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BACKGROUND PAPER FOR

THE ARCC WEST AFRICA REGIONAL CLIMATE CHANGE VULNERABILITY ASSESSMENT

March, 2013

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ARCC

African and Latin American Resilience to Climate Change Project

Curt Carnemark

BACKGROUND PAPER FOR THE ARCC WEST AFRICA REGIONAL CLIMATE CHANGE VULNERABILITY ASSESSMENT

USAID African and Latin American Resilience to Climate Change (ARCC)

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Acronyms and Abbreviations

ACMAD	African Centre of Meteorological Applications for Development
ACPC	African Climate Policy Center
Afri-FishNet	African Fisheries Experts Network
AGRHYMET	Agriculture, Hydrology, and Meteorology Regional Centre
APSIM	Agriculture Production Systems Simulator
CAADP	Comprehensive Africa Agriculture Development Programme
CCAFS	Research Program on Climate Change, Agriculture, and Food Security
CGIAR	Consultative Group on International Agricultural Research
CIA	Central Intelligence Agency
CIESIN	Center for International Earth Science Information Network
CILSS	*Comité Inter-Etate pour la Lutte contre la Sécheresse au Sahel* (Permanent Interstate Committee for Drought Control in the Sahel)
CROPSYST	Cropping Systems Simulation Model
DSSAT	Decision Support System for Agrotechnology Transfer
ECOWAS	Economic Community of West African States
ENSO	El Niño-Southern Oscillation
EPIC	Environmental Policy Integrated Climate
FAO	Food and Agriculture Organization (United Nations)
FEWS NET	Famine Early Warning Systems Network
GCM	General Circulation Model
GEF	Global Environment Fund
GDP	Gross Domestic Product
IDMC	Internal Displacement Monitoring Centre
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
IRIN	Integrated Regional Information Networks
IUCN	International Union for the Conservation of Nature
LME	Large Marine Ecosystem
MCM	Meningococcal Meningitis
MERIT	Meningitis Environmental Risk Information Technologies
NAO	North Atlantic Oscillation
NEPAD	New Partnership for Africa's Development
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
REDD+	Reducing Emissions from Deforestation and Forest Degradation Plus
SARRA-H	*Système d'Analyse Régionale des Risques Agroclimatiques*, version H
SCAD	Social Conflict in Africa Database
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
TFDD	Transboundary Freshwater Dispute Database
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WHO	World Health Organization
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

Most West African countries span two or three major ecological regions including the Sahelian, coastal, and tropical inland zones. Given this geography, the design and planning of climate change adaptation approaches must consider the social-ecological dynamics of not only these three major ecological regions, but also those of the transition zones between them.

In complexity science, social-ecological systems—encompassing spatially and functionally related social, economic, institutional, ecological, and geophysical elements—have been conceptualized to facilitate analyses of vulnerability and resilience. Agro-ecological zones, for example, can be analyzed as social-ecological systems.

In West Africa agro-ecological zones are closely related to annual rainfall amounts, which decline moving north from the southern coast to the Sahara Desert. Annual rainfall amounts as well as the timing of the seasons vary significantly from year to year. More recently, however, scientists have discovered that climate variability has also exhibited a strong decadal component related to variations in global sea surface temperatures, with a wetter period in the 1950s to 1960s and a drier period in the 1970s to early 2000s.

In the Sahel, changes in total rainfall amounts are related to fewer rainy days and longer dry spells within the season and not to reduced rainfall amounts per event or significant long-term changes in the overall duration of the season. This decadal variability, unrelated to the overall anthropogenic climate change and significant amplitude, is unique to the region and makes detection and projection of climate trends related to anthropogenic climate change difficult. Predictability and interactions between the decadal component and longer-term climate change remain unclear.

Models agree on a long-term increase in temperature on the order of 2.5–3.5°C by the end of the twenty-first century, but these strongly disagree on future precipitation. Other characteristics of climate, such as the onset and length of the rainy season and the distribution of dry spells within the season—which are critical for climate-sensitive sectors such as agriculture—are even more difficult to project with confidence. There is some indication that the rainy season in the Sahelian region might be delayed in the future and that extreme rainfall events, such as droughts and floods, might become more frequent.

Because rainfall is so critical to rural livelihoods, future uncertainties and decadal scale variations make it difficult to predict and plan for "most likely" scenarios. Governments and donors will therefore need to adopt effective risk management approaches that involve developing a robust and flexible portfolio of actions. These should be aimed at preventive risk

reduction and risk transfer as well as response to events as and after they occur—as opposed to adopting a single focus on any particular measure.

At the local level governments and donors will need to develop a climate change response portfolio in collaboration with affected communities. These should be context-specific, respond to clearly identified community needs and vulnerabilities, and empower affected populations to develop, modify, and control their own approaches in order to adapt more quickly. At the regional, transboundary, and national level, capacity-building efforts should aim to monitoring agencies and research centers such as the Agriculture, Hydrology, and Meteorology Regional Centre; the African Centre of Meteorological Application for Development; and university-based groups working on climate change.

In addition to embracing a climate risk management approach, climate change adaptation efforts in West Africa should seek to:

- Enhance climate-related technical, management, institutional, and governance capacity, including improving information and monitoring systems;
- Question existing paradigms and support flexibility in ways that advance sustainable and resilient development and encourage new response patterns;
- Address the underlying causes of climate vulnerability, including the structural inequalities that create and sustain poverty and constrain access to resources and markets; and
- Apply focused approaches that address specific priority contexts at multiple spatial and organizational scales including key transboundary issues (e.g., river basin management) in addition to promising economic activities and resource management options targeting ecological transition zones connecting Sahelian, coastal, and tropical inland areas.

These guidelines are drawn from a recent report of the Intergovernmental Panel on Climate Change (IPCC) about how to manage the risks of extreme events and disasters (IPCC, 2012).

SAHEL REGION

Water is a key and limiting factor in the semi-arid Sahelian region, where populations have experienced a series of widespread droughts, most notably in the mid-1970s and mid-1980s, that resulted in humanitarian crises associated with periodic famines, region-wide food insecurity, population displacement, and migration. The rainy season (July–September) generally starts abruptly, signaling the beginning of the farming season. Delayed rainfall onset, or early retreat, shortens the growing season, thereby reducing productivity. Rainy seasons that last too long often lead to floods and crop losses due to high humidity during the harvest and post-harvest processing periods.

Models project temperatures in the Sahel to increase more than in the coastal region, and agricultural modeling studies suggest that these will result in declines in the yields of a range of staple crops. As stated earlier, however, precipitation is difficult to model, and existing models

disagree on projected long-term evolution of annual rainfall amounts even though most project a slight increase in the central Sahel and decrease in the western Sahel. A number of models appear to agree that future climate variations could bring possible delays in the onset of the rainy season as well as higher frequency of extreme events such as droughts and floods. However, it is the confluence of temperature increases that will likely result in higher levels of evapotranspiration (a combination of evaporation from land and water surfaces and transpiration from vegetation). Coupled with precipitation changes, this will ultimately have the greatest impact on traditional livelihoods because the combined effects will tend to reduce the overall availability of water in those areas where rainfall does not increase.

Rainfall variability is highly amplified in river flow and surface water availability. Unsustainable freshwater withdrawals are already impacting freshwater availability in the Sahel. Given the high number of transboundary basins throughout the region, and their origins in tropical inland areas, it is critical that all stakeholders develop well-researched and -planned responses to future needs that will take into account all possible scenarios—as they pertain to agriculture, hydropower, domestic consumption, and water resource management.

Pastoralist systems have traditionally been well-adapted to inter-annual rainfall variability. Today, however, these systems are subject to multiple and conflicting pressures as a result of agricultural expansion and changes in land management policy that have eroded traditional transhumance passageways and grazing lands. One of the most prevalent forms of social conflict in West Africa is the recurrent struggle between pastoral livestock herders and sedentary farmers. Climate change is expected to impact and possibly worsen conflict dynamics between these two groups. It is likely to impact conflict dynamics *indirectly* by altering pastoral mobility patterns and reshaping pastoral livelihood portfolios in ways that increase friction with local farmers.

Recommendations for the Sahelian zone:

Targeted investments:

- Support better management of transboundary watersheds using multi-stakeholder approaches to avoid conflict over water resources given that surface water resources often amplify rainfall anomalies (both droughts and floods) and given expectations that there will be increased pressure on water resources due to population growth as well as water demands for irrigation and the generation of hydropower.
- Where possible, advance breeding and improve management of drought-, heat-, and waterlogging-tolerant crop varieties in both the agriculture and agro-forestry sectors. Focus should be on those agricultural products most important to the region.
- Encourage continued seasonal migration to cities and coastal areas by generating additional employment opportunities, while simultaneously developing policy options to help people better cope with climate extremes *in situ*, which could help reduce distress migration.

No-regrets strategies:

- Invest in decentralized, small-scale water supply infrastructures, such as dams and irrigation systems, to extend the length of the growing season.
- Identify opportunities to integrate climate risk management into regreening strategies through an examination of existing efforts to support regreening through farmer-managed natural forest regeneration.
- In collaboration with local communities and governments, explore innovative combinations of the most promising options for agriculture, agroforestry, and regreening to determine which are likely to be the most flexible and most sustainable given continued uncertainty over the impact of climate change.
- Develop new livelihood opportunities for pastoralist populations and investigate how to incorporate more livestock production into the livelihoods of populations that typically rely on crops. This will help build resilience and improve nutrition by meeting regional protein needs.

COASTAL ZONE

The climate in the coastal zone of West Africa is characterized by two main rainy seasons during April–June and September–November. Vegetation ranges from evergreen broadleaf forests along the coast to woody savannah farther north. The regional economy is heavily dependent on perennial tree crops.

This region is more densely populated—especially the coastal stretch from Accra, Ghana, to Lagos, Nigeria—and it sometimes experiences flooding and crop loss due to excessive precipitation. Rainfall projections point to an increase in coastal precipitation during the longer dry season (December–February). The impacts of climate change in coastal areas stem both from extreme rainfall events and storm surges that result in floods and from sea level rise.

In recent decades, people have been migrating into areas at risk of sea level rise. Climate-related stress is causing increasing hardship in the Sahel, which will likely drive more people to migrate into these coastal areas, thereby altering current social, economic, and political dynamics.

The expected impacts of climate change on the coastal fisheries of West Africa remain uncertain, and the magnitude of these impacts relative to other important factors in coastal areas is unclear (e.g., the impact of increased demand for fish as a food source due to population growth).

Recommendations for the coastal zone:

Targeted investments:

- Improve geospatial data and data infrastructure to support urban planning and the development of integrated coastal zone management plans that address risks and

opportunities as they relate to: projected sea level rise; expected increase in frequency of storms, storm surges, and floods; urbanization trends; and coastal wetlands protection and management.
- Inform decision makers and the public about the risks and potential impacts of sea level rise to guide land-use zoning and relocation of vulnerable populations.
- Improve monitoring of quality and quantity of freshwater aquifers in those coastal regions threatened with salinization due to over-abstraction and sea level rise.
- Explore how to improve governance and institutional capacity to promote sustainable fisheries landings while incorporating knowledge of potential climate change impacts.

No-regrets strategies:

- Support efforts to preserve, protect, and restore coastal wetlands (e.g., mangroves) to buffer the impacts of storms that may increase with climate change. Design and deploy effective technological and management mechanisms to mitigate and prevent the erosion of coastal wetlands.
- Integrate the development of alternative income-generating activities into coastal wetland management to relieve pressure from subsistence use of these coastal resources.
- Examine the sustainability of expanding on- and off-shore aquaculture to increase fish production as a regional food supply.

TROPICAL INLAND ZONE

The vegetation cover in tropical inland areas of West Africa ranges from woody to open savannah. Economies are characterized by a mix of tree crops, annuals such as peanuts and grains, small-scale livestock keeping, and, where available, inland fisheries. In this region agriculture is not typically limited by rainfall, though year-to-year variations can cause production shortfalls. Climate risk management in the tropical inland zone should focus on projected increases in temperature. Although the coming decades may see the tropical inland zone of West Africa greening in some areas, subsistence and commercial land use practices as well as local- to global-level market demand and consumption may counter this effect.

Recommendations for the tropical inland zone:

Targeted investments:

- In order to support those agricultural products most important to the region, encourage the breeding and improve the management of heat-resistant varieties and advance farming practices more appropriate to hotter growing conditions (e.g., agro-forestry and the cultivation of shade crops).
- Support better management of transboundary watersheds using multi-stakeholder approaches to avoid conflict over water resources given that surface water resources often amplify rainfall anomalies (both droughts and floods), and given expectations that

there will be increased pressure on water resources due to population growth as well as water demands for irrigation and the generation of hydropower.

No-regrets strategies:

- In areas that could potentially sustain higher productivity, support agricultural intensification and modernization through improved seeds (high-yielding varieties), fertilizer inputs, tractor services, improvements in small-scale livestock production (e.g., vaccination campaigns), provision of micro-credit services to farmers, and improved market linkages. This will help meet regional food needs. Sustainable agricultural intensification and modernization will help to offset decreasing availability of agricultural land and boost local employment.
- Invest in decentralized, small-scale water supply infrastructures, such as dams and irrigation systems, to extend agricultural production into the dry season and ensure year-round farming.
- Concentrate on transboundary programs that aim to promote and safeguard gains in forested and reforesting areas in order to maintain biodiversity, natural resources, and the variety of ecosystem services that support human livelihoods and wellbeing. This approach could contribute to both climate change adaptation and mitigation.
- Support carbon sequestration efforts in protected forests, tree crop plantations, and wetlands through Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+) and carbon credits.
- Take measures to control bush fires to prevent the destruction of economic trees, crops, and other types of vegetation cover.

Recommendations organized by sector and issue are summarized in the chart below.

	Research Needs	**Institutional and Governance Capacity**	**Information & Monitoring Systems**	**Technical and Management Capacity**
Agriculture	Study the probability of high-impact scenarios to identify the most vulnerable populations.	Empower farmers to actively participate in problem solving. Develop innovation platforms that bring together value chain participants and other stakeholders to help strengthen institutional capacity and improve market access. Provide functional credit and insurance institutions.	Enhance the dissemination of weather information to farmers (e.g., seasonal forecasts).	Invest in water management to benefit rain-fed agriculture in semi-arid and humid zones. Improve irrigation infrastructure and distribution of seed, fertilizer, and pesticides. Breed resilient and flexible cultivars for key staple crops.
Pastoralism & Livestock Production	Advance research on how the expected negative impacts of climate change on staple crop production may affect livestock owners who increasingly rely	Value local pastoral knowledge and understanding. Develop inclusive democratic local governance capacity to	Improve climate forecasting to provide intra-seasonal rainfall and water resource information. Provide herders with general	Rehabilitate degraded areas through rangeland enclosures managed in collaboration with local herders and farmers.

	Research Needs	Institutional and Governance Capacity	Information & Monitoring Systems	Technical and Management Capacity
	on purchased feed inputs.	enfranchise livestock herders and improve/secure pastoral herding labor markets.	information about expected climate change impacts to improve herder decision-making.	Develop measures to support the sustainable production and marketing of supplemental livestock feed.
Rivers and Water Resources	Downscale the spatial specificity of water availability, stress, scarcity, vulnerability, and footprint indices.	Prioritize and strengthen transboundary river basin management and national/local water resources management organizations.	Through existing regional monitoring programs (e.g., FEWS NET), monitor for rapid changes in water supply that outpace the ability for institutional response.	Enhance data collection for historic monitoring and modeling of future water resources. Establish systematic climate and river monitoring stations across West Africa; link these international standardized monitoring stations with local research/knowledge networks and water resources management organizations.
Inland and Coastal Wetlands	Build on previous and existing wetlands inventories and efforts to identify priority sites for wetlands conservation, monitoring, and sustainable development in ways that consider different climate change scenarios (e.g., sea level rise scenarios). Improve knowledge of wetlands biodiversity dynamics, including research on the potential consequences of climate change for habitat species composition (e.g., potential for displacement of native vegetation by non-native invasive plant species). Improve knowledge of the economic and ecological values of wetlands ecosystems to inform development of integrated management strategies and to increase awareness of the economic and ecological importance of wetlands under climate change.	Promote good governance and integrated management of inland water resources. Promote effective institutional and governance mechanisms to preserve/protect coastal wetlands from loss/degradation. Support the development of regional wetlands management institutions to foster cross-border partnerships and cooperation.	Advance use of remote sensing to monitor land-use/land-cover change in both inland and coastal wetland areas. Improve monitoring of the quality and quantity of freshwater reservoirs located in coastal regions threatened with salinization due to sea level rise.	Partner with multi-disciplinary networks of wetlands experts in the region such as the Sahelian Wetlands Expert Group and the Coastal Planning Network. Ensure that wetland resource management is adaptive in the face of uncertainties in climate change outcomes. Design/deploy effective technological/management mechanisms to mitigate and prevent the erosion of coastal wetlands. Provide wetlands managers with training on habitat restoration and rehabilitation. Integrate the management of coastal mangrove forest ecosystems within robust forestry management and integrated coastal zone management strategies. Integrate alternative income generation approaches and alternative energy sources (to reduce extraction of wood fuel) into coastal wetland management to offer alternative livelihood options to populations subsisting on coastal resources.
Forest and Woodlands	Identify opportunities to integrate climate risk management into regreening strategies.	Examine existing efforts to support regreening in the Sahel, coastal zone, and tropical inland areas through farmer-managed	Improve monitoring of land use/cover changes and vegetation cover dynamics.	Improve the management of fruit trees in agroforestry parklands to improve rural livelihoods in the Sahel.

	Research Needs	Institutional and Governance Capacity	Information & Monitoring Systems	Technical and Management Capacity
		natural forest regeneration.		
Fisheries	Examine the sustainability of expanding on- and off-shore aquaculture to increase production and to promote fish as an alternative regional food source.	Improve governance/institutional capacity to ensure that planning/management of sustainable fisheries incorporate knowledge of potential climate change impacts under different scenarios.	Improve monitoring of regional fisheries.	Collaborate with multi-disciplinary networks of fisheries and aquaculture experts in the region (e.g., the African Fisheries Experts Network). Provide fisheries and aquaculture managers with scientific and technical training and mentoring opportunities that promote sustainable practices and raise awareness of climate-related vulnerabilities, potential climate change impacts, and promising coping strategies.
Human Health	Improve hydrological models that simulate variations of mosquito breeding sites to better understand and possibly predict Rift Valley fever transmission dynamics. Research behavioral responses of malaria vectors (*Anopheles melas* and *An. gambiae*) to habitat transformations caused by sea level rise. Research the effects of climate-related human migrations on disease distribution. Advance research on the pathways by which climate impacts nutrition and food security. Advance research on the human and livestock health impacts of toxins produced by fungi (mycotoxins).	Support launch of the World Health Organization consortium aimed at developing a comprehensive policy framework to provide a scientific and evidence-based coordinated response to the climate change adaptation needs of African countries.	Utilize the Early Warning Index and risk maps at regional scales for meningitis epidemic onset prediction in order to optimally direct national and international health policy. Improve the capacity of the public health community to use climate-sensitive and environmental information for decision-making by providing platforms that bring climate scientists, public health researchers, and public health practitioners together to translate research into the evidence needed by decision makers.	Improve potable water supply, road drainage systems, and sanitary conditions to alleviate outbreaks of waterborne infectious diseases (e.g., cholera and typhoid). Support cross-sectoral initiatives to reduce the risks of aflatoxin contamination/exposure in high-risk areas. Incorporate health considerations in the development of adaptation strategies that involve water harvesting/storage.
Conflict & Security	Provide sustained support for integrated climate science and social science research on climate-security connections to better understand the causal pathways and mechanisms linking climate variability/change to societal instability/conflict in the region. Apply scenario approaches to	Promote climate change adaptation strategies that facilitate conflict management and cooperation among social groups through effective institutional frameworks and governance mechanisms. Promote accountable, transparent government institutions to better meet	Recognize that climate change is more often a "threat multiplier" than a direct trigger. Support efforts to establish regional early warning systems for sudden climate-related disturbances. Increase USAID interactions with the intelligence community to help advance existing conflict monitoring	Prioritize a range of existing development programs to adapt to changing climate patterns. Promote activities that bolster social capital and civil society participation in planning, implementation, and monitoring of disaster risk management and climate change adaptation activities.

	Research Needs	Institutional and Governance Capacity	Information & Monitoring Systems	Technical and Management Capacity
	think about: unexpected and potentially disruptive single climate events; conjunctions of events with common causes occurring simultaneously or closely in time; sequences or cascades of events in which a climate event leads to a series of consequences; and disruptions of globally connected systems that support human wellbeing.	citizen demands through regular, peaceful means. As a response to shrinking pastoral resources, promote the legalization, regularization, and management of aerial forage to feed livestock; this should be done in collaboration with local communities of herders/farmers and with local governments. Develop policies/practices that support improvement of the functioning and transparency of pastoral labor markets to ensure that conflicts involving wage-earning herders can be managed effectively.	and early warning systems in ways that integrate climate-related stress. Request analyses of high-priority countries in the region. Promote and participate regularly in efforts to establish a system of periodic "climate stress testing" to assess potentially disruptive conjunctions of climate events and socioeconomic/political conditions.	Promote activities that target likely causal pathways linking climate stress and conflict. Promote active management of pastoral resource areas where grazing is permitted but crop cultivation is not.
Migration	Research past climate variability and migration impacts as a way to understand likely future volumes of migration. Research the effects of climate-related migrations on disease distribution.	Increase the governance capacity of city and town planners and managers in order to accommodate likely future increases in rural-urban migration volume.	In the absence of "hard data" on rural-urban and international migration, there is a need for cross-national survey research on migration streams in West Africa in order to better characterize the flows.	Encourage continued seasonal migration to cities and coastal areas by generating additional employment opportunities.

INTRODUCTION

This background paper provides desk research and analysis for a regional climate change vulnerability assessment for the USAID/West Africa Regional Mission. It addresses climate change impacts and vulnerabilities across multiple sectors and also covers regional vulnerabilities around conflict and migration. Most West African countries span two or three major ecological regions including the Sahel, the coastal zone, and tropical inland areas. Given this geography, the design and planning of climate change adaptation approaches in West Africa must consider the social-ecological dynamics of not only these three major ecological regions, but also the transition zones between them.

The paper begins with a brief overview of the regional geography. This is followed by an overview of the regional climate, discussing the observed climate and its variability, climate projections, and current climate risk management institutions and activities. The paper then presents climate change vulnerabilities by sector and issue covering the following topics: agriculture, pastoralism and livestock production, rivers and water resources, inland and coastal wetlands, sea level rise, forests and woodlands, fisheries, and human health. Next, the section on regional and local challenges addresses conflict and migration in the context of climate change. The last section offers a set of guidelines drawn from a recent report of the Intergovernmental Panel on Climate Change (IPCC, 2012) followed by recommendations presented by sector, issue, and subregion.

OVERVIEW OF WEST AFRICA GEOGRAPHY

West Africa is composed of 18 countries. Cape Verde is an archipelago of 10 islands. Burkina Faso, Mali, Niger, and Chad are landlocked Sahelian countries; and Mauritania, Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and Cameroon possess low-lying coastal zones and tidal ecosystems exposed to seaward hazards along the Atlantic Ocean as well as inland areas exposed to floods and droughts (Figure 1). Combined, these countries cover a total land and water area of approximately 7.9 million km^2.

Fig. 1 Map of West Africa. *Source:* Center for Geographic Analysis at Harvard University, 2012.

The climate of West Africa varies from a humid tropical zone in the southern part of the region to semi-arid and arid zones in northern areas bordering the Sahara Desert (Figure 2). Due to latitudinal rainfall patterns, the landscapes of West Africa transition from tropical rainforest to tropical moist deciduous forest, tropical dry forest, tropical shrub land (or savannah), drylands, and desert with increasing northern latitude (FAO, 2000).

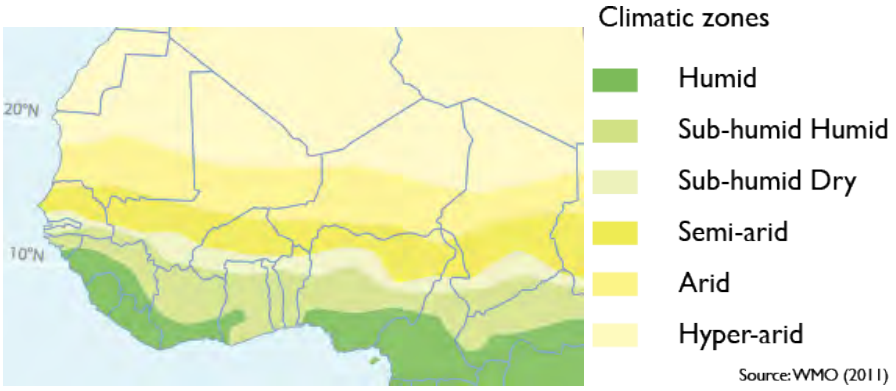


Fig. 2 Climatic zones of West Africa. *Source:* OECD (2008a: 7).

The total population of the 18 countries discussed in this report is approximately 354 million, of which more than 40% is under the age of 15 (Hiraldo, 2011; CIA, 2012). The annual population growth rate is a high 2–3% (OECD, 2007). Life expectancy at birth ranges from 49 years in Chad and Guinea-Bissau to 71 years in Cape Verde (CIA, 2012). Cape Verde is the most urban society with 61% of the total population living in cities, while Niger is the least urban with only 17% of the total population inhabiting cities (CIA, 2012). An estimated 5 million people in West Africa live between 0–3 meters above sea level (CIESIN, 2012a).

Fourteen countries are currently members of the Economic Community of West African States (ECOWAS): Benin, Burkina Faso, Côte d'Ivoire, The Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo, and Cape Verde (ECOWAS, 2012). Mauritania was an ECOWAS member state but withdrew from the organization in 2000 (Williams and Haacke, 2008). ECOWAS's objective is "to promote cooperation and integration, with a view to establishing an economic and monetary union as a means of stimulating economic growth and development in West Africa" (ECOWAS, 2007). Many West African countries have high real gross domestic product (GDP) growth rates. In 2011, Ghana was ranked second in the world with a real GDP growth rate of 13.5%, and Côte d'Ivoire and Senegal were ranked at 24 and 25 with 6.9% growth rates (CIA, 2012). There is also great variation in poverty between countries. Seventy to 80% of the population in Chad, Liberia, Nigeria, and Sierra Leone lives below the poverty line in comparison to 30–40% of the population in Ghana, Togo, Cape Verde, Mali, and Benin (CIA, 2012). Politically there is instability and volatility. The questionable legitimacy of recent elections in a number of countries has resulted in protest and societal mistrust of government (Nossiter, 2012).

OVERVIEW OF CLIMATE

3.1 OBSERVED CLIMATE AND ITS VARIABILITY

3.1.1 Average Climate

In the absence of significant mountain ranges and water bodies, rainfall and its seasonal shift are the main climate drivers in West Africa. The distribution of climatic zones and vegetation, and by extension cultivable areas, follows closely the distribution of annual total precipitation (Figure 3), characterized by a latitudinal gradient sharply decreasing from the southern coastal region where precipitation exceeds 1,500 mm per year, toward the Sahara where precipitation is lower than 50 mm per year. The main departures from this pattern are two precipitation maxima in the coastal regions, corresponding to the two main mountain ranges: (1) the Fouta Djallon in the southwest and (2) the Cameroon line in the southeast of the region. A slightly drier region called "V Baoulé" (centered on Benin) separates these two maxima. Availability of water is the main limiting factor for agricultural and pastoral activities that are mostly rain-fed, especially in the drier areas.[1] Thus climate analyses in the region mostly focus on rainfall.[2]

[1] In the Sahel, the 400–500 mm of rainfall per year isohyet usually marks the limit of areas suitable for agriculture.

[2] In the southern, more humid areas, excess of rainfall and flooding are the main climate threats.

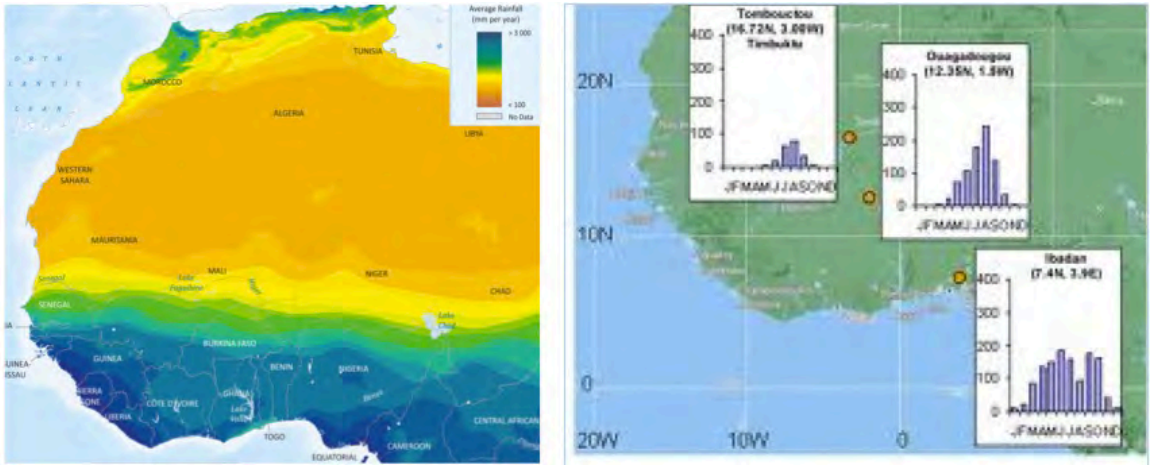


Fig. 3 Climatology of rainfall in West Africa. The map on the left shows average annual rainfall totals in mm per year. *Source:* UNEP/GRIS, 2012.

Figure 3 (above) displays the mean seasonal cycle in three locations: (1) Ibadan in southwestern Nigeria near the coast; (2) Ouagadougou, Burkina Faso, in the Sahel; and (3) Timbouctou, Mali, in the Sahelo-Saharan region. Source: COMET Program, date accessed 11 December 2012.

Higher annual precipitation totals in the coastal zone can be linked to a longer rainy season while further north rain only occurs during a few months in the year, centered on July–September (Figure 3, right). This seasonality is linked to the seasonal cycle of radiative heating of the surface that follows the movement of the sun (reaching its northernmost location at the summer solstice) and drives low-level atmospheric circulation and the West African monsoon. In a nutshell, as the sun moves north, the air overlaying the warmest regions rises and is replaced by air from neighboring regions to the north and south. Southern air is cooler and moister, fueling rainfall, while the region of the uplift migrates northward and reaches its maximum northern location in August before retreating southward. This leads to very contrasted wind and moisture patterns between the July–September and January–March seasons (shown in Figure 4) and a latitudinal migration of the rainbelt. Note that when the rainbelt is in its northernmost location the coastal region experiences a break in precipitation, referred to as the "little dry season;" even if atmospheric moisture levels are important, rainfall and convection (updrafts fueled by warm air) are inhibited and the moisture is "exported" further north. Thus, from a climatic point of view, a distinction is made between the monomodal region (with one rainy season during July–September, corresponding to the Sahel) and the bimodal coastal zone (with two main rainy seasons during April–June and September–November; this bimodal zone is not strictly confined to the coasts and extends several hundred kilometers inland) with a relatively narrow transition zone in between.

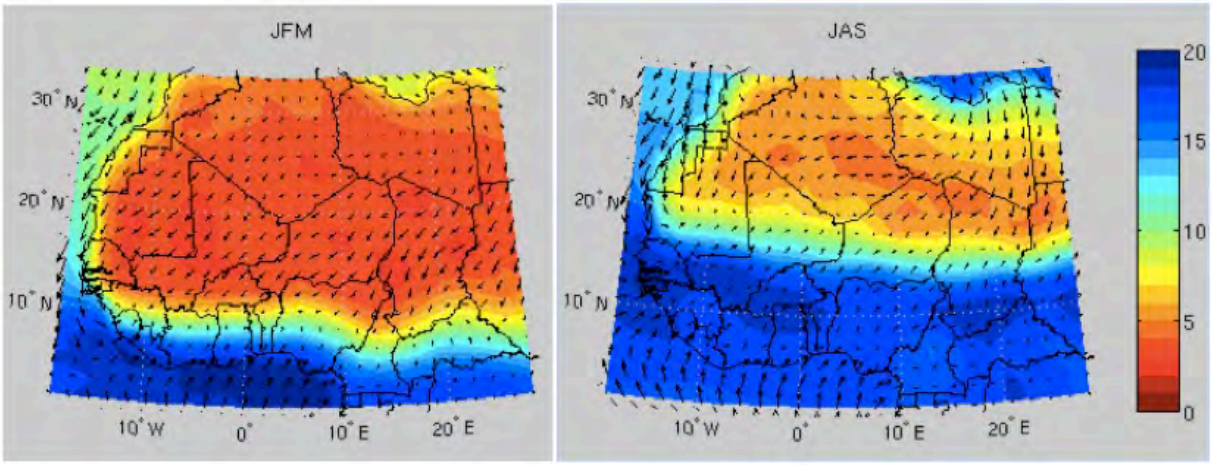


Fig. 4 Climatology of near surface wind (arrows) and atmospheric moisture (shading, in g/kg) in West Africa. The left panel shows the average over the January–March season; the right panel shows the average over the July–September season. *Data source:* NCEP Reanalysis, average period 1981–2010 (Kalnay et al., 1996).

The rainy season in the north generally starts abruptly, a process that has been termed the "monsoon jump" (Janicot and Sultan, 2001), signaling the beginning of the farming season in the Sahel. The retreat of the rains to the coastal zone is more progressive. Even in the heart of the rainy season, rainfall occurs in events separated by several days of rainless conditions known as dry spells. The distribution of rainfall within the season has greater impacts on agriculture than the overall seasonal total. The onset, cessation, and distribution of rainy days and dry spells show strong year-to-year variations to which crop, livestock, and fisheries activities have adjusted over long periods of time.

3.1.2 Current Climate Variability

Interannual Variability

Annual rainfall amounts vary strongly from year to year, and the relative departures from average precipitation (the coefficient of variation) can exceed 30% in some areas.[3] The variations are usually consistent across very wide areas, as they stem from variations in the whole West African monsoon dynamics. Dry years are characterized by weakening of the monsoon circulation, thus reducing moisture advection and overall inhibiting the rainfall. The latitude of the northernmost location of the rainbelt also varies from year to year. It is customary to think of rainfall variability in terms of coastal and Sahelian regions being similarly or inversely affected (Janicot, 1992). When similarly affected, both regions experience rainfall deficit or excess during their respective peak seasons. When inversely affected, for example, a longer excursion of the rainbelt to the north leads to a longer little dry season in the coastal

[3] By comparison, the coefficient of variation in the eastern United States barely reaches 20%, and such high levels of variability are only observed in arid Southern California and Arizona.

area and thus to a rainfall decrease in the south compared to above average rainfall in the Sahel. On the other hand, the rainbelt can be blocked in its northward movement, in which case the Sahel receives little rain while precipitation is higher during the little dry season on the coast, sometimes producing floods.

Variations in the strength of the West African monsoon and their impact on rainfall amounts are directly linked to global sea surface temperatures (SSTs) (Folland et al., 1986; Ward, 1998; Janicot et al., 2001; Giannini et al., 2003). SSTs in the Tropical Atlantic, south and north of the equator, are directly associated with the seasonal location of the intertropical convergence zone—the main rainbelt over the oceans—and with the meridional land-sea thermal contrast that drives the monsoon (Servain, 1991). High SSTs in the western Pacific (associated with El Niño-Southern Oscillation [ENSO] events[4]) and in the Indian Ocean have been related to rainfall deficits in West Africa (Palmer, 1986; Janicot et al., 1998; Janicot et al., 2001; Bader and Latif, 2003; Giannini et al., 2003).

The annual or seasonal rainfall totals reflect the variability of intraseasonal rainfall characteristics such as the onset, cessation, and distribution of rainy days and dry spells as well as extreme rainfall events, all of which have profound impacts on livelihoods. Le Barbé et al. (2002) have linked rainfall deficits to a reduced number of rainy days (larger number of dry spells) during the season rather than to the average amount of rainfall per event or the overall length of the season.

Depending on soil moisture conditions and plant development stages, long dry spells can have a very strong negative impact on crops and their productivity. Prolonged dry spells after the first rains usually require re-sowing, shortening the crop growing season. In the Sahel, delayed rainfall onset or early retreat also shorten the growing season, reducing productivity, while delayed retreat often leads to floods and crop loss due to high humidity during the harvest and post-harvest processing. Similarly, if the rainbelt is blocked in its northward progression, the coastal zone experiences flooding and crop loss due to excessive humidity.

Decadal Variability

The Sahel has been known for a series of widespread droughts with extreme impacts on food security in the region and humanitarian crises, which can lead to displacement and migration (see Migration section). The analysis of long-term rainfall time-series over the Sahel (Figure 5) shows the interannual persistence of dry conditions starting in the late 1960s and lasting until the 2000s, while the previous 50 years (roughly 1920–1968) were much wetter. These oscillations, which occur in roughly 10-year increments, are referred to as "decadal variability." The coastal zone has not experienced the persistence of the dry conditions to the same degree,

[4] ENSO, although occurring in the equatorial Pacific, impacts rainfall and temperatures around the globe (Ropelewski and Halpert, 1989; Halpert and Ropelewski, 1992). It affects the West African monsoon by modifying SSTs in the equatorial Atlantic as well as the strength of the monsoon itself. More information about El Niño can be found at: http://portal.iri.columbia.edu/portal/server.pt?open=512&objID=491&mode=2&cached=true.

and a similar analysis (not shown) shows a stronger interannual variability there, although a long-term decline is noticeable.

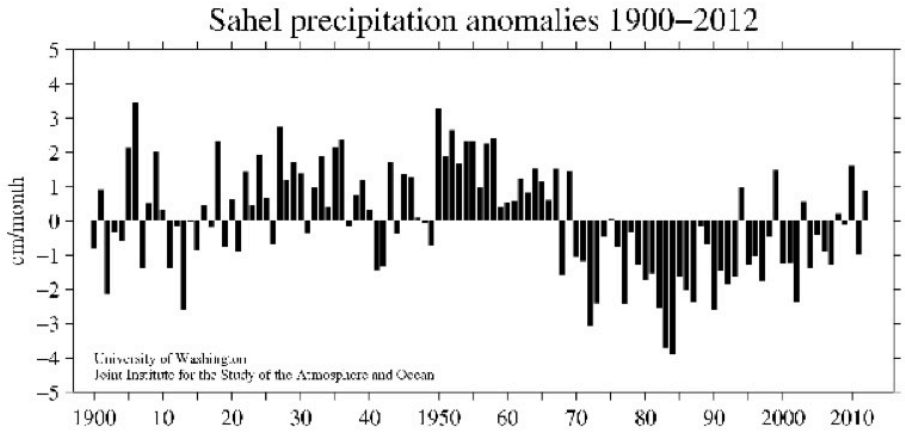


Fig. 5 Long-term evolution of seasonal rainfall in the Sahel. Bars represent rainfall averaged over June–October seasons (in cm/month) over the area 10°–20°N, 20°W–10°E, between 1900–2012. *Source:* JISAO, date accessed 11 December 2012.

Decadal variability of rainfall of this amplitude is unique to the region and has been initially attributed to the local changes in vegetation and land use following the first droughts and their subsequent feedback on monsoon dynamics (Charney et al., 1975). However, this mechanism cannot explain sporadic increases in rainfall during the dry epoch as well as a more recent return of rainfall to more average conditions. Thus the early claims that declining precipitation in the region was due to a land surface feedback owing to land degradation from population pressures have largely been put to rest (Kandji et al., 2006). Research since the 1990s has demonstrably shown that the source of this decadal variability lies in the decadal variability of global SSTs (Janicot et al., 2001; Mohino et al., 2011) with a potential impact of the Indian Ocean (Bader and Latif, 2003), while the vegetation feedback plays only a secondary role (Zeng et al., 1999).

Long-term Trends

The existence of high amplitude decadal variability in the Sahel—and to a lesser extent in the coastal region—masks potential longer-term rainfall and temperature trends in West Africa. For example, the long-term evolution in temperature shown in Figure 6 (left, following page), based on an average of 10 stations in the Sahelian region that have long-term temperature records, coincides (inversely) with the decadal variations in rainfall over the same period, thus their attribution to anthropogenic climate change is difficult. Figure 6 (right, following page) puts this evolution in the context of temperature changes predicted by the models including and not including anthropogenic atmospheric forcing. It is easy to see that current evolution seems to take a "middle path." Note also that temperature levels recorded over the past 20 years are only slightly higher than the temperatures recorded in the 1920s and 1930s. Further monitoring of temperatures is needed to assess the impact of anthropogenic climate change.

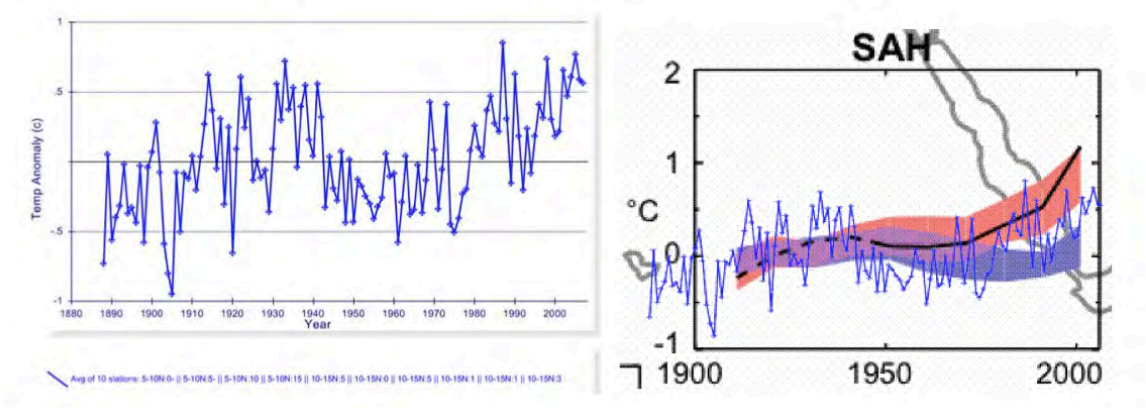


Fig. 6 Long-term evolution of annual average temperature in the Sahel. The graph on the left displays a time series of departures from the long-term average based on 10 long-term recording stations. The graph on the right shows the same time series (in blue) overlaid onto multimodel estimates of temperature evolution with (red band) and without (blue band) anthropogenic forcing. *Source:* Global Warming Science, date accessed 11 December 2012).

Several modeling studies have attempted to discriminate between natural and anthropogenic (i.e., attributable to global greenhouse gas emissions) causes of variability in the Sahel. If some studies attributed the multidecadal drying of the Sahel to changes in atmospheric composition (Biasutti and Giannini, 2006), others have shown that only 10% of the Sahelian drying in the twentieth century was attributable to anthropogenic climate change and global warming, and that long-term variations in SSTs, such as Atlantic Multidecadal Oscillation and Interdecadal Pacific Oscillation, are significantly more influential (Mohino et al., 2011). Most of the studies highlight the current difficulty in robustly attributing and quantifying the role of competing influences over the region (Lu and Delworth, 2005; Hoerling et al., 2006; Ting et al., 2009; Caminade and Terray, 2010).

3.2 CLIMATE PROJECTIONS

3.2.1 Methods and Challenges

General Circulation Model (GCM) Representation of West African Monsoon

Capturing the West African monsoon remains a challenge to climate modeling groups. The ability of models to reproduce the main features of observed climate in West Africa remains limited. Most models do not produce sufficient precipitation across the Sahel in summer (Biasutti et al., 2008) although they tend to overestimate the length of Sahelian rainy season, starting the monsoon too early and extending it too late (Biasutti and Sobel, 2009). They also fail to reproduce the fast shift between the coastal and the Sahelian locations of the rainbelt. Several important features of the monsoon itself are not well represented, mostly due to the coarse resolution of the models (Cook and Vizy, 2006). Regional models seem to simulate a more realistic West African monsoon although they still exhibit large biases in the extent and timing of the rainfall (Druyan et al., 2010). In addition, observed climate variability in West

Africa is only partially reproduced by the models. While the main connections to SST seem to be captured by most of the models (Biasutti et al., 2008), Joly et al. (2007) found that decadal variability and related SST are not present in most of them. Variability of the onset, cessation, and length of the season are underestimated and a very high variation exists among the models. It is difficult to narrow down the selection of models to use in deriving the projections because the models that produce the best mean state (i.e., average precipitation) may inadequately represent the variability and vice versa. Biasutti and Giannini (2006) also show that the models that correctly capture long-term evolution of Sahelian rainfall in the twentieth century might project strong but opposite evolutions for the end of twenty-first century.

3.2.2 Projections of Climate in West Africa

Figure 7 presents the summary of annual and seasonal temperature and rainfall projections for Africa from the last IPCC Working Group 1 (WG1) report (IPCC, 2007a). All models project an increase in temperature by the end of twenty-first century with a multimodel average of 2.5–3°C in West Africa. The increase is projected to be higher in the Sahelian than in the coastal region. The projections of rainfall point to an increase of coastal precipitation during the overall dry season (December–February) and during the rainy season the central Sahel is projected on average to get wetter while western Sahel is projected to be drier. However, the bottom series of maps point to a wide disagreement between different models in West Africa, with models splitting almost evenly between increase and decrease of rainfall. This spread between models is an important element when assessing the uncertainty level of projected anomalies.

The projections of intraseasonal characteristics of West African monsoon are even more difficult. It seems that models agree on a delay in the onset of the Sahelian rainfall (Biasutti and Sobel, 2009; Cook and Vizy, 2012), but the change in the growing season length seems to be limited to a band stretching across the Sahel but very limited in its extent (Ericksen et al., 2011). The general thermodynamic argument that a warmer atmosphere is capable of holding more moisture suggests a general increase in the intensity of high-intensity rainfall events. The recent report on projections of extreme events (IPCC, 2012) suggests that extreme daily precipitation with current return periods of 20 years[5] might occur more often. However, the spread among return time projections remains very high suggesting little confidence in this result. Conversely, the overall increase in average temperature leads to the projection of strong increase in very hot days in West Africa with much higher confidence. Temperature changes might have higher direct impact on livelihoods in coastal and equatorial areas that currently experience lower temperatures and might cross the 30°C threshold in the future and impact different crops, while in the Sahel crops are more heat tolerant and temperature change will mostly influence crops via evapotranspiration (Ericksen et al., 2011). Overall, potential increase in extreme events is thought to further adversely impact climate-sensitive sectors and increase migration as livelihoods may become unsustainable in some locations, thus increasing pressure in relocation areas (IPCC, 2012).

[5] This occurred only once in the 1981–2000 period.

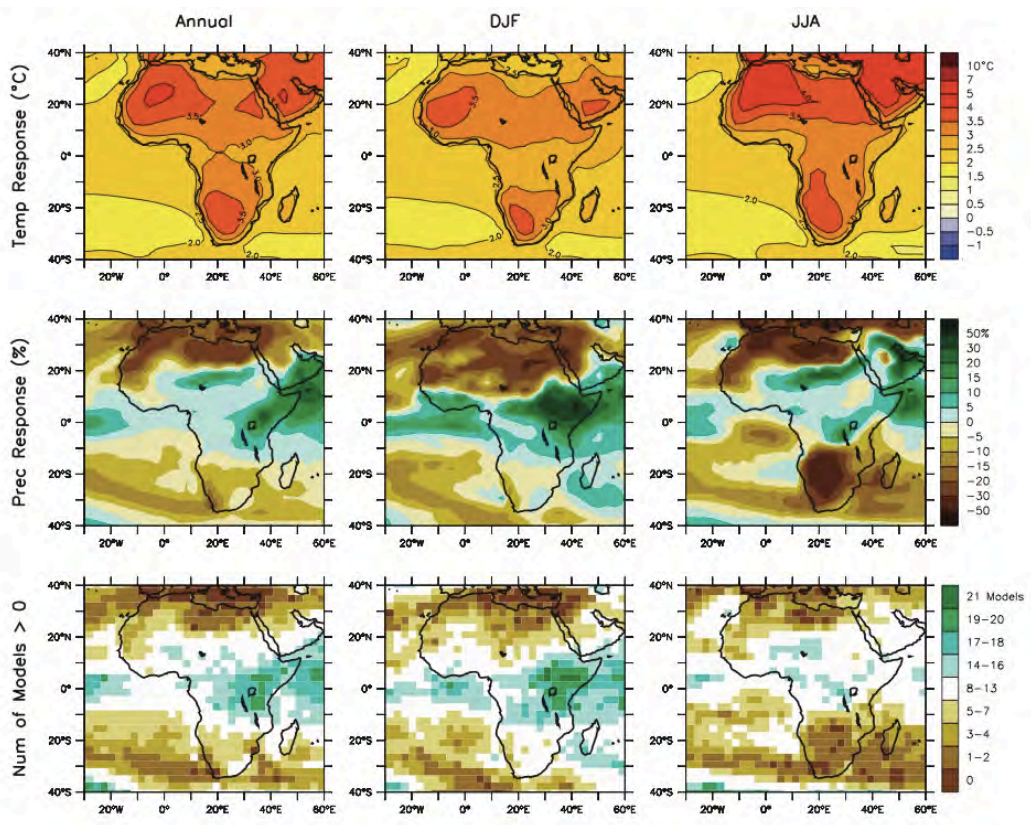


Fig. 7 Temperature and precipitation changes over Africa from the MMD-A1B simulations. Top row: Annual and seasonal (December, January, and February; June, July, and August) average temperature change between 1980–1999 and 2080–2099, averaged over 21 models. Middle row: Same as top, but for fractional change in precipitation. Bottom row: Number of models out of 21 that project increases in precipitation. *Source:* IPCC 2007a.

Confidence Levels for the Projections

Figure 8 further shows the range of projected temperature and rainfall anomalies by different models, under different emission scenarios and for two different time horizons. This view does not allow for a differentiation between the Sahel and coastal zone but shows the level of agreement among models. All the models agree on an increase in temperature by about 1°C (+/-0.7) by 2030 and by 2°C (2.7°C resp.) in lower emission scenario by 2060, with a spread among the models reaching 2°C. By contrast, rainfall averaged over West Africa seems to remain stable on average with half of the models predicting an increase of about 5% by 2030 and 10–15% by 2060, and half predicting the inverse. Despite a potential limited change in rainfall, the increase in temperatures may have large impacts on climate-sensitive sectors, especially agriculture in zones that are currently already vulnerable.

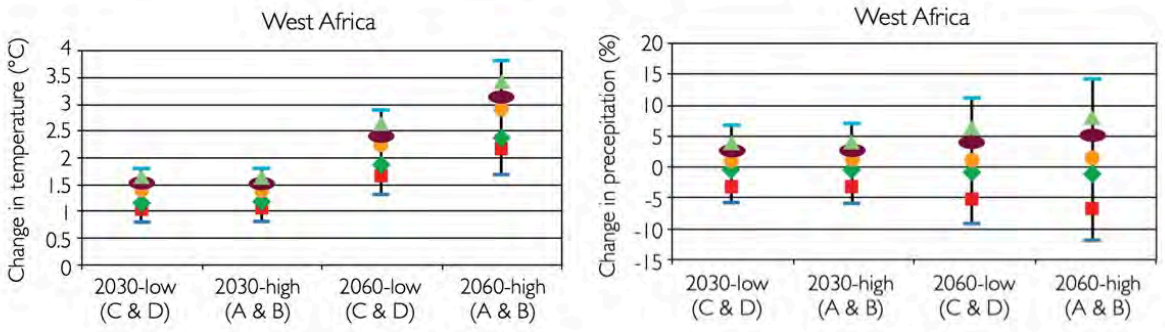


Fig. 8 Projected changes in temperature (left) and rainfall (right) by 19 individual models from IPCC AR4 WG1 under different scenarios and averaged over West Africa. *Source:* Foresight (2011: 69).

Additional uncertainty as to rainfall evolution in the near future comes from its strong decadal variability that is currently believed to arise independently of anthropogenic climate change and is not well represented in models used to project the impact of anthropogenic emissions on climate (cf. Decadal Variability section above). Its strong amplitude can mask for decades any rainfall evolution related to climate change. The ability of models to correctly predict this decadal evolution has only started to be investigated in a systematic way (Taylor et al., 2012).

3.3 CURRENT CLIMATE RISK MANAGEMENT

Decadal changes with impacts over large areas have precipitated humanitarian crises, most notably the great Sahel droughts of the mid-1970s and mid-1980s. Climate in West Africa, and particularly in the Sahel, has been extensively studied and a number of initiatives exist at regional and national levels to help manage the risk linked to high climate variability and persistence of anomalies. The Permanent Interstate Committee for Drought Control in the Sahel (CILSS) has been one of the main drivers of the initiatives at regional scale, with institutions such as the Agriculture, Hydrology, and Meteorology Regional Centre (AGRHYMET, an agricultural and hydrology meteorological research group) at the forefront. The recent World Meteorological Organization (WMO) initiative established a Global Framework of Climate Services and further fosters the development and use of climate information in climate-sensitive sectors. It is widely recognized that early warning systems for food security (i.e., USAID's Famine Early Warning Systems Network and the United Nations Food and Agricultural Organization's (FAO) Global Information and Early Warning System) have, in the past 20 years, contributed to a reduction in famine emergencies (Genesio et al., 2011).

Some countries, mostly Sahelian, provide comprehensive monitoring products on the current climate, water, agriculture, and food situation (including prices and farming advice) through interdisciplinary working groups. National-level food security authorities exist in several countries. A number of climate and weather products are issued at regional and national scales such as: daily-to-weekly weather forecasts; 10-day-to-monthly weather and related drought,

flood, pest, and disease alerts; and seasonal forecasts. In addition to agriculture and food security, seasonal forecasts were successfully used in disaster preparedness and management in the 2008 West Africa floods (Tall et al., 2012). There is a general awareness of climate-related issues, and efforts have been made to build information and capacity at different stakeholder levels. Interdisciplinary working groups in the Sahelian countries are good examples of platforms needed to better develop, share, and use climate information in climate-sensitive sectors. However, few institutions are making use of longer-term climate change scenarios in their planning and development activities, and the management of climate risk is still more reactive than planned.[6]

There are several key reports that summarize the availability of climate information and regional climate monitoring capabilities (e.g., Afouda et al., 2007; Garrison, 2010; ACPC, 2011). According to a 2009 Integrated Regional Information Networks (IRIN) report, the WMO stated that out of the 744 weather stations across Africa, only a quarter met international standards and that Africa needs at least 3,000 weather stations evenly spaced across the continent (Brahic, 2006; IRIN, 2009). The Garrison report prepared for USAID notes that national-level Meteorological (Met) Offices are weak and often lack the capacity to translate technical data into climate services to meet development needs. Local data collection is still insufficient for advanced modeling, and regional coordination appears fractured across numerous agencies and initiatives (IRI, 2006; Garrison, 2010; ACPC, 2011).

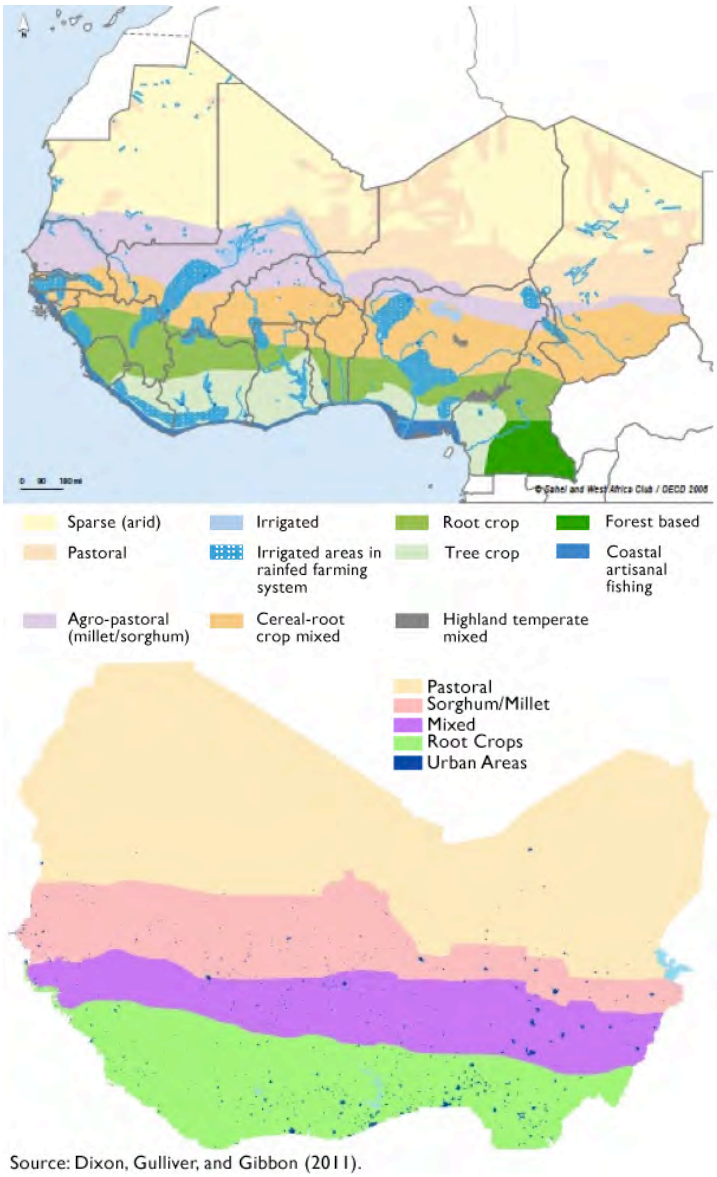
CLIMATE CHANGE VULNERABILITIES BY SECTOR AND ISSUE

4.1 AGRICULTURE

4.1.1 Overview

Agriculture is a critical sector in West Africa due to its impact on GDP, food security, and health. Owing to population growth and the socioeconomic conditions that constrain farm productivity and intensification, agriculture is also a driver of land-cover change as farmers move into new lands in order to ensure food security (PERN-PRIPODE, 2007). Three major agro-ecological zones cut east-west swathes across the region, corresponding largely to climatic zones, while a fourth, wetlands, is found both in inland and coastal areas. Farming systems and food staple crops also follow a geographic stratification that mirror rainfall, vegetation, and soil types (Figure 9).

[6] More detailed assessment of climate services can be found in Kadi et al. (2011).



Source: Dixon, Gulliver, and Gibbon (2011).

Fig. 9 Farming production systems (top) and food staple zones (bottom) in West Africa. *Sources:* Top map from OECD (2007c: 5) and bottom map from Haggblade et al. (2012: 11)

Cereal staples of maize, millet, rice, and sorghum dominate crop production. These crops are of significant importance economically. They contribute to regional trade, food security, and employment (owing to the large number of smallholder farmers) and have the potential to generate revenue through value-added industries. Other important crops in the tropical inland and coastal zones include cassava and yams, which are dietary staples, together with plantains, groundnuts, and vegetables (Haggblade et al., 2012). Pulses such as cowpea provide both dietary calories and protein and are used as "green fertilizers" to improve soil health (Thornton, 2012). As cash crops, cotton and cocoa are large contributors to export revenues (Nin-Pratt et al.,

2011). Livestock production (covered in the Pastoralism and Livestock Production section) constitutes almost half of the region's agricultural GDP (OECD, 2008b) and works synergistically with the cropping system through browsing of crop residue, livestock feed, and manure production, which is often the only fertilizer input available (USAID, 2011).

Drought conditions have shifted the areas suitable for rainfed agriculture (OECD, 2007c) and have reduced the length of the growing period in Senegal, Mali, and Niger (Sarr, 2012). Delayed onset of the rainy season is considered to be the primary cause of reductions in growing season length (Sivakumar, 1988).

4.1.2 Crops

Although farming systems in West Africa have diversified roughly according to climatic zones, the literature rarely takes the approach of examining agricultural systems in this manner, with the exception of the semi-arid Sahelian zone, which has received more attention due to its history of drought. Even in that case, focus overwhelmingly tends to be either on a crop or a region within a specific country (e.g., Barbier et al., 2009; Armah et al., 2011; Tambo and Abdoulaye, 2012; Haussmann et al., 2012; Srivastava et al., 2012). One notable exception is a study by Fungo (2011) that examined nutrition and food systems in West and Central Africa according to agro-ecological zones (semi-arid, sub-humid, humid forest, and inland valley/mangrove swamps) and 13 types of farming systems identified by FAO.

Many of the crop varieties important to subsistence farmers are not heavily studied at mid-latitude research institutions. In comparison to wheat, maize, rice, and soy, crops such as millet, sorghum, cassava, groundnut, and yam receive much less research attention (Ruane, personal communication, 2012). When one considers the great diversity of crops actually utilized by subsistence farmers, this knowledge gap becomes even more apparent (Ruane, personal communication, 2012).

Thornton and Cramer (2012) and the Consultative Group on International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture, and Food Security (CCAFS, 2012) discuss some of the relationships between climate variables and certain key staple crops in West Africa. Cassava, cowpea, millet, and yam are considered to be drought tolerant, but drought can increase the risk of viral disease in yam. Crops considered to be vulnerable to drought include groundnut, rice, and sorghum (due to increased risk of fungal diseases). Some of these crops are unable to deal with heavy precipitation and associated waterlogging during the growing season, or at specific times within the season (particularly at planting and harvest). Sorghum, millet, and maize have a relatively narrow optimum precipitation range. Rice, on the other hand, has a wide optimum precipitation range. Extended flooding and wet soils pose problems for cassava and rice and can increase root rot and pathogens in yam. Millet, maize, and cowpea are also sensitive to waterlogging. Temperatures above the maximum levels required for growth are a problem for all crops, but certain crops

react more negatively to increases in daytime temperature (e.g., maize) or nighttime temperature (e.g., rice) (Thornton and Cramer, 2012; CCAFS 2012).

A number of quantitative studies have attempted to assess the impact of climate change on crops important to West African agriculture using econometric, empirical, and process-based methodologies.[7] Significant limitations with respect to input data, methods, and assumptions of the three types of crop/climate studies lend great uncertainty to their results, limiting their predictive capacity. Econometric models that describe agricultural productivity resulting from the relationship between farmers' income, production systems, and environmental conditions are strongly limited by the lack of crop yield data (Müller et al., 2011; Roudier et al., 2011). Statistical models account for heterogeneity in farming systems, soils, and management inputs at large spatial scales also used in the most widely used climate projections (Roudier et al., 2011), but like the econometric models, they are constrained by data availability (Ruane, personal communication, 2012). Lobell and Burke (2008) found large uncertainties in average growing season temperature changes and crop responses, suggesting that more research is required to understand the effect of temperature on crop production. Moreover, these models have little explanatory power, limiting their extrapolation to conditions under climate change (Müller et al., 2011; Ruane, personal communication, 2012).

Process-based crop models (such as the widely used Decision Support System for Agrotechnology Transfer [DSSAT]; Environmental Policy Integrated Climate [EPIC] Model; Cropping Systems Simulation Model [CROPSYST]; Système d'Analyse Régionale des Risques Agroclimatiques, version H [SARRA-H]; or Agriculture Production Systems Simulator [APSIM]) are able to capture the complex physiology of crop growth.[8] However, these models use different levels of detail and have not been fully developed for most of the important crops in West Africa. Furthermore, it is difficult to capture the wide variety of different conditions, soils, and farming practices in the models. For instance, important factors such as local cultivars, CO_2 fertilization,[9] and farmer adaptation practices may not be captured. Demand and supply patterns affecting production are not taken into account (Challinor et al., 2007; Müller et al., 2011; Roudier et al., 2011; Ruane, personal communication, 2012). Nearly always, only a small selection of available climate projections is used in impact assessments (Müller et al., 2011). A scale mismatch that requires downscaling of global climate data to the regional level further adds to model uncertainties, and the use of regional climate models does not appear to improve predictive capability (Oettli et al., 2011).

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[7] We found only two quantitative studies on climate change impacts on West African livestock production, both econometric (Seo, 2010a, b). For more on climate change impacts on livestock, see the Pastoralism section.

[8] SARRA-H has been tailored to West African crops and is being used in Senegal.

[9] Plant species vary in terms of the response of photosynthesis to CO_2. C3 plants (wheat, rice, soybean, cotton, cassava, groundnut, and potato) respond well to higher CO_2 levels. C4 plants (maize, millet, and sorghum) are more photosynthetically efficient under current levels of CO_2 concentration and thus are more negatively impacted under rising emissions scenarios. However, as Müller et al. (2011) note, the validity of findings for the CO_2 effect for larger regions and entire cropping systems has not been tested.

Müller et al. (2011) illustrates the vast range of results for 14 quantitative studies of climate change impacts on African crops (Figure 10). Yield impacts ranged from -100% to +168% in econometric assessments, from -84% to +62% in process-based assessments, and from -57% to +30% in statistical assessments.

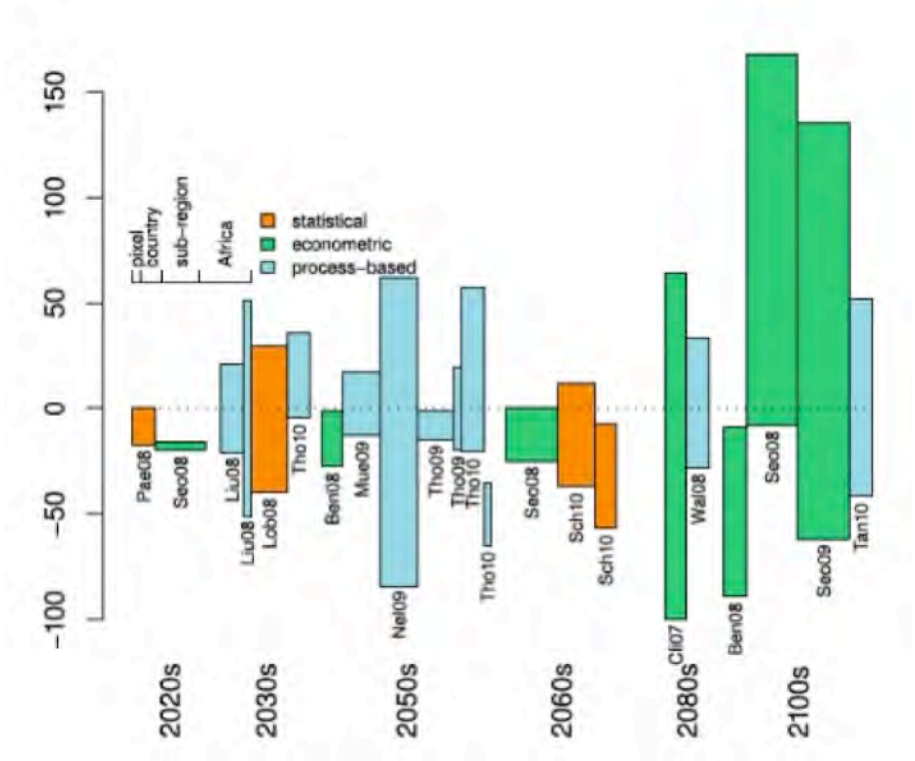

Fig. 10 Variations in projected ranges from 14 studies of climate change impacts on African crop yields, expressed as a change in percent relative to present conditions. Bar widths indicate spatial extent of the projection and color depicts methodology. *Source:* Müller et al. (2011: 4314)

A survey of findings from 16 statistical and process-based models analyzing West African crops by Roudier et al. (2011) also shows a wide variation of results, ranging from a decrease in yield of -50% to an increase in yield of +90%. Despite the wide variance of results, median values of -18% for Sahelian countries and -13% for Guinean countries are considered robust since both types of models result in negative yield values. According to the authors, "The consistently negative impact of climate change results mainly from the temperature whose increase projected by climate models is much larger relative to precipitation change. However, rainfall changes, still uncertain in climate projections, have the potential to exacerbate or mitigate this impact depending on whether rainfall decreases or increases" (Roudier et al., 2011: 1073).

CGIAR's CCAFS (2012) compared the current spatial production in West Africa of cassava, millet, rice, sorghum, maize, and cowpea and their climatic thresholds in order to determine where crop growth may be limited by future climate, paying particular attention to the Sahel. Results are open to question due to uncertainties in climate projections and the lack of crop

level data to verify results against observed yields. Temperatures within the current cultivable area for cassava will increase, while the northern growth limit may extend into the Sahel. There is even greater uncertainty in the future spatial extent of cowpea production. For rice, shifts in cultivation area are uncertain, but since rice has a fairly wide optimum precipitation range, the increasing temperatures projected are assumed to improve growth conditions. The potential cultivable area for millet is projected to expand both northward and southward. Sahelian cultivation of sorghum will be affected by rising temperatures, while maize production will be relatively unaffected. The CCAFS study also noted that if total precipitation decreases, which will already stress these crops, the increase in intra-seasonal variability of precipitation will provide a further challenge to their cultivation.

Relatively little has been done to study the effect of climate on crop biotic stress caused by weeds, pests, viruses, and pathogens (Gregory et al., 2009). These stresses cause as much as 50–60% yield reduction (Nin-Pratt et al., 2011). It is necessary to further investigate the effect of climate on crop biotic stresses to further determine yield impact (Müller et al., 2011; Ruane, personal communication, 2012; Thornton, 2012).

Ericksen et al. (2011) conducted a spatial analysis using food security and vulnerability indicators (measuring exposure, sensitivity, and capacity to cope with shocks) together with climate data in order to identify food security "hotspots," i.e. areas where "flips" in conditions conducive to crop production could be expected to occur with areas of vulnerable populations. Figure 11 (left) shows areas with a strong probability of a greater than 5% change in length of crop growing period (LGP) with vulnerability indicators, while Figure 11 (right) shows areas where rain per rainy day decreases by more than 10%. In both maps, the key areas of concern are colored in dark red (areas of high exposure and low capacity to respond) and light red (areas of high exposure and relatively higher capacity to respond).

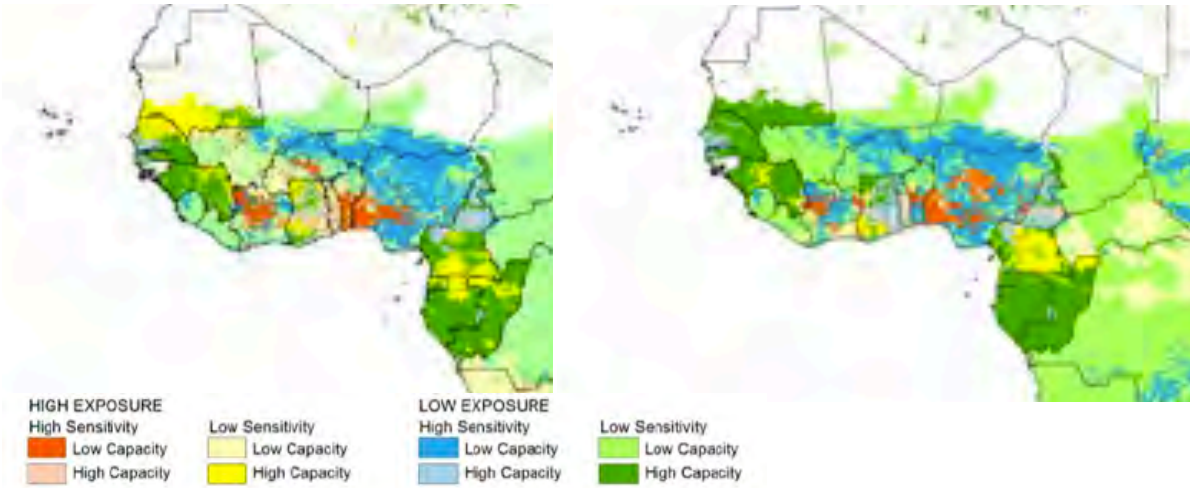

Fig. 11 Areas with >5% change in LGP (left). Rain per rainy day decrease >10% (right). *Source*: Ericksen et al. (2011: 29, 32).

Farmers have developed mixed farming systems to buffer against the risk of crop failure and to increase their income and assets in both the Sahelian (crop-livestock systems) and coastal zone (crop-livestock-tree systems) (OECD, 2008b). Jones and Thornton (2008) suggest that as areas already marginal for cropping become increasingly less productive under many climate change scenarios, farmers may shift from cropping to increased dependence on livestock.

The Agricultural Model Inter-Comparison and Improvement Project (AgMIP) under the sponsorship of the UK Department for International Development and the U.S. Department of Agriculture (USDA) seeks to link improved crop and economic models with climate data by working with multiple crop and world agricultural trade modeling groups around the world. It is expected that this will: a) address current gaps with respect to livestock, pests, and pathogens; b) lead to model improvement and better inter-comparison ability; c) provide the necessary data as well as the ability to test adaptation and mitigation strategies across a range of scales; d) build monitoring and early warning systems; and e) inform water allocation. A fast-track study in Senegal is expected to produce some results in early 2013, but more complete results and capacity are not expected until spring 2014. Pilot programs involving research on millet, sorghum, and groundnut will help to advance important West African crop research (Ruane, personal communication, 2012).

4.2 PASTORALISM AND LIVESTOCK PRODUCTION

4.2.1 Background

Livestock production represents an important component of livelihood portfolios across all of West Africa's ecological regions. In addition to being a critical productive activity, livestock rearing holds a great deal of cultural importance for certain social groups in the region, especially in the higher latitude, semi-arid areas such as the Sahel and the Sudano-Sahel (Niamir-Fuller, 1999). Livestock production takes a variety of forms across the West African ecological gradient, ranging from nomadic extensive grazing in the arid far north to sedentary intensive systems in the sub-humid areas in the south. Most livestock production in West Africa relies on some combination of geographic mobility and sedentary production.

Herein, pastoralism is defined as livestock management that includes some degree of geographic mobility. Pastoral mobility is essential to dryland livestock production due to highly variable ecological conditions that characterize dryland areas. Long distance mobility (>100 km) is required to access: highly productive semi-arid rangelands (where agricultural pressure is lower) during the rainy season; and crop residue, aerial forage (trees), and permanent water sources during the dry season. Short distance mobility (<25 km) is utilized to move herds away from cropped areas to reduce the risk of crop damages, away from riverine habitats that host livestock diseases such as animal sleeping sickness (trypanosomiaisis) (Bassett and Turner, 2007), and to exploit local-scale grazing opportunities and ecological niches.

Pastoral mobility has long been employed as a dryland production strategy and will continue to be central to pastoral livelihoods in the foreseeable future. However, the context for pastoral mobility has changed as dryland populations have grown, crop agriculture has expanded, social relations have evolved, and livelihood strategies have been modified accordingly. As a result of these changes, pastoralists must now adapt to greater competition for land and water; employ more intensive, market-based activities; and recalibrate their political strategies for securing resource access and resolving conflicts (see also the Herder-Farmer Conflict subsection in the Potential for Conflict section). All of these livelihood components are complicated and potentially threatened by regional climate change through its effects on natural resource conditions (including crop productivity), commodity prices, human and livestock mobility patterns, and many other factors.

4.2.2 Climate Change Direct Impacts

In light of the high degree of uncertainty of regional climate models (as described in the Overview of Climate section of this report), this section considers published scenarios and the likely impacts of precipitation and temperature changes on regional livestock production. There is not yet an agreement on the direction of precipitation change in West Africa, although some increase in the intensity of rainfall events is considered likely (Ericksen et al., 2011). Stronger agreement exists in the climate modeling community that regional temperatures will increase over the next 50 years.

Considering a set of climate models that predict a reduction in rainfall in the Sahel over the next 50 years, Hein et al. (2009) construct an ecological-economic model that suggests decreased rainfall combined with increases in rainfall variability in the Sahel will reduce incomes among pastoralists and require destocking to reach efficient grazing levels. Destocking is a controversial strategy that has been unsuccessfully attempted in the past. Scientific studies have shown that livestock densities in drylands rarely reach carrying capacity and that compelling pastoralists to reduce their livestock holdings can lead to unnecessary suffering and increased vulnerability to climate shocks (Turner, 1993).

In terms of periodic drought, a study conducted by Herrero et al. (2010) in East Africa found that drought recurrence every five years keeps livestock levels stable, while increasing frequency to every three years substantially, and possibly permanently, reduces livestock densities in Kenya. It is worth noting, however, that livestock densities have always varied with climate fluctuations in dryland areas. Lesnoff et al. (2012) find that recovery time following droughts is extremely variable. This variability of recovery time has implications for the impacts of droughts across different socioeconomic groups, as wealthier livestock keepers will be able to expend capital to rebuild their herds more quickly and easily than poorer ones.

Another effect of climate change on regional precipitation is the loss of peak August rainfall (Nicholson, 2005; Lebel and Ali, 2009) and increased frequency of rainy season "mini-droughts" and intense rainfall episodes, which are already reflected in local, non-expert accounts of

climate change (Roncoli et al., 2002; West et al., 2008). Intra-season changes in precipitation have important impacts on crop production, which indirectly affect livestock production through pricing, availability of crop residue and fodder, and the potential for continued extensification of cropped areas. In the Sudano-Sahel, the livestock sector is considered to be less sensitive to climate change than the rainfed crop production sector (Mertz et al., 2010). Livestock production is more viable than rainfed crop production in drier conditions and can be moved in response to spatiotemporal changes in resource availability. However, given the increasing reliance of livestock production on feed inputs, the expected negative impacts of climate change on staple crop production (Burke et al., 2009; Müller et al., 2011; Roudier et al., 2011) will likely impact livestock owners as well, especially considering the number of West Africans who rely on both livelihood activities. This topic deserves further study.

Changes in intra-seasonal precipitation patterns shape the relationship between the timing and location of grazing bouts and rainfall events (Hiernaux, 1984; Turner et al., 2005). For instance, these rainfall changes may affect the ability of vegetation to grow following the typical periods of heavy grazing at particular sites, and they may accelerate transhumance movements (increasing probability of crop damage) when late season rainfall falls off abruptly. Another impact on livestock production occurs when, by affecting grazing impact on vegetation growth, more concentrated rainfall results in a shift in species composition toward short-cycle forbs and grasses. Furthermore, changes in intra-seasonal precipitation affect the distribution and availability of ephemeral water sources, which could potentially increase the importance of boreholes and deep wells, involving associated tenure and governance issues. As pointed out by Thornton et al. (2009), climate change will substantially impact groundwater levels and runoff, which feed these water sources.[10]

Thornton et al. (2009) and Lohmann et al. (2012) emphasize the decisive importance of precipitation regimes on future changes in vegetation resources. Increased CO_2 levels and temperature, all other things being equal, will increase plant productivity (Thornton et al., 2009), but when coupled with reductions in rainfall, the opposite takes place. Length of growing season will also be affected by the interactive changes in rainfall and vegetation with potential negative impacts on livestock production (Ericksen et al., 2012). In terms of vegetation productivity, Butt et al. (2005) report that a predicted hotter and drier climate in Mali (2010-2030) will cause forage yields to decline by 5–36% and livestock animal weights to drop by 14–16%. These predictions are largely applicable to other parts of semi-arid and sub-humid West Africa. In another study conducted by Stige et al. (2006), analysis of animal slaughter weights—under climate vulnerability models based on the ENSO and North Atlantic Oscillation (NAO) weather variability models—indicates a decrease in slaughter weight of goats following years where NAO has negatively impacted crop production; such significant changes were less detectable in cattle and sheep.

[10] Thornton et al. (2009: 118) note that "attempts to quantify the impacts of climate change on water resources in the land-based livestock systems in developing countries are fraught with uncertainty, particularly in situations where groundwater accounts for a substantial portion of the supply of water to livestock, which is the case in many grazing systems."

Climate changes will impact vegetation types in different ways. Competition between C3 and C4 plant types will change, which will affect the balance between grazing and browse rangelands resources. C3 and C4 refer to different biochemical mechanisms for carbon fixation in plants. C4 plants have a competitive advantage at high temperatures and during droughts. Not only will vegetation changes influence livestock species composition (cattle versus small ruminants), it will also impact livestock nutrition as C4 plants are less nutritious in terms of crude protein than C3 varieties (Thornton et al., 2009). Thornton et al. (2009) explain that increased temperatures lead to more lignification of plant tissues and less nutrient availability for livestock and point out that little research has been done on this issue in the tropics. Drier conditions will also favor annual over perennial grass species with implications for dry season livestock forage since the annual varieties are of lesser pastoral value than perennial grass species (Le Houérou, 1989).

Lohmann et al. (2012) look at this issue by integrating grazing pressure into an ecohydrological savannah model. Their results emphasize the negative consequences of drier conditions for rangeland productivity and that the loss of perennial grasses can eventually lead to shrub encroachment and overall land degradation, loss of biodiversity, and reduced system resilience. However, it is worth pointing out that the semi-arid rangelands of West Africa are highly resilient. In a long-term field study of Sahelian rangelands in the Gourma district of Mali, Hiernaux et al. (2009) show how vegetation returned following the 1984 drought, first through pioneer woody plant recruitment, followed by some diversification since the mid-1990s and, over the long-term, a potential return to previous composition. This and other studies offer valuable policy lessons: destocking, especially in semi-arid to arid areas, is not likely to be necessary or encouraged; and, similarly, geographic mobility must continue to be promoted in order for livestock to move between patches of vegetation in varying states of recovery following periods of drought.

4.2.3 Agricultural Expansion and Resource Competition

Agricultural expansion is the principal threat to livestock mobility in dryland West Africa. It interrupts or completely blocks seasonal pastoral movements, as evidenced in Senegal by the shift from a north-south trajectory oriented toward the Ferlo rangelands to an east-west trajectory that follows the Senegal River (McPeak, 2011). Thus, agricultural expansion contributes to farmer-herder conflict as pastoralists find it increasingly difficult to avoid movement of livestock through croplands. This is a longstanding problem, but one that still consumes considerable political resources in rural West Africa and undermines the social relationships that are needed to build inclusive local institutions.

Agriculture expansion often comes at the expense of grazing areas, which can contribute to local-scale overgrazing and even undermine soil fertility, which depends on manure inputs to maintain nutrient balances, especially under land scarcity (Powell et al., 2004; Turner et al., 2005). Agricultural expansion also leads to significant ecological changes that impact livestock production by causing a shift from perennial grass species, (e.g., Andropogon spp.) that are

highly palatable for cattle to annual varieties when land is cultivated and then left fallow for less than five years.[11] Not only are these annual species of lesser pastoral value, they are also intolerant to fire (Le Houérou, 1989). In sub-humid areas (south of 14° N latitude), dry season fires affect a large portion of the landscape and instead of regenerating perennial grasses and providing rich livestock fodder, they now eliminate annual grasses until the following rainy season.

West African livestock producers are adapting to agricultural expansion in several ways. During the dry season, they increasingly rely on aerial forage through the lopping and pruning of trees (Gautier et al., 2005),[12] purchases of feed supplements such as cottonseed cakes (Moritz, 2010) and crop residues (Ramisch, 1999), herd size reductions, and shifting to small ruminants like sheep and goats. Although branch lopping can be done sustainably, it is widely seen, especially among local farmers, as an ecologically destructive practice. It greatly contributes to animosity toward livestock herders, especially in relation to species such as bamboo, which are also heavily used by farmers. The creation of sustainable aerial forage production methods and rules should be considered a principal area of intervention for climate resilient livestock development in West Africa. The purchase of feed supplements, or "cut and carry" pasture, plays a growing role in West African livestock production as, in many places, extensive rangelands are no longer adequate to support existing herds. This ties pastoralists more closely to markets and can cause them to reduce their herd sizes due to the capital requirements of feed purchases, which can also drive poorer herders to move out of livestock production altogether to become hired herders or smallholder farmers. Aerial forage and purchased inputs are likely to increase in importance for livestock herders in eastern Senegal and other parts of the Sudano-Sahelian zone of West Africa.

4.2.4 Intensification/Diversification of Livelihoods

It would be worth investigating the barriers that herders face to accessing the inputs they need and whether new livestock feed supply chains should be supported or developed. Crop residue is necessary but inadequate as dry season livestock feed. Farmers who hold their own livestock will typically reserve their post-harvest crop residue for their own animals. Moreover, farmers who are angered by uncompensated crop damage will often rather burn their residue than allow access to pastoralists. Finally, crop residue that is removed from fields to feed livestock represents a soil nutrient loss that must be compensated for in order to maintain crop production levels (Powell et al., 2004).

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[11] Perennial grass will regenerate following cultivation only after a sufficiently long fallow period. The droughts of the 1970s and 1980s also contributed significantly to the elimination of perennial grasses, especially in the northern extreme of their range.

[12] Note the difference between the cutting of small shrubby trees (*Acacia* spp.) for browsers (goats) and the lopping of branches from larger trees for both cattle and small ruminants/browsers.

Among the Fulani, the principal pastoral ethnic group in eastern Senegal, a shift from cattle to small ruminants will require overcoming a significant cultural barrier since cattle represent such a central part of the group's identity. An alternative to shifting from cattle to small ruminants, a shift that represents a significant loss in material and financial wealth, is agro-pastoralism. Not only does agro-pastoralism allow pastoralists to produce their own grain, feed supplements, and/or cash crops, it also allows them to access the benefits of local citizenship such as schools, markets, health clinics, and political resources (cf. Fratkin, 2012, for description in East Africa).

Sedentarization does not eliminate mobility-based livestock production. The lack of local pasture around settlements obliges livestock owners to send at least some animals on transhumance, which creates a labor bottleneck since at least some of their household workforce becomes occupied with farming or other forms of employment. In Cameroon, this has translated into pastoralists relying on hired labor to manage their herds, which poorer pastoral households are unable to afford and thus must significantly reduce their herd size (Kossoumna et al., 2010). The same labor constraint can also negatively impact rangeland conditions, as research has shown that the feed supplied to livestock declines in quality with reduced investment in herding time and effort (Turner et al., 2005).

4.2.5 Responses and Adaptations

Livestock keepers in dryland West Africa are highly resilient to climate shocks and long-term environmental change (Mortimore, 2010). Many of the previously described adaptations to agricultural expansion (aerial forage, feed supplements, livestock species shifts, and agro-pastoralism) are also important responses to climate change. Destocking and the gradual rebuilding of herds will continue to be principal responses to serious drought among pastoralists. It is worth noting, however, that the recurrent droughts of the 1970s and 1980s led to long-term changes in the Sahel's pastoral economy; after losing their herds, many pastoralists became wage-earning herders for absentee livestock owners, or they moved south to continue herding and/or to practice agro-pastoralism. Recognizing these types of long-term socioeconomic changes, extreme droughts should be seen less as cyclical events and more as part of a historical process that leads to both sudden shifts and incremental changes in livelihoods (cf. Bassett and Turner, 2007).

Livestock producers are vulnerable to the same climatic shocks as they always have been, and mobility plus destocking continue to be their principal response strategies. However, their adaptive capacity has permanently changed as they have taken up cultivation, secondary income generation activities (e.g., petty trade), and livestock husbandry more focused on commercial production (Dieye and Roy, 2012). In terms of vulnerability to climate change, the effects of these changes are positive (increased livelihood diversity) and negative (less labor available for herd mobility). A key question remains whether, on balance, overall vulnerability is increased or decreased by these changes. Under current conditions of resource scarcity, land competition, intensive production, and diversified market-based livelihoods, one could argue that vulnerability is increased by the absence of government support for rural livelihoods. Laws and

decrees are enacted to enhance crop and livestock production but comprehensive, sustained intervention in rural areas is not carried out. This lack of action on the part of authorities has likely been made worse by structural adjustment and perhaps, more recently, by the decentralization of political power.

It is important to consider how much the socioeconomic changes currently underway in the West African livestock sector will increase the likelihood of maladaptation (Barnett and O'Neill, 2010) to the worst case regional climate scenarios. One example is the increasing emphasis on milk production as a poverty reduction strategy and income-generating activity for West African pastoralists. Milk production is negatively impacted by hotter and drier conditions (Thornton et al., 2009), therefore agricultural extension research in places like Senegal must account for climate change as they work to build a regional dairy industry.[13]

Although many pastoralists are increasingly taking up crop production, Jones and Thornton (2009) indicate that the reverse might be a necessary adaptation in parts of semi-arid Africa by 2050 if certain climate change scenarios occur. Not only would this shift from crop farmers to livestock keepers represent a drastic change in West African agrarian economies, it also suggests that putting resources into crop agriculture rather than livestock as a development strategy may be shortsighted in certain areas. McIntyre et al. (2011), for example, argue that projects to support irrigated and rainfed rice production in Senegal may not be viable in the longer term due to climate change. If cropping does lose its viability in the drier parts of the region, pastoralists will be in a much better position to adapt than peasant farmers, of which a larger number would likely move to urban areas rather than take up livestock keeping as an alternative.

In all but the worst case climate change scenarios, a livelihood portfolio based on cropping and livestock is likely for both pastoralists and farmers. Climate change adaptation strategies must focus on livelihood and production systems that combine markets, mobility, and opportunities for intensive crop and animal production. This will include several measures that are currently underemphasized or entirely absent from livestock-oriented projects.

Rangeland degradation, particularly the loss of perennial grasses, is widespread in semi-arid West Africa and a major constraint on sustainable, mobility-based livestock production. The time is long overdue to link livestock corridors, which are a popular and necessary project component, with local-level grazing exclosures, or "zones de pâturage" (Homann et al., 2008). These projects are rife with socio-political pitfalls that lead to their failure, but they nonetheless merit increased attention and resources, particularly in collaboration with local governments.

Sustainable livestock feed production, especially in peri-urban areas, is another important measure. Attention should be placed on whether the use of supplemental livestock feed (e.g.,

[13] Increasing intensification of dairy systems in the developing world, through the use of temperate-breed genetic stock, could lead to greater vulnerability to increasing temperatures (Thornton et al., 2009).

for animal-fattening operations) is sustainable and nutritionally efficient (Diogo et al., 2010). As urban demand for meat and milk grows and is increasingly an important activity for livestock holders, the degree to which existing feed sources are adequate should be investigated. This includes annual crop production and agroforestry designed to produce livestock feed. These areas have been the focus of considerable research (cf. Dongmo et al., 2012) but, to take hold, they must be economically viable for farmers to invest their scarce labor. Development of markets for livestock feed will likely help make this happen.

Climate forecast information is not currently very useful for pastoralists, who need information on the timing of rainfall and its intra-seasonal variability (Kitchell, personal communication) although it is unclear whether this is even possible with existing climate models. The French-led African Monsoon Multidisciplinary Analyses project might be gaining insights along these lines (Genesio et al., 2011). Similarly, projects that broadly diffuse information about resource availability (water and pasture) should be approached with caution. Pastoralism is a socially stratified activity and information diffusion risks favoring larger, commercial herds to the detriment of local smallholders. Further, information provided as a public good may lead to overexploitation if too many herders/livestock move into a specific area. Educational information about climate change should be disseminated over the radio as a way to inform local peoples' longer-term decisions and livelihood planning. Although support for rural radio is strong in Senegal, climate change-focused programming appears to be lacking.

To improve governance, pastoralists must increasingly become integrated into local political communities in which they have historically operated as outsiders (Brottem, in prep.). Decentralization provides them with an opportunity to achieve this, but in many cases external support will be required due to limited local government capacity and recalcitrant peasant communities. This will likely be an incremental process, but should include specific, tractable measures. The payment of local taxes by transhumant herders should be facilitated (farmers and authorities in transhumant herders' home areas often resist this). This should lead to the establishment of more robust channels of accountability between elected local authorities and transhumance herders. Central governments could create financial incentives for municipal governments to establish and enforce land management plans that protect herd mobility.

Finally, perhaps obviously and arguably most importantly, Mortimore (2010) stresses that the adaptation policy must take local pastoralist knowledge carefully into consideration to avoid two pitfalls: (1) repeating many of the top-down mistakes of the 1970s; and (2) perpetuation of the split between climate change adaptation and poverty reduction measures. Ayantunde et al. (2011) present a set of indicators of pastoral sustainability that includes the preservation of pastoral traditions and indigenous knowledge, which risk being lost through integration, urbanization, and marketization.

4.3 RIVERS AND WATER RESOURCES

Scientific uncertainty around future rainfall and its likely impact on the water balance of West Africa's river basins is a major challenge. Precipitation outputs for GCMs for the region have been inconsistent (Afouda et al., 2007; IPCC, 2008; Oguntunde and Abiodun, 2012; Parish et al., 2012). Uncertainty is greatest in the Sahel region, with relatively less uncertainty in the coastal region (Mitchell and Jones, 2005; ACPC, 2011). However, monitoring programs have found an overall decline in water resource availability across West Africa that is greater than reductions in precipitation in the region. For instance, since the 1970s, whereas precipitation declined from 15–30% across West Africa, the observed declines in surface water supplies ranged between 30% and 50% (Afouda et al., 2007). Specifically, flows in the Senegalese and Gambian rivers declined approximately 60% from 1971 to 1989, far exceeding the observed annual decline in regional rainfall of 25% from 1951 to 1989 (Garrison, 2010; ACPC, 2011). During extremely dry years, flows completely stopped on the Bani tributary in Douna, Mali, in 1983, 1984, and 1987, and in Niamey on the Niger River in 1985 (OECD, 2006: 7).

4.3.1 Major Watershed Overview

Eleven of the 28 transboundary watersheds in West Africa are major river basins (OECD, 2006). The four largest river basins in the region have a total watershed area of approximately 3 million km^2 and traverse a combined distance of more than 8,700 km across eight countries (Figure 12). With the exception of Cape Verde, all West African countries share at least one river with one of their neighbors. These transboundary rivers pose a range of complex challenges to effective water resource management, as there is a high dependency ratio of many countries on water supplies that originate outside their territorial borders. Only five of the 28 transboundary watersheds have formal management organizations. The longest running organization is the Niger Basin Authority, established in 1963, while the most recently created transboundary management organization is the Volta Basin Authority, which was established in 2006. Table 1 below summarizes the characteristics of the four major river basins in West Africa ranging from historic discharge, management organization, and number of treaties.

Fig. 12 Transboundary watersheds in West Africa. *Source:* OECD (2006: 4).

The Fouta Djallon Highlands of Guinea, known as the "water tower" of West Africa, is the source of seven major rivers: the Niger, The Gambia, Senegal, Corubal, Kaba, Kolente, and Kayenga-Géba. Precipitation in this subregion is heavily influenced by orography and local atmospheric circulation (Sall, 2006). The Fouta Djallon is a critical source of water in the region, yet there is very limited research or monitoring in this area, except for the recently announced Global Environment Fund (GEF) program, which focuses heavily on community projects (Sall, 2007; GEF, 2009).

Studies of water balance and changing demands exist for each of major basins described in Table 1 (Rodgers et al., 2007; Höllermann et al., 2010; Oyebande and Odunuga, 2010; TFDD, 2011; Oguntunde and Abiodun, 2013). There are also a number of international agreements and multinational basin management commissions relevant to mitigating climate change impacts and ensuring stability between users and countries.

River Basin	River Origin	River length (km)	Water-shed Size (km^2)	Historic Discharge (km^3/year)	Formal Basin Organization (# of member states)	% of River by Country	Population (millions)	Treaties	Water Stress Range (m^3/year)
Volta River Basin	Burkina Faso	1,600	411,203	1,565	Volta Basin Authority (6 in West Africa)	Burkina Faso (42); Ghana (40); Togo (6); Mali (5); Benin (4); Côte d'Ivoire (93)	22.8	4	0–100
Niger River Basin	Guinea (Fouta Djallon)	4,200	2,105,196	39,530	Niger Basin Authority (8 in West and Central Africa)	Mali (30.3); Nigeria (28.3); Niger (23.8); Guinea (4.6); Cameroon (4.4); Burkina Faso (3.9); Benin (2.5); Côte d'Ivoire (1.2)	88.6	15	0–700
The Gambia River	Guinea	1,120	69,536	113	Gambia River Basin Development Organization (4 in West Africa)	Senegal (70); Guinea (16.5); The Gambia (13.3); Guinea-Bissau (0.02)	1.8	7	10–100

River Basin	River Origin	River length (km)	Water-shed Size (km²)	Historic Discharge (km³/year)	Formal Basin Organization (# of member states)	% of River by Country	Population (millions)	Treaties	Water Stress Range (m³/year)
Senegal River Basin	Guinea (Fouta Djallon)	1,800	434,518	560	Senegal River Development Organization (4 in West Africa)	Mali (53); Mauritania (26); Guinea (11); Senegal (10)	5.6	11	20–200

Table 1. Major West African river basins. *Sources:* ACPC (2011), TFDD (2011), Rodgers et al. (2007), Ayibotele (2008), and Rieu-Clarke (2011).

4.3.2 Groundwater Aquifers

The major aquifers in the region (Figure 13) are only accessible by deep drilling. Most domestic water consumption in West Africa, however, relies on shallow wells. Although the region's groundwater is an underutilized resource, the deep aquifers are non-renewable. Studies from the United Nations Educational, Scientific, and Cultural Organization/Internationally Shared Aquifer Resources Management Initiative and the Organization for Economic Cooperation and Development (OECD) identified considerable reserves in deep-water aquifers, estimated at several billion cubic meters, although specific quantities remain unknown (Afouda et al., 2007; OECD, 2006).

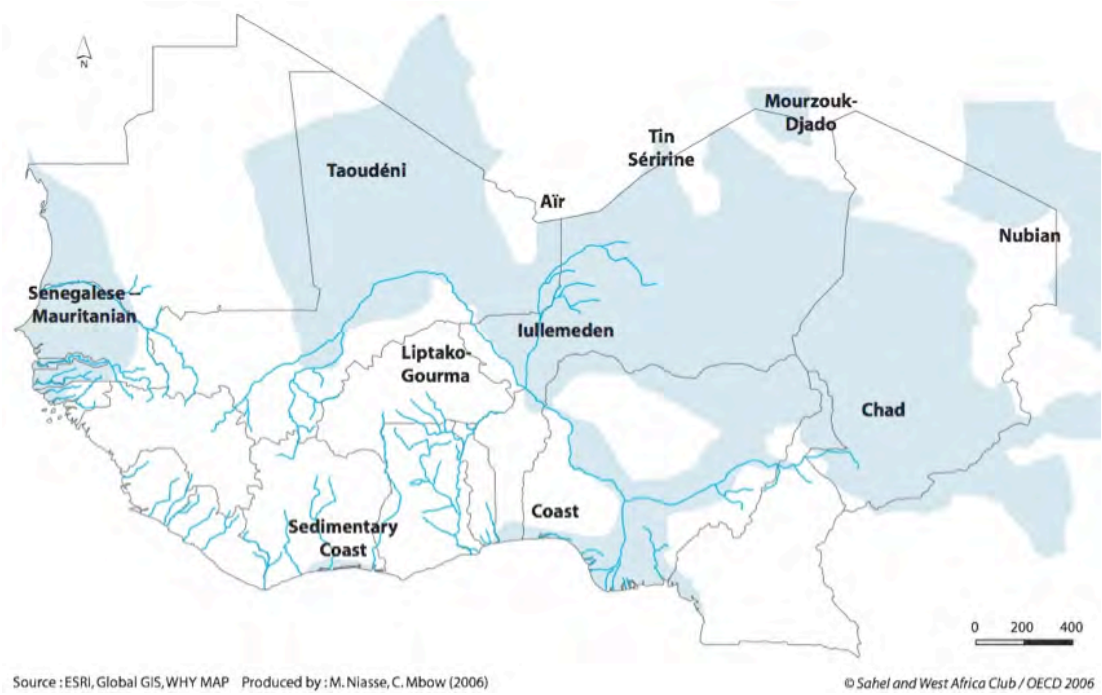

Fig. 13 Main transboundary aquifer systems in West Africa. *Source:* OECD (2006: 5).

4.3.3 Estimates of Changing Demands in Region

The Atlas on Regional Integration from the OECD reports an estimated potential six-fold increase in freshwater withdrawals between 2000 and 2025 if West African users maintain current levels of access to drinking water and food security. Increasing per capita consumption rates would further increase that withdrawal rate (OECD, 2006). The future of freshwater resources is difficult to assess due to complexity and rapidly changing geography and use patterns. There are already several global efforts to create water stress models by combining climate scenarios, water budgets, and socioeconomic information along digitized river networks (Vörösmarty et al., 2000). To date, this has not been done at the regional level for West Africa. There are examples of applied watershed management, such as the water availability and demand models for 2025 in Benin using the water evaluation and planning system (Höllermann et al., 2010) or the GLOWA Volta project run by German researchers (Rodgers et al., 2007).

Current estimates are that irrigation uses 76% of freshwater withdrawals, with 17% going toward domestic consumption and 7% for industrial use (Afouda et al., 2007). Agriculture is largely rainfed in the region. Yet some reports, like Oyebande and Odunuga (2010) on the Senegal Basin, suggest that irrigation is causing over-extraction of groundwater resources. Irrigation use generally increases with temperature and decreases when there is an increase in rainfall (IPCC, 2008).

4.3.4 Hydroelectricity

There are 150 large dams in West Africa out of a total of 1,300 on the continent. The region has fewer than two large dams per 100,000 km^2, as compared to 4.3 dams per 100,000 km^2 in Africa as a whole (OECD, 2006; Lehner et al., 2011) (Figure 14). Recently, the UN World Water Assessment Programme stated that hydropower could supply the region's entire energy need if cross-border cooperation was enhanced, using existing cooperation like the West Africa Power Pool (McKenzie, 2012). Many new hydroelectric projects are being initiated. On the Niger River alone, about 20 sites have been identified for large dams, and are at more or less advanced stages of planning. They include, in particular, Fomi and Kamarato in Guinea; Kénié, Tossaye, and Labezanga in Mali; Dyodyonga and Gambou between Benin and Niger; Kandadji in Niger; and Lokoja, Makurdi, and Onitsha in Nigeria (OECD, 2006). Similar to analysis conducted by International Union for the Conservation of Nature (IUCN), the development of new dams creates pressures on legal and management authorities, especially transboundary water allocation mechanisms (Newborne, 2010). The Senegal River Basin has four specific sub-committees providing forums for dialogue (Newborne, 2010). The presence of large hydroelectric dams have raised concerns about the impacts on biological resources, wildlife, water quality, and downstream quantity such as the IUCN impact assessment on the Gambia River Basin's Sambagalou hydroelectric dam (Diop and Niane, 2011).

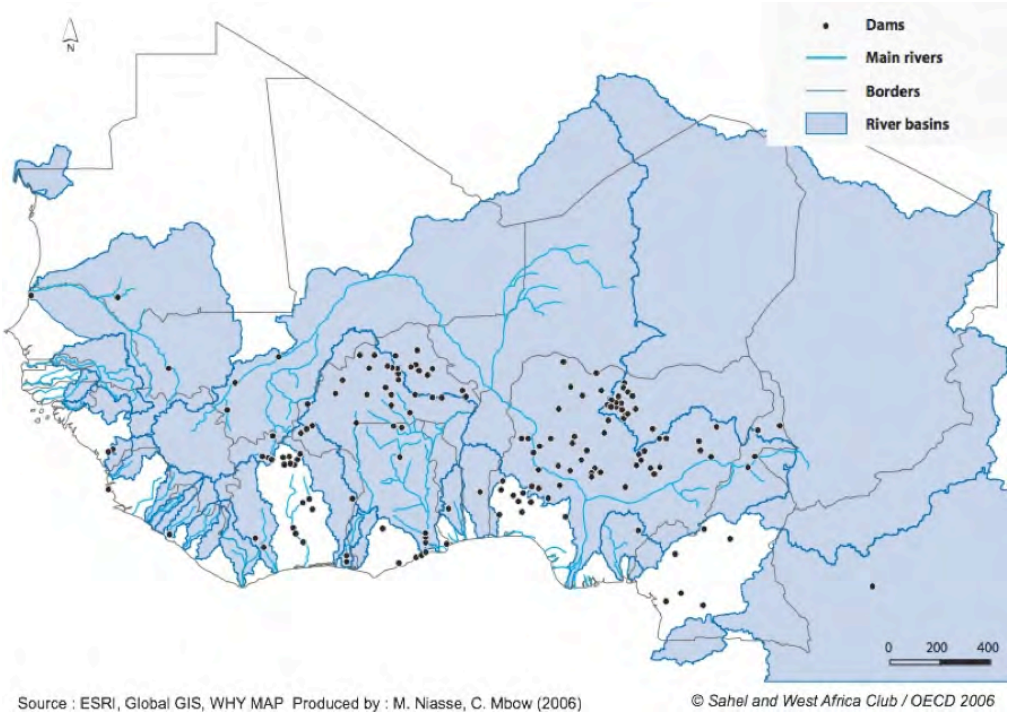

Fig. 14 Large dams in West Africa. *Source:* OECD (2006: 8).

4.3.5 Data Availability and Climate Modeling

There are a variety of water management agencies and monitoring systems across West Africa, which at present lack effective institutional arrangements to facilitate the generation, analysis, and systematic integration of relevant climate information with other information to support decision makers. These institutions include the Global Climate Observing System, monitoring and policy programs at AGRHYMET, and national-level technical coordination units (IRI, 2006; Garrison, 2010; ACPC, 2011). According to the United Nations Economic Commission for Africa (UNECA) Africa Climate Policy Center, there is a lack of downscaled modeling and scenarios to study the impact of climate change on water resources (ACPC, 2011). The Garrison report provides concrete recommendations and an overview of the institutional framework and opportunities for USAID (Garrison, 2010). There are emerging opportunities to use satellite imagery to create new monitoring sources (Dinku, 2005).

4.3.6 Risk and Water Resource Vulnerability Indices

A range of evolving methodologies to construct water resource availability and water scarcity indices monitor and quantitatively evaluate water resource vulnerability across facets of water use, supply, and scarcity, with landmark indices developed in the late 1980s by Falkenmark and Gleick (Brown and Matlock, 2011). These include the Falkenmark water stress indicator as total rainfall available per capita and have been calculated at the global scale. These methodologies remain to be applied to the West Africa region. Regional studies could include calculation of

the water footprint or watershed sustainability indices with components on hydrology, livelihoods, and governance. Such indices could then serve as tools to help prioritize and sequence financial, technical, and management support.

Wolf et al. (2003) argue that conflict mitigation is associated with the institutional capacity of management organizations. They found that many conflicts arise when demands on water resources outstrip the societal ability to address them. Other studies identify critical indicators of conflict mitigation such as the formality of joint management agreements of international basins, joint monitoring, mechanisms for conflict resolution, and mechanisms to avoid instances of unilateral project development (Wolf, 2003; De Stefano et al., 2010; Tir and Stinnett, 2012). Water stress is anticipated to combine with other stressors to exacerbate problems in areas already prone to regional instability (De Stefano et al., 2010).

4.4 INLAND AND COASTAL WETLANDS

4.4.1 Extent and Distribution of Wetlands in West Africa

Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. They have the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and saturated with water or covered by shallow water at some time during the annual growing season (Mitsch and Gosselink, 2007). Globally, wetland ecosystems can be found on every continent except Antarctica, covering approximately 2–6% of the world's land surface (Sundareshwar, 2010; Junk et al., 2013). In general, wetland ecosystems can be classified into two broad categories: coastal and inland.

Wetlands in West Africa include freshwater (non-tidal) inland wetlands in the Sahelian floodplains and tidal coastal wetlands and estuarine environments such as mangroves (Figure 15). The freshwater inland wetlands include: the floodplains of the Senegal, Niger, and Longone-Chari Rivers; inland deltas (e.g., the Niger Inland Delta in Mali); and lacustrine wetlands (e.g., Lake Chad).

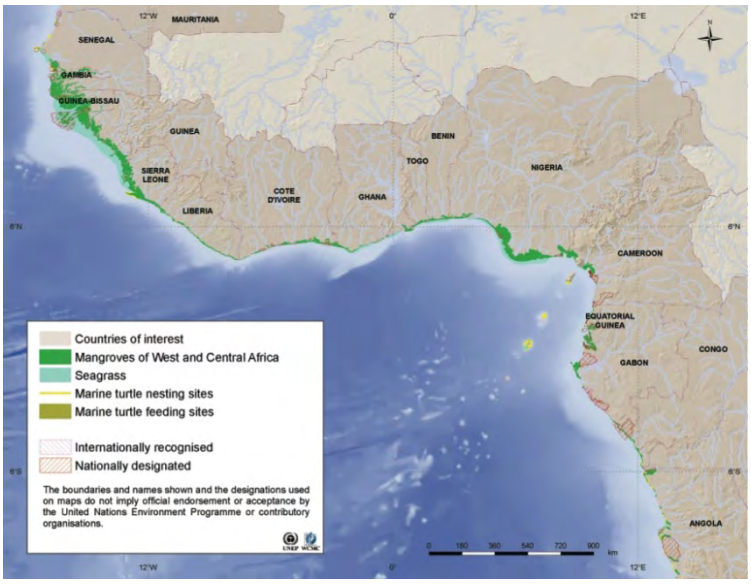

Fig. 15 Distribution of mangroves and other coastal habitats in West-Central Africa. *Source:* Compiled by UNEP-WCMC for Feka and Ajonina (2011: 218).

4.4.2 Sahelian Wetlands

The recurrent rainfall deficit in the Sahelian zones is moderated by interzonal freshwater transfer from the wet to the arid areas within West Africa. Specifically, the hydrological network of the major regional rivers—including the Niger, Senegal, The Gambia, and Volta with their source in the high-rainfall areas of the Sudano-Guinean region—flows through the drier Sahelian zones, creating a network of freshwater inland wetlands in the West African Sahel. During years of good flows, these interzonal freshwater transfers flood approximately 4.6 million hectares of the Sahel annually, of which about 3 million hectares are in the Niger Inland Delta situated in the semi-arid Sahel in Mali, about 500,000 hectares are in the Middle Senegal River Valley, about 400,000 hectares are in the Hadejia Nguru Plains in northern Nigeria, and approximately 800,000 hectares are in the Chari-Logone Plains between Cameroon and Chad (Table 2; Oyebande, 2002: 366). These Sahelian wetlands form a cornerstone of ecological and economic revenues regionally. For example, the Niger Inland Delta supports upwards of 550,000 people and, in the dry season, serves as grazing grounds for about 3 million heads of livestock including cattle, sheep, and goats. In addition, these wetlands support approximately 80,000 fishermen and 17,000 hectares of rice cultivation (Adams, 1993).

Number	River/lake system	Wetland area (10^3 ha)	Country
1	Senegal delta	300	Senegal, Mauritania
2	Senegal valley	500	Senegal, Mauritania

Number	River/lake system	Wetland area (10^3 ha)	Country
3	Niger inland delta	3,000	Mali
4	Niger fringing flood plain	300	Nigeria
5	Sokoto and Rima valleys	100	Nigeria
6	Hadejia Komadugu flood plains	400	Nigeria
7	Logone flood plain	1,100	Cameroon, Chad
8	Lake Chad flood plain	1,000	Chad
	Total	**6,700**	**West African Sahel**

Table 2. Extent of the original major wetland ecosystems in the West African Sahel. *Source:* Oyebande (2002: 366).

4.4.3 Vulnerability of Floodplain Wetlands

Despite their broad socioeconomic value, wetlands in West Africa remain among the most vulnerable to climate change and anthropogenic pressures. From the perspective of climate change impacts, models examining the trends in precipitation over the African continent predict that while some regions of the Sahel and areas to the south will have more water over the next two decades, the southwest of Africa will become drier (Mitchell, 2013; see also Rivers and Water Resources section). Although historically water levels in permanent and semi-permanent wetlands have varied in the West African Sahel as a result of climate variability inherent to this region, future climate change scenarios predict altered precipitation patterns (e.g., more frequent or intense rain or drought events) and river flows, which will have a pronounced effect on inland freshwater wetlands.

The flow of the Niger River that inundates the Inner Delta is affected by changes in climate, groundwater levels, and dam and reservoir construction. Drought conditions, which are exacerbated by climate change, have resulted in reduced river flow and subsequent decrease in flooding area. The flooding area of the Niger Inland Delta in 1956 was estimated to be 36,000 km^2. After the Great Drought in the early 1980s, flooding area decreased by 50–80% (Zwarts and Grigoras, 2005). During the period 1970–1990, the area that floods for at least four months of the year experienced a 91% decline (Oyebande, 2002). These climate change-driven reductions in water supply are worsened by higher temperatures that increase water loss through evapotranspiration.

In addition to the ecological impacts, traditional agriculture and fishing have also been adversely affected. For example, in the Logone Basin rice cultivation has dropped to 75%, while in the Niger Inland Delta annual fish catch dropped by 50% from the late 1960s to 1988 (Oyebande,

2002). Shrinking wetlands are increasingly creating conflict situations among multiple stakeholders. Pastoralists, who also use these wetlands for grazing during the drier periods, are often confronted with traditional farmers who utilize the same wetlands for cultivation during the wetter periods, with agricultural operations extending into a greater part of the drier period.

4.4.4 Vulnerability of Coastal Wetlands

With the exception of four landlocked countries, the remaining 14 countries in West Africa have significant coastlines with a combined length of approximately 6,467 km (CIA, 2012). The bulk of these countries' economic and communications infrastructures is concentrated in this coastal area. Approximately 28% of the region's population—or 88 million people—resided within 100 km of the coast in 2010 (CIESIN, 2012b). With major urban centers located along the coastline, the coastal zones of these countries face increasing pressures from rapid demographic growth, as a result of increasingly impoverished conditions in the countryside, partly due to climate change-driven drier conditions inland. Of the 14 countries with a coastline in this region, Nigeria, Togo, and Benin collectively rank among the highest in the pressure on their coastal resources (Figure 16). This suggests that land-use effects on coastal processes (e.g., deforestation due to greater exploitation of the coastal wetlands) and vice versa (i.e., effect of sea level rise) will be extreme.

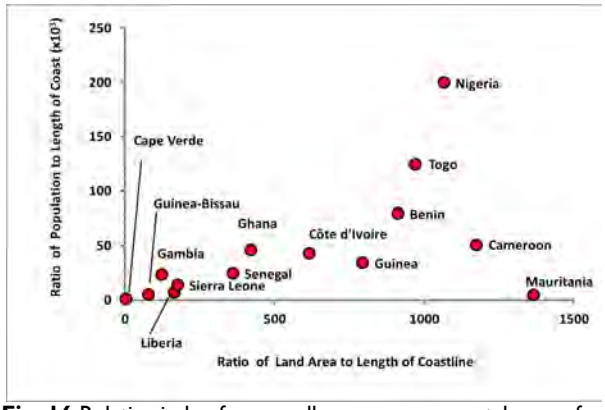

Fig. 16 Relative index for overall pressure on coastal zones for countries in the West Africa region that have a coastline (Sundareshwar, unpublished). *Data source:* CIA (2012).

Coastal erosion or sea advance is expected to lead to degradation of vital coastal wetlands, such as the mangrove forests, which cover roughly 15,000 km^2 in West Africa (Feka and Ajonina, 2011). A sea level rise of 0.5 m and 1 m will result in a loss of mangroves of 806 and 2,149 km^2, respectively (Dennis et al., 1995). The loss of coastal wetlands will likely have a direct impact on the economy of the countries and the region. Another threat from a rising sea level is the salinization of coastal wetlands, which can lead to mangrove die-offs and increased salinity in groundwater aquifer and surface water that further constrains subsistence farming in these coastal wetlands.

4.5 SEA-LEVEL RISE

Sea level is predicted to rise about 1 m over the next century. A slow to moderate rise is expected over the next two to three decades, followed by a sharp acceleration after the year 2050 (Appeaning Addo et al., 2011). On average, globally, the coastline will horizontally retreat 50 to 100 times the vertical sea level rise due to shoreline erosion and subsequent material deposition on the near-shore ocean bottom. The level of coastal recession will depend on local bathymetry and topography, but, depending on location, a coastal recession of 4.5–88 m by 2100 is expected, resulting in permanent inundation of natural habitats and major cities (Appeaning Addo et al., 2011). A relatively small rise in sea level can result in increased coastal erosion, permanent connection of lagoons to sea, penetration of salt water inland, salinization of freshwater lagoons and aquifers, and destruction of wetlands and associated industries (Conway, 2009).

The projected rise in sea level due to mean sea-level increase and changes in storm characteristics will have a major impact on the livelihoods of West African coastal populations and diverse aquatic ecosystems including mangroves, deltas, estuaries, and coral reefs. Forty percent of the population of West Africa lives in coastal cities (IPCC, 2007b). An estimated 5 million people live between 0 m and 3 m above sea level; Nigeria has the greatest population in this zone (~1.6 million people), followed by Benin with about 522,000 people (CIESIN-Columbia University, 2012). According to Nicholls et al. (2007), Lagos, Nigeria, ranks fifteenth in terms of greatest city population exposed to coastal flooding in the 2070s. Increased population density coupled with growing housing infrastructure will exacerbate flood disaster conditions (Appeaning Addo et al., 2011). Improved public awareness of seaward hazards, urban growth planning, wetland preservation, and coastal zone management can improve the resilience of coastal communities (Jallow et al., 1996). Niang et al. (2012) outline a number of approaches to preventing coastal erosion through combinations of hard engineering (e.g., seawalls, groins, and beach revetment), soft engineering (e.g., beach nourishment, dune restoration, and mangrove restoration), and integrated approaches (e.g., protecting marine ecosystems, and water resource management).

4.6 FORESTS AND WOODLANDS

4.6.1 The Regional Ecological Gradient

Two subregions within West Africa contain remnants of biologically diverse humid tropical forests. These two humid tropical forest zones are separated by the Dahomey Gap, a landscape mosaic of savannah and gallery forests in Benin that extends to the Gulf of Guinea. The Upper Guinean forests, west of the Dahomey Gap, extend across Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, and Togo. East of the Dahomey Gap, the Lower Guinean forests cover parts of Benin, Nigeria, and Cameroon (Rudel, 2005; Conservation International, 2012).

Human activities, including shifting cultivation, smallholder and plantation agriculture, timber extraction, and the expansion of settlements, have fragmented and greatly reduced the overall extent of the original Guinean humid tropical forests (Barnes, 1990; Rudel, 2005). What presently exists in this ecological zone is a human-dominated landscape of cultivated fields, fallows, secondary vegetation, roads, and human settlements surrounding small forest remnants and woodland patches. The populations of coastal cities in this subregion, such as Monrovia (Liberia), Abidjan (Côte d'Ivoire), Accra (Ghana), Lagos (Nigeria), and Douala (Cameroon), benefit from the ecosystem services these remaining humid tropical forests provide.

To the north of this humid tropical forest zone, the dry forests and woodlands of West Africa cover an ecological gradient spanning from the Guinean sub-humid dry forest to the drier Sudanian semi-arid open woodlands, wooded grasslands, and fallows (often referred to as savannah) and further north to the semi-arid and arid Sahel. Across this gradient from south to north, the climate and the land become increasingly unsuitable for rainfed agriculture. The landscape is sparsely covered by drought- and fire-resistant tree species such as baobab (*Adansonia digitata*), Shea tree (*Vitellaria paradoxa*), and *Acacia* spp. (Timberlake et al., 2010). Pastoralist land management practices applied in the semi-arid West African savannah landscape commonly incorporate the use of fire (Rudel, 2005).

4.6.2 Historical Patterns of Land Use and Forest Cover Change

West Africa's humid tropical forest zone is the source of about two-thirds of global cocoa production (OECD, 2007a). Local smallholders initiated cocoa production in this subregion in the late nineteenth century. The sector expanded rapidly over the course of the twentieth century. The growth of cocoa production drove deforestation, in-migration, and rapid settlement of the agricultural frontier. In the 1960s, in addition to the local cocoa-producing smallholders, rural migrants arriving from countries in the drylands to the north (e.g., Burkina Faso) established more cocoa farms thus contributing to increased rates of deforestation. In the mid-twentieth century, European investors began logging forest concessions in Côte d'Ivoire, Ghana, and Cameroon. Smallholders cleared forests for farming in areas along the roads built by logging companies. In the 1970s and 1980s, increased demand for agricultural labor contributed to rural population growth. Farmers often converted secondary forests to agricultural land use since they were easier to clear than mature forests. By the late twentieth century, cocoa production along the older cocoa frontiers was in decline and smallholders in these areas began planting other crops such as cassava and fruit trees (Rudel, 2005).

Farmers have converted over 50% of West Africa's dry forests and woodlands to agricultural land use, often maintaining standing trees in land use systems known as farmed parklands (Timberlake et al., 2010). Improved management of fruit trees in agroforestry parklands is viewed as an important strategy for improving rural livelihoods in the Sahel (Ræbild, 2012). In the Sudanian savannah and Sudano-Sahelian transition zone, many farmers have responded to the scarcity of forests and woodlands by protecting, pruning, and managing trees and shrubs that regenerate spontaneously on their lands. Since the 1980s, efforts have developed to

support regreening in West African drylands through farmer-managed natural forest regeneration (Sendzimir et al., 2011).

4.6.3 Land Use and Forest Cover Change Scenarios under Climate Change

Researchers have begun to investigate how global climate change may affect future distributions of humid tropical forests around the world by modifying hydrological regimes (Zelazowski et al., 2011).

When considering climate change alone, the results of a recent predictive vegetation modeling exercise suggest biome shifts toward a greening trend in West Africa by 2050, with increasing tree cover in inland areas of Benin, Burkina Faso, Côte d'Ivoire, Ghana, and Togo. However, when human impacts are incorporated, the models in this study suggest future forest degradation and potential desertification (Heubes et al., 2011).

Increasing temperature and decreasing precipitation were found to have resulted in a significant decline in tree density from 1954 to 2002 in the western Sahel at two sites in Senegal as well as a significant decline in tree species in the Sahel (Mauritania, Mali, Burkina Faso, Niger, and Chad) from 1960 to 2000 (Gonzalez et al., 2012).

Several investigators have challenged claims of large-scale land degradation and desertification in the Sahel. For instance, Herrmann et al. (2005) argue that while human-induced land degradation has been observed at local scales in the region, their analyses of the Normalized Difference Vegetation Index time series for the period 1982 to 2003 and gridded satellite rainfall estimates indicate that the observed increase in vegetation (e.g., greening) over large areas of the Sahel is attributable to human factors as well as to rainfall.

Abiodun et al. (2012) point out that reforestation in West Africa as a potential adaptive response to climate change is an important transboundary issue given that the impacts of large-scale reforestation can extend beyond country borders and result in both positive and negative impacts on the regional climate by reducing temperature in some places while increasing it in others.

More research is needed on forest cover dynamics and forest regeneration in West Africa, and on the interactions of climatic and human factors influencing forest and woodland cover in the region, including the impacts of urbanization trends and the demands of growing urban populations for forest-based resources and ecosystem services.

4.7 FISHERIES

Coastal West African states rely on the fisheries sector, to varying degrees, for formal and informal employment, foreign and domestic trade, foreign exchange earnings, local development, and household food security (Lenselink, 2002). Adverse impacts on the sector,

accordingly, have wide repercussions from regional to household levels. Climate change poses a serious risk to fisheries, affecting food security even substantially inland, but with greatest impacts on the livelihoods and food security of the artisan fisher populations in West African coastal nations.

Owing to the heightened state of vulnerability of fisheries throughout Africa and the increasing role fish production and consumption plays in food security and livelihoods, the New Partnership for Africa's Development (NEPAD) Action Plan for the Development of African Fisheries and Aquaculture, developed with Fish for All, places a high importance on on- and off-shore aquaculture while advocating for improved sustainability in national and transboundary water resource management and adaptation strategies for off-coast fisheries (NEPAD, 2005).

4.7.1 Current Role of Fisheries in West Africa

Though the fisheries sector makes up a low proportion of the GDP in many countries (as low as 2% of the total export value for West African countries [FAO, 2007]), it nevertheless plays an important role in household food security, offering an income diversification strategy for poor rural households. Artisanal fisheries play a key role in local economic development in coastal regions and inland communities such as those in the Inner Niger Delta and along the Senegal River depend substantially on fishing (Morand et al., 2012). Many in West Africa are highly dependent on fish as a source of protein. The regional fish food consumption is 14.6 kg per capita; Senegal has the highest per capita consumption at 27.8 kg (FAO, 2010). Lam et al. (2012) note that while this fish consumption is relatively high, fish protein has a much more important role in the daily diet than land animal-based protein in the coastal region. This importance of fisheries is seen in an increased push to expand aquaculture for sustainable fish production, through projects elsewhere in Africa, such as Malawi's integrated aquaculture-agriculture project, begun in 1995 with The WorldFish Center (a CGIAR Consortium Research Center), which has seen a remarkable national-level increase in annual average production from fishponds (APF, 2008: 62-65).

4.7.2 Challenges and Strategies in the Current Fisheries Sector

Two major categories of coastal fishing operations include large-scale commercial fishing vessels, often owned or employed by foreign corporations who are granted rights by domestic national governments with little to no consultation with local populations, and small-scale artisan fishers who operate with more traditional crafts for domestic markets and household consumption (Lam et al., 2012). These categories represent separate challenges for the fisheries sector and must be considered concurrently in planning for climate change adaptation given their divergent needs and representation at the local and national levels. Commercial fishing, particularly for export to the European and North American markets, has increased in recent decades; Asian markets have also emerged as importers (Lenselink, 2002). These large-scale operations are able to be regulated and subject to international standards for positive fishing practices and maintenance of ecosystems. Commercial fishing operations also represent a

livelihood option for those who have relocated from dryland or inland zones in search of employment in the growing industry.

The once highly productive West African fisheries are subject to pressures of large-scale intensification of coastal and open-water fishing, resulting in diminished stock and ecosystem health. Some industrial vessels employ trawlers that destroy habitats. The impacts of an expansion of artisanal fishing as a livelihood can have directly adverse effects on the livelihoods themselves, as increased fishing practices increases vulnerability and potential for conflict through competition for compounding limited resources (Lenselink, 2002). Use of dynamite and bycatch discard are highly damaging to ecosystems, and fine mesh nets result in juvenile fish take (Lam et al., 2012). Motorization has allowed fishers to migrate to deeper waters or new locations in search of new fish populations. Trouillet et al. (2011) detail new migration patterns of Senegalese fishermen from the overcrowded waters off the Senegalese coast to waters off the coast of Mauritania where there are healthy fish stocks and less competition. This mobilized population of fishers, even at the transnational level, requires cohesive regional adaptation strategies.

4.7.3 Potential Climate Change Impacts on Fisheries

The projected impacts of climate change on fisheries will be both social and economic for fishing fleets and fishing communities, also dependent on these populations' resilience to change and capacity for adaptation. Projected changes include the composition, production, and seasonality of plankton and fish populations (FAO, 2010). The most direct consequences of climate change on coastal fisheries include an increase in ocean temperature, acidification through increased oceanic CO_2 absorption and pH reduction, and a rise in sea levels (Doney et al., 2012). The responses of individual species to the physiological impacts of climate change will compound into difficult-to-predict large-scale changes of ecosystem dynamics, particularly food webs from microbes to the fish species fished by human populations (Doney et al., 2012). Changes to the chemical composition of ocean waters are associated with variability among the different species that create marine ecosystems, ultimately resulting in a decline or displacement of fish populations (Doney et al., 2012).

Rising sea levels and warming upper layers also disrupt current ecosystems, particularly plankton and predator fish populations (Allison et al., 2009; Doney et al., 2012). Plankton blooms in areas of upwelling (e.g., the Canary and Guinea Current Large Marine Ecosystems [LMEs]) depend on wind episodes and nutrient supply, both of which are subject to increased variability due to climate change (Sambe, 2012; Donkor and Abe, 2012). Wiafe et al. (2008) investigated the impact of climate change on zooplankton biomass in the upwelling region of the Gulf of Guinea. It was determined that zooplankton biomass during the upwelling season has declined significantly over a 24-year period. The gradually increasing trend in SST during the upwelling season accounted for more than 50% of long-term zooplankton biomass variability (Wiafe et al., 2008). Variability in the plankton ecosystems is directly linked to viability of pelagic fish populations, which account for the majority of landed fish in the Canary Current LME

(Sambe, 2012). Impacts on food webs will impact fish stocks in terms of access to prey populations, but also direct physiological responses to raising temperatures or changes in predator population patterns. Changes in spawning or migration seasonality can alter predator-prey interactions, as well as accessibility of fish populations to fishers. Additionally, increased sedimentation, coastal erosion, and salinization as a result of climate change can have adverse effects on marine and coastal ecosystems, particularly coastal wetlands and mangrove systems. Rising temperatures are also associated with increased susceptibility to diseases amongst fish populations (Allison et al., 2009; Doney et al., 2012).

Inland fishery zones, including those in the Inner Niger Delta in Mali, are impacted by potential reduction in floodplain zones for seasonal inland fishing areas as a result of lowered precipitation as projected by many climate models. Increased demand for dam infrastructure for access to water or energy exacerbates the reduction in fish landings for seasonal inland fishing (Morand et al., 2010). In addition to precipitation and temperature changes, changes in sea level rise, land-based runoff and increasing frequency of storms and storm surges threaten coastal infrastructure, aquaculture located in riparian and coastal zones, and loss of harbors or homes (Allison et al., 2009; FAO, 2010).

Allison et al. (2009) identify three principle factors of climate change vulnerability for fisheries, including exposure to the physical effects of climate change, the degree of sensitivity of the natural resource system or the dependence of the national or local economy on social or economic returns from the fisheries sector, and the adaptive capacity of populations to offset the potential impacts. Mauritania, Senegal, Mali, Niger, Guinea, Nigeria, Guinea-Bissau, and The Gambia are ranked among the 33 most vulnerable countries to climate change impacts on fisheries.[14]

Countries of the Western Sahel were among the most vulnerable to negative impacts overall. Among these, Nigeria and Ghana are expected to experience the greatest negative impact on fish landings, while impacted countries with the highest export income include Mauritania and Guinea-Bissau; Ghana and The Gambia are marked as highly dependent on fish protein, with dependency ranging from 59–67% of animal protein coming from fish. Most West African countries scored low in adaptive capacity (Allison et al., 2009). Along with other most-vulnerable nations, these countries are among the poorest nations in the world and are up to twice as dependent on fish for daily protein intake as those that are less vulnerable.

[14] To create their vulnerability index, Allison et al. (2009) analyzed 133 countries and used surface air temperature, not sea surface temperature, to predict exposure to climate change, using the A1F1 and B2 models for higher and lower emissions scenarios. Sensitivity to outcomes was determined through prediction of impact on fish landings, representing the national economic outcome and the dependence on fisheries for employment. Adaptive capacity refers to human development indicators impacted by climate change, including health and governance.

4.7.4 Food and Economic Security Impact of Reduced Landings

Lam et al. (2012) examine two climate scenarios and their impacts on fisheries: (1) an optimistic projection of constant 2000 CO_2 level of 360 ppm; and (2) the still-conservative Special Report on Emission Scenarios (SRES) A1B projection scenario. Their model of projected fisheries landings considers ocean environmental conditions including sea temperature, sea ice coverage, salinity, and advection from 2001 to 2059 under both scenarios for 14 coastal West African countries. The Lam et al. (2012) model uses data from FAO and the Sea Around Us Project database to forecast fish demand in the 2050s and to project the potential loss in fish protein and total landed values under climate change. Under the constant CO_2 level scenario, all the countries in West Africa would have a declining level of fisheries landings by 2050, except The Gambia, Mauritania, Senegal, and Western Sahara. Under the SRES A1B, the situation is more severe, totaling a reduction of approximately 26% from current levels across the region. Substantial losses of up to or over 50% are projected in Ghana, Côte d'Ivoire, Nigeria, Liberia, Togo, and Sierra Leone. These last three countries are already acutely food insecure, compounding the projected nutritional insecurity. Other countries, such as Mauritania and Senegal, rely upon fish for exports, which would be highly impacted.

To maintain the per capita food supply, fish production must increase by five times the current level by the 2050s, despite the SRES A1B projection of reduction of landings by one quarter. The increased demand for fish, driven by population growth and coupled with the decreased fish landings, may increase the price domestically and internationally of the fish that is landed. This has major implications for food security in West Africa.

Landed values are estimated to drop for the 14 countries by 21% in the high-emissions SRES A1B scenario; Côte d'Ivoire, Ghana, and Togo would suffer up to 40% declines. Under the constant 2000 scenario, only an 8% decrease in landings value is seen regionally, with projected increases in landing values predicted for Mauritania, Senegal, The Gambia, and Western Sahara. In terms of livelihoods, a decrease of up to 50% of fisheries-related jobs is expected under the SRES scenario. Indirect induced impacts resulting from climate change related fisheries losses greatly increase the economic burden under the SRES A1B scenario.

4.7.5 Adaptation Challenges

Coping strategies for climate-induced impacts to the fisheries sectors are varied, but overall adaptation strategies are challenging given the severity of many climate change scenarios. Traditional fisher populations have migrated with fish populations and used destructive fishing techniques such as dynamite to improve fish landings, though as fish populations dwindle in size and health or shift habitats, such coping strategies will not prevent decreases in landings. Inland migration patterns toward cities and increased use of land for farms puts more pressure on rapidly urbanizing centers and agricultural lands, potentially resulting in a decreased food supply that is exacerbated by diminished fish protein supply (Lam et al., 2012).

The OECD Africa Partnership Forum (2008) recognizes adaptation challenges and therefore recommends the expansion and intensification of aquaculture with links to private sector investments at national and regional levels, as outlined by the NEPAD Action Plan for Development of Fisheries and Aquaculture (NEPAD, 2005). The availability of phytoplankton and zooplankton may increase with rising temperatures; another potential positive impact is the increased salinity in deltas, which can be harnessed for high-value shrimp aquaculture (FAO, 2010).

Beyond adopting new expanded industries as a means of adaptation, a challenge in crafting adaptation strategies for the fisheries industry is the necessity of balancing state-imposed regulations and the priority drivers of traditional fishers, who often mostly operate outside of the regulatory structures. Often policies benefit the vocal large-scale corporations or local business people over the needs and priorities of the small-scale artisan fisher (Trouillet et al., 2011). It is important when building local coalitions of community leaders and stakeholders from the local and national level to consider the implications of fishing for food security and the potential for conflict to arise as a result of increased competition over fewer resources.

4.8 HUMAN HEALTH

Adaptation to climate change in West Africa, as elsewhere, requires the development of strategies that take into account multiple sectors and various human health concerns related to disease control, disease habitat transformations, land-use change, agricultural practices, food safety and nutrition, water quality and quantity, and access to safe food and water supplies.

Climate change is a recent governmental concern for African public health policy. Current climate and health adaptation plans are mostly pilot projects, research is focused on accumulating evidence of climate change impacts on health, and there are no overarching public health adaptation strategies. However, the World Health Organization (WHO) has begun to develop a comprehensive policy framework to provide a scientific and evidence-based coordinated response to climate change adaptation needs of African countries. Focus areas include surveillance, early warning systems, predictive models, and research. The overall goal of this international consortium, which is to be launched by the end of this year, is to identify country-specific health risks and strengthen national core capacities of health systems (Manga, 2013).

Climate influences transmission, spatial and seasonal distributions, epidemics, and long-term trends of parasitic, viral, and bacterial diseases (Kelly-Hope and Thomson, 2008). However, it is important to keep in mind that the relationship between climate and human health is extremely complex. Climate is only one of many variables that can affect risk of disease incidence and transmission. Establishing direct linkages between changes in climate or other environmental factors and disease transmission is extremely difficult due to the presence of many confounding socioeconomic and demographic factors (de Souza et al., 2012). Identification of key variables is strongly limited by a lack of observational health data under field conditions (Thomson et al.,

2004a), and climate forecasting models are limited as well by uncertainties with respect to climate data (Thomson et al., 2006; Lafferty, 2009).

At different spatial scales, climate change and geophysical factors (i.e., precipitation, humidity, and temperature) affect the survival, reproduction, and transmission of disease agents and vectors (de Souza et al., 2012). Temperature has the greatest overall influence on key biological processes in vectors, pathogens, and their hosts, while precipitation affects diseases associated with aquatic habitats (Lafferty, 2009). Malaria is the most temperature sensitive vector-borne disease; a small change in temperature can have a disproportionate effect on infection risk in epidemic prone regions (Kelly-Hope and Thomson, 2008). Rainfall- and flood-associated outbreaks of disease are often caused by contaminated water and the formation of breeding habitats (de Souza et al., 2012). Although drought is associated with a reduction in the occurrence of malaria, drought increases malaria's epidemic potential (Thomson et al., 2004b).

Climatic and environmental conditions can produce disease transmission zones or belts, such as the malaria and meningitis belts of West Africa (Figure 17) that have been found to closely correspond to the region's semi-arid agro-ecological zones (Thomson et al., 2004a; de Souza et al., 2012) situated in both the Sahelian and tropical inland zones. Similarly, infectious diseases such as Rift Valley fever, yellow fever, relapsing fever, sleeping sickness, schistosomiasis, lymphatic filiarasis, and onchocerciasis are also noted to occur within a "climate envelope" of a specific set of precipitation, wind, and moisture conditions (Thomson et al., 2004a; Kelly-Hope and Thomson, 2008).

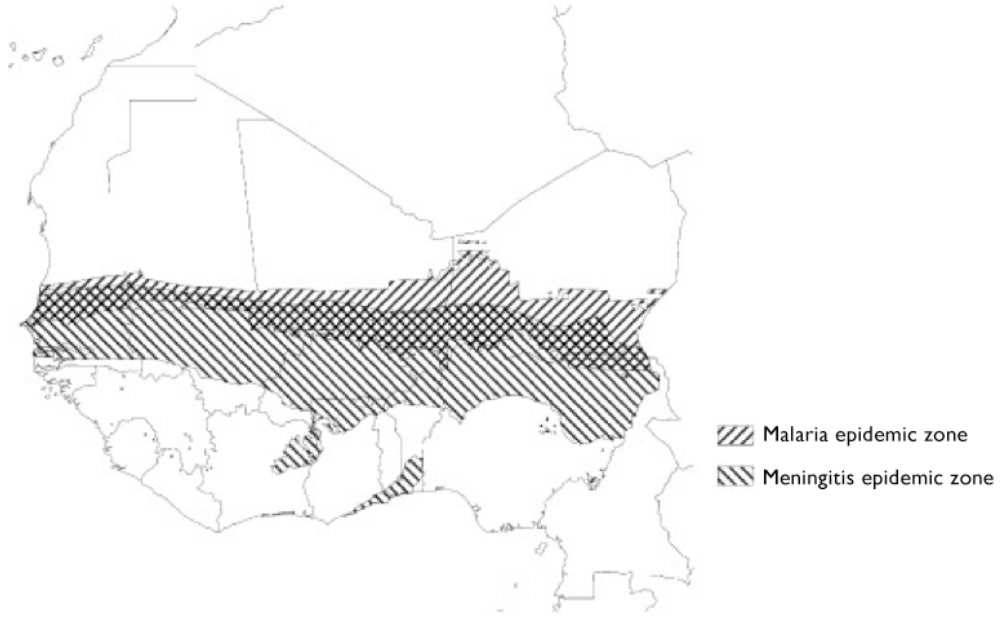

Fig. 17 Climate envelopes for malaria (Connor, 2002) and meningitis epidemics (Molesworth et al., 2002) in West Africa. *Source:* Thomson et al. (2004a: 144)

In the case of lymphatic filiarasis, Thomson, Connor et al. (2004) present a generalized ecological distribution based on elevation, vegetation cover, and climate (Figure 18). Incidence of this disease is notably higher in the coastal zones of West Africa, but there are some important exceptions. For example, lymphatic filiarasis is largely absent from coastal Togo and Benin, even though these countries are highly endemic for malaria, which is transmitted by the same mosquito vector species.

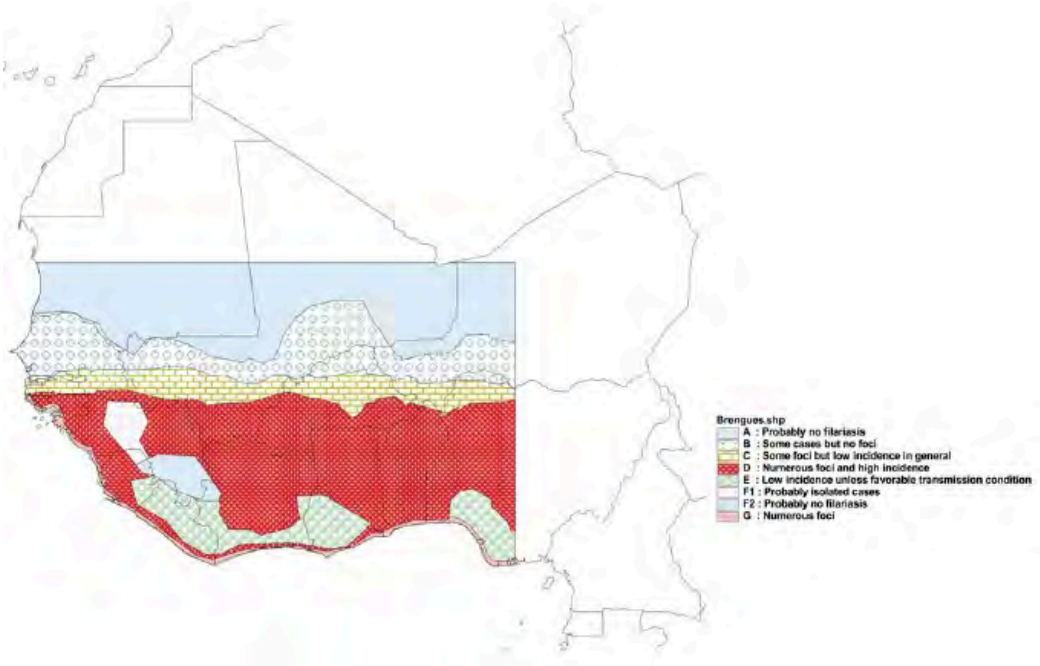

Fig. 18 Zonation map of lymphatic filiarasis endemicity in West Africa based on ecological criteria. *Source:* Thomson et al. (2004a: 146) based on Brengues (1975)

A number of diseases display distinct seasonal patterns. Outbreaks of malaria, dengue, and Rift Valley fever have been found to increase during and immediately following the warm, rainy season (Caminade and Terray, 2010). Seasonality of river flow caused by the monsoon has been found to influence breeding sites for the onchocerciasis vector (Thomson, Connor et al., 2004). Seasonal winds, another large-scale phenomenon, contribute to the periodic resurgence of meningococcal meningitis (MCM) in Mali (Sultan et al., 2005). MCM is an infection of the meninges that is extremely contagious and causes high death rates in many African communities. Outbreaks usually start at the beginning of February when the winter climate creates dry air and strong dust winds that damage the mucous membranes of the oral cavity and generate favorable conditions for the transmission of the MCM bacteria (Thomson et al., 2004a; Sultan et al., 2005; de Souza et al., 2012). The higher humidity spring and summer seasons decrease transmission capability and the epidemics generally stop with the onset of rainfall around late May (Sultan et al., 2005; de Souza et al., 2012). Thus, the correlation

between the atmospheric wind signal and the onset and seasonal course of the epidemic is valuable information for disease monitoring and prediction.

The relationship between seasonality and variability in temperature and rainfall was also examined by Bandyopadhyay et al. (2012) in the case of diarrhea in children under the age of three in sub-Saharan Africa. Maximum and minimum temperature and high rainfall were all found to be important, but their impact also depended on the season. High rainfall during dry seasons was associated with reduced diarrhea prevalence, while water shortages in the dry season increased it. This suggests that higher than average rainfall makes groundwater more plentiful, improves the quantity and perhaps the quality of available water, and enables households to adopt more hygienic practices.

The hypothesis that climate change is responsible for observed changes in malaria prevalence has been particularly controversial (Ermert et al., 2012). Based on multi-model seasonal forecasts, Caminade and Terray (2010) found that if only considering climate, the potential future malaria epidemic belt in West Africa is slightly shifted southward (from 1° to 2°) in comparison to that of the current climate, due mainly to a stimulated decrease in the number of rainy days in summer. Lafferty (2009), however, rightly cautions that disease vector habitat suitability is affected not just by climate conditions that foster growth and survival, but by barriers to dispersal, competition, predation, disease control efforts, and habitat degradation—factors that constrain the geographic distribution and transmission of disease.

Sea level rise along the coast of West Africa has the potential to impact mosquito-borne infectious diseases, such as malaria, by modifying vector habitats and breeding conditions thus changing mosquito vector populations and species compositions. The mosquito species *Anopheles gambiae* is considered to be one of the most efficient malaria vectors in sub-Saharan Africa; it is long-lived, has a short larval period, and is found in habitats associated with human activity. *Anopheles melas,* another mosquito vector, is less effective at transmitting malaria than *An. gambiae* and inhabits brackish water and saline environments such as mangroves and salt marshes (Sinka et al., 2010). Coastal inundation resulting from sea level rise may contribute to reductions in malaria transmission and incidence by creating more favorable breeding conditions for the salt-tolerant *An. melas* while hindering reproduction of *An. gambiae* (Thomson, personal communication, 24 January 2013).

Reporting on research conducted in Niger during the 2003 rainy season to assess malaria vector presence and abundance across the Sudanian, Sahelian, and Saharan zones, Labbo et al. (2004) explain that although the disappearance of the malaria vector *Anopheles funestus* from the Sahelian zone has been attributed to three decades of Sahelian drought, it is important to take into account several local and subregional hydrological processes that can create breeding sites for malaria vectors even under regional drought conditions. These hydrological processes include the formation of temporary ponds linked to local groundwater recharge and enhanced water run-off in areas where the clearing of wooded savannah and the expansion of cultivated areas changes the landscape and surface characteristics.

Other associations have been made between climate, land use, and health. For example, increases in the more severe savanna form of onchocerciasis have been linked to decreases in forest cover in Ghana (Wilson et al., 2002). The often complex relationship between climate, land-use change, and health is illustrated by the "paddies paradox" of malaria, which describes the findings that in some semi-arid areas, increased breeding sites for vectors associated with increased irrigation of rice has increased malaria prevalence, while in other areas, the inverse has been found, leading to conclusions that vector density impacted by climate does not appear to be the key driving force of malaria transmission (Thomson et al., 2004b). Similarly, another study concluded that while climate changes could be linked to determinants of intestinal schistosomiasis and intermediate host snail distribution, and that while increased temperature would certainly cause a potential habitat expansion, the greater importance of the impact of humans on habitat in the form of water development projects and human presence prevented a conclusion as to how the disease prevalence might be affected by climate change (Stensgaard et al., 2011).

Nutrition is an important driver of health outcomes (Amuna and Zotor, 2008). The multiple socioeconomic and cultural factors that impact nutrition have made it challenging to clearly understand the relationship between nutrition and climate. De Sherbinin (2011a) found drought prevalence to be significantly correlated with child malnutrition in an analysis of 367 sub-national units in Africa. Spatial modeling of water availability, malnutrition, and livelihoods across several climatic zones in Mali revealed links between climate and the stunting of children related to chronic malnutrition (Jankowska et al., 2011). Nutrition is impacted by climate through three main pathways: (1) food security, which encompasses food quality and quantity and requires sufficient caloric intake, protein, and the essential micronutrients obtained from a diversified diet (Thompson et al., 2010); (2) infectious disease (e.g., diarrheal disease, malaria, and HIV); and (3) maternal and child care (e.g., breastfeeding and labor) (Thomson, personal communication, January 24, 2013). A growing body of research is investigating the ways that climate impacts nutrition and food security, including food availability, stability of supply, access, and utilization (Tirado et al., 2010; Tirado and Meerman, 2012; Remans et al., 2013).

Gnonlonfin et al. (2013) and others call attention to the need for more research to improve understanding of the human and livestock health impacts of toxins produced by fungi (mycotoxins) in sub-Saharan Africa. This research agenda should include how climate variability and change may influence mycotoxin contamination and exposure in human food and livestock feed systems. Aflatoxins are highly carcinogenic mycotoxins produced by the fungus Aspergillus flavus. Researchers and practitioners interested in using and improving climate and agro-ecological data to inform nutrition programming have identified aflatoxin contamination and exposure as an important climate-related human health issue (Remans et al., 2013). Aflatoxin contamination is widespread throughout Africa. Many malnourished people in West Africa are chronically exposed to high levels of aflatoxin and other mycotoxins (Gong et al. 2003).

A recent review conducted by researchers at Danya International, Inc. with funding from the USAID East Africa Regional Mission summarizes the latest published research on aflatoxin

covering the health, agriculture, and trade sectors and highlights the need for cross-sectoral aflatoxin initiatives (USAID, 2012). This review of the literature published since the year 2000 is intended to serve as a resource for the Partnership for Aflatoxin Control in Africa. It emphasizes that a multi-sectoral approach is required to prevent and control aflatoxin contamination and exposure. Coordinated clinical, dietary, and agricultural interventions are needed. Aflatoxin strains are commonly found in soils and infect a wide variety of plants including grains (e.g., maize, millet, and sorghum), legumes (e.g., peanuts), nuts, seeds, coffee beans, and cassava. They have also been detected in animal products (e.g., meat, milk, poultry, and eggs). Humans are exposed to aflatoxin primarily through the consumption of contaminated agricultural or animal products.

Dietary exposure to aflatoxins has numerous negative effects on human health (USAID, 2012; Gnonlonfin et al., 2013). Chronic aflatoxin exposure (i.e., long-term exposure to low and moderate levels of aflatoxin in the food supply) has been associated with suppression of the immune system, liver cancer, cirrhosis, and problems related to malnutrition such as stunted growth. Researchers investigating aflatoxin exposure among young children in Benin and Togo, found that stunted and/or underweight children had an average of 30–40% higher levels of aflatoxin-albumen blood levels than children with a normal body weight (Gong et al., 2002) and that elevated aflatoxin levels were associated with child stunting, child mortality, immune suppression, and childhood neurological impairment (Gong et al., 2003). Chronic aflatoxin exposure has also been linked with HIV and tuberculosis. Further, aflatoxin exposure may compound pre-existing health problems (e.g., hepatitis B infection) and risk of disease transmission. Short-term aflatoxin exposure at high levels of concentration (acute exposure) causes hemorrhaging, acute liver damage, and edema and can be lethal. To date, hepatitis B vaccinations, awareness campaigns, and chemoprevention measures have been used effectively to help protect populations from these negative effects. Long-term crop storage facilitates fungal growth (Gong et al., 2003). Therefore, efforts to incorporate food and feed storage as part of climate change adaptation strategies should include support for pre- and post-harvest handling, storage, and distribution methods that minimize contamination in products for human and livestock consumption. Development of standards, guidelines, and regulations would help to limit aflatoxin contamination and exposure. Targeted monitoring and surveillance systems are needed for high-risk areas and populations.

In addition to food and feed storage, climate change adaptation strategies often involve improvements in technologies, practices, and systems for water harvesting, storage, and distribution in order to supply water when, where, and for whom it is needed, especially during drought periods. In the development of these sorts of water-related adaptation strategies, public health considerations must be incorporated to avoid the creation of disease vector breeding sites harboring diseases such as malaria and schistosomiasis (Thomson, personal communication, January 24, 2013). Boelee et al. (2012) found that there was increased transmission of schistosomiasis around small reservoirs in Burkina Faso and more malaria cases near a large Ethiopian dam.

The public health community lags behind others in the use of climate-sensitive and environmental information for decision-making, which has been attributed to structural elements in public health decision-making and the need to better translate research into the evidence required by decision makers (Thomson et al., in press). The Meningitis Environmental Risk Information Technologies (MERIT) initiative provides a model of how climate scientists and public health researchers and practitioners can work together to translate research discoveries linking climate and health to improve response to outbreaks and development of a new conjugate vaccine (Thomson et al., in press).

More research is needed to better understand the complex relationships between human health and climate change, as well the relationship between land use, climate change, and health. In establishing water management and irrigation schemes, and in the case of wetlands management, consideration should be given to the potential impact on water-related diseases (Cools et al., in press). More research is also needed to understand how nutrition and dietary diversity may be impacted by climate change as a result of changes in food security and food safety, as well as the impact of climate on ecosystems that support nutritious indigenous foods (Fungo, 2011). The breeding of crops for climate adaptation should also take these factors into account. Better partnerships are needed between the climate and public health communities so that data sharing and local capacity strengthening for local data collection can ensure proper development of integrated early warning and response systems (Connor et al., 2010).

REGIONAL AND LOCAL CHALLENGES

5.1 POTENTIAL FOR CONFLICT

5.1.1 Overview

There is a growing interest in better understanding the human security implications of climate change by examining relationships between climate and societal instability, conflict, and violence. An emerging body of research identifies climate stress as one among multiple risk factors that have the potential to increase conflict at a range of social and geographic scales. However, experts remain unable to predict the location, timing, number, or magnitude of climate-related conflicts using existing data sets and methodologies. Despite current research limitations and uncertainties, many agree that climate change and conflict need to be addressed together and that this objective presents major challenges regardless of whether or not causal pathways linking climate variables to conflict can be clearly established. Opportunities for contributing to advances in this body of knowledge and practice include supporting efforts to coordinate and integrate climate science and social science research approaches, development and refinement of climate- and conflict-related indicators, improvements in conflict monitoring and early warning systems, and improvements in techniques for data collection and analysis.

The National Research Council (NRC) Committee on Assessing the Impacts of Climate Change on Social and Political Stresses provides a general conceptual framework for thinking about climate-security relationships that involve vulnerabilities to climate events (Figure 19) (NRC, 2013: 35-52). This NRC report explains that many of these connections involve causation in both directions. The report also points out that some of these causal links are much more important than others on time-scales that are relevant for security analysis.

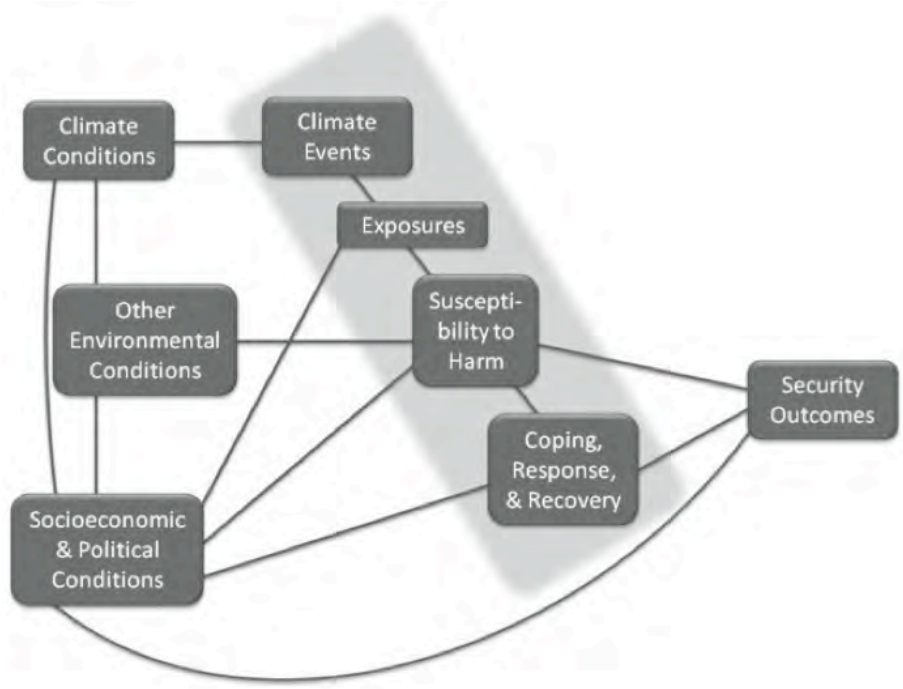

Fig. 19 Connections between climate events and outcomes of national security concern. The shaded area corresponds to the event-exposure-vulnerability model in IPCC (2012). *Source:* NRC (2013: 38).

This conceptual framework can be used to identify possible causal pathways that may link climate change and conflict, including factors such as temperature changes, precipitation changes, extreme weather, water availability, food security, livelihood security, environmental migration, and institutions. Water supply shocks, for example, may contribute to societal conflict by simultaneously increasing resource competition, adversely impacting macroeconomic outcomes, and reducing state capacity (Fjelde and von Uexkull, 2012; Hendrix and Salehyan, 2012).

The recent climate-conflict literature generally finds that climate stress does not trigger societal conflict or security breakdowns in a uniform manner, but rather that the triggers tend to be context specific. A number of studies identify climate change as a "threat multiplier" as opposed to a direct trigger. That is, climate-related variables, such as rising sea levels, erratic rainfall, longer dry periods, more intense rainfall events, more frequent and intense natural disasters, and changing ecosystems, are additional factors that stress already fragile communities and, as

such, they may reinforce or amplify the potential for conflict (e.g., Brown et al., 2007; Brown and McLeman, 2009). Table 3 provides a ranking of West African countries by levels of state fragility and coup risk.

Country	2011 State Fragility Index	2013 Predicted Coup Risk
Chad	22	High
Côte d'Ivoire	19	Low
Sierra Leone	19	Low
Guinea	18	High
Niger	18	High
Nigeria	18	Moderate
Guinea-Bissau	17	Very High
Burkina Faso	16	Low
Cameroon	16	Low
Liberia	16	Moderate
Mauritania	16	Very High
Gambia	14	Moderate
Mali	13	Very High
Togo	13	Low
Benin	12	Low
Ghana	12	Low
Senegal	9	Low
Cape Verde	6	Low

Table 3. West African countries by state fragility and coup risk (in descending order of fragility). Fragility Index from Marshall and Cole (2011). High Scores indicate high fragility. Dark Gray=within highest 20 globally; Light gray=within ranks 21–47 globally;

red=within ranks 48–121 globally. Predicted coup risk from Dart-Throwing Chimp (date accessed 15 February 2013). Categories are based on visual inspection of natural breaks.

In a study examining the linkages between rainfall variations, economic conditions, and civil conflicts, Miguel et al. (2004: 747) highlight the case of Sierra Leone where negative impacts on the agricultural sector, following adverse rainfall shocks (declines in rainfall) in the early 1990s, appears to have facilitated the recruitment to armed militias of rural youth seeking an alternative source of income and that this surge in recruitment contributed to the escalation of conflict with Liberian troops.

Brown and Crawford (2008) examined the potential for climate-induced economic and political insecurity in Ghana and Burkina Faso, presenting best-, medium- and worst-case scenarios for climate predictions to the year 2100. They concluded that climate change will not necessarily drive conflict in these countries, but it is likely to make development challenges more complex and urgent. While some investigators have found that natural disasters associated with extreme weather may increase the risk of intrastate conflict (e.g., Nel and Righarts, 2008), others find no increased risk of conflict as a result of extreme weather and, in some cases, report evidence of cooperation between social groups following natural disasters (Scheffran et al., 2012a).

In an examination of the factors that facilitate or impede recovery after disasters, Aldrich (2012) finds that people with strong social networks and access to critical information, tools, and assistance experience faster recoveries than individuals and groups with limited social capital (i.e., those who are less connected). He argues that social capital serves as an important resource by fostering trustworthiness, diffusing information, and encouraging the creation of new cooperative and civic norms. High levels of social capital accelerate post-disaster recovery. People who lack connections and embeddedness in social networks are at a disadvantage, and those surviving on the peripheries of society prior to a crisis or disasters may be further marginalized during the recovery phase. Communities with both strong ties to each other (horizontal connections) and connections to decision makers in government and/or nongovernmental organizations are likely to experience better recoveries than those without either form of social capital or those with only horizontal ties (Aldrich, 2012).

Spiegel et al. (2007) studied the occurrence and overlap of natural disasters, complex emergencies (defined as humanitarian crises with total or considerable breakdown of authority resulting from internal or external conflict that requires an international response), and epidemics during the period of 1995 to 2004. The data sources for this study were: the Center for Research on the Epidemiology of Disasters Emergency Events Database for natural disasters (www.emdat.be); the Uppsala Conflict Database Program (www.ucdp.uu.se/database) for complex emergencies; and the WHO outbreaks archive for epidemics. This research team found that epidemics have occurred much more frequently during large-scale complex emergencies than following large-scale natural disasters.

In an analysis of data on various forms of conflict, compiled in the Social Conflict in Africa Database (SCAD; www.scaddata.org), Hendrix and Salehyan (2012) study the relationship

between rainfall, water, and sociopolitical unrest in Africa by examining the effect of deviations from normal rainfall patterns (rainfall anomalies) on various types of conflict. More specifically, they examine how rainfall anomalies affect political behavior and the propensity of individuals and social groups to engage in disruptive activities, including protests, riots, strikes, inter-communal conflict, anti-government violence, government violence against civilians, and extra-governmental violence. The results of this study indicate that rainfall variability has a significant effect on both large-scale and smaller-scale instances of political conflict and that extreme deviations in rainfall are associated positively with all types of political conflict. Violent events were found to be more responsive to abundant rainfall than to scarce rainfall. At the time of Hendrix and Salehyan (2012) study, SCAD contained roughly 6,000 cases of social conflict. This database has since been expanded to include information on over 7,900 social conflict events that occurred from 1990 to 2011.

Examining the experiences of Sahelian and West Africa states, Humphreys (2005) identifies possible mechanisms that link natural resources and extractive industries to conflict onset and conflict duration, such as the ways in which natural resource revenues weaken state structures or induce grievances. To address these concerns, he recommends better management of the extraction process, better usage of resource revenues that are controlled by states, better regulation of extractive industries, better provision of public information about how and where revenues are earned and spent, and oversight of these expenditures by civil society groups. While Humphreys (2005) does not specifically address changes in climatological conditions or the relationship between climate change and social stress or instability, the approach he develops to identify potential mechanisms linking natural resource extraction to conflict can be applied to study cases involving the added element of climate stress.

In an analysis of 44 studies published during the period 1994–2012, Hsiang and Burke (forthcoming) examine the impact of climatological conditions on conflict and societal stability in both historical and modern periods. In the earlier studies, researchers found correlations between climatological changes and conflict outcomes but were agnostic on causation. As the evidence mounts, and as more sophisticated statistical methods are applied, the hypothesis that climatological changes and conflict outcomes are causally connected is gaining support. Hsiang and Burke (forthcoming) conclude that several potential mechanisms, such as government capacity, labor markets, socioeconomic inequality, climate-induced changes in food prices, logistical conditions, misattribution of poor economic conditions to governments or individuals, collective psychological responses, and migration and urbanization, may contribute to societal instability and conflict, pointing out that certain mechanisms may be more important than others depending on the context, and that multiple mechanisms may act simultaneously to produce combined effects.

Some studies attempt to determine how climate-conflict linkages are shaped by differences in the economic and/or political status of social groups. Raleigh (2010), for instance, seeks to explain how political and economic vulnerability to climate change influences the likelihood of communal conflict across ethnic groups in Africa, where economically marginalized and

politically excluded populations are likely to live in less developed and more degraded areas. This study focuses on the dynamics of marginalization and political exclusion among pastoral communities, nomadic groups, small ethnic groups, and highly dispersed groups in low-density areas. Raleigh expects that patterns of communal conflict will reflect low levels of state capacity, local poverty, and traditionally hostile relations across social groups inhabiting disaster-prone or degraded areas. She argues that certain group characteristics (e.g., size, capacity, and power potential) constrain manifestations of conflict and, further, that intergroup resource conflicts and violence serve to mediate access to vital livelihood resources in areas where government capacity is weak and populations have limited access to public goods. She points to the need to improve subnational data on communal violence, resources, accessibility, and political marginalization to better understand how strategies to access scarce or abundant resources may lead to intergroup conflict.

Several efforts are already underway in sub-Saharan Africa to develop monitoring and early warning systems, especially in zones where fragile political and economic systems are near thresholds where climate-related environmental and socioeconomic shocks could spark chain reactions that constitute security threats (e.g., Verdin et al., 2005; Duncan et al., 2010). The Famine Early Warning Systems Network (FEWS NET; www.fews.net), funded by USAID, manages a data and information system focused on food security issues and offers a variety of products, tools, and services to identify and address potential threats. The West Africa Network for Peacebuilding (www.wanep.org), based at the Peace Monitoring Centre in Accra, Ghana, implements the ECOWAS Early Warning and Response Network, which is an observation and monitoring tool for conflict prevention and decision-making. In 2002, the Intergovernmental Authority on Development (http://igad.int) in Eastern Africa established the Conflict Early Warning and Response Mechanism (www.cewarn.org) to operate an indicator-based early warning system to monitor and help prevent cross-border and interstate pastoral and related conflicts.

The NRC Committee on Assessing the Impacts of Climate Change on Social and Political Stresses (NRC, 2013) recently outlined the climate and social stress monitoring activities that the intelligence community and partners should be developing to improve anticipation of events, support more effective prevention efforts, and enable more decisive emergency response. The committee put forth the following set of factors known to influence connections between climate events and the potential for violence, conflict, or societal breakdown (NRC, 2013: 5–6):

- The nature, breadth or concentration, and depth of pre-existing social and political grievances and stresses;
- The nature, breadth or concentration, and depth of the immediate impacts of the climate event;
- The socioeconomic, geographic, racial, ethnic, and religious profiles of the most exposed groups or subpopulations, as well as their susceptibilities and coping capacities;

- The ability and willingness of the incumbent government and its internal and external supporters to devise, publicize, and implement effective, transparent, and equitable short-term emergency response and then longer-term recovery plans;
- The extent to which emergent or established anti-government or anti-regime movements or groups are able to take strategic or tactical advantage of grievances or problems related to responses to the event;
- The type, breadth, and depth of legitimacy and support for authorities, the government, the regime, or the nation-state; and
- The coercive and repressive capacities of the government and its willingness and ability to engage and carry out repression.

5.1.2 Farmer-Herder Conflict

One of the most prevalent forms of social conflict in West Africa is the recurrent struggle between pastoral livestock herders and sedentary farmers. It is widely speculated that future climate change will impact and possibly worsen conflict dynamics between these two groups (Dong et al., 2011; Maathai, 2011). Climate change will impact conflict dynamics *indirectly* by altering pastoral mobility patterns and reshaping pastoral livelihood portfolios in ways that increase friction with local farmers. In considering the climate change-conflict nexus, it is worth emphasizing three important points: (1) conflict patterns are not likely to be novel—pastoralists and farmers have negotiated such changes in the past, which have led to conflicts and ways to resolve them; (2) farmer-herder conflicts are political and notoriously complex, and even specific disputes that appear to be driven by environmental or climatic factors are more often than not deeply political struggles; and (3) model-based analysis has limitations—by relying on coarse-scale, aggregated data to predict conflict triggers and sources, quantitative models are insufficient because they do not capture the processes by which everyday disputes between herders and farmers escalate into full-blown, often bloody, conflicts.

These three issues affect the ways in which policymakers should engage with the most central question concerning climate change and pastoral conflict: how do institutions, at various scales, mediate and manage the factors that create animosity surrounding pastoral resource access? Such conflicts overwhelmingly occur between pastoral herders and farmers. In contrast to East Africa and its diversity of pastoralist ethnic groups, West African pastoralism is largely dominated by members of the Fulani ethnicity, which likely reduces the possibility of intra-group conflict (e.g., between clans or Fulani of different nationalities), although there is scant empirical data on this issue. It is possible that certain climate scenarios could create the conditions for increased conflict among pastoralists and such an eventuality could be addressed through many of the measures described below that focus on conflicts between farmers and herders.

Traditional institutions will continue to play the most important role in mediating farmer-herder disputes and preventing them from escalating. Turner et al. (2012) point out that in one agropastoral community in Niger people prefer to use informal channels to resolve their

differences amongst themselves, and care must be taken not to unintentionally erode or delegitimize these longstanding institutions. This case study reflects conflict management institutions found throughout West Africa that are based on relationships and mutual interdependence between pastoral livestock herders and farmers (Bassett and Kone, 2006). Relationships between pastoral herders and farmers are simultaneously antagonistic and friendly. The strands of friendship are relied upon to resolve disputes when they occur. Although it is widely recognized that the productive complementarity of the two groups has declined (e.g., cattle manure fertilizer for crop residue fodder; cf. Mortimore, 2010), and this is thought to increase conflict probability (cf. Davidheiser and Luna, 2008), these relationships continue to play a key role in conflict management and will continue to do so. Important strands of complementarity still exist (e.g., borrowing of draught animals, cash loans, livestock entrustment, and access to farmland), and friendships endure and even become stronger as livelihoods become more similar.

When disputes do overwhelm informal channels—and certain climate change scenarios may increase the frequency of these episodes—the issue of justice will become more critical. This represents an area where democratic local institutions can intervene effectively. This is an issue that has never achieved adequate attention yet does more than anything else to worsen farmer-herder conflicts. The practice of authorities, especially judges and law enforcement officials, taking bribes during dispute resolution proceedings aggravates tensions between the two groups, causing them to boil over occasionally (Moritz, 2010). It has been pointed out that pastoralists in Mali rely on bribery because, lacking formal land tenure, they do not have secure access to the resources on which they rely (Benjaminsen and Ba, 2009). However, this is a shortsighted strategy at best and one that is increasingly irrelevant as governments across the sub-region have enacted "pro-pastoral" legislation that protects pastoral tenure (Hesse, 2011).

The real challenge now is implementation. Structural adjustment and political decentralization throughout West Africa means that local governments, many of them weak and underfunded, are responsible for implementing national laws. All parties involved must work to reduce the role of bribery in rural affairs through more transparent, rule-based governance, especially at the local level. Evidence from Mali suggests that democratic decentralization is empowering local governments to do just this by keeping higher-level authorities out of dispute resolution. This is a promising development, although much more needs to be done considering the low level of capacity of most local institutions.

The corruption/justice issue relates directly to the threat of climate change because government issues are likely to deal with the underlying issues that cause conflict (i.e., resource competition, rural investment, crop damage) with much more frequency. Under most climate change scenarios, it is how institutions address these issues, rather than the issues themselves, that will potentially lead to more pastoral herder-farmer conflict.

Effective long-term conflict management will rely on proactive government policies to address the previously discussed issues surrounding natural resource management. Agricultural

expansion is shrinking the pastoral resource base throughout West Africa, and the time has come to begin actively managing pastoral resource areas where grazing is permitted but cultivation is not. Many farmer-herder conflicts erupt when herders intentionally damage the crops in a farmer's field because the herder believes that the farmer does not respect his right to grazing land.

Shrinking pastoral resources increasingly have led pastoralists to rely on aerial forage (tree branches) to feed their animals (Gautier et al., 2005). This is still punishable under regional forestry laws and often done unsustainably, which draws the ire of farmers, yet it is unlikely to stop. Instead, it should be legalized, regularized, and managed with the participation of local herders and farmers.

Pastoral labor shortages often cause, in addition to other problems, crop damage and ensuing conflict with farmers (Bassett, 1994). More effort should be made to improve the functioning and transparency of pastoral labor markets in the region to ensure that conflicts involving wage-earning herders can be managed effectively. This is especially true given that, as climate change forces pastoralists to diversify their livelihood portfolios, they will increasingly rely on wage labor to tend their herds.

5.2 CLIMATE CHANGE AND MIGRATION

For centuries migration has been used by rural households in West Africa to cope with climate variability, particularly in the Sahel (Rain, 1999; de Sherbinin et al., 2008; UNEP, 2011). Thus, for some, migration flows as a result of climate change and variability in the region is viewed as simply a continuation of age old patterns of transhumance, seasonal migration, and rural-urban migration (Batterbury, personal communication, 2009; Tacoli, 2011; White, 2011), while others identify what they believe to be an increase in "distress migration" owing to a lack of livelihood options in rural areas stemming from environmental degradation and climate changes (Warner et al., 2009).

Some of the polemics regarding population dynamics and migration in the Sahel have to do with a narrative, established after the great Sahel droughts of the mid-1970s and 1980s, that identified over-population as driving land degradation, with drought providing a trigger for famine and population reductions via mortality and out-migration. Out-migration itself was thus characterized as evidence that local agro-ecosystems could not sustain such large or growing populations (Higgins et al., 1982; Dietz and Veldhuizen, 2004). This has since been hotly contested (Mortimore and Adams, 2001; White, 2011). If we accept the argument that migration has been part of a long-term strategy of income diversification linking communities through trade and labor (Batterbury, 2007), the question remains, has the situation substantially changed in the past decade, and/or is it likely to do so in the future?

5.2.1 Recent Environmental Migration

In Burkina Faso, a nationally representative retrospective study on rainfall and migration conducted from 2000 to 2002 (Henry et al., 2004) found that people from drier regions are more likely to migrate temporarily and to a lesser extent permanently to other rural areas (rural-rural migration) compared with people from wetter areas. Rainfall deficits were found to increase rural-rural migration but decrease international migration, with no changes in urban-rural migration. More recent evidence from northern Burkina Faso, based on survey and focus group research conducted by the UNECA's African Climate Policy Centre, suggests that recent droughts have led pastoralists in the Sahel province to either abandon livestock raising and move west or to urban centers, or to move herds to more vegetation-abundant low lying areas resulting in the degradation of the few fertile areas left (Traoré, personal communication, 2012).

The Sahel droughts propelled a great expansion in West African cities as rural farmers and pastoralists sought food aid and alternative livelihoods. The droughts also drove some to move southward to coastal countries (Adepoju, 1995). In recent years, southward migration and urbanization have continued in the forest and savannah countries, with climatic factors contributing to the movement (Van der Geest et al., 2010; UNEP, 2011; Rademacher-Shulz and Mahama, 2012). A global migration modeling effort (CIESIN, 2011) found that roughly 10.6 million people left the drylands from 1970 to 2000, whereas a nearly equivalent number, 9.2 million, migrated to coastal ecosystems. Of the 9.2 million migrants to the coastal ecosystems, some 6.6 million people moved to the low elevation coastal zone (the area from 0–10 m above sea level), mostly to urban areas, which suggests that populations are moving toward areas at risk of sea level rise (de Sherbinin et al., 2012).

There are two emerging phenomena with respect to migration. One is the growth in migration to Europe since the 1990s, overland and by sea, using small fishing boats (Tacoli, 2011). It is difficult to determine the degree to which this migration is associated with declining environmental or climatic conditions versus other causes such as economic stagnation, the opening of new routes (however hazardous), more exposure to media images in even remote rural villages, and perceptions that European destinations offer greater opportunities (de Sherbinin, 2011). Another phenomenon is the rise of Al Qaeda in the Islamic Maghreb and the potential for growing Islamist activity to create refugee movements, as people flee strict Islamist controls and violence. The potential for a long-term conflict cannot be ruled out, and conflict is often associated with large population displacements. Some will likely resettle elsewhere while others may be stuck in refugee camps or urban slums for prolonged periods (Morinière et al., 2009; Oliver-Smith and de Sherbinin, forthcoming).

5.2.2 Future Climate Change Impacts on Migration

A report on the potential for "high end" climate change (+4°C this century) to impact on resources and society in ways that might trigger migration and displacement (New et al., 2011)

found that five West African countries (Senegal, Guinea, The Gambia, Sierra Leone, and Mauritania) are at risk of multiple impacts affecting water supplies, agriculture, and coastal zones (owing to sea level rise), which places them in the top 30 of such countries around the world. The authors do not attempt to estimate the potential migration flows resulting from these impacts, but instead note the numbers of people in regions that will likely be affected.

White (2011), on the other hand (based on the somewhat contradictory climate model outputs for the Sahel reported in Lenton et al. [2008]), suggests that if the Sahel tips toward a "greener" and moister state, migration, if correlated with drying, could actually decline. Kniveton et al. (2012) conducted agent-based modeling for Burkina Faso based on multiple population change and migration scenarios and find that most of the scenarios show that the percentage of people migrating (from the original population) declines owing to a "wetting rainfall trend" in the ENSEMBLES scenarios, but that drier scenarios do produce enhanced migration. They find that with increasing levels of projected population growth, the climate change signal is enhanced, producing more migration.

Whatever the average rainfall trends for the Sahel, the number of extreme events is likely to increase, including both floods and droughts (IPCC, 2012; Warner et al., 2012). The UK Government's Foresight project on migration and environmental change (Foresight, 2011) finds that under two scenarios of future climate and economic change there is a substantial risk of increased population displacement from river flooding in the region, along with displacement from sea level rise and flooding in the coastal zone. Nigeria, Benin, and Niger were each affected by floods from July to September 2010 that displaced an estimated 2 million, 831,000, and 226,000 people respectively (Yenotani, 2011). Drought risks remain a significant threat to the region, as evidenced by recurring droughts and famine in Niger (Nossiter, 2010; BBC, 2012), and are likely to drive displacement in the future, unless adaptive responses are developed (BBC, 2012). A number of analysts have sought to counter the perception that migration represents a failure of adaptation by emphasizing its positive aspects in terms of income diversification and risk reduction (Tacoli, 2011; UNEP, 2011).

GUIDELINES AND RECOMMENDATIONS

Given the high levels of uncertainty concerning rainfall, linked both with the uncertainty of long-term projections and the strong decadal variability in the region, risk management approaches should be prioritized.

Effective climate risk management generally involves developing a robust and flexible portfolio of actions aimed at risk reduction and risk transfer and response to events, as opposed to adopting a single focus on any particular measure. At the local level, portfolios should be developed in collaboration with communities in ways that are context specific, respond to clearly identified needs and vulnerabilities, and empower affected populations to develop, modify, and control their own approaches in order to adapt more quickly to a rapidly changing environment. At the regional, transboundary, and national level, capacity-building efforts should

aim to strengthen monitoring agencies and research centers such as AGRHYMET, African Centre of Meteorological Applications for Development (ACMAD), and university-based groups.

In addition to embracing a climate risk management approach, adaptation efforts in West Africa should seek to:

- Enhance climate-related technical, management, institutional, and governance capacity, including improving information and monitoring systems.
- Question existing paradigms and support flexibility in ways that advance sustainable and resilient development and encourage new response patterns.
- Address the underlying causes of climate vulnerability, including the structural inequalities that create and sustain poverty and constrain access to resources and markets.
- Apply focused approaches that address specific priority contexts at multiple spatial scales including key transboundary issues (e.g., river basin management), promising economic activities, and resource management options for the ecological transition zones connecting Sahelian, coastal, and tropical inland areas.[15]

Options for Capacity Building:

- Offer incentives and support to the regional climate research agendas of regional universities and technical institutes.
- Support a program (e.g., that provides post-doctoral fellowships) to advance the science and tools necessary to better predict the impacts of climate change on diverse sectors at the regional and national levels. The strongest institutions in the region (e.g., AGRHYMET, ACMAD, and the CILSS economics and policy center) are in the best position to host such a program with the objective of analyzing issues of the greatest importance to targeted countries. Efforts would be coordinated in partnership with national institutions to ensure that the program addresses real needs and provides implementable solutions. The program would be designed in collaboration with research institutions in developed countries.
- Support a series of intensive two-week courses concerning sector-specific climate change impacts in order to strengthen the understanding of climate change and to enhance the capacity to make informed decisions. These short courses should target professionals and recent graduates with limited prior experience with or knowledge of climate change-related topics.

Support Research and Adopt Iterative Approaches:

- Identify and support research agendas that target individual sectors and related linkages. Many of these research agendas are already well-defined and documented. An iterative

[15] These guidelines are drawn from a recent report of the IPCC about managing the risks of extreme events and disasters (IPCC, 2012).

strategy will lead to the most beneficial adaptation outcomes owing to the complexity, uncertainties, and long time frame associated with climate change; this should be adopted for monitoring, research, evaluation, learning, and innovation.

Address Underlying Causes of Climate Vulnerability:

Sustainability requires addressing the underlying causes of vulnerability, including the structural inequalities that create and sustain poverty and constrain access to resources and markets. Measures that already provide benefits in addition to a range of other scenarios ("no- or low-regrets options") represent a good starting point because they address other development goals and help build resilience (e.g., early warning systems, health surveillance, and access to clean water and adequate sanitation).

Recommendations for Agriculture:

In order to prepare for projected temperature increases, it is important to collect, evaluate, and breed cultivars to adjust to changes based on how long a given crop needs to mature, and to select for heat tolerance. Cultivars can also be bred and designed to better tolerate waterlogging, grow in more arid conditions, and better withstand stress. The focus should be on those Sahelian crops that are most critical to the economic wellbeing of the region and that are already at, or close to, their maximum temperature range. This is because a changing climate may subject crops—particularly in the Sahel—to conditions with no historical analogue (CCAFS, 2012). Flexible cultivars that can be integrated with intercropping, agro-forestry, and water conservation and management systems will assist farmers to diversify, more effectively manage risk, and improve yields (Haussmann et al., 2012).

The most successful adaptation measures will be those that strengthen smallholder systems, allow farmers to perceive a measureable increase in output, and are based on collective action at the local level (McCarthy et al., 2011). Moving from a "technological package" approach to empowering farmers as active participants in plant breeding, extension, and seed systems will ensure that interventions are relevant and responsive (CAADP, 2011). Innovation platforms that bring together value chain participants and other stakeholders will help to strengthen institutions and improve market access (Puskur et al., 2011).

Hounkonnou et al. (2012) suggest that institutional barriers explain a large proportion of the variance in the quantity and quality of agricultural output in sub-Saharan Africa. They argue that these institutional barriers can only be removed by engaging with the institutions themselves to develop win-win situations because farmers are too powerless to effect change against the formal and informal systems that have evolved to extract wealth from the agricultural sector.

- Recognizing that policy recommendations can best be drawn from a risk management perspective, study the probability of high-impact scenarios, which can then be assessed according to regional, country, and geographical context in order to identify the most vulnerable populations.

- Keep in mind that high uncertainty concerning rainfall amounts and timing strongly suggests the need for improvements in water management, which will benefit rain-fed agriculture in humid, in addition to semi-arid zones. When evaluating a number of climate change adaptation options for smallholder farmers, consider that decentralized, small-scale agricultural water management interventions represent low-cost, economically beneficial options for increasing agricultural resilience (Ngigi 2009).
- Strengthen smallholder farming systems by enhancing the dissemination of weather information to farmers (e.g., seasonal forecasts that can aid farmers with decision-making); investing in small-scale agricultural water management; improving irrigation infrastructure and distribution of seed, fertilizer, and pesticides; providing functional credit and insurance institutions; and improving market access (Mertz et al., 2011).
- Focus on breeding resilient and flexible cultivars for key staple crops.
- Empower farmers to actively participate in finding solutions to the issues that affect them. Develop innovation platforms that bring together value chain participants and other relevant stakeholders to help strengthen institutional capacity as well as improve market access. This includes engaging all stakeholders to overcome institutional barriers to climate change adaptation and resilience.

Recommendations for Pastoralism and Livestock Production:
In all but the worst case climate change scenarios, a livelihood portfolio based on cropping and livestock is likely for *both* pastoralists and farmers. Climate change adaptation strategies must focus on livelihood and production systems that combine markets, mobility, and opportunities for intensive crop and animal production. This will include several measures that are currently underemphasized or entirely absent from livestock-oriented projects:

- Rehabilitate areas suffering from degradation (e.g., loss of perennial grasses and shrub encroachment) through rangeland enclosures managed in collaboration with local herders and farmers.
- Develop livestock adaptation policies that include measures to support the sustainable production and marketing of supplemental livestock feed (e.g., cottonseed cakes and fodder crops).
- Advance research on how the expected negative impacts of climate change on staple crop production may affect West African livestock owners who increasingly rely on purchased feed inputs.
- If targeting livestock herders, improve, fine-tune, and calibrate climate forecasting to provide intra-seasonal rainfall and water resource information.
- Be aware that broadcasted information about resource availability (grazing areas; water) is risky because provision of this type of information as a public good may lead to overexploitation of resources and it may advantage larger, commercial herders to the detriment of smallholders.
- Improve herder decision-making by providing general information about expected climate change impacts in the region.

- Promote inclusive democratic local governance that enfranchises livestock herders, including measures to improve and secure pastoral herding labor markets. This will be critical to successful efforts to adapt to climate change. .
- Do not overlook local pastoral knowledge and understanding of these issues.

Recommendations for Rivers and Water Resources:

- Enhance data collection for both historic monitoring and modeling future water resources. Establish systematic climate and river monitoring stations across West Africa and water basins. Link these international standardized monitoring stations with local research and knowledge networks and with regional or continent-wide management.
- Downscale the spatial specificity of water availability, stress, scarcity, vulnerability, and footprint indices. Despite a range of methodologies to identify various water stresses, the availability of robust data at a higher resolution is required to advance sequencing and prioritization of various interventions and government action.
- Through existing regional monitoring programs (e.g., FEWS NET), monitor for rapid changes in water supply that outpace the ability for institutional response.
- Prioritize institutional and governance capacity regardless of projected climate changes. This includes basin management organizations, national water management organizations, and local organizations.

Recommendations for Inland and Coastal Wetlands:

Direct climate change stressors, such as increasing variability in precipitation patterns, rising temperatures, and rising sea level, represent serious threats to the integrity and sustainability of inland and coastal wetlands in West Africa. These threats are exacerbated by human actions that directly impact these resources at a local level. Further, climate change impacts that reduce the services and productivity of other regional ecosystems may indirectly contribute to increased resource use pressure on wetlands (Mitchell, 2013). Thus it will be necessary to:

- Build on previous and existing wetlands inventories and efforts to identify priority sites for wetlands conservation, monitoring, and sustainable development in ways that consider different climate change scenarios (e.g., sea level rise scenarios) (Mitchell, 2013).
- Improve knowledge of wetlands biodiversity dynamics, including research on the potential consequences of climate change for habitat species composition (e.g., potential for displacement of native vegetation by non-native invasive plant species) (Mitchell, 2013).
- Improve knowledge of the economic and ecological values of wetlands ecosystems to inform development of integrated management strategies and to increase awareness of the economic and ecological importance of wetlands under climate change (Sene et al., 2006; Feka and Ajonina, 2011).

- Promote good governance and integrated management of water resources to ensure the sustainability of inland wetlands and fisheries, as well as to mitigate the potential for conflict due to resource utilization by multiple stakeholders (Mitchell, 2013).
- Promote effective institutional and governance mechanisms to preserve and protect coastal wetlands from loss and degradation due to development activities, especially in Nigeria, Benin, and Togo where up to 40% of the country's population resides in the coastal zones.
- Support the development of regional wetlands management institutions to foster cross-border partnerships and cooperation.
- Advance use of remote sensing to monitor land-use/land-cover change in both inland and coastal wetland areas.
- Improve the monitoring of the quality and quantity of freshwater reservoirs located in coastal regions that are threatened with salinization due to sea level rise.
- Partner with multidisciplinary networks of wetlands experts in the region such as the Sahelian Wetlands Expert Group and the Coastal Planning Network (Sene et al., 2006).
- Ensure that wetland resource management is adaptive in the face of uncertainties in climate change outcomes.
- Design and deploy effective technological and management mechanisms to mitigate and prevent the erosion of coastal wetlands.
- Provide wetlands managers with training on habitat restoration and rehabilitation strategies that consider the projected impacts of climate change (Erwin, 2009).
- Integrate the management of coastal mangrove forest ecosystems within robust forestry management and integrated coastal zone management strategies.
- Integrate alternative income generation approaches and alternative energy sources (to reduce extraction of wood fuel) into coastal wetland management to offer alternative livelihood options to populations subsisting on coastal resources.

Recommendations for Forests and Woodlands:

More research is needed concerning how global climate change may affect the future distribution of humid tropical forests around the world by modifying hydrological regimes. The same holds true for forest cover dynamics and regeneration in West Africa and the interactions between climatic and human activity that influence forests and woodlands—including the impacts of urbanization trends and the demands of growing urban populations for forest-based resources and ecosystem services. In the Sudanian savannah and Sudano-Sahelian transition zone many farmers have responded to the scarcity of forests and woodlands by protecting, pruning, and managing trees and shrubs that regenerate spontaneously on their lands. Recommendations include:

- Examine existing efforts to support regreening in the Sahel, coastal zone, and tropical inland areas through farmer-managed natural forest regeneration and identify opportunities to integrate climate risk management into regreening strategies.
- Improve monitoring of land use/cover changes and vegetation cover dynamics.

- Improve the management of fruit trees in agroforestry parklands to improve rural livelihoods in the Sahel.

Recommendations for Fisheries:

Coastal and inland fisheries are critical both as a source of income and food. Coastal fisheries are already under threat due to over-fishing and harmful fishing practices. Climate change-induced acidification and increases in sea levels and sea surface temperature will likely lead to even further reductions in fish stock. Therefore we recommend that stakeholders:

- Examine the sustainability of expanding on- and off-shore aquaculture to increase production and promote fish as an alternative regional food source.
- Improve governance and institutional capacity to ensure that planning and management of sustainable fisheries incorporate knowledge of potential climate change impacts under different scenarios.
- Improve monitoring of regional fisheries.
- Collaborate with multi-disciplinary networks of fisheries and aquaculture experts in the region, such as the African Fisheries Experts Network (www.afri-fishnet.org) established as part of the Partnership for African Fisheries as a core resource for NEPAD.
- Provide fisheries and aquaculture managers with scientific and technical training and mentoring opportunities that promote sustainable practices and raise awareness of climate-related vulnerabilities, potential climate change impacts, and promising coping strategies.

Recommendations for Human Health:

Adaptation to climate change in West Africa, as elsewhere, requires the development of strategies that take into account multiple sectors and various interrelated human health concerns related to disease control, disease habitat transformations, land-use change, agricultural practices, food safety and nutrition, water quality and quantity, and access to safe food and water supplies. Recommendations include:

- Support the launching of the WHO consortium aimed to develop a comprehensive policy framework to provide a scientific and evidence-based coordinated response to climate change adaptation needs of African countries.
- Improve hydrological models that simulate variations of mosquito breeding sites in order to better understand and possibly predict Rift Valley fever transmission dynamics.
- Improve potable water supply, road drainage systems, and sanitary conditions to alleviate outbreaks of water-borne infectious diseases such as cholera and typhoid.
- In the development of adaptation strategies that involve water harvesting and storage, health considerations must be incorporated since water-based disease transmission is a potential consequence.
- Research behavioral responses of the malaria vectors (*Anopheles melas* and *Anopheles gambiae*) to habitat transformations caused by sea level rise.

- Utilize the Early Warning Index and risk maps at regional scales for meningitis epidemic onset prediction in order to optimally direct national and international health policy (Sultan et al., 2005).
- Research the effects of climate-related migrations on disease distribution (e.g., the potential spread of diseases into non-endemic regions when infected people migrate to places where vectors are present) (de Souza et al, 2012).
- Advance research on the pathways by which climate impacts nutrition and food security, including food availability, stability of supply, access, and utilization (Tirado et al., 2010; Tirado and Meerman, 2012).
- Support further research to improve understanding of the human and livestock health impacts of toxins produced by fungi (mycotoxins) (Gnonlonfin et al., 2013).
- Support cross-sectoral initiatives to reduce the risks of aflatoxin contamination and exposure. Aflatoxin exposure intervention strategies should be targeted at high-risk areas and populations, such as populations whose primary weaning foods are at high-risk of aflatoxin contamination (Gong et al. 2003).
- Improve the capacity of the public health community to use climate-sensitive and environmental information for decision-making by providing platforms that bring climate scientists, public health researchers, and public health practitioners together to translate research into the evidence needed by decision makers. The MERIT initiative provides a model (Thomson et al., in press).

Recommendations related to Conflict and Security:

Climate stress is one among multiple risk factors that have the potential to increase conflict at a range of social and geographic scales. Despite current research limitations and uncertainties, there is widespread agreement that climate change and conflict need to be addressed together and that this objective presents major challenges whether or not causal pathways linking climate variables to conflict can be clearly established. Contributions to this body of knowledge and practice could include supporting efforts to coordinate and integrate climate science and social science research approaches, development and refinement of climate- and conflict-related indicators, improvements in conflict monitoring and early warning systems, and improvements in techniques for data collection and analysis. Recommendations include:

- Recognize that climate change is more often a "threat multiplier" than a direct trigger.
- Prioritize a range of existing development programs to adapt to changing climate patterns.
- Provide sustained support for integrated climate science and social science research on climate-security connections in West Africa to better understand the causal pathways and mechanisms linking climate variability and change to societal instability and conflict in the region.
- Support efforts to establish regional early warning systems for sudden climate-related disturbances, especially where political and economic systems are so fragile that a climate shock could create a chain reaction leading to a security threat.

- Increase USAID interactions with the intelligence community to help advance existing conflict monitoring and early warning systems in ways that integrate climate-related stress. Request analyses of high-priority countries in the region.
- Apply scenario approaches to think about: unexpected and potentially disruptive single climate events ("climate surprises"); conjunctions of events (clusters) with common causes occurring simultaneously or closely in time; sequences or cascades of events in which a climate event leads to a series of consequences; and disruptions of globally connected systems that support human wellbeing (NRC, 2013).
- Promote and participate regularly in efforts to establish a system of periodic "climate stress testing" for West African countries as well as for critical global systems. These stress tests would be used to assess potentially disruptive conjunctions of climate events and socioeconomic and political conditions (NRC, 2013).
- Recognizing that the potential for conflict is largely mediated by governance structures, promote climate change adaptation strategies that facilitate conflict management and cooperation among social groups through effective institutional frameworks and governance mechanisms (Scheffran et al., 2012a: 870).
- Promote accountable, transparent government institutions to better meet citizen demands through regular, peaceful means (Hendrix and Salehyan, 2012).
- Promote activities that bolster social capital and civil society participation in planning, implementation, and monitoring of disaster risk management and climate change adaptation activities (Aldrich, 2012).
- Promote activities that target likely causal pathways linking climate stress and conflict, for example more widespread use of climate index insurance to help reduce the livelihood impact of droughts and floods.
- Promote active management of pastoral resource areas where grazing is permitted but crop cultivation is not. Many farmer-herder conflicts erupt when herders intentionally damage the crops in a farmer's field because the herder believes that the farmer does not respect his right to grazing land.
- As a response to shrinking pastoral resources, promote the legalization, regularization, and management of aerial forage (tree branches) to feed livestock. This should be done in collaboration with local communities of herders and farmers and local governments.
- Develop policies and practices that support improvement of the functioning and transparency of pastoral labor markets in West Africa to ensure that conflicts involving wage-earning herders can be managed effectively. As pastoralists diversify their livelihood portfolios in response to climate change, they will increasingly rely on wage labor to tend their herds.

Recommendations related to Migration:

Migration is a part of the fabric of West African societies. It has been an adaptive strategy for climate variability that will undoubtedly continue. Efforts to manage or limit migration have largely failed elsewhere, and therefore there is no reason to believe that they will be successful within the African context.

Migration has been conceived by some as a failure of adaptation. In this context, policy options can be developed to help people to better cope with climate extremes *in situ*, which could lead to a reduction in distress migration. Thus, stakeholders should:

- Increase the governance capacity of city and town planners and managers in order to accommodate likely future increases in rural-urban migration volume.
- Encourage continued seasonal migration to cities and coastal areas by generating additional employment opportunities.
- Research past climate variability and migration impacts as a way to understand likely future volumes of migration.
- Research the effects of climate-related migrations on disease distribution (e.g., the potential spread of diseases into non-endemic regions when infected people migrate to places where vectors are present) (de Souza et al, 2012).
- In the absence of "hard data" on rural-urban and international migration, there is a need for cross-national survey research on migration streams in West Africa in order to better characterize the flows.

Recommendations for the Sahelian Zone:

- Support better management of transboundary watersheds using multi-stakeholder approaches to avoid conflict over water resources given that surface water resources often amplify rainfall anomalies (both droughts and floods) and given expectations that there will be increased pressure on water resources due to population growth as well as water demands for irrigation and the generation of hydropower.
- Where possible, advance breeding and improve management of drought-, heat-, and waterlogging-tolerant crop varieties in both the agriculture and agro-forestry sectors. Focus should be on those agricultural products most important to the region, both economically and nutritionally.
- Encourage continued seasonal migration to cities and coastal areas by generating additional employment opportunities, while simultaneously developing policy options to help people better cope with climate extremes *in situ*, which could help reduce distress migration.
- Invest in decentralized, small-scale water supply infrastructures, such as dams and irrigation systems, to extend the length of the growing season.
- Identify opportunities to integrate climate risk management into regreening strategies through an examination of existing efforts to support regreening through farmer-managed natural forest regeneration.
- In collaboration with local communities and governments, explore innovative combinations of the most promising options for agriculture, agroforestry, and regreening to determine which are likely to be the most flexible and most sustainable given uncertainty over the impact of climate change.
- Develop new livelihood opportunities for pastoralist populations and investigate how to incorporate more livestock production into the livelihoods of populations that typically

rely on crops. This will help build resilience and improve nutrition by meeting regional protein needs.

Recommendations for the Coastal Zone:

- Improve geospatial data and infrastructure to support urban planning and the development of integrated coastal zone management plans that address risks and opportunities as they relate to: projected sea level rise; expected increase in the frequency of storms, storm surges, and floods; urbanization trends; and coastal wetlands protection and management.
- Inform decision makers and the public about the risks and potential impacts of sea level rise to guide land-use zoning and the relocation of vulnerable populations.
- Improve the monitoring of quality and quantity of freshwater aquifers in those coastal regions threatened with salinization due to over-abstraction and sea level rise.
- Explore how to improve governance and institutional capacity to promote sustainable fisheries landings while incorporating knowledge of potential climate change impacts.
- Support efforts to preserve, protect, and restore coastal wetlands (e.g., mangroves) to buffer the impact of storms that may increase with climate change. Design and deploy effective technological and management mechanisms to mitigate and prevent the erosion of coastal wetlands.
- Integrate the development of alternative income-generating activities into coastal wetland management strategies to relieve pressure from subsistence use of these coastal resources.
- Examine the sustainability of expanding on- and off-shore aquaculture to increase fish production as a regional food supply.

Recommendations for the Tropical Inland Zone:

- In order to support those agricultural products most important to the region, encourage the breeding and improve the management of heat-resistant varieties and advance farming practices more appropriate for hotter growing conditions (e.g., agro-forestry and the cultivation of shade crops).
- Support better management of transboundary watersheds using multi-stakeholder approaches to avoid conflict over water resources given that surface water resources often amplify rainfall anomalies (both droughts and floods), and given expectations that there will be increased pressure on water resources due to popAulation growth as well as water demands for irrigation and the generation of hydropower.
- In areas that could potentially sustain higher productivity, support agricultural intensification and modernization by providing improved seeds (high yielding varieties), fertilizer inputs, tractor services, improvements in small-scale livestock production (e.g., vaccination campaigns), provision of micro-credit services to farmers, and improved market linkages. This will help meet regional food needs. Sustainable agricultural intensification and modernization will help to offset decreasing availability of agricultural land and boost local employment.

- Invest in decentralized, small-scale water supply infrastructures, such as dams and irrigation systems, to extend agricultural production into the dry season and ensure year-round farming.
- Concentrate on transboundary programs that aim to promote and safeguard gains in forested and reforesting areas in order to maintain biodiversity, natural resources, and the variety of ecosystem services that support human livelihoods and wellbeing. This approach could contribute to both climate change adaptation and mitigation.
- Support carbon sequestration efforts in protected forests, tree crop plantations, and wetlands through Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+) and carbon credits.
- Take measures to control bush fires to prevent the destruction of economic trees, crops, and other types of vegetation cover.

REFERENCES

Abiodun, B., Adeyewa, Z., Oguntunde, P., Salami, A., & Ajayi, V. (2012). Modeling the impacts of reforestation on future climate in West Africa. *Theoretical and Applied Climatology,* 110, 77–96. Retrieved from http://dx.doi.org/10.1007/s00704-012-0614-1

ACPC. (2011). Climate change and water in Africa: Analysis of knowledge gaps and needs. In *Working Paper 4*, 1–23. African Climate Policy Center of United Nations Economic Commission for Africa. Retrieved from http://new.uneca.org/Portals/acpc/documents/working_papers/WP4_Water%20Gaps.pdf

Adams, W. M. (1993). Indigenous use of wetlands and sustainable development in West Africa. *The Geographical Journal,* 159, 209–218. Retrieved from http://www.jstor.org/stable/3451412

Adepoju, A. (1995). Migration in Africa: An overview. In J. Baker & T. A. Aina (Eds.), *The migration experience in Africa* (pp. 87–108). Retrieved from http://www.neaculture.it/MigrationinAfrica.pdf

Afouda, A., Ndiaye, T., Niasse, M., Flint, L., Moussa Na Abou, M., & Purkey, D. (2007). Climate change adaptation and water resources management in West Africa. In *Synthesis Report*. ENDA, UNESCO, SEI, NCAP. Retrieved from http://startinternational.org/library/items/show/739

Aldrich, D. P. (2012). *Building resilience: Social capital in post-disaster recovery*. Chicago and London: University of Chigago Press.

Allison, E. H., Perry, A. L., Badjeck, M.-C., Neil Adger, W., Brown, K., Conway, D., Halls A. S., Pilling G. M., Reynolds J. D., Andrew, N. L., & Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries,* 10, 173-196. Retrieved from http://dx.doi.org/10.1111/j.1467-2979.2008.00310.x

Amuna, P., & F. B. Zotor (2008). The epidemiological and nutrition transition in developing countries: Evolving trends and their impact in public health and human development. *Proceedings of the Nutrition Society* 67, 82–90. Retrieved from http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1681128

APF (Africa Partnership Forum). 2008. Climate Challenges to Africa: A Call for Action. Report prepared for the 10th Meeting of the Africa Partnership Forum, Tokyo, Japan, 7-8 April 2008. OECD. Retrieved from http://www.oecd.org/site/africapartnershipforum/meetingdocuments/40692762.pdf

Appeaning Addo, K., Larbi, L., Amisigo, B., & Ofori-Danson, P. K. (2011). Impacts of coastal inundation due to climate change in a cluster of urban coastal communities in Ghana, West Africa. *Remote Sensing,* 3, 2029–2050. Retrieved from http://www.mdpi.com/2072-4292/3/9/2029

Armah, F., Odoi, J., Yengoh, G., Obiri, S., Yawson, D., & Afrifa, E. A. (2011). Food security and climate change in drought-sensitive savanna zones of Ghana. *Mitigation and Adaptation Strategies for Global Change,* 16, 291–306. Retrieved from http://dx.doi.org/10.1007/s11027-010-9263-9

Ayantunde, A. A., de Leeuw, J., Turner, M. D., & Said, M. (2011). Challenges of assessing the sustainability of (agro)-pastoral systems. *Livestock Science,* 139, 30–43. Retrieved from http://dx.doi.org/10.1016/j.livsci.2011.03.019

Ayibotele, N. B. (2008). IWRM in the Niger River Basin Case #46. Niger Basin Authority and Global Water Partnership. Retrieved from http://www.gwptoolbox.org/images/stories/cases/en/cs%2046%20transboundary.pdf

Bader, J., & Latif, M. (2003). The impact of decadal-scale Indian Ocean sea surface temperature anomalies on Sahelian rainfall and the North Atlantic Oscillation. *Geophysical Research Letters,* 30, 2169. Retrieved from http://dx.doi.org/10.1029/2003GL018426

Bandyopadhyay, S., Kanji, S., & Wang, L. (2012). The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. *Applied Geography,* 33, 63-72. Retrieved from http://www.sciencedirect.com/science/article/pii/S014362281100155X

Barbier, B., Yacouba, H., Karambiri, H., Zoromé, M., & Somé, B. (2009). Human vulnerability to climate variability in the Sahel: Farmers' adaptation strategies in northern Burkina Faso. *Environmental Management,* 43, 790-803.

Retrieved from http://dx.doi.org/10.1007/s00267-008-9237-9

Barnes, R. F. W. (1990). Deforestation trends in tropical Africa. *African Journal of Ecology,* 28, 161–173. Retrieved from http://dx.doi.org/10.1111/j.1365-2028.1990.tb01150.x

Barnett, J., & O'Neill, S. (2010). Maladaptation. *Global Environmental Change,* 20, 211-213. Retrieved from http://dx.doi.org/10.1016/j.gloenvcha.2009.11.004

Bassett, T. J. (1994). Hired herders and herd management in Fulani pastoralism (northern Côte d'Ivoire). *Cahiers d'Études Africaines,* 34, 147–173. Retrieved from http://www.persee.fr/web/revues/home/prescript/article/cea_0008-0055_1994_num_34_133_2045

Bassett, T. J., & Koné, M. (2006). Grazing lands and opportunistic models: The political ecology of herd mobility in northern Côte d'Ivoire. Montpellier: *Institut de Recherche pour le Developpement*. Retrieved from http://www.mpl.ird.fr/colloque_foncier/Communications/PDF/Bassett.pdf

Bassett, T. J., & Turner, M. D. (2007). Sudden shift or migratory drift? FulBe herd movements to the Sudano-Guinean region of West Africa. *Human Ecology,* 35, 33–49. Retrieved from http://dx.doi.org/10.1007/s10745-006-9067-4

Batterbury, S. (2007). Comments on P-D-E, livelihoods, and agrarian change in the Sahel. In *Panel Contribution to the Population-Environment Research Network Cyberseminar on Population-Development-Environment Linkages in the Sudano-Sahelian Zone of West Africa* Retrieved from http://www.populationenvironmentresearch.org/papers/Batterbury_SahelCyberseminar.pdf

BBC. (2012). Amidst drought and famine, Niger leads West Africa in addressing crisis. Retrieved from http://www.pbs.org/newshour/bb/africa/july-dec12/niger_07-12.html

Benjaminsen, T. A., & Ba, B. (2009). Farmer-herder conflicts, pastoral marginalization, and corruption: A case study from the inland Niger delta of Mali. *Geographical Journal,* 175, 71–81. Retrieved from http://dx.doi.org/10.1111/j.1475-4959.2008.00312.x

Biasutti, M., & Giannini, A. (2006). Robust Sahel drying in response to late 20th century forcings. *Geophysical Research Letters,* 33, L11706. Retrieved from http://dx.doi.org/10.1029/2006GL026067

Biasutti, M., Held, I. M., Sobel, A. H., & Giannini, A. (2008). SST forcings and Sahel rainfall variability in simulations of the twentieth and twenty-first centuries. *Journal of Climate,* 21, 3471–3486. Retrieved from http://dx.doi.org/10.1175/2007JCLI1896.1

Biasutti, M., & Sobel, A. H. (2009). Delayed Sahel rainfall and global seasonal cycle in a warmer climate. *Geophysical Research Letters,* 36, L23707. Retrieved from http://dx.doi.org/10.1029/2009GL041303

Boelee, E., Yohannes, M., Poda, J.-N., McCartney, M., Cecchi, P., Kibret, S., Hagos, F., & Laamrani, H. (2012). Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. *Regional Environmental Change*, 1–11. Retrieved from http://dx.doi.org/10.1007/s10113-012-0287-4

Brahic, C. (2006). Waiting for the monsoon. *Science,* 313, 608–609. Retrieved from http://www.sciencemag.org/content/313/5787/608.full?sid=5ce27a1d-1f6e-42c4-bfe0-43b3e29aee62

Brengues, J. (1975). *La Filariiose de Bancroft en Afrique de L'Ouest*. Paris: ORSTOM.

Brottem, L. (in prep.) Where the green grass grows: Farmer-herder conflict, environmental change, and institutional response in Mali. Ph.D. thesis, Department of Geography, University of Wisconsin-Madison.

Brown, A. & M. D. Matlock. 2011. A review of water scarcity indices and methodologies. White Paper #106. The Sustainability Consortium. Retrieved from http://www.sustainabilityconsortium.org/wp-content/themes/sustainability/assets/pdf/whitepapers/2011_Brown_Matlock_Water-Availability-Assessment-Indices-and-Methodologies-Lit-Review.pdf

Brown, O., & Crawford, A. (2008). Climate change: A new threat to stability in West Africa? Evidence from Ghana and Burkina Faso. *African Security Review,* 17, 39–57. Retrieved from http://dx.doi.org/10.1080/10246029.2008.9627482

Brown, O., & McLeman, R. (2009). A recurring anarchy? The emergence of climate change as a threat to

international peace and security. *Conflict, Security & Development,* 9, 289–305. Retrieved from http://dx.doi.org/10.1080/14678800903142680

Brown, O., Hammill, A., & Mcleman, R. (2007). Climate change as the 'new' security threat: Implications for Africa. *International Affairs,* 83, 1141–1154. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1468-2346.2007.00678.x/full

Burke, M. B., Lobell, D. B., & Guarino, L. (2009). Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Global Environmental Change,* 19, 317–325. Retrieved from http://dx.doi.org/10.1016/j.gloenvcha.2009.04.003

Butt, T. A., McCarl, B. A., Angerer, J., Dyke, P. T., & Stuth, J. W. (2005). The economic and food security implications of climate change in Mali. *Climatic Change,* 68, 355–378. Retrieved from http://dx.doi.org/10.1007/s10584-005-6014-0

CAADP. (2011). Farmer first: Shifting paradigms in agricultural technology development. In *FAC CAADP Policy Brief 04*. Retrieved from www.future-agricultures.org

Caminade, C., & Terray, L. (2010). Twentieth century Sahel rainfall variability as simulated by the ARPEGE AGCM, and future changes. *Climate Dynamics,* 35, 75-94. Retrieved from http://dx.doi.org/10.1007/s00382-009-0545-4

Center for Geographic Analysis at Harvard University. (2012). *AfricaMap*. Retrieved from http://worldmap.harvard.edu/africamap

Climate Change, Agriculture, and Food Security (CCAFS). (2012). CGIAR research program on climate change, agriculture, and food security. CGIAR. Retrieved from http://ccafs.cgiar.org

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., & Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climate Change* 83, 381–399. Retrieved from http://startinternational.org/library/archive/files/challinor-etal-africa-climchan-published_42be9a001d.pdf

Charney, J., Stone, P. H., & Quirk, W. J. (1975). Drought in the Sahara: A biogeophysical feedback mechanism. *Science,* 187, 434–435. Retrieved from http://www.sciencemag.org/content/187/4175/434.abstract

CIA. (2012). The World Factbook. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/

CIESIN (Center for International Earth Science Information Network, Columbia University). (2012a). Urban-rural population and land area estimates. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Retrieved from http://sedac.ciesin.columbia.edu/data/set/lecz-low-elevation-coastal-zone

CIESIN (Center for International Earth Science Information Network, Columbia University) (2012b). National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates, v3 (PLACE III), Palisades, NY: CIESIN, Columbia University. Retrieved from http://sedac.ciesin.columbia.edu/data/set/nagdc-population-landscape-climate-estimates-v3

CIESIN (Center for International Earth Science Information Network, Columbia University). (2011). MR4: Estimating net migration by ecosystem and by decade: 1970–2010. In *Migration and Global Environmental Change*. London: Foresight Project on Environmental Migration.

COMET Program (date accessed 11 December 2012), Seasonal Precipitation in West Africa In *Introduction to Tropical Meteorology*. University Corporation for Atmospheric Research. Retrieved from http://www.meted.ucar.edu/tropical/textbook_2nd_edition/navmenu.php?tab=6&page=3.5.4

Connor, S. J. (2002). Managing health and disease in developing countries. In V. Desai & R. Potter (Eds.), *The Arnold Companion to Development Studies,* (pp. 396-400). London: Arnold.

Connor, S. J., Omumbo, J., Green, C., DaSilva, J., Mantilla, G., Delacollette, C., Hales, S., Rogers, D., & Thomson, M. (2010). Health and climate – needs. *Procedia Environmental Sciences,* 1, 27-36. Retrieved from http://www.sciencedirect.com/science/article/pii/S1878029610000058

Conservation International. 2012. Guinean Forests of West Africa. Accessed 26 November 2012 from http://www.conservation.org/where/priority_areas/hotspots/africa/Guinean-Forests-of-West-Africa/Pages/default.aspx

Conway, G. (2009). The science of climate change in Africa: Impacts and adaptation. In *Discussion Paper No. 1*, 1-21. Grantham Institute for Climate Change, Imperial London College. Retrieved from https://workspace.imperial.ac.uk/climatechange/public/pdfs/discussion_papers/Grantham_Institue_-_The_science_of_climate_change_in_Africa.pdf

Cook, K. H., & Vizy, E. K. (2006). Coupled model simulations of the West African monsoon system: Twentieth- and twenty-first-century simulations. *Journal of Climate,* 19, 3681–3703. Retrieved from http://dx.doi.org/10.1175/JCLI3814.1

Cook, K. H., & Vizy, E. K. (2012). Impact of climate change on mid-twenty-first century growing seasons in Africa. *Climate Dynamics,* 39, 2937–2955. Retrieved from http://dx.doi.org/10.1007/s00382-012-1324-1

Cools, J., Diallo, M., Boelee, E., Liersch, S., Coertjens, D., Vandenberghe, V., & Kone, B. (in press). Integrating human health into wetland management for the Inner Niger Delta, Mali. *Environmental Science & Policy*. Retrieved from http://www.sciencedirect.com/science/article/pii/S1462901112001670

Dart-Throwing Chimp. (date accessed 15 February 2013). Coup forecasts for 2013. [Web log message] Retrieved from http://dartthrowingchimp.wordpress.com/2012/12/21/coup-forecasts-for-2013/

de Sherbinin, A. (2011a). The biophysical and geographical correlates of child malnutrition in Africa. *Population, Space and Place,* 17, 27–46. Retrieved from http://dx.doi.org/10.1002/psp.599

de Sherbinin, A. (2011b). The effects of climate change on displacement and migration.

de Sherbinin, A., Levy, M., Adamo, S., MacManus, K., Yetman, G., Mara, V., Razafindrazay, L., Goodrich, B., Srebotnjak, T., Aichele, C., & Pistolesi, L. (2012). Migration and risk: Net migration in marginal ecosystems and hazardous areas. *Environmental Research Letters,* 7, 045602. Retrieved from http://stacks.iop.org/1748-9326/7/i=4/a=045602

de Sherbinin, A., VanWey, L. K., McSweeney, K., Aggarwal, R., Barbieri, A., Henry, S., Hunter, L. M., Twine, W., & Walker, R. (2008). Rural household demographics, livelihoods, and the environment. *Global Environmental Change,* 18. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959378007000398

de Souza, D. K., Owusu, P. N., & Wilson, M. D. (2012). Impact of climate change on the geographic scope of diseases. In N. Chhetri (Ed.), *Human and social dimensions of climate change* (pp. 245–264). InTech. Retrieved from http://www.intechopen.com/books/human-and-social-dimensions-of-climate-change/impact-of-climate-change-on-the-geographic-scope-of-diseases

De Stefano, L., Duncan, J., Dinar, S., Stahl, K., Strzepek, K., & Wolf, A. (2010). Mapping the resilience of international river basins to future climate change-induced water variability. In *Water Sector Board Discussion Paper Series*. The World Bank. Retrieved from http://www.transboundarywaters.orst.edu/publications/publications/De%20Stefano%20et%20al%202010.pdf

Davidheiser, M., & Luna, A. M. (2008). From complementarity to conflict: A historical analysis of farmer-Fulbe relations in West Africa. *African Journal on Conflict Resolution* 8, 77–103. Retrieved from http://www.ajol.info/index.php/ajcr/article/view/39421/29628

Dennis, K. C., Niang-Diop, I., & Nicholls, R. J. (1995). Sea-level rise and Senegal: Potential impacts and consequences. *Journal of Coastal Research*, 243–261. Retrieved from http://www.jstor.org/stable/25735711

Dietz, T., & Veldhuizen, E. (2004). Population dynamics: An important intervening variable. In *The impact of climate change on drylands-with a focus on West Africa,* eds. A. Dietz, R. Ruben & A. Verhagen, 79-82. Dordrecht: Kluwer Academic Publishers.

Dieye, A. M., & Roy, D. P. (2012). A study of rural Senegalese attitudes and perceptions of their behavior to changes in the climate. *Environmental Management,* 50, 929–941. Retrieved from http://dx.doi.org/10.1007/s00267-012-9932-4

Dinku, T. (2005). Use of TRMM precipitation radar for calibrating overland passive microwave rain retrieval. University of Connecticut. Retrieved from http://digitalcommons.uconn.edu/dissertations/AAI3187723

Diogo, R. V. C., Buerkert, A., & Schlecht, E. (2010). Resource use efficiency in urban and peri-urban sheep, goat, and cattle enterprises. *Animal,* 4, 1725–1738. Retrieved from http://dx.doi.org/10.1017/S1751731110000790

Diop, F. N., & Niane, M. (2011). Integration of freshwater biodiversity into Africa's development process: Mobilization of information and demonstration sites, demonstration project of Gambia River Basin. Retrieved from http://www.iucn.org/about/work/programmes/species/our_work/about_freshwater/what_we_do_freshwater/pan_africa_freshwater_ba/case_study__gambia_river_basin/

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate change impacts on marine ecosystems. *Annual Review of Marine Science,* 4, 11–37. Retrieved from http://www.annualreviews.org/doi/abs/10.1146/annurev-marine-041911-111611

Dong, S., Wen, L., Liu, S., Zhang, X., Lassoie, J. P., Yi, S., Li, X., Li, J., & Li, Y. (2011). Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. *Ecology and Society,* 16, 10. Retrieved from http://www.ecologyandsociety.org/vol16/iss2/art10/

Dongmo, A.-L., Vall, E., Dugué, P., Njoya, A., & Lossouarn, J. (2012). Designing a process of co-management of crop residues for forage and soil conservation in Sudano-Sahel. *Journal of Sustainable Agriculture,* 36, 106-126. Retrieved from http://dx.doi.org/10.1080/10440046.2011.620232

Donkor, S. M., & Abe, J. (2012). Impact of climate change in the Guinea Current Large Marine Ecosystem region. In K. Sherman & G. McGovern (Eds.). *Frontline observations on climate change and sustainability of large marine ecosystems* (pp. 64–80). New York, NY: UNDP. Retrieved from http://www.undp.org/content/undp/en/home/librarypage/environment-energy/water_governance/frontline-observations-on-climate-change-and-sustainability-of-l/

Douglas, E. M., Githui, F. W., Mtafya, A. R., Green, P. A., Glidden, S. J., & Vorosmarty, C. J. (2006). Characterizing water scarcity in Africa at different scales. *Journal of Environmental Management*. Retrieved from http://www.nasaids.unh.edu/pdfs/Douglasetal_JEM_in_revision.pdf

Druyan, L. M., Jinming, F., Cook, K. H., Yongkang, X., Fulakeza, M., Hagos, S. M., Konare, A., Moufouma-Okia, W., Rowell, D. P., Vizy, E. K., & Ibrah, S. S. (2010). The WAMME regional model intercomparison study. *Climate Dynamics,* 35, 175–192. Retrieved from http://connection.ebscohost.com/c/articles/51708144/wamme-regional-model-intercomparison-study

Duncan, A., Williams, G., & de Catheu, J. (2010). Monitoring the principles for good international engagement in fragile states and Situations. Fragile States Principles Monitoring Survey: Global Report. Paris: OECD. Retrieved from http://www.oecd.org/dacfragilestates/44651689.pdf

ECOWAS. (2007). ECOWAS in brief. Community Computer Centre/Department of Communication. http://www.comm.ecowas.int/sec/index.php?id=about_a&lang=en

ECOWAS. 2012. ECOWAS member states. Community Computer Centre/Department of Communication. Retrieved from http://www.ecowas.int/

Emerson, J.W., A. Hsu, M.A. Levy, A. de Sherbinin, V. Mara, D.C. Esty, and M. Jaiteh. (2012). 2012 Environmental Performance Index and Pilot Trend Environmental Performance Index. New Haven: Yale Center for Environmental Law and Policy

Ericksen, P., Thornton, P., Notenbaert, A., Cramer, L., Jones, P., & Herrero, M. (2011). Mapping hotspots of climate change and food insecurity in the global tropics. CCAFS Report No. 5. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Retrieved from http://ccafs.cgiar.org/resources/climate_hotspots

Ericksen, P., J. De Leeuw, P. Thornton, M. Said, M. Herrero & A. Notenbaert. 2012. Climate change in sub-Saharan Africa: What consequences for pastoralism? In *Pastoralism and development in Africa: Dynamic change at the margins,* eds. A. Catley, J. Lind & I. Scoones, 71-82. London, England: Routledge.

Ermert, V., Fink, A. H., Morse, A. P., & Paeth, H. (2012). The impact of regional climate change on malaria risk due to greenhouse forcing and land-use changes in tropical Africa. *Environmental Health Perspectives,* 120, 77–84. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3261943/

Erwin, K. (2009). Wetlands and global climate change: The role of wetland restoration in a changing world. *Wetlands Ecology and Management,* 17, 71–84. Retrieved from http://dx.doi.org/10.1007/s11273-008-9119-1

FAO. (2000a). Africa. In *Global ecological zoning for the global forest resources assessment 2000*. FAO: Forestry Department.

FAO. (2000b). Africa: Ecological zones. In *Global Forest Resources Assessment 2000*. FAO: Forestry Department.

FAO. (2007). The state of world fisheries and aquaculture 2006. Rome, Italy: Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations. Retrieved fromhttp://www.fao.org/docrep/009/A0699e/A0699e00.htmFAO. (2010). The state of world fisheries and aquaculture 2010. Rome, Italy: Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/docrep/013/i1820e/i1820e.pdf

Feka, N. Z., & Ajonina, G. N. (2011). Drivers causing decline of mangrove in West-Central Africa: A review. *International Journal of Biodiversity Science, Ecosystem Services & Management,* 7, 217-–230. Retrieved from http://dx.doi.org/10.1080/21513732.2011.634436

Fjelde, H., & von Uexkull, N. (2012). Climate triggers: Rainfall anomalies, vulnerability, and communal conflict in Sub-Saharan Africa. *Political Geography,* 31, 444–453. Retrieved from http://www.sciencedirect.com/science/article/pii/S0962629812001072

Folland, C. K., Palmer, T. N., & Parker, D. E. (1986). Sahel rainfall and worldwide sea temperatures, 1901–85. *Nature,* 320, 602–607. Retrieved from http://dx.doi.org/10.1038/320602a0

Foresight: Migration and Global Environmental Change. 2011. Final project report. London, UK: The Government Office for Science. Retrieved from http://www.bis.gov.uk/assets/foresight/docs/migration/11-1116-migration-and-global-environmental-change.pdf

Fratkin, E. 2012. Seeking alternative livelihoods in pastoral areas. In *Pastoralism and Development in Africa: Dynamic Change at the Margins,* eds. A. Catley, J. Lind & I. Scoones, 197-205. London, England: Routledge.

Fungo, R. (2011). An analysis of the nutrition situation, agro ecosystems, and food systems of West and Central Africa. Rome, Italy: Bioversity International. Retrieved from http://www.bioversityinternational.org/fileadmin/bioversityDocs/Research/Nutrition__new_/Landscape_Analysis_of_Nutrition_and_Agriculture_West_Africa_Final.pdf

Garrison, J. (2010). Report to USAID/West Africa: Opportunities and recommendations for the design of a new regional climate change adaptation program. USAID.

Gautier, D., Bonnerat, A., & Njoya, A. (2005). The relationship between herders and trees in space and time in northern Cameroon. *The Geographical Journal,* 171, 324–339. Retrieved from http://www.jstor.org/stable/3451205

GEF. (2009). Fouta Djallon Highlands integrated natural resources management project (FDH-INRM). Nairobi, Kenya: The Global Environment Fund. Retrieved from http://www.thegef.org/gef/project_detail?projID=1431

Genesio, L., Bacci, M., Baron, C., Diarra, B., Di Vecchia, A., Alhassane, A., Hassane, I., Ndiaye, M., Philippon, N., Tarchiani, V., & Traoré, S. (2011). Early warning systems for food security in West Africa: Evolution, achievements, and challenges. *Atmospheric Science Letters,* 12, 142–148. Retrieved from http://dx.doi.org/10.1002/asl.332

Giannini, A., Krishnamurthy, P. K., Cousin, R., & Choularton, R. J. (2011). Climate risk and food security. Volume I: Climate and livelihood sensitivities in Mali. Rome/New York: WFP/IRI.

Giannini, A., Saravanan, R., & Chang, P. (2003). Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. *Science,* 302, 1027–1030. Retrieved from http://www.sciencemag.org/content/302/5647/1027.abstract

Global Warming Science (date accessed 11 December 2012), Sahel temperature index and comparison with the projections from the IPCC 2007c. Retrieved from http://www.appinsys.com/GlobalWarming/RS_Sahel.htm

Gnonlonfin, G. J. B., Hell, K., Adjovi, Y., Fandohan, P., Koudande, D. O., Mensah, G. A., Sanni, A., & Brimer, L. (2013). A review on aflatoxin contamination and its implications in the developing world: A sub-Saharan African perspective. *Critical Reviews in Food Science and Nutrition,* 53, 349–365. Retrieved from

http://dx.doi.org/10.1080/10408398.2010.535718

Gong, Y. Y., Cardwell, K., Hounsa, A., Egal, S., Turner, P. C., Hall, A. J., & Wild, C. P. (2002). Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo: Cross sectional study. *BMJ,* 325, 20–21. Retrieved from http://dx.doi.org/10.1136/bmj.325.7354.20

Gong, Y., Egal, S., Hounsa, A., Turner, P., Hall, A., Cardwell, K. & Wild, C. (2003) Determinants of aflatoxin exposure in young children from Benin and Togo, West Africa: the critical role of weaning. *International Journal of Epidemiology,* 32**,** 556-562. Retrieved from http://ije.oxfordjournals.org/content/32/4/556.abstract

Gonzalez, P., Tucker, C. J., & Sy, H. (2012). Tree density and species decline in the African Sahel attributable to climate. *Journal of Arid Environments,* 78, 55–64. Retrieved from http://www.sciencedirect.com/science/article/pii/S0140196311003351

Graham, F. C. (2011). Contests over pastoralism in the southern Sahara and northern Sahel. Dissertation, Department of Geology and Geography, West Virginia University, Morgantown, West Virginia. Retrieved from http://gradworks.umi.com/34/76/3476410.html

Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. I. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Botany,* 60, 2827–2838. Retrieved from http://jxb.oxfordjournals.org/content/60/10/2827.abstract

Guerrant, R. L., Kirchhoff, L. V., Shields, D. S., Nations, M. K., Leslie, J., de Sousa, M. A., Araujo, J. G., Correia, L. L., Sauer, K. T., McClelland, K. E., Trowbridge, F. L., & Hughes, J. M. (1983). Prospective study of diarrheal illnesses in northeastern Brazil: Patterns of disease, nutritional impact, etiologies, and risk factors. *The Journal of Infectious Diseases,* 148, 986–997. Retrieved from http://www.jstor.org/stable/30133824

Haggblade, S., Longabaugh, S., Boughton, D., Dembele, N. N., Diallo, B. C., Staatz, J. M., & Tschirley, D. L. (2012). Staple food market sheds in West Africa. In *MSU International Development* 1–51. East Lansing, Michigan: Michigan State University. Retrieved from http://purl.umn.edu/121866

Halpert, M. S., & Ropelewski, C. F. (1992). Surface temperature patterns associated with the Southern Oscillation. *Journal of Climate,* 5, 577–593. Retrieved from http://dx.doi.org/10.1175/1520-0442(1992)005<0577:STPAWT>2.0.CO;2

Hatziolos, M., Lundin, C. G., & Alm, A. (1996). *Africa: A framework for integrated coastal zone management.* Washington, DC: World Bank.

Haussmann, B. I. G., Fred Rattunde, H., Weltzien-Rattunde, E., Traoré, P. S. C., vom Brocke, K., & Parzies, H. K. (2012). Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa. *Journal of Agronomy and Crop Science,* 198, 327–339. Retrieved from http://dx.doi.org/10.1111/j.1439-037X.2012.00526.x

Hein, L., Metzger, M., & Leemans, R. (2009.) The local impacts of climate change in the Ferlo, Western Sahel. *Climatic Change,* 93, 465–483. Retrieved from http://dx.doi.org/10.1007/s10584-008-9500-3

Hendrix, C. S., & Salehyan, I. (2012). Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research,* 49, 35–50. Retrieved from http://jpr.sagepub.com/content/49/1/35.abstract

Henry, S., Schoumaker, B., & Beauchemin, C. (2004). The impact of rainfall on the first out-migration: A Multi-level event-history analysis in Burkina Faso. *Population and Environment,* 25, 423-460. Retrieved from http://www.jstor.org/stable/27503895

Herrero, M., Ringler, C., van de Steeg, J., Thornton, P., Zhu, T., Bryan, E., Omolo, A., Koo, J., & Notenbaert, A. (2010). Climate variability and climate change and their impacts on Kenya's agricultural sector. Nairobi, Kenya: ILRI. Retrieved from http://mahider.ilri.org/handle/10568/3840

Herrmann, S. M., Anyamba, A., & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change,* 15, 394–404. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959378005000531

Hesse, C. (2011). Legislating for pastoralism: Lessons from West Africa. Paper presented at the *Future of Pastoralism in Africa* international conference, organized by the Future Agricultures Consortium and the

Feinstein Institute Centre at Tufts University, held in Addis Ababa, March 21–23, 2011. Retrieved from http://www.future-agricultures.org/events/future-of-pastoralism

Heubes, J., Kühn, I., König, K., Wittig, R., Zizka, G., & Hahn, K. (2011). Modelling biome shifts and tree cover change for 2050 in West Africa. *Journal of Biogeography,* 38, 2248–2258. Retrieved from http://dx.doi.org/10.1111/j.1365-2699.2011.02560.x

Hiernaux, P. 1984. Distribution des pluies et production herbacee au Sahel: une methode empirique pour caracteriser la distribution des precipitations journalieres et ses effets sur la production herbacee. Premiers resultats acquis dans le Sahel malien. In *CIPEA Mali-Document de Programme;AZ 98*.

Hiernaux, P., Diarra, L., Trichon, V., Mougin, E., Soumaguel, N., & Baup, F. (2009). Woody plant population dynamics in response to climate changes from 1984 to 2006 in Sahel (Gourma, Mali). *Journal of Hydrology,* 375, 103–113. Retrieved from http://dx.doi.org/10.1016/j.jhydrol.2009.01.043

Higgins, G. M., Kassam, A. H., Naiken, L., Fisher, G., & Shah, M. M. (1982). *Potential population supporting capacities of lands in the developing world*. Rome: Food and Agriculture Organization of the United Nations.

Hiraldo, R. (2011). Climate change in West Africa: Key issues. 1-20. Dakar, Senegal. Retrieved from http://southernvoices.net/files/RC_Reports and Cases/CLIMATE_CHANGE_IN_WEST_AFRICA.pdf

Hoerling, M., Hurrell, J., Eischeid, J., & Phillips, A. (2006). Detection and attribution of twentieth-century northern and southern African rainfall change. *Journal of Climate,* 19, 3989–4008. Retrieved from http://dx.doi.org/10.1175/JCLI3842.1

Höllermann, B., Giertz, S., & Diekkrüger, B. (2010). Benin 2025—Balancing future water availability and demand using the WEAP 'Water Evaluation and Planning' system. *Water Resources Management,* 24, 3591–3613. Retrieved from http://dx.doi.org/10.1007/s11269-010-9622-z

Homann, S., Rischkowsky, B., Steinbach, J., Kirk, M., & Mathias, E. (2008). Towards endogenous livestock development: Borana pastoralists' responses to environmental and institutional changes. *Human Ecology,* 36, 503–520. Retrieved from http://dx.doi.org/10.1007/s10745-008-9180-7

Hounkonnou, D., Kossou, D., Kuyper, T. W., Leeuwis, C., Nederlof, E. S., Röling, N., Sakyi-Dawson, O., Traoré, M., & van Huis, A. (2012). An innovation systems approach to institutional change: Smallholder development in West Africa. *Agricultural Systems,* 108, 74–83. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308521X12000157

Hsiang, S. M., & Burke, M. B. (forthcoming). Climate, conflict, and social stability: What do the data say? *Climatic Change*.

Hsiang, S. M., Meng, K. C., & Cane, M. A. (2011) Civil conflicts are associated with the global climate. *Nature,* 476, 438–441. Retrieved from http://dx.doi.org/10.1038/nature10311

Humphreys, M. (2005) Natural resources, conflict, and conflict resolution: Uncovering the mechanisms. *Journal of Conflict Resolution,* 49, 508–537. Retrieved from http://jcr.sagepub.com/content/49/4/508.abstract

IPCC. (2007a). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Retrieved from http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

IPCC. (2007b). Coastal zones. In IPCC Fourth Assessment Report: Climate Change 2007. Retrieved from http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch9s9-4-6.html

IPCC. (2007c). Regional climate projections. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.). Cambridge, United Kingdom and New York, NY, USA: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC. (2008). Chapter 5: Analyzing regional aspects of climate change and water resources. In IPCC Technical Paper VI, B. C. Bates, Z. W. Kundzewicz, & J. P. Palutikof (Eds.), 210. Geneva: IPCC. Retrieved from http://www.ipcc.ch/pdf/technical-papers/ccw/chapter5.pdf

IPCC. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, C. B. Field, V. Barros,

T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley (Eds.). Cambridge, UK, and New York, NY, USA: Cambridge University Press. Retrieved from http://ipcc-wg2.gov/SREX/

IRI. (2006). A gap analysis for the implementation of the global climate observing system programme in Africa. The International Research Institute for Climate and Society. Retrieved from http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_5280_2806_0_0_18/GapAnalysis.pdf

IRIN. (2009). Africa: Trying to work from the same weather page. In *Africa Section*. IRIN Humanitarian News Report. Retrieved from http://www.irinnews.org/Report/86055/AFRICA-Trying-to-work-from-the-same-weather-page

IRIN. (2012). Nigeria: Floodwaters recede but millions remain displaced. *IRIN humanitarian news and analysis*. Retrieved from http://www.irinnews.org/printreport.aspx?reportid=96739 (last accessed 11/27/2012).

Jallow, B. P., Barrow, M. K. A., & Leatherman, S. P. (1996). Vulnerability of the coastal zone of The Gambia to sea level rise and development of response strategies and adaptation options. *Climate Research,* 6, 165–177. Retrieved from http://www.int-res.com/articles/cr/6/c006p165.pdf

Janicot, S. (1992). Spatiotemporal variability of West African rainfall. Part I: Regionalizations and typings. *Journal of Climate,* 5, 489–497. Retrieved from http://dx.doi.org/10.1175/1520-0442(1992)005<0489:SVOWAR>2.0.CO;2

Janicot, S., Harzallah. A., Fontaine, B., & Moron, V. (1998). West African monsoon dynamics and eastern equatorial Atlantic and Pacific SST anomalies. *Journal of Climate,* 11, 1874–1882. Retrieved from http://journals.ametsoc.org/doi/abs/10.1175/1520-0442%281998%29011%3C1874%3AWAMDAE%3E2.0.CO%3B2

Janicot, S., & Sultan, B. (2001). Intra-seasonal modulation of convection in the West African Monsoon. *Geophysical Research Letters,* 28, 523–526. Retrieved from http://dx.doi.org/10.1029/2000GL012424

Janicot, S., Trzaska, S., & Poccard, I. (2001). Summer Sahel-ENSO teleconnection and decadal time scale SST variations. *Climate Dynamics,* 18, 303–320. Retrieved from http://dx.doi.org/10.1007/s003820100172

Jankowska, M. M., Weeks, J. R., & Engstrom, R. (2011). Do the most vulnerable people live in the worst slums? A spatial analysis of Accra, Ghana. *Annals of GIS,* 17, 221–235. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/19475683.2011.625976

JISAO (Joint Institute for the Study of the Atmosphere and Ocean, University of Washington) (date accessed 11 December 2012), Sahel Rainfall Index (20-10N, 20W-10E), 1900-October 2012. Retrieved from http://jisao.washington.edu/data/sahel/

Joiner, E., Kennedo, D., & Sampson, J. (2012). Vulnerability to climate change in West Africa. In *Student Working Paper No. 4,* D. J. W. Busby, K. L. White, & T. G. Smith (Eds.), 1-48. *Climate Change and Africa Political Stability.* Retrieved from http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?lng=en&id=152915

Joly, M., Voldoire, A., Douville, H., Terray, P., & Royer, J.-F. (2007). African monsoon teleconnections with tropical SSTs: Validation and evolution in a set of IPCC4 simulations. *Climate Dynamics,* 29, 1–20. Retrieved from http://dx.doi.org/10.1007/s00382-006-0215-8

Jones, P. G.,& Thornton, P. K. (2009). Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy,* 12, 427–437. Retrieved from http://dx.doi.org/10.1016/j.envsci.2008.08.006

Junk, W., An, S., Finlayson, C. M., Gopal, B., Květ, J., Mitchell, S., Mitsch, W., & Robarts, R. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis. *Aquatic Sciences*, 75, 151–167. Retrieved from http://dx.doi.org/10.1007/s00027-012-0278-z

Kadi, M., Njau, L. N., Mwikya, J., & Kamga, A. (2011). The state of climate information services for agriculture and food security in West African countries. In *Climate Change, Agriculture and Food Security (CCAFS)*, 1–106. Copenhagen, Denmark. Retrieved from http://ccafs.cgiar.org/sites/default/files/assets/docs/ccafs-wp-04-clim-info-westafrica.pdf

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen,

J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., & Joseph, D. (1996) The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society,* 77**,** 437-471. Retrieved from http://dx.doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2

Kandji, S.T., Verchot, L., & Mackensen, J. (2006). Climate change and variability in the Sahel region: Impacts and adaptation strategies in the agricultural sector. Nairobi: Word Agroforestry Centre (ICRAF) and United Nations Environment Programme (UNEP). Retrieved from http://www.unep.org/ecosystemmanagement/Portals/7/Documents/ClimateChangeSahelCombine.pdf.

Kelly-Hope, L., & Thomson, M. C. (2008). Climate and infectious diseases. In M. C. T. e. al. (Eds.), *Seasonal forecasts, climatic change and human health,* Springer Science + Business Media B.V.

Kitchell, E. (2012). Personal Communication, November 21, 2012 (L. Brottem).

Kniveton, D. R., Smith, C. D., & Black, R. (2012). Emerging migration flows in a changing climate in dryland Africa. *Nature Climate Change,* 2, 444–447. Retrieved from http://dx.doi.org/10.1038/nclimate1447

Kossoumna, L. a. N., Dugué, P., & Torquebiau, E. (2010). *Sédentarisation des éleveurs Mbororo et évolution de leurs pratiques au Nord Cameroun* (Change of practices by settling transhumant Mbororo farmers in Northern Cameroon). *Cahiers Agricultures,* 19, 60–67. Retrieved from http://www.jle.com/e-docs/00/04/52/94/vers_alt/VersionPDF.pdf

Labbo, R., Fouta, A., Jeanne, I., Ousmane, I., & Duchemin, J. B. (2004). Anopheles funestus in Sahel: New evidence from Niger. *The Lancet,* 363, 660. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0140673604156067

Lafferty, K. D. (2009). The ecology of climate change and infectious diseases. *Ecology,* 90, 888–900. http://dx.doi.org/10.1890/08-0079.1

Lam, V. W. Y., Cheung, W. W. L., Swartz, W., & Sumaila, U. R. (2012) Climate change impacts on fisheries in West Africa: Implications for economic, food, and nutritional security. *African Journal of Marine Science,* 34, 103–117. Retrieved from http://dx.doi.org/10.2989/1814232X.2012.673294

Le Barbé, L., Lebel, T., & Tapsoba, D. (2002). Rainfall variability in West Africa during the years 1950–90. *Journal of Climate,* 15, 187–202. Retrieved from http://dx.doi.org/10.1175/1520-0442(2002)015<0187:RVIWAD>2.0.CO;2

Le Houérou, H. N. (1989). *The grazing land ecosystems of the African Sahel.* Heidelberg: Springer-Verlag.

Lebel, T., & Ali, A. (2009). Recent trends in the Central and Western Sahel rainfall regime (1990–2007). *Journal of Hydrology,* 375, 52–64. Retrieved from http://dx.doi.org/10.1016/j.jhydrol.2008.11.030

Lehner, B., Liermann, C. R., Revenga, C., Vorosmarty, C., Fekete, B., Crouzet, P., Doll, P., Endejan, M., Frenken, K., Magome, J., Nilsson, C., Robertson, J. C., Rodel, R., Sindorf, N., & Wisser, D. (2011). Global reservoir and dam database, version 1 (GRanDv1): Dams. Palisades: NASA Socioeconomic Data and Applications Center. Retrieved from http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01

Lenselink, N. M. (2002). Participation in artisanal fisheries management for improved livelihoods in West Africa: A synthesis of interviews and cases from Mauritania, Senegal, Guinea and Ghana. In *FAO Fisheries Technical Paper*. Rome, Italy: FAO. Retrieved from http://www.fao.org/docrep/005/y4281e/y4281e00.htm

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences,* 105, 1786–1793. Retrieved from http://www.pnas.org/content/105/6/1786.abstract

Lesnoff, M., Corniaux, C., & Hiernaux, P. (2012). Sensitivity analysis of the recovery dynamics of a cattle population following drought in the Sahel region. *Ecological Modelling,* 232, 28–39. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304380012000944

Lobell, D. B., & Burke, M. B. (2008). Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. *Environmental Research Letters,* 3, 034007. Retrieved from http://stacks.iop.org/1748-9326/3/i=3/a=034007

Lohmann, D., Tietjen, B., Blaum, N., Joubert, D. F., & Jeltsch, F. (2012). Shifting thresholds and changing degradation patterns: Climate change effects on the simulated long-term response of a semi-arid savanna to grazing. *Journal of Applied Ecology,* 49, 814–823. Retrieved from http://dx.doi.org/10.1111/j.1365-2664.2012.02157.x

Lu, J., & Delworth, T. L. (2005). Oceanic forcing of the late 20th century Sahel drought. *Geophysical Research Letters,* 32, L22706. Retrieved from http://dx.doi.org/10.1029/2005GL023316

Maathai, W. (2011). Challenge for Africa. *Sustainability Science,* 6, 1–2. Retrieved from http://dx.doi.org/10.1007/s11625-010-0120-2

Manga, L. (2013). Climate change and health in Africa: Agenda, needs, and opportunities. Seminar delivered by Dr. Lucien Manga, Regional Advisor for the Protection of the Human Environment WHO Regional Office for Africa, at the Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY, January 28, 2013.

Marshall, G., & Cole, B. (2011). Global report 2011. Conflict, Governance, and State Fragility. Vienna, VA: Center for Systemic Peace. Retrieved from http://www.systemicpeace.org/GlobalReport2011.pdf

McCarthy, N., Lipper, L., & Branca, G. (2011). Climate-smart agriculture: Smallholder adoption and implications for climate change adaptation and mitigation. In *Mitigation of Climate Change in Agriculture Series 4*, 1–19. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/docrep/015/i2575e/i2575e00.pdf

McIntyre, B., Kim, Y., Fruci, J., & Rosenthal, E. (2011). The best-laid plans: Climate change and food security. *Climate and Development,* 3, 281–284. Retrieved from http://dx.doi.org/10.1080/17565529.2011.617564

McKenzie, A. (2012). Hydropower 'could supply Africa's entire power needs.' *SciDev.net.* Retrieved from http://www.scidev.net/en/climate-change-and-energy/renewable-energy/news/hydropower-could-supply-africa-s-entire-power-needs-.html

McPeak, J. 2011. Trip Diary. GSFA/RIVERS project (Senegal), USAID Livestock-Climate Change Collaborative Research Support Program (CRSP).

Mertz, O., Mbow, C., Nielson, J. Ø., Maiga, A., Diallo, D., Reenberg, A., Diouf, A., Barbier, B., Moussa, I. B., Zorom, M., Ouattara, I., & Dabi, D. (2010). Climate factors play a limited role for past adaptation strategies in West Africa. *Ecology and Society,* 15, 25. Retrieved from http://www.ecologyandsociety.org/vol15/iss4/art25/

Mertz, O., Mbow, C., Reenberg, A., Genesio, L., Lambin, E. F., D'Haen, S., Zorom, M., Rasmussen, K., Diallo, D., Barbier, B., Moussa, I. B., Diouf, A., Nielsen, J. Ø., & Sandholt, I. (2011). Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. *Atmospheric Science Letters,* 12, 104–108. Retrieved from http://dx.doi.org/10.1002/asl.314

Miguel, E., Satyanath, S., & Sergenti, E. (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy,* 112, 725–753. Retrieved from http://www.jstor.org/stable/10.1086/421174

Mitchell, S. A. (2013). The status of wetlands, threats, and the predicted effect of global climate change: The situation in Sub-Saharan Africa. *Aquatic Sciences,* 75, 95–112. Retrieved from http://dx.doi.org/10.1007/s00027-012-0259-2

Mitchell, T. D., & Jones, P. D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology,* 25, 693–712. Retrieved from http://dx.doi.org/10.1002/joc.1181

Mitsch, W. J., & Gosselink, J. G. (2007). *Wetlands*. Hoboken, New Jersey: John Wiley & Sons. Inc.

Mohino, E., Janicot, S., & Bader, J. (2011). Sahel rainfall and decadal to multi-decadal sea surface temperature variability. *Climate Dynamics,* 37, 419–440. Retrieved from http://dx.doi.org/10.1007/s00382-010-0867-2

Molesworth, A. M., Thomson, M. C., Connor, S. J., Cresswell, M. P., Morse, A. P., Shears, P., Hart, C. A., & Cuevas, L. E. (2002). Where is the meningitis belt? Defining an area at risk of epidemic meningitis in Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 96, 242–249. Retrieved from http://www.sciencedirect.com/science/article/pii/S003592030290089l

Morand, P., Kodio, A., Andrew, N., Sinaba, F., Lemoalle, J., & Béné, C. (2012). Vulnerability and adaptation of African rural populations to hydro-climate change: Experience from fishing communities in the Inner Niger Delta (Mali). *Climatic Change,* 115, 463–483. Retrieved from http://dx.doi.org/10.1007/s10584-012-0492-7

Morinie□re, L. C. E., Taylor, R., Hamza, M., & Downing, T. (2009). Climate change and its humanitarian impacts. Oxford, United Kingdom: Stockholm Environment Institute. Retrieved from http://www.humanitarianfutures.org/sites/default/files/climate-change.pdf

Moritz, M. (2010). Crop-livestock interactions in agricultural and pastoral systems in West Africa. *Agriculture and Human Values,* 27, 119–128. Retrieved from http://dx.doi.org/10.1007/s10460-009-9203-z

Mortimore, M. (2010). Adapting to drought in the Sahel: Lessons for climate change. *Wiley Interdisciplinary Reviews: Climate Change,* 1, 134–143. Retrieved from http://dx.doi.org/10.1002/wcc.25

Mortimore, M. J., & Adams, W. M. (2001). Farmer adaptation, change, and 'crisis' in the Sahel. *Global Environmental Change,* 11, 49–57. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959378000000443

Müller, C., Cramer, W., Hare, W. L., & Lotze-Campen, H. (2011). Climate change risks for African agriculture. *Proceedings of the National Academy of Sciences,* 108, 4313–4315. Retrieved from http://www.pnas.org/content/early/2011/02/23/1015078108.abstract

Nel, P., & Righarts, M. (2008). Natural disasters and the risk of violent civil conflict. *International Studies Quarterly,* 52, 159–185. Retrieved from http://dx.doi.org/10.1111/j.1468-2478.2007.00495.x

NEPAD. (2005). The NEPAD action plan for the development of African fisheries and aquaculture. In *Fish for All Summit*, 1–29. Abuja, Nigeria: The New Partnership for Africa's Development Retrieved from http://siteresources.worldbank.org/INTARD/Resources/ACTION_PLAN_endorsed.pdf

New, M., Anderson, K., Fung, F., & Thornton, P. (2011). The possible impacts of high levels of climate change in 2060 and implications for migration. UK Government's Foresight Project, Migration and Global Environmental Change.

Newborne, P. (2010). Diversity of approaches; evolution of policies and practices applying to project preparation and implementation; case studies from Cameroon and Senegal. In *Decision-making and dialogue relating to large dams and hydraulic infrastructures*.

Ngigi, S. N. (2009). Climate change adaptation strategies: Water resources management options for smallholder farming systems in Sub-Saharan Africa. The MDG Centre for East and Southern Africa of the Earth Institute at Columbia University, New York. Retrieved from http://www.rockefellerfoundation.org/news/publications/climate-change-adaptation-strategies

Niamir-Fuller, M., ed. (1999). *Managing mobility in African rangelands: The legitimization of transhumance*. London: Intermediate Technologies Publications Ltd.

Niang, I., Nai, G., Folorunsho, R., Diop, M., Sow, M., Trawally, D., Faye, S., Bihibindi, A., Diop, N., & Karibuhoye, C. (2012). A guide on adaptation options for local decision makers: Guidance for decision-making to cope with coastal changes in West Africa. IOC Manual and Guide N° 62, ICAM Dossier N°7. Paris, France: UNESCO/IOC. Retrieved from http://unesdoc.unesco.org/images/0021/002166/216603e.pdf

Niasse, M., Afouda, A., & Amani, A. (Eds.) (2004). Reducing West Africa's vulnerability to climate impacts on water resources, wetlands and desertification: elements for a regional strategy for preparedness and adaptation. IUCN.

Nicholls, R. J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J., & Muir-Wood, R. (2007). Ranking of the world's cities most exposed to coastal flooding today and in the future. In *OECD Environment Working Paper No. 1*. Paris, France.

Nicholls, R. J., Leatherman, S. P., Dennis, K. C., & Volonté, C. R. (1995). Impacts and responses to sea level rise: Qualitative and quantitative assessments. *Journal of Coastal Research*, 26–43. Retrieved from http://www.jstor.org/stable/25735699

Nicholson, S. (2005). On the question of the "recovery" of the rains in the West African Sahel. *Journal of Arid Environments,* 63, 615–641. Retrieved from http://dx.doi.org/10.1016/j.jaridenv.2005.03.004

Nin-Pratt, A., Johnson, M., Magalhaes, E., You, L., Diao, X., & Chamberlin, J. (2011). Yield gaps and potential agricultural growth in West and Central Africa. International Food Policy Research Institute.

Nori, M., Switzer, J., & Crawford, A. (2005). Herding on the brink: Towards a global survey of pastoral communities and conflict. An Occasional Working Paper from the IUCN Commission on Environmental, Economic, and Social Policy. Gland, Switzerland: IUCN. Retrieved from http://www.iisd.org/pdf/2005/security_herding_on_brink.pdf

Nossiter, A. (2010). Famine persists in Niger, but denial is past. *The New York Times*. Retrieved from http://www.nytimes.com/2010/05/04/world/africa/04niger.html?_r=0

Nossiter, A. (2012). Summer of siege for West Africa as discontent boils into street. *The New York Times*. Retrieved from http://www.nytimes.com/2012/09/09/world/africa/summer-of-siege-for-west-africa-as-discontent-shakes-streets.html?pagewanted=all&_r=0

NRC. (2013). Climate and social stress: Implications for security analysis. Committee on Assessing the Impacts of Climate Change on Social and Political Stresses, J. D. Steinbruner, P. C. Stern, & J. L. Husbands (Eds). Board on Environmental Change and Society, Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.

Nyong, A. (undated). Climate-related conflicts in West Africa. In *Report from Africa: Population, Health, Environment, and Conflict*, 36–43. Washington, DC, United States. Retrieved from http://www.wilsoncenter.org/sites/default/files/Nyong12.pdf

OECD. (2006). Transboundary river basins. In *Atlas on regional integration in West Africa: Land series*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/regional/atlasonregionalintegrationinwestafrica.htm

OECD. (2007a). Cocoa. In *Atlas on regional integration in West Africa: Economy series*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/swac/publications/39596493.pdf

OECD. (2007b). Demographic trends. In *Atlas on regional integration in West Africa: Population series*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/swac/publications/39802965.pdf

OECD. (2007c). Rural areas and agricultural changes. In *Atlas on regional integration in West Africa: Land series*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/swac/publications/38903590.pdf

OECD. (2008a). Climate and climate change. In *Atlas on regional integration in West Africa: environment series*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/swac/publications/40121025.pdf

OECD. (2008b). Livestock and regional market in the Sahel and West Africa: Potentials and challenges. In *Atlas on Regional Integration in West Africa*. ECOWAS–SWAC/OECD. Retrieved from http://www.oecd.org/swac/publications/41848366.pdf

OECD. (2009). Regional, rural, and urban development. In *Atlas on Regional Integration in West Africa*. ECOWAS–SWAC/OECD.

OECD. (2011). Cotton. In *Atlas on regional integration in West Africa: Economy series*. ECOWAS–SWAC/OECD.

Oettli, P., Sultan, B., Baron, C., & Vrac, M. (2011). Are regional climate models relevant for crop yield prediction in West Africa? *Environmental Research Letters,* 6, 1–9. Retrieved from http://stacks.iop.org/1748-9326/6/i=1/a=014008

Oguntunde, P., & Abiodun, B. (2013). The impact of climate change on the Niger River Basin hydroclimatology, West Africa. *Climate Dynamics, 40, 81–94*. Retrieved from http://dx.doi.org/10.1007/s00382-012-1498-6

Oliver-Smith, A., & de Sherbinin, A. (forthcoming). Something old and something new: Resettlement in the twenty-first century. Georgetown University Crisis Migration Project.

Oyebande, L. 2002. Sustaining wetland ecosystems in the West and central African Sahel. In *FRIEND 2002, Regional Hydrology: Bridging the Gap between Research and Practice.* Proceedings of the Fourth International FRIEND Conference held in Cape Town, South Africa, March 2002. *IAHS Publ. no. 274*, 365-372. Retrieved from http://iahs.info/redbooks/a274/iahs_274_365.pdf

Oyebande, L., & Odunuga, S. (2010). Climate change impact on water resources at the transboundary level in

West Africa: The cases of Senegal, Niger, and Volta basins. *The Open Hydrology Journal,* 4, 163–172. Retrieved from http://www.benthamscience.com/open/tohydj/articles/V004/SI0113TOHYDJ/163TOHYDJ.pdf

Palmer, T. N. (1986). Influence of the Atlantic, Pacific, and Indian oceans on Sahel rainfall. *Nature,* 322, 251–253. Retrieved from http://www.nature.com/nature/journal/v322/n6076/abs/322251a0.html

Parish, E., Kodra, E., Steinhaeuser, K., & Ganguly, A. (2012). Estimating future global per capita water availability based on changes in climate and population. *Computers and Geosciences,* 42, 79–86. Retrieved from http://www-users.cs.umn.edu/~ksteinha/papers/CAGEO12.pdf

PERN-PRIPODE. (2007). Summary of research results for the PERN-PRIPODE cyberseminar on population-development-environment linkages in the Sudano-Sahelian zone of West Africa. 1-34. Retrieved from http://www.populationenvironmentresearch.org/papers/Sahel_cybersem_res_sum.pdf

Perry, B. D., Randolph, T. F., McDermott, J. J., Scones, K. R., & Thornton, P. K. (2002). Investing in animal health research to alleviate poverty. Nairobi, Kenya: ILRI (International Livestock Research Institute). Retrieved from http://www.ilri.org/InfoServ/Webpub/fulldocs/InvestAnim/Book1/index.htm

Powell, J. M., Pearson, R. A., & Hiernaux, P. H. (2004). Crop-livestock interactions in the West African drylands. *Agronomy Journal,* 96, 469–483. Retrieved from https://www.crops.org/publications/aj/abstracts/96/2/469

Puskur, R., Baker, D., Omore, A., & Staal, S. (2011). Changing approaches to pro-poor livestock market development: Innovation and upgrading in the value chain. In *Livestock Exchange Issue Brief 17*, 1–5. International Livestock Research Institute. Retrieved from http://hdl.handle.net/10568/10629

Rademacher-Schulz, C., & Mahama, E. S. (2012). "Where the Rain Falls" Project. Rainfall, food security, and human mobility. Case study: Ghana. Results from Nadowli District, Upper West Region. No. 3, November 2012. United Nations University, Institute for Environment and Human Security (UNU-EHS).

Ræbild, A. (2012). Improved management of fruit trees in West African parklands. *Agroforestry Systems,* 85, 425–430. Retrieved from http://dx.doi.org/10.1007/s10457-012-9524-6

Rain, D. (1999). *Eaters of the dry season: Circular labor migration in the West African Sahel.* Boulder, Colorado: Westview Press.

Raleigh, C. (2010). Political marginalization, climate change, and conflict in African Sahel states. *International Studies Review*, 12, 69–86. Retrieved from http://dx.doi.org/10.1111/j.1468-2486.2009.00913.x

Raleigh, C., & Urdal, H. (2007). Climate change, environmental degradation, and armed conflict. *Political Geography,* 26, 674–694. Retrieved from http://www.sciencedirect.com/science/article/pii/S096262980700087X

Ramisch, J. (1999). The long dry season: Crop-livestock linkages in southern Mali. London: International Institute for Environment and Development, Drylands Programme Issue paper #88. Retrieved from http://pubs.iied.org/pdfs/7413IIED.pdf

Remans, R., Thomson, M., & Mantilla, G. (2013). Climate and agro-ecological information services for nutrition programming. Workshop held on January 18, 2013, on the Lamont Campus of Columbia University, New York, NY.

Rieu-Clarke, A. (2011). The UN Watercourses Convention: Regional and basin perspectives. IHP-HELP Center for Water Law, Policy & Science. In *XIV World Water Congress, 25–29 September 2011*. Porto de Galinhas, Brazil. Retrieved from http://www.slideshare.net/jmccaffery57/the-un-watercourses-convention-regional-and-basin-perspectives

Rodgers, C., Giesen, N., Laube, W., Vlek, P. G., & Youkhana, E. (2007). The GLOWA Volta Project: A framework for water resources decision-making and scientific capacity building in a transnational West African basin. In *Integrated Assessment of Water Resources and Global Change,* E. Craswell, M. Bonnell, D. Bossio, S. Demuth, & N. Giesen (Eds.), 295–313. Springer Netherlands. Retrieved from http://dx.doi.org/10.1007/978-1-4020-5591-1_18

Roncoli, C., Ingram, K., & Kirshen, P. (2002). Reading the rains: Local knowledge and rainfall forecasting in Burkina Faso. *Society & Natural Resources,* 15, 409–427. Retrieved from http://dx.doi.org/10.1080/08941920252866774

Ropelewski, C. F., & Halpert, M. S. (1989). Precipitation patterns associated with the high index phase of the

Southern Oscillation. *Journal of Climate,* 2, 268–284. Retrieved from http://dx.doi.org/10.1175/1520-0442(1989)002<0268:PPAWTH>2.0.CO;2

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change,* 21, 1073–1083. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959378011000677

Ruane, A. 2012. Personal Communication. ed. C. Simon.

Rudel, T. K. (2005). *Tropical forests: Regional paths of destruction and regeneration in the late twentieth century*. New York: Columbia University Press.

Sall, S. M., Viltard, A., & Sauvageot, H. (2007). Rainfall distribution over the Fouta Djallon — Guinea. *Atmospheric Research,* 86, 149–161. Retrieved from http://www.sciencedirect.com/science/article/pii/S0169809507000671

Sambe, B. (2012). Response of epipelagic species to climate change in the Canary Current Large Marine Ecosystem. In K. Sherman & G. McGovern (Eds.), *Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems* (pp. 51–63). New York, NY: UNDP. Retrieved from http://www.undp.org/content/undp/en/home/librarypage/environment-energy/water_governance/frontline-observations-on-climate-change-and-sustainability-of-l/

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: A crucial input for practical adaptation in agriculture. *Atmospheric Science Letters,* 13, 108–112. Retrieved from http://dx.doi.org/10.1002/asl.368

Scheffran, J., & Battaglini, A. (2011). Climate and conflicts: The security risks of global warming. *Regional Environmental Change,* 11, 27–39. Retrieved from http://dx.doi.org/10.1007/s10113-010-0175-8

Scheffran, J., Brzoska, M., Kominek, J., Link, P. M., & Schilling, J. (2012a). Climate change and violent conflict. *Science,* 336, 869–871. Retrieved from http://www.sciencemag.org/content/336/6083/869.full.pdf

Scheffran, J., Brzoska, M., Kominek, J., Link, P. M., & Schilling, J. (2012b). Disentangling the climate-conflict nexus: Empirical and theoretical assessment of vulnerabilities and pathways. *Review of European Studies,* 4(5). Retrieved from http://ccsenet.org/journal/index.php/res/article/view/19277

Sendzimir, J., Reij, C. P., & Magnuszewski, P. (2011). Rebuilding resilience in the Sahel: Regreening in the Maradi and Zinder regions of Niger. *Ecology and Society,* 16, 1. Retrieved from http://dx.doi.org/10.5751/ES-04198-160301

Sene, E. H., Thiaw, I., & Lamizana-Diallo, B. (2006). Managing wetlands in arid regions: Lessons learned. Gland, Switzerland, and Cambridge, UK: IUCN. Retrieved from http://data.iucn.org/dbtw-wpd/edocs/2006-044.pdf

Seo, S. N. (2010a). Managing forests, livestock, and crops under global warming: A micro-econometric analysis of land use changes in Africa. *Australian Journal of Agricultural and Resource Economics,* 54, 239–258. Retrieved from http://dx.doi.org/10.1111/j.1467-8489.2010.00487.x

Seo, S. N. (2010b) Is an integrated farm more resilient against climate change? A micro-econometric analysis of portfolio diversification in African agriculture. *Food Policy,* 35**,** 32-40. Retrieved from http://www.sciencedirect.com/science/article/pii/S030691920900058X

Servain, J. (1991). Simple climatic indices for the tropical Atlantic Ocean and some applications. *Journal of Geophysical Research,* 96, 15137–15146. Retrieved from http://dx.doi.org/10.1029/91JC01046

Sinka, M., Bangs, M., Manguin, S., Coetzee, M., Mbogo, C., Hemingway, J., Patil, A., Temperley, W., Gething, P., Kabaria, C., Okara, R., Van Boeckel, T., Godfray, H. C., Harbach, R., & Hay, S. (2010). The dominant *Anopheles* vectors of human malaria in Africa, Europe, and the Middle East: Occurrence data, distribution maps, and bionomic précis. *Parasites & Vectors,* 3, 117. Retrieved from http://www.parasitesandvectors.com/content/3/1/117

Sivakumar, M. V. K. (1988). Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa. *Agricultural and Forest Meteorology,* 42, 295-305. Retrieved from http://www.sciencedirect.com/science/article/pii/0168192388900391

Spiegel, P., Le, P., Ververs, M.-T., & Salama, P. (2007). Occurrence and overlap of natural disasters, complex emergencies, and epidemics during the past decade (1995–2004). *Conflict and Health,* 1, 2. Retrieved from

http://www.conflictandhealth.com/content/1/1/2

Srivastava, A. K., Gaiser, T., Paeth, H., & Ewert, F. (2012). The impact of climate change on Yam (*Dioscorea alata*) yield in the savanna zone of West Africa. *Agriculture, Ecosystems & Environment,* 153, 57–64. Retrieved from http://www.sciencedirect.com/science/article/pii/S0167880912000953

Stensgaard, A.-S., Utzinger, J., Vounatsou, P., Hürlimann, E., Schur, N., Saarnak, C. F. L., Simoonga, C., Mubita, P., Kabatereine, N. B., Tchuenté, L.-A. T., Rahbek, C., & Kristensen, T. K. (2011). Large-scale determinants of intestinal schistosomiasis and intermediate host snail distribution across Africa: Does climate matter? *Acta Tropica*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0001706X11003366

Stige, L. C., Stave, J., Chan, K.-S., Ciannelli, L., Pettorelli, N., Glantz, M., Herren, H. R., & Stenseth, N. C. (2006). The effect of climate variation on agro-pastoral production in Africa. *Proceedings of the National Academy of Sciences of the United States of America,* 103, 3049–3053. Retrieved from http://www.pnas.org/content/103/9/3049.abstract

Sultan, B., Labadi, K., Guégan, J.-F., & Janicot, S. (2005). Climate drives the meningitis epidemics onset in West Africa. *PLoS Med,* 2, e6. Retrieved from http://dx.doi.org/10.1371%2Fjournal.pmed.0020006

Sundareshwar, P. V. (2010). Wetlands and global change. *Proceedings of the International Conference on Advances in Materials and Techniques in Civil Engineering*, 125-130. VLBJCET, Coimbatore, India.

Tacoli, C. (2011). Not only climate change: Mobility, vulnerability, and socio-economic transformations in environmentally fragile areas of Bolivia, Senegal and Tanzania. In *Human Settlements Working Paper Series-Rural-Urban Interactions and Livelihood Strategies*. IIED.

Tall, A., Mason, S. J., van Aalst, M., Suarezm, P., Ait-Chellouche, Y., Dlallo, A. A., & Braman, L. (2012). Using seasonal climate forecasts to guide disaster management: The Red Cross experience during the 2008 West Africa floods. *International Journal of Geophysics,* 2012, Article ID 986016, 12 pages. Retrieved from http://dx.doi.org/10.1155/2012/986016

Tambo, J., & Abdoulaye, T. (2012). Climate change and agricultural technology adoption: The case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change,* 17, 277–292. Retrieved from http://dx.doi.org/10.1007/s11027-011-9325-7

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society,* 93, 485–498. Retrieved from http://dx.doi.org/10.1175/BAMS-D-11-00094.1

TFDD. (2011). Transboundary freshwater dispute database. Oregon State University. Retrieved from http://ocid.nacse.org/tfdd/index.php

Thébaud, B., & Batterbury, S. (2001). Sahel pastoralists: Opportunism, struggle, conflict, and negotiation. A case study from eastern Niger. *Global Environmental Change,* 11, 69–78. Retrieved from http://dx.doi.org/10.1016/S0959-3780(00)00046-7

Thompson, H. E., Berrang-Ford, L., & Ford, J. D. (2010). Climate change and food security in Sub-Saharan Africa: A systematic literature review. *Sustainability,* 2, 2719-2733. Retrieved from http://www.mdpi.com/2071-1050/2/8/2719

Thomson, M. 2013. Personal Communication, January 24, 2013 (S. Baptista).

Thomson, M. C., Connor, S. J., Ward, N., & Molyneux, D. (2004a). Impact of climate variability on infectious disease in West Africa. *EcoHealth,* 1, 138–150. Retrieved from http://dx.doi.org/10.1007/s10393-004-0004-y

Thomson, M. C., Ericksen, P. J., Ben Mohamed, A., & Connor, S. J. (2004b). Land-use change and infectious disease in West Africa. In *Ecosystems and Land Use Change*, Geophysical Monograph Series, vol. 153, R. S. DeFries, G. P. Asner, & R. A. Houghton (Eds.), 169–187. Washington, DC: AGU. Retrieved from http://www.agu.org/books/gm/v153/153GM14/153GM14.shtml

Thomson, M. C., Broutin, H., Firth, E., Jancloes, M., Mihretie, A., Nickovic, S., Onoda, M., Perea, W., Bertherat, E., & Hugonnet, S. (in press). The MERIT initiative: A climate and health partnership to inform public health decision makers. In J. Hurrell & G. Asrar (Eds.), *Priorities in climate research, analysis, and prediction*. Springer.

Thomson, M. C., Molesworth, A. M., Djingarey, M. H., Yameogo, K. R., Belanger, F., & Cuevas, L. E. (2006).

Potential of environmental models to predict meningitis epidemics in Africa. *Tropical Medicine and International Health,* 11, 781–788. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16771998

Thornton, P. (2012). Recalibrating food production in the developing world: Global warming will change more than just the climate. In *CCAFS Policy Brief* CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Retrieved from http://hdl.handle.net/10568/24696

Thornton, P., & Cramer, L. (Eds.). (2012). Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. In *CCAFS Working Paper No. 23*. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Retrieved from www.ccafs.cgiar.org

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems,* 101, 113–127. Retrieved from http://dx.doi.org/10.1016/j.agsy.2009.05.002

Timberlake, J., Chidumayo, E., & Sawadogo, L. (2010). Distribution and characteristics of African dry forests and woodlands. In E. N. Chidumayo & D. J. Gumbo (Eds.), *The dry forests and woodlands of Africa: Managing for products and services* (pp. 11–41). London and Washington, DC: Earthscan.

Ting, M., Kushnir, Y., Seager, R., & Li, C. (2009). Forced and internal twentieth-century SST trends in the North Atlantic. *Journal of Climate,* 22, 1469–1481. Retrieved from http://dx.doi.org/10.1175/2008JCLI2561.1

Tir, J., & Stinnett, D. M. (2012). Weathering climate change: Can institutions mitigate international water conflict? *Journal of Peace Research,* 49, 211–225. Retrieved from http://jpr.sagepub.com/content/49/1/211.abstract

Tirado, M., & Meerman, J. (2012). Climate change and food and nutrition security. In B. Thompson & M. J. Cohen (Eds.), *The Impact of climate change and bioenergy on nutrition* (pp. 43–60). Springer Netherlands. Retrieved from http://dx.doi.org/10.1007/978-94-007-0110-6_4

Tirado, M. C., Clarke, R., Jaykus, L. A., McQuatters-Gollop, A., & Frank, J. M. (2010). Climate change and food safety: A review. *Food Research International,* 43, 1745–1765. Retrieved from http://www.sciencedirect.com/science/article/pii/S0963996910002231

Traoré, S. (2012). Personal Communication, November 13, 2012 (A. de Sherbinin).

Traoré, S. B., Alhassane, A., Muller, B., Kouressy, M., Somé, L., Sultan, B., Oettli, P., Siéné Laopé, A. C., Sangaré, S., Vaksmann, M., Diop, M., Dingkhun, M., & Baron, C. (2011). Characterizing and modeling the diversity of cropping situations under climatic constraints in West Africa. *Atmospheric Science Letters,* 12, 89–95. Retrieved from http://dx.doi.org/10.1002/asl.295

Trouillet, B., Guineberteau, T., Bernardon, M., & Le Roux, S. (2011). Key challenges for maritime governance in West Africa: Fishery-based lessons from Guinea and Mauritania. *Marine Policy,* 35, 155–162. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308597X10001545

Turner, M. (1993). Overstocking the range: A critical analysis of the environmental science of Sahelian pastoralism. *Economic Geography,* 69, 402–421. Retrieved from http://www.jstor.org/stable/143597

Turner, M., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetation resources in semi-arid West Africa: The role of herding. *Ecosystems,* 8, 668–681. Retrieved from http://dx.doi.org/10.1007/s10021-003-0099-y

Turner, M. D., Ayantunde, A. A., Patterson, K. P., & Patterson, E. D. (2012). Conflict management, decentralization, and agropastoralism in dryland West Africa. *World Development,* 40, 745–757. Retrieved from http://dx.doi.org/10.1016/j.worlddev.2011.09.017

UNEP. (2011). Climate change, conflict, and migration in the Sahel. Nairobi, Kenya: United Nations Environmental Programme.

United Nations Environmental Programme Global Resource Information Database – Sioux Falls (date accessed), *Atlas of Our Changing Environment*. Retrieved from ttp://na.unep.net/atlas/africaWater/images/maps/pngs/annual_average_rainfall.png

USAID. (2012). Aflatoxin: A synthesis of the research in health, agriculture, and trade. Nairobi, Kenya: USAID East

Africa Mission and Danya International.

Van der Geest, K., Vrieling, A., & Dietz, T. (2010). Migration and environment in Ghana: A cross-district analysis of human mobility and vegetation dynamics. *Environment and Urbanization,* 22, 107–123. Retrieved from http://eau.sagepub.com/content/22/1/107.abstract

Verdin, J., Funk, C., Senay, G., & Choularton, R. (2005). Climate science and famine early warning. *Philosophical Transactions of the Royal Society,* 360, 2155–2168. Retrieved from http://earlywarning.usgs.gov/fews/pubs/RoyalSociety.pdf

Vörösmarty, C., Green, P., Salisbury, J., & Lammers, R. (2000). Global water resources: Vulnerability from climate change and population growth. *Science,* 289, 284–288. Retrieved from http://www.sciencemag.org/content/289/5477/284.abstract

Ward, M. N. (1998). Diagnosis and short-lead time prediction of summer rainfall in tropical North Africa at interannual and multidecadal timescales. *Journal of Climate,* 11, 3167–3191. Retrieved from http://dx.doi.org/10.1175/1520-0442(1998)011<3167:DASLTP>2.0.CO;2

Warner, K., Afifi, T., Henry, K., Rawe, T., Smith, C., & de Sherbinin, A. (2012). Where the rain falls: Climate change, food and livelihood security, and migration. Bonn, Germany: United Nations University and CARE. Retrieved from http://wheretherainfalls.org/

Warner, K., Erhart, C., de Sherbinin, A., Adamo, S. B., & Chai-Onn, T. (2009). In search of shelter: Mapping the effects of climate change on human migration and displacement. Bonn, Germany: United Nations University, CARE, and CIESIN-Columbia University.

West, C. T., Roncoli, C., & Ouattara, F. (2008). Local perceptions and regional climate trends on the Central Plateau of Burkina Faso. *Land Degradation & Development,* 19, 289–304. Retrieved from http://dx.doi.org/10.1002/ldr.842

White, G. (2011). *Climate change and migration*. New York, NY: Oxford University Press.

Wiafe, G., Yaqub, H. B., Mensah, M. A., & 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: Journal du Conseil,* 65, 318–324. Retrieved from http://icesjms.oxfordjournals.org/content/65/3/318.abstract

Williams, P. D., & Haacke, J. (2008a). Security culture, transnational challenges, and the economic community of West African States. *Journal of Contemporary African Studies,* 26, 119–136. Retrieved from http://dx.doi.org/10.1080/02589000802124813

Williams, P. D., & Haacke, J. (2008b). Security culture, transnational challenges, and the Economic Community of West African States. *Journal of Contemporary African Studies,* 26, 119–136. Retrieved from http://dx.doi.org/10.1080/02589000802124813

Wilson, M. D., Cheke, R. A., Fiasse, S. P. J., Grist, S., Osei-Ateweneboana, M. Y., Tetteh-Kumah, A., Fiasorgbor, G. K., Jolliffe, F. R., Boakye, D. A., Hougard, J. M., Yameogo, L., & Post, R. J. (2002). Deforestation and the spatio-temporal distribution of savannah and forest members of the *Simulium damnosum* complex in southern Ghana and south-western Togo. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 96, 632–639. Retrieved from http://www.sciencedirect.com/science/article/pii/S0035920302903354

Wittig, R., König, K., Schmidt, M., & Szarzynski, J. (2007). A study of climate change and anthropogenic impacts in West Africa. *Environmental Science and Pollution Research,* 14, 182–189. Retrieved from http://dx.doi.org/10.1065/espr2007.02.388

Wolf, A. T., Stahl, K. & Macomber, M. F. (2003) Conflict and cooperation within international river basins: the importance of institutional capacity. *Water Resources Update,* 125. University Council on Water Resources. Retrieved from http://www.transboundarywaters.orst.edu/publications/abst_docs/Wolf_2003.pdf

Yawson, A. E., Weetman, D., Wilson, M. D., & Donnelly, M. J. (2007). Ecological zones rather than molecular forms predict genetic differentiation in the malaria vector *Anopheles gambiae* s.s. in Ghana. *Genetics,* 175, 751–761. Retrieved from http://www.genetics.org/content/175/2/751.abstract

Yenotani, M. (2011). Displacement due to natural hazard-induced disasters: Global estimates for 2009 and 2010.

Internal Displacement Monitoring Centre (IDMC), Geneva. Retrieved from http://www.internal-displacement.org/publications/natural-disasters-2009-2010

Yoffe, S., Wolf, A. T., & Giordano, M. (2003). Conflict and cooperation over international freshwater resources: Indicators of basins at risk. *Journal of the American Water Resources Association*, 1109–1126. Retrieved from ftp://131.174.16.163/pub/toinesmits/Recommended_readings_IWRM_2009/Water_Conflict/2003YoffeConflict%20and%20cooperation%20over%20international.pdf

Zelazowski, P., Malhi, Y., Huntingford, C., Sitch, S., & Fisher, J. B. (2011). Changes in the potential distribution of humid tropical forests on a warmer planet. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 369, 137–160. Retrieved from http://rsta.royalsocietypublishing.org/content/369/1934/137.abstract

Zeng, N., Neelin, J. D., Lau, K.-M., & Tucker, C. J. (1999). Enhancement of interdecadal climate variability in the Sahel by vegetation interaction. *Science,* 286, 1537–1540. Retrieved from http://www.sciencemag.org/content/286/5444/1537.abstract

Zwarts, L. (2010). Will the Inner Niger Delta shrivel up due to climate change and water use upstream? In *A&W Rapport 1537*. Wageningen, Netherlands: Wetlands International. Retrieved from http://www.wetlands.org/WatchRead/tabid/56/mod/1570/articleType/ArticleView/articleId/2687/Default.aspx

Zwarts, L.. & Grigoras, I. (2005). Flooding of the Inner Niger Delta. In L. Zwarts, P. v. Beukering, B. Kone, & E. Wymenga (Eds.), *The Niger, a lifeline* (pp. 43–77). RIZA, Lelystad/Wetlands International.

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