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For Whom the Bell Tolls: Vulnerabilities in a Changing Climate

A Synthesis from the AIACC Project

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For Whom the Bell Tolls,
Vulnerabilities in a Changing Climate[1]

No man is an island, entire of itself; every man is a piece of the continent, a part of the main. If a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friend's or of thine own were: any man's death diminishes me, because I am involved in mankind, and therefore never send to know for whom the bell tolls; it tolls for thee.
John Donne, 1623.

1. Introduction

People have evolved ways of earning livelihoods and supplying their needs for food, water, shelter and other goods and services that are adapted to benefit from the climates in which they live. But the climate is ever variable and changeable, and deviations that are too far from the norm can be disruptive, even hazardous.

Now the climate is changing due to human actions. Despite efforts to abate the human causes, it will continue to change at least for decades, albeit at a slower and, we hope, less dangerous pace (IPCC, 2001a). Who is vulnerable to the changes and their impacts? For whom does the bell toll? We ask, against the oft quoted advice of the 17th century poet John Donne, because understanding who is vulnerable, and why, can help us to prevent our neighbors' home from washing into the sea, their family from suffering hunger, a child from being exposed to disease, the natural world around us from being impoverished. All of us are vulnerable to climate change, though to varying degrees, directly and through our connections to each other.

The propensity of people or systems to be harmed by stresses, referred to as vulnerability, is determined by their exposures to stresses, their sensitivity to the exposures, and their capacities to resist, cope with, exploit, recover from and adapt to the effects. Global climate change is bringing changes in exposures to climate stresses. The impacts will depend in part on the nature, rate and severity of the changes in climate. They will also depend to an important degree on social, economic, governance and other forces that determine who and what are exposed to climate stresses, their sensitivities to stresses, and their capacities. For some, the impacts may be beneficial. But predominantly harmful impacts are expected for much of the developing world (IPCC, 2001b).

[1] This paper is a synthesis of research from case studies of Assessments of Impacts and Adaptations to Climate Change (AIACC), a project funded primarily by the Global Environment Facility and also supported by grants from the Canadian International Development Agency, the US Agency for International Development, and the US Environmental Protection Agency. An initial draft of the paper was produced at a conference hosted and financially supported by the Rockefeller Foundation at their Bellagio Study and Conference Center, 7-14 March 2005. The views expressed in the paper are those of the authors and do not represent the views of the funding and sponsoring organizations. Direct correspondence regarding this paper to Neil Leary, E-mail: nleary@agu.org.

To explore vulnerabilities to climate change and response options in developing country regions, twenty-four regional assessments were implemented under the international project Assessments of Impacts and Adaptations to Climate Change (AIACC). The AIACC case studies were not selected to comprehensively assess all vulnerabilities and systematically identify the places and systems that are most vulnerable. Still, the case studies do span a wide range of places and systems from which some general conclusions can be drawn. Our studies are placed in Africa, Asia, Latin America and islands of the Caribbean, Indian and Pacific Oceans. They include investigations of agriculture, pastoral systems, water resources, terrestrial and estuarine ecosystems, biodiversity, urban flood risks, coastal settlements, food security, livelihoods and human health.

From these varied studies, a number of lessons have emerged regarding climate change vulnerabilities and adaptations. Lessons about adaptation are presented in Burton *et al*. (2005), while in this paper we present a synthesis of lessons concerning vulnerability. The lessons are generalized from the case studies and provide a broad view of commonalities across places and systems. While useful, vulnerability to climate change is highly context specific and many rich details are lost in this aggregation. For these details, the reader must go to the individual AIACC case study papers that are referenced in this synthesis.

The synthesis was developed following a protocol described in Section 2 and is structured around four domains of vulnerability to climate change impacts: (i) natural resources, (ii) coastal areas and small islands, (iii) rural economy and food systems, and (iv) human health. The main lessons about vulnerability to emerge from the synthesis and developed in this paper can be briefly stated as follows:

- Climate variability, extremes and change are a danger now, not just in the distant future.
- The danger is greatest where natural systems are severely degraded and human systems are failing and therefore incapable of effective response.
- A household's access to water, land and other resources are important determinants of its vulnerability.
- Heightened water scarcity that impedes development is a critical concern for areas that may become drier.
- Land degradation and desertification may also be exacerbated in these areas, posing additional threats to human well-being and development if human pressures on lands intensify and are poorly managed.
- Some ecosystems and many of their species may be lost to climate change, with consequent losses of goods and services to human societies.
- Multiple factors converge to make the people inhabiting coastal zones and small islands highly vulnerable.

- The livelihoods and food security of the rural poor are threatened by climate change. The threat is particularly great for, but not limited to, rural poor in drought-prone dryland areas.
- Vulnerability to adverse health impacts is greater where health care systems are weak and programs for disease surveillance and prevention are lacking.

2. A Protocol for Vulnerability Synthesis

The case studies are varied in their objectives, the systems and sectors that are investigated, the methods that are applied, and their location specific contexts. The variety poses a problem for comparing and synthesizing findings from the different studies. But one factor that is common to each of the studies that participated in this synthesis is that they include investigation of the vulnerability of people, places or systems to climatic stresses.

Vulnerability studies take a different approach from investigations of climate change impacts, which generally emphasize quantitative modeling to simulate the impacts of selected climate change scenarios on Earth systems and people. In contrast, vulnerability studies focus on the processes that shape the consequences of climate variations and change to identify the conditions that amplify or dampen vulnerability to adverse outcomes. The climate drivers are treated as important in vulnerability studies, but drivers related to demographic, social, economic and governance processes are given equal attention. Consequently, existing vulnerabilities to current climate variations and extremes are examined for the insights they can provide regarding vulnerability to future climate change. A motivation for this approach is that it can help to highlight where interventions might reduce vulnerability most effectively (Leary, 2002).

Our synthesis of vulnerability lessons from the AIACC case studies was developed using a three step risk assessment protocol that has been previously applied by Downing (2002) to studies of food security. The protocol was implemented by a group of investigators from the AIACC case studies during a week long workshop held in March 2005.

The first step of the protocol was to develop contexts or domains of climate change vulnerability that correspond to resources or systems that are important to human wellbeing, are potentially affected by climate change, and are a focus of one or more of the case studies. The domains that emerged from the synthesis workshop are natural resources, coastal areas and small islands, rural economy and food security, and human health. In the second step, outcomes of concern within each domain were identified and ranked as low, medium or high level concerns. In selecting and ranking outcomes, we attempted to take the perspective of stakeholders concerned about national scale risks. Outcomes are included that our studies, and our interpretation of related literature, suggest are plausible and that, should they occur, would be of national significance. Our rankings of low, medium and high level concerns are based upon the following criteria: potential to exceed coping capacities of affected systems, the geographic extent of damages, the severity of damages relative to national resources, and the persistence or reversibility of the impacts. The rankings do not take into account the likelihood that an outcome would be realized. They represent the degree of concern that would result if the hypothesized outcomes do materialize. While we have not formally assessed the likelihood of the different outcomes, each is a potential result under plausible scenarios and circumstances.

In step three, we identified the climatic and non-climatic factors that create conditions of vulnerability to the outcomes of concern within each domain. Where climatic and non-climatic drivers combine to strongly amplify vulnerability, the potential for high-level concern outcomes being realized is greatest. Conversely, where some of the drivers interact to dampen vulnerability, outcomes of lower level concern are likely to result.

The results, presented in Sections 3 through 6 and summarized in Section 7 of the paper, are a synthesis of our findings about vulnerability. Within the domains of natural resources, coastal areas and small islands, rural economy and food security, and human health we have identified outcomes from exposures to climate change that pose risks of national level concern. For each of these outcomes, the main climatic and non-climatic drivers are identified.

3. Natural Resources

Natural resources, pressured by human uses, have undergone rapid and extensive changes over the past 50 years that have degraded many of these resources (Millennium Ecosystem Assessment (MEA), 2005). Population and economic growth are likely to intensify uses of and pressures on natural resource systems. Global climate change, which has already impacted natural resource systems across the Earth, is adding to the pressures and is expected to substantially disrupt many of these systems and the goods and services that they provide (IPCC, 2001b;MEA, 2005). The AIACC studies investigated vulnerabilities from climate impacts to a variety of natural resources, which are grouped into the contexts water, land and ecosystems and biodiversity.

3.1 Water

Population and economic growth are increasing water demands and many parts of the world are expected to face increased water stress as a result (Arnell, 2004). Water resources are highly sensitive to variations in climate and consequently climate change will pose serious challenges to water users and managers (Gleick *et al*., 2000; IPCC, 2001b). Climate change may exacerbate the stress in some places but ameliorate it in others, depending upon the changes at regional and local scales.

Vulnerabilities from water resource impacts of climate change are addressed by several of the AIACC studies. Outcomes of concern for water resources from these studies and the climatic and non-climatic

Table 1. Water Resource Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ Collapse of water system leading to severe and long-term water shortage	▪ Persistent and severe decline in water balance due to reduced rainfall and/or higher temperatures ▪ Sea level rise causing salt-water intrusion into shallow aquifer of small island ▪ Disappearance of glacier	▪ High dependence on single vulnerable water source ▪ Lack of alternative water sources ▪ High and growing water demand relative to reliable supply ▪ Failure of water and land-use policy, planning and management	
High	▪ Water scarcity that retards progress on Millennium Development Goals and threatens food security	▪ Persistent, regional decrease in rainfall, increase in aridity ▪ More variable rainfall and runoff ▪ More frequent severe drought events	▪ High and growing water demand relative to reliable supply ▪ High dependence on subsistence or small-scale rain-fed crop farming and herding ▪ Land degradation ▪ High poverty rate ▪ Insufficient investment in rural development ▪ Inequitable access to water ▪ Lack of social safety nets ▪ Governance failures	▪ North Darfur, Sudan (Sanjak *et al.*, 2005) ▪ Northern Nigeria (Nyong *et al.*, 2005) ▪ Mongolia (Batima *et al.*, 2005) ▪ Mexico (Eakin *et al.*, 2005)
Medium	▪ Losses from reallocations of water among competing users ▪ Non-violent but costly conflict among competing water users	▪ Persistent and moderate decrease in rainfall, increase in aridity ▪ More variable rainfall and runoff ▪ More frequent severe drought events ▪ Changes in timing of runoff and water availability	▪ High and growing water demand relative to supply ▪ Extensive land use changes ▪ Pollution from industrial, agricultural and domestic sources ▪ Undefined or insecure water rights ▪ Poor performance of institutions for water planning, allocation and management	▪ Western China (Yin *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005) ▪ South Africa (Nkomo *et al.*, 2005)
Medium	▪ More frequent flood events that Increase loss of life, damage to infrastructure, loss of crops and disruption of economic activities	▪ Increase in heavy precipitation events	▪ Growth in populations and infrastructure in flood prone locations ▪ Poorly managed land-use change, including clearing of vegetation and filling of wetlands that can provide flood protection ▪ Ineffective disaster prevention, preparedness, warning and response systems	▪ Argentina (Eakin *et al.*, 2005) ▪ Argentina (Barros *et al.* 2005) ▪ Thailand & Lao PDR (Chinvanno *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005)
Low	▪ Losses to water users from localized, temporary and manageable fluctuations in water availability	▪ Seasonal droughts	More severe effects kept in check by: ▪ Effective management, planning and policies for water demand and supply	▪ Philippines (Pulhin *et al.*, 2005) ▪ Western China (Yin *et al.*, 2005) ▪ Thailand & Lao PDR (Chinvanno *et al.*, 2005) ▪ South Africa (Nkomo *et al.*, 2005)

drivers of the outcomes are identified in Table 1. Scenarios of future climate change indicate that many of the AIACC study regions, including much of Africa and parts of Asia, face risks of greater aridity, more variable water supply, and periods of water scarcity from drought. In contrast, scenarios suggest that the climate may become wetter and water supply greater in southeastern South America and southeastern Asia.

Changes in water balances will impact land, ecosystems, biodiversity, rural economies, food security and human health and vulnerabilities to these impacts are discussed in later sections of the paper. The outcomes are strongly dependent upon factors such as the level and rate of growth of water demands relative to reliable supplies; water and land use policies, planning and management; water infrastructure; and the distribution and security of water rights. Where water becomes less plentiful and climates drier, the changes have the potential to retard progress toward Millennium Development Goals.

The devastating impacts that can result from persistent and geographically widespread declines in water balances have been demonstrated too frequently. Sanjak *et al*. (2005) and Nyong *et al*. (2005) examine the impacts of decades of below average rainfall and recurrent drought in two parts of the Sudano-Sahel zone with case studies in Sudan and Nigeria respectively. The reduced availability of water in these arid and semi-arid areas has resulted in decreased food production, loss of livestock, land degradation, migrations from neighboring countries, and internal displacements of people. The effects of water scarcity have contributed to food insecurity, the destitution of large numbers of people and are also implicated as a source of conflict that underlies the violence in Darfur (see Section 5.3).

Non-climate factors that have contributed to the severity of impacts of past climatic events in Sudan and Nigeria create conditions of high vulnerability to continued drying of the climate and future drought. Both studies find that large and growing populations in dry climates that are highly dependent on farming and grazing for livelihoods, lack of off-farm livelihood opportunities, reliance of many households on marginal, degraded lands, high poverty levels, insecure water rights, inability to economically and socially absorb displaced people, and dysfunctional governance institutions create conditions of high vulnerability to changes in water balances. While projected water balance changes for the Sahel and Sudano-Sahel zones are mixed (Hoerling *et al*., 2005), they include worrisome scenarios of a drier, more drought-prone climate for these regions.

The Heihe River basin of northwestern China has experienced more modest drying over the past decade (Yin *et al*., 2005). But with increasing development in the basin, water demands have been rising and intensifying competition for the increasingly scarce water. As a result, water users in the basin have become more vulnerable to water shortage, reduced land productivity, and non-violent conflict over water allocations. These effects illustrate outcomes of medium and low level concern. A drier climate, as some scenarios project for the region, would exacerbate these conditions and could result in outcomes of higher-level concern if future development in the basin raises water demand beyond what can be supplied reliably and sustainably.

For the case study regions in the eastern part of the southern cone of South America (Conde *et al*., 2005, Eakin *et al*., 2005, and Camilloni and Barros, 2003), the Philippines (Pulhin *et al*., 2005), and Lower Mekong River basin (Chinvanno *et al*., 2005), climate change projections suggest a wetter climate and increases in water availability. In the southern cone of South America, increased precipitation over the past two decades has contributed to the expansion of commercially profitable rain-fed crop farming, particularly of soybeans, into cattle ranching areas that were previously too dry for cropping. While this has generated significant economic benefits, the increased rainfall has also brought losses from increases in heavy rainfall and flood events. In the future, a wetter climate in these regions would also bring benefits from increased water availability, but may also cause damages from flooding, water-logging of soils (Eakin, *et al*. 2005), and greater rainfall variability that may include both heavier rainfall events as well as more frequent droughts (IPCC, 2001a) that would add to risks faced by farmers.

In the Pantabangan-Carranglan watershed of the Philippines, increases in annual rainfall and water runoff would benefit rain-fed crop farmers, irrigators, hydropower generators, and other water users. But changes in rainfall variability, including those related to changes in ENSO variability, could intensify competition for water among upland rainfed-crop farmers, lowland irrigated-crop farmers, the National Power Corporation, and National Irrigation Administration (Pulhin, *et al*., 2005). Changes in flood risks are also of concern in the watershed. In the lower Mekong, while increases in annual rainfall may bring increases in average rice yields, shifts in the timing of rainy seasons and the potential for more frequent flooding are found to pose risks for rice farmers (Chinvanno, *et al*., 2005). Those most vulnerable to changes in variability in the lower Mekong and in Pantabangan-Carranglan appear to be small farmers with little or no land holdings, lack of secure water rights, limited access to capital and other resources, and limited access to decision-making processes.

3.2 Land

The quality and productivity of land is strongly influenced by climate and can be degraded by the combined effects of climate variations and human activities. Land degradation has become one of the most serious environmental problems, reducing the resilience of land to climate variability, degrading soil fertility, undermining food production, and contributing to famine (UNCCD, 2005a). Seventy percent of the world's drylands, including arid, semi-arid and dry sub-humid areas, are degraded, directly affecting more than 250 million people and placing 1 billion people at risk (UNCCD, 2005b).

Human caused climate change is likely to affect land degradation processes by altering rainfall averages, variability and extremes and by increasing evaporation and transpiration of water from soils, vegetation and surface waters. The effects on land will depend in part on how the climate and water balances

Table 2. Land Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ Widespread desertification of lands with irreversible changes to soil structure or nutrient status	▪ Arid, semi-arid or sub-humid climate ▪ Persistent decrease in rainfall, increased aridity ▪ Increase in climate variability, including more frequent extreme droughts	▪ Severe overuse of land, including overly intense cropping with poor soil management, poor irrigation practices, extension of cropping into marginal lands, overgrazing of rangelands, removal of vegetation and deforestation ▪ Land tenure systems, land use policies, market failures and globalization forces that create pressures for overuse and limit incentives for good land management ▪ Population pressure ▪ Breakdown of support systems ▪ Poverty ▪ Poor, erodable soils	▪ North Darfur, Sudan (Sanjak *et al.*, 2005) ▪ Northern Nigeria (Nyong *et al.*, 2005) ▪ Mongolia (Batima *et al.*, 2005)
	▪ Widespread but reversible desertification of lands	▪ Arid, semi-arid or sub-humid climate ▪ Increase in climate variability, including more frequent extreme droughts	▪ Intensive use of land that degrades land productivity during dry periods but does not irreversibly alter soils ▪ Population pressures ▪ Poverty ▪ Inability of land management systems to adapt to climate variations	▪ North Darfur, Sudan (Sanjak *et al.*, 2005) ▪ Northern Nigeria (Nyong *et al.*, 2005) ▪ Mongolia (Batima *et al.*, 2005) ▪ Mexico (Eakin *et al.*, 2005)
Medium	▪ Land degradation of limited geographic extent that is irreversible	▪ Increased aridity of limited geographic extent ▪ Increase in climate variability, including more frequent extreme droughts	▪ Locally severe overuse of land ▪ Population pressures ▪ Poverty	▪ Mexico (Eakin *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005)
Low	▪ Localized but reversible land degradation	▪ Moderate, temporary drying of localized extent	More severe effects kept in check by: ▪ Tenure systems and land policies that promote good land management ▪ Households that have sufficient resources with which to cope with reduced food and fodder production ▪ Social systems that function to absorb shocks	▪ Mexico (Eakin *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005)

change. But they will also depend strongly on non-climate factors that shape human pressures on land. The human consequences will in turn be shaped by the ability of people to cope and respond to the effects and to reduce the human pressures that drive land degradation.

Two AIACC case studies, one in Northern Darfur, Sudan (Sanjak *et al*., 2005) and the other in Mongolia (Batima *et al*., 2005), have land degradation as a central focus. Land degradation is also found to be a potential outcome as well as an amplifier of climate change vulnerability in AIACC studies in the Philippines (Pulhin, *et al*., 2005), Tlaxcala, Mexico (Ziervogel *et al*., 2005), and Tamaulipas, Mexico and the Argentine Pampas (Eakin, *et al*., 2005).

Table 2 lists some of the outcomes of concern from the studies that are related to land degradation. The ranking of outcomes is based upon the spatial extent, severity of impacts, and the reversibility or irreversibility of land degradation. The climate drivers of land degradation outcomes are increases in aridity and increases in the frequency, severity and duration of droughts. Non-climate drivers include population growth and economic incentives that create pressures to intensify land uses, expand farming and grazing activities into marginal lands, and clear vegetation. Contributing to this are land tenure systems, land policies, and market failures that limit incentives for good land and water management. Widespread poverty, breakdown of local support systems and ineffective governance institutions heighten vulnerability of populations to income and livelihood losses, food insecurity, and displacement from their homes as a result of land degradation.

In northern and central states of Sudan, the dry climate, sandy soils, and heavy human pressures on the land create conditions of high vulnerability to desertification. Below average rainfall over the past 20 years and growing land use pressures have degraded grazing and crop lands in North Darfur and reduced food and fodder production and the availability of water (Sanjak *et al*., 2005). The scarcity of these lifelines has triggered southward migrations of people and their livestock within North Darfur. In addition, persons fleeing civil war in neighboring Chad also migrated into western Sudan.

The resulting rapid increases in human population and the number of livestock have intensified pressures on the already fragile environment, including over-grazing and excessive cutting of gum arabic (*Acacia senegal*) trees to clear land for cultivation and provide fodder and firewood. The reduction in vegetation cover has increased vulnerability to loss of soil and soil fertility by exposing soils to wind erosion and encroachment of desert sands. Similar processes are degrading lands in Sudan's North Kordofan state (Ziervogel, *et al*., 2005). The human consequences of drought and land degradation in Sudan are explored below in Section 5.3. If, as some climate projections suggest, the future climate of the region becomes drier and the frequency and severity of droughts increase, desertification processes would be exacerbated.

Mongolia, a nation for which livestock herding is the dominant livelihood activity, is also experiencing serious desertification (Batima *et al.* (2005). Over the past 40 years, pasture production has declined 20-30%. Rainfall has stayed relatively constant over this period, increasing slightly in some areas and decreasing in others. However, increases in mean temperatures ranging from near 1 ºC in the low mountains and on the plains of the Gobi desert to more than 2 ºC in the high mountains have resulted in drying of the climate and soils and reduced fodder production. Overstocking and overgrazing of pastures in the drier conditions has lead to degradation of lands in parts of Mongolia. Reduced fodder production on the degraded lands has caused reductions in the numbers and weights of animals that can be raised by herders. Drought years, combined with severe winters, have had devastating impacts on animal herds and herders (see Section 5.2 below). Climate projections indicate that temperatures will continue to rise and suggest that the region may become drier. Such scenarios would worsen problems of land degradation in Mongolia.

3.3 Ecosystems and Biodiversity

Habitat change, overexploitation, invasive alien species, pollution and climate change are identified by the Millennium Ecosystem Assessment as the most important drivers presently of ecosystem change and biodiversity loss. By the end of the 21st century, it is possible that climate change may become the dominant driver (MEA, 2005). AIACC case studies in South Africa (von Maltitz and Scholes, 2005) and the Philippines (Lasco, *et al*., 2005) investigate the potential changes in the spatial extent of ecosystem types and biodiversity loss for scenarios of climate change. The findings of these studies are summarized here. Other AIACC studies examine the impacts of climate change on the productivity of ecosystems and are discussed in sections of this paper on water, land, coastal systems, and rural economy.

Outcomes of high, medium and low levels of concern from the South African and Philippine studies are presented in Table 3. At the high end of the scale, the two studies find that loss of some entire ecosystems, along with many of their species, is probable for changes in climate that are projected for a doubling of atmospheric concentration of carbon dioxide.

The vulnerability of ecosystems and species to adverse outcomes from climate change is determined in part by how specialized or general are their climate requirements, changes in the spatial extent and connectivity of areas with climates that match these requirements, the rate at which areas with suitable climates move across the landscape in response to climate change, and the potential rates at which species and communities of species can migrate. Vulnerability is also determined by human caused pressures on ecosystems in addition to climate change that may weaken their resilience, by human-made obstacles that can impede species migration, and by human efforts to relieve pressures and make obstacles more porous.

Table 3. Ecosystems and Biodiversity Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ Collapse or loss of entire ecosystem and extinction of many of the system's species	▪ Rapid rate of change in mean temperature ▪ Changes in water balance across an ecosystem's geographic distribution that are beyond tolerance limits of dominant species ▪ Changes in seasonal climate extremes, variability and means	▪ Narrow climate tolerances of dominant species of an ecosystem ▪ Extensive habitat loss and fragmentation due to land use change ▪ Severe pressure from overgrazing, over-harvesting, over-fishing, etc. ▪ Severe competition from invasive species ▪ Severe pressure from Pollution ▪ Changing fire regimes ▪ Physical barriers to species migration (e.g. islands, mountain tops, isolated valleys) ▪ Changes in grass-tree interactions due to increase CO_2 in atmosphere	▪ South Africa (von Maltitz & Scholes, 2005) ▪ Philippines (Pulhin *et al.*, 2005)
Medium	▪ Species loss and retrogressive succession	▪ Greater water stress from higher temperatures and lower precipitation	▪ Moderate pressure on ecosystems due to habitat loss and fragmentation, overexploitation, competition from invasive species, and pollution ▪ Changing fire regimes ▪ Changes in grass-tree interactions due to increase CO_2 in atmosphere	▪ South Africa (von Maltitz & Scholes, 2005)
	▪ Species loss and change in habitat compositional structure	▪ Slow changes in climate that allow most species to migrate	▪ Sufficient connections of suitable habitat persist across the landscape to enable species to migrate	▪ South Africa (von Maltitz & Scholes, 2005)
Low	▪ Genetic loss ▪ Loss of genetic variability, loss of sub-species and varieties	▪ Slow changes in climate ▪ Small absolute changes in temperature and precipitation that do not fundamentally alter water balances	More severe effects kept in check by: ▪ Managing pressures on ecosystems to a low level ▪ Connections of suitable habitat enable species to migrate	▪ South Africa (von Maltitz & Scholes, 2005)

In the South African example, projected increases in aridity in the western half of the country would cause current biomes to contract and move toward the eastern half of the country. A large proportion of South Africa would be left with a habitat type that is not currently found in the country. The impacts vary by location and biome type and for individual species.

The savanna systems of South Africa and their species are found to have relatively low vulnerability to climatically driven extinctions. In comparison, species of the fynbos biome are potentially more vulnerable to climate change than are those of the savannas. The fynbos is the major vegetation type of the Cape Floral Kingdom, which is the smallest of the world's 6 floral kingdoms. It is located entirely in

South Africa, has the highest concentration of species of any of the floral kingdoms, and has a species endemism rate of 70 percent. While the fynbos biome is projected to have relatively little loss in spatial extent, climatic habitats would move for many individual species and some climatic habitats would disappear completely. Model simulations suggest that many species of the fynbos will be able to migrate with their moving habitats, but some would not and would be lost.

The situation for the Succulent Karoo biome, an arid ecosystem of southwestern South Africa and southern Namibia that is also rich in biodiversity and high in species endemism, is more dire. Model simulations for climate change scenarios corresponding to a doubling of carbon dioxide project that almost the entire extent of the Succulent Karoo would be lost to a new climatically defined habitat type. Extinction of many of the species endemic to the biome would likely result.

In the Philippines, increasing temperature and rainfall are projected to result in the dry forest zone being completely replaced by wet forests and rainforests (Lasco, *et al*., 2005). They estimate that a 50 percent increase in precipitation would cause dry forests, which occupy approximately 1 million hectares, to disappear completely from the Philippines and moist forests, which occupy 3.5 million hectares, to decline in area by two-thirds. Most of these forest areas would become wet forests, which would more than double from their present size. If precipitation were to increase by 150 percent, which is within the range of GCM scenario projections for the end of the century, all dry and moist forests would disappear, wet forests would decline by half, and rain forests, a forest type not currently present in the Philippines, would increase to 5 million hectares. The warmer, wetter climate that is projected for the Philippines would increase the primary productivity of the forests and produce associated benefits, but the disappearance of dry and possibly moist forest types would result in losses of species.

4. Coastal Areas and Small Islands

Coasts and small islands are highly exposed to a variety of climate hazards that may be affected by global climate change. The climatic hazards converge with local and regional human pressures in coastal zones to create conditions of high vulnerability, particularly in areas with high concentrations of people and infrastructure along low-lying coasts. Barros *et al.*(2005) investigate flood risks from storm surges along the Argentine coast of the Rio de la Plata. Nagy *et al.* (2005), also working in the Rio de la Plata basin, examine changing dynamics of the estuarine ecosystem and their implications for fisheries on the Uruguayan side. Payet and De Comarmond (2005) explore problems of coastal erosion and also risks to tourism in the Seychelles, while Mataki *et al.* (2005) assess the vulnerability of coastal towns of Fiji to flooding. Outcomes of concern from these studies are summarized in Table 4.

Barros *et al*, (2005) find that sea level rise would permanently inundate only small and relatively unimportant areas along the southern coast of the Rio de la Plata during this century. However, the area and population that would be affected by recurrent flooding from storm surges would increase

Table 4. Coastal Area and Small Island Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ More frequent and greater loss of life, infrastructure damage, displacement of population and disruption of economic activities	▪ Increase in frequency and intensity of extra-tropical and tropical storms ▪ Sea level rise	▪ Large and growing population and infrastructure in exposed coastal areas ▪ Lack of land-use policies to avoid/reduce exposures ▪ Lack of maintenance of flood control infrastructure ▪ Loss of wetlands and reefs ▪ Ineffective disaster prevention, preparedness, warning and response systems	▪ Central America, (www.aiaccproject.org; LA06) ▪ Argentina (Barros *et al.*, 2005)
	▪ Loss of tourism related income, export earnings and jobs	▪ Changes number of wet days, frequency of storms	▪ Damages to infrastructure, beaches, water supply and ecosystems that provide tourism related services ▪ High dependence on tourism for income and employment	▪ Seychelles (Payet and De Comarmond, 2005)
	▪ Severe coastal erosion	▪ Increase in frequency and intensity of extra-tropical and tropical storms ▪ Sea level rise	▪ Intensive land uses in the coastal zone ▪ Loss of coastal wetlands and bleaching of coral reefs	▪ Seychelles (Sheppard *et al.*, 2005; Payet and De Comarmond, 2005) ▪ Fiji (Mataki *et al.*, 2005)
Medium	▪ Damage to coastal ecosystems and their services and resulting impacts on fishing livelihoods	▪ Sea level rise ▪ Changes in winds, water temperatures, and freshwater inflow to estuaries and coastal waters	▪ Pollution discharges into waters ▪ Nutrients carried into coastal waters by runoff ▪ Use of fertilizers that runoff into coastal waters ▪ Removal of vegetation that increases erosion ▪ Hardening of shoreline to protect against storm surges ▪ Over-harvesting of fish and shellfish	▪ Uruguay (Nagy *et al.*, 2005)
	▪ Diminishing and less reliable water supply	▪ Sea level rise ▪ Changes in water balance and ENSO and monsoon variability	▪ Increasing water demand from growing population and economic activity ▪ Increasing extraction of groundwater	▪ Fiji (Mataki *et al.*, 2005)
Low	▪ Modest acceleration of coastal erosion and modest infrastructure damage	▪ Increase in frequency and intensity of extra-tropical and tropical storms ▪ Sea level rise	More severe effects kept in check by: ▪ Low concentrations of population and infrastructure in areas exposed to erosion ▪ Intact coastal wetlands and inland vegetation ▪ Good coastal policies and management practices	▪ Argentina (Barros *et al.*, 2005)

considerably. They estimate that by 2070, sea level rise and changes in wind fields would increase the population affected by storm surges with a five-year return period from 80,000 persons at present to nearly 350,000. For storm surges with a 100 year return period, the population affected would rise from 550,000 at present to nearly 900,000 by 2070. Economic costs resulting from real estate damage and increased operational costs of coastal public facilities are estimated to range between 5 to 15 billion US dollars for the period 2050-2100, depending on the rate of sea level rise. These estimates are based on the current population and development of the basin. Continuation of trends that have been concentrating both people and infrastructure on the coast would increase the number of people exposed and the potential economic damage.

Coastal erosion is common to all coasts, but the level of concern that it engenders ranges from low to high depending upon local circumstances. Barros *et al.* (2005) find that coastal erosion is presently of little concern in the Rio de la Plata basin, though concern could rise if newly accreted lands in the Parana delta are allowed to be settled and developed. In contrast, concern about coastal erosion is high in the Seychelles (Payet and De Comarmond, 2005) and in Fiji and the Cook Islands (Mataki *et al*., 2004), where infrastructure and resources are more exposed to the impacts of erosion. A recent study in the Seychelles found that coastal erosion is significantly heightened as a result of coral bleaching events that reduce the ability of reefs to dissipate wave energy (Sheppard *et al*., 2005). They conclude that areas that have experienced mass bleaching are at a higher risk from coastal erosion under accelerated sea-level rise.

In the Seychelles, as in many island states, tourism is a major contributor to incomes. The attributes that make the Seychelles and other islands attractive tourist destinations can be highly sensitive to climate stresses. The high economic dependence on tourism and the sensitivity of tourist resources to climate create a situation of high socioeconomic vulnerability to climate change (Payet and De Comarmond, 2005). Climate change can impact tourism by accelerating beach erosion, inundating and degrading coral reefs, damaging hotels and other tourism related infrastructure, and discouraging tourists from visiting because changes in climate reduce its appeal.

While local actions can help to relieve problems of beach erosion, stresses on corals and coastal wetlands, and infrastructure damage, the latter risk is not easily mitigated. In a scenario that assumes a substantial increase in the number of wet days per month, Payet and De Comarmond estimate that tourist visits would be reduced 40 percent., They also estimate that the decrease in tourist visits would reduce tourism expenditures by 40 million USD and cause over 5000 jobs to be lost, or 15 percent of the national labor force. The effects would be felt in all areas of the economy.

The trophic state of the estuary of the Rio de la Plata has degraded since the mid-1940s. The eutrophication of the estuary is due primarily to nutrients introduced by increased fertilizer use and changes in human land uses, but climatic factors such as changes in river flows and wind patterns have also contributed (Nagy *et al*., 2005). A consequence of the eutrophication is an increase in the frequency of harmful algae blooms in the last decade, resulting in considerable economic harm to commercial fisheries and tourism as well as negative impacts on public health in Uruguay. Climate change would impact the estuary through changes in freshwater input from tributaries and changes in winds that would modify the circulation, salinity front location, stratification and mixing patterns. These changes would in turn alter oxygen content, nutrients, and primary production in the estuary.

Many of the estuary's services would be altered. But the specific changes are difficult to predict as they depend upon the balance of multiple and complex interactions. One of the concerns is the sustainability of fisheries in the Rio de la Plata. A case study of an artisanal fishery located on the northern coast of the Rio de la Plata finds the fishermen and the fishing settlement to be vulnerable to climate driven shifts in the salinity front location and other changes in the estuary that would alter fish catch or the effort and cost to catch fish.

5. Rural Economy and Food Security

Rural economies, which are based upon and dominated by agricultural, pastoral and forest production, are highly sensitive to climate variations and change. So too are the livelihoods and food security of those who participate directly in these activities, supply inputs to them, or use their outputs to produce other goods and services.

Several AIACC case studies investigate the potential impacts of climate variability and climate change on production processes of rural economies and the vulnerability of households' livelihoods and food security to the impacts. Climate change can and will have both positive and negative impacts on rural economies and livelihoods. Table 5 highlights some of the potential negative outcomes identified as concerns by the studies. The focus is on negative outcomes because our interest is in understanding who is vulnerable in rural economies, how they are vulnerable and why. This focus is appropriate as previous studies find that predominantly negative effects can be expected for agriculture in developing countries (IPCC, 2001b).

Changes in the productivity of farm fields, pastures and forests will be influenced by changes in water balances, changes in temperature averages and ranges, changes in the frequencies and severities of droughts, floods and other climate extremes, and the ameliorating effects of higher carbon dioxide concentrations on plant processes. One of the common findings of the studies is that systems with similar exposures to climate stimuli can vary considerably in their vulnerability to damage from the exposures.

The particular factors that determine vulnerability are context specific and vary from place to place. But some commonalities can be identified. Rural households' sensitivity to climate shocks and capacity to respond vary according to their access to water, land and other resources. Large and growing

Table 5. Rural Economy Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ Violent conflict ▪ Famine	▪ Persistent below average rainfall, increased aridity ▪ Severe, multi-year, geographically widespread drought events	▪ Tensions among rival groups ▪ Migrations of herders into lands of sedentary farmers ▪ Collapse of local authorities ▪ Governance failures ▪ Scarcity of food, water, other resources	▪ North Darfur, Sudan (Sanjak *et al.*, 2005) ▪ Northern Nigeria (Nyong *et al.*, 2005)
	▪ Multi-year collapse of rural production systems ▪ Widespread and persistent loss of livelihoods & impoverishment ▪ Chronic hunger & malnutrition for large % of population ▪ Long-term or permanent out-migration on large scale	▪ Persistent below average rainfall, increased aridity ▪ Severe, multi-year, geographically widespread drought events	▪ Large and growing population in dryland areas ▪ High % of households engaged in subsistence or small-scale farming and herding on lands with poor soils and no irrigation ▪ Over-use, clearing of lands leading to land degradation ▪ Lack of or insecure water rights ▪ High poverty rate ▪ Lack of off-farm livelihood opportunities ▪ Lack of social safety nets ▪ Governance failures	▪ North Darfur, Sudan (Sanjak *et al.*, 2005) ▪ Northern Nigeria (Nyong *et al.*, 2005) ▪ Mongolia (Batima *et al.*, 2005)
Medium	▪ Loss of export earnings ▪ Loss of national income ▪ Loss of jobs	▪ More frequent climate extremes over large portion of growing area of key export crop(s) ▪ Changes in average climate or shifts in rainy season that stress export crops	▪ High dependence on small number of agricultural commodities for export earnings, national income, and employment ▪ Declining or volatile export crop prices ▪ Insufficient investment in research, development & diffusion of agricultural technology	▪ Sri Lanka (Ratnisiri *et al.*, 2005)
	▪ Increased rural poverty rates ▪ Declining and more variable net farm incomes for many rural households ▪ Failures of small farms ▪ Accelerated rural-to-urban migration	▪ Region-wide increase in frequency of climate extremes that cause losses of crops, livestock & income ▪ Changes in average climate or significant shifts in rainy season that stress traditionally grown crops and available substitutes	▪ Declining output prices (e.g. due to trade liberalization) ▪ Rising input prices (e.g. due to removal of subsidies) ▪ Lack of income diversification of rural households ▪ Lack of access to credit by small farmers ▪ Stagnant rural development ▪ Poor rural infrastructure (e.g. roads, water storage) ▪ Lack of social safety nets	▪ Argentina & Mexico (Eakin *et al.*, 2005) ▪ South Africa, Nigeria, Sudan & Mexico (Ziervogel *et al.*, 2005) ▪ Thailand & Lao PDR (Chinvanno *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005)
Low	▪ Declining and more variable net farm incomes for some rural households ▪ Decreased and more variable quality of crop and livestock output ▪ Temporary migrations as strategy to obtain off-farm incomes	▪ Increase in frequency of climate extremes that cause losses of crops, livestock & income ▪ Changes in average climate or shifts in rainy season that are less optimal for traditionally grown crops	More severe effects kept in check by: ▪ Robust and diversified rural development ▪ Equitable access to resources (e.g. improved seed varieties) ▪ Adequate household savings ▪ Maintenance of social safety nets ▪ Political stability ▪ Well maintained rural infrastructure and services ▪ Access to credit and insurance	▪ Argentina & Mexico (Eakin *et al.*, 2005) ▪ Thailand & Lao PDR (Chinvanno *et al.*, 2005) ▪ Philippines (Pulhin *et al.*, 2005) ▪ Sri Lanka (Ratnisiri *et al.*, 2005)

populations, high proportion of households engaged in subsistence or small scale farming and herding, land degradation, high poverty rates, and governance failures create conditions of vulnerability for rural economies and households. Declining local authority, lack of social safety nets, violent conflict, gender inequality and competition from market liberalization are also factors that add to vulnerability in the different case study areas. These issues are developed in the sections below.

5.1 Household access to resources

Access or entitlements to land, water, labor and other inputs to rural production processes are important determinants of the vulnerability of rural households. They shape the sensitivity of households' livelihoods and food security to variations in climate and land productivity. They also underpin the capacity of households to withstand and respond to the impacts.

Ziervogel *et al.* (2005) compare the determinants of food insecurity from four case studies: Mangondi village in Limpopo Province, South Africa, Gireigikh rural council in North Kordofan, Sudan, Chingowa village in Borno State, Nigeria, and Tlaxcala State, Mexico. Each of the study sites is in a dry, drought prone climate and exposure to declining precipitation and drought are a source of risk to household food security. They find that household characteristics related to resource access play a dominant role in determining household vulnerability. These include household income, income diversification, area of land cultivated, soil quality, household labor per hectare cultivated, and health status of household members. Factors external to the household also control access to resources needed to cope with and recover from climate shocks. These include existence of formal and informal social networks, availability and quality of health services, and prices of farm inputs and outputs. In each of the case studies, labor available to the farm household is adversely affected by rural-urban migration and infectious disease such as HIV/AIDS and malaria.

Adejuwon (2005) compares the vulnerability of peasant households to climate shocks in different states of Nigeria using household census data. He finds that the percentage of households employed in agriculture, poverty rate, dependency ratio, access to potable water, health status, and educational attainment are important determinants of vulnerability. Also important is the aridity of the climate and quality of soils. The comparison identifies households in the northern states of Nigeria as the most vulnerable in the country. Nyong *et al.* (2005) conduct detailed surveys of households of this region to identify household characteristics that control vulnerability. Key characteristics include ownership of land and livestock, area and quality of land cultivated, sufficiency of annual harvest relative to household food needs, dependency ratio, cash income, livelihood diversification, gender of household head and connections to family and social networks. Women in this patrilineal society can be particularly vulnerable.

In the Pantabangan-Caranglan watershed of the northern Philippines, households are exposed to variability in rainfall and water supply as well as to flood events (Pulhin *et al*., 2005). The vulnerability of households to these exposures is found to be correlated with variables that determine access to and control of resources: ownership of land, farm size, farm income, gender, and status as a native or migrant to the basin. Larger land owners, identified by community members as "rich farmers," are less vulnerable to variable incomes and other impacts of climate events than are small-holder farmers due to their greater resources for coping and recovery, their ability to live in locations that are less exposed to flooding and erosion, and their ability to capture more of the benefits from development projects due to their ties to the institutions that implement these projects. Projections of future climate change suggest the potential for greater precipitation in the Philippines, which would ease water scarcity in most years. However, flooding would become a more frequent stress and would likely impact poor, small-holder farmers of the basin the hardest.

Chinvanno *et al.* (2005) similarly find that land ownership and other indicators of economic vitality are important determinants of the vulnerability of rice farmers in the Lower Mekong basin. Farmers of rain-fed rice in Thailand and Lao People's Democratic Republic (PDR) are exposed to variations in rice harvests and other impacts from seasonal flooding, shifts in the dates of onset and cessation of the rainy season, and variations in rainfall amounts. Farm households with small land holdings produce low volumes of rice and incomes from rice, which are often only enough to sustain the household on a year-to-year basis. As a result, smallholder farm households have very limited buffering capacity to deal with losses or to cope with anomaly during the crop season. Small land holdings also limit the ability of the farmer to implement other activities to diversify their income sources. Comparing farm households from the Thai study sites with those at the Lao PDR site, Chinvanno *et al.* (2005) find that a larger portion of the Thai farmers are at high risk from climate shocks due to higher food costs relative to farm income, lack of income diversification, little savings in the form of financial assets, livestock or food stores, and high debt relative to income.

5.2 Land degradation

Land degradation is both an outcome of climate stress and a source of additional stress that can amplify the vulnerability to climate impacts of people making a living from the land. It is found to be an important factor in several AIACC case study areas, including Mongolia (Batima *et al*., 2005), Sudan (Sanjak *et al*., 2005), Nigeria (Nyong *et al*., 2005), the Philippines (Pulhin *et al*., 2005), Argentina and Mexico (Eakin *et al*., 2005).

In the grazing lands of Mongolia, land degradation has been severe due to a harsh and variable climate, drying of the climate over a 40 year period, and heavy grazing pressures. As noted in Section 3.2, these conditions have depressed pasture productivity and livestock production. Batima *et al.* (2005) find that these stresses have created a high level of vulnerability among herders to climate extremes, as was demonstrated by events in 1999 – 2003. Several years of summer droughts and severe winter conditions (called *dzud*) combined to drastically reduce pasture production, animal weights at the start of winters, and stores of fodder for winter months. Approximately 12 million head of livestock died as a result, roughly one-quarter of Mongolia's herds. Thousands of families lost animals, an important source of savings, which increased poverty and reduced further the capacity of livestock dependant households to cope with shocks. Many lost their livelihoods with their animals and migrated to towns and urban centers where unemployment is high and few opportunities awaited them. Climate scenarios suggest the potential for further drying of the climate and Mongolia's herders continue to be in a state of high vulnerability to the effects of land degradation, drought and dzud.

In the Philippines' Pantabangan-Caranglan watershed, reforestation and community development projects were implemented to reverse land degradation problems and provide other benefits. However, the projects developed a dependency on the projects for livelihoods and after termination many of the jobs associated with the projects also ended. Affected households have resorted to charcoal making and *kaingin* (slash and burn) farming, which are damaging the fragile environment of the watershed, including the reforested areas, and increasing vulnerability to flooding (Pulhin *et al.*, 2005).

Food insecurity is increasing in Tlaxcala, Mexico for a variety of causes, including a shortage of farm labor due to out-migration of young males, declining maize prices, and severe soil erosion problems (Ziervogel *et al.*, 2005). The shortage of farm labor constrains the practice of soil conservation practices, which are labor intensive, and leads to the expansion of mono-cropping of maize, a system that increases soil erosion. In Tamaulipas, Mexico, mono-cropping of sorghum, which is resilient to water stress, was promoted by the national government as a strategy for managing drought risks. However, farming of sorghum under persistent drought conditions in the 1990s may have resulted in degradation of soils that is adding to farmers' risks from drought (Eakin *et al.*, 2005). Now the government is using incentive payments to farmers to encourage them to switch to other alternatives. In the Argentine Pampas, the dramatic expansion of soybean mono-cropping is also observed to be associated with land degradation (Eakin *et al.*, 2005). This contributes to flood problems and raises concern about the long-term sustainability of soybean farming in the region. In each of these cases, land degradation is adding to the vulnerability of farmers to climate change.

5.3 Conflict

Persistent low rainfall, recurrent drought, land degradation, high population growth, governance failures and other factors have deepened poverty and resulted in food and resource scarcity in the Sahel. The scarcities have contributed to tensions between competing groups and tribes. Cereal production in the region grew at a meager 1 percent annual rate over the past decade, while the population grew at an estimated 2.7 percent rate (Nyong, *et al.*, 2005). Against this backdrop of generally tightening food scarcity, climate and other events have created conditions of crisis. Responses can and have inflamed tensions that contribute to violent conflict, compounding the vulnerability of populations to climatic and other stresses.

Events in Sudan's Northern Darfur State illustrate a case of extremely high vulnerability of the population to loss of livelihoods, livestock, lands, and personal security leading to destitution, hunger, famine and violent death (Sanjak, *et al.*, 2005). The drivers of this human misery are multiple. Among them are twenty years of below average rainfall that has severely reduced the availability of water, food and fodder in this dryland region of infertile soils. The drying climate and human pressures on the land, exacerbated by migrations of people and their livestock into the area, are degrading the land. Traditional land management systems and practices have been disrupted and bring nomadic and sedentary tribes into more frequent contact and conflict over land and other scarce resources. These resource conflicts are a major factor contributing to the widespread violence that has taken tens of thousands of lives in Darfur and forced many more to flee their homes. The lack of physical security and access to resources have devastated livelihoods, eroded capacities to cope with climate and other stresses, and threaten people of the region with famine.

Farmers and herders of northern Nigeria face similar pressures as do those of North Darfur. In their case study of northern Nigeria, Nyong *et al.* (2005) find that food scarcity and rising food prices have lead to intensification of farming and grazing and expansion of these activities into more marginal lands. The greater land use pressures, combined with the persistent decline in average rainfall, have added to land degradation problems. The productivity of grazing lands has declined in the north. In response, herders have migrated southward into lands of sedentary farmers, as happened in Darfur. The resulting conflicts have led to the loss of lives, the destruction of crops, livestock and farmlands, and food insecurity for those affected.

5.4 Commodity export oriented economies

The sensitivity of cash crop yields to climate variability and change is of considerable importance to countries that depend heavily on the contribution of cash crops to national income and foreign exchange earnings. In Sri Lanka, coconut and tea production are the largest sources of export earnings, major contributors to national income, and significant employers of labor. Ratnasiri *et al.* (2005) investigate the effects of past climate variations on the coconut and tea sectors of Sri Lanka and develop crop models to simulate yield responses to future climate change. Below normal rainfall in coconut growing areas, historically occurring once every 2 to 4 years, has reduced coconut yields by 10 – 25 percent relative to the 30-year average. Since priority is given for domestic consumption, this results in a greater 30 – 60 percent decline of nuts available for exports, causing a significant reduction in foreign exchange earnings and national income. In the tea sector, the 1992 drought in Sri Lanka caused a 25 percent decline in tea production and a corresponding 22 percent decline in foreign exchange earnings from tea.

Projections of future climate change include scenarios of both increased and decreased average precipitation for Sri Lanka. Changes in average coconut production would follow the precipitation changes. But tea yields are sensitive to temperatures and the effects vary by location. In the lowlands, where temperatures are near the optimum for tea yields, warming would decrease yields. In the cooler uplands, tea yields would increase with warming. Hence, it is the lowland plantations, owned largely by small holders with low adaptation capacity, that are vulnerable compared to upland plantations, which are owned by large companies. But an important factor for vulnerability of these cash crop sectors will be the effect of climate change on climate variability, particularly the frequency of drought, which, as shown by past events, are a significant source of risk for these sectors.

5.5 Market forces and social safety nets

The case studies by Eakin *et al.* (2005) of crop and livestock farms in Cordoba, Argentina and Tamaulipas, Mexico demonstrate the influences of international market integration and government social programs on the vulnerability of farmers. Both countries have pursued policies of trade liberalization, privatization and deregulation. The policies have opened access to international markets and foreign investments allowing, for example, the profitable expansion of soybean farming in Argentina. But competition from overseas producers and removal of price supports and input subsidies, have created a "price squeeze" for farmers, particularly for maize farmers in Mexico.

In this highly competitive environment, farm households have less margin for absorbing shocks, including crop and livestock losses from climate extremes, and so are more vulnerable. The pressures are leading to greater concentration of farms into larger scale commercial operations as smaller family farms face a number of disadvantages, including higher cost of credit, lack of access to technical skills, high dependence on crop income, greater problems with pests, and lack of scale economies. The problems for small farmers are compounded by cutbacks in state-supported social security mechanisms, resulting in declining rural incomes and increasing inequality between small and large landholders. In Tamaulipas, small farm owners and *ejidatarios* (communal farmers) are responding to declining and uncertain farm incomes by diversifying into off-farm sources of income, a trend that is reducing their vulnerability to direct climate impacts.

6. Human Health

The paths by which climate can affect human health are diverse and involve both direct and indirect mechanisms. The most direct mechanisms operate through human exposures to climatic extremes that can result in injury, illness and death. Climate and climate change also affect human health by influencing human exposure to infectious disease through effects on the biology, habitats and behaviors of disease pathogens, hosts and vectors. Even less directly, climate and climate change can affect human health through impacts on the resources that individuals and communities need to maintain good health.

Direct health outcomes of concern highlighted in the synthesis workshop are summarized in Table 6 and are described below. Indirect health effects are briefly summarized in Section 6.2.

Table 6. Human Health Vulnerabilities

Level of Concern	Outcomes of Concern	Climate Drivers	Other Drivers	AIACC Studies
High	▪ More frequent geographically widespread and sustained epidemics of infectious and waterborne disease with high human mortality	▪ Geographically widespread changes in climate that increase the geographic area and number of disease vectors ▪ More frequent heavy rainfall and drought events that disrupt water supply and sanitation and expose people to waterborne pathogens	▪ Severely degraded or collapsed health care system ▪ Poor and declining immunity, nutritional and health status of large portion of population ▪ High poverty rates that limit access to health care ▪ Poor or non-existent programs for disease surveillance, vector control, and disease prevention ▪ Large portion of population lace reliable access to potable water and sanitation ▪ Land use changes that increase habitat for disease vectors and reservoirs for zoonotic diseases	▪ East Africa (Wandiga *et al.*, 2005) ▪ Caribbean (Heslop-Thomas *et al.*, 2005)
	▪ Emergence of new or more virulent strains of infectious disease and more efficient disease vectors ▪ More frequent but geographically and temporally limited epidemics with high or moderate mortality ▪ Increase in number of infectious disease cases and mortality in endemic areas and seasons	▪ Changes in climate that alter disease and vector ecology and transmission pathways ▪ Changes in climate that moderately increase exposures by expanding endemic areas and seasons	▪ Land use changes that increase habitat for disease vectors and reservoirs for zoonotic diseases ▪ Crowding ▪ Drug resistance ▪ International migration, travel and tradel ▪ Water storage and sanitation practices ▪ Poor programs for disease surveillance, vector control, and disease prevention ▪ Declining quality and increasing cost of health care	▪ East Africa (Wandiga *et al.*, 2005) ▪ Caribbean (Heslop-Thomas *et al.*, 2005)
Low	▪ More frequent but geographically and temporally limited epidemics with no mortality ▪ Increase in number of isolated infectious disease cases that are not life threating	▪ Changes in climate that alter disease and vector ecology and transmission pathways ▪ Changes in climate that moderately increase exposures by expanding endemic areas and seasons	More severe effects kept in check by: ▪ Access to health care ▪ Effective disease surveillance, vector control, and disease prevention ▪ Good nutritional and health status of population ▪ Access to potable water and sanitation	▪ East Africa (Wandiga *et al.*, 2005) ▪ Caribbean (Heslop-Thomas *et al.*, 2005)

6.1 Direct Health Effects

Many vector borne infectious diseases are climate sensitive and epidemics of these diseases can occur when their natural ecology is disturbed by environmental changes, including changes in climate (McMichael, *et al.*, 2001). For example, observations of numbers of malaria and dengue cases vary with interannual variations in climate (Wandiga *et al*., 2005; Heslop-Thomas *et al*., 2005; Kilian *et al*., 1999; and Lindblade, *et al*., 1999). In the Lake Victoria region of East Africa, significant anomalies in temperature and rainfall were recorded during the El Niño period of 1997 – 1998 and these were followed by severe malaria outbreaks. A similar association of dengue fever occurrences with ENSO variability is observed in Jamaica. Other infectious diseases that are observed to be sensitive to climate variability and change include other insect-borne diseases such as encephalitis, yellow fever, and Leishmaniasis, and water-borne diseases such as cholera, typhoid, and diarrhea (Aron and Patz, 2001; McMichael *et al*., 2001).

Projected changes in rainfall and temperature have the potential to expose more people to vector-borne diseases by expanding the geographic range of vectors and pathogens into new areas, increasing the area of suitable habitats and numbers of disease vectors in already endemic areas, and extending transmission seasons. For example, average temperature and precipitation in the East African highlands are projected to rise above the minimum temperature and precipitation thresholds for malaria transmission and extend malaria into areas from which it has been largely absent in the past (Githeko et al., 2000; Wandiga *et al*., 2005). Other studies suggest that, if El Niño events continue to increase in frequency, the elevated temperatures and precipitation would increase malaria transmission (Kilian at al. 1999; Lindblade et al 1999). In rural communities of the highlands studied by Wandiga *et al*. (2005), risks for developing malaria and complications from the disease are amplified by low utilization of hospitals and clinics because of distance, cost and low incomes. In consequence, self-medication has become widespread. But people often do not comply with the recommended drug regimens and the drugs most commonly used in self-medication are ones for which malaria parasites have high resistance.

The health outcome identified by workshop participants as the highest level concern is sustained or oft repeated, geographically widespread epidemics with high mortality rates. At medium and low levels of concern are more frequent epidemics or outbreaks of infectious disease that may be associated with mortality but which are geographically and temporally limited. Another concern is that changes in climate may allow more virulent strains of disease or more efficient vectors to emerge or be introduced to new areas. The movement of new disease strains into new countries is exemplified by the recent appearance of dengue hemorrhagic fever in the Caribbean, a more life threatening strain of dengue fever that is thought to result from simultaneous infection by the four strains of dengue viruses. However, climate likely played little if any role in the emergence of this disease in the Caribbean (Heslop-Thomas, *et al*., 2005).

Whether changes in climate result in greater infectious disease incidence or epidemics, and the geographic extent and severity of epidemics that might result, depend upon complex interactions that include not just the effect of climate stresses on the ecology of infectious disease, but also on demographic, social, economic and other factors that determine exposures, transmission, results of infection, treatment and prognosis. Vulnerability to severe health outcomes are greatest where the health care system is severely degraded, large numbers of people lack access to health care, the immunity, nutritional and health status of the population is low, and effective programs for disease surveillance, vector control and disease prevention are lacking (see Table 8). Where the converse of these conditions hold, the likelihood that the most severe health outcomes would be realized is much diminished.

6.2 Indirect Health Effects

Many of the climate change impacts described in previous sections of the paper can also have health impacts by reducing individuals' resilience to disease, the resources available to them to maintain and protect their health and obtain access to health care, and the ability of their community to deliver quality health care services. Examples of these indirect effects include households placed at greater risk of illness as a result of loss of livelihood, assets and support networks from severe and persistent drought, health risks associated with displacement and crowding of population that migrates in response to climate impacts, health care systems being overburdened by increases in case loads as a result of direct health effects of climate change, and impacts of climate extremes on health care infrastructure and personnel. The severity of the indirect health outcomes that are realized will depend upon the geographic extent, persistence and return period of the triggering climatic event, the severity of impact on resource productivity, livelihoods and health care infrastructure, and the resilience of the affected area as indicated by the diversity of economic opportunities, poverty rate, health status, and capacity of the health care system relative to the population.

7. Conclusion

Vulnerability to impacts from climate variation and change is shown by the regional studies of the AIACC project to have multiple causes and dimensions. The causes include not only the climatic stressors, but also stresses that derive from interactions among environmental, demographic, social, economic, institutional, cultural and technological processes. The state and dynamics of these processes differ from place to place and generate conditions of vulnerability that differ in character and degree. Consequently, populations that are exposed to similar climatic phenomenon are not impacted the same.

Differences in vulnerability are also apparent for different sub-populations or groups inhabiting a region, and even from household to household within a group. Factors such as sources and diversity of household members' livelihoods, level of wealth, ownership and access to resources, and knowledge of risks and possible responses give rise to differences in vulnerability across households.

We focus on four domains of vulnerability (natural resources; coasts and small islands; rural economy and food security; and human health) and identify and rank climate related outcomes of concern. For each of the outcomes of concern, climatic and non-climatic determinants are identified. A common finding across the domains of vulnerability is that devastating impacts ranked as high level concerns generally are not likely to result from climate stress alone. They are most likely to be realized when multiple stresses act synergistically to create conditions of high vulnerability. A climate shock or stress has the potential to do the most damage in a context in which natural systems are being severely stressed and degraded by overuse and in which social, economic or governance systems are in or near a state of failure and so not capable of effective responses.

Unfortunately, such conditions exist in many parts of the world, particularly the developing world. Places where this is true are consequently vulnerable to some of the high-level concern outcomes from exposure to climate stresses, both now, from current climate variations and extremes and, increasingly, in the future as the climate changes. Examples include famine, collapse of rural livelihood systems that deepen and widen poverty, and loss of life from widespread and persistent epidemics of infectious disease.

An exception is the potential loss of some ecosystems and their biodiversity, which might in some instances be triggered by climate change alone. For example, the rate of climate change is a key factor that threatens the Succulent Karoo biome of South Africa and a rapid rate of change could by itself be sufficient to cause its demise. But for most ecosystems, it will be the interaction of a changing climate with pressures from human uses and management of land and other resources that likely will determine their fate.

More optimistically, our studies suggest that the potential severity and risk of many of the outcomes are less where social, economic and governance systems function in ways that enable effective responses to prevent, cope with, recover from, and adapt to adverse impacts. For example, a health care system that is effective at delivering services to a population, combined with public health programs that promote preventive behaviors, disease monitoring, and disease vector control, can substantially limit the risk that climate change would cause widespread and persistent epidemics. Disaster prevention, preparedness, early warning, and response systems can similarly help to limit the extent of harm from changes in the frequency or severity of extreme climate events. Poverty reduction can provide households access to all manner of resources that can help them to cope with and overcome climate related impacts. Findings from AIACC about the capacity to adapt and adaptation strategies are explored more fully in Burton *et al.*, 2005.

These and other examples indicate that improving the performance of human systems can reduce vulnerability. But optimism should be tempered by the reality of how challenging it has been to achieve even minimal progress where key human systems have been dysfunctional.

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