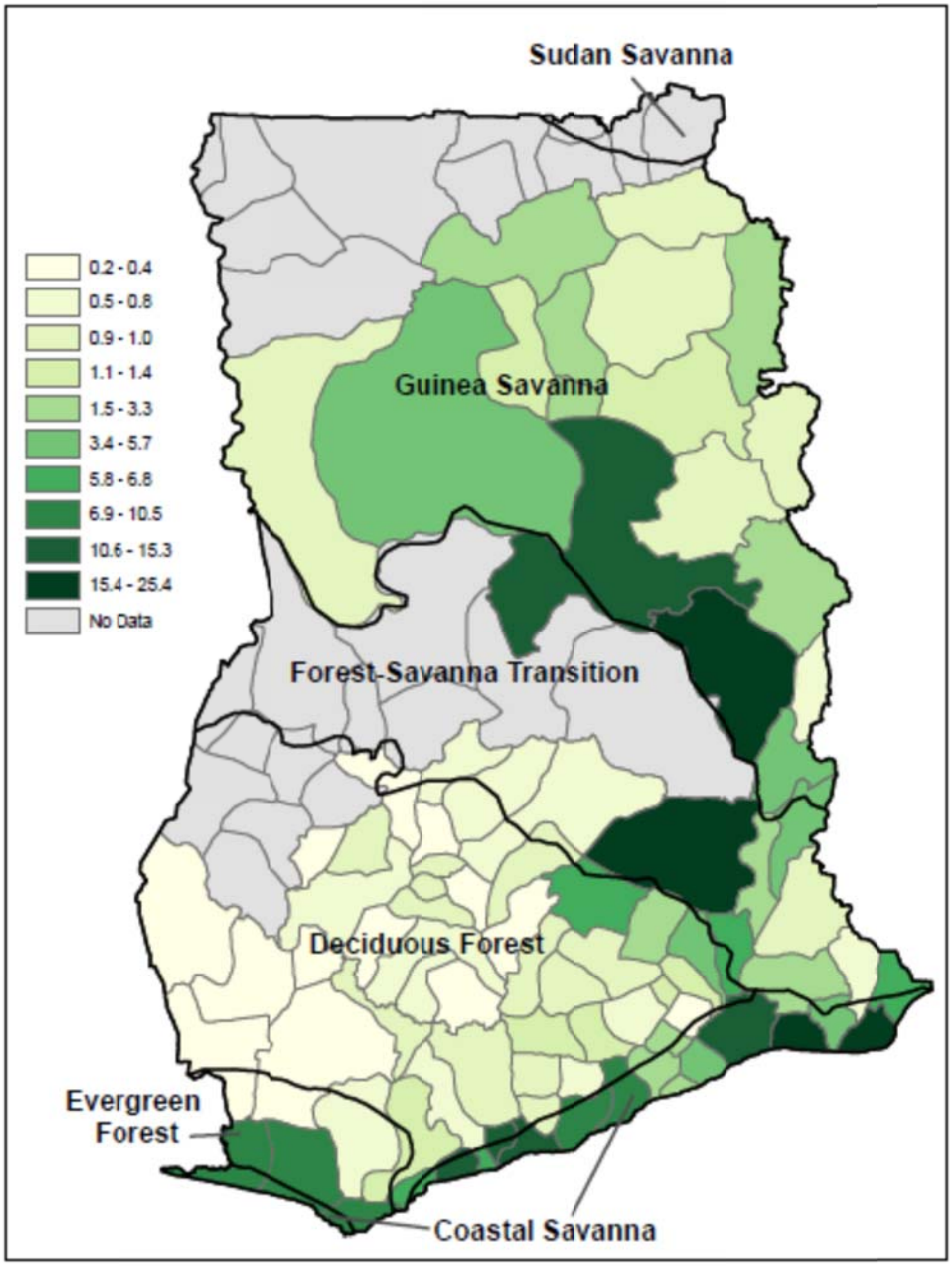
Figures 8.1 and 8.2 indicate the percentage of Ghana's population employed mainly in agriculture, hunting and forestry, and fishing by district across Ghana. It is evident that the Upper East, Upper West, and Northern administrative regions – generally corresponding to the Sudan and Guinea savanna ecological zones – have among the highest percentages of the population employed in agriculture, hunting, and forestry in Ghana. Similarly, the Coastal Savanna Zone has a high percentage of the population employed in fishing. Thus, our focus in this chapter is on rural livelihoods in the context of climate change with an emphasis on food security, in line with USAID's planned investments in food security in Ghana through the Feed the Future program. We assume that a main goal of climate change adaptation in these zones is to ensure sustainable livelihoods – defined as the capabilities, assets, and activities required to make a living in a manner that is resilient to stresses and shocks, and that maintains or enhances these capabilities, assets, and activities without undermining the natural resource base (Scoones, 1998). The areas discussed in these case studies deserve special attention for potential investments in climate change adaptation because climate change in Ghana is predicted to have significant impacts on coastal areas and on the dryland, northern savanna regions;

people residing in these regions are highly dependent on fishing and agriculture, respectively; and social vulnerability to climate change is particularly high in northern Ghana.



Source: 2000 Population and Housing Census (GSS, 2005)

Figure 8.1 Percentage of Ghana's population aged 15 and over employed mainly in agriculture, hunting, and forestry, by district.



Source: 2000 Population and Housing Census (GSS 2005)

Figure 8.2 Percentage of Ghana's population aged 15 and over employed mainly in fishing, by district.

CASE STUDY: CLIMATE CHANGE ADAPTATION IN GHANA'S COASTAL ZONE

OVERVIEW

Ghana's coastal zone, commonly defined as the land area below the 30 meter contour, has a shoreline of 528 km in length, and encompasses an area of 5,800 – 16,000 km^2 (EPA, 2008), roughly 2-7 percent of the country's land mass, depending on exact boundary placement (see Chapter 5.C, Physiography, Ecology, and Livelihoods). The shoreline transitions from sandy, relatively flat beaches of the western coast (roughly 95 km), to rocky beaches of the central coast (321 km), to the sandy east coast (149 km). Most of the country's major rivers drain into the sea, forming estuaries and lagoons along the shore.

Despite its relatively small landmass, the coastal zone is Ghana's most densely populated area, holding 25 percent of the total population (EPA, 2008). Of the 10 most populous cities in Ghana, six are located along the coast: the capital city of Accra (population 1,695,136); the twin cities of Sekondi-Takoradi in the Western Region (combined population 289,595); Ashiaman (150,312), Tema (141,479), and Teshie (92,359), all in the Greater Accra Region; and the former colonial capital of Cape Coast (population 118,105) in the Central Region (GSS, 2002). As a result of these urban centers, districts within the coastal area tend to have high population growth rates, ranging from 1.0 – 4.4 percent/year (median =2.9 percent) (Ghana Districts, 2006). The most rapidly growing urban areas are increasing at a rate nearly twice the national average, and will double in size over 16 years. However, even with this burgeoning population, social vulnerability to climate change along the coast is not as severe as in the northern regions of the country. This is due, in part, to superior transportation and communication networks, higher quality educational opportunities, better developed commercial markets, and the corresponding increase in potential for livelihood diversification that exists in urban areas. However, extraordinarily high growth rates still outpace the rate of development, exerting continually increasing pressure on resources that are already in decline (CRC 2010). And, it is important to note, although social vulnerability at a district level is less severe along the coast, households and settlements located farther from urban centers can be just as socially vulnerable as households in the northern reaches of the country (Apombwe, 2011).

LIVELIHOOD STRATEGIES AND CLIMATE CHANGE IMPACTS

Inhabitants of the coastal zone depend primarily on marine fisheries for their livelihoods (EPA, 2008; CRC, 2010; Chapter 6, Fishery Resources and Overfishing). There are five distinct fleets operating within Ghana's marine fisheries: artisanal canoe, semi-industrial, industrial, tuna, and lagoon. Men are responsible for harvesting the fish, and women dominate the onshore post-harvest activities of processing, storing, marketing, and trading the catch (EPA, 2008). In addition to fishing, most households practice some form of subsistence agriculture (CRC, 2010; GSS, 2005, 2008). Aside from fishing, urban areas benefit from tourism. Visitors come to the area to enjoy the beaches, to visit the colonial slave castles, or to venture inland and experience the biodiversity of the evergreen forests. At the present moment, little infrastructure exists to support a lucrative tourism industry outside of urban areas and many beaches are routinely used as toilets by local residents and as depositories for untreated liquid and solid waste and refuse (Briggs, 2010). The newly-established oil and gas industry, off the coast of the Western Region, promises a surge in development and has the potential to create jobs for the local population. In part because of the rather limited estimated production life of the confirmed oil finds and field development to date, the true impact of the industry remains to be seen (one field so far, producing for about 20 years, Tullow Ghana Limited, 2009; CRC, 2010).

Since occupations of coastal residents depend primarily on the marine fishery resource, livelihood vulnerabilities are tied to threats confronting this resource. Vulnerabilities of the marine fishery resource are multi-faceted with or without considerations of climate change. Climate change-related threats often increase pre-existing human induced threats to the system. Potential climate change-related threats confronting the marine fisheries include a potential rise in sea level, increased ocean temperatures, and perhaps most threatening, changes to the seasonal upwelling patterns. Persistent human-induced threats include: increased pressure on the fisheries as a result of a drastic increase in fleet size; changes in water quality from pollution caused by ineffective waste water treatment plants, agricultural runoff, and aerial mosquito spraying; destruction of mangrove, lagoon, and wetland systems that previously played important nursery roles for juvenile fish; a shift towards more destructive fishing practices and a lengthening of the harvest season, both actions that reduce the potential for stock recovery; sand harvesting practices, coupled with the construction of sea walls or harbors that disrupt nearshore currents and interfere with natural sedimentation cycles; and a general lack of management, regulation, or monitoring of any sort within the industry (EPA, 2008; CRC, 2010; Nelson & Agbey, 2005). The general outcome of these combined threats is an overall decline in the marine fishery (EPA, 2008; CRC, 2010; Atta-Mills, et al. 2004, Chapter 6, Fishery Resources and Overfishing).

When asked how this decline in the fisheries impacts individuals participating in the industry, common responses were that, on an individual level, the resulting loss of income makes feeding the family difficult, school fees unaffordable, protein too expensive, and unemployment increasingly prominent (EPA, 2008). When asked to characterize climate change-related concerns within the community, respondents observed that without a reliable source of income from the fishery, households face financial hardships that worsen living conditions and reduce standards of living (EPA, 2008).

CLIMATE CHANGE ADAPTATION STRATEGIES

Livelihood adaptation strategies can be broken down into three distinct categories. The first category, insurance strategies, can be defined as activities undertaken to avoid or prevent stress in the future (van der Geest, 2004). The second strategy, coping, has been defined as "a short-term response to an immediate and unhabitual decline" (Davies & Hossain, 1993: 60). Insurance and coping strategies can be erosive or non-erosive. Erosive strategies are activities that harm future resilience; non-erosive strategies, the preferred approach, do not jeopardize future security (van der Geest, 2004). Both insurance and coping are short-term solutions and are unsustainable in the face of permanent, long-term change. The third and final strategy, livelihood adaptation, is defined as "the dynamic process of constant changes to livelihoods which either enhance existing security and wealth or try to reduce vulnerability and poverty" (Davies & Hossain, 1997: 5). Livelihood adaptations address long-term changes and typically occur when coping strategies are exhausted and individuals are forced to "alter fundamentally the ways in which they subsist" (Davies & Hossain, 1997: 5). Adaptation can be positive or negative. Positive adaptation occurs by choice and is reversible if fortunes improve; negative adaptation tends to occur out of necessity, is usually irreversible, and often does not make contributions to lasting reductions in vulnerability (Davies & Hossain, 1997). On Ghana's coast there are examples of all three forms of the more generally defined adaptation.

Insurance strategies involve, first, developing an early warning system that enables individuals to better anticipate hazardous events or declines in production. With some level of awareness of future events, individuals can then act in ways that temporarily insure them against lost income. Minimal efforts have been made in this area; however, some fishermen have started anticipating financial hardship and putting more fish into cold storage to sell in the off season, or simply foregoing income from sales in order to put away extra reserves of smoked fish for personal consumption (EPA, 2008). Other insurance strategies include borrowing money from friends and family to get by during an economic slump or redirecting money from other areas of the household finances to temporarily cover the loss of fishing income (van der Geest, 2004). These strategies tend to be erosive because they threaten future resilience by depleting overall household resources to a point from which they might not recover if income reduction persists for more than one season.

Many of the *coping strategies* employed on the coast could be considered borderline adaptations because they have been practiced over a long period of time. That said, to combat declining catch sizes, artisanal fishermen have transitioned to semi-industrial outfits or simply increased the time they spend at sea, added engines to their canoes to travel greater distances, switched to nets with much smaller weaves to capture smaller fish, and incorporated the use of lights, dynamite, or poison into their practices (CRC, 2010; Impraim, 2010). Semi-industrial, industrial, and canoe fishers have coped with declining fisheries by adopting light fishing, extending their range, illegally moving into the inward exclusion zone, or fishing off the shore of neighboring countries (CRC, 2010, Personal Interview). All three fleets are believed to under-report their catch, which enables them to pay less of a remittance to the lead fisherman[6] (CRC, 2010; Impraim, 2010). Nearly all of these coping strategies can be considered erosive because they harm the health of the resource in the future. The Government of Ghana has invested in a more coordinated short-term coping strategy, known as the Pre-Mix Program. The Pre-Mix Program is a fuels subsidy program by which artisanal fishermen are provided with fuel for use in their two-stroke engines. The program has been controversial and riddled with corruption and mis-management, but many artisanal fishermen rely on the low-cost fuel provided through the program (CRC 2010). Although not completely clear, this practice may also be erosive by subsidizing an already over-capitalized or at least over-sized fleet relative to the sustainable fishery resource.

In addition to these short-sighted coping mechanisms, individuals on the coast have also started adopting longer term *livelihood adaptations*. Most livelihood adaptations revolve around livelihood diversification, expansion, or improved practices. Communities and households have invested in under-developed industries, like tourism, as an alternative to fishing-dependent livelihoods. An unseen benefit of this particular adaptation is that many of the new tourism-based businesses have the potential to become partners in conservation efforts that benefit the fisheries. A few examples of this are occurring already. The Green Turtle Lodge, a beach front eco-tourism lodge in the Western Region, has partnered with local and international conservation organizations to protect nesting sea turtles that their visitors come to see (CRC, 2010). Local lead fishermen have worked to instill a land ethic within their villages by discouraging destructive practices and making better attempts to monitor catches. The success of chief fishermen depends largely on their status and respect within the community, and while effective over a small area, chief fishermen do not have the authority or reach to influence change across the fisheries as a whole unless they work with collaborating partners (CRC, 2010). The Ghanaian government with funding from the World Bank experimented with Community-Based Fisheries Management Committees, hoping to strengthen the influence of local community leaders by transferring management responsibilities to local committees. The program suffered from a lack of funding and has been discontinued (Braihmah, 2009). However, the Coastal Resource Center (CRC), based in Sekondi-Takoradi in the Western Region, has resumed this movement of community involvement in fisheries management. The CRC is working today to develop a unified civil society platform with the ability to influence change in the overall governance of the artisinal fishery (CRC, 2010). Their efforts include chief fishermen, konkohene (leader of the fish sellers), traditional chiefs, and other community leaders with the potential to influence local behaviors.

Other adaptive measures are less overarching. Working to improve or diversify their existing livelihoods, fishermen have added crew members and shifted towards larger canoes, thereby increasing the capacity of their operations. Fish sellers have delved into better smoking techniques to eliminate inefficiencies by reducing waste. Communities have invested in cold storage facilities, enabling better storage and marketing

[6] At the community level, fishing is managed through lead fishermen. A lead fisherman was traditionally a particularly skilled fisherman sanctioned by the chief to regulate the activities of fishermen throughout the village, generally by assigning individuals days of the week on which they were permitted to fish. Today these positions are inherited father to son, although their function remains the same (Impraim, 2011).

(CRC, 2010). Despite these efforts to improve community resilience, many households depend upon outside remittances to subsidize their annual budgets, and many young adults or children migrate to urban centers to work in manufacturing or trade.

CLIMATE CHANGE ADAPTATION: OPPORTUNITIES AND CHALLENGES

A rapidly growing population is exerting continuous pressure on marine resources. Finding ways to reduce that pressure before it causes a collapse is the most important way to avoid disaster. Many preventative steps that are currently under-utilized can be taken to reduce this pressure. One key way to address the demand and use of resources is through democracy and governance. The Coastal Resource Center, as touched on previously, is working to evaluate the effectiveness of existing government systems and reform government policy that pertains to fisheries governance (CRC, 2010). They hope to strengthen fisheries governance by contributing to long-term planning exercises, supported by an educated and aware public.

Aside from political engagement, many other activities and strategies could help reduce vulnerability. Investments in forestry, agriculture or tourism have the potential to lessen dependence on fisheries by providing viable employment alternatives in the area. Implementing efforts to restock marine resources, and supporting the growth of alternative fishery-based industries such as cage culture or aquaculture could help release some of the pressures on the marine resource (CRC, 2010; EPA, 2008). Education and capacity building with local populations will help encourage best practices in the industry as well as open doors to other forms of employment (such as the emerging oil and gas industry). Many internationally-based conservation organizations and local businesses have partnered to restore coastal lagoons, estuaries, and mangroves, which would create better rearing habitats for juvenile fish populations. Such partnerships could create potential employment opportunities and also lessen the costs of conservation for the government by sharing the responsibility for conservation. Furthermore, by partaking in environmental stewardship, local businesses can help restore an influential land ethic in local communities to better encourage individuals to care for the remaining natural resources (CRC 2010).

Currently the marine fisheries are considered an open-access resource, which has led to an industry that grows exponentially and unchecked. Some efforts have been made to initiate a permitting or registration system; however, these attempts have been grossly unpopular with local populations. A huge potential exists for the fisheries to improve if access is better regulated or managed. Alternatives to an open access system might be introducing closed seasons to allow the fisheries time and space to regenerate, or better enforcement of catch limits and size (CRC, 2010). Another related need is for dramatically up-scaled monitoring of and enforcement across all fleets and sectors (Finegold et al., 2010). This includes trained personnel to gather accurate and timely fishery-dependent statistics and independent marine research surveys for comparative and predictive purposes to develop catch limits, season closings, gear restrictions, and other actions needed for a sustainable fishery. Currently in Ghana, monitoring, enforcement and marine fishery research are all inadequate, often woefully so, for sustainably managing an already strained fishery (see Chapter 6.B, Fishery Resources and Overfishing). Growing civil society platforms, together with community-based management and conservation initiatives, have the potential to better regulate the fisheries at a local level. Local leaders are unable to influence change across an industry as extensive as the marine fisheries; however, a coordinated approach that incorporates them into resource management could build on their positions of authority in local communities to help bring about change.

CASE STUDY: CLIMATE CHANGE ADAPTATION IN GHANA'S NORTHERN SAVANNA REGIONS


OVERVIEW

Ghana's three northern administrative regions – Upper East, Upper West, and Northern – lie in the Sudan and Guinea savanna ecological zones. Roughly 23 percent of Ghana's population resides in these three regions (GSS, 2005), and the vast majority resides in rural areas (84.3 percent percent in Upper East, 82.5 percent in Upper West, 83.9 percent in Northern) (Ghana Districts, 2006). A high percentage of each region's population depends on agriculture for their main source of employment (67.2 percent in Upper East, 73.4 percent in Upper West, 70.9 percent in Northern) (GSS, 2005a, 2005b, 2005c). Agricultural-dependent percentages rise in each administrative region if their most urban districts are not factored in (i.e., Bolgatanga Municipal, Wa Municipal, and Tamale Metropolitan). The most important crops are millet, sorghum, maize, yams, rice, soy beans, cotton, groundnuts, beans, onions, and tomatoes. Most agricultural production is rainfed, though some rice is under irrigation. Many households also raise livestock. Agricultural production takes place largely by smallholders. Mole National Park, Ghana's largest national park, is located in the Guinea Savanna in the Northern Region, covering 4,840 km² (OWGT, 2011).

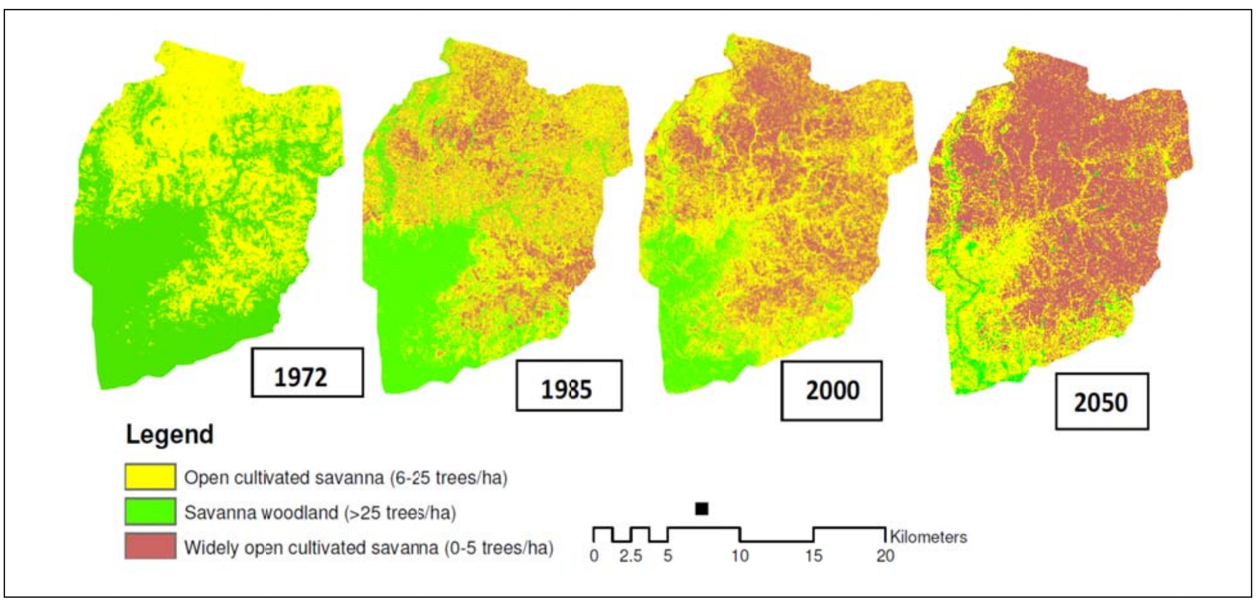
As detailed earlier in this report, these are Ghana's most vulnerable regions to climate change from both a natural resource and a social standpoint. The Sudan Savanna (roughly corresponding to the Upper East Region) suffers long-standing and very severe soil degradation; soil degradation in the Upper West and Northern Regions (the Guinea Savanna) is moderate (See Chapter 6, Resource Vulnerability--Desertification). However, all three regions exhibit either high or very high vulnerability to desertification (with the exception of the southern portion of the Northern Region, south of 10°N latitude). It is unclear how climate change will affect the process of desertification and the rate at which it occurs. The Sudan and Guinea Savanna ecological zones also have the hottest temperatures, and the second and third lowest rainfall levels (after the Coastal Savanna), in the country (see Chapter 3, Ghana's Climate and Projected Changes). Rainfall is variable, as is characteristic of dry, subhumid drylands.

Temperatures have been increasing more rapidly in northern Ghana than elsewhere in the country, and are projected to keep getting hotter. At the same time, annual decreases in total precipitation have been documented for the Guinea Savanna, and rainfall is projected to decrease in the future in both the Sudan and Guinea Savanna zones (Chapter 3). The Upper East, Upper West, and Northern Regions have high social vulnerability to climate change (Chapter 6) and the highest poverty rates in Ghana (Nelson and Agbey, 2008; Chapter 6).

PERCEPTIONS OF CLIMATE CHANGE AND ITS EFFECTS IN THE NORTHERN SAVANNA

Research has documented changes in climate taking place in Ghana's northern savannas based on the perceptions of local residents. These perceptions are described here, though it is important to note that they come from community-level studies and should not be overly generalized. In some communities in the Upper East Region, residents have reported a shorter and more unpredictable rainy season from the standpoint of both amount and timing of rain (Dietz et al., 2004). Changes to biophysical resources observed by residents that are attributed to climate change include shifts in natural vegetation from trees to grasses and a gradual disappearance of economically-important trees; the drying up of riverbeds that once supported dry-season cultivation after the rainy season ends; early drying of flowing streams in the dry season, leaving stagnant pools of mosquito-infested water of low quality; salinization of water sources; fewer swimming holes along rivers; and unreliability of traditional signs that signal the start of the rainy season (e.g., bird and insect behavior, changes in winds, onset of new leaves, water table levels in wells) (Dietz et al., 2004). In the Upper West Region, increasingly erratic rainfall is also reported with the amount, timing, and geographic distribution of rain becoming more unpredictable and the total amount of rain declining over time (Van der Geest, 2004). Shorter rainy seasons are also reported. Through interviews in Ghana's Northern Region, we learned of more frequent occurrences of floods, wind storms, and heavy rains late in the rainy season.

In Ghana's northern savanna zones (Idinoba et al., 2009), savanna woodlands (>25 trees/ha) and open cultivated savanna (6-25 trees/ha) have decreased significantly between 1972 and 2000 (Figure 8.3). In 1972 "widely open cultivated savanna" (<6 trees/ha) did not exist, but by 2000 33.6 percent of the savanna ecosystem fell into this category with a 5.9 percent increase projected by 2050. This study supports observations of local residents regarding the conversion of forests to grasslands. Anthropogenic disturbances are an important factor driving this change. However, climate change and variability are also believed to play a role, because rising temperatures and decreased rainfall increase stress on trees, making it hard for them to adapt and increase the potential for destructive bushfires. The rapid, widespread conversion of forests to grasslands in these arid zones could also greatly increase the risk of desertification for the northern savanna zones of Ghana (see Chapter 6, Resource Vulnerability, Desertification).



Source: Indinoba et al., 2009

Figure 8.3 Land Use/Land Cover in the Savanna Zones, 1972-2000 with projection to 2050

At Mole National Park, managers expressed concern that climate change would affect the distribution of wildlife that currently resides in the Park causing them to move outside of park boundaries in search of resources, especially during the dry season. The movement of wildlife near to neighboring villages can lead to conflict.

LIVELIHOOD STRATEGIES AND CLIMATE CHANGE IMPACTS

AGRICULTURAL PRODUCTION

Millet and sorghum are the most important grain staples grown in the Upper East and Upper West regions, and maize, millet, and sorghum are important staples in the Northern Region (Dietz et al., 2004; Gyasi et al., 2008). Yams are also an important food crop in the Northern and Upper West regions (EPA, 2008). Of these crops, millet is the least risky with regard to climate-induced fluctuations in yield followed closely by sorghum and maize, making all of them important for food security. Rice and cotton lie at the other extreme exhibiting much wider variation in productivity year to year. Some farmers also grow vegetables in gardens and irrigated plots during the dry season.

Northern Ghana is also the most important part of the country for livestock production, giving it an advantage over the south in this regard. Cattle, goats, sheep, chicken, guinea fowl, and pigs are the main animals raised (Dietz et al. 2004, Hesselburg and Yarro 2006). For some agriculturally-dependent communities in the Upper East and Upper West regions, household food security relies more on livestock than on farming (Dietz et al., 2004; Hesselburg and Yarro, 2006; Van der Geest, 2004). Weather and the high cost of farm inputs can make farming unreliable unless households have access to irrigated fields. Livestock represent a form of savings that people can invest in in good times and that provide a critical buffer in bad times because they can be sold for cash that can then be used to purchase food when needed. Goats, sheep and pigs have high value and play an especially important role in food security (Hesselburg and Yarro, 2006).

Climate change may affect agricultural production in a number of ways. Declines in total rainfall and increasingly unpredictable rainfall patterns make farming more risky, increasing the likelihood of crop failures and reducing agricultural productivity. Too much rain (total or at the wrong time) is bad for drought-adapted crops like millet and sorghum. Too little rain is bad for maize, yams, and rice. The timing of rain is also important; mid-season dry spells can cause crops to fail even if total rainfall for the season as a whole is normal. Flooding wipes out dry season crops grown in river valleys and stream beds, as shown by recent experience in northern Ghana. Wind storms can destroy millet tassels once they form late in the season. And bushfires, a common phenomenon, sometimes burn crops before they are harvested, burn crop residues following harvest that could otherwise be used for feeding livestock or fertilizing fields, and can alter soil structure to make it less productive for farming.

Farmers we interviewed near Mole National Park stated that they were cultivating larger areas, but overall productivity was declining. Climate change is likely one of several factors contributing to this problem. Where land is available, extensification to increase productivity is an option. But unless a household owns a tractor, oxen, and a plough, or can hire one of these, extensification requires higher labor and capital inputs. In areas of high population density, most farmers must pursue intensification strategies to maintain or improve crop yields. These strategies are often labor intensive, a barrier for some households.

Regarding livestock, we heard several reports that water and forage are becoming more difficult to obtain in the dry season. Declines in dry season grazing and water have led to reductions in livestock holdings for some households in the Upper East Region, and shifts in herd structure for others, for example, rearing more goats which are easier to feed than cattle and sheep (Gyasi et al., 2008). A growing incidence of bushfires – exacerbated by a hotter, drier climate – is reportedly burning animal fodder, also making it more difficult to obtain dry season forage.

NON-FARM ACTIVITIES

Non-farm activities play a critical role in household livelihood security in the northern savanna zones (e.g., Whitehead, 2002), as they help households widen and diversify their income-earning portfolios. Most households depend on a combination of farm and nonfarm activities (Hesselberg and Yaro, 2006). Non-farm activities help people cope with temporary adversity in the agricultural sector and also represent a longer-term adaptation strategy when other options fail (Scoones, 2008). In northern Ghana, these activities include hunting, fishing, non-timber forest product harvesting, local manufacturing, charcoal production, petty trade, and wage labor (Dietz et al., 2004; Hesselburg and Yarro, 2006; Whitehead, 2002). Non-farm income earning activities are especially important during the dry season.

Climate change may pose problems for non-farm activities that are natural resource-based. For example, declines in tree cover will make it more difficult to engage in charcoal production, the sale of firewood, and the gathering and manufacture of products from some non-timber forest species such as dawadawa and shea nuts, despite the protected status of these trees in many communities. Nevertheless, non-farm activities are likely to play an increasingly important role in household livelihoods in the future because they offer opportunities for diversification when agriculture becomes more risky.

MIGRATION

A third common livelihood strategy in the northern savanna zones is migration, often by select household members who send remittances back home. Migration includes seasonal, temporary and permanent movement between places, whether short or long distance. Migration from Ghana's three northern regions to its southern regions has been ongoing since the turn of the 20th century, when British colonial rule was introduced (Van der Geest, 2008). Between 1984 and 2000, 18.4 percent of the people who were born in northern Ghana migrated south with the Upper West Region exhibiting the highest rates of outmigration (26.9 percent) followed by Upper East (22.2 percent). The main destinations of migrants from the north are the cities of Kumasi and Accra, the cocoa belt frontier in the northern part of the Western Region, and the productive farming areas to the south (Van der Geest, 2008). Those who have skills, such as mechanics, carpenters and teachers typically migrate to urban areas; unskilled farmers typically migrate south to places where farming is more favorable. In the Upper East Region, migration is more common from areas where population density is high, there are land shortages, and opportunities for irrigated agriculture are lacking (Hesselburg and Yaro, 2006). Key factors causing migrant farmers living in the Upper West Region to move to the Brong-Ahafo Region were land scarcity, reduced soil fertility resulting in low agricultural productivity, and the abundance and fertility of land in the Forest-Savanna Transition Zone, where rainfall and farming conditions are better than in the north and there are more opportunities to earn income (Van der Geest, 2008). Climate was also a factor that led to outmigration from Upper West.

Notably, Ghana's northern savanna regions, particularly the Upper East, are also receiving areas for migrants. Fulani herders from Burkina Faso, Mali, Niger and Nigeria began moving into northern Ghana early in the 20th century (Tonah, 2006). At first, their movements were seasonal, took place mainly during the dry season, and were confined to the Upper East Region. They were drawn by relatively low populations of humans and animals and lush vegetation. Drought and growing difficulty obtaining pasture and water at home, particularly during the dry season, caused the number of migrants to rise and to settle more permanently in northeastern Ghana. By the 1960s, the Fulani population in northern Ghana had grown considerably. Competition over resources became severe leading to conflicts between herders and farmers. This caused many Fulani migrants to move farther south, especially to Ghana's Lake Volta Basin. Some worked as hired herders for farmers and traders, and others simply moved wholesale with their own cattle herds to pursue pastoral livelihoods. Although economic relations between Fulani herders and farmers can be symbiotic and mutually advantageous, they can also be contentious. The main cause of herder-farmer conflict is crop destruction by cattle (Tonah, 2006). The reasons for this conflict are many and complex (see Moritz, 2010; Tonah 2006) with the result that conflict between herders and farmers in recent years has become more violent. If climate change results in greater aridity in the region, it is likely to intensify this conflict as more herders are displaced from the even drier Sahelian region, migrate south into Ghana, and settle permanently and as resident farmers expand dry season farming in river valleys, river bottoms, and wetland areas where cattle concentrate during the dry season. Given current conditions of the savanna zones in Burkina Faso and northernmost Ghana, this may occur regardless of climate change effects, short of increase in rainfall.

ADAPTING TO CLIMATE CHANGE IN THE NORTHERN REGION

Because Ghana's northern savanna zones have historically experienced unpredictable rainfall and periodic drought, as is characteristic of dryland regions, people have developed coping mechanisms to deal with climate variability over time. Thus, they can draw on past experience to help them adapt to climate change. Traditional ecological knowledge plays an important role in this regard. Nevertheless, people's abilities to adapt will depend on the range of options they have available to them, which are a product of several factors. These include social networks, access to capital, household assets and capacities, knowledge, skills, information resources, local institutions that influence resource access and use, enabling policies, and access to infrastructure.

A number of shifts in livelihood strategies that support climate change adaptation are documented for Ghana's Upper East, Upper West, and Northern regions (Table 8.1). These can be organized into the three main categories of livelihood strategies that prevail in northern Ghana described in the preceding section. Most strategies focus on the agricultural sector. It is important to note that the drivers of these strategies may or may not be climate change per se; climate change is generally one of many social and environmental variables that interact to affect rural communities. Nevertheless, they are activities that support climate change adaptation in the northern savanna zones. Our summary is not meant to be exhaustive (Table 8.1) but rather to provide examples of adaptation strategies in the northern savannas.

Table 8.1 Climate Change Adaptation Strategies in the Northern Savannas [7]

Changes in agricultural practices	Livelihood diversification	Migration	Source
Sudan Savanna			
• Early-maturing millet varieties on the rise • Late-maturing millet varieties declining • More drought-tolerant varieties of red sorghum increasing in importance • Sheep, goats, pigs and poultry becoming more prevalent, cattle diminishing due to forage and water stress • Increased production of cash crops, like cotton, tomatoes, soy beans and onions • Multi-location farming, whereby a household cultivates plots in multiple places such as around the home compound, in the bush, in marshy areas and in irrigated areas • Expansion of land holdings, where possible • Shift towards cultivation in low lying areas, marshy areas and river valleys where soils retain more moisture • Increased irrigation development through construction of small water dams and water harvesting to grow rice and vegetables • Adoption of dry season irrigation of vegetable crops like lettuce, onion and cabbage • Greater reliance on livestock • Purchasing more food	• Women are diversifying their income streams by engaging in petty trade and selling cash crops • Gathering wild foods • Becoming a galamsey (local artisanal gold miner)	• Migration increasing over time	Dietz et al., 2004 Whitehead, 2002 Hesselberg and Yaro, 2006 Gyasi et al., 2008
Guinea Savanna			
• Increasing emphasis on sorghum and millet, which are drought resistant • Cultivating a greater variety of crops to spread risk, including sorghum, millet, maize, rice, yams, groundnuts and beans	• Adopting animal husbandry • Foraging for wild foods	• Remittances from relatives who have	Sagoe, 2008 Interviews during

[7] Strategies listed may not be confined to either the Guinea or Sudan Savanna ecological zone; they merely reflect strategies documented in the literature from these regions, and described in interviews.

Changes in agricultural practices	Livelihood diversification	Migration	Source
• Planting crops in diverse locations having different soils types and drainages • Staggering the planting of seeds over time, and planting several seeds per hole to enable transplanting • Shift planting dates • Intercropping to reduce weeds, retain soil moisture and intensify production • Mulching yam mounds to prevent dessication • Planting legumes as cover crops between grains to reduce soil and water runoff • Planting early-maturing and higher yielding crop varieties • Increasing crop density in fields • Weeding more often • Enhancing soil fertility by adding organic amendments such as agricultural waste, animal droppings or compost; retaining crop residues in fields; banning burning • Adopting mechanical measures to enhance soil fertility and retain soil moisture (e.g., contour tillage, grass strips, earth bunds, stone lines across slopes) • Using minimal tillage • Engage in dry-season gardening • Increasing use of lowland and valley bottom fields for cultivation to reduce vulnerability to drought • Accumulation of livestock as insurance against crop failure • Improving crop storage methods • Plant several varieties of yams that have different maturity periods and introduce drought-resistant and early maturing varieties • Introduce soil amendments • Intercrop fast-growing trees with yams to prevent soil degradation and increase wood products • Improve crop storage post-harvest • Increasing reliance on livestock and tree crops • Digging wells to access water for dry season vegetable growing (market is good for vegetables); dry season vegetable growing can occur as a backup to rice production if rice fails	• Brewing beer • Sheanut processing • Selling firewood • Petty trade • Fishing • Wage labor • Rent property to earn income • Charcoal production • Bee-keeping and poultry production • Ecotourism development around Mole NP • Manufacture of shea butter	migrated permanently • seasonal labor migration by youth in particular • to the southern regions, Kumasi, and Accra to earn money	mission Van der Geest, 2004

CLIMATE CHANGE ADAPTATION: OPPORTUNITIES AND CHALLENGES

The preceding summary of climate change adaptation strategies in Ghana's northern savanna zones indicates that there are many opportunities for adaptation that could be supported to increase livelihood security in the face of a changing climate. Nevertheless, challenges are also associated with many of these strategies. Households may have limited capacity to diversify; development assistance could help people widen their options by reducing barriers. Some of the opportunities and associated challenges are outlined in this section.

IMPROVING ACCESS TO CREDIT

Access to credit is important for helping people diversify their livelihood strategies inside and outside the agricultural sector. Northern Ghana suffers from high poverty, meaning many households cannot afford to invest in new businesses or agricultural production techniques because the cost of credit is extremely high in Ghana with interest rates hovering around 30 percent. Moreover, many banks require borrowers to repay loans quickly because of high default rates, often before an investment has begun to generate profits (interview). An opportunity exists to assist farmers in gaining access to credit on terms that are feasible for them. This could take place for example through micro-financing projects.

LOW-COST DIVERSIFICATION STRATEGIES

Diversification strategies that are lucrative and have low startup costs are attractive, especially for poorer households lacking access to credit. Examples are beekeeping, raising poultry, and charcoal production. Sustainable supplies of wood for charcoal production are difficult to find, and loss of tree cover may make charcoal production less viable in the future. Low-cost diversification strategies that are ecologically sustainable should be pursued.

TREE PLANTING

Planting trees to promote intercropping, increase the number of economically-valuable trees (e.g., mango, shea, dawadawa), reduce soil erosion, increase fuelwood supplies, and promote a host of other benefits that enhance livelihood security can be beneficial from an environmental and an economic standpoint. A barrier to tree planting is the tree tenure system in northern Ghana. In interviews, we were told when a person plants an economically-valuable tree they do not own it; it is the property of the chief. The chief has the right to its products, though he usually shares them with the person who planted the tree. Land and tree-tenure systems can be a strong disincentive to tree planting and need to be considered and perhaps addressed if tree planting programs are pursued.

LIVESTOCK PRODUCTION

Livestock play a critical role in supporting the livelihood security of many households in northern Ghana. Food security increases with the number and diversity of livestock owned. Although of low value, poultry are relatively low cost and maintenance and easily sold to help households respond to minor stresses. Goats, sheep, and pigs are more desirable but are more expensive to obtain and the first two require labor for herding. Livestock loan programs modeled on traditional practices in which relatives loan animals to kin who have lost their herds or who wish to start new ones have been successful in some parts of Africa. High potential exists for developing livestock husbandry as a climate change adaptation strategy in northern Ghana.

IMPROVING WATER INFRASTRUCTURE

Water infrastructure in the Northern Region is relatively under-developed compared to the rest of the country. Access to adequate water supplies for drinking, household use, livestock, and farming is likely to decrease under climate change scenarios of increased temperature and current levels or decreases in rainfall. Improving water infrastructure could help improve household drinking water quality and health; reduce travel time to water, freeing up labor; increase water supplies for livestock, an important factor limiting their production; and increase water availability to support dry season household gardens and cash crop production. Before developing new water infrastructure, careful assessment should be made to avoid some of the pitfalls that have been encountered elsewhere in Africa and Ghana in association with water development (e.g., boreholes, poorly planned irrigation projects and water diversions, poorly planned large-scale agriculture projects).

IRRIGATION DEVELOPMENT

Access to wetter areas or irrigated plots for at least some crop production increases the livelihood security of households in the northern savannas. Thus, irrigation development to support agricultural diversification by smallholders may be desirable if done appropriately. Large-scale irrigation schemes are uncommon in the three northern regions, though some irrigation schemes exist in Upper East. Irrigation development is expensive and on a large-scale relies on high input farming; poor households may not be able to afford it. It also has several risks: water management becomes more challenging, siltation can be a problem, soil quality and productivity can be decreased, existing land uses are often displaced, herder-farmer conflict can be exacerbated, and disease-carrying insects may proliferate. A community-based approach to evaluate how irrigation development can be implemented in a manner appropriate to the local context is desirable to minimize the associated risks.

IMPROVING FOOD STORAGE

Traditionally, farmers in northern Ghana stored excess grains produced in good years to serve as a reserve in bad years (Dietz et al., 2004). Grains were stored for ≤3 years in some places (Van der Geest, 2004). Today, surplus grains produced in good years are more commonly sold to obtain cash or used to brew beer to sell locally. Grain storage can provide an important buffer against crop failures resulting from climate variability. Efforts to improve food storage facilities could help promote this practice but alone may be insufficient. It may also be necessary to expand food production in order to create surpluses and to find alternative means of generating cash to meet household monetary needs.

ECOTOURISM

Ecotourism development in northern Ghana as a source of non-farm income generation has perhaps the greatest potential around Mole National Park. About 33 communities border the park. A large, unrealized potential exists to develop ecotourism around Mole and to generate associated jobs in the park and in surrounding communities. The A Rocha Ghana project has helped two local communities develop ecotourism infrastructure. Our interviews with residents of one of these villages revealed that ecotourism generates some money, but if the money must be shared with all households in the community, it gets spread too thin. The greatest benefits go to the people directly employed in tourism-related activities. Finding ways to best share the benefits of ecotourism development is one challenge that must be faced.

COMMUNITY RESOURCE MANAGEMENT AREAS (CREMAS)

Wildlife movements outside of Mole National Park boundaries are expected to occur under climate change scenarios which increase aridity. If local communities suffer more crop-raiding as a result, they may wish to kill wildlife. Animals are also more susceptible to poaching outside of park boundaries. In some parts of Ghana, CREMAs are established to give local communities a vested interest in wildlife and to help them benefit economically from their conservation. CREMAs are places where the government devolves authority to manage wildlife outside of national park boundaries to local communities. Communities develop wildlife management plans, control hunting, and benefit from revenue generated by hunting and tourism within their areas. Wildlife benefit because CREMAs create a buffer zone around parks that is otherwise lacking. The A Rocha Ghana project has been active in helping communities around Mole develop CREMAs and integrate natural resource management activities into local production systems. CREMAs represent a positive climate change adaptation strategy.

IMPROVING MARKET CONDITIONS

As this chapter indicates, cash crop production is an important climate change adaptation strategy for farming households in northern Ghana. But road infrastructure and access to markets is relatively poor in the north. Investments in improving access to markets and roads would improve market conditions. A need also exists for policies promoting stable and favorable crop prices. Better access to credit will also help farmers invest in cash crop production. Projects in northern Ghana that focus on improving the entire value chain that links farmers to agricultural services and markets, for example the Ghana Agricultural Development and Value Chain Enhancement Program (ADVANCE), also hold promise.

LOCAL PROCESSING FACILITIES

Local processing facilities are lacking or essentially so for agricultural and wild-harvested products. Establishing local processing facilities – for example, for producing shea butter or soybean oil – would make it possible to manufacture value-added products that bring higher prices than the sale of raw products. It would also help create non-farm jobs.

EDUCATION

Northern Ghana has the highest rates of illiteracy in the country. In the Northern Region, 72.3 percent of the population never attends school; in the Upper East Region, 69.4 percent never attends school; and in the

Upper West Region, 69.8 percent of the population never attends school (GSS, 2005a, 2005b, 2005c). Of those that do go to school, less than a quarter progress to secondary school. Investments in education enable people to develop skills and knowledge that can help them pursue off-farm livelihoods and work outside of the natural resource sectors, making them less vulnerable to climate change impacts. Education can also help migrants get better jobs in urban areas, earn more and increase remittances back home.

CONCLUSION

Growing population pressure in Ghana's coastal and northern savanna regions, high social vulnerability to climate change in the north, and climate change impacts such as unpredictable rainfall and sea-level rise, have necessitated that households, communities, and government respond to resulting livelihood vulnerabilities with insurance and coping strategies and livelihood adaptations. The best of these adaptations reduce vulnerabilities and contribute to long-term sustainable livelihoods. Others serve to provide for the short term but threaten the system's long-term health. Development organizations have the opportunity to help better coordinate approaches to adaptation and ensure that best practices emerge as solutions.

USAID's Feed the Future program is well positioned to support climate change adaptation strategies that increase the livelihood security of households in Ghana's coastal and northern savanna zones because of its focus on enhancing food security. Many of the activities proposed under Feed the Future directly address the opportunities for adaptation described here. It will be important to take a community-based approach in developing and implementing specific interventions to support both food security and climate change adaptation to ensure that they are appropriate to the local context and will be beneficial.

9. CLIMATE CHANGE MITIGATION IN GHANA – OPPORTUNITIES AND CHALLENGES

Climate change mitigation – actions that either reduce or limit greenhouse gas emissions or increase carbon storage in vegetation and soils – is critical in order to stabilize global climate change. A central focus of the 2010 United Nations climate change conference in Cancun, Mexico, was to address the need for nationally-appropriate mitigation plans for developed and developing countries. This section provides an overview of the current status of climate change mitigation activities in Ghana, and associated opportunities and challenges. To date, most attention has been given to REDD+ (reduced emissions from deforestation and forest degradation, plus conservation co-benefits that enhance other ecosystem services); therefore, REDD+ is the focus of this overview. Nevertheless, a number of other opportunities for climate change mitigation exist in Ghana, including the development of forest-based carbon offset projects under the Kyoto Protocol's Clean Development Mechanism; low carbon development projects, including low carbon agriculture; improved fire management; the capture and use of natural gas associated with offshore oil development (an alternative to flaring); and the production of biofuels to replace fossil fuels. We address all of these activities below.

CLEAN DEVELOPMENT MECHANISM PROJECTS

The Clean Development Mechanism (CDM) is one of two carbon offset mechanisms included in the international cap-and-trade system established by the Kyoto Protocol. The CDM enables developing countries that are signatories to the Kyoto Protocol to develop carbon offset projects from which they earn certified emission reduction credits (each equivalent to 1 ton of carbon dioxide). These credits can be traded, sold, and used by industrialized countries to meet part of their emissions reduction targets under the Kyoto Protocol. At the same time, the CDM aims to promote sustainable development in developing countries. The CDM accepts certified emission reduction credits from several sectors: energy, industrial processes, solvent and other product use, waste and land use, land-use change and forestry. Regarding land use, land-use change and forestry, afforestation, reforestation, and improved forest management projects qualify for CDM credits, but REDD+ projects do not.

Ghana's Designated National Authority (DNA) for CDM projects is the Environmental Protection Agency. The DNA has a governing council responsible for evaluating and approving CDM projects. According to the head of the Climate Change Unit at Ghana's Forestry Commission, Ghana's CDM strategy focuses on integrating CDM into its plantation development program. Although the government target for plantation development was 60,000 acres/year, Ghana has been unable to attract investment funding for plantation projects, so the target has been reduced to 30,000 acres/year. The national plantation development program would become part of a programmatic offset project using a bundling approach to reduce transaction costs and could include small projects. To date, only one CDM project has been advanced and passed through the CDM Project Design Document phase – a rubber plantation managed by Ghana Rubber Estates Limited in the Western Region. Another plantation project is under development in a government forest reserve in

Brong-Ahafo Region that entails reforesting an area that is currently mostly grassland. A Project Design Document is not yet completed for this project. No plan is developed as yet that identifies how the money earned by selling certified emission reduction credits will be distributed. However, the Ministry of Environment recently established a carbon credit policy committee to help facilitate development of CDM projects in Ghana and a policy for how the money generated by selling credits should be distributed.

Ghana was a participant in the Capacity Development for the Clean Development Mechanism (CD4CDM) Project, established to help developing countries gain awareness of, obtain information about, and build institutional capacity to implement CDM projects. Nevertheless, progress in developing forest carbon offset projects under the CDM in Ghana is hampered by a number of obstacles: (1) the rigorous nature and high cost of verification and compliance; (2) lack of financing to invest in plantation development and help meet transaction costs; (3) weak carbon markets; and (4) uncertainty over the future of the CDM once the Kyoto Protocol expires in 2012. Some CDM-related concerns raised by people we interviewed in Ghana included the biodiversity impacts of plantation development, the cost and effort needed to maintain plantations once established, the fact that CDM projects do not encourage real emissions reductions, and a belief that most of the money generated by the projects will be made by "middle men" who speculate in trading carbon credits on the carbon market, rather than to the country that develops the projects. For tracking up-to-date information about the status of CDM projects in Ghana, please visit Ghana's newly-established CDM website: http://www.epa.gov.gh/cdm/index.htm.

NATURAL GAS AND OFFSHORE OIL DEVELOPMENT

In Ghana, the issue of gas flaring from the Jubilee Oil field has created concern and controversy in civil society (e.g., Adam, 2011) and donor countries (van Tilburg and Würtenberger, 2010). Gas flaring is the direct burning of natural gas at the oil production site. This is an extremely wasteful practice – acutely so, given Ghana's ever increasing energy needs and demands. With increased international emphasis on curtailing the practice, gas flaring globally has remained largely stable over the past 12 years, but still 134-162 billion m^3 (BCM) are flared each year (data 2006-2010, World Bank, 2011). Nigeria, a nearby West African country, is the second largest contributor to the flared gas totals in the world (behind Russia). The global gas flaring estimate of 168 BCM for 2006 represented 27 percent of the natural gas consumption of the United States with a potential market value of US$40 billion. From a climate change perspective, flaring adds about 400 million tons of carbon dioxide into the atmosphere each year. In terms of reducing greenhouse gas emissions, curtailment of gas flaring and use of the gas for fuel is seen as a practical and relatively low-hanging fruit (World Bank, 2011).

Currently, the Jubilee Oil Field is the only developing offshore field in Ghana, and statements in the media by oil industry officials indicate it is in or nearing the initial stages of production (Adam, 2011). Other fields with oil producing potential will likely take 4-6 years to begin production. The target production level of the Jubilee field is 120,000 barrels of oil/day and 120 units/day (MMscfd, million standard cubic feet) of natural gas (Figure 9.1, Tullow Ghana Limited, 2009). Total projected production through the 2030 life expectancy of the field is about 760-1,140 billion cubic feet of natural gas at gas recovery levels of 40-60 percent, respectively. Of the daily gas production, about 20 units are planned to furnish power to the Floating Production, Storage, and Offloading (FPSO) vessel, which separates the oil and gas from the wells, and stores the oil for shipping. Another 30 units of gas are planned to be re-injected into the wells to maintain reservoir pressure and enhance oil recovery. The remaining 70 units of natural gas are available for other uses such as transfer to an onshore processing plant (Tullow Ghana Limited, 2009). If the processing plant removes about 20 percent of liquefied petroleum gas (LPG) and condensates, enough gas would remain to continuously power a 380 megawatt electric (MWe) modern gas power plant (3 terrawatt hours, TWh, annually), which is equivalent to about 35 percent of Ghana's national electric grid production (van Tilburg and Würtenberger, 2010).

Given the substantial production, the gas from the Jubilee Oil Field will need to be stored, transported, or flared. The Environmental Impact Statement (EIS) for the Jubilee Oil Field development repeatedly states that flaring will be short-term, minimal, and primarily related to safety and maintenance operations (Tullow Ghana Limited, 2009), and the government policy is zero gas flaring (van Tilburg and Würtenberger, 2010). The EIS also indicated a longer period of flaring will occur during the initial commissioning period of 3-6 months as the gas compression is brought to steady state (Fig. 9.1, Tullow Ghana Limited, 2009). Apparently this process is now ongoing according to oil industry statements in the media (Adam, 2011, quoting Mr. Thomas Manu, Director of Exploration and Production at the Ghana National Petroleum Corporation, GNPC).

The EIS also indicated that during full oil production, ≤100 MMscfd could be re-injected into the oil field reservoir if necessary. As noted the 100 MMscfd figure is the full daily gas production less power needs for the FPSO. However, the re-injection storage capacity has been questioned because of uncertainties of geology and reservoir operations. Further, the infrastructure to pipe gas ashore will not be ready as oil production is initiated and ramped up (van Tilburg and Würtenberger, 2010). Oil industry officials indicated in the media re-injection of gas after an 18-month period will not be possible at the Jubilee Field (Adam, 2011), but no explanation was forthcoming. Hence, long-term gas flaring at the Jubilee Field may be inevitable without accelerated development of infrastructure for storage, shipping, and processing of the gas.

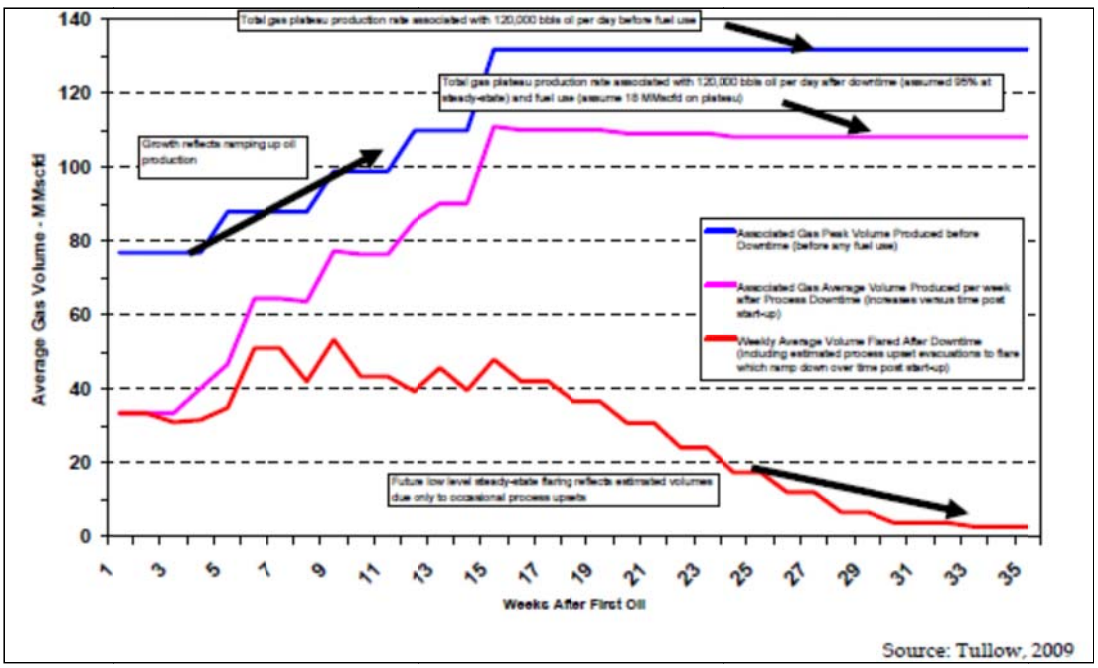


Figure 9.1 Estimated peak, average, and flaring weekly volumes of natural gas

(From Jubilee Oil Field, Ghana (Tullow Ghana Limited 2009) Note projected decrease in gas flaring about 18 weeks after oil production ramp up based on re-injection and off-site processing of gas of about 30 and 70 MMscd. Respectively)

It is critical to re-emphasize that no infrastructure is in place to transport the gas from the FPSO although time to first oil is apparently close (Adam, 2011). Minimally, a pipeline to the shore, a processing plant, and a power plant are needed to use the gas. The lead time for this infrastructure to develop is ≥3-4 years after the decision to go forward has been made (Tullow Ghana Limited, 2009; van Tilburg and Würtenberger, 2010). Ghana did recently announce a gas development joint venture partnership (Reuters, 2011); if this means rapid progress an operational natural gas transport and processing infrastructure could not be expected until 2014 (or even later). Existing infrastructure plans vary from the basic combination of pipeline, processing plant and power plant to more extensive plans of connecting to the West African Gas Pipeline in Takoradi (Tullow

Ghana Limited, 2009). Given the confirmed gas finds to date, the gas could only supply an initial basic configuration. An alternative to pipeline transport is the construction of an offshore LNG processing plant with shipping of the LNG gas. However, the high cost of LNG plants has limited their use globally. The lead time for an LNG plant is significant, and the amount of gas currently expected in Ghana is not sufficient to economically justify an LNG plant (Tullow Ghana Limited, 2009; van Tilburg and Würtenberger, 2010).

Prolonged gas flaring, the risk of which appears high at this point, of the Jubilee natural gas would produce about 1.5 million tons of CO_2 annually or about 7 percent of Ghana's total national emissions. If the gas is not flared but is used in a power plant, >13,000 barrels of oil/day are saved and 0.9 million tons of CO_2 emissions are avoided. The total emissions reduction potential from using the gas for power production instead of flaring is 2.4 million tons CO_2 equivalent or 10 percent of national emissions. Further emission reductions could be realized by domestic use of liquefied petroleum gas if it replaces diesel generation (van Tilburg and Würtenberger, 2010). Unfortunately, if the gas infrastructure development takes four years to become reality and high re-injection capacities are not feasible, the life of this valuable gas field will be reduced by about 20 percent (16 versus 20 years, Tullow Ghana Limited 2009), an estimated 152-228 billion standard cubic feet of gas will be lost for energy production, and some 6 million tons of CO_2 will be released.

10. ENERGY SECTOR

SOCIAL IMPACTS OF OIL AND GAS DEVELOPMENT

The coast makes up 2-7 percent of Ghana's land mass and holds roughly 25 percent of the country's population (Dontwi et al., 2008a). District growth rates along the coast range from 1.0 percent to 4.4 percent annually, indicating that the most rapidly growing areas are on track to double their populations in the next 16 years. Coastal inhabitants depend primarily on marine fisheries for their livelihoods (Dontwi et al., 2008a; CRC, 2010). However, the tourism industry has been rapidly growing over the last decade and currently supports about 319,000 jobs (5.9 percent of the country's total employment) and constitutes an estimated 6.7 percent of Ghana's national GDP (WTTC, 2011). Many residents anticipate that oil and gas development will play a large role in both local revenue and employment in the future; however, the full complement of impacts of the oil and gas industry have yet to be realized (Quagraire, 2011). Local governments (in the form of both district and regional assemblies) and chiefs located in coastal areas anticipate that they may receive a share of the revenues generated by the oil and gas industry. Thus far the government has not agreed to any form of benefit sharing with local communities, and the issue remains contentious.

According to Publish What You Pay, a civil society coalition based in Accra, the Ghanaian government committed to having 80 percent of managerial positions in the oil and gas sector filled by Ghanaian citizens five years after beginning production from the Jubilee Oil Field. Due to a lack of technical expertise and capacity to develop the expertise, this quota is far from being met. The few local employment opportunities available so far have been labor intensive jobs such as janitorial work (Adam, 2011; Quagraire, 2011). Coastal residents are beginning to express concern not just over the lack of local hiring, but also over the lack of available technical training opportunities. No local institutions are capable of teaching necessary skills and no training opportunities are provided by either the government or Kosmos Energy (Adam, 2011; Quagraire, 2011).

Meanwhile, in the absence of employment opportunities associated with the oil and gas industry, coastal residents have expressed concern over the long-term viability of their present livelihoods. Fishers complain that their catch is reduced, and while not attributable exclusively to oil and gas development, it is noteworthy that increasing numbers of fishers report an oil sheen on the sea surface or dead wildlife (e.g., dead whale) off the coast of the Western Region. More troublesome, fishers complain that their nets are seized when they unknowingly cross into waters zoned for the oil field, making it impossible for them to continue fishing and make any necessary payments to the bank (Adam, 2011; Quagraire, 2011). On shore, fledgling resort operators worry that pollution from gas flaring, potential oil spills or general industrial development will detract from tourism, and residents complain that landlords are increasing rents as they anticipate that oil and gas workers can afford to pay more (Adam, 2011; Quagraire, 2011).

In response to these potential disruptions, and the potential costs of long-term environmental damage that could arise from a spill, chiefs and local governments in the Western Region have asserted that they deserve a share of the revenue generated by the oil and gas industry. In early 2010 local chiefs banded together and put a unified request before Parliament that the state grant 10 percent of all revenue to the region, to be distributed between the district assembly and the stool lands (Adam, 2011; Quagraire, 2011). This follows the precedent set forth by the mining industry, whereby local chiefs and district assemblies surrounding state-owned mines are granted a share of the profits, to be distributed throughout the district. The central government has not been happy with this system, feeling it leaves too much room for corruption at the local level. Parliament rejected the request put forward by the chiefs, and has stipulated that revenue should go directly into a central government account to be spent on high priority development areas, including the coast. It remains to be seen how this money will be distributed in actuality, and what social impacts it will have at the national or local level. Thus far the lack of transparency in the process threatens to undermine any positive impacts, and has upset communities along the coast who argue that they bear the higher costs of oil and gas development without receiving any of the benefits (Adam, 2011; Quagraire, 2011). Still, communities remain hopeful that they might eventually see some benefit from these revenues. There is, however, growing resentment towards the industry over the impact it has had on the local way of life, and frustration over lack of employment opportunities to date. There is also a growing fear that Ghana will replicate the errors of countries such as Libya and Nigeria when it comes to managing oil and gas revenues.

CLIMATE CHANGE IMPACTS ON THE ENERGY SECTOR

COASTAL EROSION AND SEA-LEVEL RISE EFFECTS ON OIL AND GAS

The combined effects on the oil and gas sector of Ghana of ongoing coastal erosion and climate change-induced sea-level rise are for the most part uncertain. Even so, obviously the highest risk will be for infrastructure and associated facilities located close to the coast or low-lying coastal lagoons or river estuaries. Historic shoreline rates of change in complex and dynamic large-scale coastal systems, such as the currently eroding coastline of Ghana, cannot be assumed to continue into the future (Lakhan, 2005). Recent acceleration in sea-level rise due to global warming is evident and at the upper boundary (worst-case) of initial projections (Rahmstorf et al., 2007). With the expectation that sea-level rise will continue for centuries (IPCC, 2007), future coastal recession can generally be expected to accelerate relative to the recent past (Addo et al., 2008).

Coastal erosion is a long recognized, widespread problem and concern along most of the Ghanaian coastline (e.g., Ly, 1980; Tsidzi and Kumapley, 2001; Addo et al., 2008; Addo, 2009; CRC-URI, 2010). Crude estimates derived from aerial photographs in the mid-20th century indicated coastal recession was most severe along the eastern coast of Ghana (Keta, Ada on the Volta Delta), moderately severe along the central coast (i.e., Accra), and least severe in the west (Sekondi, Cape Coast) (Ly, 1980; Tsidzi and Kumapley, 2001). However, these underlying rates, if accurate, are likely primarily related to natural conditions (e.g., geology, longshore currents, wave action), but recent human interventions (e.g., vegetation destruction, dams, poorly placed breakwaters, groynes, or gabions, uncontrolled sand mining or sand winning activities) also have accelerated or directly caused coastal erosion in all these areas (Ly, 1980; Mensah, 1997; Tsidzi and Kumapley, 2001; Campbell, 2006; CRC-URI, 2010).

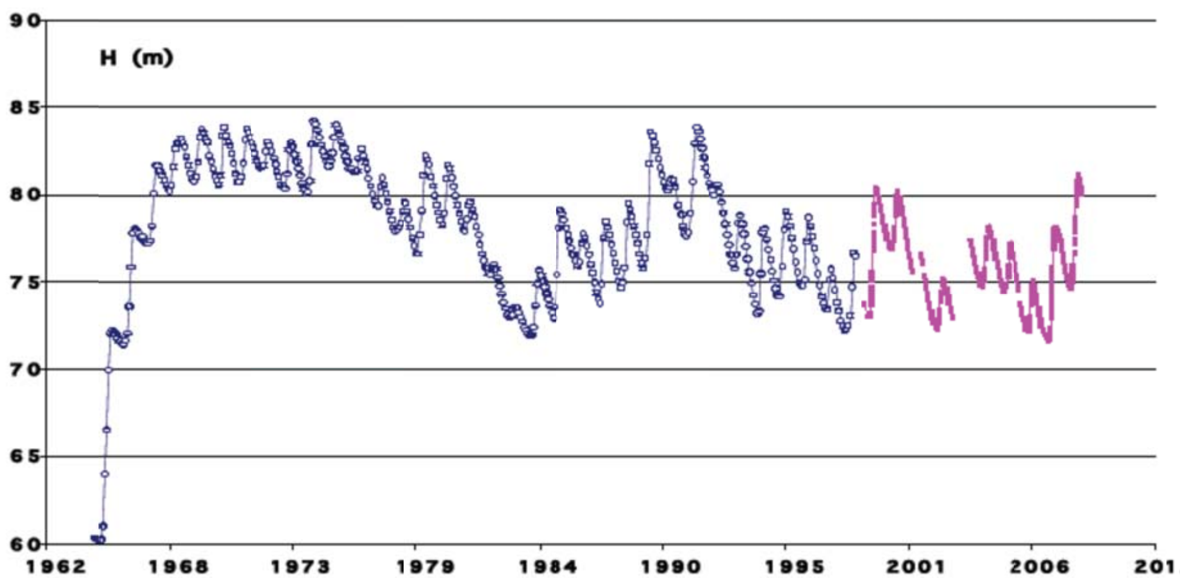
A recent carefully quantified estimate of coastal erosion was made for three sections of the coast at Accra using bathymetry maps and aerial photographs from 1904-2002 (Addo et al., 2008, 2009), which can illustrate potential changes elsewhere in Ghana. Although highly variable along the included coastal sections, the average rate of historical coastal erosion was 1.13 m/yr (range, 0.05-1.86 m/yr) with 82 percent of the coastline eroding. When projected increases in sea-level were modeled (2-6 mm/yr) with erosion and projected into the future, coastal recession increased in all study sections. For example, one section with historical erosion rates of 1.15 m/yr is projected to increase to 1.47-1.63 m/yr with rising sea level. Simply put, in 50 years that coastline is projected to recede by 74-82 m. Global climate models estimate sea-levels along Ghana will increase 8.6 cm (range, 3.8-14.4) by 2030, 12.0 cm (5.5-20.2 cm) by 2040, and 34.5 cm (161-58.4 cm) by 2080 (Minia 2008; see Chapter 3). Exactly how these two phenomena, coastal erosion and sea-level rise, might interact is not fully understood, but even taken singly, future effects will obviously be felt first and be most severe in the lowest lying coastal areas (IPCC, 2007; Addo et al., 2008; Addo, 2009).

The analyses made for Accra provide a basis for what to expect in other areas of Ghana, like the port of Takoradi, the land-based center of the Jubilee Oil Field development. Clearly, placement of infrastructure (port facilities, pipelines, storage, processing, and other physical structures) in Takoradi should be made with the risk of coastal erosion and inundation fully and seriously considered. Likewise, establishment of actual rates of erosion along the coast of Ghana is clearly needed to reduce uncertainty about future changes as the coast line advances through developed areas (e.g., housing, commercial and industrial centers, roads) in Takoradi and other coastal communities. Such information is also needed to help prioritize areas that are projected to be the first or most affected and select technically appropriate and feasible mitigation actions (Addo et al., 2008; Addo, 2009).

CLIMATE CHANGE AND HYDROPOWER

Ghana is highly dependent on hydropower for its electrical supply, and the vast majority of that energy is derived from Akosombo dam and the smaller downstream Kpong dam on the Volta River. These dams lie about 100 km from the Volta River estuary in southeastern Ghana. Lake Volta, the large impoundment behind Akosombo dam, covers 8,500 km^2 at full supply level or about 4 percent of the land area of Ghana (Andreini et al., 2000; van de Giesen et al., 2001; Lemoalle and Condappa, 2009). These two hydropower facilities at full generating capacity provide 1,180 megawatts (total annual capacity of 6,100 GWh and actual production of 4,800 GWh depending on water levels, Lemoalle and Condappa, 2009), which represents >95 percent of Ghana's power supply. Electricity from the dams is also sold to neighboring countries (Andah and Gichuki, 2005). The Bui dam, on the Black Volta, now under construction, will impound 440 km^2 and is designed to provide 980 GWh/yr under optimal operating conditions (Lemoalle and Condappa, 2009).

Water levels (and volumes) on the lake are critical to hydropower production. If water levels of Lake Volta are <71.8 m, power generation is impossible (Fig. 12). Water demand for the two operating hydropower dams is about 33 km^3/yr depending on the period considered (Lemoalle and Condappa, 2009). Akosombo dam and power plant were planned in a wet period when inflows were >40 km^3/yr. Low, irregular flows of recent decades (36.5 km^3/yr, 1985-2000) lowered generating capacity. Past droughts have lowered water levels enough in Lake Volta to cause national power disruptions for industry and urban consumers (rolling blackouts, 12 h without power every other day). Media accounts indicate 2007 low lake levels shutdown mining operations and major aluminum smelters (Valco), increased use of diesel or gasoline generators by businesses and consumers, and even motivated plans to build private coal-fired power plants (Harvey, 2007).



Sources: Lemoalle and Condappa, 2009

Figure 10.1 Water levels (m) in Lake Volta since dam in 1965

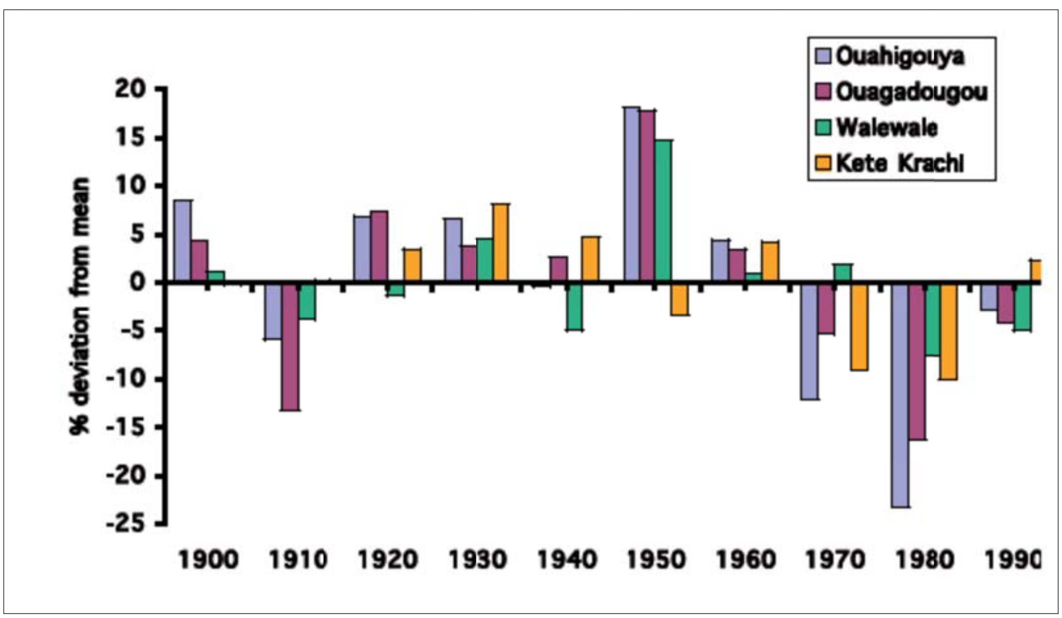
(Note the minimum operating level for power production at Akosombo dam is 71.8 m.

The distribution of the basin in riparian countries, dam construction, and the overall water balance of the Volta River Basin inform the complexity and potential precariousness of the situation from the standpoint of water supply to the hydropower dams in Ghana (van de Giesen, 2001). About 43 percent of the Volta River

Basin (total area 416,382 km^2) lies north of Ghana in Burkina Faso within the Sudan Savanna Zone (Sudano-Sahelian zone), a naturally more arid region (about 500-990 mm/yr) than the Guinea Savanna Zone of Ghana Nicholson et al., 2000; Lemoalle and Condappa, 2009). The Basin covers 63 percent of Burkina Faso. Another 40 percent of the Basin is in Ghana, covering about 63 percent of that country, mostly in the Guinea Savanna and Forest-Savanna Transition zones. Other riparian countries in the basin include Togo (6 percent), Benin (4 percent), Côte d'Ivoire (3 percent) and Mali (4 percent).

Three main tributaries comprise the Volta River basin. The Black and White (including the Red) Volta Rivers flow from Burkina Faso into Ghana and supply 19 percent and 24 percent of the water behind Akosombo dam, respectively. Even though small relative to the Black and White Volta river sub-basins, the Oti River, flowing from Benin through Burkina Faso and Togo into Ghana, supplies about 28-44 percent of the lake's waters (Andreini et al., 2000; Andah and Gichuki, 2005). The lower Volta River sub-basin (tributaries in Ghana) supplies the remaining 24 percent to the impoundment.

Increasing population size and a prolonged period of decreased rainfall and recurring drought (Figure 10.2) in the late 20th century (Nicholson et al., 2000; Andah and Gichuki, 2005; Andah et al., 2005; Kasei, 2009), led to a proliferation of dams in the Volta River Basin adding further complexity to managing water for hydropower generation in Ghana. Benin has a 15-megawatt hydroelectric power station on the Oti River (storage capacity, 350 million m^3) and another is planned (Andah and Gichuki, 2005). In recent decades, Burkina Faso has tremendously increased the number of dams in the Volta River Basin to an estimated 600 dams with a storage capacity of 4.7 billion m^3. Two hydropower dams exist (Bagre, 65 GWh/yr, Kompienga, 19 GWh/yr) and two more are planned (Nooumbiel, 203 GWh/yr; Samandeni, 17 GWh/yr, upper Black Volta basin). Notably, 1,000s of dugouts and small reservoirs exist in Burkina Faso and northeastern Ghana (Lemoalle and Condappa, 2009). Côte d'Ivoire has 43 minor dams with a storage capacity of 2.97 million m^3, Togo has five dams in the Basin (volume, 33.6 million m^3), and Mali has one significant dam, Pont-barrage of Baye. Notably, even though the Volta River Basin is critical for meeting water and power demands in Ghana and several riparian countries (especially already arid Burkina Faso), no inter-country agreement is in place concerning water allocation in the Basin (Andah and Gichuki, 2005).

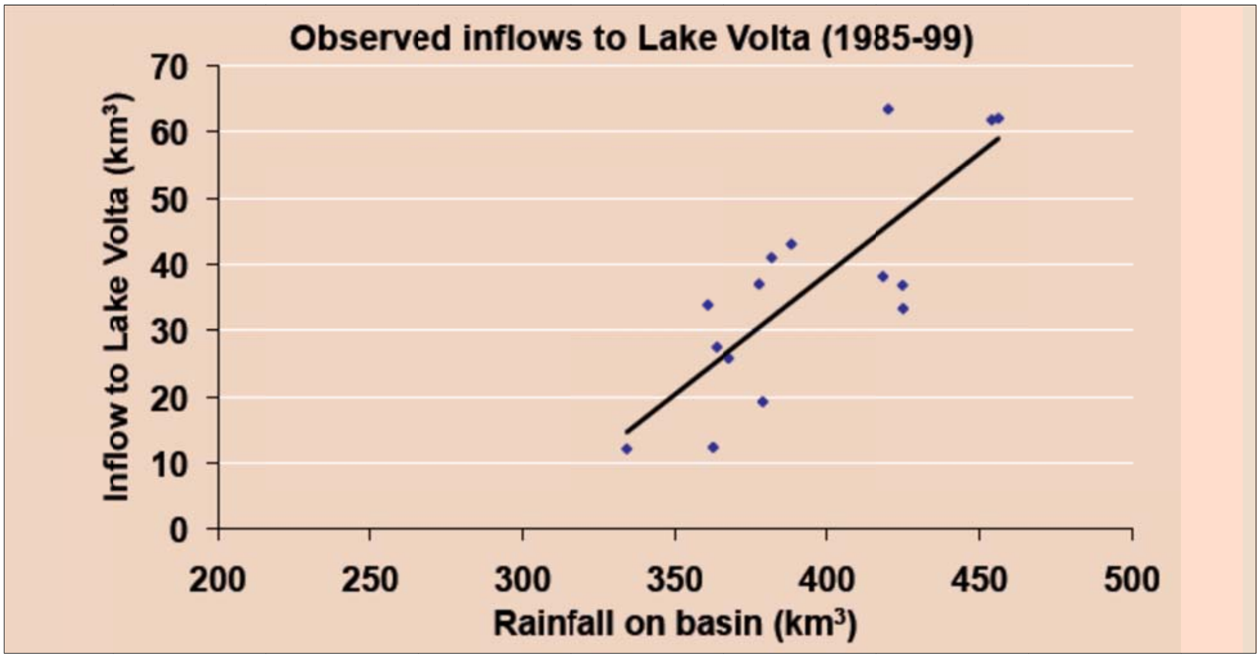


Source: Lemoalle and Condappa, 2009

Figure 10.2 Variation of rainfall since 1900, 4 locations in the Volta River Basin

(The deviation from each decadal mean is expressed as a percentage of the long-term 100-yr average. After a wet period from 1950-70, rainfall consistently remained below the long-term average. Akosombo dam hydropower facilities were designed based on much wetter conditions than experienced since 1970)

Water balance models indicate for the Basin as a whole that small changes in rainfall totals (negative or positive) can produce large changes in runoff totals (negative or positive) (Andreini et al., 2000; Lemoalle and Condappa, 2009). For example, mean runoff between 1936-1961 (pre-Akosombo dam closure) and 1965-1998 decreased between 8-14 percent in response to a small, 5 percent decrease in Basin rainfall. The models also indicate that only about 9 percent of the rain falling in the basin appears in Lake Volta as runoff. Other evaluations indicate a 10 percent change in annual rainfall produces a 39 percent change in river inflow into the Lake Volta (Figure 10.3; Lemoalle and Condappa, 2009). Hence, shifts in land use, water storage or use, or climate vagaries that have relatively small impacts on water flux through the upland areas (e.g., a change in evapotranspiration of a few percent) can result in large changes in percentage of runoff reaching the lake. Again, this also emphasizes the potential risk to hydropower production with increases in temperatures (and evaporation) and decreased or highly variable rainfall induced by climate change.



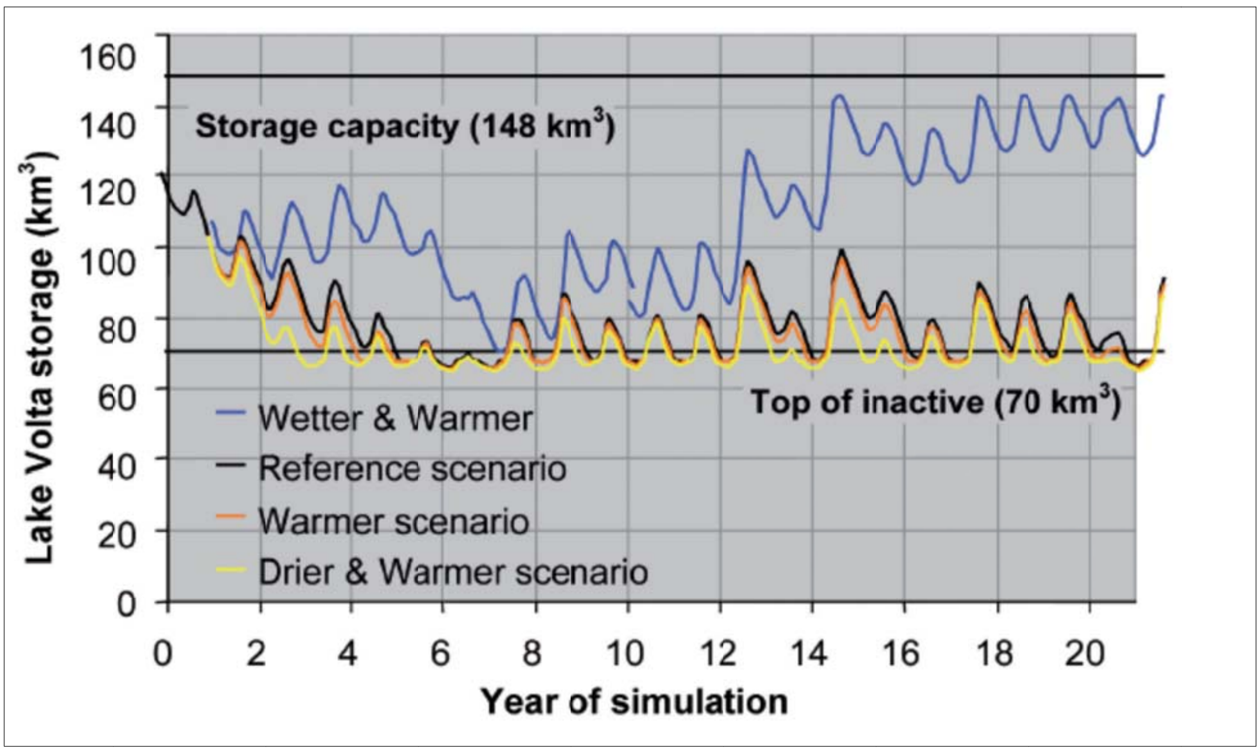
Source: Lemoalle and Condappa, 2009

Figure 10.3 Observed inflows to Lake Volta as a function of rainfall, 1985-1999

Water flowing through the Akosombo Dam increased from 28 km^3/yr to 35 km^3/yr in the 1990s, an increase of 25 percent (Andreini et al., 2000). As demand for electricity increases, the temptation to generate power at higher rates may trump concerns over drought or storage deficits. Because of drought deficits in the 1980s and continued power generation, Lake Volta levels never recovered to optimal operating conditions in the 1990s (van de Geisen et al., 2001; Kasei, 2009, Figure 10.4). The mean volume stored in the reservoir in the 1970s was 132 km^3 but in the 1980s and 1990s the mean volume was 102 km^3, a reduction of 20 percent (Andreini et al., 2000).

The response of Lake Volta to relatively small changes in runoff is also demonstrated in hydrological modeling. Hydrological model runs (WEAP software) were aimed at assessing effects of climate change and upstream reservoir storage on water levels and power generating capabilities in Lake Volta (de Condappa et al., 2008, 2009; Lemoalle and Condappa, 2009). Twenty-year scenarios (with 2000 as the initial condition) were simulated under wetter (meteorological CRU grids shifted 1° north) and warmer (2° C increase) conditions, drier (grids shifted 1° south) and warmer conditions, warmer conditions, and reference condition (no change from 1980-2000 conditions) (Figure 10.4). The scenario of increased temperature affected Lake Volta by slightly reducing the water level, but the scenarios with changed rainfall had a much more dramatic effect. In the drier scenario, the water level of lake is low and most often below the level at which hydropower production is impossible. The wetter scenarios push lake levels to near maximal operating capacities. In the reference (or no change) scenario target releases were met but storage was close to inadequate. Similar sensitivity to climate variability was indicated in another hydrological simulation (Leemhuis et al., 2009) and assessments focused on the Black Volta basin (i.e., Bui dam project, Laube et al., 2008) predict reduced water availability from reduced seasonal rainfall and river flows which will be exacerbated by higher temperatures and evapotranspiration. These factors, apparently not accounted for in dam planning and design, could negatively affect the hydropower operations at Bui dam (Biney, 2010).

Interestingly, in another 20-year modeling scenario, small upstream reservoirs with a steady state annual increase of 10 percent were projected to reduce Lake Volta inflows by about 3 percent at the end of 20 years. This is a small impact on power production relative to present variability in storage volume or to possible changes caused by climate change (Lemoalle and Condappa, 2009) but is nevertheless a reduction in power generating capacity. A question remains of whether the 10 percent annual increase in upstream reservoir capacity is an under-or over-estimate of water development in northern Ghana and riparian countries in the next 20 years.



Source: Condappa et al. 2009, Lemoalle and Condappa 2009

Figure 10.4 Simulation of water storage in Lake Volta under a reference condition

(No change from 1980-2000) and three scenarios of climate change. The black line labeled "Top of inactive (70 km^3)" indicates the storage level at which hydropower generation is impossible at Akosombo dam and the one labeled "Storage capacity (148 km^3)" is the capacity of Lake Volta at full pool)

Clearly the issue of future hydropower production from Akosombo (and Kpong) dams is complex, not simplistically related to potential climate change, and is replete with transboundary implications. First, the water development focus between the two major countries in the Volta River Basin is fundamentally different. Burkina Faso has and is concentrating effort in the Basin on improved use and increased retention of water for agriculture with demands in that country (as well as northern Ghana) expected to increase rapidly. In contrast, Ghana's primary objective is to keep Lake Volta at optimal levels for power production. Clearly potential exists for major conflict. Second, past meteorological data and hydrological modeling indicate water levels in Lake Volta are highly sensitive to even small changes in rainfall. Rainfall projections of global climate models are mixed adding to the uncertainty; however, trends from historical data indicate fairly dramatic decreases from long-term averages. Third, the design of Akosombo dam was premised on one of the wettest periods on record affecting optimal power production even during relatively short or modest dry periods in an inherently variable precipitation regime. Fourth, water allocation agreements are lacking among Ghana and the other riparian countries in the Volta River Basin. Finally, the future power production at Akosombo dam clearly will affect Ghanaian choices of alternate energy sources (i.e., fossil based or alternative) in an attempt to meet shortfalls and ever increasing demand.

SOCIAL IMPACTS OF PRESENT AND FUTURE HYDROELECTRIC DEVELOPMENT

In Ghana, dams have been a major feature of post-colonial development. The construction of the Akosombo dam was part of Ghana's "Ten Great Years," a national development plan intended to "rapidly modernize and transform an agrarian economy to an industrial-based economy […] within a generation." (Alhassan 2009, 151). Today, most Ghanaians recognize the Akosombo dam as the core of Ghana's socio-economic and industrial development. The widely perceived success of the Akosombo dam has led to the establishment of the smaller Kpong dam, and the Bui dam, now under construction. Climate change, and the increasing cost of crude oil, has led to a re-emphasis on hydroelectric power as a way to reduce global carbon emissions (Alhassan 2009). There are indeed benefits to hydro power, but there are also serious social costs that should be considered.

The chief social benefit of the Akosombo Dam was the provision of power to more than half of Ghana, making the nation one of the most industrialized countries in West Africa (Energy Commission 2005). However the construction of the dam also created Lake Volta, the world's largest artificial lake (8,520 square kilometers), and caused the forced resettlement of 80,000 people (Chambers 1970, Raschid *et al*.). Villages on the lake's periphery suffered a loss of fertile farming lands and forests, as well as a host of other ecological and health-related problems created by the flooding. Water borne diseases (such as bilharzias, river blindness, malaria, and schistosomiasis) became common around the lake: for example, prior to the dams construction schistosomiasis affected 1-5 percent of the population, but by 1979 the disease affected 75 percent of lakeside residents (Gorman & Werhane 2008). Downstream, lucrative livelihood activities, such as creek fishing and clam digging, were entirely eliminated (Tsikata 2006). Farming along the river was previously structured around seasonal cycles of floods which deposited nutrient-rich silts along the floodplains. After the construction of the dam downstream floods were interrupted and agricultural production, livestock rearing, and fishing virtually collapsed (Rahaman *et al.* 2004, Rubin *et al.* 1998, Gorman & Werhane 2008). These losses were largely ignored in the years following the dam's construction. Resettled communities did not receive much governmental support (Chambers 1970), and did not even receive power from the dam until 2001. Programs intended to offer assistance to individuals residing downstream and on the lake's periphery were often the first to experience budgetary reductions (Tskikita 2006). This lack of attention can perhaps help explain the low economic activity and high poverty rates found in resettled areas (Alhassan 2009).

Given the social impacts of the Akosombo dam on local communities, one would expect residents in the vicinity of the Bui Dam (currently under construction) to feel extremely apprehensive. Some stakeholders, largely conservation groups and non-governmental organizations, have expressed concerns centered on the loss of biodiversity and land to flooding in Bui National Park (estimates anticipate that 21 percent of the park will be flooded). Groups also express concern over the social implications that will arise from resettling the 2,500 people currently living in the area, perceived negative impacts on fishing and agriculture (resulting from erosion, sedimentation, and altered flow of the river), increased health risks from water borne diseases, and an influx of guest workers during construction to compete with for employment (Alhassan 2009, Raschid *et al.* 20XX). However, interestingly, despite these concerns, field interviews conducted in communities likely to be impacted by the flooding suggest that the Bui Dam is perceived as, "a socio-economic instrument for transforming their society and the country." (Alhassan 2009, 154).

Communities are, rightly or wrongly, anticipating benefits ranging from investments in schools, health facilities, and roads (which would make the area more accessible to the rest of the country and enable residents to access broader commercial markets), increased employment opportunities as the dam is constructed, anticipated improvements in fisheries and agriculture, and superior accommodation options available in resettlement villages (Alhassan 2009). This response is undoubtedly linked to the proximity of these local communities to Bui National Park (BNP). Communities in the area were "unanimous that the BNP was not beneficial to them because they did not have access to its resources, as it is a strict conservation area which limits their economic activities. [The Bui Dam] will 'serve the nation and the communities better than the park'" (Alhassan 2009, 155). Despite the many identified environmental and socio-economic issues presented by the establishment of large dams, the generally positive response of Ghanaians to new and existing projects suggests that the public still sees a place for hydroelectric power in Ghana's future, while emphasizing the need for better education regarding the costs and benefits of hydro projects.

11. OPTIONS FOR USAID PROGRAMMING

MAINSTREAMING CLIMATE CHANGE

Incorporating or "mainstreaming" climate change, climate variability, vulnerability, and adaptation into USAID programming offers many opportunities for USAID to help the GoG prepare for the future. The suggestions summarized below (Table 11.1) are based on the analyses conducted by the Assessment Team. Many of the options are multi-level, in that the vulnerability addressed will have to be attacked at several levels within Ghanaian society. Underlying all the options is a need to address the disconnect between customary and statutory rights in land that precludes improvements in many aspects of food security and environmental management. Without secure rights to land, smallholders lack incentives to adopt new technologies, invest in agricultural improvements and are unable to access the resources needed to increase crop productivity because they cannot obtain operating capital at less than usurious interest rates.

We categorize intervention options into five types of barriers to climate change adaptation and mitigation: Policy Environment, Governance and Tenure, Capacity and Infrastructure, Information and Analysis, and Awareness and Implementation. Under each barrier, we briefly indicate intervention options and parenthetically identify USAID programs as we understand them that could address that intervention (FtF=Feed the Future, Edu=Education, H&S=Health and Sanitation, Dem/Gov=Democracy and Governance, Gen=Gender). Options could have certainly been categorized differently, but the purpose is to communicate important information the Assessment Team gleaned regarding potential interventions. Additional ideas for intervention in the agricultural sector are contained in Table 5.6.

The policy environment barrier exposes vulnerabilities in areas directly and indirectly relevant to climate change. Decided vulnerabilities arise from uncoordinated responses to climate change. Options for intervention include supporting the completion and implementation of the Ghana National Climate Change Strategy, focus in that strategy on adaptation responses and incorporation of climate change in urban planning efforts (FtF, Edu, H&S, Dem/Gov, Gen). A national energy policy is needed that includes climate change mitigation and low emission strategies (i.e., advanced biofuels development, capturing not flaring natural gas) (Dem/Gov, FtF). Integrated national and regional level coastal development adaptation planning is needed to address sea-level rise and coastal erosion (Dem/Gov, Edu, FtF). The FtF program focuses with justification on the northern regions, but other areas exhibit high social vulnerability to climate change indicating need for a more targeted, district-based approach (i.e., expansion to Brong-Ahafo and Volta regions). Indirectly but most certainly related to climate change are uncoordinated policy responses to water allocation among riparian countries in the Volta Basin (FtF, Dem/Gov) and lack of integrated fire management and regionally adapted policies (including traditional practices) focused on managing environmentally destructive fires (FtF, Dem/Gov). Because farmers need stable and favorable crop prices to make commercial crop production profitable, a favorable policy environment is needed for cash crop production (FtF).

The governance/tenure barriers and the associated vulnerabilities to climate change adaptation and mitigation in Ghana were viewed by the Team as overarching, keystone issues not only in the climate change arena but in development generally and FtF specifically. Key interventions include advocating for examination of land tenure and property rights issues at the community level, capacity building with traditional land management authorities (e.g., chiefs, Tendanas) for transparency and equality in land use practices, and a national examination and correction of tree tenure issues that result in perverse, counterproductive incentives against carbon sequestration and maintenance and creation of forests (all FtF, Dem/Gov, Gen). Retention of carbon benefits at the national level without local benefits sharing creates yet another perverse incentive system affecting carbon sequestration. Advocacy is needed for legislation defining carbon rights to provide equity to smallholders (FtF, Dem/Gov, Gen).The land tenure system also imposes insecurity on tenants and increases their vulnerability to climate change by restricting access to credit and discouraging if not precluding long-term planning and investment by tenants and landowners. Local strategies are needed to provide affordable credit to landowners and tenant farmers (FtF). The extreme reliance on wood-based fuels in Ghana is a significant vulnerability that seems largely unaddressed by any sector at any level. The Team viewed the wood-based fuel situation as a critical issue from the perspectives of dramatically increasing social vulnerability to climate change, its clear unsustainability and environmental ramifications thereof, and for USAID, the ability of FtF to succeed. Addressing forest management and tenure challenges to sustainable firewood and charcoal production are sorely needed as are community based approaches to managing wood-based fuels sustainably (Dem/Gov, FtF). The FtF program emphasizes agricultural development which could affect land access and allocation of water resources. Social impact assessments of agricultural development projects are needed to identify mitigation measures, to ensure people are not displaced or lose land access, and to ensure conditions for marginalized groups (i.e., women and migrants) are improved not worsened (FtF). Irrigation development will redistribute water resources and perhaps increase competition for water access. An equitable system of water allocation and management should be developed as an integral part of any irrigation development project (FtF).

Many vulnerabilities under the capacity and infrastructure barrier cascade directly from the policy and governance/tenure vulnerabilities. Several relate directly to carbon sequestration and forestry issues. FtF activities need to be melded with reforestation and afforestation projects to meet community and family needs for fuel and construction wood, to produce NTFPs, to protect riparian areas, and to sequester carbon (FtF). Further, partners need to be identified that can link FtF activity to carbon financing or payments for ecosystem services markets as part of carbon offset payments (FtF). Technical capacity is needed to develop more efficient wood-based stoves to reduce deforestation, carbon emissions, and smoke (FtF, H&S, Gen). Community fuelwood programs need to be developed with technical assistance in species selection, plantation establishment and management and governance structures (FtF, Gen, H&S, Dem/Gov). Scarce fuelwood most impacts women, the traditional gatherers of wood for cooking. A national integrated fire management program, including traditional practices, is needed to manage destructive bush fires to protect soil quality, increase forage quantity and quality, increase rates of reforestation and afforestation, and mitigate trends toward desertification in vulnerable areas (e.g., northern Ghana).

Several interventions related to the agriculture sector (and thus FtF) fall under the capacity and infrastructure barrier. Transportation infrastructure limits access to markets with most households in most districts of northern Ghana traveling >30 minutes to reach a food market and in many districts <50 percent of households have year round road access to their homes. Agricultural development and crop marketing in northern Ghana should focus on carefully planned improvements to market access and transportation infrastructure (FtF). Similarly, in most districts of the Upper West and Northern regions, 15-50 percent of households travel ≥30 minutes to get drinking water with a high dependency on unimproved water sources (FtF, Gen, H&S). Well-planned development of water infrastructure will help improve human health, free up labor (especially for women), and increase household livelihood security (FtF, Gen, H&S). To adapt to climate change, people need to diversify economically, but options are limited. Investment is needed in local processing facilities to add value to agricultural and wild-harvested products, increase income, and create nonfarm jobs (FtF). Because climate variability creates food shortages, investment also needs to focus on developing improved grain storage methods and facilities so excess grains produced in good years can be stored to buffer against crop failures (FtF). Harvesting and handling losses could be lowered by developing community or cooperative drying and storage facilities (FtF). Illiteracy (15 years and older) in Ghana's northern regions is high (61.3 percent to 87.5 percent in most districts), limiting people's capacity to understand and adapt better agricultural practices and to negotiate climate change. Programs developing literacy should be emphasized (Edu, FtF).

Given a declining fishery and the threat climate change poses for that resource, the GoG should be strongly encouraged to develop the capacity and infrastructure to scientifically monitor, regulate, and manage all sectors of the marine and freshwater fisheries for long-term sustainability (FtF, H&S, Gen). Local monitoring authorities should be strengthened and connected with local, regional, and national partners and counterparts (FtF, H&S, Gen). Most coastal residents are fisheries dependent, are vulnerable to disruptions in the resource, and have few employment alternatives. Tourism, while promising, lacks the infrastructure to provide substantial income. Investments in tourism infrastructure could provide coastal residents viable alternative livelihoods. Investments in education could broaden skill sets and widen employment opportunities for youth and young adults (Edu).

The energy sector is also hampered by significant capacity and infrastructure barriers. The GoG should be encouraged to develop as soon as possible natural gas processing capabilities to avoid prolonged (months to years) gas flaring and increased GHG emissions from the Jubilee Field and use that gas to supplement an already inadequate national power grid. The lack of electricity in rural areas impedes entrepreneurial activity, calling for exploration of alternative energy systems (e.g. solar, biofuels) to meet local community needs. Because of education, training, and skill deficits, local populations are disadvantaged for competing for jobs in the nascent oil and gas industry. The GoG should be encouraged to provide training to afford locals employment opportunities in that industry (Edu).

Several other interventions were identified under the capacity and infrastructure barrier. Mainstreaming climate change in GoG activities could be advanced by improving data-sharing policies among agencies, especially for meteorology data (Dem/Gov) as well as partnering with institutions to supply climate adaptation information (FtF, H&S, Gen). Lack of technical capacity and infrastructure limits the ability to share large data files between agencies and could benefit from improved internet capabilities. Efforts to decentralize government are impeded in rural areas by lack of infrastructure. Cell phone texting features should be explored for use in online registrations, permit applications, etc. to avoid long distance travel to government offices and to increase participation. Likewise, development of a practical system of farmer credit banks in rural areas is needed to establish farmer accounts that can be used remotely to conduct financial transactions (FtF). As noted, this latter intervention needs to be superseded by addressing land tenure issues that constrain credit and by making credit affordable to smallholders.

Information and analysis represents a significant barrier to climate change adaptation and mitigation in Ghana. Data is lacking for critical decision making, planning, and forecasting. Climate change should be investigated at a sub-national level using appropriately scaled GCM models and within the context of desertification, sea-level rise, and coastal erosion, marine and inland fishery sustainability, water supply in the Volta Basin, and hydropower production (FtF, Gen). Rates of coastal erosion should be investigated nationally with an emphasis on identifying causes and on impacts to coastal infrastructure and natural resources (e.g., towns, ports, biodiversity hotspots, lagoonal and inshore fisheries) (FtF). Regional organizations (e.g., CILSS, AGRHYMET, CORAF, INSAH, FEWSNET) should be engaged in partnerships to ensure availability of and access to data (e.g., weather data, hydrological data, ground cover change, agricultural expansion, improved land productivity, fish populations) and projections (FtF).

Several items identified under the information and analysis barrier relate directly to agriculture and food security. Research and technology development programs are needed in climate prediction, to improve crop models, and to link process-based crop models to high resolution regional climate models (FtF). To help adapt to climate change, soil suitability analysis should be incorporated into agricultural development planning and updated with soil suitability analysis data on new crop varieties (FtF). The uncertainties of FtF commercial and large-scale agriculture sustainability needs to be investigated in light of increasing future costs of petroleum-based fuels and agricultural chemicals and a changing climate (FtF, Gen). Likewise, FtF irrigation projects should be analyzed in regard to impacts on surface and ground water quantity and quality and downstream effects (FtF). An evaluation of the temporal pace of vegetation change and soil degradation is needed to assess desertification in northern Ghana, especially in the context of projected population increases, food security, water demands, ecological services, and climate change.

Information and analysis needs for forestry-related items are also apparent. Land cover/land use inventories and forest inventories are needed to set baselines for deforestation, carbon pools under REDD+, and to meet MRV requirements. Investigation is needed in areas where carbon sequestration can complement FtF efforts, e.g., increasing mangroves, rangeland management, agro-forestry, farmer-managed natural regeneration (FMNR), and riparian forest management (FtF). Optimized shade-grown cocoa management schemes are needed that provide high levels of return to farmers, reduce deforestation and degradation and also offer greater biodiversity benefits than sun-grown cocoa (FtF).

Many in Ghana have a lack of awareness of and skills to use climate change, agricultural, natural resource management, or other information that would reduce their vulnerability. Partnerships with local implementers would build the climate change awareness of end users (e.g., farmers, fishermen, media, government) and enhance their ability to use information (FtF, Edu). Workshops should be organized on various topics (e.g., climate change, adaptation, carbon sequestration) for agriculture sector partners and FtF implementers. Cocoa producers lack the skills and knowledge to implement the whole technology package for sun-grown cocoa; cocoa productivity could be increased by intensification and access to inputs (FtF). Top-down approaches to fire management are unsuccessful in part because of a lack of awareness of traditional methods. GoG agencies and personnel should be educated on modern integrated fire management approaches and traditional approaches and the two integrated on the ground. Not all adaptation measures currently used are sustainable and many are erosive to future economic health and well-being at the household, community, and regional levels. Adaptations should be considered carefully so that unsustainable approaches are avoided (e.g., marine fuel pre-mix program). Short-term temporary and long-term coping mechanisms should be distinguished and the difference communicated to the public (FtF, Edu). Livestock production in the north offers a potential to diversify livelihoods in the north and hence decrease vulnerability to climate change. This potentiality should be communicated and promoted; and support should be given to schemes that help farmers adopt livestock keeping (FtF). Most crop yields in Ghana are below potential, requiring intensification to meet MIC goals. Agricultural productivity could be increased by improving distribution channels and access to technology and inputs (e.g., fertilizer) and by providing farmers access to operating capital and crop insurance to mitigate effects of climate variability. (FtF). Farmers lack information on consumer quality expectations and fail to meet market demand. Awareness of consumer expectations should be raised and quality assurance programs instituted for improved marketability (FtF).

NEW INTERVENTIONS FOR USAID PROGRAMMING

To mainstream climate change into USAID programming in Ghana, and indeed for the GoG and other donor partners to integrate climate change into their development efforts, the availability of meteorological data and interpretive information must be increased. To effectively utilize available climate information, the capacity within Ghana to use the information must also be enhanced. This need presents an opportunity for USAID Ghana to develop programs or partner with others to build capacity. The two sides of the issue are increasing available data and enhancing capacity to use the data and climate projections. Increasing data availability can be achieved by partnering with regional institutions and non-governmental partners to increase meteorological monitoring capacity by increasing the number of weather stations, especially in rural areas in the northern regions where the current monitoring network is sparse. Other initiatives could focus on building relationships among regional institutions such as FAMNET, AGRHYMET, and others to deliver data interpretation. Climate modeling at the scale of the Global Climate Models is already available over the internet, but the expertise necessary to interpret these data, state their uncertainties, and effectively use them to downscale to regional climate models is generally lacking in Ghana and elsewhere in sub-Saharan Africa, except possibly in South Africa. Thus, another opportunity for USAID is to develop interpretation and communication capacity within Ghana, either at a university, within the GoG, or in a jointly funded and maintained center.

Other options are more sectoral in nature. One need seems to be an integrated and realistic energy strategy for Ghana that depends on internal resources. There are few opportunities to expand hydropower; in fact, the current capacity will likely diminish over time as precipitation within the Volta basin declines, and neighboring countries expand their extractions for drinking water and irrigation. Ghana is developing oil and gas that will provide new energy sources, but they will have to be developed, for example by capturing the natural gas from the Jubilee Field and using it to power an energy plant. Perhaps the greatest opportunity for Ghana is to develop advanced biofuels or at least to utilize advanced conversion technology along with comparative advantages in growing woody feedstocks. Such a policy should, however be integrated with agricultural and other uses of land and is predicated upon raising the productivity of food crops to their full potential under intensification.

Woody biomass for bioenergy already provides a large share of the energy needs of the average Ghanaian, specifically fuelwood for cooking. Currently this use is inefficient (open fires, inefficient charcoal production methods) and often damaging to the environment. In addition to programs to increase fuelwood availability, improve cookstove efficiency, and improve charcoal production, the entire forestry sector of Ghana needs to be transformed. One starting point would be the transformation of the Forestry Commission into a land management and stewardship agency. Thus a transformed FC would no longer be focused simply on generating income from timber concessions and permitting fees. Rather, the FC would be responsible for conserving the remaining high forests, restoring degraded forest reserves and wetland forests, and providing technical assistance to communities in developing community forests and fuelwood plantations. In addition, the wood industry in Ghana needs to be rationalized to remove subsidies that maintain an inefficient export market, and to improve provision to meet domestic lumber needs. Improved forest management will also maximize opportunities to capture payments for carbon and other ecosystem services.

Ghana's mid-term development strategy and goal of obtaining MIC status by 2015 depends heavily upon improvements in the agricultural sector. Although we have suggested some interventions in the agricultural sector in Table 10.1, one change that requires multiple and continuing interventions is the need to overhaul agricultural research and extension in Ghana. The GoG does not provide adequate support for applied agricultural research internally, which causes research scientists to seek funding from outside sources. This usually means that agricultural research focuses more on basic research than is needed in Ghana, leading to the charge that it is irrelevant. Extension is also underfunded and is removed from the needs of the smallholder. Without a strong applied research focus on issues that matter to the smallholder, delivered by extension agents in affordable technology packages, the existing agricultural research and extension infrastructure will not contribute to meeting the needs of the Ghanaian farmer.

Finally, there is a need to conduct climate change vulnerability and adaptation analyses at the community and household levels in the different regions. Because variability and changes in climate will be felt locally, and there are a myriad of possible adaptation responses, vulnerability analysis needs to be situated in a local spatial context. USAID Ghana, working with donor partners, GoG agencies, NGOs, and CSOs should develop vulnerability and adaptation analyses as part of the project planning and design phase, and require that the results be used to modify projects before embarking on them.

Table 11.1 Options for interventions in order to overcome barriers to climate change adaption and mitigation and reduce vulnerability

(Abbreviations for USAID Programs: FtF=Feed the Future, Edu=Education, H&S=Health and Sanitation, Dem/Gov=Democracy and Governance, Gen=Gender)

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
Policy Environment	Uncoordinated response to climate change	Support the completion and implementation of the Ghana National Climate Change Strategy Increase focus in national climate change strategy on adaptation responses Incorporate climate change into town planning efforts (decreasing vulnerability, adopting low emissions development criteria)	FtF, Edu, H&S, Dem/Gov, Gen
	Uncoordinated response to climate change	Support development of a national energy policy that includes climate change mitigation and low emission strategies including advanced biofuels development and capturing flared gas	Dem/Gov FtF
	Uncoordinated response to destructive elements of frequent, hot bush fires and their interaction with climate change and climate change adaptation	Encourage GoG to develop a national policy for integrated fire management and regionally-adapted policies that include traditional practices for managing wildland fires to protect soil quality, increase forage quantity and quality, increase rates of reforestation and afforestation, and mitigate trends toward desertification in vulnerable areas (e.g., northern Ghana)	FtF, Dem/Gov, Gen
	Uncoordinated response to potential climate change effects on water quantity among riparian countries	Support development of a water allocation agreement among all riparian countries in the Volta River Basin	FtF, Dem/Gov
	Uncoordinated response to interactions among climate change-induced sea-level rise and coastal erosion, and high rates of population growth and coastal development	Support implementation of national and regional level coastal development plans that include adaptation strategies for sea-level rise (e.g., relocation of transportation, housing, and business zones) and natural mitigation measures to slow coastal erosion (e.g., mangrove zones, sand mining restrictions)	Dem/Gov, Edu, FtF
	USAID's FtF program focuses on the northern regions where donor activity is high; western Brong-Ahafo and northern Volta regions also exhibit high social vulnerability to climate change	Consider a more targeted, district-based approach to implementing the FtF program in places where it is most needed, and explore expansion to high vulnerability areas of neighboring Brong-Ahafo and Volta regions	FtF
	Farmers need stable and favorable crop prices to make investments in commercial crop production profitable; otherwise they can become poorer	Ensure a favorable policy environment for cash crop production	FtF

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
Governance/Tenure	There is a pervasive sense of insecurity, and a lack of transparency within the current customary land tenure system practiced throughout most of Ghana. This makes it difficult for small- scale farmers to maintain access to land for farming.	Advocate for an examination of land tenure and property rights issues at the community level Capacity building with traditional land management authorities, such as chiefs and the Tendanas, to include more transparency in their dealings would help restore the customary tenure regime and provide for equality in land use practices	FtF, Dem/Gov, Gen
	Tree tenure, national and traditional, offer perverse counterproductive incentives against carbon sequestration and other legitimate reasons to maintain or create forests	Advocate for national examination and correction of tree tenure issues that result in incentives for deforestation	FtF, Dem/Gov, Gen
	Ambiguity of carbon rights; retention of carbon rights at the national level without sharing benefits with local communities creates another perverse incentive	Advocate for legislation defining carbon rights that provides equity to smallholders	FtF, Dem/Gov, Gen
	Heavy reliance on wood-based fuels for cooking	Address forest management and tenure challenges that are obstacles to sustainable firewood and charcoal production; investigate potential for effective community-based approaches to managing wood-based fuels use sustainably	Dem/Gov, FtF
	Women and migrants are especially marginalized when it comes to accessing land	Consider the difficulty marginalized groups face in accessing land and resources when designing and implementing the Feed the Future program to help improve conditions for these groups and ensure that they are not further marginalized	Gender, FtF
	The current land tenure system is characterized by insecurity which makes it difficult for tenants to make long term plans or invest in best practices or new technologies. Additionally, with insecure tenancy, access to credit and investors is restricted.	Explore local strategies for providing affordable credit to landowners and tenant farmers.	FtF
	Irrigation development often implies a redistribution of water resources between users, and increases competition for access	An equitable system of water allocation and management should be developed as an integral part of any irrigation development scheme	FtF

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
	to water		
	Agricultural development may cause people to be displaced and usurp land already being used for farming, grazing, and other uses	A social assessment of the impacts of implementing agricultural development projects should be undertaken to ensure that people do not lose access to land and resources, and to identify mitigation measures	FtF
Capacity and Infrastructure	Missed opportunities to link FtF to carbon offset payments	Partner with organizations that can link FtF activity to carbon financing markets or payments for ecosystem services markets	FtF
	Missed opportunities to mainstream climate change into GoG activity	Data sharing policies among agencies need to be improved, especially for meteorology data (revenue recovery focus reduces ability for agencies to share and coordinate efforts)	Dem/Gov
	Links between FtF and forests need to be strengthened	Meld FtF activities with reforestation and afforestation projects to meet family and community needs for fuel and construction wood, to produce NTFPs, to protect riparian zones, and to sequester carbon	FtF, Gen
	Lack of technical capacity	Partner with local implementers to build capacity at institutions that supply climate adaptation information	FtF, H&S Gen
	Lack of technical capacity and infrastructure in telecommunications limits ability to move large datafiles (such as GIS data) between agencies	Improve data access, internet	No USAID program
	Lack of technical capacity and infrastructure for fisheries management; fisheries are in decline and climate change threatens to further disrupt the resource	Encourage GoG to scientifically monitor (e.g., fishery independent surveys, fisheries observers), regulate (e.g., limited access), and manage (e.g., seasonal and net restrictions) all sectors of the marine and freshwater fisheries for long-term sustainability in a changing climate Strengthen local monitoring authorities, and connect them with local, regional, and national partners. (EXP Coastal Resource Center).	FtF, H&S, Gen
	Lack of technical capacity to reduce reliance on wood-based cooking fuels	Support adoption of highly efficient charcoal and wood burning stoves that are culturally compatible with Ghanaian cooking modalities to substantially reduce wood-based fuel use, carbon emissions, and deforestation. More efficient wood based stoves will also produce less smoke, and lessen the burden on women who are traditionally responsible for gathering firewood.	Health, Gen, FtF
	Lack of technical capacity and infrastructure and heavy reliance on wood-based fuels for cooking	Develop community fuelwood program with technical assistance in species selection, plantation establishment and management, and governance structures (scarce fuelwood means extra time spent by women to walk farther to gather or household cash must be used to purchase; either way this detracts from ability to grow and buy food)	FtF, Gen, H&S Dem/Gov
	Lack of technical capacity and	Encourage GoG to advocate development of a national policy of	FtF, Gen, Dem/Gov

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
	infrastructure in mitigating the destructive effects of frequent, hot bush fires	integrated fire management and develop regionally adapted policies that include traditional practices to manage wildland fires to protect soil quality, increase forage quantity and quality, increase rates of reforestation and afforestation, and mitigate trends toward desertification in vulnerable areas (e.g., northern Ghana)	
	Lack of infrastructure to fully realize the energy benefits and GHG emissions reductions from natural gas	Encourage GoG to develop as soon as possible natural gas processing capabilities to avoid prolonged gas flaring (months to years) and increased GHG emissions at Jubilee Oil Field, and to supplement an already inadequate national power grid	Dem/Gov, H&S
	Lack of infrastructure impedes efforts to decentralize governance, especially in rural areas distant from district capitals	Explore utilization of cell phone texting features to send online registrations, permit applications, etc.	Dem/Gov
	Lack of infrastructure impedes efforts to decentralize governance especially in rural areas distant from district capitals	Explore development of farmer credit banks in rural areas to establish farmer accounts that can be used to pay for permits, etc. remotely	Dem/Gov, FtF
	Occupations of coastal residents depend primarily on the marine fisheries, and are therefore especially vulnerable to disruptions in the resource. Few employment alternatives exist outside of the marine fisheries. Tourism, while promising, lacks the necessary infrastructure to provide substantial income	Investments made in tourism infrastructure could lessen the reliance of coastal residents on marine fisheries by providing viable alternative livelihoods Investments in education could help provide a better defined skill set and widen employment opportunities for youth and young adults	No USAID program, Education
	Local populations are at a disadvantage in regards to employment opportunities through the growing oil and gas industry, as they do not possess the necessary skill set to seek gainful employment	Encourage the government to either provide training itself, or through a third party, that offers the technical skills necessary to seek employment in the oil and gas industry	Education Gender?
	Rural areas are often without electricity, which limits entrepreneurial activity	Explore alternative energy systems (e.g. solar, biofuels?) that might suit the needs of local communities	

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
	Limited infrastructure for accessing markets: over half the households in most districts of northern Ghanatravel more than 30 minutes to reach a food market; and fewer than half of the households have road access to their homes year-round in many districts.	Efforts to promote agricultural development and crop marketing in northern Ghana should evaluate how market access and transportation infrastructure can be improved, and invest in making such improvements	FtF
	Limited water infrastructure: There is high household dependency on unimproved water sources in the north and in most districts of Upper West and Northern regions, and 15-50% of households travel 30+ minutes to get drinking water	Improving water infrastructure will help improve human health, free up labor (especially for women), and increase household livelihood security; however, water development should occur in a manner that does not have negative environmentalconsequences	FtF. Gen, H&S
	Climate change creates a need for people to diversify economically but options are limited	Invest in construction of local processing facilities that add value to agricultural and wild-harvested products to increase income and create nonfarm jobs	FtF
	Illiteracy in Ghana's 3 northern regions ranges from 61.3% to 87.5% of the population 15 and older in every district except Tamale, where it is over 50%. This limits people's capacity to raise their awareness and benefit from information that will help them adapt to climate change and improve agricultural practices.	Develop and implement programs to increase literacy	Edu
	Climate variability creates food shortages	Develop improved grain storage facilities so excess grains produced in good years can be stored to buffer against crop failures	Ftf
	Many small farmers can't afford access to credit	Address land tenure constraints to obtaining credit; develop credit schemes that are feasible for smallholders	FtF
Information and Analysis	Lack of data for decision making	Partner with regional organizations (e.g., CILSS, AGRHYMET, CORAF, INSAH, FEWSNET) to ensure availability of and access to data (weather patterns, hydrological data, ground cover change, agricultural expansion, improved land productivity, fish populations) and forecast/projections	FtF
	Lack of data for decision making	Land cover/land use inventories and forest inventories are needed to	Sustainable Landscapes,

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
	and inability to secure REDD+ funding	set baselines for deforestation, carbon pools under REDD+, and to meet MRV requirements	Biodiversity
	Lack of data and analysis for decision making for adapting agriculture to climate change	Establish program of research and technology development in climate prediction, improve crop models, and link process-based crop models to high resolution regional climate models	FtF
	Lack of analysis of the sustainability of commercial and mechanized agriculture	Investigate uncertainties of commercial and large-scale agriculture sustainability in light of increasing (or minimally uncertain) future costs of petroleum-based fuels and agricultural chemicals, and a changing climate	FtF, Gen
	Lack of data and analysis for decision making for adapting agriculture to climate change	Incorporate soil suitability analysis into agricultural development planning and update soil suitability analyses with data on new crop varieties	FtF
	Lack of analysis of climate change effects using state-of-the-art models at sub-national scales limits ability to plan	Investigate climate change at a sub-national level using appropriately scaled GCM models and within the context of desertification in the north, sea-level rise and coastal erosion, marine and inland fishery sustainability, water supply in the Volta Basin, and power production from Okosombo, Kpong, and Bui dam generators	FtF, Gen
	Lack of analysis for enhancing carbon sequestration opportunities	Investigate areas where carbon sequestration can complement FtF efforts, e.g., reducing coastal erosion by increasing mangroves, rangeland management, agro-forestry, farmer managed natural regeneration (FMNR), riparian forest management	FtF
	Lack of analysis at district and project levels of the sustainability and impact of irrigation projects	Evaluate in all FtF irrigation projects the impacts on the quantity and quality of local ground and surface water supplies as well as downstream user impacts	FtF, Gen
	Lack of analysis of coastal erosion	Evaluate rates of coastal erosion nationally with an emphasis on identifying proximate and ultimate causes, and on near- and long-term effects on coastal infrastructure and natural resources (e.g., cities, villages, highways, ports, marine facilities, biodiversity hotspots, lagoonal and inshore fisheries)	FtF
	Lack of analysis of rates of desertification in northern Ghana	Conduct a quantified evaluation of the temporal pace of vegetation change and soil degradation to evaluate rates and extent of desertification in northern Ghana, especially in the context of projected population increases, food security, water demands, ecological services, and climate change	FtF, Gen
	Lack of data for decision making about how to improve cocoa productivity and reduce deforestation and forest degradation associated with cocoa	Develop optimized shade-grown cocoa management schemes that provide high levels of return to farmers and also greater biodiversity benefits than sun grown	FtF

Barriers to Adaptation and Mitigation	Vulnerability	Interventions	USAID Programs
	production		
Awareness and Implementation	Lack of awareness of and skill to use climate change information	Partner with local implementers to build the climate change awareness of end users (e.g., farmers, fishermen, media, government) and enhance their ability to use information Organize workshop on topics such as climate change, adaptation, and carbon sequestration for agriculture sector partners and FtF implementers	FtF, Edu
	Lack of awareness and skills among cocoa producers regarding the whole technology package for sun-grown cocoa	Increase cocoa productivity by intensification and access to inputs	FtF, Sustainable Landscapes
	Lack of awareness of traditional methods of fire management leads to unsuccessful top-down regulatory approaches to fire management	Support efforts to increase awareness of GoG agencies and personnel on modern integrated fire management approaches; educate staff on traditional approaches to fire management and integrate the two	FtF, Edu
	Not all adaptation measures currently utilized are sustainable; many are erosive to future economic health and well being at the household, community, and regional levels.	Think through proposed adaptations, and ensure that unsustainable adaptations are not implemented as permanent solutions. (Example, the pre-mix program.) Better distinguish between short-term temporary coping mechanisms and long-term sustainable adaptations. Communicate the difference to the public.	FtF, Edu
	People need to diversify their livelihoods to decrease their vulnerability to climate change	Livestock production is a diversification strategy that holds potential in the north. Raise awareness of this potential and support implementation of schemes that help people adopt livestock keeping. Associated governance/resource access issues will need to be addressed.	FtF
	Yields of most crops grown in Ghana are below potential and will not support efforts to achieve MIC status	Increase agricultural productivity by increasing access to technology and inputs by improving distribution channels (e.g., fertilizer), farmer access to operating capital, and crop insurance schemes to mitigate effects of climate variability	FtF
	Farmers lack information on consumer requirements and fail to meet market demand	Raise awareness of consumer quality expectations for crops like rice and yams, and institute quality assurance schemes for improved market access	FtF
	Harvesting and handling losses of agricultural crops reduce food available and financial return to farmers	Lower harvesting and handling losses by developing community or cooperative drying and storage facilities	

12. LITERATURE CITED

Abugre, S. and Kazaare, F.P., 2010. Trends and status of illegal timber logging in three forest districts of the Brong-Ahafo region of Ghana. Ghana Journal of Forestry, 26: 89-100.

Adam, B. 2011. Ghana: company flares gas. allAfrica.com, Public Agenda, Accra, Ghana. Available from: http:// http://allafrica.com/stories/201104080904.html; accessed 2 May 2011.

Adam, J. C. and Lettenmaier, D. P. 2003. Adjustment of global gridded precipitation for systematic bias, Journal of Geophysical Research, 108: 1-4.

Adam, M.A. 2011. Personal communication. National Oil Coordinator, Publish What You Pay Ghana. Accra, Ghana.

Adams, M., and Sibanda, S. 1999. Land tenure reform and rural livelihoods in Southern Africa. Natural resource Perspectives, Overseas Development Institute.

Addo, K. A., M. Walkden, and J. P. Mills. 2008. Detection, measurement and prediction of shoreline recession in Accra, Ghana. ISPRS Journal of Photogrammetry and Remote Sensing 63:543-548.

Addo, K. A. 2009. Detection of coastal erosion hotspots in Accra, Ghana. Journal of Sustainable Development in Africa 11(4):253-265.

Adeku, J.; Kwafo, S.K. 2005. Eastern Region: Analyses of district data and implications for planning. In: Twum-Baah, K.A.; Kumekpor, T.K.B.; Addae-Mensah, I.; eds. 2000 Population and Housing Census. Accra: Ghana Statistical Services. Vol. 3 [of 10].

Adeoti, A., B. Barry, et al. (2007). Treadle pump irrigation and poverty in Ghana. Colombo, Sri Lanka, International Water Management Institute (IWMI). IWMI Research Report 117.

Adger, N., 1999. Social vulnerability to climate change and extremes in coastal Vietnam. World Development, 27(2): 249-269.

Adger, W. N., T. P. Hughes, et al. (2005). "Social-ecological resilience to coastal disasters." Science **309**(5737): 1036.

Ahmad, O.B.; Nkansah, M.Y. 2005. Northern Region: Analysis of district data and implications for planning. In: Twum-Baah, K.A.; Kumekpor, T.K.B.; Addae-Mensah, I.; eds. 2000 Population and Housing Census. Accra: Ghana Statistical Services. Vol. 6 [of 10].

Agyeman, V.K.; Marfo, K.A.; Kasanga, K.R.; Danso, E.; Asare, A.B.; Yeboah, O.M.; Agyeman, F. 2003. Revising the taungya plantation system: new revenue-sharing proposals from Ghana. Unasylva 212. 54(1): 40-43. ftp://ftp.fao.org/docrep/fao/005/y4744e/y4744e10.pdf

Aggery-Fynn, J. 2007. The fishery of *Balistes capriscus* (Balistidae) in Ghana and possible reasons for its collapse. Ph.D. Thesis. Center for Tropical Marine Ecology, University of Bremen.

Akoto, I.O.; Ampabeng, I.; Fenny, A.P. 2006. Customarily Land Tenure Practices, Investment and Agricultural Production in Ghana. Draft Report. On file with: Institute of Statistical, Social and Economic Research (ISSER). University of Ghana. November, 2006.

Alhassan, H.S. 2009. Butterflies vs. hydropower: reflections on large dams in contemporary Africa. Water Alternatives. 2(1): 148-160.

Amanor, K.S. 2001. Share contracts in the oil palm and citrus belt of Ghana. IIED, London. 30 pp. http://www.iied.org/pubs/pdf/full/9008IIED.pdfAndah, W.E.I. and Gichuki F., editors. 2005. Volta River Basin: Enhancing Agricultural Water Productivity Through Strategic Research. Baseline Report Report No. 8, CGIAR Challenge Program on Water and Food, P.O. Box 2075, Colombo, Sri Lanka.

Andah, W.E. I., N. van de Giesen, and C. A. Biney. 2005. Water, climate, food, and environment in the Volta Basin. Contribution to the project ADAPT, Adapation strategies to changing environments.

Andreini, M., N. van de Giesen, A. van Edig, M. Fosu, and W. Andah. 2000. Volta basin water balance., ZEF-Discussion Papers on Development Policy Number 21, Center for Development and Research, Bonn Universitat.

Angelsen, A. and Institute, M., 2009. Reducing emissions from deforestation and forest degradation (REDD): an options assessment report. Meridian Institute.

Anim-Kwapong, G. J. and E. B. Frimpong Vulnerability of agriculture to climate change- impact of climate change on cocoa production. Vulnerability and adaptation assessment under the netherlands climate change studies assistance programme phase 2 (NCCSAP2). New Tafo Akim, Ghana, Cocoa Research Institute of Ghana.

Ansa-Emmim, M. 1979. Occurrence of the triggerfish, *Balistes capriscus* (Gmel), on the continental shelf of Ghana. Pages 20-27. *In:* Report of the special working group on the evaluation of demersal stocks of the Ivory Coast - Zaire sector, CECAF/ECAF SERIES/79/14(En), FAO, Rome.

Apombwe, M. 2011. Personal communication. Head of Ghana's national climate change unit, Environmental Protection Agency, Accra, Ghana.

Appiah, M. et al., 2009. Dependence on forest resources and tropical deforestation in Ghana. Environment, Development and Sustainability, 11(3): 471-487.

Appiah, M., L. Damnyag, et al. (2010). Forest and agroecosystem fire management in Ghana. Mitigation and Adaptation Strategies for Global Change: 1-20.

Asante, M.S., 2005. Deforestation in Ghana: explaining the chronic failure of forest preservation policies in a developing country. Univ Press of America.

Asiamah, R. D. and C. D. Dedzoe. 1999. Plinthization: a threat to agricultural production. Ghana Journal of Agriculturual Science 32.

Asiamah , R. D. 1995. Soils of the Ho-Keta plains, Volta Region. Ghana Technical Report No. 10, SRI, Kwadaso-Kumasi.

Asiamah, R. D., C. Quansah, and C. D. Dedzoe. 2000. Soil degradation: management and rehabilitation in Ghana- an overview report. Proceedings of the FAO/ISCW Expert Consultation On: Management of Degraded Soils in Southern and East Africa (MADS-SEA), 2nd Network Meeting, 18-22 September, 2000, Pretoria South Africa, Pp 89-101.

Atta-Mills, J; Alder, J.; Sumaila, U.R. 2004. The decline of a regional fishing nation: the case of Ghana and West Africa. National Resources Forum. 28: 13-21.

Bannerman, P.O., and I.G. Cowx. 2002. Stock assessment of the big-eye grunt (*Brachydeuterus auritus*, Val.) fishery in Ghanaian coastal waters. Fisheries Research 59:197-207.

Bakun, A. 1998. Ocean triads and radical interdecadal stock variability: bane and boon for fishery management science. Pages 331–358 in: Reinventing Fisheries Management, T. J. Pitcher, P.J.B. Hart, and D. Pauly, editors. Chapman and Hall, London.

Bard, F.X. and N.Y.N. Goran. 2001. Evolution of fishing effort of gill netting canoes targeting large pelagic fish in the Gulf of Guinea. Collective Volume of Scientific Papers, ICCAT 52, 483-487

Bationo, A. and B. Ntare (2000). "Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa." The Journal of Agricultural Science **134**(03): 277-284.

Batse, Z.K.M. 2005. Upper East Region: Analysis of district data and implications for planning. In: Twum-Baah, K.A.; Kumekpor, T.K.B.; Addae-Mensah, I.; eds. 2000 Population and Housing Census. Accra: Ghana Statistical Services. Vol. 7 [of 10].

Batse, Z.K.M. 2005. Upper West Region: Analysis of district data and implications for planning. In: Twum-Baah, K.A.; Kumekpor, T.K.B.; Addae-Mensah, I.; eds. 2000 Population and Housing Census. Accra: Ghana Statistical Services. Vol. 8 [of 10].

Becker, M. and D. Johnson (2001). "Cropping intensity effects on upland rice yield and sustainability in West Africa." Nutrient Cycling in Agroecosystems **59**(2): 107-117.

Belsky, J. M. and S. F. Siebert (2003). "Cultivating cacao Implications of sun-grown cacao on local food security and environmental sustainability." Agriculture and Human Values **20**(3): 277-285.

Benneh , G. 1970. The impact of cocoa cultivation on the traditional Land tenure system of the Akan of Ghana. Ghana Journal of Sociology. 6: 43-61.

Benneh, G., and G. T. Agyepong. 1990. Land degradation in Ghana. Food Production and Rural Development Secretariat, Marlborough House, Pall Mall, London, and Department of Geography and Resource Development, University of Ghana, Legon, Ghana.

Beinroth, F.H., Eswaran, H., Reich, P.F. and Van den Berg, E. 1994. Land related stresses in agroecosystems. In: *Stressed Ecosystems and Sustainable Agriculture,* eds. S.M. Virmani, J.C. Katyal, H. Eswaran and I.P. Abrol. New Delhi, India: Oxford and IBH.

Binet, D. 1995. Hypothesis accounting for the variability of *Sardinella* abundance in the northern Gulf of Guinea. Pages 98–133 in Dynamics and Uses of *Sardinella* Resources from Upwelling off Ghana and Côite d'Ivoire. F.X. Bard, and K.A. Koranteng, editors. ORSTOM Edition, Paris.

Biney, C. A. 2010. Connectivities and linkages within the Volta Basin. Pages 81-105 in Proceedings of the Global Dimensions of Change in River Basins, Threats, Linkages, and Adaptations, University Club, Bonn, Germany. Global Water System Project, International Project Office, Bonn, Germany.

Birkmann, J. and K. von Teichman (2010). "Integrating disaster risk reduction and climate change adaptation: key challenges—scales, knowledge, and norms." Sustainability Science: 1-14.

Blay, D., Appiah, M., Damnyag, L., Dwomoh, F.K., Luukkanen, O., Pappinen, A. (2008). Involving local farmers in rehabilitation of degraded tropical forests: some lessons from Ghana. Environment Development and Sustainability 10: 503-518.

Blench, R. and M. Dendo (2007) Working paper: agricultural production and the potential for commodity chain expansion in the three northern regions of Ghana in 2006.

Boateng, E. (2005). "Geographic Information Systems (GIS) as a decision support tool for land suitability assessment for rice production in Ghana." West African Journal of Applied Ecology **7**(1): 69-81.

Boko, M. et al., 2007. Chapter 9: Africa. Fourth Assessment Report of the IPCC: 441.

Braimoh, A. and P. Vlek (2004). "The impact of land cover change on soil properties in northern Ghana." Land Degradation & Development **15**(1): 65-74.

Braimoh, A. and P. Vlek (2006). "Soil quality and other factors influencing maize yield in northern Ghana." Soil use and management **22**(2): 165-171.

Braimah, L.I. 2001. Lake Volta Fisheries Management Plan. Fisheries Sub-sector Capacity Building Project. Ministry of Food and Agriculture.

Braihmah, P. 2009. Lessons from previous experience of co-management initiatives in fisheries in Ghana. Report. Ghana, Accra. World Bank. XX p.

Breisinger, C., X. Diao, et al. (2008). The Role of Cocoa in Ghana's Future Development. Ghana Strategy Support Program Background Paper No. GSSP 0011. IFPRI.

Breisinger, C., X. Diao, et al. (2008). Agriculture for development in Ghana: New opportunities and challenges. IFPRI Disucssion Paper. Washington, DC, Intl Food Policy Res Inst.

Brooks, N. (2003). "Vulnerability, risk and adaptation: A conceptual framework." Tyndall Centre for Climate Change Research Working Paper **38**: 1–16.

Brooks, N.; Adger, W.N.; Bentham, G.; Gnew, M.; Eriksen, Siri. 2004. New indicators of vulnerability and adaptive capacity. Tyndall Centre for Climate Change Research. Technical Report 7. January 2004. 102p.

Brown, O. and A. Crawford (2008). "Climate change: A new threat to stability in West Africa? Evidence from Ghana and Burkina Faso." African Security Review **17**(3): 39-57.

Campbell, M.O. 2006. The sustainability of coconut palm *Cocos nucifera* Linnaeus 1753 groves in coastal Ghana. Journal of Coastal Research 22 (5), 1118–1124.

Carter, T., R. Jones, et al. (2007). "New Assessment methods and the characterization of future conditions. Climate Change 2007: Impacts, Adaptation and Vulnerability." Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: 133-171.

Caverivière, A. 1991. L'explosion démographique du baliste (*Balistes carolinensis*) en Afrique de l'ouest et son évolution en relation avec les tendances climatiques. Pages 354–367 in P. Cury and C. Roy, editors. Variabilité, instabilité et changement dans les pêcheries ouest africaines. Editions ORSTOM, Paris.

Challinor, A., T. Wheeler, et al. (2007). "Assessing the vulnerability of food crop systems in Africa to climate change." Climatic Change **83**(3): 381-399.

Challinor, A. J., F. Ewert, et al. (2009). "Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation." Journal of Experimental Botany **60**(10): 2775-2789.

Chamberlin, J. (2007). Defining smallholder agriculture in Ghana: Who are smallholders, what do they do and how are they linked with markets? GSSP Background Paper 6. Accra.

Chambers, R. 1970. The Volta resettlement experience. London, UK: Pall Mall Press.

Clark, N. 1994. The Economy. In A Country Study: Ghana. L. V. Berry, editor. Library of Congress, Country Studies. Federal Research Division, Library of Congress. Available: http://memory.loc.gov/frd/cs/cshome.html, accessed April 2011

Coastal Resource Center. 2010. [CRC 2010]. Our coast our future: building capacity for adapting to a rapidly changing coastal zone. October 2010 Report. Nansurgent, RI and Sekondi, Ghana: Coastal Resource Center, University of Rhode Island. 64 p.

Cury, P. 2004. Comparison of the Ivoiro-Ghanaian Fishery with other exploited upwelling systems of the world. Pages 169-193 in Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. F.X. Bard and K.A. Koranteng, editors. Paris, OSTROM Editions.

Daniel, S. (2011). Land Grabbing and Potential Implications for World Food Security. Sustainable Agricultural Development. M. Behnassi, S. A. Shahid and J. D'Silva (eds.), Springer Netherlands**:** 25-42.

Dasgupta, A. and A. Baschieri (2010). "Vulnerability to climate change in rural Ghana: Mainstreaming climate change in poverty reduction strategies." Journal of International Development **22**(6): 803-820.

Davies S.; Hossain, N. 1993. Are coping strategies a cop out? Sussex: Institute for Development Studies. Bulletin 24(4): 60-72.

Davies, S.; Hossain, N. 1997. Livelihood adaptation, public action and civil society: a review of the literature. IDS Working Paper No. 57. Sussex: Institute of Development Studies.

de Condappa, D., A. Chaponnière, and J. Lemoalle. 2008. Decision-support tool for water allocation in the Volta basin. Volta Basin Focal Project Report No 10. IRD, Montpellier, France, and CPWF, Colombo, Sri Lanka, 28 p.

de Condappa, D., A. Chaponnière, and J. Lemoalle. 2009**.** A decision-support tool for water allocation in the Volta Basin. Water International 34:71-87.

Dickson, K. B., and G. Benneh. 1988. A New Geography of Ghana. Longman.

Dixon, R.K., Smith, J. and Guill, S., 2003. Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. Mitigation and Adaptation Strategies for Global Change, 8(2): 93-113.

Dietz, T.; Millar, D.; Dittoh, S.; Obeng, F.; Ofori-Sarpong, E. 2004. Climate and livelihood change in North East Ghana. In: Dietz, A.J.; Ruben, R.; Verhagen, A.; eds. Environment and Policy Series Volume 39: The impact of climate change on drylands, with a focus on West Africa. Dordrecht/Boston/Londong: Kluwer Academic Publishers: 149-172.

DOF 2003. Directorate of Fisheries 2003. Ghana: Post-Harvest fisheries overview. Directorate of Fisheries, Ministry of Food and Agriculture, GhanaFAO (2006) FAO yearbook. Fishery and Aquaculture Statistics 2006. FAO Fisheries and Aquaculture Information and Statistics Service. Rome, FAO. 2008. 57p.

Dontwi, J.; Dontwi, I.K.; Buabeng, S.N. 2008a. Climate change impacts on fisheries production. In: Allotey, J.; Mensah, L.; eds. Ghana climate change impacts, vulnerability and adaptation assessments, under the Netherlands climate assistance programme. Accra, Ghana: Environmental Protection Agency: 14-73. Chapter 2.

Dontwi, J., I. K. Dontwi, and S. N Buabeng. 2008b. Climate change impacts on fisheries production. Pages 14-71 *in* W. K. Agyemang-Bonsu, editor. Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments. Environmental Protection Agency, Accra, Ghana.

Doyi, B.A. and G. Neequaye. 1990. Report on pilot artisanal fishing gear survey in Ghana, Inf. Report No. 24, Fishery Research and Utilisation Branch, Tema, Ghana.

Dreze, J.; Sen, A.K. 1989. Hunger and public action. Oxford, U.K., Clarendon Press.

Duguma, B., J. Gockowski, et al. (2001). "Smallholder Cacao (Theobroma cacao Linn.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities." Agroforestry Systems **51**(3): 177-188.

Edwin, J. and W. A. Masters (2005). "Genetic improvement and cocoa yields in Ghana." Experimental Agriculture **41**(04): 491-503.

Energy Commission. 2005. Strategic national energy plan 2005-2025: Part 1 electricity. Accra, Ghana: Energy Commission.

Ensor, J.; Berger, R. 2009. Introduction: understanding community based adaptation. In: Ensor, J.; Berger, R.; eds. Understanding climate change adaptation: lessons from community based approaches. Warwickshire, UK: Practical Action Publishing. 13-14.

EPA (Environmental Protection Agency). 2003. National action programme to combat drought desertification, April 2002. Environmental Protection Agency, Ministry of Environment and Science, Accra, Ghana.

Eriksen, S.E.H.; Klein, R.J.T.; Ulsrud, K.; Naess, L.O.; O'Brien, K. 2007. Climate change adaptation and poverty reduction: key interactions and critical measures. Global Environmental Change and Human Security, University of Oslo. GECHS Report 2007:1. 42 p.

Evenson, R. E. and D. Gollin (2003). "Assessing the impact of the Green Revolution, 1960 to 2000." Science **300**: 758.

FAO (Food and Agriculture Organization). 2005. Fertilizer use by crop in Ghana. Rome, Food and Agricultural Organization of the United Nations.

FAO (Food and Agriculture Organization). 2005. National soil degradation maps. Land and Water Development Division. Food and Agricultural Organizaton, United Nations, Rome. Available from: http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp; accessed 18 April 2011.

FAO (Food and Agriculture Organization of the United Nations), Fisheries and Aquaculture Department. 2011. (UN FAO 2011). Fisheries and Aquaculture Country Profiles: Ghana. http://www.fao.org/fishery/countrysector/FI-CP_GH/en. (April 14, 2011).

Ferraris, J. and K.A. Koranteng. 2004. Statistical analysis of canoe fishery data in Ghana with particular reference to sardinellas. Pages 205-221 in F.X. Bard and K.A. Koranteng, editors. Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. Paris, OSTROM Editions.

Finegold, A. Gordon, D. Mills, L. Curtis, and A. Pulis. 2010. Western Region Fisheries Sector Review. WorldFish Center. USAID Integrated Coastal and Fisheries Governance Initiative for the Western Region, Ghana. 84 p.

Fischer, G., M. Shah, et al. (2005). "Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080." Philosophical Transactions of the Royal Society B: Biological Sciences **360**(1463): 2067-2083.

Franzen, M. and M. Borgerhoff Mulder (2007). "Ecological, economic and social perspectives on cocoa production worldwide." Biodiversity and Conservation **16**(13): 3835-3849.

Füssel, H.M., 2007. Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change, 17(2): 155-167.

Gedzi, V. 2009. Women and Property Inheritance after Intestate Succession, Law 111 in Ghana. Presented at IAFFE Conference. Boston, 25-28 June 2009. https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=IAFFE2009&paper_id=325

Geist, H.J. and Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience, 52(2): 143-150.

Geist, H., E. Lambin, et al. (2006). "Agricultural transitions at dryland and tropical forest margins: actors, scales and trade-offs." Agriculture and climate beyond 2015: 53-73.

Ghana Districts. 2006. District Profiles. http://www.ghanadistricts.com. (April 29, 2011).

Ghana Forestry Commission. 2011. Personal Interview. Executive Director, Head of Planning. Accra, Ghana. March 3, 2011.

Gildea, R.Y. 1964. Culture and land tenure in Ghana. Land Economics. 40(1): 102-104.

Gockowski, J. and D. Sonwa "Cocoa Intensification Scenarios and Their Predicted Impact on CO_2 Emissions, Biodiversity Conservation, and Rural Livelihoods in the Guinea Rain Forest of West Africa." Environmental Management: 1-15.

Gonzalez, P., 2001. Desertification and a shift of forest species in the West African Sahel. Climate Research, 17(2): 217-228.

Gorman, M.E.; Werhane, P.H. 2008. The Volta River Project. Case and Teaching Paper Series UVA-E-0161. Charlottesville, VA: Graduate School of Business Administration, University of Virginia. 27 p.

Government of Ghana (GoG). 2010. Republic of Ghana Forest Investment Program (FIP) Scoping Mission September 29 to October 1, 2010 Aide Memoire. Available on-line at http://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/Ghana%20FIP%20Aide%20Memoire_Final_010311.pdf

Griscom, B., Shoch, D., Stanley, B., Cortez, R. and Virgilio, N., 2009. Sensitivity of amounts and distribution of tropical forest carbon credits depending on baseline rules. Environmental Science & Policy, 12(7): 897-911.

Gregory, P., Ingram, J. and Brklacich, M., 2005. Climate change and food security. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463): 2139.

GSS 2002. Ghana Statistical Service. 2002. 2000 Population and housing census: special report on 20 largest localities. Accra, Ghana. 79 p.

GSS 2005. Ghana Statistical Service 2005. 2000 Population and Housing Census of Ghana: Demographic, Economic and Housing Characteristics, Total Country. Ghana Statistical Service, Accra, Ghana. 275 p.

GSS 2007. Ghana Statistical Service. 2007. Pattern and trends of poverty in Ghana, 1991-2006. Accra, Ghana: Central Office, Ghana Statistical Service. 74 p.

GSS 2008a. Ghana Statistical Service 2008. Ghana in figures. 32 p. Accra, Ghana.

GSS 2008b. Ghana Statistical Service 2008. Ghana living standards survey: report of the fifth round. September 2008. 131 p. Accra, Ghana.

GSS 2010. Ghana Statistical Service 2010. 2009 Ghana's Economic Performance: in figures. December 2010. 12 p. Accra, Ghana.

GGOP 2011. Government of Ghana Official Portal. 2010 Provisional Census Results Out. http://www.ghana.gov.gh/index.php?option=com_content&view=article&id=4712:2010-provisional-census-results-out&catid=88:daily-news-summary&Itemid=236. (April 18, 2010).

Gyasi, E.A. 1996. Land holding and its relationship with biophysical status: case study of tenancy and non-tenancy farming in Ghana. PLEC News and Views. 7: 21-25.

Gyasi, E.A.; Karikari, O.; Dugan, E. 2008. Climate change impacts on land management. In: Allotey, J.; Mensah, L.; eds. Ghana climate change impacts, vulnerability and adaptation assessments, under the Netherlands climate assistance programme. Accra, Ghana: Environmental Protection Agency: 110-168. Chapter 4.

Gyau-Boakye P., and Tumbulto J.W. 2000. The Volta lake and declining rainfall and streamflows in the Volta river basin. Environment, Development and Sustainability 2: 1–10.

Haan, N.; Farmer, G.; Wheeler, R. 2001. Chronic vulnerability to food insecurity in Kenya. A World Food Program Study for improving vulnerability analysis. http://one.wfp.org/operations/vam/documents/ken_vip_2001.pdf

Haile, M., 2005. Weather patterns, food security and humanitarian response in sub-Saharan Africa. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463): 2169.

Haines, A., R. S. Kovats, et al. (2006). "Climate change and human health: impacts, vulnerability, and mitigation." The Lancet **367**: 2101-2109.

Hall, J. B., and M. D. Swaine. 1976. Classification and ecology of closed-canopy forest in Ghana. Journal of Ecology 64:913-951.

Hansen, C.P., 2011. Forest law compliance and enforcement: The case of on-farm timber extraction in Ghana. Journal of Environmental Management, 92(3): 575-586.

Hansen, C.P., Lund, J.F. and Treue, T., 2009. Neither fast, nor easy: the prospect of Reduced Emissions from Deforestation and Degradation (REDD) in Ghana. International Forestry Review, 11(4): 439-455.

Hansen, C.P. and Treue, T., 2008. Assessing illegal logging in Ghana. International Forestry Review, 10(4): 573-590.

Harvey, D. 2007. Climate change turning the lights out on Ghana. Five Minutes to Midnight, June 2007 issue. Available from: http://www.11-55.org/issues3/issue.php?iss=48&art=48.3 ; accessed 4 May 2011.

Hayes, J.; Roth, M.; Zepeda, L. 1997. Tenure Security, Investment and Productivity. Gambian Agricultural Economics. 79(2): 369-382.

Herold, M. and Johns, T., 2007. Linking requirements with capabilities for deforestation monitoring in the context of the UNFCCC-REDD process. Environmental Research Letters, 2: 045025.

Herold, M. and Skutsch, M., 2009. Measurement, reporting and verification for REDD+: objectives, capacities and institutions. National REDD Architecture and Policies.

Hesselberg, J.; Yaro, J.A. 2006. An assessment of the extent and causes of food insecurity in northern Ghana using a livelihood vulnerability framework. GeoJournal. 67: 41-55.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Human Security Index. www.humansecurityindex.org. March 9, 2011. (April 26, 2011).

Hunter, H.M. 1963. Coca migration and patterns of land ownership in the Densu valley near Suhum, Ghana. Transactions and Papers of the Institute of British Geographers. 33.

Idinoba, M.; Nkem, J.; Kalame, F.B.; Tachie-Obeng, E.; Gyampoh, B. 2009. Dealing with limitation of forest ecosystem services through a vulnerability assessment and planed adaptation actions. In: April 26-30 International Human Dimensions Programme Open Meeting. Bonn, Germany: International Human Dimensions Programme on Global Environmental Change. 20 p.

International Cocoa Organization (ICCO). 2009. Annual Report. London, UK. 36 p.

Impraim, C. 2011. Personal communication. Lead fisherman. Winneba, Ghana.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. http://www.ipcc.ch/ipccreports/ar4-wg1.htm

IPCC. 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

ISSER. No Date. Land Tenure, Land Use and Environment in Ghana.

Jenik, J. and J. B. Hall. 1976. Plant communities of the Accra Plains, Ghana. Folia Geobot. Phytotax., Praha, 11:163-212.

Jones, P. G. and P. K. Thornton (2003). "The potential impacts of climate change on maize production in Africa and Latin America in 2055." Global Environmental Change **13**(1): 51-59.

Jung G. 2006. Regional Climate Change and the Impact on Hydrology in the Volta Basin of West Africa. Dissertation, Garmisch-Partenkirchen, Germany. Available from: http://www.glowa.org/de/literaturliste/dateien/doc_thesis_jung.pdf; accessed April 2011.

Kalame, F.B., 2009. The modified taungya system in Ghana's transitional zone.

Kanninen, M. et al., 2007. Do trees grow on money? the implications of deforestation research for policies to promote REDD. Serie Centroamericana de Bosques y Cambio Climático (FAO). 23(4).

Karsenty, A., Guéneau, S., Capistrano, D., Singer, B. and Peyron, J., 2008. Summary of the Proceedings of the International Workshop "The International Regime, Avoided Deforestation and the Evolution of Public and Private Policies Towards Forests in Developing Countries" held in Paris, 21-23rd November 2007. International Forestry Review, 10(3): 424-428.

Kasanga, K. 1994. Land Tenure Systems and Ecological Degradation in Northern Ghana; What Role for Local Authorities? The Royal Institution of Chartered Surveyors, London.

Kasanga, K.; Kotey, N.A. 2001. Land management in Ghana: Building on tradition and modernity. Prepared for Department for International Development, London.

Kasei, R. A. 2009. Modelling impacts of climate change on water resources in the Volta Basin, West Africa. Dissertation, Rheinischen Friedrich-Wilhelms-Universität Bonn, Germany.

Kasperson, J.X.; Kasperson, R.E., eds. 2001. Global Environmental Risk. UN University Press and Earthscan Publications. Tokyo and London.

Kelly, P.M. and Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change andFacilitating adaptation. Climatic Change, 47(4): 325-352.

Koranteng, K.A. 1984. A trawling Survey off Ghana, CECAF/TECH/84/63. Dakar, Senegal: CECAF Project (FAO). 72 p.

Koranteng, K.A. 1995. The Ghanaian fishery for sardinellas. Pages 290–299 in Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. F.X. Bard, and K. Koranteng, editors. ORSTOM Edition, Paris.

Koranteng, K.A. 1998. The impacts of environmental forcing on the dynamics of demersal fishery resources of Ghana. PhD Thesis, University of Warwick, UK. 376 p.

Koranteng, K. 2004. The Ghanaian Fishery for Sardinellas. Pages 243-257 in F.X. Bard and K.A. Koranteng, editors. Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. Paris, OSTROM Editions.

Koranteng, K.A., and J.M. McGlade. 2001. Climatic trends in continental shelf waters off Ghana and in the Gulf of Guinea, 1963-1992. Oceanologica Acta 24(2):187-198.

Koranteng , K.A., Ofori-Danson, P.K., and Entsua-Mensah, M. 2000. Fish and fisheries of the Muni lagoon in Ghana, West Africa. Biodiversity and Conservation 9:487-499.

Koranteng, K. and D. Pauly. 2004. Long-term trends in demersal fishery resources of Ghana in response to fishing pressure. In: M.L.D. Palomares, and D. Pauly, editors. West African marine ecosystems: models and fisheries impacts. Fisheries Centre Research Reports 12(7). Fisheries Centre, UBC, Vancouver.

Kunstmann H and Jung G (2005) Impact of regional climate change on water availability in the Volta basin of West Africa. In: Regional Hydrological Impacts of Climatic Variability and Change. IAHS Publ. 295. Available from: http://www.glowa-volta.de/fileadmin/template/Glowa/Downloads/Kunstmann_jung_2005.pdf; accessed April 2011

Kurukulasuriya, P., R. Mendelsohn, et al. (2006). "Will African agriculture survive climate change?" The World Bank Economic Review **20**(3): 367.

Kurukulasuriya, P. and S. Rosenthal (2003). Climate change and agriculture: A review of impacts and adaptations. Climate Change Series, Environment Department, the World Bank.

Lakhan, V.C., 2005. Coastal modelling and simulation. In: Schwartz, M.L. (Ed.), In Encyclopedia of Coastal Science. Springer, The Netherlands, pp. 266–269.

Langyintuo, A. S., E. K. Yiridoe, et al. 2005. Yield and income risk efficiency analysis of alternative systems for rice production in the Guinea Savannah of Northern Ghana. Agricultural Economics 32(2): 141-150.

Laris, P. and D. A. Wardell (2006). Good, bad or'necessary evil'? Reinterpreting the colonial burning experiments in the savanna landscapes of West Africa. Geographical Journal 172(4): 271-290.

Laube, W., C. Leemhius, and B. Amisigo. 2008. Impact of climate change on the Black Volta Basin and the Bui dam. GLOWA Volta Policy Brief, Bonn. 3 p.

Leemhuis, C., G. Jung, R. Kasei, and J. Liebe. 2009. The Volta Basin Water Allocation System: assessing the impact of small-scale reservoir development on the water resources of the Volta basin, West Africa. Advances in Geoscience 21:57–62

Lehner, Bernhard. 2005. Climate change, human water use, and freshwater ecosystems in Africa: Looking toward the future. Pages 86-89 in Michele L. Thieme, Robin Abell, Melanie L. J. Stiassny, Paul Skelton, Bernhard Lehner, Guy G. Teugels, Eric Dinerstein, Andre Kamdem, Toham, Neil Burgess, and David Olson. Freshwater Ecoregions of Africa and Madagascar, A Conservation Assessment. Island Press, Washington, D.C.

Lemoalle, J., and D. de Condappa. 2009. Water atlas of the Volta Basin. Volta Basin Focal Project (BFP Volta), PN55, Challenge Program on Water and Food, Consultative Group on International Agricultural Research. Colombo, Marseille, France.

Lokko , P., E. Asibey-Berko, and G. Nerquaye-Tetteh, G. 2001. Iodine content of marine fish in Ghana. Ghana Journal of Science 41:43-48

Ly, C. K. 1980. The role of Akosombo dam on the Volta River in causing coastal erosion in central and eastern Ghana (West Africa). Marine Geology 37:323-332.

Malhi, Y. and Wright, J., 2004. Spatial patterns and recent trends in the climate of tropical rainforest regions. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 359(1443): 311.

Marfo, E., Halladay, P., Zagt, R. and Wit, M., 2010. Chainsaw Milling in Ghana: Context, drivers and impacts. Tropenbos International, Wageningen, the Netherlands, 12: 64.

Marquette, C.M., K.A. Koranteng, R. Overa, and E.B.D. Eryeetey E.B.D. 2002. Small-scale fisheries, population dynamics and resource use in Africa: The case of Moree, Ghana. Ambio 31(4):324-336.

Maurer, E.P., Adam, J.C., Wood, A.W. 2009. Climate model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America, Hydrology and Earth System Sciences, 13: 183-194.

McSweeney, C., M. New, and G. Lizcano. not dated. UNDP Climate Change Country Profiles: Ghana. UNDP Climate Change Country Profiles, School of Geography and Environment, University of Oxford, Oxford, United Kingdom. Available from: http://country-profiles.geog.ox.ac.uk; accessed April 2011.

Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J.F.B., Stouffer, R.J., Taylor, K.E. 2007. The WCRP CMIP3 multi-model dataset: A new era in climate change research. Bulletin of the American Meteorological Society, 88: 1383-1394.

Menczer, K. and E. Quaye. 2006. USAID/Ghana Environmental Threats and Opportunities Assessment (FAA 118/9 Assessment). USAID, Accra, Ghana.

Mensah-Bonsu, A.and D B. Sarpong. (Unknown Date). Land Tenure System and Land for Farming in Ghana: An Empirical Analysis of Factors Affecting Access and Security. Theme: Customary and Statutory Land Tenure and Land Policy in Ghana. University of Ghana, Institute of Statistical, Social and Economic Research.

Mensah, J. V. 1997. Causes and effects of coastal sand mining in Ghana. Singapore Journal of Tropical Geography 18:69-88.

Mensah, M.A. 1995. The occurrence of zooplankton off Tema during the period 1969–1992. Pages 279–289 in Dynamics and Use of *Sardinella* Resources from Upwelling off Ghana and Ivory Coast. F. X. Bard, and K. A. Koranteng, editors. ORSTOM Editions, Paris.

Mensah, M.A., and K.A. Koranteng. 1988. A review of the oceanography and fisheries resources in the coastal waters of Ghana, 1981–1986. Marine Fisheries Research Report 8. 35 pp.

Minia, Z. 2008. Climate change scenario development. Pages 2-13 *in* W. K. Agyemang-Bonsu, editor. Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments. Environmental Protection Agency, Accra, Ghana.

Moritz, Mark. 2010. Understanding Herder-Farmer Conflicts in West Africa: Outlines of a Processual Approach. Human Organization 69(2):138-148.

MSE (Ministry of Science and Agriculture). 2002. National biodiversity strategy for Ghana. Ministry of Science and Agriculture. Accra, Ghana.

Müller, C., Cramer, W., Hare, W.L. and Lotze-Campen, H., 2011. Climate change risks for African agriculture. Proceedings of the National Academy of Sciences, 108(11): 4313-4315.

Nelson, W., Agbey, S.N.D. 2005. Linkages between poverty and climate change: adaptation for livelihood of the poor in Ghana. Report. Accra, Ghana: Climate and Development Knowledge Network. 71 p.

Nelson, W., Agbey, S.N.D. Climate change and poverty linkages. In: Allotey, J.; Mensah, L.; eds. Ghana climate change impacts, vulnerability and adaptation assessments, under the Netherlands climate assistance programme. Accra, Ghana: Environmental Protection Agency: 169-206. Chapter 5.

Nicholson, S. E., B. Scom, and K. Kone. 2000. An analysis of recent rainfall conditions in west Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. Journal of Climate 13:2628-2640.

Nunoo F.K.E., Boaten J.O., Ahulu A.M., Agyekum K.A., Sumaila U.R. (2009) When trash fish is treasure: the case of Ghana in West Africa, Fisheries Research 96:167-172>

O'Brien, K., Eriksen, S., Schjolden, A. and Nygaard, L., 2004a. What's in a word. Conflicting interpretations of vulnerability in climate change research. Oslo, Senter for klimaforskning: Working paper: 16.

O'Brien, K.; Leichenko, R.; Kelkar, U.; Venema, H.; Aandahl, G.; Tompkins, H.; Javed, A.; Bhadwal, S.; Barg, S.; Nygaard, L.; West, J. 2004b. Mapping vulnerability to multiple stressors: climate change and globalization in India. Global Environmental Change. 14: 303-313.

Oldeman, L. R., R. T. A. Hakkeling, and W. G. Sombroek. 1991. World Map of the Status of Human-induced Soil Degradation (GLASOD): An Explanatory Note, International Soil Reference and Information Centre, Wageningen. Available from: http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp; accessed 20 April 2011.

Oppong-Anane, K. 2001. Ghana: Country Pasture/Forage Resource Profiles. **Grassland and** Pasture Crops Group, Food and Agriculture Organization. Available from http://www.fao.org/ag/AGP/agpc/doc/pasture/forage.htm, (updated 2006) accessed April 2011.

Osafo, Y.B. 2010. A review of tree tenure and land rights in Ghana and their implication for carbon rights in a REDD+ scheme. Redd-net.org. http://redd-net.org/files/Ghana%20Case%20Study.pdf

Osei-Owusu, Y. 2011. Personal interview. Country Director, Conesrvation Alliance. Accra, Ghana. February 22nd, 2011.

Otsuka, K.; Aidoo, J.B.; Tachibana, T.; Quisumbing, A.R. Date unknown. Causes and consequences of changing land tenure institutions in western Ghana. Policy Brief. Gender and forest resource management: a comparative study in selected areas of Asia and Africa. International Food Policy Research Institute, Washington DC. 2 pgs.Place, F.; Hazell, P. 1993. Productivity effects on indigenous land tenure systems in Sub-Saharan Africa. American Journal of Agricultural Economics. 75(1): 10-19.

OWGT 2911. Official Website of Ghana Tourism. http://www.touringghana.com/ecotourism/mole.asp (May 2, 2011)

Owusu-Ansah, D. 1994. The Society and Its Environment. In A Country Study: Ghana. L. V. Berry, editor. Library of Congress, Country Studies. Federal Research Division, Library of Congress. Available: http://memory.loc.gov/frd/cs/cshome.html, accessed April 2011

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese and F.C. Torres Jr. 1998. Fishing down marine food webs. Science 279:860-863.

Pezennec O. 1995. Ecological importance of the Ivorian and Ghanaian minor upwelling season. Pages 324-345 in F.X. Bard and K.A. Koranteng, editors. Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. Editions ORSTOM, Paris.

Perry R.I, and U.R Sumaila. 2007. Marine ecosystem variability and human community responses: The example of Ghana, West Africa. Marine Policy 31:125-134.

Place, F.; Migot-Adholla, S.E. 1998. The economic effect of land registration on smallholder farms in Kenya: Evidence from Nyeri and Kakamega Districts. Land Economics. 74(1): 360-373.

Prosterman, R.L.; Hanstad, T. 2003. Land reform in the 21st century: New challenges, New responses. RDI reports on foreign aid and development, Rural Development Institute. 117.

Quagraire, F. 2011. Personal Communication. Program Manager, Oil and Gas Platform, Publish What You Pay Ghana. Accra, Ghana.

Quan, J. 1997. The importance of land tenure to poverty reduction and sustainable development in Africa: summary of findings. Chatham, Natural Resource Institute.

Rahaman, A.S.; Lawrence, S.; Roper, J. 2004. Social and environmental reporting at the VRA: institutionalized legitimacy or legitimation crises? Critical Perspectives on Accounting. 15(2004): 35-56.

Rahmstorf, S., Cazenave, A., Church, J.A., Hansen, J.E., Keeling, R.F., Parker, D.E., Somerville, R.C.J., 2007. Recent climate observations compared to projections. Science 316 (5825), 709.

Ramos A.R., Yraola I.S., Peralta L.F, Jimenez J.F.G. (1990) Informe de la Campana Guinea 90. Instituto Español de Oceanografia, Malaga.

Raschid, L.S.; Koranteng, R.T.; Akoto, E.K. [no date]. Research, development, and capacity building for the sustainability of dam development with special reference to the Bui Dam project. Accra, Ghana: The International Water Management Institute. Submitted to: National Coordinating Committee of Ghana Dams Forum, Accra, Ghana. http://ghanadamsdialogue.iwmi.org/Data/Sites/2/media/projectdocuments/issuepaper-r&d.pdf. (May 5, 2011).

Reich, P. F., S.T. Numbem, R.A. Almaraz and H. Eswaran. 2001. Land resource stresses and desertification in Africa. Pages (not paginated) in E. M. Bridges, I.D. Hannam, L.R. Oldeman, F.W.T. Pening de Vries, S.J. Scherr, and S. Sompatpanit, editors. Responses to Land Degradation. Proceedings 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India. Available from: http://soils.usda.gov/use/worldsoils/papers/desertification-africa.html; accessed 20 April 2011.

Renaud, F. and Perez, R., 2010. Climate change vulnerability and adaptation assessments. Sustainability Science: 1-3.

Reuters. 2011. Ghana taps Trinidad for natural gas joint venture. March 17, 2011. Available from: http://ghanaoilonline.org/2011/03/ghana-taps-trinidad-for-natural-gas-joint-venture/; accessed 2 May 2011.

Robertson, B. and P. Pinstrup-Andersen (2010). "Global land acquisition: neo-colonialism or development opportunity?" Food Security **2**(3): 271-283.

Rubin, J.A.; Gordon, C.; Amatekpor, J.K. 1998. Causes and consequences of mangrove deforestation in the Volta estuary, Ghana: some recommendations for ecosystem rehabilitation. Marine Pollution Bulletin. 37(8-12):441-449.

Rünger, M. (8-11 March, 2006). 'Governance, Land Rights and Access to Land in Ghana - A Development Perspective on Gender Equity.' Quoted in Gedzi, V. 2009. Women and Property Inheritance after Intestate Succession, Law 111 in Ghana. Presented at IAFFE Conference. Boston, 25-28 June 2009.

Sagoe, R. (2006). Climate change and root crop production in Ghana. A report prepared for Environmental Protection Agency (EPA), Accra-Ghana February.

Sagoe, R. 2008. Climate change impacts on root and tuber crop production. In: Allotey, J.; Mensah, L.; eds. Ghana climate change impacts, vulnerability and adaptation assessments, under the Netherlands climate assistance programme. Accra, Ghana: Environmental Protection Agency: 207-233. Chapter 6.

Sandker, M., S. K. Nyame, et al. (2010). "REDD payments as incentive for reducing forest loss." Conservation Letters **3**(2): 114-121.

Sarewitz, D., Pielke Jr, R. and Keykhah, M., 2003. Vulnerability and risk: some thoughts from a political and policy perspective. Risk Analysis, 23(4): 805-810.

Schlecht, E., A. Buerkert, et al. (2006). "A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa." Nutrient Cycling in Agroecosystems **76**(2): 109-136.

Schneider, S.H. et al., 2007. Assessing key vulnerabilities and the risk from climate change. Climate change: 779-810.

Schröter, D., Polsky, C. and Patt, A.G., 2005. Assessing vulnerabilities to the effects of global change: an eight step approach. Mitigation and Adaptation Strategies for Global Change, 10(4): 573-595.

Scoones, I. 1998. Sustainable rural livelihoods: a framework for analysis. Working Paper 72. [place of publication unkown]. Institute of Development Studies. 22 p.

Smit, B. and Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change, 16(3): 282-292.

Soussana, J.-F., A.-I. Graux, et al. (2010). "Improving the use of modelling for projections of climate change impacts on crops and pastures." Journal of Experimental Botany **61**(8): 2217-2228.

SRID (Statistics, Research and Information Directorate). 2010. Agriculture in Ghana (2009). Facts and figures. Ministry of Food and Agriculture. Accra, Ghana. Available from http://www.mofa.gov.gh/AGRICULTURE%20IN%20GHANA%20%202009.pdf, accessed April 2011.

Tanser, F. C., B. Sharp, et al. (2003). "Potential effect of climate change on malaria transmission in Africa." The Lancet **362**(9398): 1792-1798.

Taylor, J.C., N. van de Giesen, T.S. Steenhuis. West Africa: Volta discharge data and quality assessment and use. Journal of the American Water Resources Association 2006 (August):1113-1126.

Teal, F.; Zeitlin, A.; Maamah, H. 2006. Ghana Cocoa Farmers Survey 2004: Report to Ghana Cocoa Board. Centre for the Study of African Economies, University of Oxford. 26p. online at http://www.gprg.org/pubs/reports/pdfs/2006-04-teal-zeitlin-maamah.pdf

Tonah, S. 2006. Migration and Farmer-Herder Conflicts in Ghana's Volta Basin. Canadian Journal of African Studies 40(1): 152-178.

Tsidzi, K. E. N., and N. K. Kumapley. 2001. Coastal erosion in Ghana: causes and mitigation strategies. Pages 3941-3945 in Engineering Geology and the Environment, Proceedings International Symposium on Engineering, Geology and the Environment, Athens, Greece, 23-27 June 1997. P. G. Marinos and Greek National Group of IAEG, editors. Swets & Zeitlinger, Lisse.

Tsikata, D. 2006. Living in the shadow of the large dams: long term responses of downstream and lakeside communities of Ghana's Volta project. Leiden, Netherlands: Brill.

Tubiello, F. N., J.-F. Soussana, et al. (2007). "Crop and pasture response to climate change." Proceedings of the National Academy of Sciences **104**(50): 19686-19690.

Tullow Ghana Limited. 2009. Ghana Jubilee Field Phase 1 Development, DRAFT Non Technical Executive Summary of the Environmental Impact Statement. Tullow Ghana Limited, Accra, Ghana.

Turner, B. L., R. E. Kasperson, et al. (2003). "A framework for vulnerability analysis in sustainability science." Proceedings of the National Academy of Sciences of the United States of America **100**(14): 8074.

UNCCD (United Nations Convention to Combat Desertification). 1994. Elaboration of an international convention to combat desertification in countries experiencing serious drought and/or desertification particularly in Africa. United Nations General Assembly. Available from: http://www.unccd.int/convention/text/pdf/conv-eng.pdf; accessed 18 April 2011.

UNCCD (United Nations Convention to Combat Desertification). 2002. An introduction to the United Nations Convention to Combat Desertification. Fact Sheet 1-13. Available from: http://www.unccd.int; accessed April 2011.

UNEP (United Nations Environmental Program). 1997. World atlas of desertification (2nd edition). United Nations Environmental Programme, Nairobi, Kenya.

University of South Carolina, Hazards and Vulnerability Research Institute. Social Vulnerability Index for the United States. http://webra.cas.sc.edu/hvri/products/sovi.aspx. February 7, 2011. (April 26, 2011).

US Agency for International Development Ghana. 2011. (USAID 2011). Feed the future: Initial environmental examination and request for categorical exclusion. 58 p. Unpublished report. On file with: USAID Ghana, Economic Growth Program, No. 24 Fourth Circular, Cantonments, Accra, Ghana.

Valentin, C., J. L. Rajot, et al. (2004). "Responses of soil crusting, runoff and erosion to fallowing in the sub-humid and semi-arid regions of West Africa." Agriculture, ecosystems & environment **104**(2): 287-302.

van de Giesen, M., Andreini, A. van Edig, and P. Vlek. 2001. Competition for water resources of the Volta Basin. Regional Management of Water Resources. IAHS Publication Number 268.

Van der Geest, K. 2004. We're managing! Climate change and livelihood vulnerability in Northwest Ghana. Research Report 74/2004. Leiden, Netherlands: African Studies Centre. 289 p.

Van der Geest, K. 2008. North-South migration in Ghana: what role for the environment? In: 2008 International conference: Environment, Forced Migration & Social Vulnerability. Bonn, Germany. [place of publication unkown].

van Tilburg, X., and L. Würtenberger. 2010. Emissions from flaring Jubilee field gas. Policy Brief, Technical Assistance to the Ghanaian National Climate Change Policy Framework, Energy Research Center for the Netherlands, Amsterdam.

Virmani, S.M., Katyal, J.C., Eswaran, H. and Abrol, I., eds. 1994. Stressed Agroecosystems and Sustainable Agriculture. New Delhi: Oxford & IBH.

Wagner, M.R. and Cobbinah, J.R., 1993. Deforestation and sustainability in Ghana. Journal of Forestry;(United States), 91(6).

Wardell, D.A. and Lund, C., 2006. Governing access to forests in northern Ghana: micro-politics and the rents of non-enforcement. World development, 34(11): 1887-1906.

Wardell, D.A., Reenberg, A. and Tøttrup, C., 2003. Historical footprints in contemporary land use systems: forest cover changes in savannasavanna woodlands in the Sudano-Sahelian zone. Global Environmental Change, 13(4): 235-254.

Whitehead, A. 2002. Tracking Livelihood Change: Theoretical, Methodological and Empirical Perspectives from North-East Ghana. Journal of Southern African Studies 28(3): 575-598.

Wiafe, G., Yaqub, H.B., Mensah, M.A., and Frid, C.L.J. 2008. Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. – ICES Journal of Marine Science, 65: 318–324.

Wood, A.W., Leung, L.R., Sridhar, V., Lettenmaier, D.P. 2004. Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. Climatic Change, 62: 189–216.

World Bank. 2011. Fact sheet: first global satellite survey on gas flaring. Global Gas Flaring Reduction Project, World Bank. Available from: http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTOGMC/EXTGGFR; accessed 2 May 2011.

WTTC 2011. World Travel and Tourism Council. 2011. Travel and tourism economic impact, 2011: Ghana. 16 p. On file with: World Travel & Tourism Council, 1-2 Queen Victoria Terrace, Soverign Court, London, UK. http://www.wttc.org/bin/file/original_file/ghana_report_2011-pdf.pdf (May 3, 2011).

Yaro, J.A.; Zackaria, A.I. 2006. Evolving Land Tenure Systems and Sustainable livelihoods in Northern Ghana. Draft Report. On file with the Land Tenure and Policy Research Project. University of Ghana.

Yiridoe, E. K., A. S. Langyintuo, et al. (2006). "Economics of the impact of alternative rice cropping systems on subsistence farming: Whole-farm analysis in northern Ghana." Agricultural Systems **91**(1-2): 102-121.

Zhang, X. and X. Cai (2011). "Climate change impacts on global agricultural land availability." Environmental Research Letters **6**: 014014.

APPENDIX 1. TEAM ITINERARY AND CONTACTS

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
21-Feb-11	Publish What you Pay - Ghana	Mohammed Amin Adam	National Oil Coordinator	+233-20-8382222	tabat15@yahoo.com	www.pwyp-ghana.org
21-Feb-11	Publish What you Pay	Freida Quagraire	Program Manager, Oil and Gas Platform			www.pwyp-ghana.org
21-Feb-11	Public Agenda	Frederick Asiamah	Coordinator			www.publicagendaghana.org
22-Feb-11	Conservation Alliance	Yaw Osei - Owusu	Country Director	+233-21-780-906, +233-244-277-795	yosei-owusu @conservealliance.org	www.conservealliance.org
22-Feb-11	Conservation Alliance	Ernestina Doku-Marfo	Conservation Biologist	+233-21-780-906, +233-244-844-459 (M)	edoku-marfo@conservealliance.org, tinammarfo@yahoo.com	www.conservealliance.org
22-Feb-11	USAID	Nino Nadiradze	Office of Economic Growth, Senior Environmental Officer	+233-24-431-3526	nnadiradze@usaid.gov	www.usaid.gov/gh
22-Feb-11	USAID	Allen Fleming	Economic Growth Office, Office Director	+233-030-274-1132 , +233-244-313-530(M)	allen@usaid.gov	http://www.usaid.gov/gh
22-Feb-11	USAID	John Mullenax	Economic Growth Office, Advisor, Presidential Initiative to End Hunger in Africa	+233 030 274 1403, +233 024 431 3543 (M)	jmullenax@usaid.gov	http://www.usaid.gov/gh
22-Feb-11	Ghana EPA	Mr. Apombwe	Head of National Climate Change Unit			www.epa.gov.gh
Begin Field Trip to Northern Region, Mole NP, Tamale February 23-25, 2011 Trip Included the following meetings and interviews:						
23-Feb-11	Mole National Park	Enoch Ashie	Manager of Natural Resources		valueseaa@yahoo.com	www.touringghana.com/ecotourism/mole.asp
23-Feb-11	Mognori	17 individuals, 1 interpreter	Chief, Male Community Members			www.savannatourism.com/mognori.html
24-Feb-11	University for Development Studies	William Jasper Asante	Professor	+233-24-420-6175	wjasante@yahoo.com	www.uds.edu.gh
24-Feb-11	University for Development	Esther Ekua Amoako	Professor	+233-24-420-6175	ekubee@yahoo.com	www.uds.edu.gh

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
	Studies					
24-Feb-11	University for Development Studies	Bernard Batuuwie	Professor			www.uds.edu.gh
24-Feb-11	CARE International	David Sumbo	Program Coordinator, Tamale	+233-071-25700, +233-24-489-4018	david.sumbo@co.care.org,	www.care.org
24-Feb-11	CARE International	Romanus Gyang	Project Manager (ALP)	+233-24-353-3686		www.care.org
24-Feb-11	Catholic Relief Services	Kris H. Ozar	Program Quality Manager, Ghana	+233-24-431-7869	kris.ozar@crs.org	www.crs.org/ghana
24-Feb-11	Zasilari Ecological Farms Project (Walewale)	Issifu Jobila Sulemann		+233-20-828-3225	zasilari@yahoo.com	www.zefp.org/
24-Feb-11	Zasilari Ecological Farms Project (Walewale)	David Agongo	Coordinator	+233-20-828-3225	zasilari@yahoo.com	www.zefp.org/
25-Feb-11	SARI	Matthew Fosu	Scientific Officer, Northern Region Farming Systems Research Group	+233-071-22411 +233-071-23257	matthewfosu@yahoo.co.uk	www.csir.org.gh/index1.php?linkid=117&sublinkid=73
25-Feb-11	SARI	Mohammed Abdul Razak		N/A	aweetauk@yahoo.co.uk	www.csir.org.gh/index1.php?linkid=117&sublinkid=73
25-Feb-11	UDS	Dr. Francis Obeng	Lecturer, Ghana Ecological Network	N/A	N/A	www.uds.edu.gh
25-Feb-11	UDS	Mr. Conrad A. Weobong	Lecturer, Ghana Ecological Network	N/A	N/A	www.uds.edu.gh
25-Feb-11	USAID ADVANCE (Agricultural Development and Value Chain Enhancement Program)	Catherine Phiri	Agri Business Advisor	+233-03720, +233-27569, +233-37-202-7570	cphiri@acdivocaghana.org	www.acdivoca.org/site/ID/ghanaADVANCE
26-Feb-11	SAAI - Sustainable African Agricultural Initiative (Pty) Ltd	Jan Hepburn	Chief Executive Officer	+27(0)836606569 (M), +27(0)126431225	shepagricnig@yahoo.com	N/A

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
End field trip to Northern Region						
27-Feb-11	Winneba Fisherman	Collins Impraim	Lead Fisherman	N/A	N/A	N/A
28-Feb-11	USAID	Cheryl Anderson	Mission Director	N/A	N/A	www.usaid.gov/gh
28-Feb-11	USAID	Peter Argo	Deputy Director	N/A	N/A	www.usaid.gov/gh
28-Feb-11	USAID	Nino Nadiradze	Office of Economic Growth, Senior Env. Officer	+233-24-431-3526	nnadiradze@usaid.gov	www.usaid.gov/gh
28-Feb-11	USAID	Allen Fleming	Economic Growth Office, Office Director	+233 030-274-1132, +233-24-431-3530(M)	allen@usaid.gov	www.usaid.gov/gh
28-Feb-11	USAID	Justice Odoi	Environmental Specialist	N/A	jodoi@usaid.gov	www.usaid.gov/gh
28-Feb-11	USAID	Emil R. Stalis	Democracy & Special Project Coordinator	+233-030-274-1756, +233-24-431 1936(M)	estalis@usaid.gov	www.usaid.gov/gh
28-Feb-11	USAID	Susan Wright	RH & CSID Advisor (Health)	N/A	N/A	www.usaid.gov/gh
28-Feb-11	USAID	Luis Tolley	Education Advisor	N/A	N/A	www.usaid.gov/gh
28-Feb-11	USAID	Alfred Osei	Food Security Specialist	N/A	N/A	www.usaid.gov/gh
28-Feb-11	USAID	John Mullenax	Economic Growth Office, Advisor, Presidential Initiative to End Hunger in Africa	+233-030-274-1403, +233-24-431 3543 (M)	jmullenax@usaid.gov	www.usaid.gov/gh
28-Feb-11	USAID	Fenton Sand	Agriculture Advisor, Feed the Future Advisor	N/A	N/A	www.usaid.gov/gh
28-Feb-11	State Department	Aaron Fishman	Regional Environment, Science, and Technology Officer for West & Central Africa, U.S Embassy Ghana	+233-21-741-417	FishmanAD@state.gov	http://ghana.usembassy.gov
28-Feb-11	Ghana Statistical Service	N/A	Statistician	+233-24-388-8570	N/A	www.statsghana.gov.gh
1-Mar-11	UNDP- United Nations Development	Stephen Duah Yentumi	Head, Env. & Energy Unit (Programme Specialist)	+233-21-773890	stephen.duah-yentumi@undp.org	www.undp-gha.org

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
	Program					
1-Mar-11	CICOL (Civil Society Coalition on land)	Lillian Bruce	CICOL Coordinator	+233-030-224-0891, +233-24 -461-4303 (M), +233-20-589-1920	mail@cicolghana.org, cicolghana@gmail.com	N/A
1-Mar-11	IUCN (International Union for the Conservation of Nature)	Samuel Kofi Nyame	Project Coordinator (for NTFP)	+233-20-821-2486, +233-24-699-6552, +233-27-175-2502	samuel.kofi.nyame@iucn.org, samknyame02@yahoo.com	www.iucn.org
1-Mar-11	World Bank	Flavio Chaves	Natural Resources Management Specialist, Africa Environment and Natural Resources Management Unit	+233-30-221-4166, +233-54-675-1033 (M)	fchaves@worldbank.org	http://web.worldbank.org
1-Mar-11	Ghana MEST - Ministry of Environment, Science, and Technology	Dr. Nicholas K. Iddi	Naitonal Project Coordinator, Ghana Environmental Conventions Coordinating Authority	+233-21-662-626, +233-21-662-626 (M)	nicholasiddi@yahoo.com	www.ghana.gov.gh/index.php?option=com_content&view=article&id=329:ministry-of-environment-science-a-technology&catid=74:ministries&Itemid=224
1-Mar-11	Ghana MEST - Ministry of Environment, Science, and Technology	Dr. Raymond Babanawo	Project Technical Assistant, Ghana Environmental Conventions Coordinating Authority	+233-21-662-626, +233-24-059-5584 (M)	babsraymond@yahoo.ca	www.ghana.gov.gh/index.php?option=com_content&view=article&id=329:ministry-of-environment-science-a-technology&catid=74:ministries&Itemid=224
2-Mar-11	Civic Response-Forest Watch	Abdul-Razak Saeed	Programmes Officer (Climate Governance)	+233 21 521905, +233 244 686 548	saeed@civicresponse.org razymac@yahoo.com	N/A
2-Mar-11	Rainforest Alliance	Emmanuel Owusu	Sustainable Forestry Division, Project Administrator, FCAA/TREES Program, Ghana	+233 302 502210, +233 244 238252 (M)	eowusu@ra.org	www.rainforest-alliance.org
2-Mar-11	Rainforest Alliance	Elvis Kuudaar	Community Forestry & Enterprise Development Specialist, TREES	233 30 250 2210	ekuudaar@ra.org	www.rainforest-alliance.org

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
			Program			
2-Mar-11	Rainforest Alliance	Emmanuel Owusu	Project Administrator	233 30 250 2210	eowusu@ra.org	www.rainforest-alliance.org
2-Mar-11	Ministry of Lands & Natural Resources	Joseph Osiakwan (Josky)	Policy Coordinator/Senior Planning Officer	+233 21 687346, +020 8182556 (M), +024 922 7796 (M)	josephosiakwan@yahoo.com	www.ghana-mining.org/ghweb/en/ma/mlnr.html
3-Mar-11	Ministry of Lands & Natural Resources	Mathew Ababio	Policy Planning Director	N/A	abab64math@yahoo.com	www.ghana-mining.org/ghweb/en/ma/mlnr.html
4-Mar-11	Ministry of Lands & Natural Resources	Tabi Agyariw	National Coordinator	N/A	tabimlfl66@yahoo.com	www.ghana-mining.org/ghweb/en/ma/mlnr.html
3-Mar-11	Embassy of the Kingdom of the Netherlands	Dr Ton van der Zon	First Secretary, Environment and Water Resources	+233 302 214362, +233 248894652 (M)	ton-vander.zon@minbuza.nl	www.ambaccra.nl/
3-Mar-11	Forestry Commission, Climate Change Unit	Robert K. Bamfo	Head, Climate Change	+233 302 401210, +233 302 7010033, +233 28 9516504, +233 20 8237777(M)	bamforobert@yahoo.com	www.fcghana.com
3-Mar-11	Forestry Commission, Climate Change Unit	Roselyn Fosuah Adjei	Assistant Programme Manager	021-401210/028 9115496, 024 453 5772 (M)	yafossy@yahoo.com	www.fcghana.com
3-Mar-11	Forestry Commission, Wildlife Division	Cletus K. Nateg	Operations Manager (Protected Area)	028 9115489, 0244 722152(M)	kcnateg@ymail.com	www.fcghana.com
3-Mar-11	Forestry Commission, Wildlife Division	Cornelia Danso	Assistant Wildlife Officer	021 401249	ilacorne@yahoo.co.uk	www.fcghana.com
3-Mar-11	Forestry Commission, Wildlife Division	Sandra Olsen	Commercial Development	+233 21 401210, 401227, 401216, 401231 / 3 / 9	info@wd.fcghana.com	www.fcghana.com
3-Mar-11	Forestry Commission, Wildlife Division	Mohammed Issa	Manager	+233 21 401210, 401227, 401216, 401231 / 3 / 9	info@wd.fcghana.com	www.fcghana.com

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
3-Mar-11	Forestry Commission, Wildlife Division	Charles Amankwah	General services manager, wetlands conservation	+233 21 401210, 401227, 401216, 401231 / 3 / 9	camankwah@hq.fcghana.com	www.fcghana.com
3-Mar-11	Forestry Commission	Hugh Brown		N/A	hugh.brown@aya.yale.edu	www.fcghana.com
3-Mar-11	Forestry Commission	Kwakye Ameyew		N/A	N/A	www.fcghana.com
3-Mar-11	Forestry Commission	Francis S. Amoah		N/A	kwegyir2004@yahoo.com	www.fcghana.com
3-Mar-11	Canadian High Commission, CIDA	Romeo Adonmah-Darteh	Senior Environmental Analyst/Advisor, Program Support Unit	+233 302 772861/773598 ext 1128, +233 26 3004820 (M), +233 24 4715772	romeo.darteh@psu-ghana.org	www.psu-ghana.org
3-Mar-11	Canadian High Commission, CIDA	Janine Cocker	First Secretary, Senior Development Officer, Food Security Program	+233-30-221-1521 Ext. 3455	janine.cocker@international.gc.ca	www.acdi-cida.gc.ca
3-Mar-11	Canadian High Commission, CIDA	Loree Semeluk	Second Secretary, Development Officer	+233-30-221-1521 Ext. 3460	loree.semeluk@international.gc.ca	www.acdi-cida.gc.ca
3-Mar-11	Canadian High *Commission, CIDA*	Eunice Annan-Aggrey	International Development Assistant	+233-30-221-1521	eunice.annan-aggrey@international.gc.ca	www.acdi-cida.gc.ca
3-Mar-11	Water Resources Commission	Enoch Asare	Head, Groundwater Division	027 288 8499	enochasare@gmail.com	www.wrc-gh.org
3-Mar-11	Department of Commerce	Heather Byrnes	Commercial Attache to U.S. Embassy in Ghana	N/A	heatherbyrnesh@state.gov	http://ghana.usembassy.gov
4-Mar-11	Stalwart Mining	Tom Powell	CEO	054 313 4679	N/A	www.stalwartmining.com
Begin Field Trip to Central/Western Regions, Cape Coast, Kakum NP, Takoradi March 5-9 Trip included the following meetings and interviews:						
5-Mar-11	Kakum National Park	Daniel Ewur	Park Manager			www.touringghana.com/ecotourism/kakum.asp
5-Mar-11	Abrafo Area Chiefs	5 Chiefs	Chiefs	N/A	N/A	N/A
5-Mar-11	Mbaaniaye Village	50+ Community Members	N/A	N/A	N/A	N/A
5-Mar-11	University of Cape Coast	Denis Worlanyo Aheto	Professor, Integrated Coastal Zone Management Program		worlaheden@yahoo.com	www.ucc.edu.gh

Date	Organization	Interviewee	Position	Contact Tel.	Contact Email	Web Address
6-Mar-11	Center for Environmental Impact Analysis (CEIA)	Samuel Obiri	Executive Director	+233-24-470-8322	obirisamue@gmail.com sobiri@ceiagh.com	www.ceiagh.com
7-Mar-11	CEIA	Priscilla Achiaa	Program Officer	+233-24-470-8322		www.ceiagh.com
8-Mar-11	CEIA	Faustina Essuon	Administrative Secretary	+233-24-470-8322		www.ceiagh.com
7-Mar-11	Kakum National Park	Daniel Ewur	Park Manager			www.touringghana.com/ecotourism/kakum.asp
8-Mar-11	Ghana Primewood Products	Benjamin Adgei	Forest Certification Manager	+233-31-22593		N/A
8-Mar-11	Coastal Resource Center	Kofi Agbohah	Program Coordinator	+233 24 467 8007	kofi.agbogah@gmail.com	www.crc.uri.edu/index.php?projectid=110
8-Mar-11	Coastal Resource Center	Sally Deffor	Communications Officer	+233-31-2047163, +233 20 8177991, +233 261 197569	sallydeffor@yahoo.com	www.crc.uri.edu/index.php?projectid=110
End Field Trip to Central/ Western Regions						
10-Mar-11	USAID	Power Point Presentation				
11-Mar-11	Nature Conservation Research Center (NCRC)	John Mason	Founder CEO	233-21-231765 233 30 223 1765	info@ncrc-ghana.org jjmason999@yahoo.com	www.ncrc-ghana.org/
11-Mar-11	Nature Conservation Research Center	Martin Yelibora	Capacity-building Coordinator	233-21-231765	info@ncrc-ghana.org	www.ncrc-ghana.org/
11-Mar-11	The Katoomba Group	Rebecca Ashley Ashare	Coordinator West Africa Katoomba Grp.	+233 24 370 9369	rebashley@yahoo.com	www.katoombagroup.org
12- Mar-11	Team Departs from Ghana (last date, various team members depart various dates)					

APPENDIX 2. TEAM MEMBERS

Name	Role	Background
Frederick Armah	In-Country Coordination, Resource Specialist	BS (Hons)Chemistry, University of Cape Coast, Ghana 2000 MS Environmental Studies and Sustainability Science, Lund University, Sweden, 2008
Steve Brady	Team Leader	BS Forestry, University of Idaho 1973 BA Physics, University of Idaho 1973 US Forest Service 1970-2010: Forester, District Ranger, Forest Resource Staff Officer
Dr. Susan Charnley	Climate Change, Social Scientist	PhD Anthropology, Stanford University, 1994 MA Anthropology, Stanford University, 1989 BA Biology, University of California, Santa Cruz, 1981 BA Environmental Studies, UC Santa Cruz, 1981 US Forest Service, 1999-present: Research Social Scientist, National Program Leader for Human Dimensions
Joe Krueger	ETOA Specialist	B.S. Forestry, Cal Poly, 1990 US Forest Service, Environmental Planning Specialist, 1988-present
Yaw Nyako	In-Country Coordination Resource Specialist	B.Sc. Natural Resources Management, Kwame Nkrumah University of Science and Technology, 1997 M.Sc. Forest Science, Kochi University, 2007
Sophia Polasky	Climate Change, Social Scientist	B.A. Environmental Studies, College of St. Benedict 2006 Peace Corps Ghana, 2006-2008: Agro-forestry US Forest Service, 2009-present: Research Technician, Pacific Northwest Research Station,
Dr. John Stanturf	Climate Change, Group Leader	B.S., Plant and Soil Science, Montana State University, 1974 M.S., Soil Science, Cornell University, 1979 Ph. D., Forest Soils, Cornell University, 1983 Lady Davis Post-Doctoral Fellow, Technion, Haifa, Israel 1982-1983 Honorary Doctorate, Estonian University of Life Sciences, Tartu 2011 US Forest Service 1992-present, Research Ecologist
Dr. Melvin Warren	Climate Change, Research Biologist/Fisheries/Aquatic Ecology	B.S. Zoology, University of Tennessee 1974 M.S. Wildlife and Fisheries Science, University of Tennessee 1977 Ichthyologist and Project Coordinator, Kentucky Nature Preserves Commission, 1978-83 Ph.D., Zoology, Southern Illinois University, 1989 Post-doctoral Research Associate, Department of Fisheries and Wildlife Sciences, Virginia Tech, 1991-1992 US Forest Service 1992-2011: Research Biologist and Team Leader, Aquatic and Terrestrial Fauna Team

APPENDIX 3. MATRIX OF CLIMATE CHANGE ACTIVITIES IN GHANA

DP ENR Sector Activity Matrix, *December 2010*

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
Evy von Pfeil Atse Yapi	Pilot project to develop an approach on implementing the Forest Instrument	Implementation of the Non Legally Binding Instrument on all types of forests Enhancing coordination of forest related activities	300.000 €	2009 - 2011	Forestry Commission	German funds via FAO
Atse Yapi	Strengthening the participation of farmers and local communities in the community forest plantations development under the Modified Taungya System (MTS)	The socio-economic and capacity building aspects of community forest plantations development under the Modified Taungya System (MTS) are strengthened;	$170,000	2010-2011	Forestry Commission	NFP Facility funds within the NFP facility partnership with Ghana
Stephen Duah-Yentumi Stephen.duah-yentumi@undp.org	CLIMATE CHANGE AND DISASTER RISK REDUCTION: Institutional support to integrate climate change and disaster risk reduction into national development plans	The project will provide support towards advocacy, strategic policy advice and capacity development to targeted institutions for Climate Change and Disaster Risk Reduction (DRR). In the area of Climate Change, the support will focus on: scaling up the CC/DRR mainstreaming process especially in newly but vulnerable districts and in relevant MDAs; enhancing key elements of the climate change mitigation and low carbon development by building institutional and human capacities among major sector stakeholders; providing continued support to upstream capacity enhancement and leadership strengthening actions at the highest possible level in climate decision-making, in order to improve coordination, overall directions and enhance Ghana's	$ 525,000	2011	EPA NADMO NDPC	

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
		competitiveness to participate effectively in global climate negotiations In the case of Disaster Risk Reduction, the support will focus on strengthening Ghana's resilience to natural disasters, by incorporating DRR into school curricula and building guides, and by promoting a gender responsive culture in DRR at the district and community level				
Stephen Duah-Yentumi Stephen.duah-yentumi@undp.org	CLIMATE CHANGE MITIGATION: Promoting of Appliance Energy Efficiency and Transformation of the Refrigerating Appliances Market in Ghana	The project objective is to improve the energy efficiency of appliances manufactured, marketed and used in Ghana through the introduction of a combination of regulatory tool such as Minimum Energy Performance Standards and Information Labels (S&L), and innovative economic tools. Domestic refrigeration appliances will be the first end-use to be tackled, with a specific focus to address ozone depleting substances contained in the current stock of equipment.	$1,722,727	2011 - 2014	Energy Commission Ministry of Energy EPA	
Stephen Duah-Yentumi Stephen.duah-yentumi@undp.org	CLIMATE CHANGE MITIGATION / OZONE DEPLETION HCFC Phase Out Management Plan (HPMP)	The XIXth Meeting of the Parties to the Montreal Protocol in September 2007, through its Decision XIX/6, adopted an accelerated phase-out schedule for HCFCs. The first control is the freeze on production and consumption of HCFCs through the first 10% reduction step to the 35% on 1 January 2020. The early stages of the HPMP will focus on the establishment of safe hydrocarbon and natural refrigerant use culture to enable their safe general long term use. Activities will be undertaken to convert HCFC use into environmentally sound alternatives and to draw on the experienced gained and lessons learned from the previous programmes to phase out CFCs in the servicing sector.	$1,356,311	2011 - 2019	National Ozone Unit	

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
Stephen Duah-Yentumi Stephen.duah-yentumi@undp.org	POLLUTION PCB management in Ghana, from Capacity Building to Elimination	This project is aimed at strengthening the capacities and capabilities of government officials and stakeholders outside of government to address PCB identification, manage existing sources of PCBs as well as their elimination/destruction, as identified as a priority in the National Implementation Plan for Persistent Organic Pollutants for the Republic of Ghana.	$2,945,700	2009 - 2013	EPA MEST	
Stephen Duah-Yentumi Stephen.duah-yentumi@undp.org	UNITED NATIONS ENVIRONMENTAL CONVENTIONS Establishing an Effective and Sustainable Structure for Implementing Multilateral Environment Agreements	The project is to improve coordination structures and mechanisms, so that stakeholders in Ghana are addressing the conservation of the environment in an effective manner. The proposed project will first help the Government to merge all existing management structures at national level into one structure consisting of the Ghana Environmental Conventions Coordinating Authority (GECCA) and its Secretariat. The project will then help these mechanisms become operational by building their capacity and supporting them to perform specific tasks. Finally, the project will help these mechanisms provide support to five pilot districts, in order to build national level capacity to support districts. The result will be a far more coherent, streamlined and effective allocation of resources to meeting the Rio obligations. In turn, it is expected that this increased efficiency will attract additional investors to support Ghana as it meets its Rio Convention obligations.	$745,00	2009-2012	MEST GECCA	
Loree Semeluk (Environment Lead, CIDA)	Ghana Environment Management Project (GEMP)	To strengthen Ghanaian institutions and rural communities to enable them to reverse land degradation and desertification trends in Ghana's three northern regions (as part of the	$7.25 M CAD	2007- 2012	MEST and EPA	To guide the implementation of the NAP, the Government of Ghana invited the

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
		implementation of Ghana's National Action Programme (NAP) to Combat Drought and Desertification)				Government of Canada CIDA to act in the role of *chef-de-file* for desertification issues under the United Nations Convention to Combat Desertification (UNCCD). An RFP has been issued for interested organizations, institutions, communities and individuals to submit proposals for funding of sub-projects.
Loree Semeluk (EnvironmentLead, CIDA)	Food Security and Environment Facility (FSEF)	To deliver and disseminate innovative food security and sustainable agricultural programming in the three northern regions of Ghana.	$14.3 M CAD	2008-2016	MLGRD (with MoFA's technical input)	An RFP has been issued for interested organizations, institutions, communities and individuals to submit proposals for funding of sub-projects.
Loree Semeluk (Environment Lead, CIDA)	Northern Region Small Towns Water and Sanitation Project (NORST)	To provide increased access to potable water and sanitation services in up to 30 selected small towns through the design, installation , and capacity building support for the operation of water supply systems and appropriate sanitation facilities	$30 M CAD	2009-2016	MWRWH	Environmental issues were integrated into the project with the conduct of an SEA. The recommendation s of the SEA are being

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
						implemented in addition to an environmental action plan.
Loree Semeluk (Environment Lead, CIDA)	District Wide Assistance Project (DWAP)	To reduce poverty in 34 districts in the three northern regions by improving access to basic infrastructure facilities such as health, school, security, places of convenience and potable water among others	$15 M CAD	2003-2012	MLGRD	Environmental issues were integrated into the project with the conduct of an SEA. Sub-project planning and implementation are informed by the guidelines outlined in the SEA
Loree Semeluk (Environment Lead, CIDA)	Support to Food and Agriculture Development Policy (SFASDEP)	To support the achievement of FASDEP II as outlined by the Government of Ghana	$100 M CAD	2009-2014	MoFA	MoFA has developed a Sustainable Land Management (SLM) Strategy and Action Plan for addressing environmental and land management issues in agricultural production.
Florent Clair (Agriculture & Environment Project Officer; AFD) clairf@afd.fr	Natural Resources and Environmental Governance Budget Support	To preserve the growth potential of the Ghanaian economy by preventing the degradation of its natural capital through the strengthening of the governance of sectors contributing most to this decline	5 M €	2008-2012	MLFM, MEST	An external evaluation of environmental degradation cost is currently being launched
Florent Clair (Agriclture & Environment Project Officer; AFD) clairf@afd.fr	Amansuri Estuary/Mangrove Swamp Forest Conservation	Conserving and managing the Amansuri estuary and mangrove and swamp forest ecosystem including the coastal areas in partnership with chiefs and people in the	44.000 €	2010-2012		FFEM (French Fund for global environment) grant to Ghana

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
		5 communities				Wildlife Society (NGO)
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu)	Programme on Environment and Tropical Forests in Developing Countries	Developing alternatives for illegal chainsaw lumbering through multi-stakeholder dialogue in Ghana and Guyana	2,186,010.00 €	2007 - 2012	FC	
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu)	Thematic Programme for Environment and sustainable management of natural resources, including energy	Supporting the integration of legal and legitimate domestic timber markets into Voluntary Partnership Agreements	1,999,265.00 €	2011 - 2015	FC	
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu)	Thematic Programme for environment and sustainable management of natural resources, including energy	Governance Initiative for Rights & Accountability in Forest Management (GIRAF)	999,973.00 €	2009 - 2013	FC	
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Natural Resource and Environmental Governance (NREG) SPSP	The programme seeks to contribute to the implementation of the sector strategy and address issues in the inter-related sub-sectors of forestry and wildlife, mining and environmental protection.	8,000,000.00 €	2009 - 2013	FC, MC, EPA MEST MLNR	
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Forest Law Enforcement, Governance and Trade Support Project for ACP Countries FLEGT-ACP	Strengthening the capabilities of forest fringe communities in Southern Ghana to halt illegal logging	$ 134,500.00	2008 - 2012	FC / Forest Research Institute	FAO-ACP FLEGT Support Programme
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Forest Law Enforcement, Governance and Trade Support	Preparation of a training centre to support FLEGT implementation and the adoption of Sustainable Forest Management practices in Ghana and the	$ 132,897.00	2008 - 2012	FC + Form International + Kumasi Wood Cluster	FAO-ACP FLEGT Support Programme

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
	Project for ACP Countries FLEGT-ACP	West African Region				
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Forest Law Enforcement, Governance and Trade Support Project for ACP Countries FLEGT-ACP	Facilitating compliance with FLEGT and Due Diligence Regulation in Cote d'Ivoire, Ghana and Liberia	$ 134,810.00	2008 - 2012	FC + WWF West Africa Forest Programme	FAO-ACP FLEGT Support Programme
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Forest Law Enforcement, Governance and Trade Support Project for ACP Countries FLEGT-ACP	Empowering Forest Stakeholder to monitor the implementation and compliance of VPA in Ghana	$ 132,000.00	2008 - 2012	FC / Working Group on Forest Certification	FAO-ACP FLEGT Support Programme
Emmanuel B. Ansong (emmanuel.ansong@eeas.europa.eu	Forest Law Enforcement, Governance and Trade Support Project for ACP Countries FLEGT-ACP	Integrating Civil Society in timber harvest validation processes for improved governance and reduced illegal logging under the European Union and Ghana Voluntary partnership Agreement	$ 96,000.00	2008 – 2012	FC / Resource Management Support Centre	FAO-ACP FLEGT Support Programme
Willem.ROODHART@ec.europa.eu	Use of Jatropha plant to improve sustainable renewable energy development and create income-generating activities: an integrated approach to ensure sustainable livelihood conditions and mitigate land degradation effects in rural areas of	The project aims by promoting and introducing perennial drought-resistant energy crop (Jatropha species) to provide the rural communities with adequate access and security of sustainable energy; to reduce poverty and ensure livelihood security by developing alternative and sustainable income generating activities. Furthermore the project aims to introduce desertification mitigation actions as well as to promote gender equality and strengthen management capacities of local stakeholders.	1,916,863.14 €	2009 - 2014		

DP - contact person	Activity	Objective	Budget	Timeline	Sector -GoG organisation counterparts	Additional information
	Ghana					
Georgios.Tsitsopoulos@ec.europa.eu	Social justice in forestry	To improve forest governance in ten countries in Africa and Asia - securing local rights, developing forest product legitimacy and combating climate change	2,000,000.00 €	2009 - 2014		Action is being managed from Brussels

APPENDIX 4. TABLE OF POTENTIAL COLLABORATORS AND THEIR FOCUS AREAS

Key

Type: N=NON GOVERNMENTAL ORGANISATION G= GOVERNMENTAL

Relationship to USAID: I=IMPLEMENTER D=DEVELOPMENT PARTNER N= None

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
Government Institutions																		
Environmental Protection Agency (Climate Change focal point)	Ensure environmentally sound and efficient use of both renewable and non-renewable resources in the process of national development; Create awareness to mainstream environment into the development process at the national, regional, district and community levels; To apply the legal processes in a fair, equitable manner to ensure responsible environmental behaviour in the country	G	I	Daniel Amlalo www.epaghana.gov.gh	√	√					√		√	√	√		√	
Forestry Commission	Regulation of utilization of forest and wildlife resources, the conservation and management of those resources and the coordination of policies related to them	G	I	Robert Bamfo www.fcghana.com	√	√			√	√								
Water Resources Commission	Processing of water rights and permits; Planning for water resources development and management with river basins (catchments) as the natural units of planning; Collating, storing and disseminating data and information on water resources in Ghana; Monitoring and assessing activities and	G	I	www.wrc-gh.com			√				√							

					CURRENT FOCUS AREAS													
Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
	programmes for the utilisation and conservation of water resources																	
Energy Commission	Recommend national policies for the development and utilization of indigenous energy resources; advice the Minister responsible for Energy on national policies for the efficient and safe supply of electricity, natural gas, and petroleum products having regard to the economy; provide the legal, regulatory and supervisory framework for providers of energy in Ghana(i.e. licensing, prescription of uniform rules of practice by legislative instrument, inspection, monitoring and compliance of rules); secure a comprehensive database for national decision making as regards the development and utilization of energy resources available to the nation; promote competition in the energy market and enforce standards of performance.	G	I	http://new.energycom.gov.gh/							√			√				

					CURRENT FOCUS AREAS													
Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
Fisheries Commission	Rebuild and maintain robust fisheries resources through policy reforms, cooperative regulatory planning; Develop and implement appropriate management frameworks that ensure fisheries resources are harvested sustainably, improved intra-regional and international trade of fish and fishery products and maximum economic and social benefits are obtained from the fisheries. Develop the capacity of Small-scale fishers and other operators to create sustainable livelihoods for their people from the sustainable harvest, processing and marketing of their fisheries resources	G	I				√	√			√	√		√				
Minerals Commission	Formulate recommendations of national policy for exploration and exploitation of mineral resources. Emphasis on setting national priorities cognizant of the national economy. Advise the Minister on matters relating to minerals; Monitor the implementation of Government Policies on minerals and report to the Minister; Monitor operations of all bodies or establishments with responsibility for minerals and report to the Minister; Receive and access public agreements relating to minerals and report to Parliament; Secure comprehensive data on national mineral resources and technologies of exploration and	G	I	http://www.ghana-mining.org/ghweb/en/ma/mincom.html							√				√			

Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	CURRENT FOCUS AREAS													
					REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
	exploitation for national decision making																	
Resource Management Support Centre (RMSC)	Provide technical mapping services to the Forestry Commission	G	I	Edward Obiaw info@rmsc.fcghana.com					√	√								
NGOs																		
Civic Response		N	N	Kyeretwie Opoku www.civicresponse.org	√	√			√	√	√						√	
Nature Conservation Research Centre	Assist communities/ private sector manage lands to maximize carbon sequestration and biodiversity conservation; Facilitate introduction of more sustainable methods for domestic charcoal trade in rural Ghana; Provide expertise on protecting endangered plant and animal species to communities, private sector and govt.; Promote carbon trading and payments for ecosystem services in the sub-region, as well as solar energy solutions linked to conservation initiatives for rural communities ; Build expertise within the West African sub-region regarding climate change and carbon issues	N	I	John Mason http://www.ncrc-ghana.org/	√	√			√	√							√	
Arocha Ghana	Environmental action through community-based conservation interventions; promote community, conservation, cross-cultural cooperation and via underlying Christian principles to sensitize people to care for the world's natural resources	N	N	Baba Abubakari		√			√	√							√	

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
Coalition of Civil Society on Land (CICOL	The CICOL is a network of Civil Society Organizations working and advocating equitable land tenure practices, policies and management in Ghana.	N	N	Lillian Bruce cicolghana@gmail.com												√		
KASA-Care International	A natural resource and environment sector specific civil society support mechanism in Ghana; Builds on and strengthens existing non state actors' coalitions and experiences and seeks to promote direct engagement between Ghanaian civil society organizations, the media and government at all levels	N	I	Zakaria Yakubu www.kasa.co.care.org					√	√	√	√			√		√	
New Energy Ghana	Working in partnership with local communities and other stakeholders to improve access to social services, infrastructure and other development opportunities to the underserved in Ghana. Supports the development, testing and dissemination of a wide range of appropriate technologies for water and sanitation, energy services, and small-holder agriculture.	N	N	Thomas Imoro info@newenergygh.org							√		√				√	
SEND Foundation	Advocacy on development that provides men and women with equal opportunities to actively participate in and contribute to political, economic and social transformation of communities; promote community-driven development initiatives, economic literacy and policy	N	N	Country Director www.sendwestafrica.org			√											√

					CURRENT FOCUS AREAS													
Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
	advocacy; Forge strong partnerships with state and non-state actors characterized by mutual accountability, openness and effective communi cation. Provide an enabling environment for innovative development.																	
Kumasi Inst of Tech and Environment (KITE)	Conducting evidence-based and comparative research to generate relevant knowledge that informs and influences policy formulation and implementation for poverty reduction and economic growth; promote enterprise-centered approaches and models through technical support and financing as a sustainable option for the delivery of energy services.	N	N	Ishmael Edjekumhene www.kiteonline.net									√	√			√	
Coastal Resources Center	Mobilizes governments, business and communities around the world to work together as stewards of coastal ecosystems. With our partners we strive to define and achieve the health, equitable allocation of wealth, and sustainable intensities of human activity at the transition between the land and the sea	N	I	Mark Fenn www.crc.edu			√	√		√	√	√		√			√	
Catholic Relief Services	Support water and sanitation, agribusiness, and peace-building reach some of Ghana's most vulnerable communities, in addition to building a solid network of committed and experienced partners.	N	N	Kris Ozar www.crs.org			√				√							

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
Rain Forest Alliance	Conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices and consumer behaviour	N	I	Elvis Kudaar www.rainforest-alliance.org	√	√	√		√	√								
Centre for Environmental Impact Analysis	Undertake information dissemination and advisory services through an international, national and local environmental information network; Independently monitor and assess the levels of pollutants in the environment; Advocate for sound environmental practices in all aspects of Ghana's economy	N	N	Samuel Obiri http://www.ceiagh.com					√	√	√	√	√	√	√		√	
Zasilari Ecological Farms	Support Ghana's efforts at developing the agricultural base which is the backbone of local economy through the use of Organic Agriculture (for food security) and, promoting sound and sustainable use of natural resources in the districts of Northern Region.	N	N	David Agongo www.zefp.org			√		√	√								
Friends of the Nation	Serves as a catalyst for increased action for sustainable natural resource management and health environment; Service to wetland and forest dependent communities as well as poor urban communities through education, training, networking and advocacy	N	N	Donkris Mevuta				√	√	√	√	√		√				
WACAM	Network for the protection of the environment, natural resources and the rights of marginalized mining communities through advocacy, campaign and representation within a legal	N	N	Daniel Owusu-Koranteng www.wacamghana.com					√	√	√	√		√	√			√

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
	framework that is sensitive to the concerns of mining communities.																	
Working Group on Forest Certification (WGFC)	Guaranteeing the functioning of forest and chain of custody certification in Ghana through setting and promoting internationally acceptable standards, facilitation of certification processes and monitoring the implementation of the standards with recognized arbitration procedures for forest, industry and community sectors operators.	N	N	Ernest Abeney www.workinggroupgh.org					√	√								
Association of Jasikan Civil Society Organizations AJADSCO	Address the issues of illegal logging, bushfire menace. Strengthening CSOs on environmental issues in the Project area. Addressing specific NREG issues such as effective law enforcement under the forestry sub sector and strengthening functional partnerships and participation in environmental management under the environmental protection sub sector.	N	N	Kofi Asare Baffour					√	√								
Development Institute	Enable African communities confront their development challenges with passion and commitment towards social stability and care for nature. Policy research, dialogue, advocacy and capacity building for sustainable community development	N	N	Ken Kinney www.thedevin.org				√	√	√	√							

					CURRENT FOCUS AREAS													
Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
Forest Watch Ghana	Deepen the political economic analysis of grassroots groupings and to facilitate their networking towards the emergence of articulate social movements that could lead in the democratization and development of African societies and in international development struggles	N	N	Kingsley Bekoe www.forestwatchgh.org	√	√			√	√							√	
Friends of the Earth	Conservation and sustainable use of the world's natural resources to improve the economic and social well-being of present and future generations. Emphasizes on the need to integrate environmental sustainability with gender equity	N	N	Noble Wadzah www.foeghana.org	√				√	√	√							
ISODEC	works in solidarity with those striving for social justice towards a life of dignity by promoting rights and accountability; defending and promoting public goods (water, education and health) and basic human rights	N	N	Bishop Akologo www.isodec.org.gh					√	√					√		√	√
TWN-Africa	Research and Advocacy on issues of social and economic policy that advances the needs and interests of peoples of African and other third world countries (especially marginalized social groups), a fair distribution of world's resources, and forms of development which are sustainable and fulfill human needs	N	N	Yao Graham www.twnafrica.org					√	√					√		√	√

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
International Union for Conservation of Nature (IUCN)	International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges. IUCN supports governments, NGOs, international conventions, UN organizations, companies and communities to develop laws, policy and best-practice.	N	N	Samuel Nyame www.iucn.org	√	√	√		√	√							√	√
Friends of Rivers and Water Bodies	an advocacy group for Integrated Water Resource Management (IWRM) by using a combination of traditional and contemporary technologies to provide a sustainable solution to the depletion of this precious natural resource – WATER	N	N	waterfriendsgh.org														
Ghana Wildlife Society	he Society is a non-governmental, non-political, non-profit making environmental organization which seeks to conserve wildlife in all its forms to ensure a better environment and improved quality of life for all people.	N	N	www.ghanawildlifesociety.org					√	√								
Civil Society Platform on Oil and Gas	Is a forum for civil society to share knowledge about oil and gas exploration and governance, strengthen civil society voice and forge a common strategy for engaging with other stakeholders such as the Government of Ghana, Petroleum Companies and frontline oil communities.	N	N	Mohammed Amin Tabat15@yahoo.co										√				√

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
Climate Focus	Independent expert in international and national climate law, policies, project design and finance; pioneering carbon markets since their inception; services range from the development of policies to protect the rainforest to structuring greenhouse gas mitigation projects in energy sector.	N	N	Charlotte Streck www.climatefocus.com	√	√			√	√								
Tropenbos International	A platform supporting the forest and development agenda in developing countries for improving knowledge, personal capacity and institutional capacity for better governance and management of tropical forest resources. We operate partnership programs between research institutions in the North and the South to build capacity that meets the needs of forest stakeholders.	N	N	Samuel Nketsia www.tropenbos.org	√	√			√	√								
Conservation Alliance	Assisting fringe communities in Africa in creating economic opportunities that result in improved wildlife and habitat management, and wealthier healthier communities.	N	N	Yaw Osei-Owusu www.conservealliance.org	√	√			√	√	√							
Conservation International	Empowerment of societies to responsibly and sustainably care for nature, global biodiversity, for the well-being of humanity.	N	N	Nicholas Jengre http://www.conservation.org/Pages/default.aspx	√	√			√	√								
Katoomba Group	An international network of individuals working to promote, and improve capacity related to, markets and payments for ecosystem services (PES); a	N	N	Rebecca Ashley Asare www.katoombagroup.org	√	√			√	√								

Organization Name	Institutional objective/ mission	Type	Relationship to USAID	Contact	CURRENT FOCUS AREAS													
					REDD	CDM	Agriculture	Fisheries	Forestry	Biodiversity	Water	Coastal	Bio-energy	Oil & Gas	Mining	Land Tenure	Research	Gov/ Health
	forum for the exchange of ideas and strategic information about ecosystem service transactions and markets, as well as site for collaboration between practitioners on PES projects and programs.																	
Development Partners																		
SNV Netherlands Development Organisation	The development goal of SNV Ghana is to contribute to the national development agenda as espoused in the Millenium Developement Goals (MDGs).	D	D	Southern Portfolio Team ghana@snvworld.org			√		√				√		√		√	√
Canadian International Development Agency	CIDA's mission is to lead Canada's international effort to help people living in poverty.	D	D	Romeo Adomah-Darteh www.psu-ghana.org			√		√	√	√						√	√
UK Department for International Development	- Ensuring that the government of Ghana's resources are well managed for the benefit of all citizens - Encouraging enterprise and wealth creation - Ensuring quality education services - Reducing maternal mortality and child death	D	D	Sean Doolan www.dfid.gov.uk	√	√											√	
Norwegian Agency for Development Cooperation	The Norwegian Agency for Development Cooperation (Norad) is a directorate under the Norwegian Ministry of Foreign Affairs	D	D	Arne Olsen www.emb-norway.com.ng										√			√	
Netherlands Embassy	Represent the Government of the Netherlands in developing and maintaining productive relations with the GoG and its people	D	D	Ton van der Zon http://ghana.nlembassy.org		√			√	√	√			√				√

					CURRENT FOCUS AREAS													
Organization Name	**Institutional objective/ mission**	**Type**	**Relationship to USAID**	**Contact**	**REDD**	**CDM**	**Agriculture**	**Fisheries**	**Forestry**	**Biodiversity**	**Water**	**Coastal**	**Bio-energy**	**Oil & Gas**	**Mining**	**Land Tenure**	**Research**	**Gov/ Health**
United Nations Development Program, UNDP	The UN's global development network, an organization advocating for change and connecting countries to knowledge, experience and resources to help people build a better life	D	D	Stephen Yentumi www.undp-gha.org		√												√
WaterAid	WaterAid has been working in Ghana since 1985 helping the most vulnerable in society gain access to safe water supplies, sanitation and hygiene education	D	D	Abdul-Nashiru Mohammed www.wateraid.org							√							√
Oxfam America	Oxfam America is an international relief and development organization that creates lasting solutions to poverty, hunger, and injustice	D	D	Wendy Sherman www.oxfamamerica.org	√		√		√	√	√			√	√		√	
GTZ/GIZ	GTZ (now GIZ) implements programmes and projects there on behalf of the German Federal Ministry for Economic Cooperation and Development	D	D	Fred Brandl www.gtz.de			√				√							
DED is now also GIZ	The DED Ghana promotes complex reforms and change processes. Its corporate objective is to improve people's living conditions on a sustainable basis and to transfer knowledge to our partner countries. It provides viable, forward-looking solutions for political, economic, ecological and social development	D	D	Kay Andraschka www.ghana.ded.de			√				√							
World Bank	The World Bank is a source of financial and technical assistance to developing countries around the world	D	D	Flavio Chaves www.worldbank.org	√	√			√					√	√			√

APPENDIX 5. SCENARIOS OF TEMPERATURE CHANGES (MID-RANGE VALUES) FOR THE VARIOUS ECO-CLIMATIC ZONES IN GHANA

a. SUDAN SAVANNA

	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
Month	**T-Max.**	**T-Min.**	**T-Mean**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	35.2	19.5	27.3	0.6	2.5	4.0	27.9	29.8	31.3
Feb	37.6	22.0	29.8	0.7	2.1	4.1	30.5	31.9	33.9
Mar	38.9	25.0	32.0	0.7	2.1	4.2	32.7	34.1	36.2
Apr	38.2	26.1	32.1	0.8	2.6	5.0	32.9	34.7	37.1
May	36.0	25.1	30.5	0.8	2.2	5.2	31.3	32.7	35.7
Jun	33.0	23.3	28.2	0.6	1.9	4.0	28.8	30.1	32.2
Jul	31.2	22.6	26.9	0.5	1.8	3.4	27.4	28.7	30.3
Aug	30.4	22.3	26.3	0.5	1.7	3.4	26.8	28.0	29.7
Sep	31.2	22.1	26.6	0.5	1.6	3.6	27.1	28.2	30.2
Oct	34.2	22.2	28.2	0.5	1.6	3.3	28.7	29.8	31.5
Nov	36.2	20.1	28.1	0.6	2.0	4.2	28.7	30.1	32.3
Dec	35.1	19.0	27.0	0.6	2.0	4.0	27.6	29.0	31.0
Ann.	34.8	22.4	28.6	0.6	2.0	4.0	29.2	30.6	32.6

b. GUINEA SAVANNA

	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
Month	**T-Max.**	**T-Min.**	**T-Mean**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	35.0	18.9	26.9	0.6	2.0	4.1	27.5	28.9	31.0
Feb	36.9	22.0	29.4	0.7	2.2	4.2	30.1	31.6	33.6
Mar	37.0	24.1	30.6	0.7	2.1	4.2	31.3	32.7	34.8
Apr	35.3	24.4	29.9	0.6	2.3	4.5	30.5	32.2	34.4
May	33.5	23.5	28.5	0.6	2.2	4.4	29.1	30.7	32.9
Jun	31.1	22.3	26.7	0.5	1.9	3.8	27.2	28.6	30.5
Jul	29.7	21.8	25.7	0.5	1.7	3.5	26.2	27.4	29.2
Aug	29.4	21.7	25.5	0.5	1.8	3.4	26.0	27.3	28.9
Sep	30.2	21.5	25.8	0.5	1.6	3.2	26.3	27.4	29.0
Oct	32.5	21.7	27.1	0.5	1.6	3.4	27.6	28.7	30.5
Nov	34.5	20.2	27.3	0.6	2.0	3.9	27.9	29.3	31.2
Dec	34.4	18.4	26.4	0.6	2.0	4.0	27.0	28.4	30.4
Ann.	33.3	21.7	27.5	0.6	2.0	3.9	28.1	29.4	31.4

c. TRANSITIONAL ZONE

Month	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	33.4	20.4	26.9	0.6	2.0	4.1	27.5	28.9	31.0
Feb	35.2	22.8	29.0	0.7	2.2	4.2	29.7	31.2	33.2
Mar	34.9	23.8	29.3	0.7	2.1	4.2	30.0	31.4	33.5
Apr	33.5	23.8	28.6	0.6	2.3	4.5	29.2	30.9	33.1
May	32.2	23.2	27.7	0.6	2.2	4.4	28.3	29.9	32.1
Jun	30.3	22.4	26.3	0.5	1.9	3.8	26.8	28.2	30.1
Jul	28.8	21.9	25.4	0.5	1.7	3.5	25.9	27.1	28.9
Aug	28.8	21.8	25.3	0.5	1.8	3.4	25.8	27.1	28.7
Sep	29.5	21.8	25.7	0.5	1.6	3.2	26.2	27.3	28.9
Oct	30.6	21.9	26.3	0.5	1.6	3.4	26.8	27.9	29.7
Nov	32.0	21.8	26.9	0.6	2.0	3.9	27.5	28.9	30.8
Dec	32.0	20.4	26.2	0.6	2.0	4.0	26.8	28.2	30.2
Ann.	31.8	22.2	27.0	0.6	2.0	3.9	27.5	28.9	30.8

d. DECIDUOUS FOREST ZONE

Month	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	32.2	20.7	26.5	0.6	2.0	4.1	27.1	28.5	30.6
Feb	33.6	22.3	27.9	0.7	2.2	4.2	28.6	30.1	32.1
Mar	33.1	22.7	27.9	0.7	2.1	4.2	28.6	30.0	32.1
Apr	32.4	22.8	27.6	0.6	2.3	4.5	28.2	29.9	32.1
May	31.5	22.4	27.0	0.6	2.2	4.4	27.6	29.2	31.4
Jun	29.7	21.9	25.8	0.5	1.9	3.8	26.3	27.7	29.6
Jul	28.4	21.5	24.9	0.5	1.7	3.5	25.4	26.6	28.4
Aug	28.2	21.3	24.8	0.5	1.8	3.4	25.3	26.6	28.2
Sep	29.1	21.5	25.3	0.5	1.6	3.2	25.8	26.9	28.5
Oct	30.3	21.6	26.0	0.5	1.6	3.4	26.5	27.6	29.4
Nov	31.3	21.8	26.6	0.6	2.0	3.9	27.2	28.6	30.5
Dec	31.0	21.2	26.1	0.6	2.0	4.0	26.7	28.1	30.1
Ann.	30.9	21.8	26.4	0.6	2.0	3.9	26.9	28.3	30.2

e. RAIN FOREST ZONE

Month	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	30.0	23.4	26.7	0.6	2.0	4.1	27.3	28.7	30.8
Feb	30.6	24.4	27.5	0.7	2.2	4.2	28.2	29.7	31.7
Mar	30.9	24.3	27.6	0.7	2.1	4.2	28.3	29.7	31.8
Apr	30.9	24.2	27.6	0.6	2.3	4.5	28.2	29.9	32.1
May	30.0	23.6	26.8	0.6	2.2	4.4	27.4	29.0	31.2
Jun	28.4	23.3	25.8	0.5	1.9	3.8	26.3	27.7	29.6
Jul	27.4	23.2	25.3	0.5	1.7	3.5	25.8	27.0	28.8
Aug	26.9	22.8	24.8	0.5	1.8	3.4	25.3	26.6	28.2
Sep	27.4	22.9	25.1	0.5	1.6	3.2	25.6	26.7	28.3
Oct	28.5	23.4	25.9	0.5	1.6	3.4	26.4	27.5	29.3
Nov	29.9	23.1	26.5	0.6	2.0	3.9	27.1	28.5	30.4
Dec	30.0	23.2	26.6	0.6	2.0	4.0	27.2	28.6	30.6
Ann.	29.3	23.5	26.4	0.6	2.0	3.9	26.9	28.3	30.2

f. COASTAL SAVANNAH ZONE

Month	Baseline Mean Temp.			Mean Temp. Change			Climate Scenarios		
	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	31.2	23.7	27.5	0.6	2.0	4.1	28.1	29.5	31.6
Feb	31.9	24.7	28.3	0.7	2.2	4.2	29.0	30.5	32.5
Mar	31.9	24.8	28.3	0.7	2.1	4.2	29.0	30.4	32.5
Apr	31.7	24.8	28.3	0.6	2.3	4.5	28.9	30.6	32.8
May	31.0	24.4	27.7	0.6	2.2	4.4	28.3	29.9	32.1
Jun	29.2	23.7	26.4	0.5	1.9	3.8	26.9	28.3	30.2
Jul	27.6	22.9	25.3	0.5	1.7	3.5	25.8	27.0	28.8
Aug	27.5	22.4	24.9	0.5	1.8	3.4	25.4	26.7	28.3
Sep	28.3	22.8	25.6	0.5	1.6	3.2	26.1	27.2	28.8
Oct	29.7	23.2	26.4	0.5	1.6	3.4	26.9	28.0	29.8
Nov	31.2	24.0	27.6	0.6	2.0	3.9	28.2	29.6	31.5
Dec	30.9	23.5	27.2	0.6	2.0	4.0	27.8	29.2	31.2
Ann.	30.2	23.7	26.9	0.6	2.0	3.9	27.5	28.9	30.8

APPENDIX 6. SCENARIOS OF CHANGES IN PRECIPITATION AMOUNT (MID-RANGE VALUES) FOR THE VARIOUS ECO-CLIMATIC ZONES IN GHANA

a. SUDAN SAVANNA

	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	1.0	1	1.4	-4.8	-12.8	-31.0	1.0	0.9	0.7	1.0	0.9	0.7
Feb	3.7	1	4.6	-9.0	-29.7	-58.4	3.3	2.6	1.5	3.3	2.6	1.5
Mar	18.3	2	10.0	-7.3	-23.8	-47.2	17.0	14.0	9.7	8.5	7.0	4.8
Apr	57.4	5	12.2	-7.2	-23.8	-36.8	53.3	43.8	36.3	10.7	8.8	7.3
May	95.7	8	12.5	-4.6	-14.8	-18.0	91.3	81.5	78.5	11.4	10.2	9.8
Jun	125.2	10	12.5	-1.6	-12.8	-17.4	123.2	109.2	103.4	12.3	10.9	10.3
Jul	193.9	14	14.2	0.2	-4.6	-4.9	194.3	185.0	184.4	13.9	13.2	13.2
Aug	266.7	18	15.0	0.6	-0.5	-8.4	268.3	265.3	244.3	14.9	14.7	13.6
Sep	173.4	14	12.4	-0.6	-3.8	-10.8	172.4	166.8	154.7	12.3	11.9	11.0
Oct	48.4	7	7.2	0.0	-0.1	-9.9	48.4	48.3	43.6	6.9	6.9	6.2
Nov	4.8	1	7.2	-1.4	-4.8	-12.7	4.7	4.6	4.2	4.7	4.6	4.2
Dec	3.4	1	4.4	-0.6	-1.6	-3.6	3.4	3.3	3.3	3.4	3.3	3.3
Ann.	992.0	82	12.1	-1.1	-6.7	-12.8	980.6	925.3	864.5	12.0	11.3	10.5

b. GUINEA SAVANNA

	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	2.0	1	2.0	-3.9	-12.8	-25.3	1.9	1.7	1.5	1.9	1.7	1.5
Feb	7.8	1	7.8	-9.1	-29.7	-58.9	7.1	5.5	3.2	7.1	5.5	3.2
Mar	51.3	5	10.3	-6.0	-19.9	-39.4	48.2	41.1	31.1	9.6	8.2	6.2
Apr	81.9	8	10.2	-4.4	-14.5	-28.7	78.3	70.0	58.4	9.8	8.8	7.3
May	124.8	11	11.3	-4.4	-25.8	-28.4	119.3	92.6	89.3	10.8	8.4	8.1
Jun	152.1	12	12.7	-3.8	-12.6	-24.8	146.4	133.0	114.4	12.2	11.1	9.5
Jul	174.5	14	12.5	-0.8	-2.8	-5.4	173.1	169.6	165.1	12.4	12.1	11.8

Aug	191.5	16	12.0	-0.1	-0.5	-1.0	191.3	190.5	189.6	12.0	11.9	11.8
Sep	219.3	18	12.2	-0.5	-1.8	-3.5	218.2	215.3	211.6	12.1	12.0	11.8
Oct	90.7	10	9.1	0.0	-0.3	-0.7	90.7	90.4	90.0	9.1	9.0	9.0
Nov	12.2	2	6.1	-1.4	-4.8	-9.4	12.0	11.6	11.1	6.0	5.8	5.5
Dec	7.2	1	7.2	0.5	-1.6	-3.6	7.2	7.0	6.9	7.2	7.0	6.9
Ann.	1115.3	99	11.3	-1.9	-7.8	-12.8	1093.7	1028.5	972.2	11.0	10.4	9.8

c. TRANSITIONAL ZONE

	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	5.7	1	5.7	-3.9	-12.8	-25.3	5.5	5.0	4.3	5.5	5.0	4.3
Feb	19.0	2	9.5	-9.1	-29.7	-58.9	17.3	13.4	7.8	8.6	6.7	3.9
Mar	76.6	5	15.3	-6.0	-19.9	-39.4	72.0	61.4	46.4	14.4	12.3	9.3
Apr	117.2	7	16.7	-4.4	-14.5	-28.7	112.0	100.2	83.5	16.0	14.3	11.9
May	156.1	10	15.7	-4.4	-25.8	-28.4	149.2	115.8	111.8	14.9	11.6	11.2
Jun	185.9	15	12.4	-3.8	-12.6	-24.8	178.8	162.5	139.8	11.9	10.8	9.3
Jul	168.2	16	10.5	-0.8	-2.8	-5.4	166.9	163.5	159.2	10.4	10.2	9.9
Aug	151.5	15	10.1	-0.1	-0.5	-1.0	151.4	150.8	150.0	10.1	10.1	10.0
Sep	211.8	13	16.3	-0.5	-1.8	-3.5	210.8	208.0	204.4	16.2	16.0	15.7
Oct	163.3	12	13.6	0.0	-0.3	-0.7	163.3	162.8	162.1	13.6	13.6	13.5
Nov	33.8	3	11.4	-1.4	-4.8	-9.4	33.3	32.2	30.6	11.1	10.7	10.2
Dec	12.1	2	6.1	0.5	-1.6	-3.6	12.2	12.0	11.7	6.1	6.0	5.9
Ann.	1301.3	101	12.9	-2.2	-8.8	-14.6	1272.7	1187.4	1111.7	12.6	11.8	11.0

d.. DECIDUOUS FOREST ZONE

	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	17.1	2	10.1	-3.9	-12.8	-25.3	16.4	14.9	12.7	8.2	7.4	6.4
Feb	54.8	5	11.5	-9.1	-29.7	-58.9	49.8	38.5	22.5	10.0	7.7	4.5
Mar	114.9	9	12.8	-6.0	-19.9	-39.4	108.0	92.0	69.6	12.0	10.2	7.7
Apr	134.4	11	12.5	-4.4	-14.5	-28.7	128.5	114.9	95.9	11.7	10.4	8.7

May	169.4	13	13.2	-4.4	-25.8	-28.4	161.9	125.7	121.3	12.5	9.7	9.3
Jun	215.2	16	13.5	-3.8	-12.6	-24.8	207.0	188.1	161.8	12.9	11.8	10.1
Jul	121.9	13	9.5	-0.8	-2.8	-5.4	120.9	118.5	115.3	9.3	9.1	8.9
Aug	80.9	11	7.4	-0.1	-0.5	-1.0	80.9	80.5	80.1	7.4	7.3	7.3
Sep	142.0	14	10.2	-0.5	-1.8	-3.5	141.3	139.5	137.1	10.1	10.0	9.8
Oct	153.8	15	10.4	0.0	-0.3	-0.7	153.8	153.4	152.8	10.3	10.2	10.2
Nov	67.0	8	8.6	-1.4	-4.8	-9.4	66.0	63.7	60.7	8.3	8.0	7.6
Dec	31.9	3	11.1	0.5	-1.6	-3.6	32.1	31.4	30.8	10.7	10.5	10.3
Ann.	1303.4	120	10.9	-2.8	-10.9	-18.6	1266.8	1161.2	1060.6	10.6	9.7	8.8
e. RAIN FOREST ZONE												
	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	34.0	4	9.3	-3.9	-12.8	-25.3	32.6	29.6	25.4	8.2	7.4	6.3
Feb	66.2	5	13.1	-9.1	-29.7	-58.9	60.1	46.5	27.2	12.0	9.3	5.4
Mar	130.1	9	14.8	-6.0	-19.9	-39.4	122.3	104.2	78.8	13.6	11.6	8.8
Apr	175.3	12	15.1	-4.4	-14.5	-28.7	167.6	149.9	125.0	14.0	12.5	10.4
May	345.1	23	15.0	-4.4	-25.8	-28.4	330.0	256.1	247.1	14.3	11.1	10.7
Jun	579.7	22	26.4	-3.8	-12.6	-24.8	557.7	506.6	435.9	25.3	23.0	19.8
Jul	211.7	1.5	14.4	-0.8	-2.8	-5.4	210.0	205.7	200.2	140.0	137.2	133.5
Aug	79.7	13	6.3	-0.1	-0.5	-1.0	79.6	79.3	78.9	6.1	6.1	6.1
Sep	95.3	15	6.5	-0.5	-1.8	-3.5	94.9	93.6	92.0	6.3	6.2	6.1
Oct	168.7	17	10.1	0.0	-0.3	-0.7	168.7	168.2	167.5	9.9	9.9	9.9
Nov	136.8	14	10.0	-1.4	-4.8	-9.4	134.9	130.2	123.9	9.6	9.3	8.9
Dec	70.1	8	9.1	0.5	-1.6	-3.6	70.4	69.0	67.6	8.8	8.6	8.4
Ann.	2092.7	143.5	14.6	-3.1	-12.1	-20.2	2028.8	1839.0	1669.6	14.1	12.8	11.6
f. COASTAL SAVANNA												
	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	10.8	2	6.3	-3.9	-12.8	-25.3	10.4	9.4	8.1	5.2	4.7	4.0

Feb	25.6	3	9.4	-9.1	-29.7	-58.9	23.3	18.0	10.5	7.8	6.0	3.5
Mar	63.2	5	13.7	-6.0	-19.9	-39.4	59.4	50.6	38.3	11.9	10.1	7.7
Apr	103.1	8	13.3	-4.4	-14.5	-28.7	98.5	88.1	73.5	12.3	11.0	9.2
May	151.2	12	13.0	-4.4	-25.8	-28.4	144.5	112.2	108.3	12.0	9.3	9.0
Jun	226.2	17	13.5	-3.8	-12.6	-24.8	217.6	197.7	170.1	12.8	11.6	10.0
Jul	73.0	8	9.3	-0.8	-2.8	-5.4	72.4	70.9	69.0	9.0	8.9	8.6
Aug	32.6	7	4.9	-0.1	-0.5	-1.0	32.6	32.4	32.3	4.7	4.6	4.6
Sep	64.4	8	8.4	-0.5	-1.8	-3.5	64.1	63.2	62.1	8.0	7.9	7.8
Oct	81.5	8	10.6	0.0	-0.3	-0.7	81.5	81.3	80.9	10.2	10.2	10.1
Nov	39.0	5	8.3	-1.4	-4.8	-9.4	38.4	37.1	35.3	7.7	7.4	7.1
Dec	19.7	2	9.8	0.5	-1.6	-3.6	19.8	19.3	19.0	9.9	9.7	9.5
Ann.	890.2	85	10.5	-3.1	-12.3	-20.5	862.5	780.4	707.4	10.1	9.2	8.3

APPENDIX 7. SCENARIOS OF TEMPERATURE CHANGES (UPPER BOUND VALUES) FOR THE VARIOUS ECO-CLIMATIC ZONES OF THE COUNTRY

a. SUDAN SAVANNAH

	Baseline Mean Temp.			Mean Temp. Change			Mean Temp. Scenarios		
Month	**T-Max.**	**T-Min.**	**T-Mean**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	35.2	19.5	27.3	0.8	2.6	5.4	**28.1**	**29.9**	**32.7**
Feb	37.6	22.0	29.8	0.8	2.9	5.7	**30.6**	**32.7**	**35.5**
Mar	38.9	25.0	32.0	0.9	3.0	5.9	**32.9**	**35.0**	**37.9**
Apr	38.2	26.1	32.1	1.0	3.7	7.8	**33.1**	**35.8**	**39.9**
May	36.0	25.1	30.5	1.0	2.9	7.2	**31.5**	**33.4**	**37.7**
Jun	33.0	23.3	28.2	0.8	2.2	5.6	**29.0**	**30.4**	**33.8**
Jul	31.2	22.6	26.9	0.7	2.1	4.8	**27.6**	**29.0**	**31.7**
Aug	30.4	22.3	26.3	0.7	2.1	4.7	**27.0**	**28.4**	**31.0**
Sep	31.2	22.1	26.6	0.7	2.2	5.0	**27.3**	**28.8**	**31.6**
Oct	34.2	22.2	28.2	0.8	2.2	5.6	**29.0**	**30.4**	**33.8**
Nov	36.2	20.1	28.1	0.9	2.6	5.8	**29.0**	**30.7**	**33.9**
Dec	35.1	19.0	27.0	0.8	2.5	5.6	**27.8**	**29.5**	**32.6**
Ann.	34.8	22.4	28.6	0.8	2.6	5.8	**29.4**	**31.2**	**34.4**

b. GUINEA SAVANNAH

	Baseline Mean Temp.			Mean Temp. Change			Mean Temp. Scenarios		
Month	**T-Max.**	**T-Min.**	**T-Mean**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	35.0	18.9	26.9	0.8	2.5	5.6	**27.7**	**29.4**	**32.5**
Feb	36.9	22.0	29.4	0.9	2.9	5.9	**30.3**	**32.3**	**35.3**
Mar	37.0	24.1	30.6	0.9	2.8	5.9	**31.5**	**33.4**	**36.5**
Apr	35.3	24.4	29.9	1.0	3.1	6.4	**30.9**	**33.0**	**36.3**
May	33.5	23.5	28.5	1.0	2.9	6.0	**29.5**	**31.4**	**34.5**
Jun	31.1	22.3	26.7	0.8	2.4	5.1	**27.5**	**29.1**	**31.8**
Jul	29.7	21.8	25.7	0.7	2.2	4.8	**26.4**	**27.9**	**30.5**
Aug	29.4	21.7	25.5	0.7	2.1	4.7	**26.2**	**27.6**	**30.2**
Sep	30.2	21.5	25.8	0.7	2.0	4.4	**26.5**	**27.8**	**30.2**
Oct	32.5	21.7	27.1	0.7	1.9	4.6	**27.8**	**29.0**	**31.7**
Nov	34.5	20.2	27.3	0.8	2.4	5.5	**28.1**	**29.7**	**32.8**
Dec	34.4	18.4	26.4	0.9	2.4	5.6	**27.3**	**28.8**	**32.0**
Ann.	33.3	21.7	27.5	0.8	2.5	5.4	**28.3**	**30.0**	**32.9**

c. TRANSITIONAL ZONE									
	Baseline Mean Temp.			Mean Temp. Change			Mean Temp. Scenarios		
Month	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	33.4	20.4	26.9	0.8	2.5	5.6	**27.7**	**29.4**	**32.5**
Feb	35.2	22.8	29.0	0.9	2.9	5.9	**29.9**	**31.9**	**34.9**
Mar	34.9	23.8	29.3	0.9	2.8	5.9	**30.2**	**32.1**	**35.2**
Apr	33.5	23.8	28.6	1.0	3.1	6.4	**29.6**	**31.7**	**35.0**
May	32.2	23.2	27.7	1.0	2.9	6.0	**28.7**	**30.6**	**33.7**
Jun	30.3	22.4	26.3	0.8	2.4	5.1	**27.1**	**28.7**	**31.4**
Jul	28.8	21.9	25.4	0.7	2.2	4.8	**26.1**	**27.6**	**30.2**
Aug	28.8	21.8	25.3	0.7	2.1	4.7	**26.0**	**27.4**	**30.0**
Sep	29.5	21.8	25.7	0.7	2.0	4.4	**26.4**	**27.7**	**30.1**
Oct	30.6	21.9	26.3	0.7	1.9	4.6	**27.0**	**28.2**	**30.9**
Nov	32.0	21.8	26.9	0.8	2.4	5.5	**27.7**	**29.3**	**32.4**
Dec	32.0	20.4	26.2	0.9	2.4	5.6	**27.1**	**28.6**	**31.8**
Ann.	31.8	22.2	27.0	0.8	2.5	5.4	**27.8**	**29.4**	**32.3**

d. DECIDUOUS FOREST ZONE									
	Baseline Mean Temp.			Mean Temp. Change			Mean Temp. Scenarios		
Month	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	32.2	20.7	26.5	0.8	2.5	5.6	**27.3**	**29.0**	**32.1**
Feb	33.6	22.3	27.9	0.9	2.9	5.9	**28.8**	**30.8**	**33.8**
Mar	33.1	22.7	27.9	0.9	2.8	5.9	**28.8**	**30.7**	**33.8**
Apr	32.4	22.8	27.6	1.0	3.1	6.4	**28.6**	**30.7**	**34.0**
May	31.5	22.4	27.0	1.0	2.9	6.0	**28.0**	**29.9**	**33.0**
Jun	29.7	21.9	25.8	0.8	2.4	5.1	**26.6**	**28.2**	**30.9**
Jul	28.4	21.5	24.9	0.7	2.2	4.8	**25.6**	**27.1**	**29.7**
Aug	28.2	21.3	24.8	0.7	2.1	4.7	**25.5**	**26.9**	**29.5**
Sep	29.1	21.5	25.3	0.7	2.0	4.4	**26.0**	**27.3**	**29.7**
Oct	30.3	21.6	26.0	0.7	1.9	4.6	**26.7**	**27.9**	**30.6**
Nov	31.3	21.8	26.6	0.8	2.4	5.5	**27.4**	**29.0**	**32.1**
Dec	31.0	21.2	26.1	0.9	2.4	5.6	**27.0**	**28.5**	**31.7**
Ann.	30.9	21.8	26.4	0.8	2.5	5.4	**27.2**	**28.8**	**31.7**

e. RAIN FOREST ZONE									
	Baseline Mean Temp.			Mean Temp. Change			Mean Temp. Scenarios		
Month	T-Max.	T-Min.	T-Mean	2020	2050	2080	2020	2050	2080
Jan	30.0	23.4	26.7	0.8	2.5	5.6	**27.5**	**29.2**	**32.3**
Feb	30.6	24.4	27.5	0.9	2.9	5.9	**28.4**	**30.4**	**33.4**
Mar	30.9	24.3	27.6	0.9	2.8	5.9	**28.5**	**30.4**	**33.5**

Apr	30.9	24.2	27.6	1.0	3.1	6.4	**28.6**	**30.7**	**34.0**
May	30.0	23.6	26.8	1.0	2.9	6.0	**27.8**	**29.7**	**32.8**
Jun	28.4	23.3	25.8	0.8	2.4	5.1	**26.6**	**28.2**	**30.9**
Jul	27.4	23.2	25.3	0.7	2.2	4.8	**26.0**	**27.5**	**30.1**
Aug	26.9	22.8	24.8	0.7	2.1	4.7	**25.5**	**26.9**	**29.5**
Sep	27.4	22.9	25.1	0.7	2.0	4.4	**25.8**	**27.1**	**29.5**
Oct	28.5	23.4	25.9	0.7	1.9	4.6	**26.6**	**27.8**	**30.5**
Nov	29.9	23.1	26.5	0.8	2.4	5.5	**27.3**	**28.9**	**32.0**
Dec	30.0	23.2	26.6	0.9	2.4	5.6	**27.5**	**29.0**	**32.2**
Ann.	29.3	23.5	26.4	0.8	2.5	5.4	**27.2**	**28.8**	**31.7**

f. COASTAL SAVANNAH ZONE									
	Baseline Mean Temp.			**Mean Temp. Change**			**Mean Temp. Scenarios**		
Month	**T-Max.**	**T-Min.**	**T-Mean**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	31.2	23.7	27.5	0.8	2.5	5.6	**28.3**	**30.0**	**33.1**
Feb	31.9	24.7	28.3	0.9	2.9	5.9	**29.2**	**31.2**	**34.2**
Mar	31.9	24.8	28.3	0.9	2.8	5.9	**29.2**	**31.1**	**34.2**
Apr	31.7	24.8	28.3	1.0	3.1	6.4	**29.3**	**31.4**	**34.7**
May	31.0	24.4	27.7	1.0	2.9	6.0	**28.7**	**30.6**	**33.7**
Jun	29.2	23.7	26.4	0.8	2.4	5.1	**27.2**	**28.8**	**31.5**
Jul	27.6	22.9	25.3	0.7	2.2	4.8	**26.0**	**27.5**	**30.1**
Aug	27.5	22.4	24.9	0.7	2.1	4.7	**25.6**	**27.0**	**29.6**
Sep	28.3	22.8	25.6	0.7	2.0	4.4	**26.3**	**27.6**	**30.0**
Oct	29.7	23.2	26.4	0.7	1.9	4.6	**27.1**	**28.3**	**31.0**
Nov	31.2	24.0	27.6	0.8	2.4	5.5	**28.4**	**30.0**	**33.1**
Dec	30.9	23.5	27.2	0.9	2.4	5.6	**28.1**	**29.6**	**32.8**
Ann.	30.2	23.7	26.9	0.8	2.5	5.4	**27.8**	**29.4**	**32.3**

APPENDIX 8. SCENARIOS OF CHANGES IN PRECIPITATION AMOUNTS (UPPER BOUND VALUES) FOR THE VARIOUS ECO-CLIMATIC ZONE IN GHANA

a. SUDAN SAVANNAH												
	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	1.0	1	1.4	-13.8	-45.2	-60.5	0.9	0.6	0.4	0.9	0.6	0.4
Feb	3.7	1	4.6	-11.5	-37.6	-47.0	3.2	2.3	1.9	3.2	2.3	1.9
Mar	18.3	2	10.0	-10.0	-32.5	-65.9	16.5	12.4	6.3	8.3	6.2	3.1
Apr	57.4	5	12.2	-9.9	-32.6	-65.7	51.7	38.7	19.7	10.3	7.7	3.9
May	95.7	8	12.5	-4.9	-16.0	-25.1	91.0	80.4	71.7	11.4	10.0	9.0
Jun	125.2	10	12.5	-2.2	-14.1	-20.7	122.5	107.6	99.3	12.2	10.8	9.9
Jul	193.9	14	14.2	2.5	-6.2	-7.6	198.8	181.9	179.2	14.2	13.0	12.8
Aug	266.7	18	15.0	1.8	-1.4	-11.6	271.5	262.9	235.7	15.1	14.6	13.1
Sep	173.4	14	12.4	-0.8	-4.8	-22.2	172.0	165.1	134.9	12.3	11.8	9.6
Oct	48.4	7	7.2	0.0	-0.2	-13.8	48.4	48.3	41.7	6.9	6.9	6.0
Nov	4.8	1	7.2	-3.8	-6.0	-45.6	4.6	4.5	2.6	4.6	4.5	2.6
Dec	3.4	1	4.4	-10.4	-2.5	-5.0	3.0	3.3	3.2	3.0	3.3	3.2
Ann.	992.0	82	12.1	-5.3	-16.6	-32.6	939.9	827.4	669.0	11.5	10.1	8.2
b. GUINEA SAVANNAH												
	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	2.0	1	2.0	-5.3	-17.4	-35.2	1.9	1.7	1.3	1.9	1.7	1.3
Feb	7.8	1	7.8	-12.4	-40.5	-82.2	6.9	4.7	1.4	6.9	4.7	1.4
Mar	51.3	5	10.3	-8.3	-27.2	-55.0	47.0	37.3	23.1	9.4	7.5	4.6

Apr	81.9	8	10.2	-6.0	-19.8	-40.0	77.0	65.7	49.2	9.6	8.2	6.1
May	124.8	11	11.3	-6.0	-25.8	-39.6	117.3	92.6	75.4	10.7	8.4	6.9
Jun	152.1	12	12.7	-5.2	-17.0	-34.6	144.2	126.3	99.5	12.0	10.5	8.3
Jul	174.5	14	12.5	-1.2	-3.8	-7.6	172.4	167.9	161.2	12.3	12.0	11.5
Aug	191.5	16	12.0	-0.2	-0.6	-2.8	191.1	190.3	186.1	11.9	11.9	11.6
Sep	219.3	18	12.2	-0.8	-2.4	-4.8	217.5	214.0	208.8	12.1	11.9	11.6
Oct	90.7	10	9.1	0.0	-0.5	-1.0	90.7	90.2	89.7	9.1	9.0	9.0
Nov	12.2	2	6.1	-2.0	-6.5	-13.2	12.0	11.4	10.6	6.0	5.7	5.3
Dec	7.2	1	7.2	0.8	-2.3	-5.0	7.2	7.0	6.8	7.2	7.0	6.8
Ann.	1115.3	99	11.3	-3.9	-13.7	-26.8	1072.0	963.0	816.9	10.8	9.7	8.3

c. TRANSITIONAL ZONE												
	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	5.7	1	5.7	-5.3	-17.4	-35.2	5.4	4.7	3.7	5.4	4.7	3.7
Feb	19.0	2	9.5	-12.4	-40.5	-82.2	16.6	11.3	3.4	8.3	5.7	1.7
Mar	76.6	5	15.3	-8.3	-27.2	-55.0	70.3	55.8	34.5	14.1	11.2	6.9
Apr	117.2	7	16.7	-6.0	-19.8	-40.0	110.1	94.0	70.3	15.7	13.4	10.0
May	156.1	10	15.7	-6.0	-25.8	-39.6	146.7	115.8	94.3	14.7	11.6	9.4
Jun	185.9	15	12.4	-5.2	-17.0	-34.6	176.2	154.3	121.6	11.7	10.3	8.1
Jul	168.2	16	10.5	-1.2	-3.8	-7.6	166.2	161.8	155.5	10.4	10.1	9.7
Aug	151.5	15	10.1	-0.2	-0.6	-2.8	151.2	150.6	147.3	10.1	10.0	9.8
Sep	211.8	13	16.3	-0.8	-2.4	-4.8	210.1	206.7	201.7	16.2	15.9	15.5
Oct	163.3	12	13.6	0.0	-0.5	-1.0	163.3	162.5	161.6	13.6	13.5	13.5
Nov	33.8	3	11.4	-2.0	-6.5	-13.2	33.1	31.6	29.3	11.0	10.5	9.8
Dec	12.1	2	6.1	0.8	-2.3	-5.0	12.2	11.9	11.5	6.1	5.9	5.8
Ann.	1301.3	101	12.9	-3.9	-13.7	-26.8	1250.8	1123.7	953.2	12.4	11.1	9.4

d. DECIDUOUS FOREST ZONE

	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	17.1	2	10.1	-5.3	-17.4	-35.2	16.2	14.1	11.1	8.1	7.0	5.5
Feb	54.8	5	11.5	-12.4	-40.5	-82.2	48.0	32.6	9.8	9.6	6.5	2.0
Mar	114.9	9	12.8	-8.3	-27.2	-55.0	105.4	83.6	51.7	11.7	9.3	5.7
Apr	134.4	11	12.5	-6.0	-19.8	-40.0	126.4	107.8	80.7	11.5	9.8	7.3
May	169.4	13	13.2	-6.0	-25.8	-39.6	159.2	125.7	102.3	12.2	9.7	7.9
Jun	215.2	16	13.5	-5.2	-17.0	-34.6	204.0	178.6	140.7	12.8	11.2	8.8
Jul	121.9	13	9.5	-1.2	-3.8	-7.6	120.4	117.2	112.6	9.3	9.0	8.7
Aug	80.9	11	7.4	-0.2	-0.6	-2.8	80.8	80.4	78.7	7.3	7.3	7.2
Sep	142.0	14	10.2	-0.8	-2.4	-4.8	140.9	138.6	135.2	10.1	9.9	9.7
Oct	153.8	15	10.4	0.0	-0.5	-1.0	153.8	153.1	152.3	10.3	10.2	10.2
Nov	67.0	8	8.6	-2.0	-6.5	-13.2	65.6	62.6	58.1	8.2	7.8	7.3
Dec	31.9	3	11.1	0.8	-2.3	-5.0	32.2	31.2	30.3	10.7	10.4	10.1
Ann.	1303.4	120	10.9	-3.9	-13.7	-26.8	1252.8	1125.5	954.7	10.4	9.4	8.0

e. **RAIN FOREST ZONE**

	Baseline Means			Mean change in rainfall.			Scenarios: Mean Rainfall Amount.			Scenarios (Mean DailyRainfall)		
	Mean	No. of Raindays	Daily mean		(per cent)			(mm)			(mm per day)	
Month	(mm)	(days)	(mm/day)	2020	2050	2080	2020	2050	2080	2020	2050	2080
Jan	34.0	4	9.3	-5.3	-17.4	-35.2	32.2	28.0	22.0	8.0	7.0	5.5
Feb	66.2	5	13.1	-12.4	-40.5	-82.2	58.0	39.4	11.8	11.6	7.9	2.4
Mar	130.1	9	14.8	-8.3	-27.2	-55.0	119.3	94.7	58.5	13.3	10.5	6.5
Apr	175.3	12	15.1	-6.0	-19.8	-40.0	164.8	140.6	105.2	13.7	11.7	8.8
May	345.1	23	15.0	-6.0	-25.8	-39.6	324.4	256.1	208.5	14.1	11.1	9.1
Jun	579.7	22	26.4	-5.2	-17.0	-34.6	549.5	481.1	379.1	25.0	21.9	17.2

Jul	211.7	1.5	14.4	-1.2	-3.8	-7.6	209.1	203.6	195.6	139.4	135.8	130.4
Aug	79.7	13	6.3	-0.2	-0.6	-2.8	79.6	79.2	77.5	6.1	6.1	6.0
Sep	95.3	15	6.5	-0.8	-2.4	-4.8	94.6	93.0	90.8	6.3	6.2	6.1
Oct	168.7	17	10.1	0.0	-0.5	-1.0	168.7	167.8	167.0	9.9	9.9	9.8
Nov	136.8	14	10.0	-2.0	-6.5	-13.2	134.1	127.9	118.7	9.6	9.1	8.5
Dec	70.1	8	9.1	0.8	-2.3	-5.0	70.7	68.5	66.6	8.8	8.6	8.3
Ann.	2092.7	143.5	14.6	-3.9	-13.7	-26.8	2011.4	1807.0	1532.9	14.0	12.6	10.7
f. COASTAL SAVANNAH												
	Baseline Means			**Mean change in rainfall.**			**Scenarios: Mean Rainfall Amount.**			**Scenarios (Mean DailyRainfall)**		
	Mean	**No. of Raindays**	**Daily mean**		**(per cent)**			**(mm)**			**(mm per day)**	
Month	**(mm)**	**(days)**	**(mm/day)**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	10.8	2	6.3	-5.3	-17.4	-35.2	10.2	8.9	7.0	5.1	4.5	3.5
Feb	25.6	3	9.4	-12.4	-40.5	-82.2	22.4	15.2	4.6	7.5	5.1	1.5
Mar	63.2	5	13.7	-8.3	-27.2	-55.0	57.9	46.0	28.4	11.6	9.2	5.7
Apr	103.1	8	13.3	-6.0	-19.8	-40.0	96.9	82.7	61.8	12.1	10.3	7.7
May	151.2	12	13.0	-6.0	-25.8	-39.6	142.1	112.2	91.3	11.8	9.3	7.6
Jun	226.2	17	13.5	-5.2	-17.0	-34.6	214.5	187.8	148.0	12.6	11.0	8.7
Jul	73.0	8	9.3	-1.2	-3.8	-7.6	72.1	70.2	67.4	9.0	8.8	8.4
Aug	32.6	7	4.9	-0.2	-0.6	-2.8	32.5	32.4	31.7	4.6	4.6	4.5
Sep	64.4	8	8.4	-0.8	-2.4	-4.8	63.9	62.8	61.3	8.0	7.9	7.7
Oct	81.5	8	10.6	0.0	-0.5	-1.0	81.5	81.1	80.7	10.2	10.1	10.1
Nov	39.0	5	8.3	-2.0	-6.5	-13.2	38.2	36.5	33.8	7.6	7.3	6.8
Dec	19.7	2	9.8	0.8	-2.3	-5.0	19.8	19.2	18.7	9.9	9.6	9.3
Ann.	890.2	85	10.5	-3.9	-13.7	-26.8	855.6	768.7	652.1	10.1	9.0	7.7

APPENDIX 9. SCENARIOS OF MEAN SEA SURFACE AIR TEMPERATURES IN THE OFF-SHORE WATERS OF GHANA

a. OFF-SHORE COASTAL AREA (Median values)

	B-Line	Mean Temp. Change(°C)			Mean Temp.(°C)		
	T-Mean.	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	27.1	0.4	1.3	2.6	27.5	28.4	29.7
Feb	27.5	0.4	1.4	2.6	27.9	28.9	30.1
Mar	27.6	0.4	1.3	2.6	28.0	28.9	30.2
Apr	27.8	0.4	1.4	2.8	28.2	29.2	30.6
May	27.5	0.5	1.4	2.8	28.0	28.9	30.3
Jun	25.7	0.5	1.5	3.0	26.2	27.2	28.7
Jul	24.5	0.5	1.6	3.0	25.0	26.1	27.5
Aug	23.5	0.5	1.4	3.0	24.0	24.9	26.5
Sep	24.5	0.4	1.4	2.7	24.9	25.9	27.2
Oct	25.3	0.4	1.3	2.6	25.7	26.6	27.9
Nov	26.3	0.4	1.2	2.5	26.7	27.5	28.8
Dec	26.8	0.4	1.3	2.5	27.2	28.1	29.3
Ann.	26.2	0.4	1.4	2.7	26.6	27.6	28.9

b. OFF-SHORE COASTAL AREA (Upper bound values)

	B-Line	Mean Temp. Change(°C)			Mean Temp.(°C)		
	T-Mean.	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Jan	27.1	0.6	1.8	3.6	27.7	28.9	30.7
Feb	27.5	0.6	1.8	3.6	28.1	29.3	31.1
Mar	27.6	0.6	1.8	3.5	28.2	29.4	31.1
Apr	27.8	0.6	1.9	3.8	28.4	29.7	31.6
May	27.5	0.6	2.0	4.0	28.1	29.5	31.5
Jun	25.7	0.6	2.0	4.2	26.3	27.7	29.9
Jul	24.5	0.6	2.1	4.3	25.1	26.6	28.8
Aug	23.5	0.6	2.0	4.1	24.1	25.5	27.6
Sep	24.5	0.6	1.9	3.8	25.1	26.4	28.3
Oct	25.3	0.5	1.8	3.6	25.8	27.1	28.9
Nov	26.3	0.5	1.7	3.4	26.8	28.0	29.7
Dec	26.8	0.6	1.8	3.6	27.4	28.6	30.4
Ann.	26.2	0.6	1.9	3.8	26.8	28.1	30.0

APPENDIX 10. SCENARIOS OF SEA LEVEL CHANGE WITH RESPECT TO 1990 MEAN (CM)

Year	Change (Central Value) (cm)	Change (Range) (cm)
2010	3.6	1.6 to 6.0
2020	5.8	2.6 to 9.8
2030	8.6	3.8 to 14.4
2040	12.0	5.5 to 20.2
2050	16.5	7.6 to 27.6
2060	21.9	10.3 to 36.7
2070	28.0	13.1 to 47.1
2080	34.5	16.1 to 58.4

This page is intentionally left blank

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov