IMPACTS OF PRESENT AND FUTURE CLIMATE VARIABILITY ON AGRICULTURE AND FORESTRY IN THE HUMID AND SUB-HUMID TROPICS

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Abstract. Although there are different results from different studies, most assessments indicate that climate variability would have negative effects on agriculture and forestry in the humid and sub-humid tropics. Cereal crop yields would decrease generally with even minimal increases in temperature. For commercial crops, extreme events such as cyclones, droughts and floods lead to larger damages than only changes of mean climate. Impacts of climate variability on livestock mainly include two aspects; impacts on animals such as increase of heat and disease stress-related death, and impacts on pasture. As to forestry, climate variability would have negative as well as some positive impacts on forests of humid and sub-humid tropics. However, in most tropical regions, the impacts of human activities such as deforestation will be more important than climate variability and climate change in determining natural forest cover.

1. Introduction

Based on the third assessment reports (TAR) of IPCC (2001), the globally averaged surface temperatures have increased 0.6 ± 0.2 °C over the 20th century with sharper increases in the mid- and high latitudes of the northern hemisphere continents. It is very likely that precipitation has increased by 0.5–1% per decade over most of the mid- and high latitudes of the northern hemisphere continents and that rainfall has increased by 0.2–0.3% per decade over the tropical land areas. Although the changes of mean climate for the tropics have not been obvious, climate variability and extreme events, (dominated by inter-decadal to multi-decadal variability) have likely increased in intensity and frequency in some places. The projected climates in the future include not only changes of mean climate such as global warming that varies with region, and increases and decreases in precipitation, but also changes in the variability of climate and changes in the frequency and intensity of some extreme climate phenomena.

Climate variability will affect agriculture and forestry through effects on crops and forests; soils; weeds, pests and diseases; and also livestock. Variation of climatic conditions across the world leads to different local and regional impacts although the humid and sub-humid tropics have much more special climates and ecosystem

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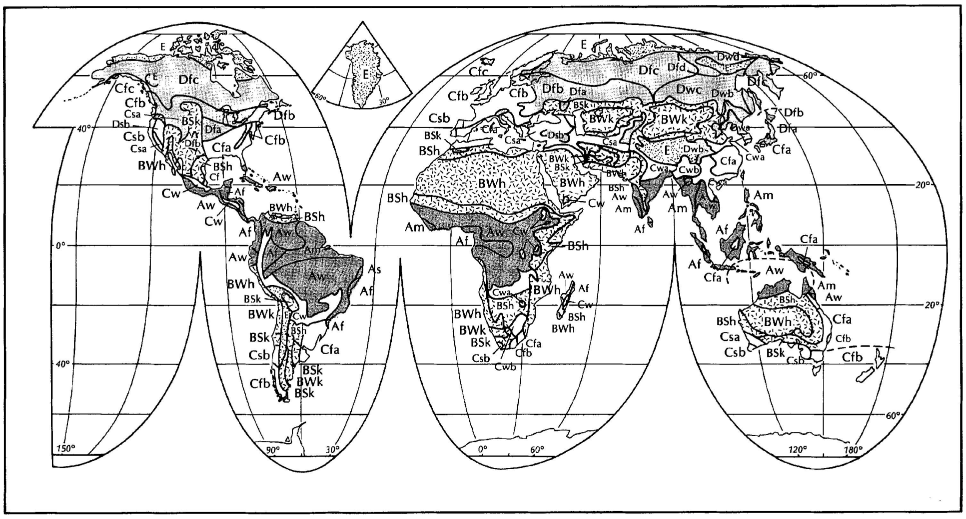

Figure 1. World map showing Koppen's climate classification (Af: tropical rainy; Aw: tropical wet-and-dry; Am: tropical monsoon).

environments. Climate variability and extreme events will definitely bring impacts on agriculture and forestry in these latitudes.

2. Characteristics of Climate of Humid and Sub-humid Tropics

Humid and sub-humid tropics usually refer to the tropical rainy climate zones and most parts of the tropical monsoon or tropical wet–dry climate zones. The tropical rainy climate prevails mainly in lowlands within 5° N and 5° S of the equator (also known as the equatorial climate). The climate is characterized by a combination of constantly high temperatures and abundant rainfall well distributed throughout the year. Humid tropics are commonly associated with the luxurious evergreen forests. The tropical monsoon climate differs from the tropical rainy climate in that it has a distinct dry season; its annual rainfall totals and temperature conditions are similar to those in the tropical rainy climate but rainfall regime is similar to that of tropical wet–dry climate. The tropical wet–dry climate has alternating wet and dry seasons. Annual rainfall totals are less than those in the tropical rainy and monsoon climates. The dry season here is severe and has a profound effect on vegetation and crops unlike in the monsoon tropical climate.

Humid and sub-humid tropical conditions are found over nearly 50% of the tropical land mass and 20% of the earth's total land surface (Figure 1). This total is distributed among three principal regions (Oliver and Hidore, 1984). Tropical Central and South America contain about 45% of the world's humid and sub-humid tropics; Africa, about 30%; and Asia, about 25%. As many as 62 countries are located partly or entirely within the region.

Tropical monsoon Asia is dominated by the two monsoons; the summer southwest monsoon influences the climate of the region from May to September, and the winter northeast monsoon controls the climate from November to February. The monsoons bring most of the region's precipitation. The equatorial monsoon climate comprises of the Indonesian archipelago, Malaysia, New Guinea and some other islands. The wet–dry monsoon climate prevails in the Indian subcontinent, including the northern parts of Sri Lanka and coastal parts of Bangladesh, Burma, Thailand and Indo-China; Philippine archipelago; and northern Australia, and southeastern Indonesia. Tropical cyclone is another important feature of the weather and climate in this region. Two core areas of cyclogenesis exist; one in the northwestern Pacific Ocean, which particularly affects Philippines and Vietnam, and the other in the northern Indian Ocean, which particularly affects Bangladesh. In addition, geographically much more extensive is the El Niño–Southern Oscillation (ENSO) phenomenon, which has an especially important influence on the climate and interannual variability of climate in a number of countries in these latitudes and also over the globe.

The region of humid and sub-humid central and western Africa consists of three main areas; the Congo Basin, between about 5° N and 5° S, the southern coast of western Africa, at latitudes between 5° N and 9° N; and the remaining parts of the region at latitudes between 15° N and 15° S. Climatic conditions differ from those in the tropical monsoon Asia in many ways. The climate of the first two areas is characterized by heavy rainfall throughout the year. Convection is the main process causing precipitation; seasonal variations are mainly the result of large-scale airmass movements and the movements of the intertropical convergence zone (ITCZ). The common feature of this climate is the gradual decrease in the length of the rainy season and in the total amount of rainfall with latitude, basically characterized by wet–dry climate.

The most important topographic feature of Central America and the northern part of South America is the high and continuous mountain backbone of the Andes range, which has important climatological consequences. The Caribbean islands and Atlantic coastal areas of Central America all have a similar climate. The trade winds are the dominating element of its general circulation, which bring much rainfall. The Pacific side of Central America is generally drier than the Atlantic side because of the influence of the subtropical high-pressure cell over the North Pacific. The largest humid part of tropical South America lies to the east of the Andes Mountains. It is a predominantly flat area, with a low center, occupied by the Amazon Basin. The general circulation over this region, the seasonal movements of which are much smaller than over Southeast Asia or tropical Africa, is controlled by the position of the ITCZ. Although Central America and the northern part of South America are characterized largely by humid and sub-humid conditions, important areas (e.g., northeastern Brazil) are subject to droughts and floods due to the ENSO phenomenon.

Atmospheric extremes which are seen as hazards in the humid and sub-humid tropics mainly include droughts, floods, and tropical cyclones. Droughts and floods often occur in the tropical monsoon and wet–dry climate zones. For a number of countries in tropical Asia, the major hazards are tropical cyclones and floods. Droughts, on the other hand, are severe in the northern part of South America and some regions of sub-humid Africa.

3. Features of Agriculture and Forestry in the Humid and Sub-Humid Tropics

Agriculture is very important for most countries in the humid and the sub-humid tropics. Take tropical Asia as an example. In tropical Asia, agriculture is a key economic sector. In 1993, it had employed more than half of the labor force, accounting for 10–63% of the GDP in most countries of the region (IPCC, 1998). Substantial foreign exchange earnings also are derived from exports of agricultural products. Climate-sensitive crops – such as rice, other grains and cereals, vegetables, and spices – are particularly important in this region. Rice is the most important cereal crop. About 88.5% of the world's rain-fed lowland rice is cultivated in South and Southeast Asia. In almost all the countries, rice constitutes over 80% (even 98% individually) of total cereal production. Maize and wheat are the second important cereals (IPCC, 1998).

However, there already exists some degree of vulnerability of the agriculture in the humid and sub-humid tropics due to a number of factors. Tropical Asia supports a large population so that there is a relatively high population density per hectare of intensely cultivated land. Tropical cyclones are one of the most important climatic features and often cause great damages to agriculture. Except for Africa, where food security has been a pressing problem for a number of years now, agriculture of the other countries in the humid and sub-humid tropics is also vulnerable, but with less severity than those in tropical Asia due to their moderate population density and relatively large croplands.

3.1. CROPS AND LIVESTOCK

In the wet equatorial climate zone, commercial agriculture is largely based on perennials, such as rubber, oil palm, bananas, liberica coffee and, to a lesser extent, coconut and cocoa. Some other perennials, such as arabica and robusta coffee, mango and citrus, which need a short drier and cooler spell, are not well suited to the climate. Native farming often includes a plot of fruit trees and other perennials of economic value, but roots are commonly the most important food crops, especially yams, cassava, cocoyams, dasheen or eddo and tannia. Rice is grown extensively. It thrives best in climates with a brief dry season, but the main rice-producing zones here have climates with a more pronounced dry season. Maize is the only other cereal grown appreciably, and its successful cultivation demands adapted varieties. Efficient cultivation and weed control, especially in annual crops, are difficult because of the continuous wet weather during which, weed growth is extremely rapid and luxuriant. Soil fertility is commonly limited by nutrient deficiencies. Apart from pigs and poultry, livestock are unimportant mainly because there are no extensive natural grasslands and there are endemic diseases (Webster and Wilson, 1980).

In areas with good rainfall, usually two rainy seasons with only short dry seasons, perennial crops such as coffee, tea and bananas can be satisfactorily grown. There are two cropping seasons a year for annuals, the first commonly devoted to food crops and the second generally to cotton or vegetable. In the southern coast of west Africa, the chief perennial crops are oil palms and cocoa, while annuals are mainly maize, pulses, yams and cassava. Rice is the chief annual crop under similar climatic conditions in Southeast Asia. Owing to the absence of good natural grasslands and the presence of endemic diseases, livestock have hitherto been relatively unimportant.

In the areas with two short rainy seasons and pronounced intervening dry seasons, climatic conditions are far less suitable than the preceding type for perennial crops, except for some markedly drought-resistant types. The commonest crops are maize, sorghum, finger millet, sweet potatoes, cassava, groundnuts, beans and other pulse crops. The importance of cattle varies considerably, depending upon the presence or absence of tsetse fly and, in part, on traditional agricultural systems.

In the wet climates of the tropical windward coasts, mainly along the east of the Malagasy Republic, Central America and the northern part of South America, the high rainfall and absence of a severe dry season permit the cultivation of a wide range of perennial and annual crops, such as rice, maize, yams, tannia, dasjeen, sweet potato, arrowroot, sugarcane, cocoa, coconut and nutmeg. Perennials such as coffee and citrus, which do best under more moderate rainfall and with a short dry season accompanied by lower temperatures, are commercially profitable. Crops requiring a lower rainfall and a more pronounced dry season for harvesting, such as cotton, tobacco or groundnut, are difficult in the wetter areas, but grown quite extensively in the dry parts of the zones (Webster and Wilson, 1980).

3.2. FORESTRY

Tropical forests represent about 40% of the world's forested area and contain about 60% of global forest biomass. Rainforests and monsoon forests are two major types in the humid and sub-humid tropics. Rainforests grow in ever-wet conditions where rainfall is heavy and spread throughout the year, such as in the Amazon Basin and the Congo delta. These forests are evergreen or semi-evergreen and include lowland, montane, and swamp forests. Monsoon forests grow in the Southeast Asian region where rainfall is high but unevenly spread throughout the year. Most monsoon forest trees are deciduous; they shed their leaves in the dry season. Owing to no management, under the pressure of increasing population, many of these two types of forest are degraded by logging, farming, and fire. In the Asia-Pacific region, where most of the world's managed tropical forests are found, less than 20% of production forests receive systemic silvicultural treatment (FAO and UNEP, 1981). Only 0.2% of the world's humid and sub-humid tropical forests is being managed for sustained timber production (Poore et al., 1990).

Except large areas of tropical natural forest biome, plantation forestry also plays an important role in the humid and sub-humid tropics. Most tropical tree plantations were established after the 1960s, particularly in sub-humid and premontane tropics (Lugo, 1988). Plantations are usually established on damaged or deforested lands for sawn wood, veneer, and pulpwood production, environmental protection, or for supplying firewood. Mixed tree systems, a kind of tree plantation known as home gardens and mixed tree orchards, is also a common form for the harvest of various forest products including firewood, food for the household and marketplace, medicines, and construction materials, and the environmental benefits such as resulting in more local reforestation.

Humid and sub-humid tropical forest is one of the richest regions in biodiversity. Frontier forests in Asia are home of more than 50% of the world's terrestrial plant and animal species (Rice, 1998). Central America has about 8% of the world's biodiversity concentrated in only 0.4% of the emerged surface of the planet. But biodiversity in this region is at risk due to climate change, land-use, and population pressure.

3.3. SYSTEMS OF AGRICULTURE AND FORESTRY

The efficiency of tropical agriculture and forestry is determined by a combination of environmental factors that include climate, soil, and biological conditions, social, cultural, and economic factors. Agriculture and forestry systems and techniques that have evolved over time to meet the special environmental conditions and economic demands of the region include the paddy rice systems of Southeast Asia; terrace, mound, and drained field systems; raised bed system; and a variety of agroforestry, and shifting cultivation. Monocultural systems have been successfully introduced over large areas of the humid and sub-humid tropics, and include production of coffee, tea, bananas, citrus fruits, palm oil, rubber, sugarcane, and other commodities produced primarily for export (National Research Council, 1993).

3.3.1. *Intensive Cropping Systems*

Intensive cropping systems are concentrated in lands with adequate water, naturally fertile soils, low to modest slope, and other environmental characteristics conducive to high agricultural productivity. But the systems face critical challenges in order to respond to the food and other subsistence needs of expanding populations. Fallow period that allowed for the accumulation of nutrients and the suppression of pests have essentially been removed from the crop rotation sequence. Furthermore, pressures from pests and diseases are increasing as the area devoted to the cultivation of new varieties (Fearnside, 1987). In some countries in some regions, lowland areas that are relied on for producing staple and cash crop are in danger of becoming unfit for crop production as a result of improper management, such as nutrient loading from fertilizers, water contamination from pesticides and herbicides, and waterlogging and salinization.

3.3.2. *Shifting Cultivation*

Shifting cultivation is one of the most widespread farming systems throughout the humid and sub-humid tropics. Temporary forest clearings are planted for a few years with annual or short-term perennial crops, and then allowed to remain fallow for a longer period than they were cropped. However, it is often labeled as the most serious land use problem in the tropical world (Grandstaff, 1981). In many of the areas, where it had formerly been practiced successfully for centuries, population and poverty pressures have forced the shortening of the fallow period and field rotation cycle and consequently, a loss of productivity.

3.3.3. *Agropastoral System*

Agropastoral systems combine crop and animal production. In Asia, the animal components of small farming operations vary with cropping systems. In lowland rice-farming areas, buffalo, cattle, fowl, and swine are commonly raised. In highland areas, swine, poultry, buffalo, and cattle are raised in combination with rice, maize, cassava, bean, and small grains. In humid Africa, these systems are dominated by crops such as rice, yams, and plantains, and animals such as goats and poultry. The small farms of Latin America typically include crop mixtures of beans, maize, and rice. Cattle, swine and poultry are dominant animals. Agropastoral systems can enhance agroecosystem productivity and stability through efficient nutrient management, integrated management of soil and water resources, and a wider variety of both crop and livestock products. At the same time, it may provide relatively high levels of income and employment in resource-poor areas.

3.3.4. *Cattle Ranching*

Livestock production in the humid part of Africa is not important as an economic activity; only few lands are cleared for cattle pasture (Brown and Thomas, 1990), and cattle are vulnerable to the effect of trypanosomiasis and tsetse fly (Linear, 1985). Cattle raising on pasturelands takes place in some countries of Southeast Asia, but it is not a significant factor in increasing deforestation since crop production systems are dominant. However, cattle ranching on a large scale has been identified as a leading contributor to deforestation and environmental degradation in the humid and sub-humid parts of Latin America where cattle raising is common due to its socio-economic and ecological importance. Overall pasture degradation is the primary problem that cattle ranching faces in the humid and sub-humid tropics (particularly evident in Latin America) due to its low soil fertility.

3.3.5. *Agroforestry System*

Agroforestry systems include a range of options in which woody and herbaceous perennials are grown on land that also supports agricultural crops or animals. Under ideal conditions, such as a compatible association of trees, annual crops and animals, these systems offer multiple agronomic, economic, environmental, and socioeconomic benefits for resource-poor small-scale farmers, including enhanced nutrient cycling, fixing of atmospheric nitrogen through the use of perennial legumes, efficient allocation of water and light, conservation of soil, natural suppression of weeds, and diversification of farm products (Lal, 1991). It is important to note, however, that trees have both positive and negative effects on soils. Negative effects include growth suppression caused by competition for limited resources (nutrients, water, and light). Mismanagement of trees (for example, through improper fertilizer application or inadequate water control) can also cause soil erosion, nutrient depletion, water logging, drought stress, and soil compaction.

4. Climate Variability

Climate variability means the alternation between the "normal climate" and a different, but recurrent, set of climatic conditions over a given region of the world (IPCC, 1998). Natural climate variability can produce floods, droughts, cyclones, heat waves, frosts, and other extremes in the humid and sub-humid tropics. GHG-induced climate change could further alter the frequency and magnitude of the climate extremes and associated disasters.

Over the past 100 years, the amount of changes of mean surface temperatures and precipitations has been less in the tropics than the global average, but either in the past climate or in the projected scenarios, climate variability, particularly multidecadal ones, are obvious (IPCC, 1998). Across the tropical Asia, there have not been observed identifiable changes in the number, frequency, or intensity of tropical cyclones in the two core regions of cyclogenesis over the past 100 years; but there is some evidence of substantial multidecadal variability of increases in the intensity or frequency of some extreme events on regional scales throughout the 20th century. Increased precipitation intensity, particularly during the summer monsoon, could increase flood-prone areas in temperate and tropical Asia. There is potential for drier conditions in sub-humid Asia during summer, which could lead to more severe drought. Many countries in temperate and topical Asia have experienced severe droughts and floods frequently in the 20th century (IPCC, 2001). In the Latin American region, there is ample evidence of climate variability and high confidence that ENSO is responsible for a large part of the climate variability at interannual scales (TAR). For example, El Niño is associated with dry conditions in northeast Brazil, northern Amazonia, the Peruvian-Bolivian Altiplano, and Pacific coast of Central America, The most severe droughts in Mexico in recent decades have occurred during El Niño years, whereas southern Brazil and northwestern Peru have exhibited anomalously wet conditions (Horel and Cornejo-Garrido, 1986). La Nina is associated with heavy precipitation and flooding in Colombia and drought in southern Brazil (Rao et al., 1986).

TABLE I
Climate change scenarios of humid and sub-humid tropics

Regions	Temperature	Rainfall
Africa	Increase	–
Asia		
South Asia	Increase	Increase
Southeast Asia	Increase	Increase
Latin America		
Mexico	Increase	Decrease
Costa Rica		
Pacific sector	Increase	
Southeast Caribbean sector	Increase	Small increase
Nicaragua		
Pacific sector	Increase	Decrease
Caribbean sector	Increase	Decrease
Brazil		
Central and south central sector	Increase	Increase for autumn, decrease for summer

Source: Construction based on WGII TAR Sections 10.1.4, 11.1.3, 14.1.2.

For the projected climate changes based on TAR, temperature will increase and precipitation increase or decrease in humid and sub-humid tropics (see Table I). High-resolution modeling studies suggest that over some areas the peak wind intensity of tropical cyclones is likely to increase by 5–10% and precipitation rates may increase by 20–30%, but none of the studies suggest that the locations of the tropical cyclones will change. There is little consistent modeling evidence for changes in the frequency of tropical cyclones (WGI TAR Box10.2). Current projects show little changes or a small increase in amplitude for El Niño events over the next 100 years. But many models show a more El Niño-like mean response in the tropical Pacific (particularly in Latin America). Even with little or no change in El Niño strength, global warming is likely lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions (WGI TAR Section 9.3.5-6, WGII TAR Section 14.1.2). In short, there is a potential for an increased occurrence of droughts, floods and heavy rainfall and some other extreme weather events in most of humid and sub-humid tropics (see Table II).

It should be noted that there is great uncertainty in projections of likely changes in tropical cyclones, El Niño and monsoons so that vulnerabilities related to these hazards are qualitative and scientists do not discount possibilities of “climate surprises” in the future (IPCC, 2001).

TABLE II
The examples of climate variability and extreme climate (related to tropics) and examples of their impacts (related to agriculture and forestry)

Projected changes during the 21st century in extreme climate phenomena and their likelihood	Representative examples of projected impacts (all high confidence of occurrence in some areas)
Higher maximum temperature, more hot days and heat waves over nearly all land areas (very likely)	Increased heat stress in livestock and wildlife
	Increased risk of damage to a number of crops
Higher minimum temperature, fewer cold days, frost days and cold waves over nearly all land areas (very likely)	Decrease risk of damage to a number of crops, and increased risk to others
	Extend range and activity of some pest and disease vectors
More intense precipitation events (very likely, over some areas)	Increased flood, landslide, and mudslide damage Increase soil erosion
Increased in tropical cyclone peak wind intensities, mean and peak precipitation intensities (likely, over some areas)	Increased damage to coastal ecosystems such as mangroves
Intensified drought and floods associated with El Niño events in many different regions (likely)	Decreased agricultural and rangeland productivity in drought- and flood-prone regions
Increased Asian summer monsoon precipitation variability (likely)	Increase in flood and drought magnitude and damages in tropical Asia

Source: Adapted from WGII TAR Table SPM-1.

5. Impacts of Climate Variability on Agriculture and Forestry

Agriculture and forestry, due to their direct dependence on climate and weather, are two of the widely studied sectors in the context of climate change. There are two aspects of climate change on agriculture: firstly, the potential direct effect of increased CO_2 and secondly, the potential effects of changes in temperature, precipitation. The changes in climate parameters could also have an influence on factors constraining their growth such as soil quality, pests, and diseases. Either in the past or at present, a number of the studies capture impacts due to change in average climate. It is widely believed, however, that changes in climate variability would imply much larger impacts than those due to changes in average climate alone. Agricultural production in lower-latitude and lower-income countries is more likely to be negatively affected by climate change (IPCC, 1996, 1998, 2001). It is seen that climate variability and climate change, particularly in terms of frequency/intensity of droughts, have larger impacts on the sub-humid than on the humid regions. If climate variability induced disasters become more common, widespread, and persistent, many countries in the sub-humid and humid tropical regions may have difficulty in sustaining viable agricultural and forest practices. Increasing atmospheric CO_2 levels could elevate the photosynthetic rate and stimulate plant growth and will generally be beneficial to the crop and forest in the humid and sub-humid tropics.

5.1. IMPACTS ON CROP AGRICULTURE

In general, it is expected that areas in mid- and high-latitudes will experience increases in crop yield; yields in lower latitudes generally will decrease (IPCC, 2001). The response of crop yields to climate change varies, depending on the species, cultivar, soil conditions, CO_2 direct effects, and other locational factors. Based on TAR, there is high confidence that, in the tropics, where some crops are near their maximum temperature tolerance, yields would decrease generally with even minimal changes in temperature; higher minimum temperatures will be beneficial to some crops, especially in temperate regions, and detrimental to other crops, especially in low latitudes. Degradation of soil is one of the major future challenges for tropics agriculture. It is established with high confidence that this process is likely to be intensified by adverse changes in temperature and precipitation. But another important advance in research on the direct effects of CO_2 on crops suggest that beneficial effects may be greater under certain stressful conditions, including warmer temperatures and drought. So that would be a positive aspect for agriculture.

Globally, the economic impacts of climate change on agriculture are expected to be relatively minor, decreasing food production in some areas will be balanced by increases in productivity in others (Rosenzweig and Parry, 1993; IPCC, 2001). However, b*ased on TAR, the adaptive capacity of human systems in Africa, Asia and Latin America is low and vulnerability is high*. Changes in average climate conditions and climate variability could have significant effects on agriculture in many parts of the humid and sub-humid tropics. Agriculture in these regions, particularly in the sub-humid areas, is vulnerable to many environmental hazards – including frequent floods, droughts, tropical cyclones and storm surges and high temperatures. Low-income rural populations that depend on traditional agricultural systems or on marginal lands are particularly vulnerable (Amadore et al., 1996). Table III shows excerpts of a table of recent studies of yield and production in selected countries in the humid and sub-humid regions.

Food security is facing a threat because there would then be rapid changes in supply and demand structures most especially in the developing countries, especially in the tropics. Assessments of the consequences of climate for the number of people at risk of hunger as defined by the Food and Agriculture Organization (FAO) have also been done. Results of the study by Parry et al. (1999) indicate that the additional number of people at risk of hunger as a result of climate change by 2080 is estimated to be about 80 million and those at higher risk are from the arid and sub-humid tropics.

TABLE III
Recent agricultural studies

Study	Scope	Crops	Climate scenario	Yield impact without adaptation	Yield impact with adaptation	Socio-economic impact	Comments
			(a) Studies with explicit global economics and/or global yields				
Parry et al. (1999)	Global	Wheat, rice, maize, soybeans	Transient scenarios: 4 HadCM2 ensemble scenarios, 1 HadCM3 (both assume IS92a forcing)		All cereals by 2080s: NA (–10 to +3%); LA (–10 to +10%); WE (0 to +3%); EE (–10 to +3%); AS (–10 to +5%); AF (–10 to +3%)	By the 2080s: global cereal production (–4 to –2%), cereal prices (+13 to +45), number of people at risk or hunger (+36 to +50%)	Farm-level adaptations (changes in plant date, varieties, irrigation, fertilizer); economic adjustments (increased investment, reallocation of resources, more land in production); no feedback between economic adjustments and yields; CO_2 direct effects included
Winters et al. (1999)	Africa, Asia, Latin America	Maize, rice, wheat, coarse grains, soybean, "cash crops"	GISS, GFDL, UKMO		Africa [maize (–29 to –23%), rice (0%), wheat (–20 to –15%), coarse grains (–30 to –25%), soybean (–2 to +10%), cash crops (–10 to –4%)]; Asia [maize (–34 to –20%), rice (–12 to –3%), wheat (–54 to 8%), coarse grains (–34 to –22%), soybean (–9 to +10%), cash crops (–13 to +2%)]; Latin America [maize (–26 to –18%), rice (–26 to –9%), wheat (–34 to –24%), coarse grains (–27 to –19%), soybean (–8 to +12%), cash crops (–20 to –5%)]	Africa [total agricultural production (–13 to –9%), GDP per capita (–10 to –7%), agricultural prices (–9 to +56%)]; Asia [total agricultural production (–6 to 0%), GDP per capita (–3 to 0%), agricultural prices (–17 to +48%)]; Latin America [total agricultural production (–15 to –6%), GDP per capita (–6 to –2%), agricultural prices (–8 to +46%)]	Yield impacts based on Rosenzweig and Parry (1994) values for "level 1" (farm level) adaptations and CO_2 direct effects; yield impacts are weighted (by production) average of country-level yield changes; values for total agricultural production and per capita GDP include both yield and price impacts; range for agricultural prices is across food and cash crops, and GCMs

(b) Studies with of yield and production in economies-in-transition and developing regions, nations, and sub-national regions

Matthews et al. (1997)	Asia	Rice	Sensitivity analysis (+1 °C, +2 °C, +4 °C); GFDL, GISS, UKMO	+1 °C (–7 to 26%), +4 °C (–31 to –7%), –8 to +5%	+14 to +27% (with change in variety)	Change in production: China with change in cropping system (+37 to +44%), region with change in variety (+13 to +25%)	Includes CO_2 direct effects; adaptation (single to double cropping system, planting date shift, change in variety)
Smith and co-workers (1996)	The Gambia	Maize, millet-early, millet-late, groundnuts	CCC, GFDL, GISS	–26 to –15%, –44 to –29%, –21 to –14%, +40 to +52%			CO_2 direct effects considered in all cases but Mongolia; adaptation in Mongolia consists of earlier seeding
	Zimbabwe	Maize	CCC, GFDL	–14 to –12%			
	Kazakhstan	Spring wheat, winter wheat	CCC, GFDL CCC, GFDL, incremental scenarios	–70 to –25%			
	Mongolia	Spring wheat	GFDL, GISS	–35 to +17%			
	Czech Republic	Winter wheat	Incremental scenarios	–3 to +16%			
Amien et al. (1996)	Indonesia	Rice	GISS transient	2050 (–14 to –9%)			Includes direct effects of CO_2
Buan et al. (1996)	Philippines (six sites)	Rice, corn	CCC, GFDL, GISS, UKMO	Rice (–13 to +9%), corn (–14 to –8%)			Includes direct effects of CO_2
Karim et al. (1996)	Bangladesh	Rice, wheat	CCC, GFDL	Rice (–17 to –10%), wheat (–61 to –20%)			CO_2 direct effects not considered
Jinghua and Erda (1996)	China	Maize	GFDL, UKMO, MPI	–19 to +5%		Change in production: –6 to –3%	CO_2 direct effects not considered

5.1.1. *Africa*

Per capita food production in Africa, as a whole has already decreased over the recent years. Food security in Africa is affected severely by extreme events, particularly flood and droughts. For example, the 1998 ENSO floods had wrought extensive damage to crops in Kenya which was estimated at US$ 1 billion (Ngecu and Mathu, 1999). Irrespective of whether climate change will cause more frequent or more intense extreme events, it is seen that agricultural productivity is sensitive to climate hazards such as droughts and floods. The already deficient food production in many areas of Africa could result in worsening the problems of food security.

The TAR further cites some specific examples of impacts on crops here. Among these are the studies done by Pimentel (1993) that indicates that global warming is likely to alter production of rice, wheat, corn, beans and potatoes which are major food crops in Africa and by Odingo (1990) that notes that rice may disappear because of higher temperatures in the tropics.

Projections indicate the dominant impacts of increase in temperature which show decreases in growing season and reduction in runoff. And although increased CO_2 could increase photosynthesis rates and water use efficiency in crops like wheat, rice and soybeans, increased temperatures could have deleterious effects on crops during sensitive development stages which could lead to a decline in grain yield and quality. In addition, the risks of adverse effects on agriculture in the sub-humid areas of the region with more frequent and prolonged droughts could also be considerable (IPCC, 2001). There is a consensus in all IPCC assessment reports (1996, 1998) that climate variability and climate change (primarily droughts) would generally have significant impacts on almost all farming systems in Africa.

The most significant constraint for African agriculture is water supply. Due to the relatively rich water sources, climate change and variability would lead to less impacts on the agriculture in humid and sub-humid Africa, compared with other areas in Africa.

5.1.2. *Asia*

According to TAR, the developing countries of temperate and tropical Asia already are quite vulnerable to extreme climate events such as floods, typhoons/cyclones, and droughts. Climate change and variability would exacerbate these vulnerabilities with high confidence. Increased precipitation intensity, particularly during the summer monsoon, could increase flood-prone areas. There is potential for drier conditions in sub-humid Asia during summer, which could lead to more severe drought (medium confidence). The expected increase in the frequency and intensity of climatic extremes will have significant potential effects on crop growth and agricultural production, as well as major economic and environmental implications.

The IPCC (2001) has defined a number of vulnerabilities of the agricultural productivity in Asia. Asia is a region in which climate-change-induced vulnerabilities are highly dependent on the population density and rate of economic growth in each of the countries. The growth rate of rice production in a number of countries such as Philippines, Indonesia and Sri Lanka has been unable to match, much less cope with fast population growth rate due to a number of factors which includes the impacts of a highly variable climate. Food insecurity also appears to be the primary concern for Asia.

The variability of rainfall in the developing countries of tropical Asia is rather high so that these countries have also been rendered quite vulnerable to extreme climate events such as droughts and floods. Moisture stress due to prolonged dry spells/droughts and in some sub-humid areas, coupled with heat stress, have already been seen to affect crops, especially when these environmental conditions occur during the critical stages of the crops (Rounsevell et al., 1999). On the other hand, excessive moisture also causes substantial crop losses due to floodings and loss of nutrients and soil erosion. The predicted increase in frequency and/or severity of extreme events could further exacerbate adverse impacts. Furthermore, all climate scenarios point to an increase in area-averaged annual mean precipitation over its entire region which could lead to increased frequency and severity of floods. So, it is seen that agricultural productivity in this region could suffer severe losses.

Results also show that increasing minimum temperatures could have an impact on rice yields while wheat crops are likely to be sensitive to increases in maximum temperatures. The adverse impacts due to temperature increases could also be further exacerbated by the occurrence, development and spread of crop diseases because some common diseases such as wheat scab, rice blast, and sheath and culm blight of rice could be more widespread as a result of warmer and wetter climates. Ninety percent of the more than 10,000 different species of insect pest found in the tropics are active in the humid areas. Higher temperature during winter is highly favorable to pathogen survival rates.

Results of a large number of simulations/experiments confirm beneficial effect of elevated CO_2 on crops (IPCC, 1996), but variations in crop response among species exist, depending on availability of plant nutrients, temperature, and water stress. When impact assessments combine the effects of increasing temperatures, changing rainfall patterns/amounts and rising CO_2 concentrations, varied results are seen. Three impact assessment studies done on rice crops in South and Southeast Asia are summarized in Table IV. The results of the Matthews et al. (1995) show substantial variation across the entire Asian region among the climate scenarios used. Decreased rice yields are seen for the low-latitude areas, but increased rice yields for higher latitudes. Such results indicate a possible shift in the rice-growing regions away from the equatorial regions to higher latitudes. In the rice-producing countries of China, India, Bangladesh, Japan, South Korea, Malaysia, Myanmar, Philippines and Vietnam, doubled-CO_2 scenarios give results showing positive effects of enhanced photosynthesis, although these are more than offset by the negative effects of increases in temperatures greater than 2 °C (Kropff et al., 1995; Matthews et al., 1995). Additionally, the tea industry (considered as the main source of income) in Sri Lanka is also expected to suffer adverse impacts since the island will experience extreme rainfall intensities and warmer temperatures as a result

TABLE IV
Summary of some recent impact studies in South and Southeast Asia

Study	Scenario	Geographic scope	Crops	Yield impact (%)	Comments
Rosenzweig and Iglesias	GCMs	Pakistan	Wheat	–61 to +67	UKMO, GFDL, GISS, and +2, +4 °C and ±20% precipitation. Range is over sites and GCM scenarios with direct CO_2 effects; scenarios w/o CO_2 and w/adaptation also were considered. CO_2 effects important in offsetting losses of climate-only effects; adaptation unable to mitigate losses
		India	Wheat	–50 to +30	
		Bangladesh	Rice	–6 to +8	
		Thailand	Rice	–17 to +6	
		Philippines	Rice	–21 to +12	
Parry et al. (1992)	GISS	Indonesia	Rice, soybean, maize	Approximately –4, +10 to –10, –25 to –654	Indonesia: low estimates consider adaptation; also estimated overall loss of farmer income ranging from US$ 10 to 130 annually
		Malaysia	Rice, maize, oil palm, rubber	–12 to –22, –10 to –20, increase, –15	Malaysia: maize yield affected by reduced radiation (increased clouds); variation in yield increase; range is across seasons
		Thailand	Rice	5–8	
Matthews et al. (1995)	Three GCMs	India	Rice	–12 to +23	GISS, GFDL, UKMO scenarios; included the direct CO_2 effects; range is across GCMs; varietal adaptation was shown to be capable of ameliorating detrimental effects of a temperature increase in currently high-temperature environments

(*Continued on next page*)

TABLE IV
(*Continued*)

Study	Scenario	Geographic scope	Crops	Yield impact (%)	Comments
		Bangladesh		–12 to –2	GISS, GFDL, UKMO scenarios; included the direct CO_2 effects; range is across GCMs; varietal adaptation was shown to be capable of ameliorating detrimental effects of a temperature increase in currently high-temperature environments
		Indonesia		–6 to +22	
		Malaysia		+21 to +26	
		Myanmar		–9 to +30	
		Philippines		–2 to +12	
		Thailand		–20 to –34	

Source: *Water, Air and Soil Pollution*, vol. 92.

of climate change (Wijeratne, 1996). The Howden et al. (1999) study, however, as reported in the TAR indicate that deleterious effects of higher temperatures could be offset for cropping systems with growth in the cooler months. And, it also appears that there is greater relative enhancement of growth due to increased CO_2 under drier soils.

5.1.3. *Latin America*

Extremes in climate variability already severely affect agriculture in Latin America. There is high confidence that a decreased yield for numerous crops (e.g., maize, wheat, barley) is projected, even when the direct effects of CO_2 fertilization and implementation of moderate adaptation measures at the farm level are considered (IPCC, 2001).

The largest area with marked vulnerability to climate variability in Latin America is northeast Brazil. Periodic occurrences of severe El Niño-associated droughts in northeastern Brazil have resulted in occasional famines (Hastenrath, 1993; Kovats et al., 1999; IPCC, 2001). The Rosenzweig et al. model simulations indicate that any change in climate could mean major consequences in northeastern Brazil. Under doubled-CO_2 scenarios, yields are projected to fall by 17–53%, depending on whether direct effects of CO_2 are considered.

It is also seen that temperature increases in the future could exacerbate losses caused by extreme events and also could offset the positive physiological effects

TABLE V
Assessment of climate change impacts on annual crops in Latin America

Study	Climate scenario	Scope	Crop	Yield impact (%)
Downing (1992)	+3 °C, –25% precipitation	Norte Chico, Chile	Wheat, maize, potato, grapes	Decrease, increase, increase, decrease
Baethgen (1994)	GISS, GFDL, UKMO	Uruguay	Wheat, barley	–30, –40 to –30
de Siqueira et al. (1994)	GISS, GFDL, UKMO	Brazil	Wheat, maize, soybeans	–50 to –15, –25 to –2, –10 to +40
Liverman et al. (1994)	GISS, GFDL, UKMO	Mexico	Maize	–61 to –6
Sala and Paruelo (1994)	GISS, GFDL, UKMO	Argentina	Maize	–36 to –17
Baethgen and Magrin (1995)	UKMO	Argentina, Uruguay (nine sites)	Wheat	–5 to –10
Conde et al. (1997a)	CCCM, GFDL	Mexico (seven sites)	Maize	Increase–decrease
Magrin et al. (1997a)	GISS, UKMO, GFDL, MPI	Argentina (43 sites)	Maize, wheat, sunflower, soybean	–16 to +2, –8 to +7, –8 to +13, –22 to +21

Source: IPCC (2001).

under enriched CO_2 scenarios in some areas. The assessment done on wheat, maize and soybean production under doubled-CO_2 scenario in Brazil by de Siqueira et al. in 1994 predicted declines in yield for the first two crops and −10 to +40% yield for the last one as shown in Table V which summarizes assessments of climate change impacts on annual crops in Latin America.

Information about some cash crops in countries of the Central American isthmus indicate that under current climate conditions, the productivity of banana crops is severely affected particularly in flood-prone areas. These crops could be additionally stressed if climate change-induced variability includes increasing frequency of storms and precipitation (IPCC, 1998).

In addition, for some tropical inlands such as Cook Islands, the possible changes in climate parameters could affect some species/cultivars of crops such as papaya, citrus, and vegetables, which are more sensitive to climate. Increase in sea level can dramatically affect the Islands. They may see greater flooding of by seawater and can cause major damage of agricultural production.

5.1.4. *Uncertainty*

It should be considered, however, the impacts of climate change and variability on agriculture remains uncertain on some extent, not only because of uncertainties in climate projections, but also because the agronomic and economic models used to predict these changes are not perfect. Some models do not include changes in insets, weeds and disease; changes in soil management practices; changes in water supply. Moreover, the magnitude and persistence of effects of increased CO_2 concentration on crop yield under realistic farming conditions, and other uncertainties.

5.2. IMPACTS ON LIVESTOCK

Climate affects livestock in four ways; through the impact of changes on availability and price of feedgrain, impacts on livestock pastures and forage crops, the direct effects of weather and extreme events on animal health, growth, and reproduction, and changes in the distribution of livestock diseases.

For developing countries, the impact of climate variability on livestock is generally negative in the humid and sub-humid tropics, particularly in the latter. For animals, heat stress has a variety of detrimental effects, with significant effects on milk production and reproduction in dairy cows, and swine fertility (Berman, 1991; Hahn and Mader, 1997; Hahn, 1999). Moreover, warming in the tropics during warm months would likely impact livestock reproduction and production negatively (e.g., reduced animal weight gain, dairy production, and feed conversion efficiency) (Klinedinst et al., 1993). Impacts, however, may be minor for relatively intense livestock production systems.

5.2.1. *Africa*

Range-fed livestock in any African region is dependent on annual precipitation. Any change in mean annual precipitation is expected to have a negative impact on pastoral livelihood.

Livestock distribution and productivity could be indirectly influenced by the changes in the distribution of vector-borne livestock diseases (Hulme, 1996). Livestock in humid areas in Africa are prone to diseases such as those carried by the tsetse fly. With warming, its distribution could extend westward in Angola and northeast in Tanzania but with reductions in the prevalence of tsetse in some current areas of distribution. In areas with high moisture content, animal productivity is limited by the protein content of the fodder (Ellery et al., 1996; IPCC, 2001). Protein availability will not increase with the increase in rainfall or the CO_2 concentration, hence livestock would not respond to the direct effects of climate change. Additionally, since even the domestic livestock should be under a certain climate environment for optimal performance, any change that could alter the limits of this climate environment could have an impact on the meat and milk production.

5.2.2. *Asia*

There is very little literature on impact of climate variability and climate change on livestock production in tropical Asia. However, because of the increasing trend for meat consumption, there is a higher demand for livestock feed. Production of feed grain in Asia, especially maize, is adversely affected by climate variability and climate change. Livestock productivity is also highly dependent on the climate environment. Any change that is beyond the limits of the optimal climate environment would impact livestock production.

5.2.3. *Latin America*

Livestock in much of Latin America is raised in rangelands. It is predicted that its production would be negatively affected by increased variability of precipitation since those areas which are drought/flood-prone would be severely affected.

Compared with animals, pastures in the sub-humid tropics are more vulnerable to the climate variability. Rangelands are noted for high climatic variability and high frequency of drought events. They have a long history of human use. The combination of climatic variability and human land use make rangeland ecosystems more susceptible to rapid degeneration of ecosystem properties (Parton et al., 1996). Seasonal water availability and chronically low soil-nutrient availability appear to be the most limiting factors in the pasture of the region (Solbrig et al., 1992). In addition, the already low nutritional value of most tropical grassland and savannas may decrease as a consequence of increased C:N ration (Oechel and Strain, 1985; Gregory et al., 1999). Thus, the carrying capacity for herbivores may be reduced. For example, because of an alteration in the amount and pattern of rainfall, the occurrence of extreme events (e.g., hurricanes, drought), and the ENSO which could become more frequent and bring more severe weather under the $2 \times CO_2$-climate, the northern South America savannas could fail to function as they do now (Aceituno, 1988).

5.3. IMPACTS ON FORESTRY

Tropical forests cover about 1.9 billion ha of the world's surface, representing about 40% of the world's forested area. They contain more than half of all plant and animal species. The impacts of climate change on forests includes to effect forest physiological processes, geographical distribution and biodiversity.

There are different impacts of climate change on forests; some are likely to be detrimental while others can be beneficial. When considered separately, temperature increases could have direct effects on plant growth by changing photosynthesis and respiration rates, and plants can tolerate even extremely high temperatures, provided sufficient water is available (Kirschbaum, 1998). Increasing CO_2 concentration can increase photosynthetic rates and this effect is more pronounced in C_3 plants at higher temperatures and under water-limited conditions. For different combinations of increases in temperature and CO_2 concentration and for systems primarily affected by water and nutrient limitations, different overall effects on plant productivity could be expected.

Most tropical forests are likely to be more affected by changes in soil water availability (e.g., seasonal droughts). Some evergreen species of the humid forest clearly will be at a disadvantage in areas that experience more severe and prolonged droughts. Significantly, drought affects the survival of individual species; those without morphological or physiological adaptations to drought often die. Species in moist tropical forests, including economically important hardwoods, are the least drought-adapted in the tropics, and their survival in some areas must be considered at risk from climate change. Droughts would favor forest fire; therefore, with a likely increase of droughts, the incidence of forest fires may also increase.

Humid and sub-humid tropical forests contain large numbers of insects and pathogens that can cause serious damage to some plant species and may play a role in regulating species diversity. Based on FAO (1997), insect and disease outbreaks are reported mostly for plantation forests; although relatively less is known about these in native forests. Many factors have been associated with the susceptibility of tropical plants to pest and diseases and with the virility of pests and pathogens. Drought stress can sometimes increase host plant suitability, whereas high temperatures and humidities can decrease the growth rate, survival, and fecundity of some insects (IPCC, 1996). Consequently, there is still great uncertainty as to whether the impacts of climate change on the relationship between host plants and pests and pathogens will lead to forest loss or gain.

However, studies show that climate variability also has positive effects on forests. Strong winds associated with tropical cyclones frequently damage tree canopies, but also create gaps in the forest, and modify the forest structure and micrometeorological environment. This may allow more radiation to reach the forest floor, increase soil temperature, and make more soil water and nutrients available, which could promote the growth of new vegetation (IPCC, 1996). The effects in fertilization of elevated CO_2 concentrations are also beneficial to sub-humid and humid forest.

In addition, it should be noted that although climate variability would generally have some negative effects on forests of the humid and sub-humid tropics, the impacts of human activities such as deforestation will be more important than climate change and climate variability in determining natural forest cover. It has been seen that the main causes of deforestation in tropical region are population resettlement schemes, forest clearance for large-scale agriculture, demands of forestry production, and, in particular, shifting cultivation. The rate of deforestation had been highest in Africa (1.7%), followed by Asia (1.4%) and Latin America (0.9%). The areal extent of deforestation, however, was highest in Latin America (7.3 million ha), followed by Africa (4.8 million ha) and Asia (4.7 million ha) (National Research Council, 1993).

5.3.1. *Africa*

The moist tropical forests of the Congo constitute the second most extensive rainforest in the world. A large fraction of the population lives in rural areas, totally dependent on trees and shrubs for their subsistence. Climate change could render vulnerable this large part of the African population.

The following are some of the indicated vulnerabilities in the TAR:

- Dry sub-humid areas have experienced declines in rainfall which result in decreases in soil fertility and range, and forest production.
- Untested assumptions are the transformation of parts of Africa, largely in the sub-humid tropics, into pastures. Increased cattle production means more tree-cutting, which could lead to a number of cascading effects.
- The desertification during the last half of the 20th century have caused a 25–30 km southwest shift in Sahel, Sudan and Guinea vegetation zones at an average rate of 500–600 m per year. This rate could increase further in a CO_2-induced climate change (Davis and Zabinski, 1992; IPCC, 2001).
- Dry woodlands and savannas in sub-humid areas could be subjected to more drying as climate change leads to increasing temperatures. Risks from vegetation fires could also be exacerbated.
- Geographical shifts in the ranges of individual species and changes in productivity are the most likely impacts of CO_2-induced climate change. Research in countries like Senegal has confirmed the retraction of mesic species to the areas of higher rainfall and lower temperature. Meanwhile, simulations of forest species distribution in Tanzania and the Gambia indicate changes from mesic to xeric vegetation in these two countries (Jallow and Danso, 1997).

Floristic biodiversity hotspots could be threatened by shift in rainfall patterns and these include the mountains of Cameroon, the island-like Afromontane habitats that stretch from Ethiopia to the higher latitudes of Africa at altitudes above 2000 m (Mace et al., 1998). Montane centers of biodiversity could be rendered at risk by increases in temperatures because there could be no possibility of migration.

5.3.2. *Asia*

In the developing countries of Asia, sensitivity of natural systems like forests is linked to the projected climate change-induced impacts, the degree to which natural systems have been degraded and the unsustainable utilization of resources. Examples are the increased risks of uncontrolled forest fires due to the conversion of natural forests to palm oil plantations in a number of Southeast Asian countries (e.g., Indonesia). Increase in population often result in the conversion of forest lands to cultivation and more intensive farming. There are also expected impacts on soil erosion, fertility in the soils, depletion of water resources and genetic variability of crops (Sinha et al., 1998; IPCC, 2001).

As many as 16 countries of tropical Asia are situated within the humid tropical forest region. Climate change is expected to affect the boundaries of forest types and areas, primary productivity, species population and migration, the outbreak/incidence of pests and diseases and forest degeneration in these countries.

More than 50% of the world's terrestrial plant and animal species are in the frontier forests in Asia. There already are trends of increasing risks to this rich array of living species being seen in China, India, Malaysia, Myanmar and Thailand partly due to the degeneration of their habitat (IPCC, 2001). Since distribution of species is limited to a narrow range of environmental conditions, there are possibilities that climate change could change these conditions which could result in it being unsuitable. This could cause the loss of a large number of unique species that currently inhabit the world's tropical forests (Kirschbaum, 1998).

With climate change, the distribution of suitable habitat will change. Species will respond individually and differently to environmental changes. For some species, a temperature increase of even 2 °C can change the environment from being suitable to totally unsuitable (Bazzaz, 1998). Species with narrow tolerances are likely to be lost at the expense of species with broader tolerances. For tropical forests, this could lead to the loss of many of these unique species at the expense of those that can tolerate the new conditions or species that have the potential to invade newly suitable habitats (Phillips, 1997; Bawa and Dayanandan, 1998; Bazzaz, 1998) and ultimately, species composition of forests could change.

The fact however remains that tropical forests are currently endangered more by land use practices than by climatic change. Much of the tropical forest is affected by deforestation due to land conversion and increasing resource use (Fearnside, 1995). Large areas of undisturbed forests are being impacted by removal of wood for timber and fuel (Brown et al., 1997). In addition, there are pressures on them through increasing incidence of wildfires (Goldammer and Price, 1998) and ecological threats through habitat fragmentation (Skole and Tucker, 1993) and selective removal of indigenous or introduction of exotic species (Phillips, 1997).

Specific examples of projected impacts on forests in tropical Asia are those seen in studies in Thailand and Sri Lanka. In Thailand, despite the many uncertainties in the models used in the studies, it is seen that climate change could lead to a shift in the boundaries of major forest types in the country (Boonpragob and Santisirisomboon, 1996). Areas of tropical dry forests would appear and there could be an increase in tropical moist and tropical wet forests. A northward shift of tropical wet forests into areas currently occupied by tropical dry forest is also being predicted due to climate change-driven increases in temperature and rainfall in the northern part of the islands. Table VI shows the areas of major forest types in Thailand under current and changed climate conditions.

Similarly in Sri Lanka, climate change would cause a northward shift of tropical wet forests into areas currently occupied by tropical dry forests due to the predicted increase in temperature and in rainfall also in the northern parts of the country (Somaratne and Dhanapala, 1996). The approximate areas of current and potential life zones in Sri Lanka under climate change conditions as a result of the

TABLE VI

Areas of major forest types in Thailand under current and changed climate conditions according to three GCM scenarios

		Climate change area ($\times 10^3$ km^2)		
Forest type	Current area ($\times 10^3$ km^2)	UK89	GISS	UKMO
Subtropical dry forest	5.9 (1.2)	–	–	–
Subtropical moist forest	234.5 (47.7)	87.7 (17.8)	9.5 (1.9)	59.4 (12.1)
Subtropical west forest	22.2 (4.5)	6.6 (1.3)	5.3 (1.1)	1.8 (0.4)
Tropical very dry forest	–	–	11.9 (2.4)	3.0 (0.6)
Tropical dry forest	156.5 (31.8)	218.6 (44.4)	341.3 (69.3)	290.1 (58.9)
Tropical moist forest	71.5 (14.5)	166.8 (33.9)	120.5 (24.5)	128.0 (26.0)
Tropical wet forest	1.6 (0.3)	12.6 (2.6)	3.7 (0.8)	9.9 (2.0)

Source: *Water, Air and Soil Pollution*, vol. 92. Values given in parentheses are percentage.

simulations using the Holdridge Life Zone Classification with current climate and climate scenarios are shown in Figures 2a–2c.

5.3.3. *Latin America*

There have also been a number of natural and human activities that have borne adverse impacts on the forests of Latin America. These could be exacerbated by climate change-driven impacts. A continued conversion of large areas of humid tropical forests to pasture/agricultural activity could reduce water cycles and precipitation in the region. There is high confidence that if extent of deforestation in the Amazonia expands to substantially larger areas, reduced evapotranspiration would lead to less rainfall during its dry periods. If this dry period becomes larger and more severe, it could have deleterious impacts on the forest. Many trees could die due to increased water stress. Greater severity of droughts coupled with deforestation could lead to erosion in what remains of the forests in this region. Moreover, occasional severe droughts likely to occur during the El Niños would kill many trees of susceptible species and would result in a replacement of tropical moist forests with drought-tolerant species (Shukla et al., 1990).

Additionally, it is being projected that human action could now turn even less intensive El Niño events into catastrophes in terms of forest fires because there already have been considerable incursions of these fires into standing forest in the eastern Amazonia during dry years. Previously, burning in the Amazonia forests had been limited to where trees had been felled and the fire had previously stopped upon reaching the edge of the clearing.

There is also medium confidence that increases in the amount of biomass burning could affect nutrient cycling in the Amazonia forest ecosystems, although the extent to which nutrient sources such as smoke and dust could increase the growth of

Amazonia forests is still not known. But as a consequence, forest composition could be altered.

Globally, climate-driven scenarios at doubled-CO_2 concentration point to 10–15% expansion of the area that is suitable for tropical forests with tropical rainforests expanding from 7 to 40% (Solomon et al.), but these simulations have not, however, taken into consideration the influence of human populations. By and large, the combination of forces responsible for continued deforestation may not at all allow tropical forests to expand; although one particular model, which includes climate and human changes, has indicated decreases in forest areas in Latin America by about 5% by 2050 (Zuidema et al., 1994). And for plantation forestry, a major land use in Brazil, climate change could reduce silvicultural yields due to changes in water availability, spawning adverse impacts on pests and fire hazards.

Latin America accounts for one of the Earth's largest concentrations of biodiversity, and the impacts of climate change can be expected to increase the risk of biodiversity loss with high confidence (IPCC, 2001). The remaining Amazonian

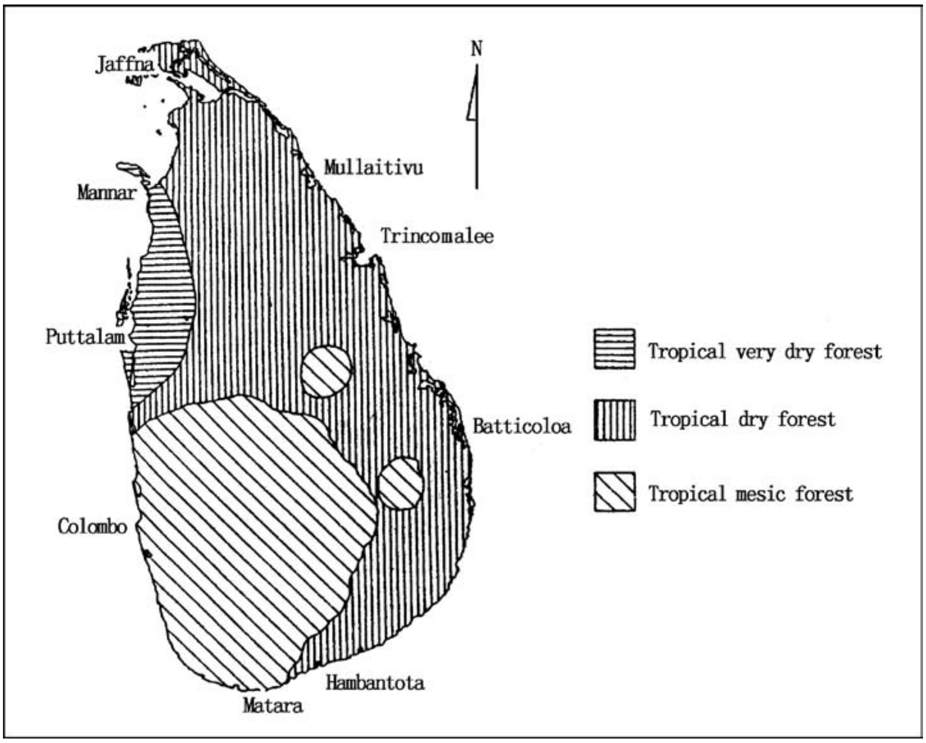

Figure 2. (a) Holdridge life zones of Sri Lankan forests under current climate conditions. (b) Holdridge life zones of Sri Lankan forests under CCCM derived climate change scenarios. (c) Holdridge life zones of Sri Lankan forests under GFDL derived climate change scenarios.

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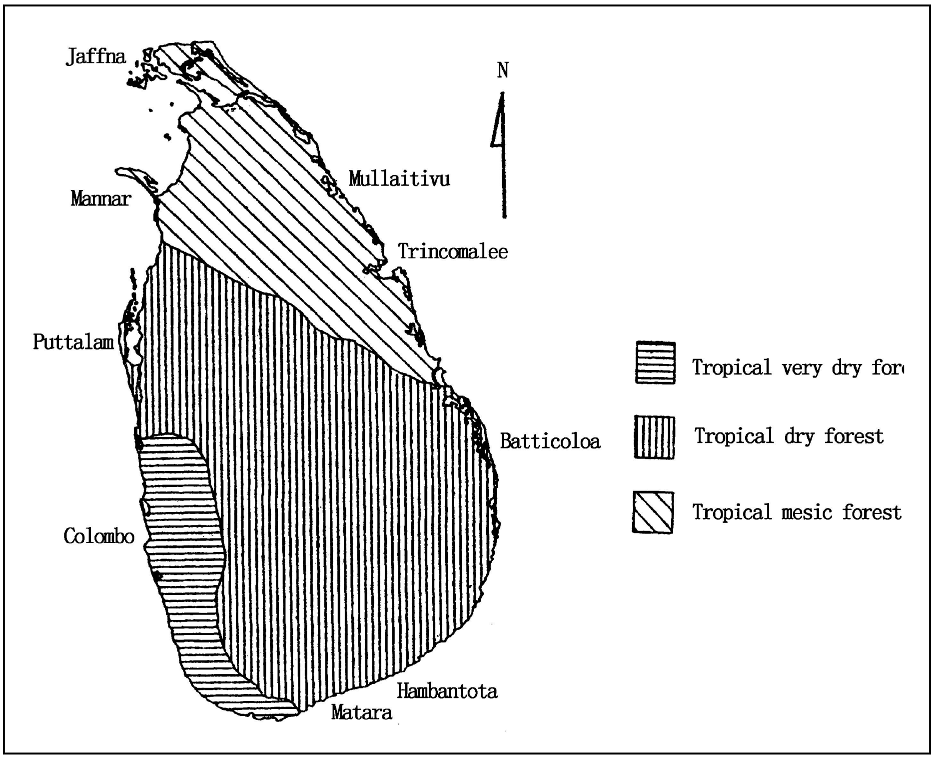

Figure 2. (*Continued*)

forest is threatened by the combination of human disturbance, increase in fire frequency and scale, and decreased precipitation from evaportranspiration loss, global warming, and El Niño.

5.4. CASE STUDIES

5.4.1. *Philippines*

Philippines lies at the western rim of the Pacific Ocean and just off the southeastern portion of the Asiatic continent. It consists of approximately 7100 islands and islets distributed over an area from 4.7 to 22.5 °N and about 117 to 127 °E. It has relatively warm temperatures and mean annual rainfall ranging from 2000 to 4000 mm. Extreme climate events consist an inherent component of Philippine climate system and natural hazards due to these extreme events are strong winds, storm surges, floods, and droughts. And like its neighboring countries, it is much affected by ENSO events.

5.4.1.1. *Impacts of Climate Variability on Philippine Agriculture.* Agriculture is the economic lifeline of Philippines. Total agricultural land amounts to about 10

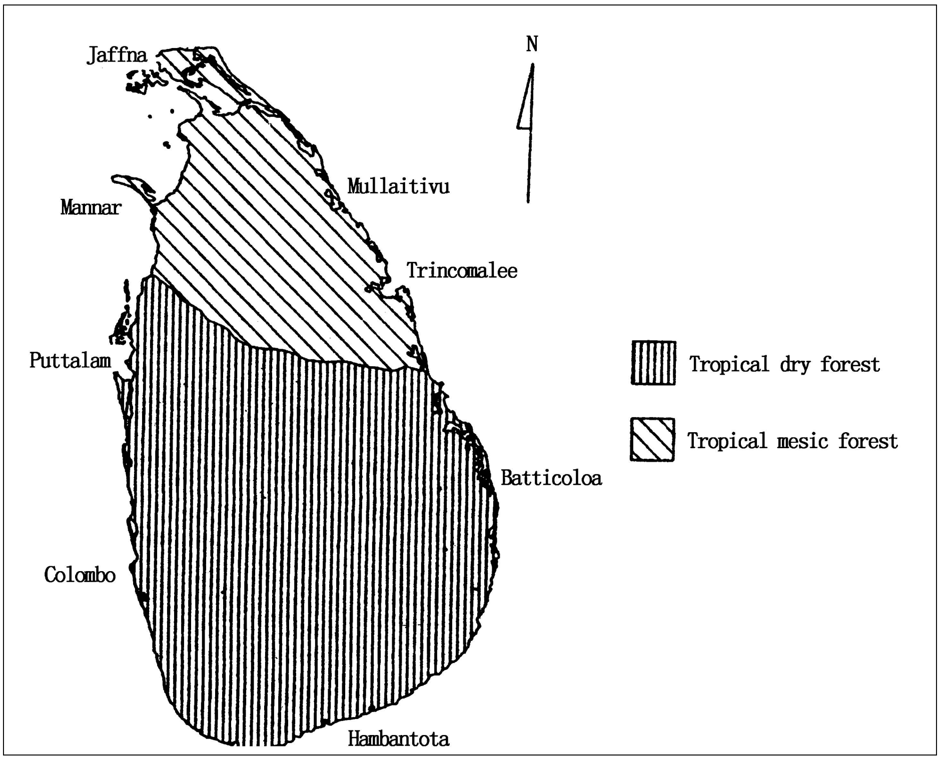

Figure 2. (*Continued*)

million ha, 45% of which is located in lowlands and 33% in the uplands. Rice and corn, being the country's staple food, remain its most important crops. Coconut, sugarcane and some cash crops like bananas constitute important export commodities. Rice production plays a dominant role in Philippine agriculture and its economy as a whole. Rice production growth rate has been pegged at 2.33% annually. However, population growth rate has been estimated to be 2.4% per annum, so that Philippines will most likely continue to depend on rice imports for about 5% of its national requirements.

There are also a number of non-climate factors which could affect the degree of vulnerability of the sector. These include population growth, land use conversion that leads to depletion of agricultural/riceland areas, inadequate development of irrigation facilities, deterioration of agricultural resources and the country's entry into international economic agreements.

In the documentation and analysis study (PAGASA, 2001) conducted to determine the impacts of and responses to extreme climate events during the 1961–2000 period, the following results are indicated:

- Declines in GVAs (defined as differences between *gross outputs* or gross value of the good and services produced during the accounting period and the

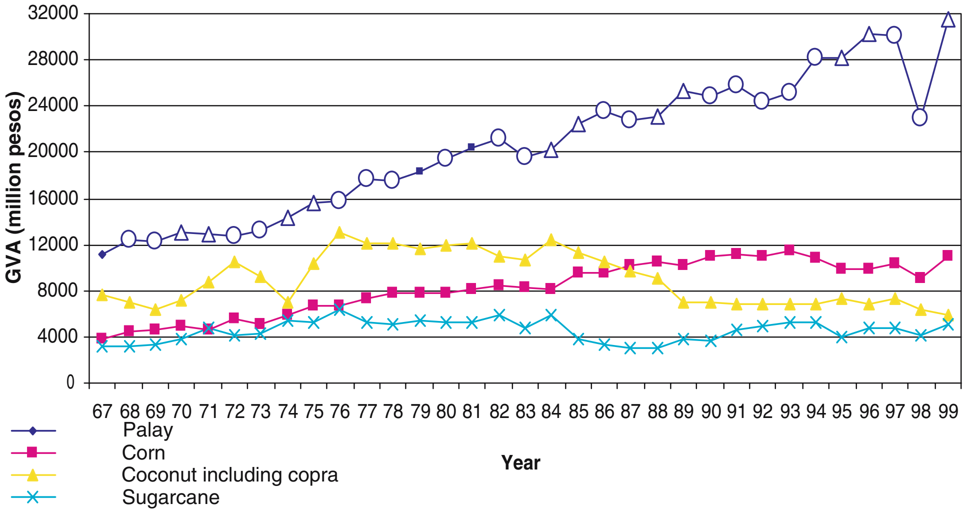

Figure 3. Gross value added in four principal crops at constant 1985 prices.

intermediate outputs or value of goods and services such as raw materials and supplies, fuel, etc. used in the production process during the accounting period estimated at constant 1985 prices) and in volume of production in four principal crops namely rice, corn, sugarcane and coconut, generally coincide with El Niño years; while the increases concur with La Niña years (see Figure 3). Sharpest falls in GVAs and volume of production in the agricultural sector had been in 1982–1983 and 1997–1998, the periods, which saw the birth, peaks and decay of the two strongest El Niños of the 20th century. On the other hand, increases in GVAs in rice and corn had been attributed mainly to favorable rainfall conditions during the La Niña years.

- Livestock and poultry as a sub-sector had not been sensitive to extreme climate events as shown in Figure 4; although, at the farm level, there could have been impacts of climate variability/extreme events.
- Some third-order impacts had also been indicated such as shortfalls in the projected annual economic growth due to dips in the agricultural growth rates, increased burden on urban resources as a result of the migration of displaced agricultural workers to the cities for jobs and/or increased dependence of these workers on government aid, worsening poverty situation, etc.

5.4.1.2. *Impacts of Climate Change on Philippine Agriculture.* Projected impacts as a result of enriched CO_2 concentration will range from a likely intensification of the degradation of soil and water resources due to increases in temperature and changes in precipitation. There could be decreases in agricultural productivity due to thermal (temperature/heat increases) and water stresses. Increased intensity of rainfall would increase flood risks and would therefore cause an increase in

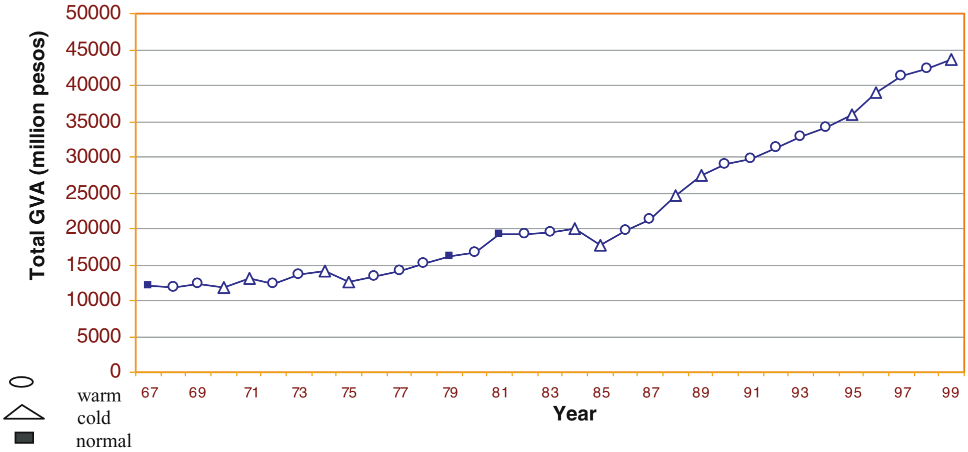

Figure 4. Gross value added in poultry and livestock at constant 1985 prices.

production losses; and there would be more declines in crop yields if frequency and intensity of El Niño events increase. Incidence of pests and diseases is also likely to increase and could cause more negative impacts. Tropical cyclones would diminish food security if their intensities and peak winds increase.

There would be more consistent yield losses from climate change if no adaptation measures are put in place. However, there could be increases in rice yields, provided correct management and farm practices are put in place.

Vulnerability assessments done on rice and corn production using global circulation models (GCMs) to give simulations of climate change scenarios and process-based crop models gave varied results.

Simulations showed, generally, increases in rice yield except for those scenarios generated by the GISS model, but decreases in corn yield (Centeno et al., 1995; Buan et al., 1996). Assessments done by Escaño and Buendia at the International Rice Research Institute, as part of the Rosenzweig and Iglesias study in 1994 gave varied results. Changes in rice yields varied from a decrease of 21% to an increase of 12%, depending on the GCM and the site used. Results of the simulations employing adaptation options showed adaptation was unable to mitigate losses. The Centeno et al. study simulated potential rice yields in 16 sites using the ORYZA1 rice crop model under various scenarios of changed climate. Results were a yield increase of about 30% at doubled-CO_2 with no temperature increment, decreased yields with increasing temperatures but at current levels of CO_2 and more pronounced decreases during the dry season due to the already high temperatures, usually prevailing during this period, and decreases in yield in all increments of CO_2 concentration in both seasons and with a +4 °C increase in temperature.

The projected rice yields over all sites and all seasons under climate change were computed. Overall, it was predicted that the national rice production of the country would change by +6.6, –14.0 and +1.1% for the GFDL, GISS and UKMO doubled-CO_2 scenarios respectively as could be seen in Table VII.

TABLE VII
Estimated changes in rice production in each administrative region and in the whole Philippines

		GFDL		GISS		UKMO	
Region	Current (t)	% Change	t	% Change	t	% Change	t
NCR	152,559	2.6	156,476	–11.1	135,669	16.9	178,319
I	898,584	–3.8	864,238	–17.0	745,538	2.2	918,241
II	1,033,615	–3.8	994,108	–17.0	857,571	2.2	1,056,226
III	1,748,491	2.6	1,793,379	–11.1	1,554,911	16.9	2,043,730
IV	1,118,085	10.2	1,232,604	–6.2	1,048,730	–0.4	1,113,437
V	744,223	5.4	784,357	–32.0	506,260	–20.5	591,716
VI	1,183,887	11.9	1,324,583	–11.1	1,053,064	–7.4	1,096,816
VII	207,700	11.9	232,384	–11.1	184,749	–7.4	192,424
VIII	382,954	11.9	428,465	–11.1	340,637	–7.4	354,789
IX	399,038	18.5	473,040	5.7	421,617	11.1	443,166
X	531,777	10.5	587,861	–22.1	414,386	–39.5	321,605
XI	688,302	13.3	779,593	–16.9	571,880	–1.4	678,580
XII	584,047	13.3	661,510	–16.9	485,259	–1.4	575,798
Total	9,673,262		10,312,598		8,320,271		9,564,847
% Change from current			6.6		–14.0		–1.1

Source: IRRI (1995).

Further analysis was done using a number of adaptation strategies which include changing planting dates, applying irrigation, employing more site-specific fertilizer management, etc. For rice, yields would definitely increase when planted in some suitable times of the year, especially with the application of irrigation and the more site-specific crop and soil management. Corn yield, however, would be more negatively affected.

These simulation results, however, could only serve as a range of what could be expected inasmuch as there are inherent limitations in the climate scenarios and in the process-based crop models used. For instance, the Buan et al. (1996) model did not consider the effect of extreme climatic events, including that of strong winds due to tropical cyclones. Moreover, one of the assumptions made was that the soil conditions during the simulations are the same even when CO_2 is doubled.

What is certain though is that when the agricultural sector in any local area has already been rendered vulnerable by increasing climate variability, including occurrences of extreme events, and other non-climatic factors like increasing population, diminished/degraded agricultural areas and ineffective/insufficient agricultural support services such as lack of irrigation facilities, the projected adverse impacts will certainly contribute to decreases in crop yield.

5.4.1.3. *Impact of Climate Variability on Philippine Forest Resources.* Philippine forests can equal any of those in many areas of the tropics in terms of diversity. Indigenous flowering plants are estimated to be around 8000 species, belonging to almost 6500 genera and 20 families. They contain quite a diverse collection of plants and animals; thus, there is a gene pool of living organisms with a value that could exceed much beyond its current market price.

Forest-based industries used to constitute a major contributor to the country's GNP for three decades from the 1950s until the 1970s. With the massive deforestation that had taken place over a number of years, its contribution had come down to only 0.18% in 1995. Yet, it remains a major source of income for many upland dwellers, including a good number of indigenous tribes. More than 9 million people are estimated to inhabit the forestlands, where they marginally subsist through cultivation and utilization of the already degraded forest resources. Forest-based industries continue to generate more than 300,000 employment opportunities, not including those who are employed in downstream industries. Any further deterioration of the forest resources is certain to diminish these opportunities and will not augur well for those who inhabit these lands and depend on them for subsistence.

Results of the study done by Cruz, in 1997, indicated that forest resources which are already highly vulnerable are timber, water and biodiversity. Timber resource is already highly depleted due to a number of pressures. Among these is climate variability, both directly and indirectly. For example, excessive floods have caused soil erosion which ultimately has degraded the land. Also, when man gets little harvests from upland cultivation, he is driven to scavenge wood products/wood which could augment his income. Similarly, water resource has been highly degraded due to the denudation of watershed forest cover. Many watersheds are already suffering from non-climate factors like destructive cultivation, encroachment and improper management, and from climate-related pressures such as excessive soil erosion and surface runoff due to floods.

Biodiversity in many of the country's forested areas may have been affected by natural variability of climate because prolonged dry periods may have threatened some species. When climatic factors combine with untenable practices like excessive logging and lack of protection and unsustainable management, then local biodiversity becomes at risk. Forest boundaries in the country may also have been changed due to prolonged dry periods during El Niño events. Droughts have been known to cause significant damages to the productivity and biological integrity of forest ecosystems.

Furthermore, the documentation and analysis of impacts of extreme climate events on the environment sector (PAGASA, 2001) indicate that forest fires due to El Niño events pose a threat to the remaining forest reserves. Figure 5 shows the forest fire destruction in the country. Areas damaged by forest fires were extensive during the 1982–1983, 1991–1992 and 1997–1998 El Niño events because of the prolonged dry spell.

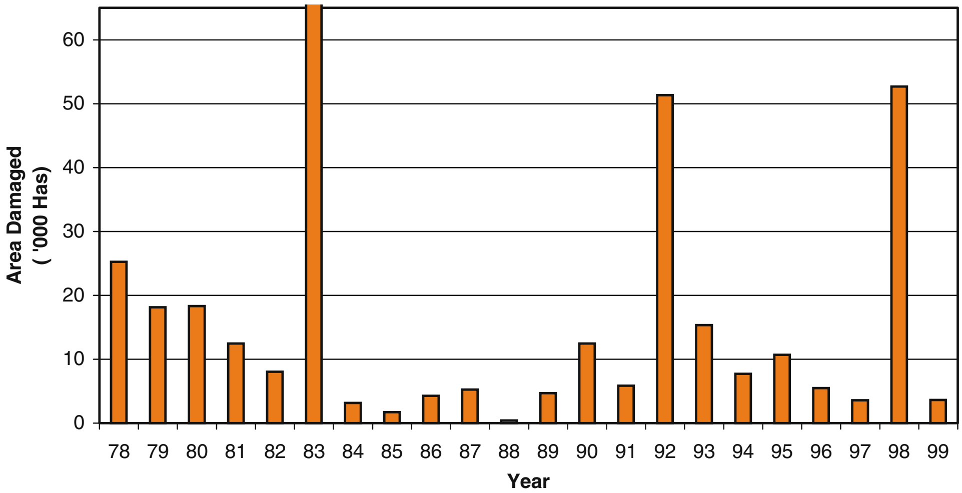

Figure 5. Extent of forest fire destruction in Philippines (1978–1999).

5.4.1.4. *Impacts of Climate Change on Philippine Forest Resources.* In the case of Philippine forestry sector, no simulation studies have been made yet, although there is now an on-going 3-year integrated assessment of watersheds. The initial vulnerability assessment done was based on the current projections and IPCC assessment reports for Asia and two national studies (that of Thailand and of Sri Lanka) because of resource constraints. Results of the related regional and national studies were used as analogues of the potential impacts of future climate change on Philippine forests. Changes expected to happen in Philippine forests include the likelihood of the expansion of its rainforests as temperature is expected to increase substantially, along with modest increase in precipitation in many areas which already get excessive moisture. On the other hand, the generally increasing trend in precipitation especially during the wettest months will possibly cause serious soil erosion and flood problems in currently denuded forests and watersheds which are dominated by grasses. This could exacerbate the declining productivity of these denuded watersheds and the downstream areas that act as repository of silt transported by surface runoff and streamflow. However, in areas where temperature is expected to increase significantly but rainfall is projected to remain unchanged or even decrease, the expected loss in forested areas may be small. This, however, may lead to the loss of a few species of plants and animals that can significantly erode the biodiversity in these areas and also in the forest in the adjacent areas. And because climate change could exacerbate the loss of local biodiversity already brought about by other pressures through extinction and inhibition of re-immigration from adjacent areas, the greatest impacts are on those whose subsistence depends on the goods and services these forest resources provide.

Additionally, the increase in the frequency of drought/floods due to changes in El Niño will likely render many areas currently under cultivation unfit for agricultural production. Population growth and shrinking arable lands could increase the pressure of forested areas to be converted, thereby challenging the protection of the remaining natural forests. Grasslands and other areas dominated by shrub and shrub species could become more vulnerable to fire with the increase in temperature and the inadequate increase or even marked decrease and rainfall. This could be further aggravated by any prolonged dry periods which are bound to happen during El Niños. Frequent fires could make these areas more difficult to rehabilitate.

Any changes in temperature and precipitation may result in the outbreak of pests and diseases. This can significantly change the species composition, structure and functions of forest ecosystems in ways similar to the disturbances that come about through forest destruction by man.

5.4.2. *Malaysia*

Malaysia sits on the South China Sea at the center of Southeast Asia. The country is crescent-shaped, starting with Peninsular Malaysia (West Malaysia) and extends to another region, Sabah and Sarawak (East Malaysia), located on the island of Borneo. The total area of Malaysia is approximately 330,000 km^2, with most of it island of Borneo. Peninsular Malaysia comprises approximately only 40% of the total area.

Peninsular Malaysia is located entirely within the equatorial zone. It had 82% of the nation's population in 1990. Economic activity accounted for 84% of Malaysia's gross domestic product in 1987, and 74% of Malaysian land in agricultural use was in Peninsular Malaysia in 1990. Tree crops represent the principal agricultural land use in Peninsular Malaysia. Rubber, oil palm, coconut, and cacao accounted for 83% of the area devoted to agriculture in 1988. Agriculture (including forestry and wood products) is a major sector of Peninsular Malaysia's economy and is important on a global scale as well. Malaysia is the world's largest producer and exporter of natural rubber, palm oil, and tropical logs and sawn wood.

Malaysia's climate is hot and humid with relative humidity ranging from 80 to 90%, except in the highlands. The temperature averages from 20 to 30 °C throughout the year. The tropical climate is experienced year-round with the rainy season varying on the coasts of Peninsular Malaysia. The west coast has its rainy season from September through December with the east coast (and Sarawak and Sabah) experiencing it from October through February. East Malaysia (the northern slopes) gets up to 5080 mm of rain a year *versus* West Malaysia's 2500 mm. There exists the possibility of drought in West Malaysia (i.e., Peninsular Malaysia which is the major agricultural area) although the weather disaster of Malaysia is floods.

There are forests covering over half of Malaysia, with notable tropical forests in Sabah and Sarawak. Deforestation is a problem the country is dealing with due to logging and hydroelectric projects.

5.4.2.1. *Climate Change and Variability in Malaysia.* Like many countries in the world, temperature records in Malaysia in the last 50 years have shown warming trends (see Figure 6). Climate change may bring about an increase in the frequency

TABLE VIII
Climate change scenarios for Malaysia

	2020	2040	2060
Northern hemisphere summer			
Changes in temperature	+0.3to + 1.4 °C	+0.4to + 2.4 °C	+0.6to + 3.4 °C
Changes in rainfall	–0.4 to +14%	–0.7 to +23%	–1.0 to +32%
Northern hemisphere winter			
Changes in temperature	+0.4 to +1.9 °C	+0.7 to +3.2 °C	+1.0 to +4.5 °C
Changes in rainfall	–4.0 to +7.0%	–7.0 to +12%	–10 to +17%

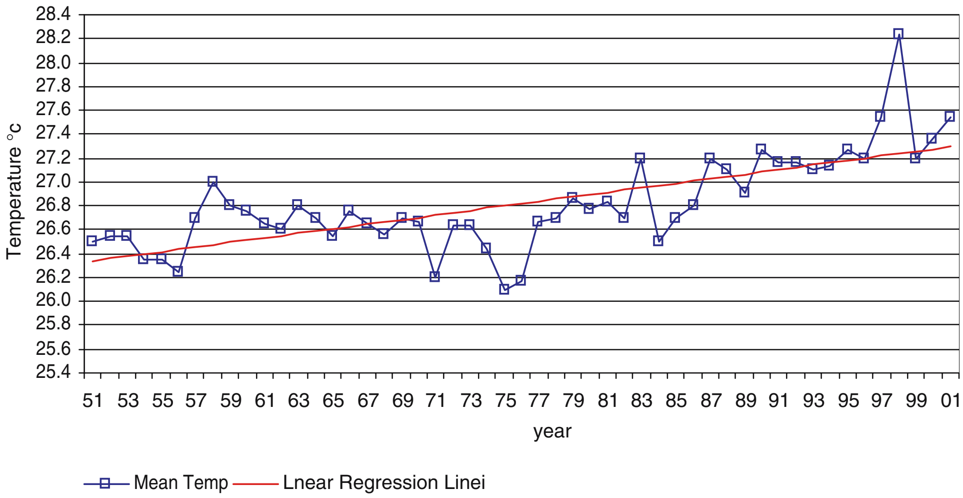

Figure 6. Temperature records in Malaysia in the last 50 years.

and intensity of extreme weather events, such as, drought, storms and floods. There is still, however, insufficient data to determine whether the frequency of extreme events has indeed increased. It has been observed that, since 1977, there have been more frequent ENSO warm phase episodes. This behavior, especially the persistent warm phase from 1990 to mid-1995, was unusual in the last 120 years and significantly influenced rainfall in Malaysia.

Table VIII is the climate change scenarios for Malaysia. Generally, the temperature will increase; rainfall may increase probably, but there exists possibility of some decreases. The impacts of climate change on Malaysia agriculture are estimated based on the combinations of higher temperature and increasing rainfall, and higher temperature and decreasing rainfall.

5.4.2.2. *Impacts of Climate Change and Variability on Malaysia Agriculture.* Most of the materials for this case study are drown from the Malaysia initial National Communication as an output of the UNDP/GEF Project: Enhancement of Technical

Capacity to Develop National Response Strategies to Climate Change.

(1) *Impacts on rubber.* Rubber flourishes in a tropical climate with a high mean daily air temperature of between 25 and 28 °C and high rainfall exceeding 2000 mm per year. Even distribution of rainfall with no dry seasons exceeding 1 month and at east 2100 h of sunshine per year are ideal conditions for growing rubber. The following impacts of climate change on rubber are expected:

- If the mean daily air temperature increases by 4.5 °C above the mean annual temperature, more dry months and hence more moisture stress can occur. A crop decrease of 3–15% due to drought conditions is projected if mean annual temperature increases to 31 °C. The degree of yield decrease will be dependent on clonal susceptibility, as well as the length and severity of the drought.
- Based on the above climate change scenario, some states may experience a reduction in production. It is projected that 273,000 ha of land, or 15% of current rubber land, may be affected. With the availability of higher yielding clones and improved cultural practices, this impact, however, may be minimized.
- If rainfall increases, loss of tapping days and crop washout occur. As a result, yielding losses can range from 13 to 30%. Thus, if the number of rain days were to increase, then most parts of the country will suffer from rainfall interface with tapping.
- If sea level rises by 1 m, low-lying areas may be flooded. Rubber cultivation in these areas would not be possible.

Table IX shows the projected rubber yield in relation to climate change over time.

(2) *Oil palm*. Oil palm is best suited to a humid tropical climate in which rain occurs mostly at night and days are bright and sunny. For optimum yield, minimum monthly rainfall required is around 1500 mm with absence of dry seasons, and an evenly distributed sunshine exceeding 2000 h per year. A mean maximum temperature of about 29–33 °C and a mean minimum temperature of 22–24 °C favor the highest bunch production.

- A high mean annual temperature of 28–31 °C is favorable for high production. If these higher temperatures lead to drought conditions, however, an estimated 208,000 ha of land or 12% of the present oil palm areas would be considered marginal-to-unsuitable for oil palm cultivation, particularly in drought-prone areas.
- Increased rainfall favors oil palm productivity unless it leads to flooding. With an anticipated sea level rise of 1 m, an estimated 100,000 ha of area, currently planted with oil palm, may be deemed unsuitable and would have to be abandoned.

TABLE IX
Projected rubber yield with climate change

Year 2020			
CO_2(ppm)	400	400	400
Temperature Increase °C	0.3	0.85	1.4
Rainfall change (%)			
+14%	1.26	1.26	1.23
+7%	1.44	1.44	1.42
+0.4%	1.60	1.60	1.60
0%	1.60	1.60	1.60
−0.4%	1.60	1.60	1.60
−7%	1.55	1.55	1.54
−14%	1.46	1.46	1.44
Year 2040			
CO_2(ppm)	600	600	600
Temperature Increase °C	0.4	1.4	2.4
Rainfall change (%)			
+23%	1.42	1.42	1.42
+11%	1.53	1.53	1.53
+0.7%	1.80	1.80	1.80
0%	1.80	1.80	1.80
−0.7%	1.80	1.80	1.80
−11%	1.69	1.69	1.69
−23%	1.53	1.53	1.49
Year 2060			
CO_2(ppm)	800	800	800
Temperature Increase °C	0.6	2	3.4
Rainfall change (%)			
+32%	1.40	1.40	1.40
+15%	1.58	1.58	1.58
+1%	2.00	2.00	2.00
0%	2.00	2.00	2.00
−1%	2.00	2.00	1.82
−15%	1.80	1.78	1.72
−32%	1.60	1.60	1.52

Table X shows the projected oil palm yield in relation to climate change. It can be seen that a decrease in rainfall affects yield significantly.

(3) *Cocoa*. Although cocoa is planted in areas where annual rainfall is in the range of 1250–2800 mm, it prefers areas where annual rainfall is in the range of 1500–2000 mm and the number of dry months is three or less. It should not be

TABLE X
Projected oil palm yield with climate change

Year 2020			
CO_2(ppm)	400	400	400
Temperature Increase °C	0.3	0.85	1.4
Rainfall change (%)			
+14%	21.5	21.5	21.5
+7%	23.0	23.0	23.25
+0.4%	22.5	22.5	22.75
0%	22.0	22.0	22.0
−0.4%	22.0	22.0	22.0
−7%	17.6	17.6	17.0
−14%	15.4	15.4	15.4
Year 2040			
CO_2(ppm)	600	600	600
Temperature Increase °C	0.4	1.4	2.4
Rainfall change (%)			
+23%	24.0	24.0	24.0
+11%	25.0	25.0	25.0
+0.7%	24.5	24.5	24.5
0%	24.0	24.0	24.0
−0.7%	23.5	23.5	23.0
−11%	19.2	19.2	18.7
−23%	15.6	15.6	14.9
Year 2060			
CO_2(ppm)	800	800	800
Temperature Increase °C	0.6	2	3.4
Rainfall change (%)			
+32%	26.0	26.0	26.0
+15%	27.0	27.0	26.0
+1%	26.0	26.0	25.0
0%	26.0	26.0	26.0
−1%	24.0	24.0	22.0
−15%	18.0	18.0	15.6
−32%	14.3	14.3	13.0

planted in areas with annual rainfall below 1250 mm, unless irrigation is provided. Areas with annual rainfall exceeding 2500 mm are also not favorable as it reduces yield by 10–20% due to water logging. Besides, the excessive rainfall causes high disease incidence, especially Phytophthora and pink diseases.

- Most of the cocoa-growing areas have maximum temperature ranges of 30–32 °C and minimum temperature of 18–21 °C. The temperatures in Malaysia is within this range throughout the year. The temperatures exceeding 32 °C may result in moisture stress, leading to yield of 10–20%.
- Based on these considerations, the states that experience a distinct dry season are marginal areas for cocoa cultivation. Irrigation is required in these areas if cocoa is to be cultivated.
- Some areas, which register high rainfall, are not suited for cocoa cultivation due to the high incidence of diseases. This can result in yield loss of more than 20%.
- With climate change, a high incidence of drought is expected to reduce yield. On the other hand, excessive rainfall with reduced insolation can also result in low yields. In addition, under such weather conditions, a high incidence of fungal diseases such as vascular streak disease and black pod can depress yields.

Table XI shows that cocoa yield is sensitive to both excessive and reduced rainfall. In both cases, the yield is decreased.

(4) *Rice*. Rice constitutes 98% of total cereal production in Malaysia. Generally, long periods of sunshine are favorable for high rice yields. Growth is optimal when the daily air temperature is between 24 and 36 °C. The difference between day and night temperatures must be minimal during flowering and grain production.
Climate change can affect rice production in the following ways:

- Grain yields may decline by 9–10% for each 1 °C rise in temperature.
- If drought conditions are prolonged, the current flooded rice ecosystem can not be sustained. It may be necessary to develop non-flooded and dry land rice ecosystem to increase the level of national rice sufficiency.

National food security may thus be threatened in both cases. Table XII shows that rice yield is sensitive to climate change.

5.4.2.3. *Impacts of Climate Change on Forestry.* Table XIII shows the impacts of climate change on forests in Malaysia by examining its physiological process, geographical distribution and biodiversity.

(1) *Physiology of the forest*. Several climate variables such as air temperature, moisture availability and the concentration of ambient CO_2 have direct effects on forest physiology, depending on the species, location, nutrient levels of the soil and the other environmental conditions. Current scientific understanding indicates that elevated CO_2 concentrations may lead to increased biomass growth by as much as 40%, resulting from stimulated photosynthesis, leading

TABLE XI
Projected cocoa yield with climate change

Year 2020			
CO_2(ppm)	400	400	400
Temperature Increase °C	0.3	0.85	1.4
Rainfall change (%)			
+14%	1.86	1.59	1.54
+7%	2.10	1.85	1.79
+0.4%	3.10	2.65	2.56
0%	3.10	2.65	2.56
−0.4%	3.10	2.65	2.56
−7%	2.79	2.39	2.30
−14%	2.79	2.39	2.30
Year 2040			
CO_2(ppm)	600	600	600
Temperature Increase °C	0.4	1.4	2.4
Rainfall change (%)			
+23%	1.55	1.33	1.02
+11%	2.17	1.86	1.44
+0.7%	3.10	2.65	2.05
0%	3.10	2.65	2.05
−0.7%	3.10	2.65	2.05
−11%	2.79	2.39	1.85
−23%	2.48	2.12	1.64
Year 2060			
CO_2(ppm)	800	800	800
Temperature Increase °C	0.6	2	3.4
Rainfall change (%)			
+32%	1.33	1.25	0.95
+15%	1.59	1.50	1.14
+1%	2.65	2.50	1.90
0%	2.65	2.50	1.90
−1%	2.65	2.50	1.90
−15%	2.39	2.25	1.71
−32%	1.59	1.50	1.14

to in increased concentrations of CO_2 inside the leaves. On the other hand, higher CO_2 level may reduce the nitrogen to carbon ration in plant tissue that may affect the rate of litter breakdown. Trees in the forest also respond positively to temperature increase; the temperature and primary productivity

TABLE XII
Projected rice yield with climate change

Year 2020			
CO_2(ppm)	400	400	400
Temperature Increase °C	0.3	0.85	1.4
Rainfall change (%)			
+14%	6.15	5.81	5.59
+7%	6.65	6.31	6.09
+0.4%	7.20	6.86	6.64
0%	7.20	6.86	6.64
−0.4%	7.20	6.86	6.64
−7%	6.67	6.38	6.18
−14%	6.19	5.90	5.71
Year 2040			
CO_2(ppm)	600	600	600
Temperature Increase °C	0.4	1.4	2.4
Rainfall change (%)			
+23%	7.34	6.94	6.54
+11%	8.20	7.80	7.40
+0.7%	9.04	8.64	8.24
0%	9.04	8.64	8.24
−0.7%	9.04	8.64	8.24
−11%	8.05	7.69	7.34
−23%	6.96	6.65	6.35
Year 2060			
CO_2(ppm)	800	800	800
Temperature Increase °C	0.6	2	3.4
Rainfall change (%)			
+32%	8.62	8.06	7.50
+15%	9.83	9.27	8.71
+1%	10.96	10.4	9.84
0%	10.96	10.4	9.84
−1%	10.96	10.4	9.84
−15%	9.32	8.84	8.37
−32%	7.45	7.07	6.69

are positively correlated by this and depend on the availability of water, which is in turn is dependent on rainfall distribution.

(2) *Forest distribution*. Given the temperature and CO_2 concentration projections of some global climate models, the expansion of upland forest by 5–8% may be expected. This would however be nullified by a loss between 15 and 20% of mangrove forests located along the coastline as a result of sea level rise. The

TABLE XIII
Impacts of climate change on forests in Malaysia

Process/habitat	Impacts
Physiological process	Up to 40% increase in biomass growth due to increase in photosynthesis processes
Forest distribution/habitat	
Upland tropical rainforest	Expansion of suitable forest areas by 5–8%
Mangrove forest	Reduction in mangrove area by 15–20% due to sea level rise
Forest plantation	Minimal impacts due to its limited area
	Increased susceptibility to pest and infestation of diseases
	Increased fire occurrence

problem of climate-change-induced disease infestation in forest plantation species may also occur.

Forest biodiversity. Tropical forests in Malaysia are rich in diversity, and therefore, the impacts of climate change on biodiversity are of great concern. The change in the climate has likely effects on species composition of the forest, but marked variations are expected due to local effects of soil and topography. Given the intricate interrelationships between plant and animal species in tropical forests, the impact on any species will have inevitable consequences for other species as well.

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