.IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 5: Food, Fibre and Forest Products

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Executive Summary

[CLA note: this section is simply a cut and paste of the conclusions and will be condensed to approximately a page of major findings and conclusions for the next draft.]

Important findings of the chapter are:

- The impact of climate change on food security should be seen against the expected long-term developments in the overall economy (e.g. on average strong increase in purchasing power), its sectoral composition (e.g. declining share of agriculture) and related characteristics (e.g. less people dependent on agriculture and less dependence on natural resources).
- A large number of short-term responsive (or autonomous) adaptations are possible in cropping systems. Many of these are extensions of existing risk management activities. The potential effectiveness of the adaptations varies from only marginally reducing negative impacts to more than fully offsetting them. The likely adoption rate of these adaptations is uncertain.
- Research on fibre crops in rural economies, such as Jute and Kenaf, is lacking.
- The outcome of future increases in CO_2 levels favouring C3 over C4 crop and forage plants versus temperature increases favouring C4 over C3 plants is not clear.
- Because forestry is already in a transition toward the establishment of planted forests, management can assist natural processes in restructuring forest composition and harvest practices that are consistent with regional climate changes.
- Natural adaptation of fisheries to climate change may result from selection of tolerant strains, but these are most likely to occur at the edges of ranges, which are most vulnerable to being depletion by overexploitation
- Increasing the capacity of subsistence, small-holder and pastoral agriculture households to respond to climate variability and climate change will largely depend on improvements in institutions and policy, including increased understanding of subsistence agriculture by policy-makers, improved management of agricultural knowledge, and more secure property rights

It is concluded with *high confidence*:

Food crops and livestock

- In the short-term, impacts of climate change on food crops are more severe in the equatorial and dry tropics than in temperate latitudes; Potential negative yield impacts are particularly pronounced in several regions where food security is already challenged and where the underlying natural resource base is already poor. Medium and longer term (2050 and beyond) impacts are uniformly stressful to crop yields globally.
- International agricultural trade flows are foreseen to rise dramatically (even in the absence of further trade liberalization or climate change). The impact of climate change would lead to an increased flow of temperate products (e.g. cereals and livestock products) from the temperate countries to tropical countries. More economic equilibrium analyses with explicit account of trade, show that inter-regional and international trade generally mitigate impacts of climate change.
- Under optimal conditions doubled CO_2 increases leaf photosynthesis by 30-50% in C3 plant species and by 10-25% in C4 species. In terms of final food, fodder, fibre and wood products, the range of observed responses under elevated CO_2 is larger, about 0-50%, due to species, sector and management regimes interactions, modulating optimal leaf responses; Elevated CO_2 will shift current photosynthetic optima towards higher

temperatures; and increase stomatal resistance, improving water-use efficiency and drought resistance. In the field many factors such as soil and water quality; pests and disease, and resource competition reduce gains observed in experimental settings.

- Elevated carbon dioxide levels will alter food quality to grazers both in terms of fine-scale (protein content, C/N ratio) and coarse-scale (C-3 versus C-4 and versus pasture legume) changes;
- Plant species composition change induced by climate change will be an important mechanism altering pasture production and its value for grazing livestock, especially in drier rangelands with woody shrub invasion and in warm humid climates with C_4 invasion;
- The heat stress of domestic animals will also increase (High confidence) as well as the death rate in drought prone areas (Medium confidence). The impact on animal productivity due to increased variability in weather patterns will likely be far greater than effects associated with the average change in climatic conditions (High confidence)
- Observed recent increases in temperature are extending growing seasons in temperate and boreal ecosystems.
- The rise in temperature in humid and temperate grasslands will reduce the need for winter housing and for feed concentrates for livestock. Many developing countries, by contrast, are likely to suffer production losses through greater heat stress to livestock;

Forestry

- Climate change is virtually certain to impact forestry in commercially important regions by altering species composition and productivity. Confirming the effect first reported in TAR, a number of studies predict that moderate temperature increase is likely to positively affect global forest growing stock volume.

Fisheries

- No compelling evidence has emerged since the TAR that marine fisheries production will increase or decline due to climate change.
- Fisheries are dependent on plankton production, which will be affected by changes in nutrients, stratification, pH and ice cover, but the scale and scope of future changes in plankton is poorly known.
- Plankton and fish distributions have changed, with rapid poleward shifts in middle and high latitudes (e.g. North Atlantic), where temperature has increased. Seasonal patterns of plankton production have changed, with consequences for fisheries production. Further temperature increase will continue to cause distribution shifts.
- Local fish extinctions are occurring at the edges of ranges, particularly in freshwater and diadromous species (e.g. salmon, sturgeon). Fishing impacts are particularly harmful where climate induced decline in productivity occurs without corresponding reduction in exploitation rates. This is most likely to occur at the edges of species ranges.

It is concluded with *medium confidence:*

Food crops and livestock

- Increases in climatic extremes, were they to accompany climate change, will increase crop and livestock losses, thus increasing associated insurance and disaster relief costs in regions where they occur. There also will be increased risks of soil degradation and reduced grain yield and quality. The frequency and severity of extreme cold conditions such as frost events diminish with increased temperatures, allowing increased flexibility in crop management, thus increasing yields and returns.
- In intensive farming systems, where management flexibility is possible, land managers are

in a position to buffer the negative effects of climate change and to benefit from the positive effects. In more extensive farming systems, which are operating close to the threshold of sustainability, management options are fewer and consequently, these systems remain far more vulnerable to climate change;

- Climate changes increase irrigation demand in the majority of world regions due to a combination of decreased rainfall and increased evaporation arising from increased temperatures. This combines with reduced water availability to provide a significant challenge to future water and food security. In a few regions, water demand decreases, partly as a result of management changing growing seasons.
- Warming favours over-wintering of pathogens, leading to increased disease severity. Additional disease problems as climate change and related variability alter geographic ranges of hosts and pathogens.
- While nutrient *quantity* may increase, nutrient *quality* of food grown under elevated CO_2 and climate change will be lower than at present. Grain protein concentration is reduced under elevated CO_2, downgrading its use and economic value and impacting on the diet of people in areas where dietary protein is currently marginal. Increased frequency of temperature extremes also reduces grain quality in affected crops.

Forestry

- New data from FACE studies and simulation results suggest that the effect of CO2 fertilization on forest NPP will probably be somewhat lower than expected in many regions if limiting factors such as N availability are taken into account.
- Climate change will shift the current boundaries of insect species and modify tree physiology and tree defences resulting in more frequent and severe events of insect damage;
- Many forests will be unable to adjust to warming, and will be replaced by species better adapted to warmer temperatures such as grasslands. As warming continues, many tree species shift to higher altitudes and/or latitudes.
- Regional changes in comparative advantage of timber production will reshape the current system of global timber trade; timber prices are expected to fall in light of anticipated increased global supply, the benefits will mainly go to consumers.

Subsistence, smallholder, and pastoral agriculture

- Subsistence, smallholder and pastoral (SSAP) households suffer from multiple sources of vulnerability: environmental, market-related and governance-related. These constrain the extent to which these households can cope with climate variability, and are thus likely to constrain the extent to which they can adapt to climate change.
- SSAP households will suffer hard-to-predict impacts of climate change, with impact being a location and farming-system specific compound of direct impacts on crop, livestock, forest and fisheries productivity, combined with additional location-specific impacts such as sea-level rise and snow-pack decrease.
- Climate change in regions characterised by subsistence and smallholder agriculture and pastoralism, particularly when combined with population growth, will accelerate land degradation and endanger biodiversity.

It is concluded with *low confidence:*

Food crops and livestock

- At the global level, climate change will lead to an increase in agricultural production potential;

Industrial crops, biofuels, and plantation crops

- Long-term experiments recently concluded that certain plantation tree crops show long-term decline in the level and activity of photosynthetic enzymes as the plants acclimate to their environment through *down-regulation*; down-regulation is suggested for future plantation tree crops;

Forestry

- Increased temperatures and altered precipitation extremes will increase fire risks to commercial forests;

Fisheries

- Freshwater fisheries are more sensitive to climate variation and change due to geographic discreteness.
- Further temperature increase on top of those observed to date will continue to cause local fish extinctions.

5.1 Importance, scope, summary of TAR conclusions, specific methods and uncertainty

The goods and services provided by agriculture, forestry, and fisheries are highly sensitive to variations in climate. Major scientific progress has been made since the Third Assessment Report in understanding how they may be affected by future climate change. This chapter critically evaluates progress in understanding and assessing the impacts of climate change on production of food, fibre, wood and other ecosystem services, as well as their implications for global food security, human development, rural livelihoods, and land use/cover change.

5.1.1 Importance of agriculture, forestry, and fisheries

At present, roughly 35% of the Earth's ice-free land is managed for agriculture, specifically 10% for cropland (1.5 B ha) and 25% for pastures (4.5 B ha) (FAO, 2001). Natural forests cover another 30% (3.9 billion ha) of land; though only about 5% of forest cover is managed for forestry (about 200 M ha). In developing countries nearly 70% of people live in rural areas where agriculture is the largest supporter of livelihoods—growth in agricultural incomes in developing countries fuels the demand for non-basic goods and services, fundamental to human development. The FAO estimates that the livelihoods of roughly 450 million of the world's poorest people are entirely dependent on managed ecosystem services. Capture fisheries and aquaculture accounted for 15% of total global animal protein supplies in 2000.

The FAO reports substantial progress toward increasing global capacity of food and fibre over the past quarter century. Annual growth in global crop production slowed from 2.5% in the 1970s to 1% in the 1990s mostly because of decreasing demand due to slowing population growth and growing share of better-fed people. Between the 1960s and 1990s meat consumption in developing countries rose by 150%. Yet, one person in six remains undernourished in developing countries (FAO, 2001). Net deforestation reduced global forested area by 9.4 million ha (+2.6 million ha in temperate regions and -12 million ha in tropical regions) during the 1990s, less than the previous decade. Three-quarters of global fisheries are currently over-fished, depleted, or used to their biological limits (Vitousek *et al.*, 1997). The larger, more effective reproducing classes of nearly every commercial fish species are being disproportionately depleted (Lubchenco, 20xx).

Global climate change will surely alter current trends in the productivity of crops, livestock, forest goods, and fisheries, in some situations and places for the worse and in some for the better—at least temporarily.

5.1.2 Scope of the chapter

The scope of this chapter is:

- for agricultural (crops, livestock, biofuels, small-holder and subsistence), forestry (commercial enterprise forests), and fisheries:
    - to examine current climate sensitivities/vulnerabilities
    - to consider future trends in climate, global and regional food security, forestry, and fisheries production
    - to review key impacts of and autonomous adaptation to climate change in food and tree crops, livestock production, industrial crops and biofuels, forestry, fisheries, and subsistence agriculture;
    - to consider planned adaptation to climate change
    - to explore the implications of responding to climate change for sustainable development;
    - to summarize key findings and conclusions and their uncertainties from the foregoing, and identify key research gaps and priorities.
- major questions to be addressed include:
    - which regions, cropping/managed forest systems are most sensitive to current climate variability?
    - what is the likelihood that agriculture, forestry, and fisheries in various systems and regions can adapt to climate change, and which strategies are available to assist adaptation?
    - what is the likelihood that global capacity in agriculture, forestry, and fisheries can keep pace with growing demand, with and without climate change? Are there important distributional (over people, production systems, regions) differences from the global situation?
    - what difference does a change in climate variability (in addition to mean changes) make in estimates of impacts?

5.1.3 Important findings of the TAR

The key findings of the Third Assessment Report with respect to food, fibre, forestry, and fisheries are an important benchmark for this chapter. In reduced-form, they are:

Food crops

- Experiments have shown that relative enhancement of productivity caused by elevated CO_2 usually is greater when temperature rises but may be less for crop yields at above-optimal temperature. The net positive CO_2 effect may be relatively greater for crops under moisture stress than those with unlimited moisture.
- Modelling studies suggest crop yield losses with minimal warming in the tropics. Temperate crops may be able to withstand a small amount of warming(~+2˚C) before declining with additional warming.
- Countries with greater regional resource endowments are likely able to cope with crop impacts than those with less.

Forestry

- Free-air CO_2 enrichment (FACE) experiments suggest that tree growth rates may increase, litterfall and fine root increment may increase, and total NPP may increase, but these effects are expected to saturate because forest stands tend toward maximum carrying capacity, and plants may become acclimated to increased CO_2 levels.
- Research reported since the SAR confirms the view that the largest and earliest impacts induced by climate change are likely to occur in boreal forests.
- Contrary to the SAR, global timber market studies that include adaptation suggest that climate change will increase global timber supply and enhance existing market trends toward rising market share in developing countries.

Fisheries

- Global warming will confound the impact of natural variation and fishing activity and make management more complex.
- Climate-ocean-related changes in the distribution of fish populations suggest that the sustainability of the fishing industries of many countries will depend on increasing flexibility in bilateral and multilateral fishing agreements, coupled with international stock assessments and management plans.
- Increases in seawater temperature may directly impact aquaculture; such increases already have been associated with increases in diseases and algal blooms.

5.1.4 Methods and uncertainty

Key findings of research on climate change interactions with food, fibre, forestry, and fisheries are based on methodologies that include experimentation, statistical indicators and models, simulation models, and social-scientific research on real-world production systems. Parametric and structural uncertainties are associated with each of these methodologies.

5.1.4.1 Experimentation

In situ experiments provide data necessary to advance understanding of ecosystem processes and to test predictive models. In situ manipulative experiments apply climate change factors to small land areas. Most recent experiments strive to include field-like conditions, often by adopting free-air methods to alter the climate and atmosphere (e.g. Free Air Carbon Dioxide Enrichment, FACE). However, many key factors present in typical field conditions, such as resource competition, soil and water quality, pest and disease, etc., remain understudied (e.g., Tubiello and Ewert, 2002). In addition, changes in impact factors occur instantaneously in these experiments, in contrast to the gradual changes in climate predicted by climate change scenarios. Up to now, most experiments have used only one driver of climate change; only few experiments have tried to combine the different factors (e.g. Shaw *et al.*, 2003). The complex structure of ecosystems, feedbacks and lagged reaction to changes in climatic parameters, difficulties controlling these parameters, and relatively slow growth processes complicate direct measurement of climate effects, particularly in perennial vegetation systems (Van der Meer *et al.*, 2002). Finally, methodologies for upscaling experimental results to field and regional levels are still incomplete

5.1.4.2 Statistical modelling and indicators

Empirical statistical modelling is commonly used to develop relationships between climate, ecological, and socioeconomic variables. Climate change assumptions are used to force the models to produce predicted impacts. These models are often used to provide first-order analyses of complex systems, whenever more detailed input data are lacking for more complex descriptions. There are many sources of parametric and structural uncertainty in such approaches. The models are typically reduced-form, black-box variable-process interactions. Ritchie, 1994 points out the difficulty of separating climate and technology trends in statistical crop-climate models. Data from climate change model simulations that force the models are often outside the range of historic observation, thus causing problems of over-fitting. Relationships are static, which poses a problem with predicting into the future. Agroclimatic and ecological indices in combination with climate change scenarios have been used extensively to examine the effects of climate change on agriculture and forests, and risk factors such as droughts and wildfires. Holden used the hydro-thermal and crop yield data to define the agroclimatic regions of Ireland (Holden and Brereton, 2004). However, quantifying these indices in complex ecosystems is difficult (Knoepp *et al.*, 2000).

5.1.4.3 Physiological modelling

A considerable number of physiologically-explicit models have been developed to simulate various aspects of global change impact on food and forests at various spatial and temporal scales, but there are no comparable global simulations for fish species. For plants, physiological models may include explicit schemes for plant phasic development, light interception, CO_2 uptake, and the partitioning of biomass in the growing organs of the plant. They allow for detailed sensitivity analysis of specific plant-environment interactions, and management adaptation can be explicitly tested. Uncertainties in their predictions arise from several sources including:

- impossibility to include all relevant processes within any given model
- incomplete validation of all parameterization schemes included in such models
- differences in parameterization schemes among models
- variable quality data input which greatly influences the accuracy of tuning the model to local conditions
- absence of critical variable-process relations such as the effects of pests and pathogens, tillage effects on soil and water conservation, dynamics of nutrients other than nitrogen, and effects of extreme climate events such as flooding or severe storms.

5.1.4.4 Characterizing uncertainty

[CLA note: consistent treatment of uncertainty across all chapter sections is not achieved yet, but will be focus of SOD.]

We strive for consistent treatment of uncertainty in this chapter. Traceable accounts of final judgments of uncertainty in the findings and conclusions are maintained. These accounts explicitly state sources of uncertainty in the methods used by the studies that comprise the assessment. It is neither practical nor feasible to fully characterize uncertainty in all findings. We do, however, concentrate on all major policy-relevant findings and conclusions. At the end of the chapter, we summarize those findings and conclusions and provide a final judgment of their uncertainties.

5.2 Current sensitivity/vulnerability: to weather and climate (including extreme events); and to other stresses; recent and current trends; current adaptation

Climate variability is a major determinant of fluctuations in the productivity of agricultural, forestry, and fisheries systems. The impact of climate variability on crop yields is clearly demonstrated in the literature. Production systems have developed numerous strategies for coping with climate risk. For example, farmers irrigate and diversify the crops they plant, foresters breed for drought hardiness and fisheries managers alter catch quotas.

5.2.1 Climate variability and extreme events

The inter-annual, seasonal and hourly distribution of climate variables (e.g. temperature, radiation, precipitation, water vapour pressure in the air, and wind speed) affects a number of physical, chemical and biological processes that drive the productivity of agricultural, forestry and fisheries systems. The phenology of plants and animals is sensitive to temperature variability and recent research has shown that the distinct changes in temperature since the end of the 1980s have led to responses in plant phenology and in plant and animal distributions in many parts of the world (see Chapter 1). Several methods have been used to convey climate variability and its impacts in terms that are meaningful to the agriculture, forest and fisheries sectors and to assess the range and extent of extreme events. Water is an important mediator of the vulnerability of agriculture, forests, and fisheries to extremes, and deserves special mention.

5.2.1.1 Extreme events

An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. An extreme climate event is an average of a number of weather events over a certain period of time, an average which is itself extreme (e.g. rainfall over a season) (IPCC, 2001b). Moreover, extreme events have a potential for negative impacts on the systems studied. Extreme events include: heat waves and droughts; frosts, ice and snow damage; flooding; storms and high winds, wildfires. Both frequency and intensity of extreme climate events impact crops, livestock, forestry and fisheries sectors. The importance of extreme events and climate thresholds for crop production is well-established. For example, in three key regions of Africa—the Sahel, the Horn of Africa, and Southeast Africa—severe droughts occur on average once every 30 years. These droughts triple the number of people exposed to severe food and water scarcity at least once in every generation, leading to major food and health crises (2005).
Some extreme events are likely to occur in combination. For example, the frequency and intensity of forest and rangeland fires is usually increased during drought periods. Moreover, ecosystems tend to be more vulnerable after an extreme event: insect and pest outbreaks tend to be more frequent after a drought *(REF. to be added).*

5.2.1.2 Using plant-climate thresholds to benchmark vulnerability

Existing knowledge of climatic thresholds of crucial biological processes and management operations may be useful to project potential stresses of extremes from climate change before they happen. The temperature response of biological processes follows usually an inverted U-shape, with a maximum of activity reached at an optimal temperature. Optimal temperatures have been studied for a number of biological processes (e.g. photosynthesis). Fisher, 2002 shows relationships between photosynthesis and temperature for major classes of crops. Fish species also exhibit U shaped responses to temperature variability, for example the annual production of young by Atlantic cod, which determines the range of the species and the productivity of cod in different temperature regimes (Brander, 2000) (Figure 5.1). The latitudinal distribution of crops indicates clear envelopes under the current climatic and atmospheric conditions (Leff *et al.*, 2004). The definition of threshold temperatures is, however, more complex due to i) the uneven distribution of temperatures in plant canopies, in soils and in water columns, ii) variable durations of exposure to below or to above optimal temperatures and iii) for some processes (e.g. pollination, flower sterility, bud outgrowth) strong interactions with phenology. For example, cold damage is often observed after mild winters that lead to an earlier onset of buds and flowers and, hence, render trees and fruit production more vulnerable to spring frosts (Hänninen, 1991).

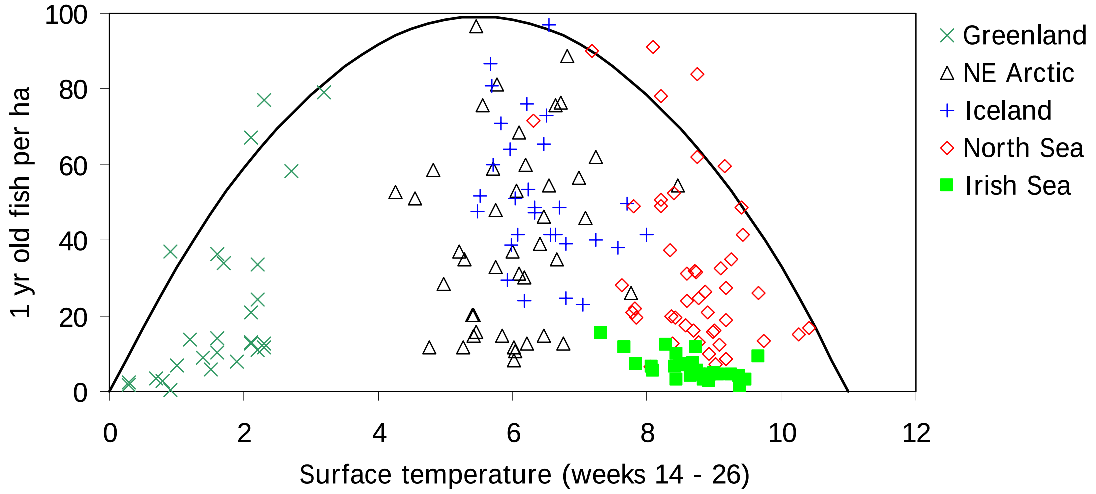


***Figure 5.1** One year old fish density versus sea surface temperature in spring.*

5.2.1.3 The global importance of water to crops, pastures and forests

In many regions, the balance between precipitation and evapotranspiration is the main factor limiting production of agriculture, rangelands or forestry. Globally, some 3.6 billion ha (about 27% of the Earth's land surface) are too dry for rain-fed agriculture. Considering water availability, only about 1.8% of these dry zones are suitable for producing cereal crops under irrigation (Fischer *et al.*, 2002). In many other areas, water resources are already stressed and are highly vulnerable, with intense competition for water supply. Further runoff reduction and increasing water demand under warmer temperatures are likely to amplify the direct impact of changing temperature and precipitation. Climate variability affects precipitation, evaporation, runoff, and soil moisture storage. Water balance is directly impacted by temperature/rainfall, but also indirectly through complex interactions between climate variables: e.g., warming may increase water demand, reduce air moisture content and reduce runoff (see Chapter 3). Therefore, runoff reduction and increasing water demand under warmer temperatures tend to amplify the direct impacts of high temperature or low rainfall events. Total seasonal precipitation as well as its pattern of variability (Olesen and Bindi, 2002) are both of major importance for agricultural, pastoral and forestry systems.

5.2.2 Degradation of natural resources and multiple stresses

The degradation of natural land resources by agriculture includes land degradation; salinization of irrigated areas; over-extraction of underground water; growing susceptibility to disease and build-up of pest resistance favoured by the spread of monocultures and the use of pesticides; loss of biodiversity and erosion of the genetic resource base when modern varieties displace traditional ones (FAO, 2003). Agriculture also generated adverse effects on the wider environment, e.g.

deforestation, loss or disturbance of habitat and biodiversity, emissions of greenhouse gases and ammonia, leaching of nitrate into water bodies (pollution, eutrophication), off-site deposition of soil erosion sediment and enhanced risks of flooding following conversions of wetlands to cropping. Pressures on the primary productivity of ecosystems from agriculture, livestock, forestry and fisheries have been estimated in land equivalents (Wackernagel *et al.*, 2002) (Figure 5.2), showing that resources are increasingly stretched and further deterioration may aggravate the impacts of climate change on the agriculture sector.

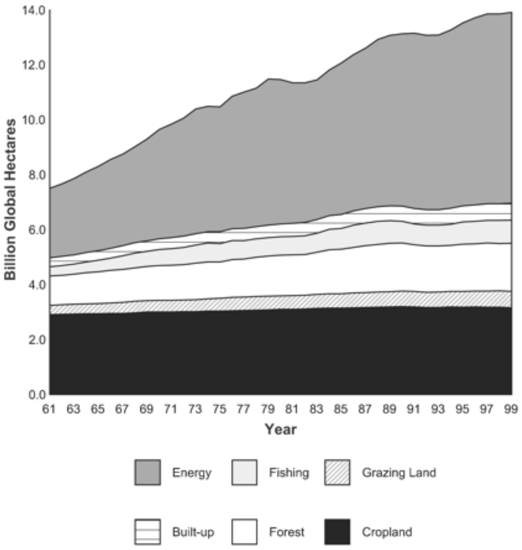


Figure 5.2 *Pressures on primary productivity converted in land equivalents (billion global hectares) from agriculture (cropland), livestock (grazing land), forest and fisheries compared to pressures from energy use and from built-up areas (From Wackernagel et al., 2002, PNAS).*

5.2.2.1 Effect of soil/vegetation degradation—desertification—on soil productivity

Soil degradation emerges as one of the major challenges for global agriculture. It is induced via erosion, chemical depletion, water saturation, and solute accumulation. Restoration of degraded soils is a development strategy to reduce desertification, soil erosion and environmental degradation, and alleviate chronic food shortages with great potential in sub-Saharan Africa and other parts of the world (Vagen *et al.*, 2005). Excessive grazing pressure is detrimental to plant productivity and may lead to declines in soil organic matter. Universal rehabilitation of overgrazed grasslands could sequester approximately 45 Tg C yr^{-1}, most of which can be achieved simply by cessation of overgrazing and implementation of moderate grazing intensity (Conant and Paustian, 2002).

Drylands occupy 41% of Earth’s land area and are home to more than 2 billion people—a third of the human population in the year 2000. Drylands include all terrestrial regions where water scarcity limits the production of crops, forage, wood, and other ecosystem provisioning services. Some 10–20% of drylands are already degraded (medium certainty). Based on these rough estimates, about 1–6% of the dryland people live in desertified areas, while a much larger number is under threat from further desertification (2005). Persistent, substantial reduction in the provision of ecosystem services as a result of water scarcity, intensive use of services, and climate change is a much greater threat in drylands than in non-dryland systems. The greatest vulnerability is ascribed to sub-Saharan and Central Asian drylands.

5.2.2.2 Biodiversity loss and invasive species

Resilience of grasslands, forests and marine ecosystems to climate change tends to be reduced by losses in key species or functional groups, as well as a decline in species diversity (see Chapter 4). Moreover, the genetic resources within one species are of major importance for plant/animal breeding. Evidence is accumulating, primarily from studies of terrestrial plant (Chapin, 1998) that the systems with higher diversity also demonstrate higher resilience and potential to adapt by ensuring that there is sufficient redundancy to guard against the risks associated with environmental disturbances (Naeem, 1998). All three levels of biodiversity, genetic, species, and ecosystem, are important; reduction of biodiversity through climate change acting in combination with other factors, such as habitat loss, land use change, introduction and spread of invasive species, is likely to accelerate climate induced changes. For example, the decline in the vulnerability of rice to pathogens can be obtained by increasing the genetic diversity (Zhu *et al.*, 2000).

Since capture fisheries rely on natural populations, biodiversity (including genetic diversity) is critical for "passive autonomous adaptation". Populations at the edges of ranges will be particularly valuable source of genetic variability capable of adaptation. However the same populations are also most likely to become less resilient as climate changes (see the inverted U curve) and therefore more vulnerable to fishing. This raises a fundamental dilemma for management: preserve such populations, because they are valuable for adaptation or accept that distributions will inevitably shift and edge population will disappear anyway. The cost of protecting edge populations may be to forgo harvests of co-occurring species which are not edge populations. The issue of invasive marine species is complex and raises concerns about commercial and ecological fungibility. Current concerns about invasive species are mainly in connection with accidental introductions (ballast water etc.) but there are some climate related issues (e.g. through the unfreezing Arctic archipelagos).

5.2.3 Current coping strategies for dealing with climate variability

A number of avoidance strategies are currently used to avert negative impacts of climate variability. Irrigation is a widespread technique that has allowed farmers to substitute stored groundwater and surface water for precipitation to avoid drought, drainage to avoid flooding, and buildings for animals to avoid heat or cold. Farm level adaptations that favour tolerance to climate variability include: diversifying towards climatically optimal crops and livestock varieties, adjusting land use and cropping patterns, intensifying fertiliser application and improving water management practices (Mathur, 2004). Other agronomic adaptations also include switching to drought resistant cultivars and adapting planting and sowing dates. Coping with risks in agriculture, forestry and fisheries also implies insurance systems and incentives and subsidies to promote the adoption of improved technologies.

5.2.3.1 Current coping systems in subsistence and smallholder agriculture, and pastoralism

"Subsistence and smallholder agriculture" is used here to describe rural producers, predominantly in developing countries, who farm using mainly family labour and for whom the farm provides the principal source of income (Cornish, 1998). These farmers can be found on a continuum between subsistence production, defined by direct consumption of most of the farm outputs and minimal purchase of inputs (Barnett, 1997), and concentration on crop production for the market.

Smallholder, subsistence and pastoral systems, especially those located in marginal environments, areas of high variability of rainfall or high risks of natural hazards, are often characterised by livelihood strategies that that have been evolved a) to reduce overall vulnerability to climate shocks ("adaptive strategies"), and b) to manage their impacts *ex-post* ("coping strategies"). The distinction between these two categories is however frequently blurred (Davies, 1996): what start as coping strategies in exceptional years can become adaptations, for households or whole communities.

Many defining features of dryland livelihoods in Africa and elsewhere can be regarded as adaptive strategies to climate variability. Mortimore and Adams, 2001 for Northern Nigeria mention five major elements of adaptation:

- allocating farm labour across the season in ways that follow unpredictable intra-season rainfall variations: "negotiating the rain"
- making use of biodiversity in cultivated crops and wild plants
- increasing integration of livestock into farming systems (at a cost of increased labour demands)
- working land harder, in terms of labour input per hectare, without increasing external non-labour inputs
- diversifying livelihoods.

Other authors have mentioned on-farm storage of food and feed, strategic use of fallow, and late planting of legume crops when cereals fail as drought responses (Swearingen and Bencherifa, 2000 for rain fed areas of Morocco).

Shifting to irrigated farming is sometimes seen as a coping strategy in the face of climate variability, across the developing world. Eakin, 2003 describes this for Mexico, but notes that the interaction of market uncertainty with climatic risk may in fact increase the vulnerability of households making this shift. In South Asia, (Moench and Dixit, 2004), agricultural strategies such as increasing livestock production relative to crops, and selection of crop varieties, are responses to both drought and floods, but several case studies show the importance of livelihood diversification, both responsively to disaster and proactively, including establishment of non-agricultural livelihoods within villages, commuting to towns, and urban migration with consequent flows of remittances. These studies also show the importance of information and networks or social capital in coping with climate change and variability (see also Winkels and Adger, 2002).

Box 5.1: Pastoralist Coping Strategies in Northern Kenya and Southern Ethiopia

African pastoralism has evolved in adaptation to harsh environments with very high spatial and temporal variability of rainfall (Ellis, 1995). Several recent studies (Ndikumana *et al.*, 2000, Oba, 2001, McPeak and Barrett, 2001, Hendy and Morton, 2001, Morton, forthcoming) have focussed on the coping strategies used by pastoralists during recent droughts in Northern Kenya and Southern Ethiopia, and the longer-term adaptations that underlie them:

- *Mobility* remains the most important pastoralist adaptation to spatial and temporal variations in rainfall, and in drought years many communities make use of fall-back grazing areas unused in "normal" dry-seasons because of distance, land tenure constraints, animal disease problems or conflict. But encroachment on and individuation of communal grazing lands, and the desire to settle to access human services and food aid, have severely limited pastoral mobility.

- Pastoralists engage in *herd accumulation* and most evidence now suggests that this is a rational form of insurance against drought. There is considerable debate on the extent to which pastoralists cope by systematically selling livestock during drought or drought-onset, and why they might not do this, but some evidence that they would sell more stock if markets were more efficient.
- A small proportion of pastoralists now hold some of their wealth in bank accounts, and others use informal savings and credit mechanisms through shopkeepers.
- Pastoralists also use *supplementary feed* for livestock, purchased or lopped from trees, as a coping strategy, they intensify *animal disease management* through indigenous and scientific techniques, and they increasingly pay for *access to water* from powered boreholes.
- *Livelihood diversification* away from pastoralism in this region predominantly takes the form of shifts into low-income or environmentally unsustainable occupations such as charcoal production, rather than an adaptive strategy to reduce *ex-ante* vulnerability.
- There are a number of *intra-community mechanisms*, to distribute both livestock products and the use of live animals to the destitute, but these appear to be breaking down due to high levels of covariate risk within communities.

5.2.4 Current vulnerability in perspective

[WE to KO: is it possible to make any broad statements about changing global vulnerability or vulnerability in select regions?]

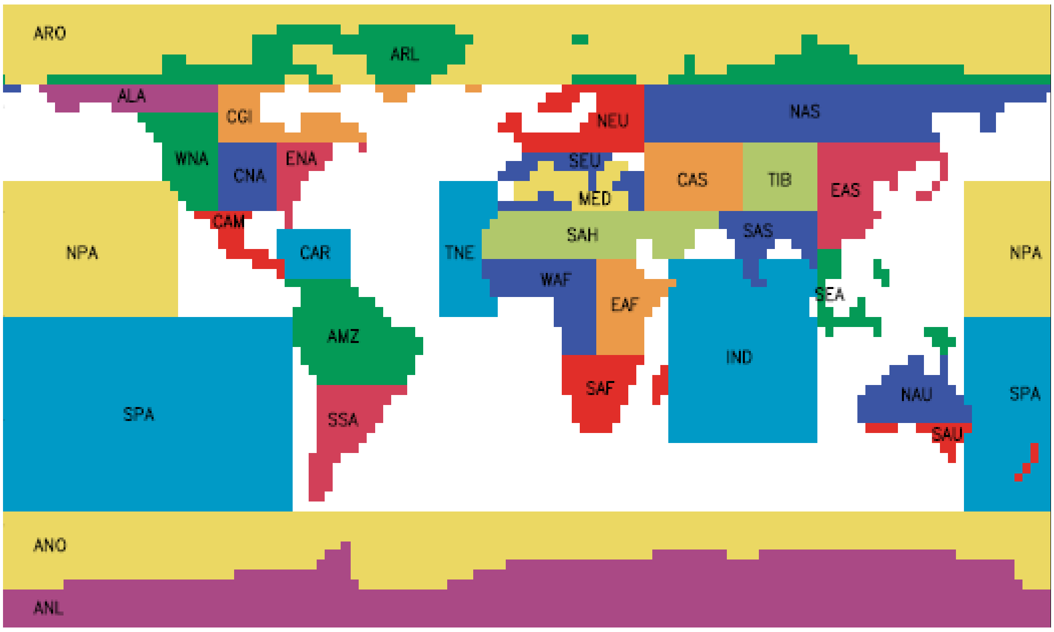
Current vulnerability to climate variability and long-term changes in climate is dependent not only on the nature of the climatic event or change, but also on the social, economic, and institutional context within which it occurs. In many cases, the most vulnerable are not those regions, sectors or groups that are most exposed to the negative biophysical effects of climate change, but those that have a limited capacity to adapt to changing conditions. Furthermore, some communities have a higher adaptive capacity than others, depending on economic wealth, social structures, and previous experience with climate variability. Municipalities or farmers with lower adaptive capacity are likely to be less able to meet the challenges of changing conditions, even if climate change creates beneficial conditions (O'Brien *et al.*, Forthcoming).
Current vulnerability is closely related to adaptive capacity, as well as the capacity to cope with climate variability (Adger *et al.*, 2005). These capacities differ across regions and social groups. Some regions, communities or individuals that are reliant on resource-based activities such as agriculture, forestry, or fisheries may currently be better able to cope with climate extremes and long-terms changes, whereas others may have more limited capacities (*add references*). Nevertheless, vulnerability is dynamic, and increases or decreases as biophysical, socioeconomic, and institutional conditions change. Economic and institutional changes associated with globalization, for example, are creating dynamic changes in rural vulnerability to climate variability and change (Leichenko and O'Brien, 2002).

5.3 Assumptions about future trends: climate, global and regional food security, and forestry production and demand

Long-term developments in the overall economy and its sectoral composition (e.g. declining share of agriculture) and related characteristics (e.g. less people dependent on agriculture and less dependence on natural resources) are likely to alter the setting in which climate changes interact with the crop, livestock, fisheries and forestry sectors (Bruinsma, 2003). It is crucial to take these trends into account when evaluating the potential impacts of climate changes that are decades into the future.

5.3.1 Climate

CLA note: This section is under construction but the intent is to develop a map that overlays the 17 FAO world regions shown in the table below onto a map of the IPCC sub-regions (shown below) developed by Tim Carter to show regional variation in climate model projections. This map, we assert, will provide useful information on ranges of climate change expected in major agricultural production regions.



IPCC Sub-region	Code	FAO regions
AlaskaNWCanasa	ALA	North America
ECanada	CGI	North America
WesternNAmerica	WNA	North America
CentralNAmerica	CNA	North America
EasternNAmerica	ENA	North America
CentralAmerica	CAM	Central America (incl. Caribbean)
Caribbean	CAR	Central America (incl. Caribbean)
Amazonia	AMZ	South America
SouthernSAmerica	SSA	South America
NorthernEurope	NEU	Western Europe, Eastern Europe
SEuropeNAfrica	SEU	Western Europe
Mediterranean	*MED*	Near East incl. Israel
Sahara	*SAH*	Near East incl. Israel
WesternAfrica	WAF	West Africa, Central Africa
EasternAfrica	EAF	East Africa

SouthernAfrica	SAF	Southern Africa (incl. Rep. SOAFR)
NorthernAsia	NAS	Russia
CentralAsia	CAS	Central Asia
TibetanPlateau	TIB	East Asia (incl. Japan)
EasternAsia	EAS	East Asia (incl. Japan)
SouthernAsia	SAS	South Asia
SoutheastAsia	SEA	South-East Asia
NorthernAustralia	NAU	Oceania
SouthernAustralia	SAU	Oceania
SouthernPacific	SPA	Oceania

5.3.2 Balancing future global supply and demand in agriculture and forestry.

The latest UN population projections to 2050 (UN, 2005) indicate that the deceleration of world population growth may be even faster than thought only a few years ago. The Medium Variant projection for the world population in 2050 has been revised to 9.1 billion. By that time, the annual addition to world population will be 34 million persons, compared with 76 million at present, and the growth rate will have fallen to only 0.38 percent p.a. Longer-term projections (UN, 2004) suggests that the peak may be reached in 2075 at 9.2 billion, to be followed by a slight decline and then by slow growth again to reach just under 9 billion by 2300 (Medium Variant projection).

5.3.2.1 Agriculture

The slowing population growth combined with an ever increasing share of world population reaching medium to high levels of calorie intake (e.g. over half of the population in developing countries now already lives in countries with over 2700 kcal /person/day), leads to a gradual deceleration of growth in world demand for food and, correspondingly, in world production required to meet demand. Nevertheless, average daily energy supply per person would rise from 2790 kcal now to 3120 kcal by 2050 (3060 kcal in developing countries).

Provisional projections to 2050 (FAO, 2005) indicate that annual growth in world agricultural production would fall from 2.2% in 1969-99 to 1.6% in 2000-15, 1.3% in 2015-30 and 0.8% in 2030-50. This still implies a roughly 55% increase in world production by 2030 (as compared with production in 1999/01) and an 80% increase by 2050. This assumes that in the developing countries (where almost all global land expansion takes place, mainly in sub-Saharan Africa and Latin America) another 185 million ha of arable land (+19%) will be brought into production between now and 2050, and another 60 million ha of irrigated land (+30%). Average cereal yields in the developing countries would have to rise from 2.7 tonnes/ha now to 3.8 tonnes/ha by 2050.

Two important qualifications need to be made. First of all, in spite of the expected progress, chronic under nourishment (mainly caused by a lack of access or, in other words, poverty) will likely continue to prevail in several developing countries. Provisional estimates (FAO, 2005) indicate that there may still be some 300 million persons undernourished in 2050 – down from the present some 800 million but still a significant 4 percent of the population of the developing countries. Second, the local picture can be quite different from the global picture. A number of countries, mainly in sub-Saharan Africa, will continue to experience high population growth and at the same time remain highly dependent on agriculture while being endowed with only scarce natural resources (land, water). If such countries were not to develop their non-agricultural sectors, it is unclear how they will be able to feed their rapidly growing populations. There is a real risk that they will remain extremely food-insecure and will continue to depend on foreign aid (Alexandratos, 2005).

International agricultural trade flows would rise dramatically with, for example, developing countries importing (on a net basis) some 300 million tonnes of cereals by 2050, up from 110 million at present. Similar increases are foreseen for other temperate products such as meat and milk products.

5.3.2.2 Forestry

A number of long-term studies of supply and demand of forestry products have been undertaken in recent years (e.g., Sedjo and Lyon, 1990, 1996; FAO, 1998; Hagler, 1998; Sohngen *et al.*, 1999;Sohngen *et al.*, 2001). These studies have projected a shift from natural forest harvests to those of plantations. Similarly, both Hagler,) and Häggblom,) foresee a shift in the supply in the future from natural forests to plantations. Hagler, 1998) foresees a shift in the probable supply from plantations starting with about 20% in 2000 to over 40% in 2030. In fact, the FAO, 2004b estimates that about 34% of the world's industrial wood harvest was from plantation forests by 2001, well above Hagler's estimate for 2000, and this portion is expected to increase to 44% by 2020 (Carle *et al.*, 2002) and 75% by 205 (Sohngen *et al.*, 2001). The driving forces for this shift are: competitiveness, wood availability, and environmental constraints. This also means that there will be a shift in the industrial wood supply from the Northern to the Southern Hemisphere. Hagler, 1998 also concludes that there will be increased trade in forest products in the future in order to balance the regional imbalances in demand/supply.

In recent decades forecasts of industrial wood demand have tended to be consistently too high. Actual harvest levels have fallen well below all of the forecasts of two decades ago (see Sedjo and Lyon, , pps. 175-78). Furthermore, total industrial wood demand in the first years of the 21st century, about 1.6 billion cubic meters, has barely increased from the 1.5 billion cubic meters level of the early 1980s (FAO selected issues).

The recent projections of the FAO, Sedjo and Lyon and Sohngen *et al*. project a modest demand growth, with all three projecting the industrial wood harvest being about 1.8 billion cubic metres by 2010. The rationale for the lower growth in demand is found in the recent observed stability of global demand in the past two decades, despite rapid global economic and population growth. It should be noted that the negligible growth in demand occurred despite the absence of any increase in real prices (FAO, 1999 p 34), which could, had it occurred, be viewed as choking off demand. Some of the stability may be due to the recent phenomenon of the dematerialization of the industrial sector. Given the anticipated decline in global population growth (UN, 2005) and the implications of a rapidly aging population, anticipation of slow increases in future demand is not surprising.

By contrast, Hagler's projections forecast the highest levels of demand for industrial wood, rising to 2.7 billion cubic meters by 2030, compared to an actual 1.6 in 2002. This increase is well in excess of the recent trend. Häggblom, 2004 notes the slower than projected demand growth and provide his own projected industrial harvest of 1.9 industrial harvest by 2015, well below the 2.1 billon of Hagler. Hagler's forecast demand growth is 1% to 2% annually, while the FAO, Sedjo and Lyon, and Sohngen *et al.* generally project demand growth at less than 0.5% per annum, decreasing through time.

It is clear there are major differences among analysts regarding the likely path of industrial wood demand thru the first half of the 21st century, nevertheless, the very slow demand growth rates since the early 1980s should caution against expectations of high industrial wood demand growth rates.

Hagler (1998) also assesses the roundwood demand for fuelwood and charcoal to increase from 1.9 billion in 1997 to 2.5 billion cubic meters in 2030. This estimate is based on FAO statistics of 1997. However, the more recent FAO (2001) study suggests that global fuelwood use has peaked and is stable or declining. This finding projects global fuelwood consumption at less than 2 billion cubic meters in 2030. This result is also noted in the 2005. However, there are individual country-specific studies suggesting that fuelwood uses in those countries may increase substantially. Additionally, there are studies demonstrating that although global fuelwood use peaked around the year 2000, the use of charcoal continues to rise — doubling between 1975–2000 (e.g., Arnold *et al.*, 2003). The IEA (2002) projects that by 2030 there will still be some 2.6 billion people fully dependent on biomass for cooking and heating.

In summary, if the trend for the past two decades continue, there is little prospect of large demand increases being driven by either demand for industrial wood or fuelwood. Although there are uncertainties with respect to the consumption of fuelwood and charcoal by the year 2030 but it seems reasonable to assume that it will be in the same magnitude as the demand on industrial wood. However, fuelwood use could dramatically increase in the face of rising energy prices, particularly if incentives are created to shift away from fossil fuels and toward biofuels. Finally, there are many other products and services that wood demanded from the forest resources. However, there are not any satisfactory estimates on the global future demand of these products and services.
[WE to KB or SdC: we will need an assessment of fisheries trends similar to above in the SOD]

5.3.3 Future of subsistence and smallholder agriculture and pastoralism

Subsistence and smallholder farmers and pastoralists suffer, in varying degrees, problems associated both with subsistence production (isolation and low levels of technology), and with uneven and unpredictable exposure to world markets. Pastoralists, depending on livestock for their livelihoods usually to some extent mobile, appear highly traditional, but almost all depend on the sale of livestock and livestock products to buy staple foods and other necessities, and thus suffer analogous problems of exposure to unpredictable markets.

Though not all such farmers are poor, poverty is strongly associated with these “complex, diverse and risk-prone” systems (Chambers *et al.*, 1989), at least in developing countries. Farms are generally small, often held under traditional or informal tenure, and in marginal or risk-prone environments. Production systems are complex and diverse in the plant and animal species exploited, the types of integration between them, the production objectives and the institutional arrangements for managing natural resources. Risks are also various - drought and flood, crop disease and market shocks - and may be felt by individual households or entire communities (Morton and Martin, nd). Smallholder and subsistence farmers and pastoralists often practice hunting/gathering of wild resources as well as crop and livestock production, to fulfil energy, clothing and health needs as well direct food requirements. They also widely participate in off-farm or non-farm employment.

Subsistence and smallholder agriculture and pastoralism are currently experiencing a number of interlocking trends, including population increase, land fragmentation, rural-urban migration and rural livelihood diversification, increasing market integration, environmental degradation, particularly of drylands, and erosion of traditional property rights.

Areas practicing smallholder and subsistence agriculture are centres of population expansion, as they are often poorly served by family planning services and as such farmers still in many areas view children as useful additions to family labour and security in old age. These areas will therefore show further fragmentation of landholdings, increasing the overall problem of livelihood security for the farmers. Land holding sizes have become smaller in South Asia over time and projections are available to show that these may become even smaller.

Processes of environmental degradation affect subsistence and smallholder farmers and pastoralists worldwide, with complex and hotly debated relations between population pressure, poverty, technology, and climate (Grimble *et al.*, 2002). Partly driven by these, there is accelerating diversification of rural livelihoods in developing countries (Ellis, 2000, Bryceson *et al.*, 2000), including (but not limited to) rural-urban migration, and the development of substantial remittance flows from urban workers to rural households.

Agriculture itself is changing, with a general trend towards higher proportions of farm production marketed, and higher dependence on the market for consumption goods and for agricultural inputs. Some smallholders in developing countries will benefit from increased market opportunities resulting from globalization. Many, however, will experience severe constraints on increased market involvement (Hazell,), including:

- regionalised and globalised markets, and regulatory regimes, increasingly concerned with issues of food quality and food safety (Reardon *et al.*, 2003)
- market failures in input supply, following the withdrawal of governments from this activity (Kherallah *et al.*, 2002)
- continued protectionist agricultural policies in developed countries, and continued declines and unpredictability in the world prices of many major developing-country agricultural commodities.

Vorley, 2002 sees the class of secure but traditionally-oriented family farms as shrinking due to its inability to operate within new forms of supply chains. Many will be reduced to increased self-provisioning, poverty, vulnerability, and a survival orientation. Hazell, 2004 and Lipton, 2004 see the possibility, given appropriate policies, of pro-poor growth based on the efficiency and employment generation associated with family farms.

A further threat to smallholder and subsistence farmers is the HIV/AIDS pandemic, particularly in Southern Africa, but possibly in future in South and South-East Asia, attacking agriculture by causing mass-deaths of prime-age adults, diverting labour resources to caring, eroding household assets which are spent on care and funeral expenses, disrupting intergenerational transmission of agricultural knowledge, and reducing the capacity of agricultural service providers Barnett and Whiteside, 2002.

Pastoralists are currently vulnerable to many adverse trends, most notably encroachment on grazing lands and a failure to maintain traditional natural resource management, also the prevalence of armed conflict, blockages of transboundary livestock trade due to animal disease considerations, and a lack of positive opportunities for diversification. Many observers are therefore deeply pessimistic about the development of pastoralism (Blench, 2001).

5.4 Key future impacts, vulnerabilities, and their spatial distribution

BOX 5.2 – Primary effects of elevated CO_2 on Food, Fibre and Forestry: New Knowledge Since the TAR

Common Features. Studies confirm and extend previous observations that elevated CO_2 concentrations stimulate photosynthesis, leading to increased plant productivity and modified water and nutrient cycles (e.g., Nowak, 2004; Kimball *et al.*, 2002. Experiments under optimal conditions show that doubled CO_2 increases leaf photosynthesis by 30-50% in C3 plant species and by 10-25% in C4 species (e.g., Ainsworth and Long, 2005; Ellsworth *et al.*, 2004). In terms of final food, fodder, fibre and wood products, the range of observed responses under elevated CO_2 is much wider, however (ranging roughly 0-50%; e.g., Ainsworth and Long, 2005; Norby *et al.*, 2003; Jablonski *et al.*, 2002: this is because depending on species, sector and management regime, many interactions between plants and their environment can greatly modulate the initial leaf-level responses. Examples are phenological control (e.g., Kim *et al.*, 2003a); source-sink relationships, leading to adjustments in fruit units and production rates (e.g., Ainsworth *et al.*, 2004); water management, modifying plant transpiration, root growth and water uptake dynamics (Wullschleger *et al.*, 2002); and N applications, enhancing plant responses to CO_2 (e.g., Kimball *et al.*, 2002). Under more typical field conditions, many factors such as soil and water quality; pests and disease, and resource competition may reduce crop yield gains observed in experimental settings (e.g., {Chen Peng *et al.*, 2004; Fuhrer, 2003).

Crops. The effects of elevated CO_2 on crop yields are well-known; indeed they have been put into practice by greenhouse vegetable growers since the 1930s. Recent FACE (Free Air CO_2 Enrichment) experiments indicate mean increases in crop yields by 15% at 550ppm CO_2 ({Ainsworth and Long, 2005}); specifically, wheat and rice yields increased by 10-15%, and potato yields by 30% (Derner *et al.*, 2003). Baker, 2004 found that 700 ppm CO_2 increased yield of rice by up to 50%. Several factors in the field may limit crop response; for instance weed competition may increase (e.g., Ziska, 2004; Ziska, 2003b). More experiments and simulations studies focusing on typical field conditions are needed (e.g., Tubiello and Ewert, 2002). Experiments confirm that, while food nutrient *quantity* may increase, nutrient *quality* of food grown under elevated CO_2 may be lower than at present, with respect to mineral nutrients, lysine and crude protein concentrations (e.g., Wu *et al.*, 2003; Fangmeier *et al.*, 2002). Crop responses to CO_2 will be modulated by water and N management (e.g., Triggs *et al.*, 2004; Reddy *et al.*, 2004; Kim *et al.*, 2003b; Widodo *et al.*, 2003). Finally, plant competition in mixtures will alter responses observed in monocultures (e.g., Darner *et al.*, 2003).

Pastures. Doubled CO_2 levels may enhance grassland production by 15-20% (e.g., {Nowak, 2004{; Ainsworth *et al.*, 2003). Experiments confirm that high N levels increase relative response to elevated CO_2 (e.g., {Nowak, 2004}), while effects of water stress are less clear (Morgan *et al.*, 2004a, Marchi *et al.*, 2004). Elevated CO_2 may alter species composition as well as functional type distribution (e.g., Soussana *et al.*, 2005). For instance, high CO_2 may favour growth of broadleaved and legume species, provided soil P levels are not limiting ({Körner, 2003); Byrne and Jones, 2002). This mechanism might provide a positive feedback to CO_2 response: more legumes would increase soil-N availability and further enhance productivity (e.g., {Ross, 2004}; Picon-Cochard, 2004). Management (i.e., cutting frequency) may critically modify CO_2 impacts on pastures (e.g., Harmens *et al.*, 2004). For instance, elevated CO_2 increased the proportion of forbs under infrequent defoliation, and of legumes under frequent defoliation (e.g., Ross *et al.*, 2004; Teyssonneyre, 2002). Nutrient quality will change under elevated CO_2: feed protein content may be reduced, while feed energy content may increase (e.g., Pal *et al.*, 2004; Allard *et al.*, 2003); changes in species composition could ultimately determine nutrient quality and digestibility of nutrient feed (e.g., Morgan *et al.*, 2004b; Picon-Cochard, 2004). Finally, pest damage and predator-prey relations may be altered in elevated CO_2 (e.g., Agrell *et al.*, 2004; Chakraborty and Datta, 2004).

Industrial Crops, biofuels, and plantation crops. Fibre: Experiments confirm that yield of cotton may increase under elevated CO_2, with no effects on fibre quality at high N levels (e.g., Reddy *et al.*, 2004. Damages caused by the cotton bollworm may increase, even in genetically-modified varieties, such as Bt-cotton; modified C:N ratios may alter insect predator-prey relations, with consequences for crop management (e.g. Chen *et al.*, 2005b;Chen *et al.*, 2005a; Agrell *et al.*, 2004). Research on the effects of elevated CO_2 on Jute and Kenaf, two fibre crops of key importance to rural economies in East Asia and Latin America, is lacking. *Industrial and Bio-energy crops*: Perennial woody energy crops such as willow and miscanthus may be favoured under elevated CO_2 (e.g., Veteli *et al.*, 2002; Johnson *et al.*, 2002). *Plantation Crops*. Effects of elevated CO_2 on plantation crops may span several years to decades, due to long life cycles. In sour orange trees, long-term (14 years) CO_2 enrichment resulted in leaf photosynthetic down-regulation due to acclimation (Adam *et al.*, 2004).

*Forestry***.** Many experiments including FACE indicate that elevated CO_2 will enhance the growth of many tree species. Yet recent studies suggest that in natural ecosystems these effects may be small, due to limiting factors such as water and N availability, increased competition from weeds, pests and invasive species, disease, and co-occurring atmospheric pollutants, such as NO_x and O_3 (e.g., Marin *et al.*, 2005; Waterhouse *et al.*, 2004; Beedlow *et al.*, 2004; Karnosky, 2003; Poorter and Navas, 2003; Ainsworth, 2002; Hymus *et al.*, 2002; Finzi *et al.*, 2002). Response of slow-growing forestry species may also be small (e.g., Vanhatalo *et al.*, 2003). However, fast-growing commercial forestry species may respond to elevated CO_2 more strongly, provided fertilizer N levels are high. For instance, in commercial poplar species productivity and harvestable wood increased by 15-25% at 550 ppm (Wittig *et al.*, 2005; Liberloo *et al.*, 2005; Calfapietra *et al.*, 2003). Finally, models suggest that ecosystem response will vary geographically, depending on interactions with weeds, invasive species, disease and atmospheric pollutants (Lexer *et al.*, 2002; Lasch *et al.*, 2002; Van der Meer *et al.*, 2002; Sabaté, 2002).

BOX 5.3. Climate Change and CO_2 Interactions Effects on Food, Fibre and Forestry: New Knowledge Since the TAR

Common Features. Temperature and precipitation change will impact food, fodder, fibre and wood products, likely reducing positive CO_2 effects. Impacts may critically depend on climate scenarios, particularly on precipitation changes (e.g., Tubiello *et al.*, 2002). Interactions of climate variables and CO_2 will be important (e.g., Aranjuelo *et al.*, ; Henry *et al.*, 2005; Xiao *et al.*, 2005). Higher temperatures will extend growing periods at northern latitudes. At mid to low latitudes, yield of current cultivars may be reduced due to faster maturity; heat stress may depress yields, depending on precipitation minus evapo-transpiration changes (e.g., Fuhrer, 2003). Interactions with CO_2 will modify impacts. Elevated CO_2 may shift current photosynthetic optima towards higher temperatures; and it may increase stomatal resistance, improving water-use efficiency and drought resistance. Warmer climates and modified precipitation regimes, including increased frequency of extreme events, may increase ecosystem stress due to increased physical damage, migration pressures, and altered distributions of invasive species, pests and disease.

Crops. Higher temperatures may increase crop production at northern sites, by increasing growing periods while reducing frost damage (e.g., Howden, 2003). By contrast, higher temperatures and increased water demands in southern regions may depress yields (Hitz and Smith, 2004). At the same time, plant development of current cultivars will accelerate with warming, in some cases reducing yields (e.g., Asseng *et al.*, 2004), but not in all observations (e.g., Chmielewski *et al.*, 2004). High temperatures during flowering may lower crop yields by reducing grain number, size, development and quality (e.g., Caldwell *et al.*, 2005; Baker, 2004; Thomas *et al.*, 2003). High temperatures may also increase the frequency and duration of heat stress during a crop life cycle. For given increases in mean temperature, asymmetries in T_{min} or T_{max} may result in differential crop impacts; rice yield declined by 10% for each 1°C increase in T_{min} in dry seasons, whereas effects of T_{max} were not as significant (Peng *et al.*, 2004).

Interactions of temperature with CO_2 will be important; experiments with rain fed wheat grown at 450 ppm CO_2 show yield increases up to 0.8°C warming, then declines beyond 1.5°C warming, due to water stress; additional irrigation helped to adapt and to counterbalance these observed negative effects (Xiao *et al.*, 2005). Finally, since more than 80% of world agricultural land is rain fed, changes in precipitation will critically shape both the direction and magnitude of climate impacts (Tubiello, 2005; Reilly *et al.*, 2003; Olesen and Bindi, 2002).

Pastures. Experiments with elevated CO_2 and increases in temperature, precipitation, and nitrogen deposition showed increased net primary production (NPP) with strong multifactor interactions, including changes in species distribution and litter composition (e.g., Aranjuelo *et al.*, 2005; Henry *et al.*, 2005; Zavaleta *et al.*, 2003; Shaw *et al.*, 2003). One recent experiment indicates no significant CO_2-temperature interactions, including T_{min}/T_{max} asymmetries (Volder *et al.*, 2004). Human management (e.g., cutting frequency) may play a significant role in modifying overall pasture responses to climate (e.g., Harmens *et al.*, 2004). Climate change may lead to changes in pasture species composition, altering grassland production and thus its value for grazing livestock. Experiments and simulations confirm that impacts on community stability may be more important than changes in productivity itself (e.g., Batima, 2003; Sukumar *et al.*, 2003). Future CO_2 levels may favour C3 plants over C4 due to higher responsiveness of the former group; yet associated temperature increases may again favor C4 species (e.g., Shukla, 2003). Increases in climatic extremes may suppress C3 dominance and promote C4 species, including weeds, due to faster migration rates, greater production of seeds, better ability to colonize many habitats and quick maturity (e.g., White *et al.*, 2001).

Industrial crops and biofuels, including plantation crops. Sensitivity to change in temperature and precipitation, including extreme events, may impact plantations more than annual crops, due to longer risk exposure during multi-year life cycles, especially between flowering and maturity. Tea and coffee plantations may specifically be at risk from warming. On the other hand, for plantations currently at the temperature limits and/or at high altitudes, increased temperatures may reduce losses from frost damage (e.g., Domroes, 1997). Warming may favour over-wintering of pathogens, leading to increased disease severity. Additional disease problems may occur if climate change alters the current geographic ranges of hosts or pathogens. The potential for outbreaks is illustrated by the introduction of coffee from Africa to Asia, where it suffered damage by fungi native to the new habitat (Harvell *et al.*, 2002).

Forestry. Observed recent increases in temperature are extending growing seasons in temperate and boreal ecosystems. As warming continues, tree species may shift to higher altitudes and/or latitudes where possible. In west Canada, the southern edge of the boreal forest may move northward by as much as 1100 km by the end of the century; while in the east, southern edges could shift up to 500 km north (Canadian Forest Service, 2003). In the Siberian taiga, northern boundaries could shift by up to 600 km (e.g., Kirilenko, 2002;Tchebakova *et al.*, 1999).

However, slow tree migration rates (typically 1 km per year) compared to temperature shifts under climate change (up to 100 km per degree of warming) suggest that many forests may be unable to adjust, and may thus be replaced, especially at ecosystem boundaries, by species better adapted to warmer temperatures such as grasslands (e.g., Rennerberg *et al.*, 2004; Chapin *et al.*, 2004). Yet increased seed production in elevated CO_2 may provide a counterbalance (e.g., Stiling *et al.*, 2004), enhancing migration rates of forests through greater seed dispersal. Precipitation changes may modify ecosystem productivity and function, particularly in marginal; higher water-use efficiency and greater density of root systems under elevated CO_2 may alleviate drought pressures (e.g., Centritto, 2005; Norby *et al.*, 2004; Shafer *et al.*, 2002). Importantly, increased temperatures and altered precipitation extremes may increase fire risks (Crozier *et al.*, 2002), and promote forest diseases and pests (Alig and al., 2004; Gan, 2004). Recent warming trends in the western U.S. and Canada have resulted in earlier insect spring activity and proliferation of some species such as the mountain pine beetle (e.g., {FS, 2003}; Crozier *et al.*, 2002).

5.4.1 Food-crop farming including tree crops

[WE to MA: This section will need to be restructured better to accommodate JA's new Table 5.2 for the SOD.]

Cropping systems occur in almost all climatic conditions and range from low input subsistence activities to high input industrialised systems, from annual to perennial. Generally they are simplified systems, often monocultures. This aspect provides greater ability to assess their responses to global changes than, for example, complex rangeland systems. The TAR identified that the combination of increases in CO_2 concentration in conjunction with changes in rainfall and temperature were likely to have significant impacts on cropping systems globally through both direct and indirect effects. The net impact of these changes was dependent on many other factors including crop management, soil factors and the specific crops involved. Many further studies on such impacts have been undertaken since the TAR, mostly providing confirmatory views (see Boxes 5.3 and 5.4 and Table 5.2). Six categories of findings have emerged since the TAR: 1) the picture on how grain yield and quality will be impacted by climate change has gotten clearer, 2) more studies have been done that focus on the impacts of changes in climate variability jointly with changes in climate means rather than presumed simple changes in climate means alone that tended to characterise the earliest studies, 3) there has been a proliferation of regional studies showing that the combined effects of CO_2 and adaptation mitigates yield impacts; 4) more studies confirm the finding that impacts are generally more adverse in the tropics than the temperate zones, although there is substantial regional variation in impacts and impacts are severe everywhere in the long term; 5) enough studies using economic equilibrium analysis with explicit trade components have been done since the TAR to suggest that inter-regional and international trade generally mitigates impacts of climate change, and 6) studies show the importance of irrigation water in mitigating crop impacts. Findings 3-6 are supported by studies summarized in Table 5.2. The remainder of 5.3.1 discusses Findings 1-6.

5.4.1.1 Enterprise scale: biophysical and socioeconomic impacts (plot, animal, etc)- where

possible, modelled yields, irrigation demand, costs/earnings for: Yield and grain quality changes

Enterprise scale impacts will be a result of the interaction of CO_2 level, temperature increases and rainfall changes (Boxes 5.2 and 5.3) and will also vary depending on the resource base, technologies and input level as well as management adaptation (Table 5.3). Many studies have explored the implications of such changes using simulation models that are increasingly able to represent these CO_2 responses and their variation with water-stress and nutrient level (Tubiello *et al.*?, Asseng *et al.*, 2004).

The potential impacts on rice production of climate changes and increases in CO_2 appear to vary with the assessment technique (i.e. experimental results vs. simulation) and location. Rice yields respond to elevated CO_2 with De Costa *et al*. (2003) measuring an increase ranging from 23 to 39% between seasons in Sri Lanka with CO_2 levels of 570ppm. Olszyk, 1999 found that with elevated CO_2 and elevated temperature (300ppm and 4°C above ambient) experiments there was no significant change (-3%) in grain yield of rice in the Philippines whereas simulated yields increased under these conditions by an average of 25% using the ORYZA1 model. Saseendran, 2000) simulated rice production in Kerala, India using the CERES-Rice model to assess impacts of changes in temperature (1.5°C), rainfall (+2mm/day) and CO_2 (460ppm) drawn from a GCM to suggest increases in yield of about 12% by 2049. Temperature increases generally reduced grain yield by 6% per degree warming whilst decreases in rainfall resulted in yield loss at a constant rate of about 4% per mm/day. These results contrast with those for China where simulations indicate that rice yield will decrease 12% to 27% by 2050-2080 under an A2 climatic scenario (Peng *et al.*, 2004).

Yields of key C_4 crops (maize, sorghum and millet) are more likely than not to be reduced in Africa, Eastern Europe, the Mediterranean, Canada and parts of the USA with negative impacts increasing over time (Table ??), increasing risks to food security. However, there is likely to be substantial spatial variability with for example, potential yields increasing in the Great Lakes and Corn Belt regions of the USA. Several other analyses have concluded that impacts are likely to show considerable spatial variation in response to soil resources, management adaptation and economic factors as well as variation in climate forcing factors (e.g. Southworth *et al.*, 2000). Such spatial variation may be a source of resilience, allowing progressive re-allocation of land to different and more appropriate uses (e.g. Antle *et al.*, 2004). However, in other situations it may be a source of vulnerability as 1) regional differences in food security may be increased with climate change making dependence on effective trade and transport more critical and 2) areas poorly endowed with natural resources may become increasingly vulnerable as Antle *et al.*, 2004 found a general inverse relationship between resource endowment and vulnerability to climate change.

Grain protein concentration is likely to be reduced under elevated CO_2 due to greater increases in grain mass compared with plant nutrient uptake (Sinclair *et al.*, 2000; Kimball *et al.*, 2001). Decreased grain protein can downgrade its use and economic value but perhaps more importantly it may impact on the diet of people in areas where dietary protein is currently marginal. Grain protein may be maintained under conditions of elevated CO_2 by increasing nitrogen supply to the plants (e.g. Kimball *et al.*, 2001) however, the restricted capacity of poor people to increase fertiliser inputs may limit their capacity to adapt to this change, increasing vulnerability. Furthermore, in situations where soil nitrogen is limiting, the full benefit of increased growth from elevated CO_2 is unlikely to be realised (e.g. Kimball *et al.*, 2001) limiting the potentially beneficial impacts of elevated CO2 on food security.

Since the TAR there have been a few studies that have investigated impacts as a function of spatial scale. Generally, these studies have found that the impacts of changes in climate are of greater magnitude when fine-scale scenarios are used compared with coarse-scale scenarios (e.g. Carbone *et al.*, 2003; Doherty *et al.*, 2003) due to different patterns of moisture stress and timing and degree of temperature change during particular growth phases in the different representations.

Table 5.2 *Themes in Food Crops Emerging Since the Third Assessment Report as Supported by Illustrative Studies*

Theme 1: Many new studies of regional impacts. Impacts mitigated by adaptation and CO2 direct effect, and differ by location, crop, model, GCM scenario

Study	Location	Sector / crop	Impact	Comments
Alexandranov *et al.*, 2002	Austria	Winter wheat, soybean	Winter wheat (2080s) yield decrease without CO_2 effect (-7% to –10%); With CO_2 direct effect: (+10% to 13%) Rain fed soybean (2080s) - Without CO_2 direct effect: (+4% to 30%); With CO_2 direct effect: (+50% to 95%)	Adaptation mentioned – crop planting date, tech changes, etc, would improve results
Antle *et al.*, 2004	Agro-ecozones in northern Great Plains, United States	Dryland winter wheat, spring wheat, barley, in fallow rotation and continuously cropped	Adaptation modelled as changes in land use and management. Without adaptation or CO2 effects: yields -20 to -50%, net returns -50 to -70%; without adaptation but with CO2 effects: yields -25 to +25%, net returns -30 to 0%; with adaptation and without CO2 effect: net returns -55 to -25%; with CO2 fertilization, net returns -10 to +20%.	Relative and absolute measures of vulnerability used; vulnerability sensitive to type of measure and economic conditions; areas with poorest resource endowment found most vulnerable
Easterling *et al.*, 2001	United States (MO, IA, NE, KS)	Maize, soybeans, wheat	Generally positive yield changes for all crops. Adaptation benefits corn and soy crops most. CO2 direct effect also improved all relative yield potential, with and without adaptation	Compared high and low resolution methods of mapping climate
Howden and Jones, 2004	Australia	Wheat	Without adaptation: Nationally -0.3% but large range (-49% to +10%). Large variation between regions. With adaptation: Nationally +5% with range of -25% to +16%. Adaptation of changed varieties and planting dates worth $100M to $550/yr. Further adaptations possible.	Productivity sensitive to rainfall reductions.
Mearns *et al.*, 2001	Great Plains, United States	Corn, soybean, wheat	Wheat: generally positive yield change with climate change (+4% to +12.8%) Corn and Soy: -18% to +2.5%	Spatial scale of soils was important to corn and soy results.

Theme 2: Impacts are generally more adverse in the tropics, and favourable in the temperate zone, with substantial regional variation in impacts

Mendelsohn and Williams, 2004	Global, by region	Agricultural sector	Overall, tropical nations will be hurt, temperate regions will be barely affected, and high latitude nations will benefit. Net global market impacts will be small, but the main burden of negative impacts will fall on poor developing tropical countries.	
Parry *et al.*, 2004	Global, by region	Wheat, Rice, Maize, Soybean	Developed countries fare much better: Developing countries = -7% to +8% change in average crop yields (but largely negative). Developed countries: 6.6% to 10.4% change (all results positive)	Included CO$_2$ effects, price changes, and shifts in production
Ramankutty *et al.*, 2002	Global, by region	Cropland	16% increase in suitable cropland by 2080; most benefit in North Tropics will experience lass in agricultural suitability	
Fischer *et al.*, 2002	Global, by region	cereals, pulses, oilseeds, etc	For SSA, on rain fed cereal production, on currently cultivated land in 2080: -1.3% to –11.7% change in regional production potential. China gains in cereal production: -5% to 23%, with most models resulting in positive changes.	Study also looks at food security impacts

Theme 3: Impacts are generally more severe in long run.

Aggarwal and Mall, 2002	India	Irrigated Rice	In 2010, regional yield changes ranging from 1.3% to 7.4% In 2070, regional yield changes ranging from 3.6% to 30%	Results are highly sensitive to thresholds of phenology and photosynthesis to changes in temp used in the models.
de Jong *et al.*, 1999	Canada	Field crops	Barley, spring wheat and canola did not change significantly with double CO$_2$ Soybean yields (+12%); Potato yields (+14%); Winter Wheat yields (+16%) Temporal yield variability increased in all crops with double CO$_2$ scenario	Used daily climate data from GCM for 3 different 21 year periods.
Alexandranov and Hoogenboom, 2000	Bulgaria	Winter wheat, maize,	Percentage yield changes: 2020s: Maize mostly <0 (-14% to 12%); Wheat all +: (8 to 30%) 2050's: Maize mostly negative (-21 to +6%) ; Wheat all+: (14 to 45%) 2080's: Maize (-7% to –28%); Wheat (10% to 49%)	Adaptation mentioned – crop planting date, tech changes, etc, would improve results

Theme 4: More economic equilibrium analysis with trade, showing that inter-regional and international trade generally mitigate impacts of climate change.

Butt *et al.*, 2003	Mali	Field crops	Cereal production 95-113% of base. Prices increase 66-107% Risk of Hunger index ranges from 21 to 45 (base = 34).	"Economic adaptations through trade may be realized if markets work well"

Harasawa *et al.*,	Global	crops, livestock, other products	Sample of Production Change Findings (1990 to 2100 %): China: Rice= -1.6%, Wheat=8.5%, Livestock =-.1% USA: Wheat=4.8%, Grains=-2% Livestock =-1% EU Wheat=8.9%, Grains=-3% Livestock =0%	Accounts for trade, price changes, production changes, and income changes, etc.
Mendelsohn *et al.*, 2000	Global	all	Average GDP in 2100 (billions of 1990 USD per year): Total = 145, Africa = -16, Asia = 21, Lat Am=-5, W Eur=6, former USSR & Eastern Bloc=102, Nam=40, Oceania=-2.	Uses COSMIC climate forecasting model in combination with a global impact model to predict market impact of 14 GCM projections

Theme 5: Irrigation and water constraints

Abou-Hadid *et al.*, 2003	Egypt, Tunisia, Morocco	Wheat	Irrigation reduced impacts with -14.03% to -11.44% change in wheat yield with 300 to 450mm/season irrigation under 1.5 temp change. -34.5% to -32.41% change in wheat yield with 300 to 450 mm/season irrigation under 3.6 temp change.	High vulnerability to severe water deficit under climate changes.
Döll, 2002	Global	Irrigation; rice and non-rice	Cropping intensity increase in Northern Africa, South Asia, East Asia, SE Asia, Oceania and Japan; Cropping intensity decreases in the Former USSR. Overall Global Net Irrigation requirements increase	Results are reported as change in irrigation requirements by region
Tao *et al.*, 2003	China	General	+-5% change in agricultural net returns, depending on region. Agricultural water demand in south China is expected to drop with climate change	

Impacts of changes in climate extremes and variability

Climate change is likely to increase the frequency and magnitude of some extreme weather events and disasters (Mirza, 2003). If the frequency of weather extremes increases in future, as projected by some GCMs, the cost of crop losses in future could rise dramatically. In the US, the maize production losses due to this factor may double during the next thirty years, causing additional damages totalling an estimated $3 billion per year, which will consequently impact insurance and disaster relief programs (Rosenzweig *et al.*, 2002). Developing countries are thought to be more vulnerable to extremes of normal climatic variability due to their limited institutional and adaptation capacity (TAR). However, in addition to the higher risk of storm damage, there could be changes in other risks associated with climate extremes such as changes in rainfall intensity, heat stress, frost and drought.

Risks of soil degradation in croplands are likely to alter. Global climate models suggest that there may be increases in rainfall intensity even in locations where mean rainfall may decrease *(reference WG I).* Higher rainfall intensity is likely to increase the risks and magnitude of soil erosion from cropping systems (Nearing *et al.*, 2004) requiring management adaptations such as increased stubble retention (Table 5.3). Increased rainfall intensity is also likely to increase the movement of water past the root zone of crops, increasing the risk of dryland salinisation in areas affected by this form of land degradation (van Ittersum, 2004). The effects of elevated CO_2 in reducing cumulative evapotranspiration from crops (e.g. Conley, 2001) are also likely to increase these risks (van Ittersum, 2004).

Increased frequency of extreme high temperatures is likely to negatively affect grain yield and quality. High temperatures during anthesis can have deleterious effects on crop yield, reducing grain count and size and processing quality as noted in the TAR. For example, high temperatures are well known to lead to spikelet sterility in rice and elevated CO_2 levels may enhance this problem through increased canopy temperatures (Horie, 2000, Matsui *et al.*, 1997, Ziska *et al.*, 1997). However, since the TAR we learn that there is considerable genotypic variability in the response of spikelet sterility to temperature (Matsui *et al.*, 2001. Increasing temperatures bring 1) the prospect of increases in the frequency of heat stress and 2) expansion of the part of the year in which this risk occurs. However, higher temperatures also increase the rate of crop development, resulting in heat-sensitive developmental stages such as anthesis occurring earlier in the year during cooler months (at least for cool-season crops). A risk assessment approach analysing the trade-off between these two factors across Australia suggested that for temperature increases up to 4^oC there would be no net increase in heat stress risk for temperate cropping regions but some increased risk for sub-tropical regions (Howden, 1999). Adaptation options include varying planting times and varieties to avoid high temperatures, targeted irrigation to reduce water stress during sensitive periods and breeding of less heat-sensitive cultivars.

Crop damage from frost may decline with global warming. Frost damage during anthesis and grain fill is a limiting factor in crop yields in many mid-latitude regions of the world. Trends of increased minimum temperatures over the past decades have in some regions substantially reduced the risk of crop damage from frost. This has allowed farmers in those regions to plant winter crops earlier so that the crops can mature earlier when the risk of water stress is lower and environmental yield potentials are higher. {Howden, 2003)} showed that planting decisions that used an adaptive strategy to allow for the historical trends in frost risk in north-eastern Australia resulted in a clear economic advantage ($52/ha/year) when compared with two alternative strategies ($29 and $34/ha/year). Further reductions in frost risk associated with global warming are likely to provide farmers with further latitude for planting options to reduce other climatic, environmental or economic risks.

Many studies since the TAR have reinforced its findings that increases in atmospheric CO_2 concentrations is likely to have some ameliorating effect on yield reduction due to water stress such as that occurring in droughts (e.g. Amthor, 2001). Elevated CO_2 can increase the duration of growth into drought through changes in the time-course of canopy water use (e.g. Conley, 2001), increase the water-use efficiency of the crop (expressed as yield per unit evapotranspiration) (e.g. Mitchell, 2001) and increase the rate of grain filling (e.g. Adger *et al.*, 2001). Whilst these effects are beneficial in drought conditions they will usually only partially offset the yield reductions. Nevertheless, simulation analyses indicate that these effects could reduce the variability of yield and profitability that arises from drought stresses (e.g. Reyenga *et al.*, 1999).

Increases in climate variability are likely to reduce average crop yields. The impacts of increases in the variability of climate as well as changes in mean climate state have been assessed in several studies since the TAR. Generally, increases in variability reduce mean yields due to the very low yields in years with extreme conditions (e.g. Southworth *et al.*, 2000, Southworth *et al.*, 2002).

Crop yield reductions arising from increased variability could arise from several causes including: 1) reduction in seed number when high temperatures coincide with flowering (e.g. Wheeler, 2000), 2) non-linear responses in response to heat stress, vapour pressure deficit, storm damage, waterlogging or soil moisture stress (e.g. Easterling *et al.*, 2000) 3) reductions in farm inputs such as fertiliser application with increased variability (e.g. Antle *et al.*, 2004). Consequently, for two scenarios with equivalent change in mean climate, the scenario with an increase in climate variability is likely to have lower yields.

Regional Studies with autonomous adaptation more numerous

The number of regional studies with explicit short-term responsive (or autonomous) adaptations has grown considerably since the TAR (examples are shown in Table 5.2). Such adaptations may be feasible in cropping systems either because of sub-annual timeframes for management allowing continuous adjustment and/or due to high management inputs. A significant range of potential adaptations has been identified (e.g. Table 5.3) with many of these being extensions of existing risk management activities.. Some of these have been assessed as having substantial potential to offset negative climate change impacts. For example, Tubiello *et al.*, 2000? assessed for two sites in Italy simple, currently practicable adaptations of earlier planting of spring crops and adoption of slow maturing winter crop cultivars. Early planting of spring crops helps to avoid plant drought and heat stress during the hotter and drier summer months predicted under climate change. Slower-maturing winter cultivars are needed to counterbalance the reduction of potential crop yield due to accelerated phenological development in a warmer climate. At the Modena site climate change reduced sorghum yield by 48 to 58% without adaptations. These impacts were reversed with adaptations with yields increasing by 0 to 12%. The equivalent figures for wheat were -6 to 15% without adaptations and -6 to 0% with adaptations and for maize -17 to -24% and -9 to -17%. However, there has been little evaluation of how effective these and other adaptations may be given the complex nature of farm decision-making, the likely diversity of responses within and between regions in part due to possible differences in climate changes, the possible interactions between different adaptation options and economic, institutional and cultural barriers to change.

Tropical versus temperate crop yield differences

[CLA note: A graph is being prepared that plots yields from several studies versus 1 degree increments of warming—out to the maximum warming for which there are data from studies. Such a graph showing the trends in major grain crops (maize, wheat, rice) will be done for the tropics and again for temperate zones. These graphs combined with discussion of results from Table 5.2 will comprise this subsection.]

The role of trade as an adaptation tool

[CLA note—this section to be written by J. Antle for the SOD.]

Irrigation demand

Climate changes are likely to increase irrigation demand in many regions due to a combination of decreased rainfall and increased evaporation arising from increased temperatures. This could combine with reduced water availability (FAR Chapter ??) to provide a significant challenge to future water and food security. Doll (2002) assessed changes in irrigation requirements arising from climate changes as represented in two different GCMs. She found that the irrigation requirement increases in 11 out of the 17 world regions by the 2020s, but not more than 10% (except Southeast Asia with 19%). By the 2070s, an increase will have occurred in 12 regions, with the highest absolute increases predicted for South Asia (Pakistan, India and Bangladesh).

Irrigation demand in Northern Africa and the Middle East was assessed to decrease by 5% until the 2020s and by about 15% until the 2070 due to shifting of the (optimal) growing seasons away from summer months with supra-optimal temperatures for crop growth to the winter months when potential evapotranspiration is lower. For up to half of the total irrigated area, the expected anthropogenic climate change in the first decades of the 21st century will have a larger impact on irrigation requirements than the long-term climate variations that occurred during the 20th century.

Table 5.3 *Autonomous adaptation in the agricultural sector to issues arising from anticipated future climate change*

Adaptation measures	**Climate or atmospheric change and/or impact**
Development and use of technologies to conserve soil moisture (e.g. crop residue retention) and maintain groundcover. [2]	D
Identify and develop species/varieties more adapted to prospective climates (including genetically developed varieties) through appropriate thermal time and vernalisation requirements, increased resistance to heat shock and drought, maintenance of high protein levels under elevated CO_2. [2, 3,6, 7, 9]	D, T, ET, R, CO_2
Develop capacity and technologies for changing planting times. [2]	D, R, T,
Maintaining nutrient supply to retain grain and fruit quality through application of fertiliser, enhanced legume-sourced nitrogen inputs or through varietal selection. [3]	T, D, R, CO_2
Improve the effectiveness of pest, disease and weed management practices through use of integrated pest management, development and use of varieties and species resistant to pests and diseases and maintaining or improving quarantine capabilities, sentinel monitoring programs. [3, 8]	P
Develop capacity to better use agrometeorology in farm system planning including using seasonal climate forecasting. [7]	ET, Fl, D
Develop new investment strategies and institutions e.g. risk-spreading through income diversification [1, 4]	All
Addressing underlying social issues, such as poverty, social vulnerability, the inequitable distribution of resources and collective security. [4, 7]	All
Improve water use efficiency by development of effective water-trading systems that shift water allocation to high value uses, improve regional water distribution systems to reduce leakage and evaporation, develop appropriate water-saving technologies and training farmers in their use. [3, 6]	D

Superscripts: 1) Bryant, 1992, 2) Easterling, 1993, 3) Howden, 2003, 4) Kelly, 2000, 5) McKeon *et al.*, , 6) Mendelsohn, 2000, 7) Salinger, 2000, 8) Sutherst, 1998, 9) Southworth *et al.*, 2000, Southworth *et al.*, 2002. The effectiveness of the individual adaptation options will vary considerably depending on crop, management, region, climate changes and also on whether adaptations are implemented alone or in concert.

Impact codes: T= higher mean temperatures; ET = extreme hot and cold temperatures; D = decreased rainfall and increased evaporation; R=increased rainfall; Fl = flood and high intensity rainfall; CO_2=effect of increased carbon dioxide levels; P = spread of pests and diseases; S= increased incidence of tropical storms, tornadoes and strong wind.

5.4.1.2 Perennial crops (viticulture, fruit and nuts, tree-crops)

Perennial crops could be vulnerable to climate change since they typically need several years to reach reproductive maturity and remain economically productive for a long time. Additionally, reduced response to CO_2 after long-term exposure (down-regulation: see Box ??) means that this offsetting factor may have less effect than for annual crops. Many perennial crops, especially those in the tropics, are located in areas that are vulnerable to climatic disturbances or sea level rise, are ecologically vulnerable or are restricted to high elevations. Livelihood security of millions and economy of several developing countries such as Sri Lanka, Malaysia and Kenya, is significantly dependent on the income from such plantations. Several studies since the TAR have been conducted on high value (economic and environmental) perennial crops like grapevine and olive.

Grapevine is a woody perennial with four distinct developmental phases that vary between varieties and with climate. Matching the grapevines developmental phases to climate is an important factor in the location of any vineyard. Global warming will cause earlier ripening, impacting on the grapevines in either positive or negative ways depending on the present climate of the region. Global warming will affect warmer viticulture regions (e.g. California, Mediterranean, parts of Australia), in that higher ripening temperatures allow for an even shorter window from which to determine the optimum harvest time. In intermediate climates the season will begin earlier and phenological stages will be accelerated leading to ripening in the earlier, hotter months with the chance of reduced quality as has happened already with fruit trees (Chmielewski *et al.*, 2004). In cooler climates (e.g. northern Europe) global warming may allow new areas to be planted or varieties that are marginal now, to be grown and ripened more fully. A climatic warming will therefore expand the suitable areas northwards and eastwards in Europe (Harrison, 2000) and to higher latitudes and altitudes in other continents. In the current production areas the yield variability (fruit production and quality) may be higher under global change than at present. Such an increase in yield variability would neither guarantee the quality of wine in good years nor meet the demand for wine in poor years, thus implying a higher economic risk for growers (Bindi, 2000). However, grapevine yields may be strongly stimulated by increased CO_2 concentration without negatively affecting the quality of grapes and wine (Bindi, 2001).

Olive is a typical Mediterranean-climate species that is particularly sensitive to low temperature and water shortage. Thus the northern and southern limits of cultivation in Europe are conditioned by climate. The area in the Mediterranean Basin climatically suitable for olive cultivation could be enlarged via increases in temperature and changes in precipitation patterns that could make some areas of France, Italy, Croatia, and Greece newly suitable for olives (Bindi, 1992). Elsewhere in Europe a greater total area and a northward shift of the potential area of olive cultivation is expected under a climate warming. Similar changes are anticipated on other continents.

Tea is grown in high rainfall areas on sloping terrain often at high elevations (about 1,200 meters above sea level) where the cool nights restrict growth, concentrating flavour in the tea leaves. Consequently, areas currently suitable for tea plantations such as those in Kenya are likely to become climatically less suitable with increased temperatures (UNEP 2005 website ??). However, such temperature increases are also thought to be likely to reduce current losses in areas currently too exposed to frost. Frost damage can restrict productivity for up to 6 months (Domroes, 1997). Changes in crop distribution will be strongly influenced by soil type and by exposure to climatically-based risks such as droughts and high rainfall events that will adversely affect growth and yield of tea by eroding top soil and washing away fertilizers and other chemicals (Martin, 1997; Anandacoomaraswamy *et al.*, 2001).

Similar issues may arise for coffee plantations where yield from fruit to dry coffee is greater in plantations at altitudes greater than 650 m above sea level (Gonzalez Arcos, 2001). Temperature increases are likely to affect the currently economically viable areas suitable for producing coffee. For example, the total area suitable for growing *Robusta* coffee in Uganda would be dramatically reduced with a temperature increase of 2°C (Figure ??). If there are changes in the distribution of coffee plantations there may be unexpected and serious pest or disease problems as was illustrated in the past by the introduction of coffee from Africa to Asia where it suffered epidemics caused by fungi native to its new habitat (Harvell *et al.*, 2002).

Coconut plantations appear to be particularly susceptible if there is increased frequency of droughts, heat waves and storms due to long interval between inflorescence primordial initiation to nut maturity (~ 44 months). Consequently, the effects of climate disturbances impacts can be seen even four years after the drought event ({Rajagopal *et al.*, 2002}). Droughts cause major losses because irrigation is generally not used. The long establishment period of coconut plantations means that damage from cyclones can result in many years before the level of production can be brought back that of the pre-cyclone period ({Dash *et al.*, 2002}).

5.4.2 Pastures and livestock production

Pastures and livestock production systems are extremely diverse. They occur over a large variation in climate and soil conditions and range from very extensive pastoral systems where domestic herbivores graze and browse rangelands to intensive systems based on forage and grain crops, where animals are mostly kept indoors. Grasslands and pastures contribute to the livelihoods of over 800 million people including many poor smallholders (Reynolds *et al.*, 2005). Livestock production is growing faster than any other agricultural sub-sector and is projected to increase by 2.5-3.0% per year in the developing world until 2020 (Delgado, 2005). Meat or milk output per animal remains higher in industrial countries than in developing ones (FAO, 2003). On a global scale, livestock use 3.4 billion hectares of grazing land, in addition to the production of about a quarter of the land under crops (Delgado, 2005). By 2020, it will produce about 30% of the value of global agricultural output and, directly or indirectly, use 80% of the world’s agricultural land (World Bank, 2001).

Pastures include both grasslands and rangelands. Grasslands are the natural climax vegetation in areas (e.g. the Steppes of central Asia and the prairies of North America) where the rainfall is low enough to prevent the growth of forests. In other areas, where rainfall is normally higher, grasslands do not form the climax vegetation (e.g. north-western and central Europe, New Zealand, parts of North and South America and Australia) and are more productive (Whitehead, 1995). Rangelands are characterized by low stature vegetation, due to temperature and moisture restrictions, and found on every continent. Rangelands are often said to include deserts (cold, hot and tundra), scrub, chaparral and savannas (see e.g. Allen-Diaz, 1996).

Our ability to predict responses to global changes of pastures and livestock production systems is limited by the intrinsic complexity and variability of such systems, where production is the result of a mix of several plant and animal species that may be affected in different ways by climate factors. The TAR identified that the combination of increases in CO_2 concentration in conjunction with changes in rainfall and temperature were likely to have significant impacts on grasslands and rangelands, with some regions having higher plant production (humid temperate grasslands) while the production in the more arid regions could be reduced substantially. The net impact of these changes was dependent on many other factors including agricultural management, soil factors and the specific plant species involved. Many further studies on such impacts have been undertaken since the TAR, mostly providing confirmatory views. In many parts of the world that are dominated by rangelands, the lack of infrastructure and investment in sectors such resource management limits the available options for adaptation and also makes these areas more sensitive to the direct impacts of climate change. Adaptation options to future changes have received considerable attention since the TAR. This section aims to outline the new information on both impacts and adaptations for pastures and livestock productions systems.

5.4.2.1 Impacts on soils

Carbon storage in fresh soil organic matter pools (i.e. in coarse particulate organic matter) is often increased under elevated CO_2, (Allard *et al.*, 2004). This may imply a greater sink capacity for atmospheric CO_2, but could also be accompanied by a more rapid turnover of the older, finer and more recalcitrant pools (Niklaus *et al.*, check). The increase in C storage in the particulate soil organic matter with CO_2 concentration was found to be non linear and declining at above ambient CO_2 concentrations, which may indicate that the soil C sink in grasslands will become saturated in a high CO_2 world (Gill *et al.*, 2002) (Medium confidence).

Hu *(et al.*, 2001) have demonstrated a reduction in microbial decomposition in grassland after exposure to elevated CO_2 and suggested that elevated CO_2 reduces the amount of N available to microbes due to enhanced plant growth. Atmospheric CO_2 elevation changed soil microbial populations (structure and/or size) (Montealegre *et al.*, 2002), but had little effect on nitrifying and denitrifying enzyme activity in four European grasslands (Barnard, 2004). Nevertheless, an increased greenhouse gas emissions of N_2O was found in response to elevated CO2 (Baggs *et al.*, 2003), which may exacerbate the forcing effect of elevated CO_2 on global climate. In a tall grass prairie ecosystem. The response of below-ground respiration to artificial warming of about 2 degrees C indicated that the temperature sensitivity of soil respiration decreases-or acclimatizes-under warming (Luo, 2001).

5.4.2.2 Changes in productivity and pasture species composition

A survey of experimental data worldwide suggested that a mild warming generally increases the grassland productivity, with the strongest positive response in currently colder regions (Rustad *et al.*, 2001). Productivity and plant species composition in rangelands are highly correlated with precipitation (Knapp and Smith, 2001). Elevated CO_2 can reduce soil water depletion in different native and semi-native temperate and Mediterranean grassland (Morgan *et al.*, 2004). Moreover, increased variability in rainfall may create more severe soil moisture limitation and reduced productivity (Laporte *et al.*, 2002; Fay *et al.*, 2003).

Much of the world's grasslands are characterised by swards that are botanically diverse. Stability of vegetation communities may be more important than simply predicting levels of productivity for answering questions related to the impacts of climate change on semi-natural grassland and rangeland ecosystems (Mitchell, 2001). In managed grasslands, with adequate phosphorus availability, the CO_2 response of legumes and of forbs has on average been greater than that of grasses (Luscher *et al.*, 2005). When transplanting grassland from a cooler to a warmer site, Bruelheide, 2003 found that the community had changed into a different plant association. In a Mediterranean annual grassland, the largest increase in forb species number and in plant species diversity was found in response to the combination of warming, elevated CO_2 and increased precipitation (Zavaleta *et al.*, 2003). In a field experiment at varying levels of plant species diversity, the enhanced biomass accumulation in response to elevated levels of CO_2 was less in species-poor than in species-rich assemblages Reich *et al.*, 2001.

Pasture diversity may change as plants follow the shifting climate zones. For example 11 % of the steppe pasture in Mongolia would be replaced by desert and accordingly the pasture species will be changed (Batima, 2003). Similarly combination of temperature increase and rainfall decrease would cause major changes in the composition of present-day vegetation in southern, central and northwestern India (Sukumar *et al.*, 2003). In Europe, according to a climate envelope model, on average, one third of the European plant species migrate out from 44% of the modelled area (Bakkenes,). Moreover, climate variability is likely to affect productivity and succession. Gap recolonisation by annuals with a persistent seed bank was observed in sown grasslands after severe droughts (Luscher *et al.*, 2005).

Species composition change is likely to be an important mechanism altering production and its value for grazing livestock, especially in drier rangelands with woody shrub invasion and in warm humid climates with C_4 invasion (High confidence). Woody plant proliferation in grasslands and savannas in recent history has been widely reported around the world. The causes for this shift in vegetation are controversial and centre around changes in livestock grazing, fire, climate, and atmospheric CO_2 (Hibbard, 2001). The direction of future change is difficult to predict (Van Auken, 2001). Increased CO_2 levels is also predicted to increase C_3 plants over C_4 but the projected increase in temperature will favour the C_4 plants (Shukla, 2003). Results from White *et al.*, 2001 indicate that competition is highly important in limiting the invasion of C_3 grasslands by C_4 species. Future increases in climatic variability and the incidence of extreme climatic events are expected to suppress C_3 competitive dominance and promote invasion of C_4 species, especially weeds (White *et al.*, 2001). In Australia, temperature increases of 3°C, particularly under the doubled CO_2 scenario, generally moved southward the 50% C_4 line (Howden, Check Year).

5.4.2.3 Grazing and animal behaviour

Animal requirements for crude proteins (CP) from pasture range from 7 to 8% for animals at maintenance up to 24 % for the highest producing dairy cows. In conditions of very low N status the reduction in crude proteins under elevated CO_2 may put a system into a sub-maintenance level for animal performance (High confidence). C-4 grasses are a less nutritious food resource than C-3 grasses both in terms of reduced protein content and increased C/N ratios. Elevated carbon dioxide levels will likely alter food quality to grazers both in terms of fine-scale (protein content, C/N ratio) and coarse-scale (C-3 versus C-4) changes (Ehleringer, 2002). However, when legume development is not restricted by adverse factors (such as low phosphorus and low soil water), an increase in the legume content of swards may compensate for the decline in the protein content of the non-fixing plant species (Allard *et al.*, 2003, Picon-Cochard, 2004). Large areas of upland Britain are already colonised by relatively unpalatable plant species such as bracken, matt grass and tor grass. At elevated CO_2 further changes may be expected in pasture plant, which could have detrimental effects on the nutritional value of extensive grasslands to grazing animals. (Defra, 2000). During last 60 years in Mongolia high nutrient plants decreased by 1.5-2.3 times, and low nutrient plants like *Carex duriuscula-Artemisia* became dominant in pasture communities (Batima, 2003).

5.4.2.4 Interactions with rodents

In Mongolia, overgrowth in numbers of voles (*Microtus brandtii*) occurred on average every 12 years before 1960. Since 1960, more frequent overgrowth events have been recorded (once in 5-9 years) (Batima, 2003). In Texas, according to a modelling study, two rodent species (a rat, *Oryzomys cousei* and a vole, *Microtus mexicanus*) were predicted to go extinct because their suitable habitats did not occur under a climate change scenario. These results demonstrated that the type of climate change (warmer, drier or warmer, wetter) and its severity would be important for rodent distributions. Climate change was predicted to have the greatest impact on rodent distributions in eastern Texas under a scenario of a warmer and wetter climate because forests expanded, whereas the impact would be greatest in western and southern Texas if climate becomes warmer and drier because desert and shrub habitats expanded. (Cameron, 2001). The activity of small mammals that forage under and near shrub canopies appear to significantly inhibit the expansion of existing vegetative patches, and may have a stronger influence on grassland habitat structure than previously recognized (Curtin, 2000).

5.4.2.5 Effects on domestic animals physiology.

As environmental conditions result in core body temperature approaching and/or moving outside normal diurnal boundaries, animals must begin to converse or dissipate heat to maintain homeostasis. The onset of a thermal challenge often results in declines in physical activity with associated declines in eating and grazing (for ruminants and other herbivores) activity (Mader and Davis, 2004). Adverse environmental stress can illicit a panting or shivering response, which increases maintenance requirements of the animal and contributes to decreased productivity. Depending on the domestic species of livestock, longer term adaptive responses include hair coat gain or loss through growth and shedding processes, respectively. In addition, heat stress is directly related to respiration and sweating rate in most domestic animals.

Production losses in domestic animals are largely attributed to increases in maintenance requirements that are associated with maintaining a constant body temperature, and altered feed intake (Mader *et al.*, 2002; Davis *et al.*, 2003). As a survival mechanism, voluntary feed intake (VFI) increases (after a one to two day decline) under cold stress and decreases under heat stress (NRC, 1987). Depending on the intensity and duration of the environmental stress, VFI can average as much as 30% above normal to as much as 50% below normal. The potential impacts of climatic change on overall performance of domestic animals can be determined using defined relationships between climatic conditions and VFI, climatological data, and GCM output. Because ingestion of food/feed is directly related to heat production any change in VFI and/or energy density of the diet will change the amount of heat produced by the animal (Mader *et al.*, 1999b). Ambient temperature has the greatest influence on VFI. However, animals exposed to the same ambient temperature will not exhibit the same reduction in VFI. Body weight, body condition, and level of production affect the magnitude of VFI and ambient temperature at which changes in VFI begin to be observed. Intake of digestible nutrients is most often the limiting factor in animal production. Animals generally prioritize available nutrients to support maintenance needs first, followed by growth or milk production, and then reproduction.

5.4.2.6 Animal diseases

Increasing spread of animal diseases and pests which were previously found only at low latitudes is likely. The TAR concluded that under climate change, a shift toward milder winter temperatures may enable expansion of the range of Lyme disease into higher latitudes and altitudes (see also Health chapter). Bluetongue mainly affects sheep, occasionally goats and deer and, very rarely, cattle. Since 1998, the Bluetongue virus has spread from its traditional tropical homelands to southern Europe and continues to move further north each year. The main vector, Culicoïdes imicola, is a tropical insect whose geographic distribution range was, until now, rarely reported north of the 40° line of North latitude. Its development is closely linked to climatic conditions. Over the last 2 years, the disease has spread to several countries in the Mediterranean basin, including France (Corsica). The forecasting models show that an increase in temperature would lead to an inevitable and lasting progression of the culicoïdes' population, which would put a large population of animals at risk from contamination (Hendrick, 2005).

Malignant Catarrhal Fever (MCF) is an infectious viral disease of cattle, pigs and deer that causes cells of the lymphatic system to grow excessively and kill normal cells. Two viruses are responsible for the disease, one harboured by wildebeest and the other by sheep. The wildebeest related infection only occurs in Africa, while the other has been reported in the majority of cattle-producing countries. Some studies in Britain (Defra, 2000) states that most parasites and bacteria are exotherms: their growth rates depend on temperature. Viral reproduction rates also depend on temperature when they have an intermediate exothermic host or vector. Hence, increased temperatures are likely to increase exposure to pathogens significantly due to enhanced pathogen survival, extended warm seasons and increased rates of development and reproduction. Exposure will also increase because of increased duration or abundance of insect vectors of pathogens. There may also be increased vector competence as viruses replicate faster. Queensland and CSIRO (White *et al.*, in press) investigated the vulnerability of the Australian beef industry to the cattle tick (*Boophilus microplus*) under climate change. Compared to current estimated losses of 6000 tonnes per year, they found potential losses in live weight gain from 7800 tons per year by 2030 to 21,600 tonnes per year by 2100.

5.4.2.7 Biophysical and socioeconomic impacts and adaptation: enterprise level

Adaptations of feed and forage production

There is strong evidence for interactions between grassland and rangeland management options and climate change drivers such as elevated CO_2 and temperature increase (High confidence). For example, fertiliser additions of N (Daepp *et al.*, 2001) and P (Almeida *et al.*, 1999) vary the CO_2 responses of grasses and legumes, respectively. Moreover, the type (cutting or grazing) of herbage use and its frequency both alter the botanical composition and the productivity of swards (Teyssonneyre, 2002; Newton *et al.*, 2005). In sown grasslands (Wright *et al.*, 2005), as for grain crops (Ziska, 2004), there is also the potential to select plant cultivars that will take advantage of the rise in atmospheric CO_2 concentration.

The rise in temperature in humid and temperate grasslands will reduce the need for winter housing and for feed concentrates because of higher pasture growth and of an extended grazing season Parsons, 2001 (High confidence). In contrast, at warmer locations, the decline in pasture growth as a result of above-optimal temperatures and low soil water, will increase the need for supplemental roughage and concentrates (High confidence). The pressure on and competition for resources such as water availability and pasture productivity are projected to increase in developing countries as a result of increased temperature and reduced precipitation, but could be reduced through adaptations of the land tenure and common property of grasslands and rangelands (FAO, 2003).

Animal productivity and farming systems

Lack of prior conditioning to weather events most often results in catastrophic losses in the domestic livestock industry. In the central United States (US) in 1992, 1995, 1997, and 1999, individual feedlots (confined cattle feeding operations) lost in excess of 100 head each during severe heat episodes. The heat waves of 1995 and 1999 were particularly severe with documented cattle losses in individual states approaching 5,000 head each year (Busby and Loy, 1996; Hahn and Mader, 1997; Hahn *et al.*, 2001). The winter of 1996-97 also caused hardships for cattle producers because of excessive wind and greater than normal snowfall with some feedlots reporting losses in excess of 1,000 head. Economic losses from reduced cattle performance likely exceed those associated with cattle death losses by several-fold (Mader, 2003). The impact on animal productivity due to increased variability in weather patterns will likely be far greater than effects associated with the average change in climatic conditions.

In an effort to maintain optimum levels of production, climate change will likely result in livestock producers selecting breeds and breed types that have genetically adapted to conditions that are similar to those associated with the climate change. However, in warmer climates, breeds that are often found to be more heat tolerant are generally breeds that have lower levels of productivity, which is likely the mechanism by which they were able to survive as a dominant breed for that region. In addition, climate change and associated variation in weather patterns will likely result in more livestock being managed in or near facilities that have capabilities for imposing microclimate modifications (Mader *et al.*, 1997a, 1999a; Gaughan *et al.*, 2002). In general most domestic species of livestock can cope with or adapt to gradual changes in environmental conditions, however, rapid changes in environmental conditions or extended periods of exposure to extreme conditions drastically reduces productivity and is potentially life-threatening.

The potential impact of climate change by the year 2050 on British grazing livestock systems has been assessed through the use of simulation models of farming systems representing eastern (dry) lowlands, western (wet) lowlands and uplands. Such systems should be able to adapt to the expected climatic changes. There is likely to be a small increase in grass production, possibly allowing an increase in total productivity in some cases(Parsons, 2001). In Ireland, the major impacts of yield change were considered to be: (i) grass may cease to be a viable crop in some regions if it requires irrigation to compensate for drought; (ii) theoretical turnout date may become earlier in the season; (iii) stock may have to remain housed at times when currently grazed outside, thus extending storage requirements; and (iv) alternative forage crops may become more suitable for winter feed conservation (Hodden and Brereton, 2002). In intensive farming systems, where management flexibility is possible, land managers are in a position to buffer the negative effects of climate change and to benefit from the positive effects (Luscher *et al.*, 2005) (High confidence).

In more extensive farming systems, which are operating close to the threshold of sustainability, management options are fewer and consequently, these systems remain far more vulnerable to climate change. Animal productivity of pastoral system in many developing countries in Africa and Asia depends primarily on the productivity of natural pastures. The observation data shows that ewe weight has been decreased by 2-12 kg and projected to decrease up to 15 percent up to 6-10 kg from current level in pastoral system of Mongolia (Bayarbaatar, 2003).

Fluctuating rainfall and the occurrence of drought are accepted features of arid and semi-arid areas in general and the pastoral areas of Africa and Asia in particular. Some studies shows a strong relationship (Batima, 2003) between drought and animal death. Projected increased temperature and reduced precipitation would reinforce drought in future and the mortality of domestic herbivores in some of the drought prone area (Medium confidence). In cold regions specially where pastoral system still exit the increased snow fall and its untimely melting due to decreased winter temperature and shortened cold wave duration also bring high negative impact rather than positive (Batima *et al.*, 2005).

5.4.2.8 Regional scale: biophysical and socioeconomic impacts

Impacts for intensive livestock production

Production/response models for growing confined swine and beef cattle, and milk-producing dairy cattle, based on predicted climate outputs from GCM scenarios, have been developed by Frank *et al.*, 2001. The production response models were run for one current (pre-1986 as baseline) and two future climate scenarios: a double CO_2 (~2050) and a triple of CO_2 (~2090) levels. This data base employed the output from two GCM, the Canadian Global Coupled Model, Version I (CGC), and the United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research (Hadley) model. In the central US days to slaughter weight for swine, associated with the CGC 2050 scenario, increased an average of 3.7 days from the baseline of 61.2 days. Potential losses under this scenario averaged 6% and would cost swine producers in the region US$12.4 million, annually. Losses associated with the Hadley scenario are less severe. Increased time to slaughter weight averaged 1.5 days or 2.5% and would cost producers US$5 million, annually. For confined beef cattle reared in the central part of the US, time to slaughter weight associated with the CGC 2050 scenario increased 4.8 days (above the 127-day baseline value) or 3.8%, costing producers US$43.9 million, annually. Climate changes predicted by the Hadley model resulted in a loss 2.8 days of production or 2.2%. For dairy, the projected CGC 2050 climate scenario would result in a 2.2% (105.7 kg/cow) reduction in milk output and cost producers US$28 million, annually. Production losses associated with the Hadley scenarios would average 2.9% and cost producers US$37 million annually. Across the entire US, percent increase in days to market for swine and beef and the percent decrease in dairy milk production for the 2050 scenario averaged 1.2 %, 2.0 %, and 2.2 %, respectively, using the CGC model and 0.9 %, 0.7 %, and 2.1 %, respectively, using the Hadley model. For the 2090 scenario, respective changes averaged 13.1 %, 6.9 %, and 6.0 %, using the CGC model and 4.3 %, 3.4 %, and 3.9 %, using the Hadley model.

A production measure in which global climate change may have a negative effects that is not offset by a positive winter effect is conception rate. This is particularly the case for cattle in which the primary breeding season occurs in the spring and summer months. Mader *et al.* (2005) reported a decrease in conception rates of *Bos taurus* cattle of 3.2% for each increase in THI above 70 and a decrease of 3.5% for each increase in temperature above 23.4 ^{o}C. Clearly, increases in temperature and/or humidity have the potential to affect conception rates of domestic animals not adapted to those conditions.

Regional scale for extensive livestock production systems
(No reference found yet, to be completed)

5.4.2.9 Environmental consequences

In dry regions, there are risks that severe vegetation degeneration leads to a positive feedback between rainfall reduction and degradation of soils and vegetation with consequences in terms of loss of pastoral areas and of farmlands (Zheng *et al.*, 2002) (Medium confidence).

The risk of dryland salinisation may also alter with climate change. Elevated CO_2 levels are likely to increase the risk of dryland salinisation due to the reduction in stomatal conductivity. However, elevated temperatures and/or reductions in rainfall can reduce the historical level of risk (van Ittersum, 2004).

In pastoral systems, extensive grazing systems have typically increased production by herd expansion rather than by substantial increase in productivity. Therefore, in pastoral systems from developing countries it is most likely that herd size would be increased in the future which could bring additional stress to pasture grass yield (Medium confidence). Increased heat stress in the future also suggests that water requirements will increase significantly when compared with current conditions (Howden and Turnpenny, 1997) suggesting that any overgrazing near watering points is likely to be exacerbated under global change.

5.4.3 Industrial Crops and biofuels, including plantation crops

Understanding the impacts of climate change on primary food crops has received considerable attention as is evident from previous sections. However, the impacts on perennial agricultural crops such as plantations and other industrial crops such as fibre crops has not received sufficient attention despite their importance in national and global trade. The purpose of this section is to review the possible impact future climate change could have on such crops.

Plantation crops, being perennial in nature, have to face the impact of climate change during individual seasons as well as during their whole life cycle. Around the world, plantations crops are mostly grown in ecologically vulnerable coastal or hilly areas or in areas with high rainfall and high humidity. Livelihood security of millions and economy of several developing countries such as Sri Lanka, Malaysia and Kenya, is significantly dependent on the income from such plantations. Such countries are, therefore, especially vulnerable to climatic changes considering the sensitivity of the growing environment to ecological disturbances and that the establishment of plantations take several decades. For example, the cyclones that struck several states of India in 1952, 1955, 1996 and 1998 have destroyed so many coconut palms that it will take years before the level of production can be brought back that of the pre-cyclone period (Dash *et al.*, 2002).

Very few studies have been conducted in recent years on the impact of climate change on industrial crops. An exception is cotton for which several experiments have been recently established to study the impact of expected climate change scenarios and increased CO_2 concentration. Several of these studies were conducted under field conditions (Chen *et al.*, 2005; Zhao *et al.*, 2003; Derner *et al.*, 2003 while others were based on simulation models and GCM-projected scenarios Chen *et al.*, 2001a; Chen *et al.*, 2001b; Doherty *et al.*, 2003). Using climate scenarios with 3-5°C temperature increases and rainfall changes of -14 to +30%, these studies revealed a range of increased yields in rainfed cotton of 3-25 with most frequent values of 7-9% (yield increase range for irrigated cotton was 9-30% with most frequent values of 16-20%).

Some recent research also focused on the impact of expected climate change scenarios and enhanced CO2 on various factors affecting cotton production. For example Chen *et al.*, 2001a reported expected increases in water requirement for irrigated cotton that ranged from 17 to 70%. The same author Chen *et al.*, 2001b also concluded that pesticide use costs would increase under climate change scenarios projected by two GCMs. In a more recent study, Chen *et al.*, 2005 concluded that most herbivorous insects (with the exception of phloem-feeding insects) would be negatively affected by elevated CO2 because of the reduction in foliar N and the increase in C:N ratio. These apparently contradicting results (negative impacts on insects but increased pesticide use) could be explained by the fact that warming can result in decreased plant resistance to pathogens due to higher host density caused by faster plant growth rates in warmer climates (Harvell *et al.*, 2002).

A large proportion of the industrial crops are plantations i.e., crops that are planted and grown for several years with annual or biennial harvests. Several recent studies can be illustrative of the expected impacts of climate change and enhanced CO2 on plantation crops. For example a number of experiments were conducted to study the effect of enhanced CO2 on root production. Van Noordwijk *et al.*, 2000 concluded that optimum root length density is likely to increase under elevated atmospheric CO2 concentrations, but root turnover and average life span of fine roots may remain unchanged. These authors also concluded that changes in plant strategies on root turnover may also be expected if the likely period of water stress in between rainfall events increases. Moreover, Eissenstat *et al.*, 2000 showed that reduced tissue N concentration and reduced root maintenance respiration, both of which are predicted to result from elevated CO2, should lead to slightly longer root life spans. However, the authors add that complex interactions with soil biota and shifts in plant defences against root parasitism might alter the effects of future climate change on root longevity in unpredicted ways.

Another subject recently studied that is also valuable for exploring the possible impacts of climate changes and enhanced CO2 on plantation and industrial crops is the expected change of pest and disease pressure. Harvell *et al.*, 2002 conducted a very comprehensive study on climate warming and disease risks for several terrestrial biota. Their article explains that winter is a major period of pathogen mortality in temperate climates, potentially killing more than 99% of the pathogen population annually. Greater success of pathogens to survive throughout the winter period will likely increase disease severity. Because temperatures are expected to increase more in winter than in other seasons, an important population restriction may be removed for many pathogens. The authors also conclude that the most severe and least predictable disease problems could occur if climate change alters the current geographic ranges of hosts or pathogens, causing formerly disjunct species and populations to converge. An example of the potential for such outbreaks was illustrated in the past by the introduction of coffee from Africa to Asia where it suffered epidemics caused by fungi native to its new habitat Harvell *et al.*, 2002.

One of the main challenges for studying the impacts of expected scenarios of climate change and enhanced CO2 on plantation crops is the need to assess such impacts throughout several years to decades. Two very valuable field experiments were recently conducted by Idso and Kimball, 2001 and Adam *et al.*, 2004 with Citrus aurantius (sour orange), that lasted 13 and 14 years and included treatments of 400 and 700ppm CO2. Previous research had suggested that the initial stimulation of photosynthesis observed when plants grow at elevated CO2 may be counterbalanced by a long-term decline in the level and activity of photosynthetic enzymes as the plants acclimate to their environment, an event referred to as *down-regulation*.

In the first of the mentioned experiments Idso and Kimball, 2001 had reported that during the first 2-3 years citrus trees growing under enhanced CO2 conditions had produced more than 3 times aboveground wood biomass than the tress grown under ambient CO2 conditions. However, after the initial years the ratio experienced exponential decay and levelled out at a value of approximately 1.8 at the end of the 8th year. The results of the second experiment Adam *et al.*, 2004 indicated that in fact long-term CO2 enrichment can result in photosynthetic down-regulation in leaves of trees, even under non-limiting nitrogen conditions and was likely the reason for the equilibrium level of wood biomass production shown by Idso and Kimball, 2001. The results of these experiments are crucial for the general research on the impacts of enriched CO2 environments on plant growth since they suggest that the magnitude of the commonly reported positive effects, can be expected to be reduced in the longer term when plants and their enzymes acclimate to the new environmental conditions.

5.4.3.1 Environmental impact

The major environmental significance of plantation crops with respect to climate change is how such crops might affect carbon cycling. The majority of plantation crops are C3 plants and possess a large structure and thus are the potential sinks for atmospheric carbon. Oil from plantations such as coconut is also useful for Biodiesel. The carbon savings through such uses can provide additional income to the coconut farmer (Tan, 2004). Even the energy generated through use of plantation biomass can qualify for carbon credits.

Use of biofuels diminishes fossil fuel combustion thereby also reducing net greenhouse gas emissions. However, Schneider and Schneider and McCarl, 2003 observed that subsidies are needed to make agricultural biofuel production economically feasible. They examined the economic potential of bioenergy crops such as switchgrass, hybrid poplar, and willow in a greenhouse gas mitigation market. Their results indicated no role for biofuels below carbon prices of $40 per ton of carbon equivalent. At these incentive levels, emission reductions via reduced soil tillage and afforestation were more cost efficient. For carbon prices above $70, biofuels dominated all other agricultural mitigation strategies.

5.4.4 Forestry

Climate change will almost universally increase air temperature, which is virtually certain to prolong vegetation seasons in boreal and temperate zones. It is also virtually certain to drive the migration and dieback of tree species, resulting in changes in the geographic distribution of forest types, new combinations of species within forests, and alter productivity. With high confidence, changing temperature and precipitation and, possibly, the frequency of extreme weather events, will affect the frequency and pattern of insect outbreaks, fire, wind and snowstorm damage.

All these factors, affecting the forests individually or interactively, will have an impact on forestry in commercially important regions. The forest sector will react by adaptation to the new conditions through shifting to new species, corrections to forest management, shifting to new products, and the like. This is expected to lead to shifts in raw material supply, relocation of processing capacities and related socioeconomic effects, such as employment and income. These alterations are likely to result in wide social and environmental changes. Globally, it is likely that climate change could increase timber production, with moderate benefits for consumers. However, these effects will be highly variable and region-specific.

5.4.4.1 Enterprise level biophysical and socioeconomic impacts

Simulated impacts on productivity of commercially important species
Climate change will modify the production, distribution and geographic range of forests, change species composition, affect non-timber values, and increase areas lost due to natural disturbances. Economic concerns include regional and national timber supplies, changes in economically appropriate land-use, land values, and accessibility for harvesting and tourism. Both the rates of change and the duration of periods of adjustment may be critical.

Most studies agree that forest area and productivity will increase, especially when the models take into account carbon fertilization enhancing forest growth *[WE to AK: please list a few references in support in the next draft]*. Carbon fertilization effects will often be limited by competition, disturbance, and nutrient limitations, yet only a few models consider such limitations. In natural forests, and even in managed industrial forests, enhanced growth in trees could be offset by increased natural mortality. This is certainly the case for plantation forests where foresters usually predict increased thinning with higher growth in well-stocked stands (Shugart *et al.*, 2003).

Forests in different regions of the world could become more or less productive, depending on how much climate changes (including both temperature and precipitation), how forests respond to higher carbon concentrations in the atmosphere, whether mortality changes, and whether disturbance-induced dieback increases or decreases. Aside from the change in productivity, forest composition will also be changed, providing an additional impact.

Generally, the results of simulation models show an increase in forest productivity following climate change, which is much more significant if CO2 fertilization is taken into account. A considerable improvement since TAR was achieved with development of Dynamic Global Vegetation Models (DGVMs), spatially explicit and dynamic transient models that include biophysical processes. *[WE to AK: are all of these acronyms previously defined?]*For example, both LPJ-DGVM (Sitch *et al.*, 2003) and MC (Bachelet *et al.*, 2001) predict the composition of deciduous/evergreen trees, forest biomass, production, water and nutrient cycling, simulate fire effects. A broad discussion of DGVMs and SBMs can be found in (Peng, 2000;Moorcroft, 2003;Cramer *et al.*, 2001; Brovkin, 2002). Despite this success, there are still inconsistencies between the models used by ecologists to estimate the effects of climate change on forest production and composition, and the models used by foresters to predict forest yield; as a result, the effects of climate change on timber production is usually estimated from ecological models, using net primary productivity (NPP) as a proxy for forestry yield (Shugart *et al.*, 2003). Future development of the models that integrate both the NPP and forestry yield approaches (Peng *et al.*, 2002,Nabuurs *et al.*, 2002) will significantly improve the predictions.

Interactions of fire and climate change

Both forest composition and production are shaped by fire frequency, size, intensity, seasonality, type and severity. All these components are heavily impacted by climate variability and are determined by combination of fuel, ignition source, relief, and weather. Combination of these factors leads to extreme year to year variability of forest fires. Increasing fire damage could negatively impact forest industry, especially paper and pulp operations, pose health threats and affect landscape recreational value (Flannigan *et al.*, 2000).

The FAO (Goldammer and Mutch, 2001) study has shown that that there is no unidirectional tendency of forest fire damage over time, mainly due to extremely high temporal and spatial variability. Most of tropical Asia, Africa, the Americas and Oceania regions experienced extremely extended wildfire situations in 1982-1983 and 1997-1998. Central-Eastern Asia was affected most severely in 1987, particularly Central-Eastern Siberia and the northeast of China. The Far East of Russia was severely affected by wildfires during the 1998 drought. In some cases, the large areas of degraded forests were further converted to grasslands and shrublands, prone to burn much more frequently, thus inhibiting the succession back to tree cover (Goldammer and Mutch, 2001).

In a changing climate, increased temperatures and altered precipitation patterns can elevate fire risk in areas that experience increased aridity; also, climate change can promote the proliferation of diseases and pests that attack tree species, as well as forest fires. Wetter conditions can also lead to larger fires because of fuel build-up during wet years, which is consumed by fire during dry years. For the USA, analysis in the U. S. National Assessment indicate the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States under changed climate (Crozier *et al.*, 2002). Canadian studies generally agree that both fire frequency in the boreal forest and the total area burned have increased in the last 20 to 40 years. Fire season severity is generally projected to increase in the future due to longer fire seasons, drier conditions and more lightning storms. There is relatively high uncertainty associated with most studies of climate change and forest fires because of limited understanding of future changes in precipitation patterns, which amongst others result in changing regions with prolonged drought stress and changes in vegetation types (Natural Resources Canada, 2002, Shugart *et al.*, 2003).

For many forest types, periodic events of insect outbreaks are major sources of natural disturbance. The effects vary from defoliating and growth loss, to timber damage, to massive forest diebacks, and can be both amplified and caused by other extreme events such as wildfires, wind damage, and droughts. Climate change can shift the current boundaries of insect species and modify tree physiology and tree defences; more frequent and severe events of insect damage are probable. Warmer temperatures in the western United States have already enhanced the opportunities for insect spread across the landscape (Crozier *et al.*, 2002). It is very likely that these natural disturbances will be altered by climate and will have an impact on US forests and forestry (Alig and al., 2004).

Insect damage

Even though a few models that simulate climate change impacts on insect outbreaks have been developed, their predictions remain highly uncertain. Pests migrate much faster than forests as the climate changes. Higher temperatures will generally benefit insects in temperate and boreal regions by accelerating development, expanding current ranges and increasing over-winter survival rates. It has already been demonstrated in Canada that insect activity in the spring occurs a week earlier than it did 25 years ago, which corresponds to a northward migration of 2° to 3° in latitude. In western Canada, mild winters have led to a proliferation of mountain pine beetles (Canadian Forest Service, 2003). As new forests would not have any natural defences against them, insects will have the potential to cause harmful damages. Global changes also include the increased introduction of exotic pests. Forests thereby are becoming increasingly vulnerable to exotic diseases and insects, such as the Asian longhorn beetle in Canada (Canadian Forest Service, 2003). Climate change can also benefit some insects and detriment others, depending on species, precipitation regime, and other factors (Lyamtsev *et al.*, 1999;Isaev *et al.*, 1999).

Impacts of weather extremes

The effects of weather extremes on commercial forestry include reduced access to forestland because of flooding, deep snow, or wind- and ice-damaged trees; increased costs for road and facility maintenance; direct damage to trees by wind, snow, or ice; indirect damage from higher risks of wildfires and insect outbreaks; subsequent effects on timber supplies, market prices, costs of insurance etc. (DeWalle *et al.*, 2003). The effects of increased severe weather risks due to climate change will have extremely high spatial heterogeneity; while overall it is expected to have low or moderate impact, some areas will be heavily affected.

The events of catastrophic wind, ice, and snow damage to forests show very high spatial diversity, with damage to individual trees ranging from branch breaking to crown loss to trunk breakage, resulting in slower growth and loss of timber value; this damage can be further aggravated by increased damage from insect outbreaks and wildfires. also, Wind damage can result from specific events, such as tornadoes and downbursts, from heavy winds during storms, especially when combined with heavy snowfall. High winds occurring during warm season can be especially damaging for species with shallow root system growing on shallow substrate. A warmer climate may be more conducive to extreme wind events, although the results are speculative (Natural Resources Canada, 2002). Site characteristics such as physiography, soil moisture, and soil depth; stand characteristics like density and canopy roughness; and tree characteristics such as size, species, rooting depth, and wood strength, are the factors most recognized as influencing damage patterns (Peterson, 2000). There are evidences that introduced species are more damaged than native trees (Irland, 2000.) Expected faster build-up of growing stocks in a warmer climate and under CO2 fertilisation may create a less stable forest resource in terms of risks to extreme weather event damage (Nabuurs *et al.*, 2002). The extent of possible damage is yet to be estimated and the results are still exploratory as only a models are able to simulate these effects (e.g., Blennow and Sallnas, 2004).

The impact of temperature growth combined with moderate growth or reduction in precipitation on forests are likely to increase risks of droughts in many areas. Likely consequences of severe drought for forestry come from the increased mortality of seedlings and saplings; however, severe or prolonged drought may render even mature trees more susceptible to insects or disease. Effects of droughts are often combined with insect and pathogens damage and wildfires, e.g., drought-induced reductions in decomposition rates may cause a build-up of organic material on the forest floor, with ramifications for fire regimes.

Early model predictions of climate change impacts suggested extensive forest dieback and composition change, but more recent analyses suggest that catastrophic dieback will be a local phenomenon, and changes in forest composition will be a relatively gradual process. The effects of droughts can be at some degree ameliorated by increasing plant water use efficiency, and also by higher production during the other parts of the season under elevated CO2 levels. Another mediating effect could be increasing under elevated CO2 density of root system (Hanson and Weltzin, 2000)

Interaction with land use change

Recent studies suggest that the net direct and indirect climatic effects of historical changes in land use could be as important in explaining observed global warming over the past two decades as the net forcing from increasing concentrations of greenhouse gases and aerosols. Furthermore, land use change may also have been a factor in recent changes in global circulation, and hence in temperature and precipitation extremes over regional land areas (2004.) Land use change directly impacts forestry through deforestation (esp. in tropical rainforests) or reforestation and afforestation (e.g., on former agricultural lands in higher latitudes). The indirect impact includes changes in hydrology, pollutions, regional climate, etc. Forest adaptations to changing climate can act very differently in anthropogenically altered landscapes – e.g., species migration in highly fragmented forest landscapes can be slowed down due to ecological barriers. More remote, but potentially very costly is sea level rise, which can force movement of pulp and paper mills currently located in the coastal regions inland.

Socioeconomic impacts

Climate change impact on forests will further translate into many different social and economic impacts, which will affect businesses, landowners, consumers, governments and tourism. The magnitude of socio-economic impacts will depend on 1) the nature and rate of climate change; 2) the response of forest ecosystems; 3) the sensitivity of communities to the impacts of climate change and also to mitigation policies introduced to address climate change; 4) the economic characteristics of the affected communities; and 5) the adaptive capacity of the affected group (Natural Resources Canada, 2002). The size of affected population varies drastically between the regions. Tropical countries as a group have higher dependence on forests for subsistence and income and greater pressures for forest conversion to other land uses. It is estimated that 60 million highly forest-dependent people live in the rainforests of Latin America, South-east Asia and West Africa. An additional 350 million people are directly dependent on forest resources for subsistence or income, and 1.2 billion people in developing countries use trees on farms to generate food and cash (FAO, 2004b). However we don’t know of any study that would have quantitatively explored the full set of social impacts; the tendency is to restrict to economic assessments only.

Social consequences of climate change impact on forests include the fate of rural communities that rely on local forests as economic drivers (forest operations, saw- and pulp-milling, tourism, hunting, picking wild berries and mushrooms as subsistence commodities or for resale, firewood, collecting plants used in pharmacy, etc.) Forest-based communities may be especially vulnerable, not only due to the anticipated climatic impacts to forest ecosystems but also due to constraints on adaptability in rural, resource dependent communities to respond to risk in a proactive manner, "overadaptation" to a particular sector, the nature of commercial forestry investment planning and management decision-making, the potential by members of these communities to underestimate the risk associated with climate change, the multiplicity of climate change risk factors, etc. (Davidson *et al.*, 2003). Climate change can also lead to the changes in the availability of non-timber forest products (NTFP). The NTFPs play an extremely important role in local forest-based communities, especially in the developing regions under stress (for example see Lawrence, 2003).

5.4.4.2 Autonomous adaptations

The future effects of climate change will be a function of both the ecological responses and human adaptation. Most of the projected problems related to fire, disease, insects and reforestation failure are already addressed in forest management, but as the location and intensity of the problems change, the management should follow (Natural Resources Canada, 2002, Shugart *et al.*, 2003.) Some companies already conduct experimental silvicultural programs preparing for the types of risks associated with climate change – such as thinning management options to reduce the effect of droughts or consideration of long-term model forecasts in planning.

Several adaptation strategies can be used in the forest sector, including changes in land use choice, management intensity, hardwood/softwood species mix, timber growth and harvesting patterns within and between regions, rotation periods, salvaging dead timber, shifting to species more productive under the new climatic conditions, landscape planning to minimize fire and insect damage and provide connectivity, adjusting to altered wood size and quality (Alig *et al.*, 2002; Spittlehouse and Stewart, 2003). Adaptation strategies to control insect damage can include prescribed burning for reducing forest vulnerability to increased insect outbreaks, non-chemical insect control (e.g., baculoviruses), adjusting harvesting schedules, so that those stands most vulnerable to insect defoliation would be harvested preferentially. Changes in forest fire regimes as a result of climate change would necessitate adjustments in fire management systems. If professional foresters take proactive measures to substitute thriving tree species for failing species, to relocate elements of the forestry industry to productive regions, and to salvage trees during dieback, the sector may minimize the negative economic consequences of climate change, however, large-scale disturbances can have substantial effects on markets (Shugart *et al.*, 2003.)

Intensification of forest sector management can accommodate both short-term decrease in timber supply, such as might happen in 2040s-2080s in the USA (Alig *et al.*, 2002) and lower profits, yet market incentives for investments are likely to change. This trend in intensified forest management is consistent with greater reliance globally on managed forests, private forests, and plantations, along with greater reliance on smaller diameter, more uniform wood raw material. For some regions, especially the high-intensity forest plantation in the boreal regions, shifting to the short-rotation forestry can also help to optimize the benefits from the higher CO2 levels and warmer temperatures (Weih, 2004). Adaptation can also occur at the market level, such as changing the types of species used in producing end products. End products are made from a wider variety of species today than 30 years ago; such adaptations help protect the market from large-scale changes in supply (Shugart *et al.*, 2003.)

The long time lags between planting and harvesting trees, however, complicate the decisions for landowners. The adjustment dynamics will be complex, as adaptation may take place at multiple times during a forestry rotation. Introduction of monitoring systems, development of predictive models, engaging public in dialog on managing under changing climate can help adaptation process. Heavily managed forests receive significant amounts of human intervention in the form of planting, thinning, fertilizer treatments and other management activities, easy to adapt (Natural Resources Canada, 2002, Shugart *et al.*, 2003). However, large areas of forests, especially in developing countries (FAO and FRA, 2000) receive minimal direct human management, and thus may be more vulnerable to the effects of climate change.

Insurance

Worldwide, the insurance industry losses related to weather- and climate- related events are increasing through the last 50 years (MunichReGroup, 2004). It is likely that the frequency of extreme weather events will increase, leading to escalation in damage cost is likely (European Environment Agency, 2004). Furthermore, climate change will shift forests optimal geographical zones, stressing the existing vegetation, which will become more vulnerable to damage from fires, insects, pathogens, etc. All these factors increase the climate-related risks of forests landowners, inflating the cost of insurance. The cost and availability of insurance will be an additional factor influencing adaptation strategies of forest sector to changing climate-related risks; the government-backed disaster insurance may alleviate the costs (Rosenbaum *et al.*, 2004).

Industry and market: changed distribution of raw material (production, fluctuation, increase in global trade)

Adaptation in product markets may include using alternative species in the manufacturing process, changing the nature or location of capital and machinery, changing reliance on imports or exports, or adopting new technologies. With more potential forest inventory to harvest, the costs of wood and paper products to consumers are likely to decrease, as are the returns to owners of timberland. The changes in climate and consequent impact on forests are likely to change market incentives to harvest and plant trees, and shift land uses between agriculture and forestry. These changes will likely vary within a region. Market incentives for forestry are likely to moderate some of the climate-induced decline in the area of natural forests.

In 2002, more than 215 millions m3 of wood raw material was supplied to the international markets. International wood products trade comprises 3% of international merchandise trade, (FAO, 1995) involving every country in the world, with an industry annual turnover of US$ 330 billion (FAO, 2004b). It is expected that climate change will first benefit the producers in lower latitudes. The resulted increase of timber supply could re-shape and intensify international timber trade, affecting timber prices in mid- and lower latitude countries.

Production substitutes

It is unlikely that climate change will lead to decreasing supply of timber products; even if increasing tree dieback briefly hampers the production in Northern latitudes, indeed, salvage logging could increase supply during times of extreme dieback. Additionally, the supply of timber products can be achieved by the importation of growing timber harvested at the low latitudes. However, increasing frequency of extreme events can cause fluctuations in supply of particular commercially important species and force the market to use substituting products. This kind of substitution can be almost irreversible due to involved modifications to manufacturing equipment. Another factor for substitution of non-wood products with wood in consumption can be increasing supply of timber products (Alig *et al.*, 2002). Major transfer to renewable sources of energy will bring further development of the wood fuel and biofuel market (FAO, 2004b).

5.4.4.3 Regional level biophysical and socioeconomic impacts

The forest sector is affected by a series of interrelated factors which can be grouped into three classes: resource availability, the marketplace and the socio-economic context in which the industry operates. The most direct impact of climate change will be on resource availability. Climate change will be virtually certain to modify productivity, rotation cycle, species composition and (exploratory) timber quality, thus affecting timber supply. Climate change, possible increase in frequency of extreme events, and increasing supply can also affect markets. Additional factor of potential demand increase is replacing fossil fuels with renewable energy sources, carbon farming (see Chapter 9 of WGIII), carbon trading and carbon credits. New accounting and transaction methods could significantly change international trade in wood products. Finally, forest industry creates jobs and contributes to collective wealth (Canadian Forest Service, 2003). It is virtually certain that changes in timber supply, demand, major relocation of forest industry, increased reliance on import from low-latitude countries will bring numerous socioeconomic changes.

There is a modest confidence based on model simulations that global climate change will increase timber production. For example, Sohngen *et al.*, 2001 predicted a moderate increase of timber yield due to both rising NPP and poleward shift of the most productive species. The total merchantable yield increase by year 2145 was found to increase by 34-41% for North America, 4-24% for Europe, 44-66% for FSU, 27-32% for China, and 10-29% for Oceania. For Low-Mid latitude forests, yield will increase by 23-42% for South America, 29-47% for India, 11-28% for Asia-Pacific, and 21-37% for Africa. This in turn translates into the higher number of jobs in forestry. Bartelheimer, 2002 estimated, that for Germany each million m3 of domestic production leads to an increase of 10.000 jobs in forestry and the timber industry and a change in the value added of 500 mil £.

As the demand for timber production is quite inelastic, global economic impact assessments predict a general decline or a small growth of wood prices (Perez-Garcia *et al.*, 2002, Nabuurs *et al.*, 2002, Sohngen *et al.*, 2001, Joyce, 2000, Solberg, 2003, Ireland, 2004), and the benefits of higher production will mainly go to consumers. Producers' welfare sensitivity is roughly 10 times in percentage terms that of consumers' welfare, which in turn is roughly five times that of total societal welfare (Alig *et al.*, 2002). For the US, (Joyce *et al.*, 2001, McCarl, 2000, Alig *et al.*, 2002) indicated that the net impacts of climate change on the forestry sector will be small, ranging from slightly negative to positive impacts. Shugart *et al.*, 2003 come to the conclusion that the United States timber markets have low susceptibility to climate change because of the large stock of existing forests, technological change in the timber industry, and the ability to adapt. Consumers gain while producers could be harmed by declining prices, especially the existing timberland owners with the most productive forests.

As an example of local market analysis, Mendelsohn, 2003 in his modelling analysis done for California found that at first, climate change increases harvests by stimulating growth in the standing forest. In the long run, these productivity gains are offset by reductions in the area where productive softwoods can grow. The present value of these ecological effects is beneficial but small (1 %-3% gains). The long run consequences are harmful to the timber market, however, as the acreage of commercial forestland shrinks. California timber will be highly vulnerable to global price reductions due to increasing timber harvest. This leads to economic losses to California timber producers of over $1 billion but very large gains to California consumers of as much as $14 billion. As a result of a northward shift in forest productivity over the next century, timber markets would move to the mid- Atlantic region which is likely to experience more favourable growth conditions than South or West, though prices and inventories are difficult to predict.

5.4.4.4 Environmental consequences

Aside from timber production, long-term change in forest composition is likely to be of little or, at most, moderate significance to the value of such ecological services as landscape and water quality, protection against soil erosion, recreation and tourism. Bottomland forests play an important role in flood prevention. Moreover, climate change may substantially impact other quasi-market services, such as seeds, nuts, hunting, resins, plants used in pharmaceutical and botanical medicine, and in the cosmetics industry.

5.4.5 Capture fisheries and aquaculture: marine and inland waters

World capture production of fish, crustaceans and molluscs in 2003 was more than twice the quantity of aquaculture (Table 5.4), but capture production decreased by nearly 5% since 1997, whereas aquaculture increased by nearly 50%. Aquaculture resembles terrestrial animal husbandry more than it does capture fisheries and therefore shares many of the vulnerabilities and adaptations to climate change with that sector. Similarities between aquaculture and terrestrial animal husbandry include ownership, control of inputs, diseases and predators and use of land and water.

Table 5.4 *World Fisheries Production in 2003*

World fisheries production in 2003 in tons	Inland	Marine
Capture production		
Fish, crustaceans, molluscs etc.	8 941 754	81 277 992
Aquaculture production		
Fish, crustaceans, molluscs etc.	25 234 015	17 070 126
Aquatic plants	90	12 481 610
(source: FAO, Yearbook of Fisheries Statistics)		

Some aquaculture, particularly of plants and molluscs, depends on naturally occurring nutrients and production, but rearing of fish and crustacea usually requires addition of suitable food, often obtained from capture fisheries. Capture fisheries depend on the productivity of the natural ecosystems on which they are based and are therefore vulnerable to changes in primary production and how this production is transferred through the aquatic food chain. (Climate induced change in production in natural aquatic ecosystems is dealt with in chapter 4).

5.4.5.1 Primary effects and interactions

The positive and negative impacts of climate change on aquaculture outlined in the TAR remain valid. Potential negative impacts include (i) stress due to increased temperature and oxygen demand and decreased pH (ii) uncertain future water supply (iii) extreme weather events (iv) increased frequency of disease and toxic events (v) sea-level rise and conflict of interest with coastal defence needs (vi) uncertain future supply of fishmeal and oils from capture fisheries. Potential positive impacts include (i) increased growth rates and food conversion efficiencies (ii) increased length of growing season (iii) range expansion (iv) use of new areas due to decrease in ice cover.

Increasing temperature interacts with other global changes, including declining pH and increasing nitrogen and ammonia to increase metabolic costs. The consequences of these interactions is speculative and complex; an experimental study of Rainbow trout (*Oncorhyncus mykiss*) showed positive effects on appetite, growth, protein synthesis and oxygen consumption of a 2°C increase in winter, but negative effects of the same temperature increase in summer. Thus rising temperature may cause seasonal increases in growth, but also risks to fish populations living towards the upper end of their thermal tolerance zone (Morgan *et al.*, 2001).

Direct effects of increasing temperature on marine and freshwater ecosystems are already evident, with rapid poleward shifts in regions, such as the NE Atlantic, where temperature change has been rapid. (see box on Changes in plankton, fish distribution and production in the NE Atlantic). Local extinctions are occurring at the edges of current ranges, particularly in freshwater and diadromous species e.g. salmon (Friedland *et al.*, 2003) and sturgeon (Reynolds *et al.*, 2005).

Changes in primary production and transfer through the food chain due to climate will have a key impact on fisheries. Such changes may be either positive or negative and the aggregate impact at global level is unknown. There is evidence from the Pacific and the Atlantic that nutrient supply to the upper productive layer of the ocean is declining due to reduced meridional overturning circulation and upwelling (McPhaden and Zhang, 2002; Curry and Mauritzen, 2005) and changes in windborne nutrients. This has resulted in reduction in primary production (Gregg *et al.*, 2003), but there is considerable regional variability (Lehodey *et al.*, 2003; See also box on NE Atlantic plankton, fish distribution and production). At a more local level, the decline in pelagic fish catches in Lake Tanganyika since the late 1970's has been ascribed to climate induced increase in vertical stability of the water column, resulting in reduced availability of nutrients and lower primary production (O'Reilly *et al.*, 2004).

Coupled simulations used six different models to determine the ocean biological response to climate warming between the beginning of the industrial evolution and 2050. They show global increases in primary production of 0.7 to 8.1%, but with large regional differences. In the North Pacific simulation chlorophyll declined due to retreat of the marginal sea-ice biome. In the North Atlantic and Southern Ocean simulations chlorophyll increased, but it decreased adjacent to the Antarctic continent due to freshening within the marginal ice zone (Sarmiento *et al.*, 2005). Palaeological evidence and simulation modelling show North Atlantic plankton biomass declining by 50% during periods of reduced meridional overturning circulation (Schmittner, 2005). Such studies are speculative, but an essential step in gaining better understanding.

Climate change has been implicated in mass mortalities of many aquatic species, including plants, fish, corals and mammals, but lack of standard epidemiological data and information on pathogens generally makes it difficult to attribute causes (Harvell *et al.*, 1999). An exception is the northward spread of two protozoan parasites (*Perkinsus marinus* and *Haplosporidium nelsoni*) from the Gulf of Mexico to Delaware Bay and further north, where they have caused mass mortalities of Eastern oysters (*Crassostrea virginica*). Winter temperatures consistently lower than 3°C limit the development of the MSX disease caused by *Perkinsus* (Hofmann *et al.*, 2001) and the poleward spread of this and other pathogens can be expected to continue as such winter temperatures become rarer.

5.4.5.2 Enterprise scale

Although the positive and negative impacts of climate change on aquaculture, which are identified above, all act at the enterprise scale, many of the possible adaptations require coordinated action and funding at national and regional level. These include the introduction of new species for aquaculture, development of tolerant and resistant varieties of existing species, control of diseases and harmful algal blooms, policy for regulating water demand and forecasting extreme events.

In many parts of the world climate change is likely to exacerbate conflicts and pressures which affect fisheries at enterprise scale. Areas particularly affected will be (i) coastal areas which are vulnerable to sea-level rise and increasingly frequent storm surges (ii) areas where the development of fish-farming has compromised natural flood defences (iii) inland fisheries and fish farms relying on a continuing seasonal water supply, which is affected by changes in precipitation and water use.

5.4.5.3 Regional scale

Capture fisheries are based almost entirely on natural production and non-exclusive access to shared resources. Possibilities for enterprise-scale adaptation are therefore very limited and most of the impacts and adaptations occur at regional scale. The principal factors determining regional impacts and adaptations are: (i) characteristics of regional climate change (ii) changes in productivity and species composition of the fish resources (iii) regional dependence on fishing (in terms of employment, economic scale, food supply) (iv) fungibility, i.e. replacement of species by others which are functionally similar (v) adaptability of the industry to change in types of fish and fishing (vi) quality of governance (vii) level of understanding of the ecosystem response to climate change and to management measures.

Population fluctuations and changes in fish distribution due to interannual and decadal climate variability have been a historic feature of most capture fisheries. As a result the affected fishing enterprises and communities have developed considerable adaptability. In other cases, where the resource base has been more stable, traditional fishing methods, species, processing and markets have persisted.

Table 5.5 *Largest marine capture fisheries in 2003 (FAO, Yearbook of Fisheries Statistics)*

Species	**Landings (t)**	**% of Total**
Peruvian anchovy *(Engraulis ringens)*	6 202 447	9.1%
Walleye pollock *(Theragra chalcogramma)*	2 887 962	4.2%
Blue whiting (*Micromesistius poutassou)*	2 385 007	3.5%
Skipjack tuna (*Katsuwonus pelamis)*	2 110 681	3.1%
Japanese anchovy *(Engraulis japonicus)*	2 088 744	3.1%
Atlantic herring *(Clupea harengus)*	1 958 795	2.9%
Chub mackerel *(Scomber japonicus)*	1 851 753	2.7%
Chilean jack mackerel *(Trachurus murphyi)*	1 725 625	2.5%
Yellowfin tuna (*Thunnus albacares*)	1 484 825	2.2%
Largehead hairtail *(Trichiurus lepturus)*	1 450 803	2.1%

Most of the large global marine capture fisheries listed in the Table 5.5 are affected by regional climate variability. Recruitment of the two tropical species of tuna (skipjack and yellowfin) and the subtropical albacore (*Thunnus alalunga*) in the Pacific is related to regimes in the major climate indices, ENSO and the Pacific Decadal Oscillation (Lehodey *et al.*, 2003). Large-scale distribution of skipjack tuna in the western equatorial Pacific warm pool can also be predicted from a model linked to changes in ENSO (Lehodey, 2001). ENSO events have adverse effects on Peruvian anchovy production in the eastern Pacific (Jacobson *et al.*, 2001).

North Pacific ecosystems are characterised by "regimes shifts" - fairly abrupt changes in both physics and biology which then persist for periods of a decade. These changes have major consequences for the productivity and species composition of fisheries resources in the region (King, 2005). ENSO influences the regional climate of the North Pacific quite strongly and it should therefore be possible to extend the predictability of the system, which for ENSO is currently about 9 months.

Major changes in Atlantic ecosystems, from plankton to fish and birds, can also be related to regional climate indicators, in particular the NAO (Drinkwater *et al.*, 2003; See also box on NE Atlantic plankton, fish distribution and production). Surplus production of fish stocks, such as cod in European waters, has been adversely affected by the positive trend in the NAO since the 1960's and the recruitment is more sensitive to climate variability when stocks are at low levels (Brander, 2005). In order to reduce sensitivity to climate stocks must be maintained at higher levels.

Climate related reductions in surplus production cause fish stocks to decline at levels of fishing which had previously been sustainable, therefore the effects of climate must be correctly attributed and taken into account in fisheries management. Stocks at the edges of ranges are adapted to extremes and their genetic diversity is particularly valuable for continuing autonomous adaptation.

In order to make better use of information on climate change in planning management adaptations models relating interannual variability, decadal (regional) variability and global climate change must be improved.

Box 5.4 Changes in plankton, fish distribution and production in the NE Atlantic

The principal climate indicator for the N Atlantic, the NAO, has been rising over the past 30 years and the surface waters of the North Atlantic have been warming. This has caused extensive changes in the planktonic ecosystem. Although the precise mechanisms are not fully understood, we can detect consequences for plankton production, biodiversity, species distribution, and fisheries production.

Phytoplankton abundance in the NE Atlantic increased in cooler regions (north of 55^{o}N) and decreased in warmer regions (south of 50^{o}N) . The effects propagate up through herbivores to carnivores in the plankton food web (bottom-up control), because of tight trophic coupling. Similar effects may be expected for other mid-latitude pelagic ecosystems, because the proposed mechanisms are general and the results for the NE Atlantic are consistent and based on very large scale, long-term sampling. Richardson and Schoeman, 2004.

In the North Sea the population of the previously dominant copepod species, Calanus finmarchicus declined and was replaced by southern species. Beare *et al.*, 2002. The seasonal timing of plankton production also altered in response to climate changes. This has consequences for plankton predator species, including fish, whose life cycles are timed in order to make use of seasonal production of particular prey species. (Edwards and Richardson, 2004). The survival of young cod in the North Sea appears to depend on the abundance, seasonal timing and size composition of their prey. Changes in all of these since 1958 resulted in increased survival and good recruitment of cod throughout the 1960's and 70's and then a progressive decline over the past thirty years (Beaugrand *et al.*, 2003).

The decline of the European cod stocks due to overfishing has been exacerbated by climate induced changes in plankton production and these stocks are no longer able to provide as much surplus for the fishery as in the 1960's and 70's. As the stocks declined they have become more sensitive to the effects of the climate indicator (the NAO), due to shrinkage of the age distribution and geographic extent (Brander, 2005). This interaction between fishing and climate change effects has important implications for management policies.

To some extent the adverse effects of warming on fisheries production of the traditional "northern" species, such as cod, may be offset by increases in "southern" species, such as red mullet. There has been a northward shift in the distribution of many plankton and fish species by more than 10^o latitude over the past thirty years (Beaugrand *et al.*, 2002, Beaugrand *et al.*, 2003). This shift is particularly associated with the shelf edge current running north along the European continental margin and the northward shift does not apply across the whole Atlantic, because warming is not uniform across the whole basin.

Future warming is likely to alter the spatial distribution of primary and secondary pelagic production, affecting ecosystem services such as oxygen production, carbon sequestration and biogeochemical cycling and placing additional stress on already-depleted fish and mammal populations.

Box 5.5 The consequences of climate change on the fisheries of the Mekong River system

Fisheries are central to lives of the people, particularly the rural poor, who live in the lower Mekong countries. Two thirds of the basin's 60 million people are in some way active in fisheries, which represent about 10% of the GDP of Cambodia and Lao PDR. There are approximately 1000 species of fish commonly found in the river, with many more marine vagrants, making it one of the most prolific and diverse faunas in the world (MRC 2003).

The vast area of floodplain inundated during the wet season drives extraordinary fisheries productivity. Life cycles of fish are adapted to the geographical configuration of the river and its seasonal cycle of flood and recession. Many species undertake annual migrations from dry season refugees in the deeper sections of the river to inundated floodplains where they spawn, nurse and feed. Recent estimates of the annual catch from capture fisheries alone exceed 2.5 million tonnes (Hortle and Bush, 2003).

Direct effects of climate will occur due to changing patterns of rainfall, snow melt and rising sea level which will affect hydrology and water quality. Indirect effects will result from changing vegetation patterns that may alter the food chain and increase soil erosion. It is likely that human impacts on the fisheries (caused by population growth, flood mitigation, increased water abstractions, changes in land use and overfishing) will be greater than the effects of climate, but the pressures are strongly interrelated.

From an analysis of the impact of climate change scenarios on the flow of the Mekong, Hoanh *et al.* (2004) estimated increases in maximum monthly flows of 35 – 41% in the basin and 16 - 19% in the delta (comparing the periods 2010 - 38 and 2070 – 99 with 1961 - 90 levels). Minimum monthly flows were estimated to fall by 17 - 24% in the basin and 26 - 29% in the delta. Increased flooding would be positive for fisheries yields, but a reduction in dry season habitat may reduce recruitment of some species. However, planned water management interventions, primarily dams, are expected to have opposite effects on hydrology, namely marginally decreasing wet season flows and considerably increasing dry season flows (Anon. 2004).

Rising sea levels could result in transgression of marine waters into the Mekong delta. Inland movement of salt water would significantly alter the species composition of fisheries, but would possibly not be detrimental for overall fisheries yields. The delta currently contributes over 30% of the Mekong's capture fisheries.

5.4.6 Rural livelihoods: subsistence and smallholder agriculture and pastoralism

5.4.6.1 Current status of subsistence and smallholder agriculture and pastoralism

The fuzziness of definitions of both subsistence and smallholder agriculture mean that there are few informed estimates of world or regional population of these categories. While by no means all smallholders, even in developing countries, are poor, data generated by agencies concerned with rural poverty give some idea of the scale of these livelihood systems. 75% of the world's 1.2 billion poor (defined as consuming less than one purchasing-power adjusted dollar per day), or 900 million poor people, live and work in rural areas (IFAD, 2001). Earlier IFAD figures (Jazairy *et al.*, 1992 suggest that for developing countries as a whole, 52% of the rural population are smallholders (defined as farming 3 ha or less of crop land), 6% nomadic pastoralists, 7% indigenous minority peoples, and 4% small and artisanal fishermen. 25% were landless, which may have included some agricultural labourers, specialist livestock keepers and poor people not engaged in agriculture, and 6% refugees or internally displaced people. The proportion of smallholders in sub-Saharan Africa was higher at 73%.

5.4.6.2 Probable impact of climate change and increased climatic variability

The impacts of climate change on subsistence and smallholder agriculture and pastoralism will be a compound of location and livelihood-system impacts in different sectors/commodities (food crops, livestock, forestry, fisheries, also the subsistence use of fuelwood and medicinal plants), in different ecosystems and regions of the world, within a very specific context of high vulnerability and limited capacity for adaptation. As they are compounds it is and will remain hard to ascribe levels of confidence to these predicted impacts. Impacts will include not only the direct impacts of increased temperature, lower and/or more variable precipitation on crop yields, but also the effects of sea level-rise on coastal areas, increased frequency of landfall tropical storms (Adger, 1999), decreasing snowcap on major smallholder irrigation systems, particularly in the Indo-Gangetic plain, and other forms of environmental impact still being identified, such as increased forest fire risk (Agrawala *et al.*, 2003 for the Mount Kilimanjaro ecosystem) and remobilization of dunes (Thomas *et al.*, 2005 for semi-arid Southern Africa). Given rural livelihood diversification, impacts on other major rural activities, such as tourism, will be important to farmers and their communities.

Information on, generally negative, projections of yield changes in major smallholder crops in certain developing countries is included in Table 5.1. Of particular importance are the findings of Jones and Thornton, 2003 that aggregate yields of smallholder rainfed maize in Africa and Latin America are likely to show a modest decrease by 2055, but that these results hide enormous variability and give grave cause for concern, especially in some areas of subsistence agriculture. However more research is needed on climate change impacts of major smallholder crops such as cassava.

The location of a large body of SSAP households in the dryland tropics gives rise to especial concern over temperature-induced decline in crop yields, and increasing frequency and severity of drought. These will lead to (again, with difficulty of specifying confidence):

- increased likelihood of crop failure
- increased mortality of livestock and/or forced sales of livestock at disadvantageous prices
- livelihood impacts including sale of other assets, indebtedness, out-migration and dependency on food relief
- eventual impacts on human development indicators such as health and education.

Impacts of climate change will also be experienced in combination with impacts of globalisation (O'Brien and Leichenko, 2000). There is a similar risk of interactions with the impacts of HIV/AIDS.

5.4.6.3 Autonomous adaptation

There is a close and complex relation between coping strategies and adaptive strategies in the face of climate variability (Davies, 1996) and between both and adaptation to climate change. Adaptation to climate change among subsistence and smallholder farmers and pastoralists is likely therefore to take the form of intensification of existing coping and adaptive strategies, some of which have been described in 5.1.3 above: close attention to crop and varietal selection and planting dates, use of livestock (and switching between livestock species), diversification away from agriculture, and migration. However, Adger *et al.*, 2003 note firstly that there may be non-linearities in the extent to which autonomous adaptation can succeed in the face of climate change, and secondly that adaptation by farmers and by governments cannot be seen as separate: governments constrain or enable successful adaptation by farmers.

5.4.6.4 Increasing the adaptive capacity of farmers

Increasing the capacity of subsistence farmers to respond to climate aberrations and to adapt long-term to hotter, drier and most importantly more variable climates will very largely depend on improvements in institutions and policy. Many of these improvements will parallel those needed anyway to strengthen rural livelihoods.

- Increased understanding by decision-makers of subsistence and smallholder agriculture and the constraints, climate-related and otherwise, under which it operates.
- Improved management of agricultural knowledge: agricultural research and extension that incorporates the indigenous knowledge and experimentation of poor farmers, and better corresponds to their outstanding information needs (Pound *et al.*, 2003).
- Increased security of tenure for land, though not necessarily through land markets or formal titling, and an enhanced space for poor farmers to manage their own resources at community level (Toulmin and Quan, 2000, Deininger, 2003).
- Given the importance of female labour and female knowledge in subsistence and smallholder agriculture, natural resource management, and coping with disasters,

recognition of these will have to be mainstreamed into policies (Nelson *et al.*, 2002).

- In some regions of the world, physical security through management of armed conflict is an important precondition for increasing adaptive capacity.
- The ending of perverse incentives to engage in environmentally unsustainable farming (such as artificial floor prices for cereals grown in rainfed areas, or subsidised mass supply of animal feed as "drought relief") (Oram, 1998, Hazell *et al.*,).

5.4.6.5 Environmental consequences of impacts and adaptation

Many of the regions characterized by subsistence and smallholder agriculture are storehouses of unexplored biodiversity (Hannah *et al.*, 2002). Pressure to cultivate marginal land or to adopt unsustainable cultivation practices as yields drop, and the break down of food systems more generally (Hannah *et al.*, 2002) may endanger biodiversity of both wild and domestic species. Smallholder and subsistence farming areas are often also environmentally marginal (which does not necessarily conflict with biodiversity) and at risk of land degradation as a result of climate trends, but mediated by farming and livestock-production systems (Dregne, 2000).

5.5 Costs and other socioeconomic aspects, including food supply and security

5.5.1 Global economic costs

Fischer *et al.*, 2002) quantify the impact of climate change on global agricultural GDP by 2080 as between -1.5% and + 2.6% with considerable regional variation. In general, developed countries stand to benefit from climate change, while developing countries – with the exception of Latin America – would be confronted with a decline in their agricultural GDP.

Parry *et al.*, 1999 estimate that, compared to the no climate change situation, cereal yields could change between -5% and + 2.5% (by 2050) depending on the region. Fischer *et al.*, 2002 however estimate that, taking into account economic adjustment, global cereal production by 2080 falls within a 2% boundary of the no climate change reference production.

Again there are considerable regional variations with increases of 6-9% in North America and the Russian Federation and declines of 4-10% in Asian developing countries.

There is considerable uncertainty as to the impact of the CO2 fertilization effect which could compensate for much of the yield reductions due to changes in temperature and rainfall. Rosenberg *et al.*, 2001 suggest that such benefits (gains in water use efficiency) could continue until the end of the century (2095 to be exact). A report of the Royal Society, 2005, however mentions that recent research shows that the impact of the CO2 fertilization is considerably lower than assumed thus far.

Livestock production in developing countries might suffer due to heat stress and deteriorating grass lands, while climate change might favour livestock production in temperate areas (including China and Argentina) due to a reduced need for winter housing and feed concentrates (because of higher pasture growth).

Alig and al., 2004 discuss that climate variability and climate change may alter the productivity of forests shifting resource management, economic processes of adaptation and forest harvests both nationally and regionally. Such changes may also alter the supply of products to national and international markets as well as change the prices of forest products and economic welfare. However, as pointed out by Irland, 2001, there are difficulties in modelling these impacts.

These authors stress the uncertainties in specific forest impacts at a regional scale, the difficulties to model decision makers handling of climate change in real decision making and that economic models to date have relied heavily on assumptions including the assumptions employed in the forest growth models. Current studies consider mainly the one way impact of climate change on forest resources, industry and economy. Integrated analysis would include feedbacks in the ecological system and with the greenhouse gas cycling in forest ecosystems and forest products. There are a number of studies analyzing the effects of climate change on the forest industry and the economy (e.g. Binkley, 1988; Joyce, 1995; Perez-Garcia, 1997; Sohngen, 1998). The authors stress the view that the impacts on the industry and the economy cannot be predicted with confidence due to uncertainties in regional climate scenarios, ecological feedback responses and in the decision making with respect to climate change.

If the world develops as the models predict, there will be a general decline of the wood raw material prices due to increased wood production (Perez-Garcia, 1997; Sohngen, 1998). The same authors conclude that the economic welfare effects are relatively small — an increase with some percentages. However, the regional imbalances in supply/demand are assessed to increase and in this case there will be increased international trade. The analysis also suggests that appropriate policy measures in the market place can mitigate and even reverse the economic impacts of climate change.

With respect to the non-wood services from the forest resources there is no solid global analysis carried out but it can be concluded that the impacts on these services by climate change will be spatially very specific and detailed spatial analysis are required to assess these impacts.

The above results are achieved given the uncertainties stated above and with a very simple or no representation of the risks and vulnerability associated with climate change.

[Keith: Fisheries needs inclusion in this discussion, can Sophie add to this discussion for the SOD?--WE]

5.5.2 Changes in trade

The impact of climate change on temperate products (e.g. cereals and livestock products) is an increased production potential in the temperate zones matched by a declining potential in the tropics. This could lead to corresponding shifts in production and an increased flow of such products from the temperate countries to tropical countries. This would be additional to the already dramatic increase in such trade flows as foreseen in Bruinsma, 2003, and FAO, 2005 , under a no climate change situation. E.g. Fischer *et al.*, 2002 estimate the additional cereal imports into developing countries by 2080 at between 10 and 40%.

5.5.3 Regional costs and associated socioeconomic impacts

Fischer *et al.*, 2002, quantify the impacts for major countries and country groups as follows: globally there will be major gains in potential agricultural land by 2080, particularly in North America (20-50%) and the Russian Federation (40-70%). Substantial losses (up to 9% however are predicted for sub-Saharan Africa. Developing countries would experience a considerable decline in wheat production potential.

Africa

Yields of grains and other crops could decrease substantially across the African countries due to increased frequency of drought, even if potential production should raise because of the increase in CO_2 concentrations. Some crops (e.g. maize) could be forced out of production. Livestock production would suffer due to deterioration in the quality of rangeland associated with higher concentrations of atmospheric carbon dioxide and to changes in areas of rangeland (increase of unproductive shrub-land and desert). Socio-economic factors influences responses to changes in crop productivity, with price changes and shifts in comparative advantage (Parry *et al.*, 2004.

There is a general belief that climate change, through increased extremes, will worsen the food security situation in Africa. Africa is already experiencing a major deficit in food production in several regions, and potential declines in soil moisture will aggravate the situation. The nature of the food supply system is complex, as moderate increases in air temperatures do not necessarily mean shortfalls in cereals (Parry *et al.*, 2004). In all countries of sub-Saharan Africa, where agriculture is the main source of national incomes/revenues, climatic fluctuation is one of the important elements that must be taken into account in long-term decision making (Sivakumar, 1997).

Asia

According to the Murdiyarso, 2000 rice production in Asia could decline by 3.8% over the current century. Similarly, a 2 ^{o}C increase in mean air temperature could decrease rice yield by about 0.75 tonne/ha in India and rain-fed rice in China could decrease by 5-12% (Lin *et al.*, 2004). Suitability for wheat growing could decrease in large portions of South Asia and the Southern part of East Asia (Fischer *et al.*, 2002). For example, a 0.5 ^{o}C increase in winter temperature would reduce wheat yield by 0.45 ton/ha in India (Naveen *et al.*, 2003) and Chinese rain-fed wheat production could decrease by 4 to7% by 2050, but wheat production would increase from 6.6 to 25.1% in 2050 if the CO_2 fertilization effect is taken into account (Lin *et al.*, 2004). According to Hadley Centre global climate model, HadCM2, the direct physiological effects of CO_2 on crop yields (wheat, maize, rice) show increases up 20% in East and South East Asia while it would decrease up to 30% in Central and South Asia.

Climate change can affect not only crop production per hectare but also the extent of area suitable for production. Most land that is suitable for cultivation is already in use (IPCC, 2001a). According to the study of Fischer *et al.*, 2002, GCM projections for the 2080s show decreases in potentially good agricultural land in Western Asia, East Asia and Japan, but substantial increases in suitable areas and production potentials in all land as well as in current cultivated land in Central Asia. There is a clear indication of the northward shift of agricultural zones: by 2040 the dry steppe zone that currently occurs in the eastern part of Mongolia pushes shifts northward (Batima, 2003) (Batima *et al.*, 2004). Seven climate change scenarios derived from GCM suggest that the triple-planting boundary will shift 500 km to northern China from the Yangtz river valley to the Yellow River basin, and double planting regions will move to the middle part of the current single planting areas, while single planting areas will decrease by 23.1% in 2050 (Wang, 2002).

Latin America

Several studies using crop simulation models and future climatic scenarios based on GCM projections were carried out for commercial annual crops. The magnitude of the impacts was highly dependent on the GCM used. For example, in Argentina (Magrin and Travasso, 2002;

LA27 2004), rainfed yields for maize, wheat and soybean could increase up to 45% or decrease roughly 20%. Under irrigated conditions, yields could be reduced up to 18% or increased up to 42%. The same behaviour was observed in Brazil (De Siqueira *et al.*, 2000; LA27, 2004) where future rainfed wheat yields could oscillate between increases of 13% and reductions of 31%.

The aggregate production impact of possible future climate change to 2055 on smallholder rainfed maize production in Latin America (Jones and Thornton, 2003) would be close to a reduction of 10%. This decrease is certainly serious but it can reasonably be expected that this level of decrease will be compensated for by plant breeding and technological interventions in the intervening period, given the history of cereal yield increases since 1950 (Pardey and Beintema, 2001). In some countries, such as Colombia, overall yields will remain essentially unchanged to 2055, while in others, such as the Venezuelan piedmont, they are predicted to decline to almost zero.

Impacts of climate change on land use were also reported. In Brazil under actual climate conditions the coffee area in San Pablo occupies 39% of the total state's area. Considering increases of 15% in precipitation and increases of 1ºC and 5.8ºC in temperature, this area would be reduced to 29.9% and 1.1% respectively (Pinto *et al.*, 2002).

5.5.4 Food security

Globally an increased agricultural production potential due to climate change (Fischer *et al.*, 2002) should in principle add to food security, but locally the situation can be very different. A reduction of production potential (yields, land suitability) in tropical developing countries, many of which are already faced with a serious food insecurity situation, would add to the burden of such countries.

For most countries however, the main factor determining food security is not climate change but general economic development, i.e. a country's capacity to purchase the food needed in world markets. This is also the conclusion of Fischer *et al.*, 2002.

Bruinsma, 2003 concludes that it is unlikely that the level of world market food prices will be much influenced by climate change.

5.5.4.1 Food insecurity

In most parts of the world, food security is influenced by political, economic, and social conditions, in addition to climatic factors (Leichenko and O'Brien, 2002). Economic development in particular is a key determinant of food security, as it increases a country's capacity to purchase food in world markets (Fischer *et al.*, 2002).

5.6 Planned Adaptation Options and Capacities

Many options for planned (i.e., policy-based) adaptation to climate change have been identified for agriculture and other managed ecosystems such as forests (Aggarwal *et al.*, 2004; Bryant *et al.*, 2004; Howden, 2003; Easterling *et al.*, 2004; Kurukulasuriya and Rosenthal, 2003). In broad terms, these include: investments in research to better understand how crop and livestock species can be adapted to changing environmental conditions, including the use of conventional breeding and biotechnology (see Box 5.3); programs and technologies to better inform farmers and other resource managers about possible climate changes and options to adapt to them; investments in infrastructure for water management and for product transportation and marketing. In additional, changes in policies and institutions may be needed to facilitate adaptation to climate change. These could include changes in international agreements governing exploitation of natural resources such as fishers and forests, as well as domestic and trade policy liberalization, already promoted through the World Trade Organization, that increases market efficiency and reduces the local price and production impacts of climate shocks (both positive and negative) to agricultural production systems. It is important to note that many technology, policy and institutional changes may not be motivated by climate change but may well have significant impacts on the capacity to adapt to climate change, as confirmed by recent studies, as noted in Table 5.2. A key challenge for climate change research is to identify these linkages and interactions so they may be factored into the policy formation process at national and international levels.

The capacity to plan and implement adaptation, at local, national and international levels, remains largely untested and uncertain. Much of this uncertainty is due to the fact that few governments or non-governmental institutions have yet made serious attempts to incorporate climate change considerations into their policy formation and implementation. Experience thus far with international institutions that operate on a consensus basis, including the World Trade Organization and the United Nations Framework Convention on Climate Change, show that reaching an international consensus can be a slow process. Reaching a consensus on climate change is even more difficult than other negotiations because of the uncertainty about climate change itself. Moreover, it is difficult to assess in an *ex ante* sense the capacity to adapt, because there is a limited understanding of the processes that govern political decision making and institutional change. There is little or no scientific consensus about the ability of social organizations to respond predictably or rationally to perceived changes in the drivers of the global systems on which life depends, whether they be environmental, technological, or social and political (Ruttan, 2003).

Many researchers conclude that the magnitude of climate change impacts will depend on the rate of climate change, and likewise the rate of change should have important implications for adaptation. If the rate of climate change is slow enough, then climate change will likely have little impact on the depreciation and obsolescence of various forms of capital (natural, physical, human, social). But if climate change is sufficiently rapid, it will necessitate changes in the type and location of various forms of capital at a more rapid rate than would be experienced otherwise, implying higher costs of adaptation (Quiggin and Horowitz, 2003).

The process of investment in physical and human capital is relatively well understood (can provide citations). The processes governing ecosystem dynamics also have received much scientific attention and continue to be a focus of research (citations?). Economists also have studied the various aspects of the process of technological innovation and how it is influenced by economic conditions and government policy. One of the important economic concepts is *induced innovation*, namely that the direction of innovation brought about purposeful investment in research and development, is influenced by resource scarcity and by prices of factors of production (land, labor, capital, etc.). Research has confirmed, for example, that the patterns of technological innovation in agriculture have generally served to reduce the dependence on the scarcest resources in each country where high rates of productivity growth have been observed during the 20th Century (Hayami and Ruttan, 1985). Importantly for the analysis of planned adaptation, much of the agricultural technology that was developed in response to resource scarcity came from public research institutions in the United States and other countries. This experience suggests that if climate change causes a change in resource scarcities, public institutions do have some capacity to respond to those evolving scarcities.

However, experiences over the past 50 years have shown a highly varied capacity of governments and institutions to respond effectively to recognized trends in environmental, economic and social conditions. The World Bank's experience with economic development policy has led it to recognize the importance of all types of institutions in successful economic development (World Bank *et al.*, 2002). Available data show positive correlations between rates of economic growth and political stability, democratic institutions, application of the rule of law, and well-defined and enforced property rights, although sorting out causality among these indicators is difficult. Based on this experience, there should be a positive relationship between well-functioning institutions and a society's capacity to design and implement policies that promote adaptation to climate change through research, infrastructure investment, and related policy and institutional changes.

Box 5.6 Is Biotechnology the Answer to Agricultural and Forest Adaptation to Climate Change?

Biotechnology can be defined as any technique that uses living organisms or substances from living organisms to make or modify products for specific use (FAO, 2004). Modern biotechnology includes a range of tools that scientists employ to understand and manipulate the genetic makeup of organisms for use in the production or processing of agricultural products. It has the potential for a quantum leap in agricultural and forestry productivity in developed and developing countries (Cheikh *et al.*, 2000; FAO, 2001; Cockburn, 2004). Breakthroughs in molecular genetic mapping of the plant genome have led to the identification of bio-markers that are closely linked to known resistance genes such that their isolation is clearly feasible in the future. When the desired trait is found in an organism that is not sexually compatible with the host, it may be transferred using genetic engineering. Biotechnology has the potential to relieve both abiotic (e.g., drought, heat and cold, salinity, heavy metals) and biotic (e.g., insects, pathogens, weeds) stresses, all of which are directly or indirectly affected by climate change. Two forms of stress resistance especially relevant to climate change are drought and temperature. A number of studies have demonstrated genetic modifications to target plants that increased their water-deficit tolerance (as reviewed by Cheikh *et al.*, 2000: Pilon-Smits *et al.*, 1995; Drennen *et al.*, 1993; Kishor *et al.*, 1995). Concern that water stress resistance found in the narrow range of target plants may not extend to the wider range of crop plants exists among researchers but they agree that the potential for progress is high. Cheikh *et al.*, 2000 point out that less effort has gone into genetic engineering for high-temperature resistance than low temperature resistance. It is generally believed that plant cells respond to heat stress through the expression of heat shock proteins and that heat-tolerance gain may be possible by engineering plants to overexpress such proteins (Hinderhofer *et al.*, 1998).

Although biotechnology shows great potential as an adaptation tool for dealing with climate change, it is still in its earliest developmental stages. Farmers' use of transgenic crops is limited but growing rapidly, particularly in the United States, China, and Argentina. Globally, plantings of transgenic crops grew from 1.7 million hectares in 1996 to 67.7 million hectares in 2003 (ISAAA, URL: http://www.isaaa.org). While genetic modification activities in forestry occur in at least 35 countries and over 200 field trials involving genetically modified trees are known, only China has so far reported commercial tree plantations (1.4 million planted trees on between 300 and 500 ha in 2002) (FAO, 2004.1).

In the United Kingdom and Europe, there is considerable public resistance to allowing genetically-modified (GM) plants and animals to enter the food chain due to concerns over potential health and environmental risks (Falk *et al.*, 2002). Such resistance is low elsewhere and may be lessening in the United Kingdom and Germany where GM crops recently have been approved for production (Vogel, 2004). People from poorer countries are, in general, more likely to agree that the benefits from biotechnology exceed the risks and that it will be beneficial to them (FAO, 2004a). However, clearly, public attitudes toward GM crops and animals will be an important factor regulating the degree to which biotechnology will be used to adapt to climate change. Public education and effective government evaluation and approval standards are required for wider dissemination of GM organisms (Falk *et al.*, 2002).

Biotechnology is not expected to replace conventional agronomic breeding, but Cheikh *et al.*, 2000 and FAO, 2004a argue that it will be a crucial adjunct to conventional breeding and both will be needed to meet future demographic and environmental challenges, including climate change. It is likely to be part of the answer to successful adaptation of agriculture and forestry to climate change.

5.7 Implications for sustainable development

5.7.1 Implications of environmental consequences of adapting agriculture, fisheries and forestry

Sustainability is a dynamic concept referring to a certain time horizon, under which the environmental, social and economic needs of the present generation are met without compromising the needs of future ones (World Commission on the Environment and Development, 1987**).** Adaptation is the adjustment of natural or human systems to changed environments (IPCC, 2001b). Both are clearly linked, and it can be argued that adaptation is required to maintain the sustainability. Current knowledge of adaptation to climate change and adaptive capacity is insufficient for a rigorous evaluation of planned adaptation options, measures and policies (IPCC, 2001b).

Human societies have, through the centuries, developed the capacity to adapt to environmental change (Easterling *et al.*, 2004), and some knowledge about the implications of climate change adaptation for sustainable development can thus be deduced from historical and analogous cases in the past (IPCC, , ch 18:9).

The vulnerability of human populations and natural systems to climate change differs across regions and within regions (IPCC, 2001b), with LDC being amongst the most vulnerable (Huq *et al.*, 2003). Vulnerability arises from a set of socio-economic, cultural and biophysical conditions. The impact of climate change is mediated by social adaptive capacity. The direct link between low economic income, limited adaptive capacity and vulnerability, for individuals as well as for countries, has been described earlier (Rayner and Malone, 1998, IPCC,). It is the poor who are among the most vulnerable to famine, malnutrition and hunger. This vulnerability is also “exacerbated by recurrent droughts, inequitable land distribution, environmental degradation and natural resource mismanagement” (Dixon *et al.*, 2003). “The ability to adapt is clearly dependent on the state of development” (IPCC, 2001b, ch.18).

Sustainable economic development and poverty reduction remain top priorities for developing countries (Aggarwal *et al.*, 2004). Any adaptation measures have therefore to be developed as part of, and closely integrated into, overall development strategies and programmes, into country programmes, Poverty Reduction Strategy Programmes (Eriksen and Naess, 2003 and Pro- Poor strategies ; Kurukulasuriya and Rosenthal, 2003), and to be understood as a "shared responsibility" (Ravindranath and Sathaye, 2002- in: Climate change and developing countries: 86). GEF provides funding for such adaptation measures through the Adaptation Fund established under the Kyoto Protocol, and to a limited extent through the Special Climate Change Fund and the Least Developed Country Funds, both established under the UNFCCC. The fostering of economic growth is one of the factors that will strengthen the adaptive capacity of countries, e.g. in Sub-Saharan Africa (Ikeme, 2003). It needs to be complemented, though, by investments in human and social capital and strategies for pro-active, adaptive ecosystem monitoring and management that strengthen the resilience of our complex socio-economic systems.

Evaluation criteria and systems are required to assess the impacts of adaptation measures, weigh their benefits against the costs and reduce risks (European Environment Agency, 2004: 79-81) are essential for the measures to positively contribute to sustainable development. One decision-making framework for adaptation strategies is the Multiple Criteria Evaluation (MCE) framework. It involves a scoring system with the criteria of effectiveness, flexibility, institutional compatibility, farmer implementability and independent benefits of adaptation measures and their risks as part of a broader evaluation (Dolan *et al.*, 2001).

The shift in land productivity may lead to a shift in agriculture and livestock systems in some regions, and to agricultural intensification in others. Environmental costs will include soil degradation, siltation, reduced biodiversity, and others (Stoate *et al.*, 2001). Many adaptation measures to deal with these changes may be modifications of ongoing farm practices (Smit and Skinner, 2002).

Adaptive measures like crop changes or changes in land-use can also alter basic patterns of productivity stability and sustainability in agro-ecosystems. Adaptation responses have therefore to be long-term and location-specific (Viglizzo *et al.*, 1997). Limited non-climate stress on the agricultural sector will increase the resilience of stakeholders and systems to deal with the new challenge. Without also addressing the wide-ranging problems that make the agricultural sector vulnerable, adaptation measures will have limited success (Kurukulasuriya and Rosenthal, 2003).

Adaptation is applied at national and local levels. However, in responding to water shortages, for example, adaptation has to be coordinated at regional and international levels. Unilateral adaptation measures to climate change-related water shortage can lead to competition for water resources and, potentially, to conflict. Inter-regional and cross-border approaches are required to develop joint solutions, such as, for example, Trifinio in Lempa valley (Honduras, Guatemala, El Salvador) (Dalby, 2004).

It is predicted that climate change will lead to habitat and ecosystem shifts. Adaptive measures such as expansion of agriculture into previously forested areas will lead to additional loss and fragmentation of habitats. In response, conservation strategies will have to focus increasingly on regional and international landscape development (Opdam and Wascher, 2004).

For temperate forests in the US, as for Central Europe, a redistribution of tree species can be expected (Iverson and Prasad, 2002), where Picea abies may give way to Pinus sylvestris (Borchert and Kölling, 2004; Jönsson. *et al.*, 2004). Increased disturbance may foster invasion by exotic species (Loehle, 2003. This altered mix of species, resulting both from natural and planned adaptation, and the conservation strategies adopted will impact forest products trade (Perez-Garcia *et al.*, 2002) and thus development at local and national levels.

5.8 Key Conclusions and their Uncertainties, Confidence Levels, Research Gaps

This concluding section summarises key conclusions about the consequences of climate change for food, fibre, forestry, and fisheries. Levels of uncertainty are expressed by degrees of confidence in major conclusions. Key vulnerabilities are summarised in Table 5.6 *[CLA note: this table will likely be moved to Chapter 19]*. We also identify key research gaps that constrain our understanding and recommend key research priorities.

5.8.1 Findings and Key Conclusions

Important findings of the chapter are:

- the impact of climate change on food security should be seen against the expected long-term developments in the overall economy (e.g. on average strong increase in purchasing power), its sectoral composition (e.g. declining share of agriculture) and related characteristics (e.g. less people dependent on agriculture and less dependence on natural resources).
- a large number of short-term responsive (or autonomous) adaptations are possible in cropping systems. Many of these are extensions of existing risk management activities. The potential effectiveness of the adaptations varies from only marginally reducing negative impacts to more than fully offsetting them. The likely adoption rate of these adaptations is uncertain.
- research on fibre crops in rural economies, such as Jute and Kenaf, is lacking.
- the outcome of future increases in CO_2 levels favoring C3 over C4 crop and forage plants versus temperature increases favoring C4 over C3 plants is not clear.
- because forestry is already in a transition toward the establishment of planted forests, management can assist natural processes in restructuring forest composition and harvest practices that are consistent with regional climate changes.
- natural adaptation of fisheries to climate change may result from selection of tolerant strains, but these are most likely to occur at the edges of ranges, which are most vulnerable to being depletion by overexploitation
- increasing the capacity of subsistence, small-holder and pastoral agriculture households to respond to climate variability and climate change will largely depend on improvements in institutions and policy, including increased understanding of subsistence agriculture by policy-makers, improved management of agricultural knowledge, and more secure property rights

It is concluded with *high confidence*:

Food crops and livestock

- In the short-term, impacts of climate change on food crops are more severe in the equatorial and dry tropics than in temperate latitudes; Potential negative yield impacts are particularly pronounced in several regions where food security is already challenged and where the underlying natural resource base is already poor. Medium and longer term (2050 and beyond) impacts are uniformly stressful to crop yields globally.
- International agricultural trade flows are foreseen to rise dramatically (even in the absence of further trade liberalization or climate change). The impact of climate change would lead to an increased flow of temperate products (e.g. cereals and livestock products) from the temperate countries to tropical countries. More economic equilibrium analyses with explicit account of trade, show that inter-regional and international trade generally mitigate impacts

of climate change.

- Under optimal conditions doubled CO_2 increases leaf photosynthesis by 30-50% in C3 plant species and by 10-25% in C4 species. In terms of final food, fodder, fibre and wood products, the range of observed responses under elevated CO_2 is larger, about 0-50%, due to species, sector and management regimes interactions, modulating optimal leaf responses; Elevated CO_2 will shift current photosynthetic optima towards higher temperatures; and increase stomatal resistance, improving water-use efficiency and drought resistance. In the field many factors such as soil and water quality; pests and disease, and resource competition reduce gains observed in experimental settings.
- Elevated carbon dioxide levels will alter food quality to grazers both in terms of fine-scale (protein content, C/N ratio) and coarse-scale (C-3 versus C-4 and versus pasture legume) changes;
- Plant species composition change induced by climate change will be an important mechanism altering pasture production and its value for grazing livestock, especially in drier rangelands with woody shrub invasion and in warm humid climates with C_4 invasion;
- The heat stress of domestic animals will also increase (High confidence) as well as the death rate in drought prone areas (Medium confidence). The impact on animal productivity due to increased variability in weather patterns will likely be far greater than effects associated with the average change in climatic conditions (High confidence)
- Observed recent increases in temperature are extending growing seasons in temperate and boreal ecosystems.
- The rise in temperature in humid and temperate grasslands will reduce the need for winter housing and for feed concentrates for livestock. Many developing countries, by contrast, are likely to suffer production losses through greater heat stress to livestock;

Forestry

- Climate change is virtually certain to impact forestry in commercially important regions by altering species composition and productivity. Confirming the effect first reported in TAR, a number of studies predict that moderate temperature increase is likely to positively affect global forest growing stock volume.

Fisheries

- No compelling evidence has emerged since the TAR that marine fisheries production will increase or decline due to climate change.
- Fisheries are dependent on plankton production, which will be affected by changes in nutrients, stratification, pH and ice cover, but the scale and scope of future changes in plankton is poorly known.
- Plankton and fish distributions have changed, with rapid poleward shifts in middle and high latitudes (e.g. North Atlantic), where temperature has increased. Seasonal patterns of plankton production have changed, with consequences for fisheries production. Further temperature increase will continue to cause distribution shifts.
- Local fish extinctions are occurring at the edges of ranges, particularly in freshwater and diadromous species (e.g. salmon, sturgeon). Fishing impacts are particularly harmful where climate induced decline in productivity occurs without corresponding reduction in exploitation rates. This is most likely to occur at the edges of species ranges.

It is concluded with *medium confidence:*

Food crops and livestock

- Increases in climatic extremes, were they to accompany climate change, will increase crop and livestock losses, thus increasing associated insurance and disaster relief costs in regions where they occur. There also will be increased risks of soil degradation and reduced grain yield and quality. The frequency and severity of extreme cold conditions such as frost events diminish with increased temperatures, allowing increased flexibility in crop management, thus increasing yields and returns.

- In intensive farming systems, where management flexibility is possible, land managers are in a position to buffer the negative effects of climate change and to benefit from the positive effects. In more extensive farming systems, which are operating close to the threshold of sustainability, management options are fewer and consequently, these systems remain far more vulnerable to climate change;
- Climate changes increase irrigation demand in the majority of world regions due to a combination of decreased rainfall and increased evaporation arising from increased temperatures. This combines with reduced water availability to provide a significant challenge to future water and food security. In a few regions, water demand decreases, partly as a result of management changing growing seasons.
- Warming favours over-wintering of pathogens, leading to increased disease severity. Additional disease problems as climate change and related variability alter geographic ranges of hosts and pathogens.
- While nutrient *quantity* may increase, nutrient *quality* of food grown under elevated CO_2 and climate change will be lower than at present. Grain protein concentration is reduced under elevated CO_2, downgrading its use and economic value and impacting on the diet of people in areas where dietary protein is currently marginal. Increased frequency of temperature extremes also reduces grain quality in affected crops.

Forestry

- New data from FACE studies and simulation results suggest that the effect of CO2 fertilization on forest NPP will probably be somewhat lower than expected in many regions if limiting factors such as N availability are taken into account.
- Climate change will shift the current boundaries of insect species and modify tree physiology and tree defences resulting in more frequent and severe events of insect damage;
- Many forests will be unable to adjust to warming, and will be replaced by species better adapted to warmer temperatures such as grasslands. As warming continues, many tree species shift to higher altitudes and/or latitudes.
- Regional changes in comparative advantage of timber production will reshape the current system of global timber trade; timber prices are expected to fall in light of anticipated increased global supply, the benefits will mainly go to consumers.

Subsistence, smallholder, and pastoral agriculture

- Subsistence, smallholder and pastoral (SSAP) households suffer from multiple sources of vulnerability: environmental, market-related and governance-related. These constrain the extent to which these households can cope with climate variability, and are thus likely to constrain the extent to which they can adapt to climate change.
- SSAP households will suffer hard-to-predict impacts of climate change, with impact being a location and farming-system specific compound of direct impacts on crop, livestock, forest and fisheries productivity, combined with additional location-specific impacts such as sea-level rise and snow-pack decrease.
- Climate change in regions characterised by subsistence and smallholder agriculture and pastoralism, particularly when combined with population growth, will accelerate land degradation and endanger biodiversity.

It is concluded with *low confidence:*

Food crops and livestock

- At the global level, climate change will lead to an increase in agricultural production potential;

Industrial crops, biofuels, and plantation crops

- Long-term experiments recently concluded that certain plantation tree crops show long-term decline in the level and activity of photosynthetic enzymes as the plants acclimate to their environment through *down-regulation*; down-regulation is suggested for future plantation tree crops;

Forestry

- Increased temperatures and altered precipitation extremes will increase fire risks to commercial forests;

Fisheries

- Freshwater fisheries are more sensitive to climate variation and change due to geographic discreteness.
- Further temperature increase on top of those observed to date will continue to cause local fish extinctions.

Table 5.6 headed for Chapter 19. Key Vulnerabilities. *First inputs from Chapter 5 (Food, Feed, Fibre, Fisheries). Please note that this is not a final product of our chapter, only ZOD stage thinking.*

Vulnerable system	**Impacts (confidence)**	**Description (criteria)**	**Critical level (confidence)**	**Comments**
Fisheries	Declining pH in oceans *(high confidence)*	Affects corals, calcareous diatoms, squids etc... Unknown effects on the marine food webs.	To be checked	Recent finding on pH drop is known with high confidence, but the impacts on fisheries are not established.
Fisheries	Increased water temperature in freshwater and closed sea systems (high confidence)	In such water systems, migration is constrained. Populations at the edge of their adaptation limits are likely to decline. Biodiversity loss.	To be checked	Empirical evidence in various regions. Magnitude of impacts and thresholds to be established
Forestry	Decline in water balance (P-PE) in forest areas *(not established)*	Forest die-back in tropical to boreal (e.g. Amazonia, Siberia) zones	Not known, but some global model results	Such predictions were made by coupling GCM to terrestrial ecosystem models (egg Cox *et al.*)

Forestry	Warming, heat waves and droughts affecting forests	Affects tree populations and shifting boundaries of insects and pathogens and this tends to increase risks of fires and of pest attacks.	Not known.	Some historical analogs; see Heat Wave 2003
Food and crops	Temperature increase, heat waves and droughts at mid to low latitudes (high confidence).	Productivity negatively affected by direct and indirect effects, such as high-temperature stress during flowering and increased transpiration demands, with rainfed agriculture at greater risk . Elevated CO_2 may alleviate to a limited extent impacts by raising crop water use efficiency. Potential for increases in regional disparities.	Unknown. Historical analogs such as the Dust Bowl; Sahel Drought, European Heat Wave 2003.	Pronounced dependency on GCM scenario of precipitation, evapotranspiration and PE-E trends.
Food and crops, pastures, Forest	Temperature increase, increased climate variability (medium to high confidence).	Productivity negatively affected by increased overwintering of insect pests and latitudinal shifts of weeds, pest and disease. Potential increases in outbreaks following extreme events.	Unknown.	Some historical analogs.
Food and crops	Temperature increase, heat waves and droughts(high confidence).	Food security: i) Subsistence systems directly impacted, especially in marginal lands: e.g. Subsaharian Africa and South Asia ii) Multiple stresses for food production: e.g. Southern Africadrylands, soil degradation, water quality and availability, resource competition from other sectors. iii) Increases in mean food prices and their volatility affecting poor consumers.	i) and ii) thresholds unclear, seriousness of impacts in part related to climate variability. iii) above 2.5 to 3.5°C threshold suggested by TAR seems to hold for global food prices (what does this mean?)	Difficult to assess joint impacts of climate change and socio-economic pressures simultaneously. Yet most studies to date agree in indicating negative impacts in poor developing countries, mostly sub-Saharan Africa.
Crops, pastures, forestry	Extreme precipitation events,	Direct physical damage to crops from hail, heavy	Unknown. Many recent	Empirical evidence mostly. Models: see

	sea level rise, storm surge, low coastal areas (medium confidence).	precipitation. Indirect crop damage from excess soil moisture. Increased flooding damage. More frequent storm surges in coastal area may lead to increased salinization from either flooding or infiltration.	events, such as 1993 Midwest floods; 1998 Hurricane Mitch; 2000 El Niño floods in Somalia.	Rosenzweig *et al.* (2002).
Feed, pastures and livestocks	Temperature increase, heat waves and droughts in rangelands *(high confidence)*	Animal carrying capacity. Heat stress, spread of diseases and reduction in pasture productivity and quality at low latitude. This implies declines in animal production especially in drylands with degraded soils. Affects food security.	Thresholds unclear, impacts strongly related to climate variability (e.g. ENSO) and to extreme events	Confirms TAR, more on heat stress and animal diseases
Feed, pastures and livestocks	Temperature increase, heat waves and droughts in rangelands *(high confidence)*	Desertification. Increased land degradation, overgrazing, biological diversity loss, dominance of invasive species.	Thresholds unclear, impacts strongly related to climate variability (e.g. ENSO) and to extreme events	

5.8.2 Research Gaps and Priorities

[to be drafted for the SOD]

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