*Chapter–4*

# The Theory and Concept

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## 1. CLIMATE CHANGE

"Climate Change is a long term change in the earth's climate, especially a change due to an increase in the average atmospheric temperature".

IPCC Def: Climate Change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

UNFCCC( United Nations Framework Convention on Climate Change ) a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Weather changes all the time. The average pattern of weather, called climate, usually stays pretty much the same for centuries if it is left to itself. However, the earth is not being left alone. People are taking actions that can change the earth and its climate in significant ways.

Climate change is one of the most important global environmental issues of our generation. It is distinct from natural climate variability in that it exists because of human activities that have altered the composition of the Earth's atmosphere. Climate change can lead to things such as desertification, more intense storms, melting of the polar ice caps, and rising sea levels, changing the physical face of the Earth and the pattern of our everyday lives. While the possible consequences of climate change are alarming, there are many ways for every individual to take part in preventing these consequences from reaching their most dangerous potential.

Climate, whether of the earth as a whole or of a single country or location, is often described as the synthesis of weather recorded over a long period of time. It is defined in terms of long-term averages and other statistics of weather conditions, including the frequencies of extreme events. Climate is far from static. Just as weather patterns change from day to day, the climate changes too, over a range of time frames from years, decades and centuries to millennia, and on the longer time-scales corresponding to the geological history of the earth. These naturally occurring changes, driven by factors both internal and external to the climate system, are intrinsic to climate itself. But not all changes in climate are due to natural processes. Humans have also exerted an influence. Through building cities and altering patterns of land use, people have changed climate at the local scale. Through a range of activities since the industrial era of the mid-19th century, such as accelerated use of fossil fuels and broad scale deforestation and land use changes, humans have also contributed to an enhancement of the natural greenhouse effect.

The greenhouse effect is a natural process that plays a major part in shaping the earth's climate. It produces the relatively warm and hospitable environment near the earth's surface where humans and other life-forms have been able to develop and prosper. It is one of a large number of physical, chemical and biological processes that combine and interact to determine the earth's climate. This enhanced greenhouse effect results from an increase in the atmospheric concentrations of the so-called greenhouse gases, such as carbon dioxide and methane, and is widely believed to be responsible for the observed increase in global mean temperatures through the 20th century. The relationship between the enhanced greenhouse effect and global climate change is far from simple. Not only do increased concentrations of greenhouse gases affect the atmosphere, but also the oceans, soil and biosphere. These effects are still not completely understood. Also, complex feedback mechanisms within the climate system can act to amplify greenhouse-induced climate change, or even counteract it.


ISBN: 978-81-930585-3-4

Climate change has implications on food production, water supply, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action at national and global level. Historically, the responsibility for greenhouse gas emissions increase lies largely with the industrialized world, though the developing countries are likely to be the source of an increasing proportion of future emissions. The projected climate change under various scenarios is likely to have implications on food production, water supply, coastal settlements, forest ecosystems, health, energy security, etc. The adaptive capacity of communities likely to be impacted by climate change is low in developing countries. The efforts made by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol provisions are clearly inadequate to address the climate change challenge. The most effective way to address climate change is to adopt a sustainable development pathway by shifting to environmentally sustainable technologies and promotion of energy efficiency, renewable energy, forest conservation, reforestation, water conservation, etc. The issue of highest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to the projected climate change. India and other developing countries will face the challenge of promoting mitigation and adaptation strategies, bearing the cost of such an effort, and its implications for economic development.

**The major factors that determine the patterns of climate on earth can be explained in terms of:**

- The strength of the incident radiation from the sun, which determines the overall planetary temperature of the earth;
- The spherical shape of the earth and the orientation of its axis;
- The greenhouse effect of water vapour and other radiatively active trace gases;
- The various physical, chemical and biological processes that take place within the atmosphere-geosphere-biosphere climate system, in particular:
  - The global energy balance,
  - The global water cycle,
  - The global carbon cycle and other biogeochemical cycles;
- The rotation of the earth, which substantially modifies the large-scale thermally-driven circulation patterns of the atmosphere and ocean;
- The distribution of continents and oceans.

Most global warming emissions remain in the atmosphere for decades or centuries, the choices we make today greatly influence the climate our children and grandchildren inherit. The quality of life they experience will depend on if and how rapidly the world will reduce these emissions.

## 2. GLOBAL WARMING

The concept of global warming and its consequences have been theorized, discussed and predicted by the scientists and environmentalists world-wide during the last two decades. However, there is little or no micro-level study depicting the actual change in climatic conditions and its impact on people and natural resources, particularly in a developing country like India. It is known that the people who are most vulnerable to climate change are the poor people in rural areas that include cultivators, marginal farmers and forest-dependent population. The diverse ethnic indigenous populations of north-east India are particularly susceptible to climate change because of their dependence on natural resources for livelihood. The people in this region are chiefly cultivators and forest gatherers depending much on ecosystem services for their survival. Their cultures, beliefs and traditions reflect their profound knowledge on the land, forests, and climate that surround them.

Global warming is the gradual warming of the earth's atmosphere. It has resulted in an increase in the sea level. It has also led to changes in climatic conditions all over the world. Warming and cooling of the Earth's atmosphere has been a natural phenomenon. It has occurred over the ages but the warming of the atmosphere in the last few decades had been faster than before. The atmospheric temperatures have gone up by three times


ISBN: 978-81-930585-3-4

the average for the 20th century since 1970.Global Warming has been attributed to the increased emission of green house gasses. The increase in the amount of green house gases has made Earth warmer than usual. It is also causing great problems for the survival of planet earth.

Many things cause global warming. One thing that causes global warming is electrical pollution. Electricity causes pollution in many ways, some worse than others. In most cases, fossil fuels are burned to create electricity. Fossil fuels are made of dead plants and animals. Some examples of fossil fuels are oil and petroleum. Many pollutants (chemicals that pollute the air, water, and land) are sent into the air when fossil fuels are burned. Some of these chemicals are called greenhouse gasses.

We use these sources of energy much more than the sources that give off less pollution. Petroleum, one of the sources of energy, is used a lot. It is used for transportation, making electricity, and making many other things. Although this source of energy gives off a lot of pollution, it is used for 38% of the United States energy.

**Some other examples of using energy and polluting the air are**

- Turning on a light
- Watching T.V.
- Listening to a stereo
- Washing or drying clothes
- Using a hair dryer
- Riding in a car
- Heating a meal in the microwave
- Using an air conditioner
- Playing a video game
- Using a dish washer

When you do these things, you are causing more greenhouse gasses to be sent into the air. Greenhouse gasses are sent into the air because creating the electricity you use to do these things causes pollution. If you think of how many times a day you do these things, it’s a lot. You even have to add in how many other people do these things! That turns out to be a lot of pollutants going into the air a day because of people like us using electricity. The least amount of electricity you use, the better.

When we throw our garbage away, the garbage goes to landfills. Landfills are those big hills that you go by on an expressway that stink. They are full of garbage. The garbage is then sometimes burned. This sends an enormous amount of greenhouse gasses into the air and makes global warming worse.Another thing that makes global warming worse is when people cut down trees. Trees and other plants collect carbon dioxide (CO2), which is a greenhouse gas.

Carbon dioxide is the air that our body lets out when we breathe. With fewer trees, it is harder for people to breathe because there is more $CO_2$ in the air, and we don’t breathe $CO_2$, we breathe oxygen. Plants collect the $CO_2$ that we breathe out, and they give back oxygen that we breathe in. With less trees and other plants, such as algae, there is less air for us, and more greenhouse gases are sent into the air. This means that it is very important to protect our trees to stop the greenhouse effect, and also so we can breathe and live.

This gas, $CO_2$, collects light and heat (radiant energy), produced by the sun, and this makes the earth warmer. The heat and light from the sun is produced in the center of the sun. This layer is called the core. Just like a core of an apple, it is in the middle. Here there is a very high temperature, about 27,000,000$^{o}$F. This heat escapes out of this layer to the next layer, the radiative zone. This layer is cooler, about 4,500,000$^{o}$F. Gradually, the heat and light will pass through the convection zone at a temperature of around 2,000,000$^{o}$F. When it gets to the surface, the temperature is about 10,000$^{o}$F. Finally, the heat and light is sent into space. This is called radiant energy (heat and light). The radiant energy reaches the earth’s atmosphere. As a result of this process we get light and heat. When you pollute, you send chemicals into the air that destroy our atmosphere, so more heat and light cannot escape from the earth’s atmosphere.


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**Greenhouse gasses**

Gases that contribute to global warming are known as greenhouse gases. Water vapour is the most abundant greenhouse gas, followed by Carbon di oxide ($CO_2$), methane ($CH_4$),nitrous oxide($N_2O$), halogenated fluorocarbons(HCFCs), ozone($O_3$), per fluorinated carbons(PFCs),and hydro fluorocarbons (HFCs).

Green house gases have increased due to various human activities such as combustion of coal, oil and gas. Every year humans add over 30 billion tonnes of CO2 in the atmosphere. Methane traps 20 times more heat than $CO_2$ and each year 350 -500mt of methane are added to the air. The amount of nitrous oxide is also increasing by 7-13 mt every year. Greenhouse gases absorb the infrared radiation in the earth's atmosphere. The greenhouse gases act as a natural blanket to the earth.

With too many greenhouse gasses in the air, the earth's atmosphere will trap too much heat and the earth will get too hot. As a result people, animals, and plants would die because the heat would be too strong.

**Green house effect**

The green house effect is one of earth's natural processes. It is essential for life on Earth. It helps to regulate the temperature of our planet. Certain gases in the earth's atmosphere trap the sun's energy. Without these gases all the heat from the sun would escape back into space. This would make the earth an extremely cold and uninhabitable place. This natural process that keeps the earth warm is known as greenhouse effect.

This is like when heat is trapped in a car. On a very hot day, the car gets hotter when it is out in the parking lot. This is because the heat and light from the sun can get into the car, by going through the windows, but it can't get back out. This is what the greenhouse effect does to the earth. The heat and light can get through the atmosphere, but it can't get out. As a result, the temperature rises.

The sun's heat can get into the car through the windows but is then trapped. This makes whatever the place might be, a greenhouse, a car, a building, or the earth's atmosphere, hotter. Sometimes the temperature can change in a way that helps us. The greenhouse effect makes the earth appropriate for people to live in. Without it, the earth would be freezing, or on the other hand it would be burning hot. It would be freezing at night because the sun would be down. We would not get the sun's heat and light to make the night somewhat warm. During the day, especially during the summer, it would be burning because the sun would be up with no atmosphere to filter it, so people, plants, and animals would be exposed to all the light and heat.

Although the greenhouse effect makes the earth able to have people living on it, if there gets to be too many gases, the earth can get unusually warmer, and many plants, animals, and people will die. They would die because there would be less food (plants like corn, wheat, and other vegetables and fruits). This would happen because the plants would not be able to take the heat. This would cause us to have less food to eat, but it would also limit the food that animals have. With less food, like grass, for the animals that we need to survive (like cows) we would even have less food. Gradually, people, plants, and animals would all die of hunger.

**Effects of global warming on our ecosystem**

Global warming is affecting many parts of the world. Global warming makes the sea rise, and when the sea rises, the water covers many low land islands. This is a big problem for many of the plants, animals, and people on islands. The water covers the plants and causes some of them to die. When they die, the animals lose a source of food, along with their habitat. Although animals have a better ability to adapt to what happens than plants do, they may die also. When the plants and animals die, people lose two sources of food, plant food and animal food. They may also lose their homes. As a result, they would also have to leave the area or die. This would be called a break in the food chain, or a chain reaction, one thing happening that leads to another and so on.

The oceans are affected by global warming in other ways, as well. Many things that are happening to the ocean are linked to global warming. One thing that is happening is warm water, caused from global warming, is harming and killing algae in the ocean. Algae are producer that you can see floating on the top of the water. (A producer is something that makes food for other animals through photosynthesis, like grass.) This floating green algae is food to many consumers in the ocean. (A consumer is something that eats the producers.) One kind of a consumer is small fish. There are many others like crabs, some whales, and many other animals. Fewer algae are a problem because there is less food for us and many animals in the sea.

Global warming is doing many things to people as well as animals and plants. It is killing algae, but it is also destroying many huge forests. The pollution that causes global warming is linked to acid rain. Acid rain gradually destroys almost everything it touches. Global warming is also causing many more fires that wipe out whole forests. This happens because global warming can make the earth very hot. In forests, some plants and trees leaves can be so dry that they catch on fire.

The net impact of global warming so far has been modest, but near-future effects are likely to become significantly negative, with large-scale extreme impacts possible by the end of the century. The predicted effects of global warming on the environment and for human life are numerous and varied. It is generally difficult to attribute specific natural phenomena to long-term causes, but some effects of recent climate change may already be occurring. Rising sea levels, glacier retreat, and altered patterns of agriculture are cited as direct consequences, but predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, and drastic economic impact. Concerns have led to political activism advocating proposals to mitigate, eliminate, or adapt to it.

Greenhouse gases can stay in the atmosphere for an amount of years ranging from decades to hundreds and thousands of years. No matter what we do, global warming is going to have some effect on Earth.

## 3. IPCC REPORTS AND OBSERVATION

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (fig.1)

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) (fig.1). The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans (fig. 2 and 4)

Rising sea level is consistent with warming (fig.1). Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear.

Observed decreases in snow and ice extent are also consistent with warming (fig.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3] % per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres.

From 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has likely increased since the 1970s.

It is very likely that over the past 50 years: cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is likely that: heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level has increased worldwide.

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970.


ISBN: 978-81-930585-3-4

Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years. Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

Changes in snow, ice and frozen ground have with high confidence increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions and led to changes in some Arctic and Antarctic ecosystems.

There is high confidence that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers and through effects on thermal structure and water quality of warming rivers and lakes.

In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant and animal ranges are with very high confidence linked to recent warming. In some marine and freshwater systems, shifts in ranges and changes in algal, plankton and fish abundance are with high confidence associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation.

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (fig.2). However, there is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. There is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.

**They include effects of temperature increases on**

- Agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests
- Some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes
- Some human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports).

**Changes in temperature, sea level and Northern Hemisphere snow cover**

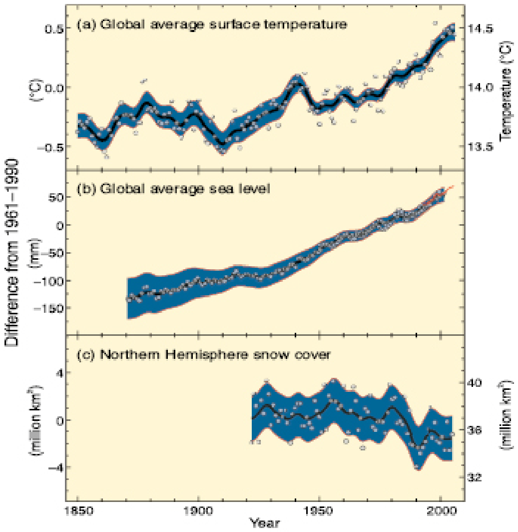


**Fig. 1:** Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences


ISBN: 978-81-930585-3-4 

are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series.

**Changes in physical and biological systems and surface temperature 1970-2004**

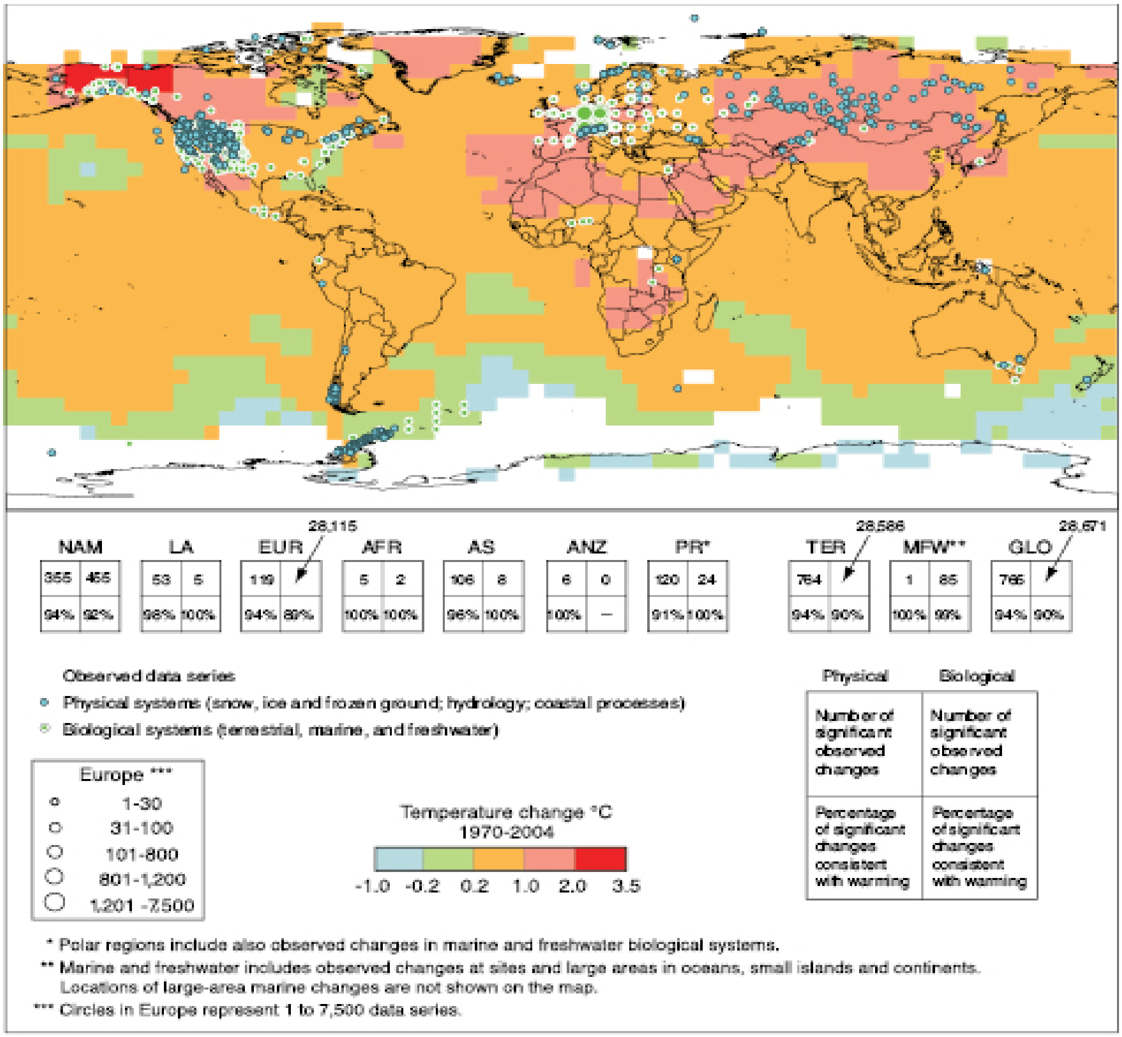


**Fig. 2**: Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 × 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, EUR, AFR, AS, ANZ, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map.


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**Causes of Change**

- Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the climate system.
- Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (fig.3)
- Carbon dioxide (CO2) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO2 emissions per unit of energy supplied reversed after 2000.
- Global atmospheric concentrations of CO2, methane (CH4) and nitrous oxide (N2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.
- Atmospheric concentrations of CO2 (379ppm) and CH4 (1774ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH4 concentration is predominantly due to agriculture and fossil fuel use. CH4 growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N2O concentration is primarily due to agriculture.
- There is very high confidence that the net effect of human activities since 1750 has been one of warming.
- Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (fig.4)
- During the past 50 years, the sum of solar and volcanic forcings would likely have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic forcings. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales.

**Global anthropogenic GHG emissions**

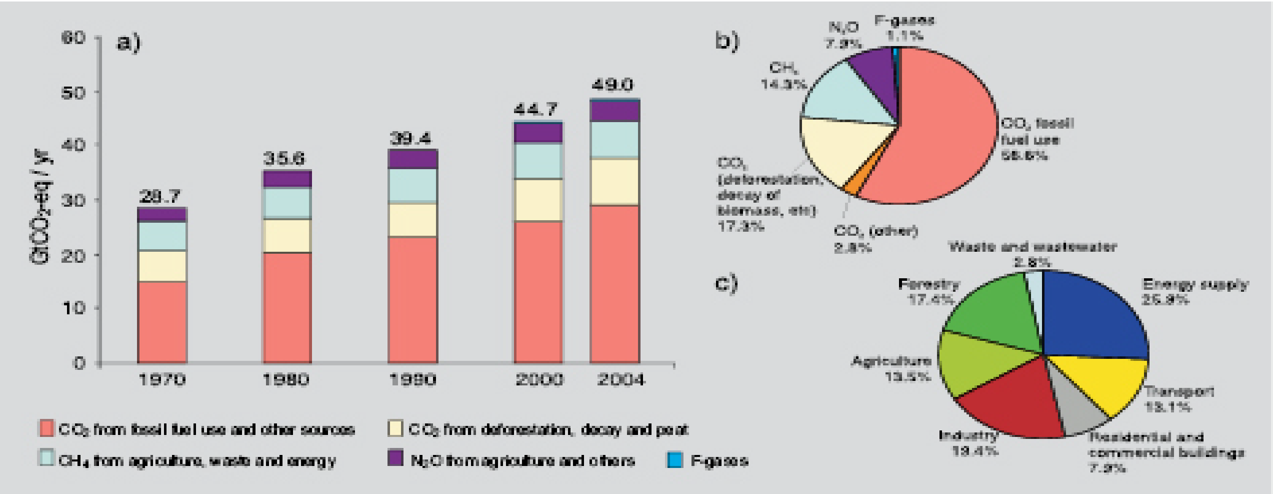


**Fig. 3**: (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.(b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents ($CO_2$-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of $CO_2$-eq. (Forestry includes deforestation.)


ISBN: 978-81-930585-3-4

- Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate.
- Human influences have: very likely contributed to sea level rise during the latter half of the 20th century likely contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns likely increased temperatures of extreme hot nights, cold nights and cold days more likely than not increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.
- Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems.
- Spatial agreement between regions of significant warming across the globe and locations of significant observed changes in many systems consistent with warming is very unlikely to be due solely to natural variability. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming.
- More complete attribution of observed natural system responses to anthropogenic warming is currently prevented by the short time scales of many impact studies, greater natural climate variability at regional scales, contributions of non-climate factors and limited spatial coverage of studies.

**Global and continental temperature change**

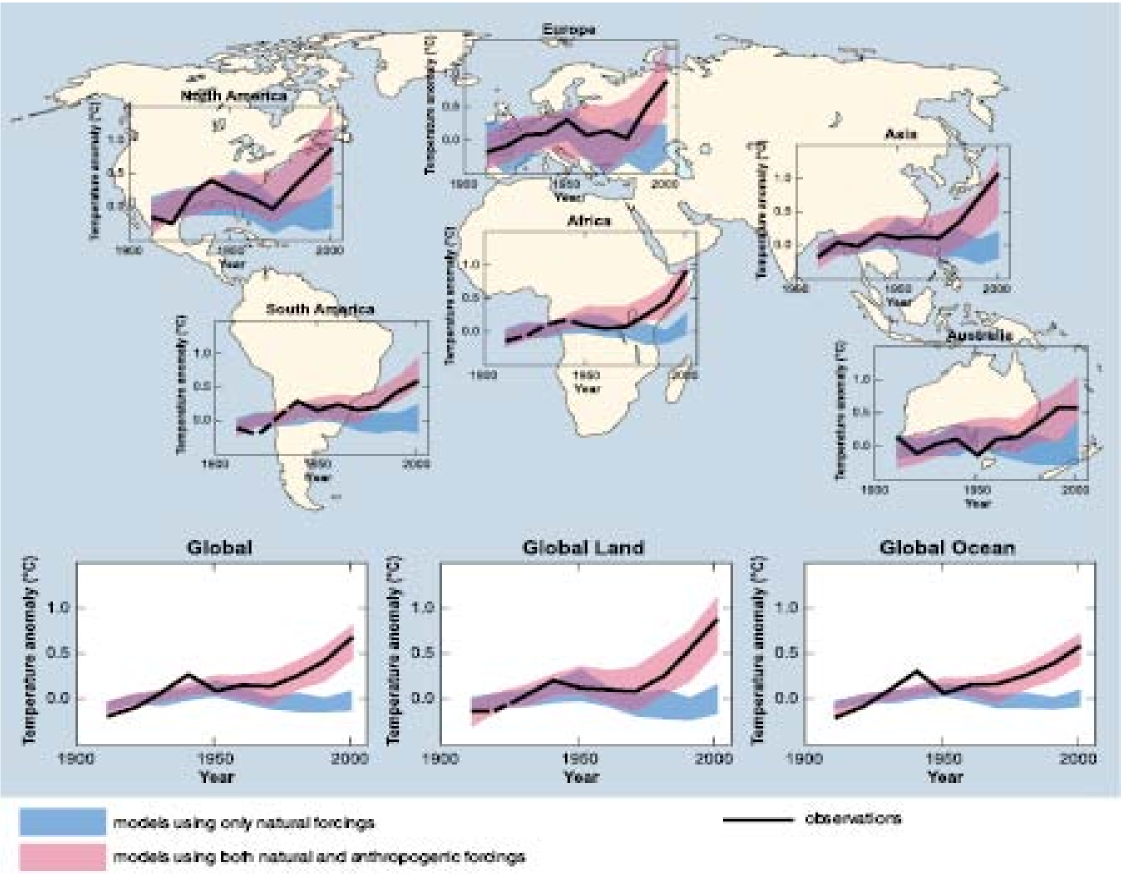


**Fig. 4**: Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less


ISBN: 978-81-930585-3-4

than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.

## 4. CLIMATE CHANGE AND HILL ECOSYSTEM

As “Water Towers”, Mountains are the source of over 60-80 percent of world’s fresh water; repositories of nearly half of the world’s biodiversity ‘hot spots’, destinations for recreation, areas of cultural diversity, knowledge and heritage. They provide food, energy, non-timber forest produce (NTFP) and timber. Deforestation and imprudent infrastructural development have led to their degradation. The number of people living in mountainous region is estimated to be 1.2 billion, with 90% of this population residing in developing and transition countries (poorest and food-insecure populations), one-third in China and two-thirds in Asia and the Pacific. Nearly 10 % of the world population is directly dependent on the mountain resources such as water, forests, agriculture and NTFP for their livelihood.

Fragility of mountain ecosystems and their vulnerability to adverse effects of climate are well established. Increasing anthropogenic pressures and natural perturbations on the mountain ecosystems result in the depletion of natural resources increase the recurrence of natural hazards and adversely affect the livelihoods of the local people, with far reaching implications at local, regional and global level. Therefore, there is an urgent need to safeguard the health of this region.

Throughout the IHR there is a perceived change in the patterns of precipitation and shifts in weather regime. However, in order to determine the degree and rate of climatic trends, there is a need for long-term data sets which are lacking for most of the Himalayan region. Hence, scientific knowledge on climate change and its impact on mountain ecosystems need to be incorporated in our land use planning and natural resource use policies.

## 5. IMPACTS OF CLIMATE CHANGE ON

### I. HEALTH

Over the last 50 years, human activities – particularly the burning of fossil fuels – have released sufficient quantities of carbon dioxide and other greenhouse gases to trap additional heat in the lower atmosphere and affect the global climate. In the last 100 years, the world has warmed by approximately 0.75$^{o}$C. Over the last 25 years, the rate of global warming has accelerated, at over 0.18$^{o}$C per decade. Sea levels are rising, glaciers are melting and precipitation patterns are changing. Extreme weather events are becoming more intense and frequent. Although global warming may bring some localized benefits, such as fewer winter deaths in temperate climates and increased food production in certain areas, the overall health effects of a changing climate are likely to be overwhelmingly negative. Climate change affects the fundamental requirements for health – clean air, safe drinking water, sufficient food and secure shelter.

Extreme high air temperatures contribute directly to deaths from cardiovascular and respiratory disease, particularly among elderly people. In the heat wave of summer 2003 in Europe for example, more than 70 000 excess deaths were recorded. High temperatures also raise the levels of ozone and other pollutants in the air that exacerbate cardiovascular and respiratory disease. Urban air pollution causes about 1.2 million deaths every year. Pollen and other aeroallergen levels are also higher in extreme heat. These can trigger asthma, which affects around 300 million people. Ongoing temperature increases are expected to increase this burden. Globally, the number of reported weather-related natural disasters has more than tripled since the 1960s. Every year, these disasters result in over 60 000 deaths, mainly in developing countries. Rising sea levels and increasingly extreme weather events will destroy homes, medical facilities and other essential services. More than half of the world's population lives within 60 km of the sea. People may be forced to move, which in turn heightens the risk of a range of health effects, from mental disorders to communicable diseases.

Increasingly variable rainfall patterns are likely to affect the supply of fresh water. A lack of safe water can compromise hygiene and increase the risk of diarrhoeal disease, which kills 2.2 million people every year. In


ISBN: 978-81-930585-3-4

extreme cases, water scarcity leads to drought and famine. By the 2090s, climate change is likely to widen the area affected by drought, double the frequency of extreme droughts and increase their average duration six-fold. Floods are also increasing in frequency and intensity. Floods contaminate freshwater supplies, heighten the risk of water-borne diseases, and create breeding grounds for disease-carrying insects such as mosquitoes. They also cause drowning and physical injuries, damage homes and disrupt the supply of medical and health services.

Rising temperatures and variable precipitation are likely to decrease the production of staple foods in many of the poorest regions – by up to 50% by 2020 in some African countries. This will increase the prevalence of malnutrition and under nutrition, which currently cause 3.5 million deaths every year. Climatic conditions strongly affect water-borne diseases and diseases transmitted through insects, snails or other cold blooded animals. Changes in climate are likely to lengthen the transmission seasons of important vector-borne diseases and to alter their geographic range. For example, climate change is projected to widen significantly the area of China where the snail-borne disease schistosomiasis occurs.

Malaria is strongly influenced by climate. Transmitted by Anopheles mosquitoes, malaria kills almost 1 million people every year – mainly African children under five years old. The Aedes mosquito vector of dengue is also highly sensitive to climate conditions. Studies suggest that climate change could expose an additional 2 billion people to dengue transmission by the 2080s. Measuring the health effects from climate change can only be very approximate. Nevertheless, a WHO assessment, taking into account only a subset of the possible health impacts, concluded that the modest warming that has occurred since the 1970s was already causing over 140 000 excess deaths annually by the year 2004. All populations will be affected by climate change, but some are more vulnerable than others. People living in small island developing states and other coastal regions, megacities, and mountainous and polar regions are particularly vulnerable. Children in particular, children living in poor countries – are among the most vulnerable to the resulting health risks and will be exposed longer to the health consequences. The health effects are also expected to be more severe for elderly people and people with infirmities or pre-existing medical conditions. Areas with weak health infrastructure – mostly in developing countries – will be the least able to cope without assistance to prepare and respond.

**Key facts**

- Climate change affects the fundamental requirements for health – clean air, safe drinking water, sufficient food and secure shelter.
- The global warming that has occurred since the 1970s was causing over 140 000 excess deaths annually by the year 2004.
- Many of the major killers such as diarrhoeal diseases, malnutrition, malaria and dengue are highly climate-sensitive and are expected to worsen as the climate changes.
- Areas with weak health infrastructure – mostly in developing countries – will be the least able to cope without assistance to prepare and respond.
- Reducing emissions of greenhouse gases through better transport, food and energy-use choices can result in improved health.

## II. AGRICULTURE

Despite technological advances, such as improved varieties, genetically modified organisms, and irrigation systems, weather is still a key factor in agricultural productivity, as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns. The Earth's average surface temperature has increased by 1.5°F {0.83°C} since 1880. Consequently, agronomists consider any assessment has to be individually consider each local area. On the other hand, agricultural trade has grown in recent years, and now provides significant amounts of food, on a national level to major importing countries, as well as comfortable income to exporting ones. The international aspect of trade and security in terms of food implies the need to also consider the effects of climate change on


ISBN: 978-81-930585-3-4

a global scale. A study published in Science suggests that, due to climate change, "southern Africa could lose more than 30% of its main crop, maize, by 2030. In South Asia losses of many regional staples, such as rice, millet and maize could top 10%".

The Intergovernmental Panel on Climate Change (IPCC) has produced several reports that have assessed the scientific literature on climate change. The IPCC Third Assessment Report, published in 2001, concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence. In Africa and Latin America many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall sharply for even small climate changes; falls in agricultural productivity of up to 30% over the 21st century are projected. Marine life and the fishing industry will also be severely affected in some places.

Climate change induced by increasing greenhouse gases is likely to affect crops differently from region to region. For example, average crop yield is expected to drop down to 50% in Pakistan according to the UKMO scenario whereas corn production in Europe is expected to grow up to 25% in optimum hydrologic conditions.

More favourable effects on yield tend to depend to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth and increase of efficiency in water use. Decrease in potential yields is likely to be caused by shortening of the growing period, decrease in water availability and poor vernalization.

In the long run, the climatic change could affect agriculture in several ways :

- Productivity, in terms of quantity and quality of crops
- Agricultural practices, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers
- Environmental effects, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity.
- Rural space, through the loss and gain of cultivated lands, land speculation, land renunciation, and hydraulic amenities.
- Adaptation, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

There are large uncertainties to uncover, particularly because there is lack of information on many specific local regions, and include the uncertainties on magnitude of climate change, the effects of technological changes on productivity, global food demands, and the numerous possibilities of adaptation. Most agronomists believe that agricultural production will be mostly affected by the severity and pace of climate change, not so much by gradual trends in climate. If change is gradual, there may be enough time for biota adjustment. Rapid climate change, however, could harm agriculture in many countries, especially those that are already suffering from rather poor soil and climate conditions, because there is less time for optimum natural selection and adaption.

## Observed Impacts

So far, the effects of regional climate change on agriculture have been relatively limited. Changes in crop phenology provide important evidence of the response to recent regional climate change. Phenology is the study of natural phenomena that recur periodically, and how these phenomena relate to climate and seasonal changes. A significant advance in phenology has been observed for agriculture and forestry in large parts of the Northern Hemisphere.

## Projections

As part of the IPCC's Fourth Assessment Report, Schneider *et al.* (2007) projected the potential future effects of climate change on agriculture. With low to medium confidence, they concluded that for about a 1 to 3 °C global mean temperature increase (by 2100, relative to the 1990–2000 average level) there would be productivity decreases for some cereals in low latitudes, and productivity increases in high latitudes. In the


ISBN: 978-81-930585-3-4

IPCC Fourth Assessment Report, "low confidence" means that a particular finding has about a 2 out of 10 chance of being correct, based on expert judgement. "Medium confidence" has about a 5 out of 10 chance of being correct. Over the same time period, with medium confidence, global production potential was projected to;

- Increase up to around 3 °C,
- Very likely decrease above about 3 °C.

Most of the studies on global agriculture assessed by Schneider *et al.* (2007) had not incorporated a number of critical factors, including changes in extreme events, or the spread of pests and diseases. Studies had also not considered the development of specific practices or technologies to aid adaptation.

**Shortage in grain production**

Between 1996 and 2003, grain production has stabilized slightly over 1800 millions of tons. In 2000, 2001, 2002 and 2003, grain stocks have been dropping, resulting in a global grain harvest that was short of consumption by 93 millions of tons in 2003.

The Earth's average temperature has been rising since the late 1970s, with nine of the 10 warmest years on record occurring since 1995. In 2002, India and the United States suffered sharp harvest reductions because of record temperatures and drought. In 2003 Europe suffered very low rainfall throughout spring and summer, and a record level of heat damaged most crops from the United Kingdom and France in the Western Europe through Ukraine in the East. Bread prices have been rising in several countries in the region.

Temperature potential effect on growing period

Duration of crop growth cycles are above all, related to temperature. An increase in temperature will speed up development. In the case of an annual crop, the duration between sowing and harvesting will shorten (for example, the duration in order to harvest corn could shorten between one and four weeks). The shortening of such a cycle could have an adverse effect on productivity because senescence would occur sooner.

**Effect of elevated carbon dioxide on crops**

Carbon dioxide is essential to plant growth. Rising $CO_2$ concentration in the atmosphere can have both positive and negative consequences.

Increased $CO_2$ is expected to have positive physiological effects by increasing the rate of photosynthesis. Currently, the amount of carbon dioxide in the atmosphere is 380 parts per million. In comparison, the amount of oxygen is 210,000 ppm. This means that often plants may be starved of carbon dioxide, due to the enzyme that fixes $CO_2$, rubisco also fixes oxygen in the process of photorespiration. The effects of an increase in carbon dioxide would be higher on C3 crops (such as wheat) than on C4 crops (such as maize), because the former is more susceptible to carbon dioxide shortage. Studies have shown that increased $CO_2$ leads to fewer stomata developing on plants which leads to reduced water usage. Under optimum conditions of temperature and humidity, the yield increase could reach 36%, if the levels of carbon dioxide are doubled.

Further, few studies have looked at the impact of elevated carbon dioxide concentrations on whole farming systems. Most models study the relationship between $CO_2$ and productivity in isolation from other factors associated with climate change, such as an increased frequency of extreme weather events, seasonal shifts, and so on.

In 2005, the Royal Society in London concluded that the purported benefits of elevated carbon dioxide concentrations are “likely to be far lower than previously estimated” when factors such as increasing ground-level ozone are taken into account."

**Effect on quality**

According to the IPCC's TAR, "The importance of climate change impacts on grain and forage quality emerges from new research. For rice, the amylose content of the grain—a major determinant of cooking


ISBN: 978-81-930585-3-4

quality—is increased under elevated $CO_2$" (Conroy et al., 1994). Cooked rice grain from plants grown in high-$CO_2$ environments would be firmer than that from today's plants. However, concentrations of iron and zinc, which are important for human nutrition, would be lower (Seneweera and Conroy, 1997). Moreover, the protein content of the grain decreases under combined increases of temperature and $CO_2$ (Ziska et al., 1997)." Studies using FACE have shown that increases in $CO_2$ lead to decreased concentrations of micronutrients in crop plants. This may have knock-on effects on other parts of ecosystems as herbivores will need to eat more food to gain the same amount of protein. Studies have shown that higher $CO_2$ levels lead to reduced plant uptake of nitrogen (and a smaller number showing the same for trace elements such as zinc) resulting in crops with lower nutritional value. This would primarily impact on populations in poorer countries less able to compensate by eating more food, more varied diets, or possibly taking supplements. Reduced nitrogen content in grazing plants has also been shown to reduce animal productivity in sheep, which depend on microbes in their gut to digest plants, which in turn depend on nitrogen intake.

## Erosion and fertility

The warmer atmospheric temperatures observed over the past decades are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events. Erosion and soil degradation is more likely to occur. Soil fertility would also be affected by global warming. However, because the ratio of carbon to nitrogen is a constant, a doubling of carbon is likely to imply a higher storage of nitrogen in soils as nitrates, thus providing higher fertilizing elements for plants, providing better yields. The average needs for nitrogen could decrease, and give the opportunity of changing often costly fertilisation strategies.

Due to the extremes of climate that would result, the increase in precipitations would probably result in greater risks of erosion, whilst at the same time providing soil with better hydration, according to the intensity of the rain. The possible evolution of the organic matter in the soil is a highly contested issue: while the increase in the temperature would induce a greater rate in the production of minerals, lessening the soil organic matter content, the atmospheric $CO_2$ concentration would tend to increase it.

### Potential effects of global climate change on pests, diseases and weeds

A very important point to consider is that weeds would undergo the same acceleration of cycle as cultivated crops, and would also benefit from carbonaceous fertilization. Since most weeds are C3 plants, they are likely to compete even more than now against C4 crops such as corn. However, on the other hand, some results make it possible to think that weed killers could gain in effectiveness with the temperature increase. Global warming would cause an increase in rainfall in some areas, which would lead to an increase of atmospheric humidity and the duration of the wet seasons. Combined with higher temperatures, these could favour the development of fungal diseases. Similarly, because of higher temperatures and humidity, there could be an increased pressure from insects and disease vectors.

## Glacier retreat and disappearance

The continued retreat of glaciers will have a number of different quantitative impacts. In areas that are heavily dependent on water runoff from glaciers that melt during the warmer summer months, a continuation of the current retreat will eventually deplete the glacial ice and substantially reduce or eliminate runoff. A reduction in runoff will affect the ability to irrigate crops and will reduce summer stream flows necessary to keep dams and reservoirs replenished. Approximately 2.4 billion people live in the drainage basin of the Himalayan rivers. India, China, Pakistan, Afghanistan, Bangladesh, Nepal and Myanmar could experience floods followed by severe droughts in coming decades. In India alone, the Ganges provides water for drinking and farming for more than 500 million people. The west coast of North America, which gets much of its water from glaciers in mountain ranges such as the Rocky Mountains and Sierra Nevada, also would be affected.

## Ozone and UV-B

Some scientists think agriculture could be affected by any decrease in stratospheric ozone, which could increase biologically dangerous ultraviolet radiation B. Excess ultraviolet radiation B can directly affect plant


ISBN: 978-81-930585-3-4

physiology and cause massive amounts of mutations, and indirectly through changed pollinator behaviour, though such changes are simple to quantify. However, it has not yet been ascertained whether an increase in greenhouse gases would decrease stratospheric ozone levels. In addition, a possible effect of rising temperatures is significantly higher levels of ground-level ozone, which would substantially lower yields.

## ENSO effects on agriculture

ENSO (El Niño Southern Oscillation) will affect monsoon patterns more intensely in the future as climate change warms up the ocean's water. Crops that lie on the equatorial belt or under the tropical Walker circulation, such as rice, will be affected by varying monsoon patterns and more unpredictable weather. Scheduled planting and harvesting based on weather patterns will become less effective.

Areas such as Indonesia where the main crop consists of rice will be more vulnerable to the increased intensity of ENSO effects in the future of climate change. University of Washington professor, David Battisti, researched the effects of future ENSO patterns on the Indonesian rice agriculture using [IPCC]'s 2007 annual report and 20 different logistical models mapping out climate factors such as wind pressure, sea-level, and humidity, and found that rice harvest will experience a decrease in yield. Bali and Java, which holds 55% of the rice yields in Indonesia, will be likely to experience 9–10% probably of delayed monsoon patterns, which prolongs the hungry season. Normal planting of rice crops begin in October and harvest by January. However, as climate change affects ENSO and consequently delays planting, harvesting will be late and in drier conditions, resulting in less potential yields.

## Mitigation and adaptation in developing countries

The Intergovernmental Panel on Climate Change (IPCC) has reported that agriculture is responsible for over a quarter of total global greenhouse gas emissions. Given that agriculture’s share in global gross domestic product (GDP) is about 4 per cent, these figures suggest that agriculture is highly Green House Gas intensive. Innovative agricultural practices and technologies can play a role in climate mitigation and adaptation. This adaptation and mitigation potential is nowhere more pronounced than in developing countries where agricultural productivity remains low; poverty, vulnerability and food insecurity remain high; and the direct effects of climate change are expected to be especially harsh. Creating the necessary agricultural technologies and harnessing them to enable developing countries to adapt their agricultural systems to changing climate will require innovations in policy and institutions as well. In this context, institutions and policies are important at multiple scales.

Travis Lybbert and Daniel Sumner suggest six policy principles: (1) The best policy and institutional responses will enhance information flows, incentives and flexibility. (2) Policies and institutions that promote economic development and reduce poverty will often improve agricultural adaptation and may also pave the way for more effective climate change mitigation through agriculture. (3) Business as usual among the world’s poor is not adequate. (4) Existing technology options must be made more available and accessible without overlooking complementary capacity and investments. (5) Adaptation and mitigation in agriculture will require local responses, but effective policy responses must also reflect global impacts and inter-linkages. (6) Trade will play a critical role in both mitigation and adaptation, but will itself be shaped importantly by climate change.

### III. BIODIVERSITY

UNCBD defines Biodiversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystem and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.” IPCC also emphasizes these three levels- that is genetic, species and ecosystem. Climate change directly affects the functions of individual organisms (e.g. Growth and behaviour), modifies population (e.g., size and age structure), and affects ecosystem function and structure, (e.g., decomposition, nutrient cycling, water flows and species composition and species interactions) and the distributions of ecosystems within landscapes; and indirectly through, for e.g.


ISBN: 978-81-930585-3-4

Changes in disturbance regimes. For the purpose of this paper, changes in ecosystem structure and functions are assumed to be related to changes in various aspects of bio diversity.

The link between climate change and biodiversity has long been established. Although throughout Earth's history the climate has always changed with ecosystems and species coming and going, *rapid* climate change affects ecosystems and species ability to adapt and so biodiversity loss increases. Biodiversity and Climate Change, Convention on Biological Diversity, December, 2009 From a human perspective, the rapid climate change and accelerating biodiversity loss risks human security (e.g. a major change in the food chain upon which we depend, water sources may change, recede or disappear, medicines and other resources we rely on may be harder to obtain as the plants and fauna they are derived from may reduce or disappear, etc.).

The UN's Global Biodiversity Outlook 3, in May 2010, summarized some concerns that climate change will have on ecosystems:

Climate change is already having an impact on biodiversity, and is projected to become a progressively more significant threat in the coming decades. Loss of Arctic sea ice threatens biodiversity across an entire biome and beyond. The related pressure of ocean acidification, resulting from higher concentrations of carbon dioxide in the atmosphere, is also already being observed. Ecosystems are already showing negative impacts under current levels of climate change which is modest compared to future projected changes…. In addition to warming temperatures, more frequent extreme weather events and changing patterns of rainfall and drought can be expected to have significant impacts on biodiversity.

Some species may benefit from climate change (including, from a human perspective, an increase in diseases and pests) but the rapid nature of the change suggests that most species will not find it as beneficial as most will not be able to adapt.

**Importance of biodiversity**

Ecosystems provide many goods and services that are crucial to human survival. Some indigenous and rural communities are particularly dependent on many of these goods and services for their livelihoods. This goods and services include food, fibre, fuel and energy, fodder, medicines, clean water, clean air, flood/ storm control, pollination, seed dispersal, pest and disease control, soil formation and maintenance, biodiversity, cultural, spiritual, and aesthetic and recreational values. Ecosystems also play a critical role in biogeochemical processes that underlie the functioning of earth system.

**Pressures on biodiversity from human activities**

The earth is subjected to many human-induced and natural pressures, collectively referred to as global change. These include pressures from increased demand for resources; selective exploitation or destruction of species; land use or land cover change; the accelerated rate of anthropogenic nitrogen deposition; soil, water and air pollution; introduction of non native species; diversion of water to intensively managed ecosystems and urban systems; fragmentation or unification of landscapes; and urbanization and industrialization. Climate change constitutes an additional pressure on ecosystems, the biodiversity within them, and the goods and services they provide. Quantification of the impacts of climate change alone, given the multiple and interactive pressures acting on the earth's ecosystems is difficult.

**Inter linkages between biodiversity and climate change**

The links between biodiversity and climate change run both ways: biodiversity is threatened by climate change, but proper management of biodiversity can reduce the impacts of climate change.

In the Arctic, shorter periods of sea ice coverage endanger the polar bear's habitat and existence by giving them less time to hunt.

Climate fluctuations in North America reduce plankton populations, the main source of food of the North Atlantic right whale. Only about 300 individuals remain at present and the reduced availability of food due to climate change is becoming an increasing cause of mortality.


ISBN: 978-81-930585-3-4

Warmer temperatures in the Pacific regions could reduce the number of male sea turtle offspring and threaten turtle populations. The sex of sea turtle hatchings is dependent on temperature, with warmer temperatures increasing the number of female sea turtles.

There is evidence that climate change is already affecting biodiversity and will continue to do so. The Millennium Ecosystem Assessment ranks climate change among the main direct drivers affecting ecosystems. Consequences of climate change on the species component of biodiversity include:

- Changes in distribution,
- Increased extinction rates,
- Changes in reproduction timings, and
- Changes in length of growing seasons for plants.

Some species that are already threatened are particularly vulnerable to the impacts of climate change. The following are examples of species and of their vulnerabilities:

Since frogs rely on water to breed, any reduction or change in rainfall could reduce frog reproduction. Moreover, rising temperatures are closely linked to outbreaks of a fungal disease that contributes to the decline of amphibian populations, especially frogs in Latin America.

Some of the largest remaining areas where tigers occur are the mangrove forests of Asia. The projected rise in sea levels could cause the disappearance of the tigers' habitat, threatening the survival of the species. In Africa, pressures from longer dry periods and shrinking living spaces are making elephants highly vulnerable to climate change.

Australia's Great Barrier Reef could lose up to 95% of its living coral by 2050 due to changes in ocean temperature and chemistry. The resilience of ecosystems can be enhanced and the risk of damage to human and natural ecosystems reduced through the adoption of biodiversity-based adaptive and mitigative strategies. Mitigation is described as a human

intervention to reduce greenhouse gas sources or enhance carbon sequestration, while adaptation to climate change refers to adjustments in natural or human systems in response to climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

**Examples of activities that promote mitigation of or adaptation to climate change include**

- Maintaining and restoring native ecosystems,
- Protecting and enhancing ecosystem services,
- Managing habitats for endangered species,
- Creating refuges and buffer zones, and
- Establishing networks of terrestrial, freshwater and marine protected areas that take into account projected changes in climate.

## IV. FORESTRY

Changing temperature and precipitation pattern and increasing concentrations of atmospheric CO2 are likely to drive significant modifications in natural and modified forests.

Globally, forests cover _4 billion hectares (ha) of land, or 30% of the Earth's land surface. In 2005, 3.5 billion m3 of wood of 434 billion m3 of growing stock were removed from the forests (Fig.5); _60% of this amount was industrial round wood and the rest was fuel wood. The majority of the forest land is covered with primary (36%) or modified (53%) natural forests. The primary forest area has been slowly decreasing by_6 million ha annually since the 1990s, and this rate is especially high in Brazil and Indonesia; these two countries are responsible for the loss of 4.9 million ha of forests annually. Forest loss tends to occur in low-income countries, largely in the tropics, whereas higher-income countries have reversed their earlier forest losses and are already experiencing forest expansion.


ISBN: 978-81-930585-3-4

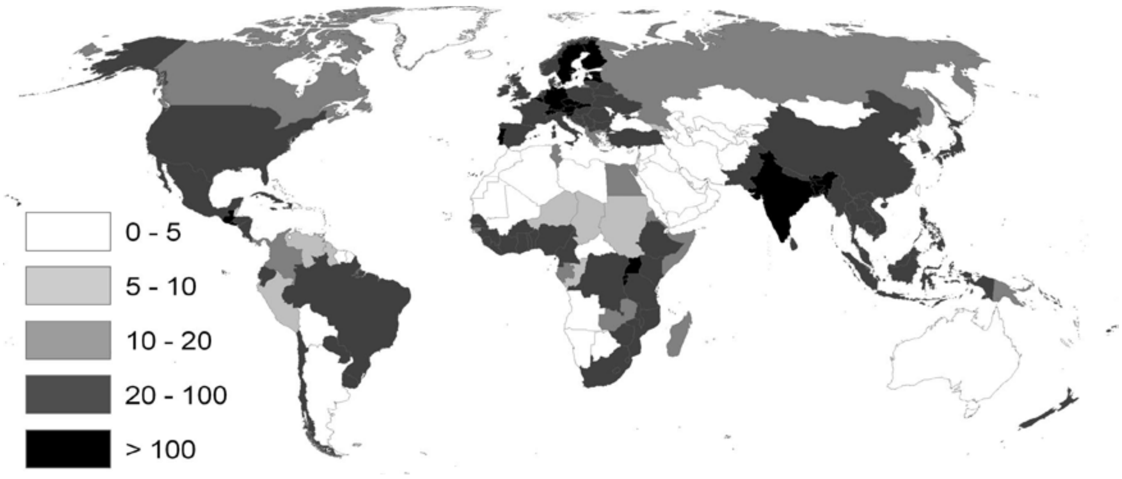


**Fig. 5: Global wood harvest (including wood fuel) computed on a per country base, m3/km2. White areas correspond to low harvest or no data.**

Only 3% of the forest land is covered with productive forest plantations; however, this area had been growing rapidly by 2 million ha annually in the 1990s and by 2.8 million ha through this decade. Plantations are being established largely in the tropics and subtropics, e.g., Brazil and Indonesia, but also in highproductivity temperate regions, e.g., Chile and China. Despite their relatively small area, forest plantations provide more than a third of industrial roundwood, and the shift of production from natural forests to the plantations is projected to accelerate to 40% in the 2030s and 75% in the 2050s.

Approximately half of the total wood harvest is reported by the countries to the Food and Agriculture Organization (FAO) as fuels. This estimate must, however, be increased up to as much as 60–65% (making fuel the single most important product of the sector), as _15% of the industrial round wood is eventually used for energy by the forest industry. The role of wood for fuel is especially high in developing countries, which use it as a source of 15% of their primary energy consumption and effectively produce _90% of global wood fuels. Whereas in developing countries the wood fuels are typically consumed in a form of wood or charcoal, in the developed countries more than half of wood fuels are recovered from the burning of black liquor, which is a byproduct of the papermaking industry. Aside from timber and fuel production, the wide range of services supplied by the forests includes non timber forest products, such as berries and mushrooms, providing wildlife habitats, soil and water protection, biodiversity conservation, tourism and recreation opportunities, medicinal plants, etc. These services are especially important for 1.2 billion forest-dependent people, living in extreme poverty. In many rural sub-Saharan Africa communities, non timber forest products may contribute _50% of a farmer’s cash income, provide the health needs for _80% of the population, and supply 2⁄3 of annual meat consumption. An increasingly important service of the forests is carbon sink and preservation, although there are new doubts on the effectiveness of afforestation in the boreal and midlatitude zones to curb the temperature increase caused by lower albedo of forest land cover as compared with grasslands or crops.

**Climate Change Impact on Forests**

Effects of Temperature, Precipitation, and CO2 Concentration Change. It is likely that changing temperature and precipitation pattern will produce a strong direct impact on both natural and modified forests. A number of biogeographical models demonstrate a polarward shift of potential vegetation for the 2_CO2 climate by 500 km or more for boreal zones. The equilibrium models and some dynamic vegetation models project that this vegetation shift toward newly available areas with favourable climate conditions will eventually result in forest expansion and replacement of up to 50% of current tundra area. There is, however, a concern that the lagged forest migration (compare the tree species migration rates after the last glacial period of few kilometers per decade or less to projected future climate zones shift rate of 50 km per decade) may lead to massive loss of natural forests with increased deforestation at the southern boundary of the boreal forests and a correspondent


ISBN: 978-81-930585-3-4

large carbon pulse . At the same time, some researchers maintain that tree species migration rates can be much more rapid . For timber production, which relies on managed forests with migration facilitated by human actions, this negative effect of lagged migration might be of lesser importance than for natural forests.

Increasing concentrations of the atmospheric CO2, aside from modifying the temperature and precipitation pattern, may also increase the production through the ‘‘carbon fertilization effect.’’ Earlier experiments in closed or open-top chambers demonstrated very high potential for CO2-induced growth enhancement, such as an 80% increase in wood production for orange trees. It is, however, unknown how this response would be modified in the field without the size limitations of the chamber. The free-air CO2 enrichment (FACE) experiments demonstrated a smaller effect of increased CO2 concentration on tree growth. Long-term FACE studies suggest an average net primary production (NPP) increase of 23% in response to doubling CO2 concentration in young tree stands with the range 0–35%. Further, in the only FACE study of the mature 100-year-old tree stand little long-term increase in stem growth was found, which might be partially explained by the difficulties in controlling for constant CO2 concentration in a large-scale experiment. Further, the initial CO2-induced growth enhancement is both limited with and modifies the effects of competition, disturbance, air pollutants such as troposphere ozone, and nutrient limitations. As a contrast, models often presume high fertilization. The lack of long-term experimental data for mature tree stands prevents better estimation of CO2-induced growth enhancement in model coefficients.

Regardless of the contradictory effects of variations in CO2 concentration, insolation, nutrients availability, temperature, and precipitation, the forest growth rate have been increasing since the middle of the 20th century. Some of this growth enhancement may be caused by the trend in land-use change and the carbon fertilization effect, but generally it is attributed to warmer climate conditions and extended growing season. Simulated by the yield models growth enhancement seems to be consistent with these historical changes.

**Fires, Insects, Pathogens, and Extreme Events**

For forestry, the climate change-induced modifications of frequency and intensity of forest wildfires, outbreaks of insects and pathogens, and extreme events such as high winds, may be more important than the direct impact of higher temperatures and elevated CO2. At the same time, very few forest production models include these effects, which severely limits the reliability of the model results.

Forest fire may be an exclusion here. The last two decades demonstrated increasing burned areas in Canada, the western United States, and Russia, because of both climatic conditions and other factors such as fuel conditions, ignition sources, land-use change, and variations in fire protection. Other regions demonstrated both increasing and decreasing fire activity. In warmer climates of this century, prolonged snow-free period and increasing frequency and intensity of droughts are expected to elevate the frequency of forest fires in many regions. In Canada, the burned area might double by the end of the century under the 3_CO2 scenario such as the IS92a Intergovernmental Panel on Climate Change ‘‘business as usual’’ scenario. The potential losses of the timber, pulp, and paper production, as well as the damage to health and non timber forest products caused by elevated fire activity, are quite uncertain as much of the fire damage is expected to occur in less-accessible regions.

For many forest types, forest health questions are of great concern with pest and disease outbreaks as major sources of natural disturbance. The effects vary from defoliation and growth loss, to timber damage, to massive forest diebacks. For example, in 1998–2002, 5 million ha of forest (1.7% of the forest area) was adversely affected by insects in the United States, and 14 million ha was affected in Canada (4.5%); the area annually damaged by insects in North America is 2.9% of the total forest area. It is very likely that these natural disturbances will be altered by climate change and have an impact on forestry.

There is evidence that warmer temperatures have already shifted the habitats of some forest insects, e.g., the mountain pine beetle. Other important forest insects, such as the gypsy moth, are more responsive to precipitation change. Climate change can dramatically shift the current boundaries of insects and pathogens and modify tree physiology and tree defense mechanisms.


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A growing concern is that at the new habitats the insects may damage the tree species that presently cannot tolerate insect outbreaks, e.g., under a very moderate 2°C warming the mountain pine beetle is likely to seriously threaten the Rocky Mountain white bark pines, which provide food for many wildlife species.

Even without fires or insect damage, the change in frequency of extreme events, such as strong winds, winter storms, droughts, etc. can bring massive loss to commercial forestry. These effects of climate extremes on commercial forestry are region-specific and include reduced access to forestland, increased costs for road and facility maintenance, direct damage to trees by wind, snow, frosts, or ice, effects of wetter winters and early thaws on logging, etc. High wind events can damage trees through branch breaking, crown loss, trunk breakage, or complete stand destruction, especially caused by faster build-up of growing stocks in a warmer climate. For example, in January 2005 Hurricane Gudrun with maximum gusts of 43 m/s damaged _60 million m3 of timber in Sweden. The salvaged timber doubled the harvest level of southern Sweden. In a warmer climate, the frequency of some extreme events such as heat waves and severe droughts will increase, although many uncertainties still exist.

The damage from the extreme events such as a severe drought can be further aggravated by increased damage from insect outbreaks and wildfires. For example, the 2003 Europe heat wave led to an extreme forest fire season. In Portugal, 0.4 million ha of forests (5.6% of the total forest area in the country) was destroyed. At a larger scale, a positive feedback between deforestation, forest fragmentation, wildfire, and increased frequency of droughts appear to exist in the Amazon basin, so that a warmer and drier regional climate may trigger massive deforestation. The model simulations show that during the 2001 El Nino Southern Oscillation period_1⁄3 of Amazon forests had already become susceptible to fire. Further, a widely used Lund–Potsdam–Jena dynamic vegetation model points at a possibility of eventual loss of Amazonian rainforests under a very significant, yet plausible, warming signal corresponding to IS92a's more than triple concentration of CO2 by the end of the century.

Forest fires, insect outbreaks, wind damage, and other extreme events result in substantial economic damage to forest sector, e.g., in the United States, the 2003 forest fires resulted in a $337 million loss in wood. Other adverse effects included reductions in biodiversity and non timber forest products, negative impacts on erosion and hydrology, and loss of aesthetic and recreational values. In a changing climate, higher direct and indirect risks caused by more frequent extreme events will affect timber supplies, market prices, and cost of insurance, although the costs are highly uncertain.

**Impact of Climate Change on Forest Sector**

**Change in Supply:** Yield models demonstrate that climate change can increase global timber production through location changes of forests, i.e., through a polarward shift of the most important for forestry species. Climate change can also accelerate vegetation growth caused by a warmer climate, longer growth seasons, and elevated atmospheric CO2 concentrations. Changing timber supply will affect the market, generally lowering prices. It will also impact supply for other uses, e.g., enhancing the potential of using various types of wood biomass energy.

UIUC, University of Illinois at Urbana–Champaign; TEM, Terrestrial Ecosystem Model; CGTM, Center for International Trade in Forest Products Global Trade Model; MIT, Massachusetts Institute of Technology; EPPA, Emissions Prediction and Policy Analysis; ECHAM-3, European Center Hambury Model, version 3; TSM 2000, Timber Supply Model; BIOME 3, Global Biome Model, version 3; HadCM2, Hadley Centre Coupled Model, version 2; IPCC, Intergovernmental Panel on Climate Change.


ISBN: 978-81-930585-3-4

**Table 1: Examples of simulated climate change impacts on forestry**

| Study area (ref.) | Scenario, general circulation model (GCM) | Production impact | Economic impact |
|---|---|---|---|
| Global (21) | UIUC and Hamburg T-106 for $CO_2$ topping 550 ppm in 2060 | 2045: production up by 29–38%; reductions in North America, Russia; increase in South America and Oceania; 2145: production up by 30%, increase in North America, South America, Russia | 2045: price reduced, high latitudes' loss, low latitudes' gain; 2145: price increase up to 80% (no climate change), 50% (with climate change), high latitudes' gain, low latitudes' loss; benefits go to consumers. |
| lobal (58) | TEM and CGTM MIT GCM, MIT EPPA emissions | Harvest increase in the American West (2–11%), New Zealand (10–12%), South America (10–13%);harvest decrease in Canada | Demand satisfied; price drop with an increase in welfare to producers and consumers |
| Global (62) | ECHAM-3 (2_CO2 in 2060), TSM 2000, BIOME | 2080s, no climate change: increase of the industrial timber harvest by 65% (normal demand) or 150% (high demand); emerging regions triple their production; with climate change: increase of the industrial timber harvest by 25% (normal demand) or 56% (high demand), Eastern Siberia and American South dominate production | No climate change: pulpwood price increases 44%; solid wood increase 21%; With climate change: pulpwood price decrease 25%; solid wood decrease 34%; global welfare 4.8% higher than in no climate change scenario. |
| Europe (38) | HadCM2 under IS92a | 18% climate-related increase in stemwood growth by 2030, slowing down on a longer term | Decrease or increase in prices is possible |
| Europe (46) | Baseline, 20–40%, increase in forest growth by 2020 | Increased production in Western Europe, decreased production in Eastern Europe | Price drop with an increase in welfare to producers and consumers; increased profits of forest industry and forest owners. |


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| | | | |
|---|---|---|---|
| Europe (63) | IPCC A1f, A2, B1, B2 up to 2100;<br>Several options of management | Increased forest growth (especially in Northern Europe) and stocks, except for<br>A1f; 60–80% of stock change is caused<br>by management, climate explains 10–30%, and the rest is caused by land-use change. | In the A1f and A2 scenarios, wood demand exceeded potential felling, particularly in the second half of the 21st century; in the B1 and B2 scenarios future wood demand can be satisfied |
| United States (34, 64) | Combinations of two GCMs and two<br>vegetation models under IS92a | Increase in timber inventory by 12% (midterm); 24% (long term) and small increase in harvest; major shift in species<br>and increase in burnt area by 25–50%; generally, high elevation and northern forests decline, southern forests expand | Reduction in log prices; producer welfare<br>reduced comparing to no climate<br>change scenario; lower prices;<br>consumers will gain and forest owners<br>will lose |
| United States (61) | Combinations of two GCMs, three<br>biogeographical and three biogeochemical models | Depending on the models used, productivity gains or losses are predicted; major shift or loss of species distribution. | Small, yet usually generally positive, impact on welfare economic market for all scenarios onsidered in the model with losses in productivity dampened in economic model |

**Change in Demand**

Contrary to earlier FAO predictions of fast-growing demand for industrial timber to 2.1 billion m3 by 2015 and 2.7 billionm3 by 2030, actual demand growth has been much slower. Current demand for 1.6 billion m3 is just slightly above the demand for 1.5 billionm3 in the early 1980s . Recent projections of the FAO and models of the global forest sector often assume a more modest demand growth to 1.8 billion to 1.9 billion m3 by 2010–2015. Similarly to this correction of earlier projections for industrial timber, global fuel wood use has already peaked at 1.9 billion m3 and is stable or declining, with the share of charcoal continuing to increase as fuel wood is converted to charcoal. However, the use of wood for fuel and biomass energy could dramatically escalate in the face of rising energy prices and new technologies, particularly if incentives are created to shift away from carbon-emitting fossil fuels and toward bio fuels, which are viewed as recycling the emitted carbon.

Some model-based estimates project an increase in bio fuel demand during the next 50 years by as much as a factor of 10. In some countries, bio fuels, particularly ethanol from grains and other plant materials, e.g., sugarcane, have already become an important source of nonconventional transport energy. Bio fuels derived from cellulosic biomass (fibrous and wood portions of trees and plants) offer an even more attractive opportunity as an alternative to conventional energy sources. Also, wood cellulose can be used in gasification processes, e.g., integrated gasification combined cycle process, to produce synthetic gases, including hydrogen. These gases can be further used to produce energy directly or as feedstock to produce a variety of energy products, including not only ethanol but also bio crude, using processes such as Fisher-Tropsch. Wood-fired gasification plants can be constructed as stand-alone projects, as is now under consideration in some locations. An intriguing possibility is that new gasification bio refineries replace aging traditional boilers in


ISBN: 978-81-930585-3-4

existing pulp mills. Pulp mills have large energy requirements and are designed to facilitate the flow of large amounts of wood. Should wood bio fuels become common the forest industry would face the same types of challenges that the American grain industry has faced since ethanol came into larger-scale production: associated with the expansion of land under corn cultivation are ever-increasing pressures on the land resource, as reflected in the dramatic increases in corn prices and the doubling of corn land rents in much of the corn-belt region. Currently these concerns seem to be premature as the cost of cellulosic ethanol ($0.8 to $1 per liter compared with _$0.6 per liter of corn ethanol in the United States) precludes its commercial use.

However, with rapid evolution of the technology, the prices for renewable wood-based fuels are decreasing, even though it is still impossible to estimate the extent to which wood-based fuels will become competitive with petroleum or other bio fuels. Hence, the actual demand for forest products could be higher than FAO projections, affecting viability of simulation studies, discussed in the next section. Additionally, there are many other products and services that depend on forest resources for which, again, there are no satisfactory estimates of global future demand.

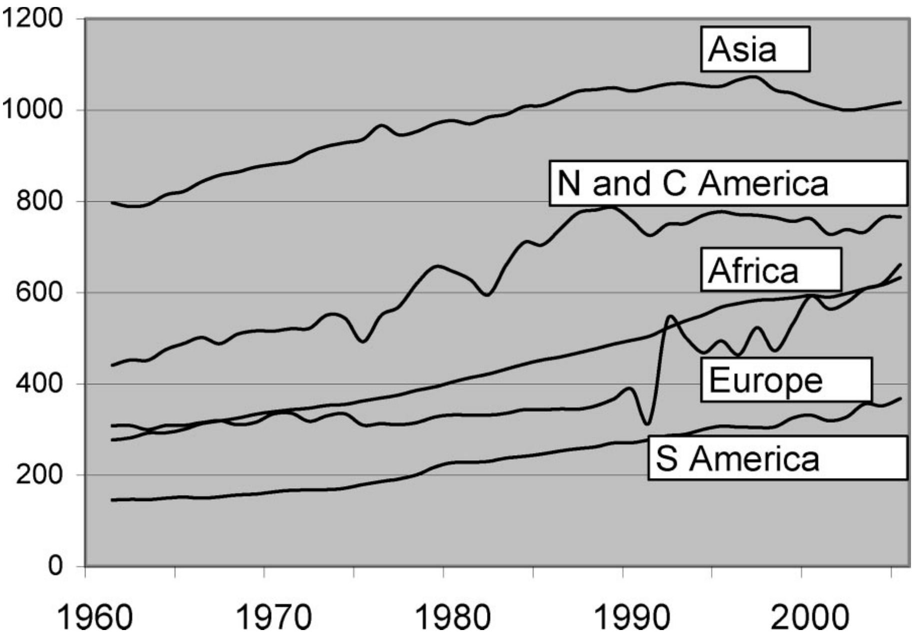


**Fig. 6: The trends in global timber production, billion m3**

## Timber Production

Driven by changing supply and demand, total round wood production, including both industrial wood and fuel wood, has been growing steadily from 2.5 billion m3 in 1960s to 3.2 billion m3 in 1990s. In 2005 production was at a peak 3.5 billion m3 because of a long trend of increasing production in Europe, Africa, and South America, whereas Asia and North America remained constant or declined (Fig.6). Modeling studies generally predict further increase of global industrial round wood production, with increases or decreases in prices in the future in the order of _20% (5, 21, 34, 38, 44, 45, 58), and with benefits of higher production mainly going to consumers.

The future trend of fuel wood is more problematic depending in large part on the use to which wood is put to substitute for high-priced carbon-emitting fossil fuels. At the same time, a global shift in the industrial wood supply between the temperate and tropical zones and between the Northern and Southern Hemispheres is possible. The current trend is toward high productivity south and away from temperate and boreal forests. However, warming could shift some of the activities back toward the north. These changes could increase international trade in forest products to balance the regional imbalances in demand and supply. For the United States, the net impact of climate change on the forestry sector may be small because of the large stock of


ISBN: 978-81-930585-3-4

existing forests, technological change in the timber industry, and the ability to adapt fast. The results of simulation studies are summarized in Table 1.

## V. WATER RESOURCES

Water is necessary for life. It is the key resource for human health, prosperity and security. Beyond water's functions in the hydrological cycle, it has social, economic and environmental values, and is essential for sustainable development. Unprecedented population growth, a changing climate, rapid urbanization, expansion of infrastructure, migration, land conversion and pollution translate into changes in the fluxes, pathways and stores of water – from rapidly melting glaciers to the decline of groundwater due to overexploitation. Population density and per capita resource use have increased dramatically over the past century, and watersheds, aquifers and the associated ecosystems have undergone significant modifications that affect the vitality, quality and availability of the resource. Current United Nations predictions estimate that the world population will reach 9 billion people in 2050.

This exponential growth in population – a major driver of energy consumption and anthropogenic climate change – is also the key driver behind hydrologic change and its impacts. Rapid urban growth strains the capacity of governments to provide basic services such as water and sewerage. More than half of the world's population currently lives in cities; urban dwellers will account for 70 percent of humanity in 2050. Arid and semi-arid areas face the greatest pressure to deliver and manage freshwater resources globally.

By the mid-1990s, some 40 percent of the world's population were suffering water shortages. In less than 25 years, two-thirds of the world's population will be living in water-stressed countries. More than half of the world's population relies on the freshwater that accumulates in mountainous regions. These areas are under pressure from deforestation, agriculture and tourism, all of which are placing unsustainable demands on water. The quality and quantity of freshwater from rivers, lakes, groundwater, soil moisture, and ice is under stress around the world. Water pollution is a serious global problem which impacts the health of freshwater systems and the people who rely on them for water.

Many major rivers no longer consistently make it to the ocean; hundreds of meters of decline in fossil groundwater sources are now endemic in some of the largest and most productive aquifers in the world; and pollution has dramatically impacted the aquatic habitat in many of the world's prized water bodies.

### Key global change drivers

Global change involves more than climate change. The major drivers of global change are population growth, climate change, urbanization, expansion of infrastructure, migration, land conversion and pollution.

Water resources are significantly affected by global change. There are few areas of the world where river basins and aquifer systems are not impacted by the numerous other drivers related to human activity. Important increases in urbanization are modifying areas near river courses and low lying coastal areas. Seventy percent of water is currently withdrawn for agricultural use. Intensification of agriculture is contributing to deforestation and desertification. Increased water use associated with agriculture and urbanization is leading to changes in storage infrastructure, high rates of groundwater use, and new conveyance networks. Collectively these changes lead to cumulative effects on water quality.

Climate change increases the uncertainty associated with the future availability and variability of freshwater resources, and may even lead to permanent desertification of certain regions of the world. The impacts of floods and droughts in many areas will have to be managed more frequently than in the 20th century. These are exacerbating factors on top of the direct human-induced changes in the local terrestrial hydrologic cycle that are further translated into large cumulative effects as one moves from watersheds to river basins, and as one looks at the chronic and progressive depletion and pollution of surface and groundwater reservoirs.

Climate exigencies such as drought can lead to increased groundwater pumping or investment in new surface storage, which have long-term hydrologic effects. Increased uncertainty with regards to climatic outcomes and hence to the renewable freshwater supply can change the investment and use directions in regional water


ISBN: 978-81-930585-3-4

resources. Increased flood magnitude and frequency can translate into changes in sediment fluxes and the mobility of biological and chemical pollutants, as well as in investment in flood control works which, in turn, impact future sediment and water residence times.

There is a need to learn more about these global drivers of water use in conjunction with local water availability. Agriculture is a dominant global water consumer and virtual water transactions through the global agricultural trade are now a significant part of this water budget. The policy and the physical dimensions of this component of the water budget and its interaction with local and regional water availability need to be better understood. Energy availability and use for water production, as well as water constraints on energy production enter the water access and availability equation as determined by local energy and water subsidy policies. We also need to better understand and further develop the vulnerability, resilience and adaptability of different water management institutions and structures in stimulating and dealing with a changing environment. Water resources infrastructure development and management has historically required significant public funding by national and international agents. More research on the interaction between local and global actors in determining the future vulnerability and resilience of these systems and their local management to adapt to changing conditions is necessary.

Many regions already face crises related to the cumulative effects of global change drivers, especially on water resources. The consequence of these effects is aquifer depletion and water pollution, increased water stress and impacts of climate extremes, food security, access to safe drinking water, as well as socio-economic and ecological vulnerability. Yet change detection and attribution are difficult due to the absence of accessible data on the causative factors and outcomes.

Formal risk assessment and scenario analysis procedures can help us identify the vulnerabilities to change, predict risk, assess the significance of the risk relative to the impact and uncertainties, and to propose and test adaptation strategies. Both climate and other factors need to be considered in assessing sensitivity to change. Such a framework would be useful to focus and guide global change research.

Specific issues and tools in the application settings related to inter-basin transfer or upstream-downstream competition for water should be formulated in this context. There are prospects for modelling and predicting floods and droughts at different time scales using a variety of methods. Such events have huge global economic and social impacts, and a classification and prediction capacity is a prerequisite for adaptive management.

**Impact of climate change on water resources**

The impact of global climate change on water resources is a primary concern for local and global water resources management. The impacts of climate change – including changes in temperature, precipitation and sea level rise – are expected to have varying consequences for the availability of freshwater around the world. Climate change impacts the hydrological cycle and thus impacts the management of freshwater resources.

Changes in river runoff, for example, will affect the yields of rivers and reservoirs, navigation, and have an impact on the energy sector, finally affecting the recharging of groundwater. An increase in the rate of evaporation will also affect water supply and contribute to the salinization of irrigated agricultural lands. Climate change impacts at all levels are projected to become increasingly strong in the decades following 2025. It is at the national level that the most important decisions need to be made, and adaptation strategies developed. Higher temperatures and decreased precipitation may lead to decreased water supplies and increased water demand. This may cause deterioration in the quality of freshwater bodies, putting further strain on the already fragile balance between supply and demand in many countries. Even where precipitation might increase, there is no guarantee that it would occur at the time of year when it would be useful. There is also a likelihood of increased flooding.

- **Extremes floods and droughts**

In recent years many countries around the world experienced devastating floods resulting in many deaths and damage to infrastructure. The IPCC predicts that by 2080, millions more people will experience flooding every


ISBN: 978-81-930585-3-4

year due to sea level rise. Decreased land precipitation and increased temperatures are important factors which have contributed to more regions experiencing droughts. Droughts aggravate food security and lead to an increase in food prices which, in turn, puts further stress on the most vulnerable in society.

The European (EURO) FRIEND Water group is researching the impact of climate change on droughts through the “Global Change and Ecosystems” project, as part of the ECfunded project WATCH (Water and Global Change). A study on trends in observed low flow and stream flow drought has been conducted and indicates the difficulty in detecting the climate signal in the hydrological time series. The research shows that the frequency and severity of droughts in Europe depend on the hydro-geological conditions (storage capacity) of the basins, the time period selected and the selection of the drought index itself.

- **Arid and semi arid environments**

Arid and semi-arid areas globally face the greatest pressures to deliver and manage freshwater resources. These areas are particularly vulnerable to climate variability or climate change, with consequences that may have very serious social and environmental effects.

- **Cold environments: snow, glaciers and permafrost**

Glaciers are an intrinsic element of the culture, landscape, and environment in high mountain regions, and are key indicators and unique demonstrations of global warming and climate change. With rising global temperatures, glaciers are experiencing a rapid decline in mass. Changes in mountain glaciers will have significant effects on livelihoods and ecology.

- **Erosion and sedimentation**

Every year human lives are lost to erosion, landslides and debris flows. The negative impacts of erosion and sedimentation are further exacerbated by global changes brought on by a rapidly growing population and increased vulnerability to severe climatic conditions, which increase soil erosion.

- **Urban settlements**

Urban water and sanitation services are directly affected by climate change. Changes in rainfall patterns, their seasonality and spatial distribution will influence the quantity and quality of water resources, and will impact both surface water and groundwater.

- **Biodiversity**

Biodiversity is directly affected by climate change. Biodiversity within wetlands is a good example of such degradation. For many watersheds, there is an increased likelihood of warmer summers and therefore an increase in water temperatures with associated impacts on aquatic ecosystems and water quality.

- **Ground water**

Climate change affects groundwater recharge and discharge rates, as well as groundwater quality. Since knowledge of current recharge and levels in both developed and developing countries is poor, research efforts are underway to help us better understand the future impact of climate change on groundwater.

Groundwater is the primary source of drinking water for more than 1.5 billion people worldwide. In rural areas, groundwater is often the only source of water. In many countries groundwater is also important for sustaining agriculture, industrial uses, streams, lakes, wetlands, and ecosystems. Understanding the processes controlling the geochemical evolution of groundwater and differentiating between climate change and human impacts on groundwater quality are essential elements of sustainable integrated groundwater quality and land use management, and are necessary in formulating an effective groundwater protection policy.

Direct human influences on groundwater quality are likely to be more important than climate change in the foreseeable future. Primary climatic stress issues have to do with recharge zones, especially for shallow aquifers, and sea water intrusion in coastal aquifers, related to sea level rise, in conjunction with other stresses. At high latitudes, the thawing of permafrost causes changes in both groundwater levels and quality, due to increased coupling with surface waters. Since many groundwater bodies both charge into and are recharged


ISBN: 978-81-930585-3-4

from surface water, the impacts of surface waterflow regimes are expected to affect groundwater. Increased precipitation variability may decrease groundwater recharge in humid areas.

- **Water quality**

The impact of climate change on water quality is likely to be considerable. The projected reductions in precipitation and runoff will lead to a decrease in both the quantity and quality of water supply. Droughts deteriorate water quality since less water is available for the dilution of wastewater. Higher water temperatures, increased precipitation intensity, and longer periods of low flows are projected to exacerbate many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution. This promotes algal blooms and increases bacterial and fungal content, and, in turn, impacts ecosystems, human health, and the reliability and operating costs of water systems. Rising temperatures are likely to lower water quality in lakes through increased thermal stability and altered mixing patterns, resulting in reduced oxygen concentrations and an increased release of phosphorus from sediments.

More intense rainfall is expected to lead to a deterioration of water quality since it enhances the transport of pathogens and other dissolved pollutants (such as pesticides) to surface water and groundwater. It also results in increased erosion, which in turn leads to the mobilization of adsorbed pollutants such as phosphorus and heavy metals. More frequent heavy rainfall will overload the capacity of sewer systems, and water and wastewater treatment plants more often. In areas with overall decreased runoff such as in semi-arid areas, water quality deterioration will be even worse. IHP is addressing water quality issues through a program aimed at protecting water quality. The impact of climate change on water quality is one of the key areas where specific activities, projects and casestudies on related topics are being developed. In addition, IHP is working on policy recommendations for mitigation and adaptation measures.

**The activities will focus on the following strategies**

- Minimizing pollution load in rivers and surface water bodies during extreme weather events such as floods and droughts;
- Developing sustainable approaches to sanitation and wastewater management in order to prevent the increased sewage contamination of surface and groundwaters and transmission of water- and vector-borne diseases during flood events;
- Developing strategies for augmenting and maintaining the resilience capacity of the natural aquatic environment to cope with pollution.

## 6. FISHERIES

Impacts of Climate Change on Fisheries and Aquaculture Fish have been an important part of the human diet in almost all countries of the world. It is highly nutritious; it can provide vital nutrients absent in typical starchy staples which dominate poor people’s diets (FAO, 2005a; FAO, 2007a). Fish provides about 20 % of animal protein intake (Thorpe et al., 2006) and is one of the cheapest sources of animal proteins as far as availability and affordability is concerned. While it serves as a health food for the affluent world owing to the fish oils rich in polyunsaturated fatty acids (PUFAs), for the people in the other extreme of the nutrition scale, fish is a health food owing to its proteins, oils, vitamins and minerals and the benefits associated with the consumption of small indigenous fishes (Mohanty et al., 2010a).

Although aquaculture has been contributing an increasingly significant proportion of fish over recent decades, approximately two-thirds of fish are still caught in capture fisheries. The number of people directly employed in fisheries and aquaculture is estimated at 43.5 million, of which over 90 % are small –scale fishers (FAO, 2005a). In addition to those directly employed in fishing, over 200 million people are thought to be dependent on smallscale fishing in developing countries, in terms of other economic activities generated by the supply of fish (trade, processing, transport, retail, etc.) and supporting activities (boat building, net making, engine manufacture and repair, supply of services to fisherman and fuel to fishing boats etc.) in addition to millions for whom fisheries provide a supplemental income (FAO, 2005a). Fisheries are often available in remote and rural areas where other economic activities are limited and can thus be important sources for economic growth


ISBN: 978-81-930585-3-4

and livelihoods in rural areas with few other economic activities (FAO, 2005a) 4.1 Potential impacts of climate change on fisheries Climate change is projected to impact broadly across ecosystems, societies and economics, increasing pressure on all livelihoods and food supplies. The major chunk of earth is encompassed by water that harbors vast majority of marine and freshwater fishery resources and thus likely to be affected to a greater extent by vagaries of climate change. Capture fisheries has unique features of natural resource harvesting linked with global ecosystem processes and thus is more prone to such problems. Aquaculture complements and increasingly adds to the supply chain and has important links with capture fisheries and is likely to be affected when the capture fisheries is affected.

The ecological systems which support fisheries are already known to be sensitive to climate variability. For example, in 2007, the International Panel on Climate Change (IPCC) highlighted various risks to aquatic systems from climate change, including loss of coastal wetlands, coral bleaching and changes in the distribution and timing of fresh water flows, and acknowledged the uncertain effect of acidification of oceanic water which is predicted to have profound impacts on marine ecosystems (Orr et al., 2005). Similarly, fishing communities and related industries are concentrated in coastal or low lying zones which are increasingly at risk from sea level rise, extreme weather events and wide range of human pressures (Nicholls et al., 2007a). While poverty in fishing communities or other forms of marginalization reduces their ability to adapt and respond to change, increasingly globalized fish markets are creating new vulnerabilities to market disruptions which may result from climate change.

Fisheries and fisher folk may have the impact in a wide range of ways due to climate change. The distribution or productivity of marine and fresh water fish stocks might be affected owing to the processes such as ocean acidification, habitat damage, changes in oceanography, disruption to precipitation and freshwater availability (Daw et al., 2009). Climate change, in particular, rising temperatures, can have both direct and indirect effects on global fish production. With increased global temperature, the spatial distribution of fish stocks might change due to the migration of fishes from one region to another in search of suitable conditions. Climate change will have major consequences for population dynamics of marine biota via changes in transport processes that influence dispersals and recruitment (Barange and Perry, 2009). These impacts will differ in magnitude and direction for populations within individual marine species whose geographical ranges span large gradients in latitude and temperature, as experimented by Mantzouni and Mackenzie (2010) in cod recruitment throughout the north Atlantic. The effects of increasing temperature on marine and freshwater ecosystems are already evident, with rapid pole ward shifts in distributions of fish and plankton in regions such as North East Atlantic, where temperature change has been rapid (Brander, 2007). Climate change has been implicated in mass mortalities of many aquatic species, including plants, fish, corals, and mammals (Harvell et al., 1999; Battin et al., 2007).

Climate change will have impact on global biodiversity; alien species would expand into regions in which they previously could not survive and reproduce (Walther et al., 2009). Climate driven changes in species composition and abundance will alter species diversity and it is also likely to affect the ecosystems and the availability, accessibility, and quality of resources upon which human populations rely, both directly and indirectly through food web processes. Extreme weather events could result in escape of farmed stock and contribute to reduction in genetic diversity of wild stock affecting biodiversity.

Climate variability and change is projected to have significant effects on the physical, chemical, and biological components of northern Canadian marine, terrestrial, and freshwater systems. According to a study conducted by Prowse et al. (2009), the northward migration of species and the disruption and competition from invading species are already occurring and will continue to affect marine, terrestrial, and freshwater communities. This will have implications for the protection and management of wildlife, fish, and fisheries resources; protected areas; and forests. Shifting environmental conditions will likely introduce new animal-transmitted diseases and redistribute some existing diseases, affecting key economic resources and some human populations. Stress on populations of iconic wildlife species, such as the polar bear, ringed seals, and whales, will continue as a result of changes in critical sea-ice habitat interactions. Where these stresses affect economically and culturally important species, they will have significant effects on people and regional economies. Further integrated,


ISBN: 978-81-930585-3-4

field-based monitoring and research programs, and the development of predictive models are required to allow for more detailed and comprehensive projections of change to be made, and to inform the development and implementation of appropriate adaptation, wildlife, and habitat conservation and protection strategies.

Fisheries will also be exposed to a diverse range of direct and indirect climate impacts, including displacement and migration of human populations; impacts on coastal communities and infrastructure due to sea level rise; and changes in the frequency, distribution or intensity of tropical storms. Inland fisheries ecology is profoundly affected by changes in precipitation and run-off which may occur due to climate change. Lake fisheries in Southern Africa for example, will likely be heavily impacted by reduced lake levels and catches. The variety of different impact mechanisms, complex interactions between social, ecological and economic systems and the possibility of sudden and surprising changes make future effects of climate change on fisheries difficult to predict. In fact, understanding the ecological impacts of climate change is a crucial challenge of the twenty-first century. There is a clear lack of general rules regarding the impacts of global warming on biota. A study conducted by Daufresne et al. (2009) provided evidence that reduced body size is the third universal ecological response to global warming in aquatic systems besides the shift of species ranges toward higher altitudes and latitudes and the seasonal shifts in life cycle events. Many diseases display greater virulence at higher temperatures that might be the result of reduced resistance of the host due to stress or increased expression of virulence factors/ increased transmission of the vectors. Some examples have been summarized in table-2

**Table.2: Impact of climate change on parasitic and other diseases of aquatic animals**

| Host | Disease /Parasite | Response to high temperature | Reference |
|---|---|---|---|
| Largemouth bass (Micropterus salmoides) | Red sore disease /bacterium Aeromonas hydrophila | Susceptibility to the disease increases | Esch and Hazen (1980) |
| Mosquitofish (Gambusia affinis) | Asian fish tapeworm (Bothriocephalus acheilognathi) | | Granath and Esch (1983) |
| Trout (Onchorhynchus spp.) | Whirling disease / Myxozoan Myxobolus cerebralis | | Hiner and Moffitt (2001) |
| Juvenile coho salmon (O. kisutch) | Blackspot disease/ trematode larvae (metacercariae) | Virulence is directly correlated with daily maximum temperature | Cairns et al., 2005 |
| A variety of reef Fish | Ciguatera fish poisoning (CFP) caused by bioaccumulation of algal toxins | Increased incidence of CFP due to increased temperature | Tester et al., 2010 |
| Rainbow trout, Oncorhynchus mykiss | Infected with Ichthyophonus sp | More rapid onset of disease, higher parasite load, more severe host tissue reaction and reduced mean-day-todeath at higher temperature | Kocan et al., 2009 |


ISBN: 978-81-930585-3-4

| Host | Disease /Parasite | Response to high temperature | Reference |
|---|---|---|---|
| Freshwater bryozoans infected with myxozoan, Tetracapsuloides bryosalmonae | Spores released from sacs produced by the parasite during infection of freshwater bryozoans are infective to salmonid fish, causing the devastating Proliferative Kidney Disease (PKD) | Exacerbate PKD outbreaks and increase the geographic range of PKD as a result of the combined responses of T. bryosalmonae and its bryozoan hosts to higher temperatures. | Tops et al., 2009 |

As the emergence of disease is linked directly to changes in the ecology of hosts or pathogens, or both (Harvell et al., 1999), climate change will have a profound impact on the spread of parasites and disease in aquatic ecosystems (Harvell et al., 1999; Marcogliese, 2001; Harvell et al., 2002). Climate change will affect parasite species directly resulting from the extension of the geographical range of pathogens (Harvell et al., 2002). In addition increased temperature may cause thermal stress in aquatic animals, leading to reduced growth, sub-optimal behaviors and reduced immune competence (Harvell et al., 1999; Harvell et al., 2002; Roessig et al., 2004) resulting in changes in the distribution and abundance of their hosts (Marcogliese, 2001). In the oceans, diseases are shown to increase in corals, sea urchins, molluscs, sea turtles and marine mammals, although not all can be linked unequivocally to climate alone (Lafferty et al., 2004). However, it was recently suggested that diseases may not increase with climate change, although distributions of parasites and pathogens will undoubtedly shift (Lafferty, 2009). Other factors may dominate over climate in controlling the distribution and abundance of pathogens, including: habitat alteration, invasive species, agricultural practices and human activities.

**Table 3: General effects of increased temperature on parasite life cycles, their hosts and transmission processes (Marcogliese, 2008)**

| Effects on parasites | Effects on hosts | Effects on transmission |
|---|---|---|
| Faster embryonic development and hatching | Altered feeding | Earlier reproduction in spring |
| Faster rates of development and maturation | Altered behavior | More generations per year |
| Decreased longevity of larvae and adults | Altered range | Prolonged transmission in the fall |
| Increased mortality of all Stages | Altered ecology<br>Reduced host Resistance | Potential transmission year round |

Outbreaks of numerous water- borne diseases in both humans and aquatic organisms are linked to climatic events, although it is often difficult to disentangle climatic from other anthropogenic effects. In some cases, these outbreaks occur in foundation or keystone species, with consequences throughout whole ecosystems. There is much evidence to suggest that parasite and disease transmission, and possibly virulence, will increase with global warming. However, the effects of climate change will be superimposed on a multitude of other anthropogenic environmental changes. Climate change itself may exacerbate these anthropogenic effects. Moreover, parasitism and disease may act synergistically with these anthropogenic stressors to further increase the detrimental effects of global warming on animal and human populations, with debilitating social economic ramifications (Marcogliese, 2008).


ISBN: 978-81-930585-3-4

The repercussions of climate change are not limited solely to temperature effects on hosts and their parasites, but also have other possible effects such as: alteration in water levels and flow regimes, eutrophication, stratification, changes in acidification, reduced ice cover, changes in ocean currents, increased ultra- violet (UV) light penetration, run off, weather extremes (Cochrane et al., 2009).

Anticipated impacts in next few decades In addition to incremental changes of existing trends, complex social and ecological systems such as coastal zones and fisheries, may exhibit sudden qualitative shifts in behaviour when forcing variables past certain thresholds (Daw et al., 2009). For example, IPCC originally estimated that the Greenland ice sheet would take more than 1000 years to melt, but recent observations suggest that the process is already happening faster owing to mechanisms for ice collapse that were not incorporated into the projections (Lenton et al., 2008). The infamous collapse of the Northwest Atlantic northern cod fishery provides a non-climaterelated example where chronic over fishing led to a sudden, unexpected and irreversible loss in production from this fishery. Thus, existing observations of linear trends cannot be used to reliably predict impacts within the next 50 years (Daw et al., 2009).

A study by Veron et al. (2009) also emphasizes impact of increasing atmospheric CO2 levels due to global warming on mass coral bleaching world-wide. According to this group, temperature-induced mass coral bleaching causing mortality on a wide geographic scale started when atmospheric CO2 levels exceeded approximately 320 ppm. At today's level of approximately 387 ppm, allowing a lag-time of 10 years for sea temperatures to respond, most reefs world-wide are committed to an irreversible decline. Mass bleaching will in future become annual, departing from the 4 to 7 years return-time of El Niño events. Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO2 levels are allowed to reach 450 ppm (due to occur by 2030-2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinctions. Reefs will cease to be large-scale nursery grounds for fish and will cease to have most of their current value to humanity. There will be knock-on effects to ecosystems associated with reefs, and to other pelagic and benthic ecosystems.

This is likely to have been the path of great mass extinctions of the past, adding to the case that anthropogenic CO2 emissions could trigger the Earth's sixth mass extinction (Veron et al., 2009)

**Adaptation and mitigation options**

Adaptation to climate change is defined in the climate change literature as an adjustment in ecological, social or economic systems, in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change, or take advantage of new opportunities. Adaptation is an active set of strategies and actions taken by peoples in response to, or in anticipation to the change in order to enhance or maintain their well being. Hence adaptation is a continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life and that reflects existing social norms and processes (Daw et al., 2009). Many capture fisheries and their supporting ecosystems have been poorly managed, and the economic losses due to overfishing, pollution and habitat loss are estimated to exceed $50 billion per year (World Bank & FAO, 2008). The capacity to adapt to climate change is determined partly by material resources and also by networks, technologies and appropriate governance structures. Improved governance, innovative technologies and more responsible practices can generate increased and sustainable benefits from fisheries.

There is a wide range of potential adaptation options for fisheries. To build resilience to the effects of climate change and derive sustainable benefits, fisheries and aquaculture managers need to adopt and adhere to best practices such as those described in the FAO ‘Code of Conduct for Responsible Fisheries’, reducing overfishing and rebuilding fish stocks. These practices need to be integrated more effectively with the management of river basins, watersheds and coastal zones. Fisheries and aquaculture need to be blended into

National Climate Change Adaptation Strategies. In absence of careful planning, aquatic ecosystems, fisheries and aquaculture can potentially suffer as a result of adaptation measures applied by other sectors such as increased use of dams and hydro power in catchments with high rainfall, or the construction of artificial coastal defenses or marine wind farms (ftp://ftp.fao.org/FI/brochure/climate_change/policy_brief.pdf). Mitigation solutions reducing the carbon footprint of Fisheries and Aquaculture will require innovative approaches. One example is the recent inclusion of Mangrove conservation as eligible for reducing emissions from deforestation and forest degradation in developing countries, which demonstrates the potential for catchment forest protection. Other approaches to explore include finding innovative but environmentally safe ways to sequester carbon in aquatic ecosystems, and developing low-carbon aquaculture production systems (ftp://ftp.fao.org/FI/brochure/climate_change/policy_brief.pdf). There is mounting interest in exploiting the importance of herbivorous fishes as a tool to help ecosystems recover from climate change impacts. Aquaculture of herbivorous species can provide nutritious food with a small carbon footprint. This approach might be particularly suitable for recovery of coral reefs, which are acutely threatened by climate change. Surveys of ten sites inside and outside a Bahamian marine reserve over a 2.5-year period demonstrated that increases in coral cover, including adjustments for the initial size distribution of corals, were significantly higher at reserve sites than those in non-reserve sites: macro algal cover was significantly negatively correlated with the change in total coral cover over time. Reducing herbivore exploitation as part of an ecosystem-based management strategy for coral reefs appears to be justified (Mumby and Harborne, 2010).

Furthermore, farming of shellfish, such as oysters and mussels, is not only good business, but also helps clean coastal water, while culturing aquatic plants help to remove waste from polluted water. In contrast to the potential declines in agricultural yields in many areas of the world, climate change opens new opportunities for aquaculture as increasing numbers of species are cultured. Marine fish is one of the most important sources of animal protein for human use, especially in developing countries with coastlines. Marine fishery is also an important industry in many countries. The depletion of fishery resources is happening mainly due to anthropogenic factors such as overfishing, habitat destruction, pollution, invasive species introduction, and climate change. The most effective ways to reverse this downward trend and restore fishery resources are to promote fishery conservation, establish marine protected areas, adopt ecosystem-based management, and implement a "precautionary principle." Additionally, enhancing public awareness of marine conservation, which includes eco-labeling, fishery ban or enclosure, slow fishing, and MPA (marine protected areas) enforcement is important and effective (Shao, 2009).

The assessment report of the 4th International Panel on Climate Change confirms that global warming is strongly affecting biological systems and that 20-30% of species risk extinction from projected future increases in temperature. One of the widespread management strategies taken to conserve individual species and their constituent populations against climate-mediated declines has been the release of captive bred animals to wild in order to augment wild populations for many species. Using a regression model based on a 37-year study of wild and sea ranched Atlantic salmon (Salmo salar) spawning together in the wild, McGinnity et al. (2009) showed that the escape of captive bred animals into the wild can substantially depress recruitment and more specifically disrupt the capacity of natural populations to adapt to higher winter water temperatures associated with climate variability, thus increasing the risk of extinction for the studied population within 20 generations. According to them, positive outcomes to climate change are possible if captive bred animals are prevented from breeding in the wild. Rather than imposing an additional genetic load on wild populations by releasing maladapted captive bred animals, they propose that conservation efforts should focus on optimizing conditions for adaptation to occur by reducing exploitation and protecting critical habitats.

## 7. SEA LEVEL RISE AND COASTAL ECOSYSTEM

Climate change effects such as sea temperatures and sea level rise, increased frequency and magnitude of tropical storms and other extreme events will have negative impacts on both ecosystems (coral bleaching, saltwater intrusion, flooding, erosion) and human well-being (loss and/or reduced productivity in goods and services provided by ecosystems). Reduced protective and regulatory services of coastal ecosystems will leave coastal communities more vulnerable to climate-related disasters. Degradation or disappearance of productive


ISBN: 978-81-930585-3-4

coastal ecosystems will further jeopardize food security and livelihoods in marginalized coastal communities with little adaptive capacity. Low-lying coastal areas have already suffered from the negative impacts of more frequent flooding events. Coastal ecosystems, especially mangrove forests and coral reefs, act as buffers against extreme weather conditions and natural disasters, thereby reducing the vulnerability of coastal communities and their investments (Macintosh and Epps, 2009). Sea grasses, which provide indispensable nursery grounds for many fish species, and feeding habitat for turtles and dugongs, have also declined at an alarming rate and even disappeared in some parts of the Indian Ocean. Thousands of hectares of mangrove forests have been cleared for shrimp farming and other forms of coastal development. In several Asian countries mangrove loss has exceeded 60 percent, on average, in recent decades (Macintosh and Ashton, 2002), while the total area has decreased to less than 15 million hectares worldwide from an estimated 32 million hectares originally.

Rising sea temperature is considered to be the largest threat to coral reefs today. According to the CORDIO 2008 Status Report released by the Global Coral Reef Monitoring Network, 19 percent of the world's coral reefs have already been lost and the remaining may disappear within 20-40 years if current trends in carbon dioxide emissions continue (Obura et al., 2008). Coastal ecosystems would, however, have a better chance of survival if other stress factors related to human activity were minimized.

**Climate change in the coastal zones**

The effect that climate change will have on the coastal zone will vary dependent upon geographic location. The Intergovernmental Panel on Climate Change (IPCC) has confirmed that sea level rise and its associated impacts are expected through the 21st century and beyond due to human emissions of greenhouse gases. Likely impacts physical changes resulting from the effects of climate change, i.e. sea level rise leading to coastal erosion and inundation will be superimposed on an evolving coastal system, primarily shaped by human development. The potential impacts of climate change, climatic changes must be considered on a regional to local scale.

**Sea-level Rise**

Climate warming will lead to thermal expansion of water and melting of glacier and polar land ice, with a subsequent rise in sea level. The effects of sea-level rise will vary with location, speed of the rise, and the geological and biological responses of the affected ecosystems (see Neumann et al. (2000) for a detailed review of the factors affecting the vulnerability of coastal habitat to sea-level rise).

Sea-level rise is a particular threat to the low-lying, shallow-gradient wetlands of the Middle and South Atlantic and Gulf of Mexico. Coastal storms put the two Atlantic regions at further risk from sea-level rise, and the central Gulf Coast region faces an added risk because the deltaic plain is sinking. In general, sea-level rise will inundate coastal lands and erode susceptible shores (Fig. 7). In salt marsh and mangrove habitats, sea-level rise may submerge wetlands, waterlog soils, and cause plant death from salt stress. Most wetland habitats can survive sea-level rise by migrating inland to areas of decreasing tidal inundation along undeveloped (by humans) shores with relatively gentle slopes. In the absence of human effects, there would not be a catastrophic effect on most Gulf of Mexico coastal wetlands, at least at the rates of rise currently projected for the next 50 to 100 years. On developed coasts, wetland plant systems cannot move inland as sea level rises on sedimentary shores because seaside development by humans limits that option (Fig. 7). if sediment inputs are limited.

| A.EXISTING SITUATION | B.RESPONSE TO SEA LEVEL RISE |
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ISBN: 978-81-930585-3-4

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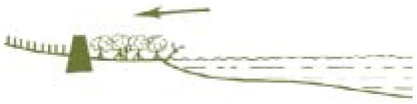
|  |  |
| **C.WITH SEA WALL** | **D.EVENTUAL SITUATION** |

*Source*: Bird (1995)

**Fig. 7*:* Sea-level Rise Effects on Mangrove Forests**

The above figures depict changes in a mangrove forest (could also apply to a salt marsh) that inhabits a depositional terrace that is over 6000 years old (A). In (B), sea level rises at a rate that erodes the foreshore yet allows the forest to retrogress inland. In the presence of human attempts to prevent sea level from inundating the land by building a seawall, the mangrove forest will be eroded away (C and D) and the seawall may have to be strengthened (armored) against wave action that is no longer buffered by the mangroves. BP = before present; MSL = mean sea level. or prevented by the presence of flood-control, navigational, or other anthropogenic structures, marshes and mangroves may be starved for sediment and normal accretion (vertical accumulation of sediment) will be hindered. If inundation outpaces accretion, the marsh or mangrove forest will be submerged, die, and disappear. The continued loss of wetlands in Louisiana indicates that, under the present rate of sea-level rise of 2.3 mm per year and land subsidence of 4 mm per year, total marsh area will be critically reduced as humans alter water and sediment distributions. Estimates of the critical rates of sea-level rise above which south Florida and Caribbean mangrove ecosystems will collapse range from 1.2 mm per year (Ellison and Stoddart, 1991) to 2.3 mm per year (Wanless et al., 1994). However, these rates are only for mangroves in regions with little sediment input, and there has been strong criticism of these threshold values (Snedaker et al., 1994). The most vulnerable mangrove ecosystems in the Gulf of Mexico include those in micro-tidal limestone settings, and those with extensive inland residential development. For example, the extensive coastal development of south Florida would squeeze many species into smaller habitat spaces, with high risk to vulnerable species such as the endangered American crocodile and perhaps sea turtles (Harris and Cropper, 1992).

Louisiana is already undergoing high rates of relative sea-level rise because of land subsidence (Neumann et al., 2000). Development of interior wetland margins by humans as well as the relatively steep gradient of the Pleistocene terrace escarpment prevent landward migration of most Louisiana wetlands, so this ecosystem can be maintained only through vertical accumulation of soil. This process is impaired in Louisiana by major human modifications to the hydrology of the Mississippi River deltaic plain. However, where the Mississippi River connects with its deltaic plain, such as in western Terrebonne Bay where the outflow from the Atchafalaya River nourishes adjacent areas, coastal wetlands appear to respond by adequately maintaining their elevation in the face of subsidence (Day et al., 1997). The same is true for largely unaltered coastal basins such as Pascagoula Bay in Mississippi. It is when sea-level rise is combined with other human land use changes in the drainage basins of the Gulf of Mexico that the consequences may be severe (Cahoon et al., 1998).

Wetland marshes are important contributors to the biological productivity of coastal systems and function as nurseries and as refuges from predators for commercially important shellfish and fish and for birds like some rails, gulls, and terns. Rising sea levels will initially increase access to marsh surfaces by fish and invertebrates, perhaps increasing their production in the short term (e.g., Gulf of Mexico shrimp harvests). However, depletion or loss of marshes will have important effects on nutrient flux, energy flows, essential habitat for a multitude of species, and biodiversity (Ray et al., 1992). Such effects will be positive or negative, depending on the species. For example, birds that require the marsh for rearing young (e.g., Black and Clapper Rails, some terns and plovers) will be affected negatively by its loss, whereas birds that feed in shallow water or on intertidal sand and mud flats that replace the marsh (e.g., dabbling ducks, some shorebirds) will be affected positively. Some coastal zones are habitat for rare, threatened, or endangered species of plants and


ISBN: 978-81-930585-3-4

animals and, if the changes threaten rather than enhance their habitat, they may be lost. Such loss represents the loss of much unique and potentially significant genetic information. Human interference with natural barrier island processes increases the islands' vulnerability to even a small rise in sea level. Many barrier islands move toward the mainland through a process of beach erosion on their seaward flank, overwash of sediment across the island during storms, and deposition of the eroded sediment in the quieter waters of the inland bay. The rate of this natural migration depends largely on the rate of sea-level rise, and also on the frequency and severity of storms and hurricanes.

Even a small rise in sea level sets this process in motion. The construction of buildings, roads, bulkheads, seawalls, and any other type of shore hardening disrupts overwash and sediment movement. In response, the beach face and near shore erode, threatening buildings and narrowing the beach, but the "ribbon of sand" does not grow landward. Eventually, this threatens not only human habitation on barrier islands but also the barrier islands themselves and the habitats they provide. Finally, accelerated rates of subsidence and sea-level rise may alter the depth and width of shallow estuaries. For example, many estuaries in the Gulf of Mexico are only 1 to 3 meters deep and have little topographical relief, so that small absolute changes in relative sea level will greatly change their relative bottom area. Because of the strongly wind-driven nature of these estuaries, bottom friction is very important in controlling hydrodynamics. Changes in bottom area will have an immediate and important effect on the pattern of energy dissipation in estuaries (Schroeder et al., 1990). Rapid changes in bottom area and configuration can also have ecological consequences if they bury or scour important fishery nursery habitats such as seagrass meadows and oyster reefs.

**Impacts of climate on coastal organisms**

The temperature of an animal's (or plant's) body affects virtually all of its physiological processes, and therefore its reproduction, growth, and survival. The rates at which enzymes functions are strongly temperature dependent, and if temperatures become too high enzymes (and other proteins) literally cook (a reaction known as denaturing). Conversely, when body temperatures become too low, enzymes become sluggish and cannot function properly. For many organisms scientists have a very good understanding of the upper and lower temperature tolerances from years of controlled experimental work, and especially in recent years, scientists are beginning to understand the molecular basis of these responses.

By matching up the physiological tolerance limits against body temperatures in the field, scientists also have some idea of the range limits in nature. The geographic limits of species are sensitive indicators of the interactions of organisms and their environment, and are likely to be among the first signals of the impact of climate change on the biota of the planet. At their geographic range limits, populations may suffer stresses that restrict adult survival or recruitment of young. Whenever an organism's temperature exceeds its physiological tolerance, the animal dies, and if temperatures are extreme enough the entire population may go locally extinct. As climatic conditions change, geographic limits migrate toward more benign regions where populations can survive and reproduce. Thus, the bio geographic limits of species can serve as "miner's canaries" for the processes of long-term climate change. In recent years, evidence of such range shifts has become more and more common. For example, a meta analysis by Root et al. found that more than 80% of species examined showed evidence of species range shifts.

A recent analysis by Helmuth et al. found that intertidal species range boundaries may be migrating by up to fifty kilometers per decade, much faster than most recorded shifts in terrestrial ecosystems. Often range shifts and extinction events can occur in unexpected locations. As humans, we have a rather unique perspective on temperature because of our rather tight regulation over the temperature of our bodies. Like other mammals, we have a remarkable ability to thermo regulate, and our physiological processes work over a very narrow range of temperatures; increases in body temperature of just 3-4°C above normal can be deadly. In contrast, most plants and animals on Earth have temperatures that are driven by their ambient environments. Like pavement on a hot sunny day, their temperatures are contingent upon the amount of solar radiation they receive or the amount of heat they release to surrounding wind, and as a result, the temperatures of their bodies are highly subject to changes in the ambient air or water.

Thus, the temperature of many nonhuman plants and animals can be several degrees higher than the temperature of the surrounding air due to the influence of solar radiation. While these organisms generally display much more flexibility in their physiological responses, they too often live in environments that are at the limits of their physiological tolerance limits. For example, estimates suggest that as many as half of the world's coral reefs have either been destroyed or are under imminent risk of collapse.

While many factors have contributed to these declines over the last half century, one of the most recent causes of mortality has been coral bleaching due to slight increases in water temperature. Coral animals harbor symbiotic algae (zooxanthellae) within their tissues; these microorganisms give corals much of their color, and provide the coral host with much of its nutritional requirements. However, slight increases in water temperature cause this symbiosis to break down, forcing the zoo xanthellae to leave the coral animal, causing it to have a ghostly bleached appearance. In cases of prolonged or extreme exposure, coral animals may die, either directly due to physiological stress or due to complications from disease.

As corals provide the basis of reef ecosystems, their loss is enormous; their economic value to humans (in terms of tourism and fisheries) was estimated to be approximately 375 billion U.S. dollars per year a decade ago. Such direct effects of temperature on organisms are one of the most obvious effects of climate change. Whenever local environmental conditions cause the temperature of an organism's body to exceed some threshold tolerance level, either chronically or during an extreme event (e.g. heat wave), the organism exhibits a physiological response.

In extreme cases, as with corals, the organism may die. In other cases, responses may be more subtle but no less significant. For example, on the shores of Europe, the barnacle Semi balanus fails to reproduce when wintertime water temperatures exceed 10°C.70. Recent evidence has shown that as a result of slight increases in winter temperatures, the geographic range of this species has moved 300 kilometers in France since 1872, at a rate of up to fifty kilometers per decade.

Simultaneously, anecdotal evidence suggests that an invasive species of Pacific oyster may be invading regions of Britain and mainland Europe for precisely the opposite reasons due to its tolerance of this slightly higher temperature. The direct effects of temperature are just one of several ways in which climate change impacts coastal species, however. The recently released (2007) Intergovernmental Panel on Climate Change ("IPCC") report estimates the total 20th century sea level rise as 0.17 meters (6.7 inches). This small increment has been sufficient to wreak havoc on coastlines that are only a few inches above sea level.

While some intertidal salt marsh habitats may be able to keep pace with rates of erosion through the accretion of sediment, others may not, and these may literally be drowned by rising sea levels. In a similar vein, coral reefs rely on ambient sunlight to grow. As growth rates decline as a result of increasing temperatures and changes in seawater chemistry, many will not be able to keep pace with rising sea levels. In other words, the seas may rise faster than the corals can keep pace. Changes in ocean chemistry are also occurring and are expected to impact marine organisms. At the present, approximately half of the CO2 released by humans over the last 200 years is now stored in the ocean. While the ability of the oceans to absorb CO2 has slowed, approximately 30% of current emissions is taken up by the oceans.

As a result, the pH of the oceans has been reduced and is expected to continue to decrease. These reductions in pH have significant effects on corals and organisms with shells. While we are just beginning to understand the effects of this increased acidity on marine organisms, results suggest, for example, that the reduced growth rate of corals may prevent them from keeping pace with rising sea levels, essentially increasing the chances that coral reefs may "drown" as sea levels rise.

**Corals**

Increased concentrations of CO2 in seawater will lead to ocean acidification reducing calcification rates of calcifying organisms such as corals. Disintegration of degraded reefs following bleaching or reduced calcification may result in increased wave energy across reef flats with potential for shoreline erosion. There is limited ecological and genetic evidence for adaptation of corals to warmer conditions. It is very likely that


ISBN: 978-81-930585-3-4

projected future increases in sea surface temperature will result in more frequent bleaching events and widespread mortality, if there is not thermal adaptation or acclimatization by corals and their symbionts. The ability of coral reef ecosystems to withstand the impacts of climate change will depend on the extent of degradation from other anthropogenic pressures and the frequency of future bleaching events. Many reefs are affected by tropical cyclones; impacts range from minor breakage of fragile corals to destruction of the majority of corals on a reef and deposition of debris as coarse storm ridges. Such storms represent major perturbations, affecting species composition and abundance, from which reef ecosystems require time to recover. An intensification of tropical storms could have devastating consequences on the reefs themselves, as well as for the inhabitants of many low-lying islands.

**Seagrasses**

Sea grasses appear to be declining around many coasts due to human impacts, and this is expected to accelerate if climate change alters environmental conditions in coastal waters. Changes in salinity and temperature and increased sea level, atmospheric CO2, storm activity and ultraviolet irradiance alter sea grass distribution, productivity and community composition. Increases in the amount of dissolved CO2 and, for some species, HCO3 present in aquatic environments, will lead to higher rates of photosynthesis in submerged aquatic vegetation, similar to the effects of CO2 enrichment on most terrestrial plants, if nutrient availability or other limiting factors do not offset the potential for enhanced productivity. An increase in epiphytic or suspended algae would decrease light available to submerged aquatic vegetation in estuarine and lagoonal systems.

**Estuaries and Lagoons**

Global mean sea-level rise will displace existing coastal plant and animal communities inland. Estuarine plant and animal communities may persist as sea level rises if migration is not restricted and if the rate of change does not exceed the capacity of natural communities to adapt or migrate. Some of the greatest potential impacts of climate change on estuaries may result from changes in physical mixing characteristics caused by changes in freshwater runoff. A globally intensified hydrologic cycle and regional changes in runoff all portend changes in coastal water quality. Freshwater inflows into estuaries influence water residence time, nutrient delivery, vertical stratification, salinity and control of phytoplankton growth rates. Increased freshwater inflows decrease water residence time and increase vertical stratification, and vice versa. The effects of altered residence times can have significant effects on phytoplankton populations, which have the potential to increase fourfold per day. Consequently, in estuaries with very short water residence times, phytoplankton are generally flushed from the system as fast as they can grow, reducing the estuary’s susceptibility to eutrophication and algal blooms. Changes in the timing of freshwater delivery to estuaries could lead to a decoupling of the juvenile phases of many estuarine and marine fishery species from the available nursery habitat. A projected increase in the intensity of tropical cyclones and other coastal storms could alter bottom sediment dynamics, organic matter inputs, phytoplankton and fisheries populations, salinity and oxygen levels, and biogeochemical processes in estuaries.

**Sandy beaches & Rocky shores**

Acceleration in sea-level rise will exacerbate beach erosion. The local response will depend on the total sediment budget. An indirect influence of sea-level rise on the beach sediment budget is due to the infilling of coastal embayments. As sea-level rises, estuaries and lagoons attempt to maintain equilibrium by raising their bed elevation in tandem, and act as a major sink of sand which is often derived from the open coast, implying the potential for major coastal instability due to sea-level rise in the vicinity of tidal inlets. Beach protection strategies and changes in the behaviour or frequency of storms can be more important than the projected acceleration of sea-level rise in determining future beach erosion rates. The combined effects of beach erosion and storms can lead to the erosion or inundation of other coastal systems. Hard rock cliffs formed in softer lithologies are likely to retreat more rapidly. Cliff failure and retreat may be amplified by increased precipitation and higher groundwater levels.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**Mangroves**

Modelling data suggests that global losses of coastal wetlands from 2000 to 2080 of 33% and 44% given a 36 cm and 72 cm rise in sea level, respectively. Mangrove communities are likely to show a blend of positive responses to climate change, such as enhanced growth resulting from higher levels of $CO_2$ and temperature, as well as negative impacts, such as increased saline intrusion and erosion, largely depending on site-specific factors. The sedimentary response of the shoreline is a function of both the availability of sediment and the ability of the organic production by mangroves themselves to fill accommodation space provided by sea-level rise. Groundwater levels play an important role in the elevation of mangrove soils by processes affecting soil shrink and swell.

Hence, the influence of hydrology should be considered when evaluating the effect of disturbances, sea-level rise and water management decisions on mangrove systems. Vertical accretion of mangroves is variable but commonly approaches 5 mm/yr. However, many mangrove shorelines are subsiding and thus experiencing a more rapid relative sea-level rise.

**The value of mangroves in reducing $Co_2$ emissions**

MFF supports and endorses the concept of REDD (Reducing Emissions from Deforestation and Ecosystem Degradation) as a climate change mitigation option. If well designed, REDD can result in substantial $CO_2$ emissions reductions and could also be a potential sustainable source of income for marginalized coastal communities in the Indian Ocean. Mangrove forests, our first line of natural defense against climate-related disasters are disappearing at a rapid rate due to land-use change and deforestation, leading to lower capacity of carbon sequestration and increasing global green house gases (GHG) emissions. It is time to realize the value of mangroves and their efficient carbon sequestration capabilities. Without mangroves in the solution, it will be impossible to maximize carbon sequestration. But it is not only about trees, it is about people. Although, natural mangrove forests restoration will help to maintain adaptive capacity, there are other benefits of REDD far beyond carbon sequestration such as ecosystem services which include local climate regulation (cooling through transpiration, shade and wind protection), local erosion control (slope stabilization) and coastal protection. Commitments by governments, donors, NGOs and local communities to reduce emissions from deforestation and degradation offers an opportunity to help resolve the pressing issues that are leading to massive deforestation, increased vulnerability of coastal communities, biodiversity loss, and change in climate.

**What is MFF?**

The Mangroves for the Future (MFF) initiative is based on a vision of a healthier, more prosperous and secure future for all sections of coastal populations in Indian Ocean countries. It is an IUCN and UNDP-led partnership-based initiative which includes the countries worst-affected by the tsunami; India, Indonesia, Maldives, Seychelles, Sri Lanka, and Thailand, as well as dialogue countries in the region that face similar issues. MFF uses mangroves as a flagship ecosystem but is inclusive of all coastal ecosystems. The MFF initiative’s objective is to strengthening the environmental sustainability of coastal development and promoting sound investment in coastal ecosystem management, as a means of enhancing resilience and supporting local livelihoods. In the present context of global environmental change, sustainability must incorporate measures to address the likely impacts of short-term climate variability and long-term climate change. Individual interventions supported through the MFF, and the programme as a whole, ensures that the investments in coastal ecosystem management addresses the issue of increasing adaptive capacity (capacity of society to cope with the expected or actual climate changes) to deal with the likely impacts of climate change. Furthermore, increasing adaptive capacity is an integral part of each MFF intervention.

**MFF and Climate Change Considerations**

Considering the large number of people in coastal areas that could be displaced by climate change, MFF seeks to conduct activities that: mobilizes local communities and governments to undertake joint actions for sustainable coastal management; ensure food security through sound ecosystem management; build knowledge to better understand the links between livelihoods and climate system; and increase adaptive capacity to meet


ISBN: 978-81-930585-3-4

the long-term development needs of coastal communities, while securing their livelihoods against climate change impacts and helping them prepare for potential climate-related disasters. The MFF also adopts a new approach by moving from a reactive response to progressive activities that address long-term sustainable management needs and develop community resilience, including building awareness and capacity for improved food and livelihood security, disaster preparedness, and climate change adaptation. MFF undertakes collective actions to build knowledge, strengthen empowerment, and enhance governance with climate change as a cross-cutting theme, to address the current and future threats, and to conserve and restore coastal ecosystems. MFF works in four key areas of influence: regional cooperation, national programme support, private sector engagement and community action.

The programmes of work are implemented through a series of on-the-ground projects, through small and large grantmodalities.

**Integrating Disaster Risk Reduction into Coastal Zone Management**

Coastal ecosystems and associated watersheds provide a wide range of services to coastal communities, which are fundamental to building community resilience to coastal hazards; yet these services are under threat from a variety of sources and global climate change is expected to increase the frequency and intensity of climate related hazards. Approaches to Disaster Risk Reduction (DRR) address vulnerability to natural hazards and climate variability, and therefore have explicit alignment to the objectives of climate change adaptation. The aim is to ensure that adaptation addresses both current climate variability, as well as long-term climate changes, which threaten ecosystem sustainability. Integrating DRR into coastal zone management helps build disaster resilient communities. Raising awareness of the importance of DRR should be an integral component of sustainable coastal development. While there are many coastal zone managers in Indian Ocean countries, there is still a limited understanding of the principles of reducing underlying risk factors and limited engagement with national disaster reduction mechanisms and resources.

MFF takes a partnerships approach to DRR, seeking to involve individuals, communities and institutions such as UN ISDR, which is the focal point in the UN System to promote links and synergies between, and the coordination of, disaster reduction activities in the socio-economic, humanitarian and development fields, as well as to support policy integration.

**Climate Change Adaptation**

Climate change is only one of the many interacting stressors in the coastal zone. Consequently, it is important that climate change adaptation is considered in conjunction with the multiple management objectives for integrated coastal management (ICM). Climate change mainstreaming is a tool to facilitate the incorporation of climate change adaptation within existing policies and practices that inform ICM. There are a number of different adaptation measures that support climate change adaptation, which can be broken into three primary options; Protect; Retreat; and Accommodate. Successful adaptation requires a combination of adaptation measures that each contribute to the coastal management goals and objectives. The selection and success of an adaptation measure will relate to the level in which the measure addresses the adaptive capacity of the community in which it is applied.

**Climate Change Mitigation**

MFF partners are seeking opportunities to develop specific activities related to REDD under the MFF initiative by means of; supporting local livelihoods and enhancing coastal ecosystem and community resilience by promoting investment in conservation of coastal ecosystems while also providing adaptation benefits and improving local livelihoods. MFF and its partners are developing and testing tools at project sites in the region. It will further aim to identify mechanisms for REDD based on an ecosystem approach that enhances natural sequestration and storage of carbon in existing mangrove forests and restore degraded mangroves areas. The effectiveness of REDD activities will ultimately depend on the success of its contribution to the development needs of communities that rely on mangrove products.


ISBN: 978-81-930585-3-4

The MFF climate change considerations work programme will focus on climate change mitigation and climate change adaptation, with a greater emphasis to the latter, to assist MFF countries in the Indian Ocean to build capacity and help develop national strategies. MFF seeks more effective and inclusive institutions, policies and mechanisms for cooperation at national and regional levels by prioritizing coastal climate change considerations across national development agendas, policies and budgets.

**Forecasting future impacts**

The coastal zone has served as a natural ecological laboratory for examining the impacts of climate on natural ecosystems, and we now understand a great deal about the mechanisms of how these systems work. There is no doubt that ecological communities are complex: predicting the impacts of climate change on natural ecosystems not only mandates that we understand how and where climate will be altered, but also that we understand the physiological and ecological responses of organisms. Moreover, forecasting future ecological responses mandates an understanding of how climate translates into changes at the scale of the organism. For example, it is now possible to model the body temperature of intertidal animals using remote sensing data, data from weather stations and coastal buoys. Therefore, using projections from global climate change models, we can forecast temperatures in the future.

Comparisons of model outputs against measurements made in the field suggest that while daily fluctuations of 25°C are quite common, errors in predictions of monthly maxima are on the order of ~1°C. By comparing these measurements against the physiological tolerances of animals, it is then possible to predict (and hindcast) changes in the geographic ranges of animals that have occurred as a result of shifts in climate. In other words, these models can be used to generate explicit hypotheses which can be tested (either contemporarily or retroactively using historical data sets) under field conditions. These approaches have the potential to serve as an interface between policy and science using global climate change models, given an appropriate understanding of the uncertainty in the input used.

It may be possible to predict, for example, the most likely location for the emplacement of a marine reserve based on the likelihood that a mortality event will occur. Conversely, areas where mortality is certain to occur may be "triaged" without needless expenditure of funds.

While such endeavors are possible, they, like other mathematical approaches, involve large amounts of uncertainty at every step. Given the potential for error, are such models useful? No model can capture every intricacy of the natural world or predict every vicarious event; by necessity, models must be presented in terms of probability and likelihood, even when based on an underpinning of mechanism and physics. And, as has been pointed out, models have the potential for misuse as is true for any other management tool. However, the application of models requires a frank discussion of the nature of uncertainty and the application of science to matters of policy.

In many ways, predicting the impacts of climate change on natural ecosystems is much like predicting the landfall and magnitude of a hurricane. The farther from shore the hurricane is, the less certain we are of the strength of the storm or the exact position that it will be when it reaches shore. As the storm gets closer to shore, the more confident we become in our model predictions. The question then becomes, what should our response be: (a) to abandon our attempts to model hurricane movement and not worry about landfall until we have a high level of certainty of precisely where it will land, (b) to make only qualitative predictions and to shore up the entire coastline because hurricane prediction is difficult, or (as, unfortunately seems to be in vogue) (c) deny that hurricanes exist at all because we cannot model every last parcel of wind? The answer lies at the interface of policy and science. Our understanding of the effects of climate on natural ecosystems is quite strong, as is our understanding of the physics of climate, and of the interface of organisms with their local microclimates. The precautionary principle would mandate that we protect the entire natural environment and eliminate greenhouse gas production altogether; the opposite extreme would call for a complete denial of the reality of climate change, and to forge ahead with a "business as usual mentality." Neither is realistic.

Production solutions must obviously involve compromise, and will by necessity mandate some form of prediction and forecasting. While the potential for misuse is very real, this does not invalidate the tool of thoughtful modeling; the alternative is to forego any hope of planning for the future with meaningful input from decades of science. Our current challenge is to embed deterministic scientific knowledge within a framework of probability, and to enact policy that recognizes varying levels of uncertainty. This challenge will not be easy, but with an open an honest dialog between scientists, policy makers, members of the business community, and other relevant stakeholders, both economic and ecological concerns can be realized.

## 8. HILL ECOSYSTEM

The Himalaya and adjacent mountain ranges in the north-east region within Indian Territory, collectively known as Indian Himalaya Region (IHR), represent highly fragile and vulnerable Mountain Ecosystems in the country.

The Himalaya and adjacent hill ranges in the north-eastern India represent a complex array of physical and geo-political environment, well known for geo-hydrological, biological, aesthetic and cultural values. The region, collectively referred to as Indian Himalaya Region (IHR) , encompasses a series of lofty ranges many of which exceed 7000 m above sea level, alpine meadows, lake basins, cold deserts, inter-montane valleys, deep gorges, snowfields, glaciers and alluvial plains. Some of the Asia’s mighty rivers namely Indus, Sutlej, Ganges, and Brahmaputra and their numerous tributaries flow through these ranges which support a myriad of human civilizations along their fertile valleys.

Although the main Himalaya and the hills of North-eastern states have a number of similarities in their physiography and ecology, they differ inherently in terms of origin and evolution. On the other hand the Khasi, Jaintia and Patkai ranges of North Eastern Hill Region (NEHR) are of ancient origin.

### Glaciers and Hydrology

The main Himalaya is divisible into four morpho-tectonic belts each with peculiar lithological features. The outermost range, popularly known as Shivalik or Outer Himalaya, represents the youngest range comprising fragile sandstones and siltstones. The second range, Lesser Himalaya consists of meta-sedimentaries superposed by older blocks or nappes. The highest range i.e., Higher Himalaya or the Himadri comprises the crystalline rocks which are sparsely vegetated and largely covered by glaciers and snow. The mountain ranges north of the higher Himalaya, frequently termed as trans-Himalaya or cold deserts, are dry, exposed and frequently devoid of green vegetation cover due to extremely harsh climatic conditions.

The higher Himalaya houses largest snow mass outside the polar region and also gives rise to most important glacier systems in the world. These glaciers form the source of most of north India’s river systems, which form the life line for the millions of people living in their lower basins. Hence they are regarded as important ‘water towers’ on earth. According to the Geological Survey of India, there are more than 5000 glaciers in the Indian Himalaya covering about 38,000 $km^2$ areas. The distribution of glaciers in the Himalaya is uneven due to complexity of mountain ranges, altitudinal variation and different climatic environment.

Generally, the north-western Himalaya has higher concentration of glaciers as compared to the eastern Himalaya. Some of the important glaciers are listed below:

The Himalayan Rivers carry enormous silt and fertile soil that influences agro-economy in the plains. The perennial river system of the Himalaya is fed by melt water contributions from snow cover, glaciers and permafrost regions. The total amount of water flowing from the Himalaya to the plains of the Indian subcontinent is estimated to be about 8.6 x 106 M 3 per year (IPCC, 2001); out of which the contribution of snow to the runoff of major rivers in the eastern Himalaya is about 10% (Sharma, 1993) and more than 60% in the western Himalaya (Vohra, 1981). In the IHR besides rivers, streams, lakes, ponds, groundwater through springs are the main sources of water for drinking and household consumption. In recent years, attention has been drawn towards decline in the discharge of springs.


ISBN: 978-81-930585-3-4

**Table 4: Important glaciers of IHR and their locations**

| SN | Name of Glacier | LengthKm. | Geographical/Location | Altitudinal Range |
|---|---|---|---|---|
| 1. | Siachen | 72 | Karakoram | 3800-7000 |
| 2. | Hispar | 62 | Karakoram | 3400-6000 |
| 3. | Baifo | 69 | Karakoram | 3500-6200 |
| 4. | Batura | 59 | Karakoram | 3600-6200 |
| 5. | Kolahai | 06 | Kashmir | 3600-5100 |
| 6. | Machai | 08 | Kashmir | 3400-5000 |
| 7. | Shishram | 06 | Kashmir | 3800-5200 |
| 8. | Liddar | 05 | Kashmir | 3600-5200 |
| 9. | Bara Shigri | 30 | Himachal | 4000-6200 |
| 10. | Chhota Shigri | 09 | Himachal | 4000-6000 |
| 11. | Sara Umga | 17 | Himachal | 3900-6000 |
| 12. | Parvati | 08 | Himachal | 4000-5800 |
| 13. | Samudra Tapu | 09 | Himachal | 4000-5900 |
| 14. | NorthNanda Devi | 19 | Uttaranchal | 4000-6000 |
| 15. | SouthNanda Devi | 19 | Uttaranchal | 4100-6100 |
| 16. | Trisul | 15 | Uttaranchal | 3900-5800 |
| 17. | Gangotri | 30 | Uttaranchal | 4000-6200 |
| 18. | Dokriani | 05 | Uttaranchal | 3900-6200 |
| 19. | Chorabari | 07 | Uttaranchal | 3900-6200 |
| 20. | Gantotri | 19 | Uttaranchal | 4100-6200 |
| 21. | Chowkhamba | 12 | Uttaranchal | 4000-5900 |
| 22. | Satopanth | 13 | Uttaranchal | 4000-6200 |
| 23. | Pindari | 08 | Uttaranchal | 4200-5600 |
| 24. | Milam | 19 | Uttaranchal | 3900-6200 |
| 25. | Zemu | 26 | Sikkim | 4400-5900 |
| 26 | Khangchendzonga | 16 | Sikkim | 4200-6000 |

Source-Report of the Task force on mountain ecosystems (2006)

**Natural Hazards**

The Himalayan frontal arc is one of the seismically active regions of the world. The 50 km wide zone between the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT), is seismically most active. This zone is also known as the Main Himalayan Seismic Belt in hich the massive earthquakes (M>8) have been occurring along the detachment surface that separates under-thrusting Indian plate from the Lesser Himalaya. In addition to four great earthquakes of magnitude exceeding 8 (1897 Assam, 1905 Kangr a , 1934 Bihar ,Nepal and 1950 Assam) another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the past 100 years. The regions between the epicenters of these earthquakes, known as the seismic gaps, are the potential sites for future big earthquakes.

The IHR is prone to landslips, landslides, flash floods and other changes in the surface topography owing to high seismic activity and fragility of the land mass. Recurrent landslides cause heavy damage to property, disruption of road communication and loss of human lives every year. Notable among such events are Malpa landslide in the Kali valley (1998), Varunavrat landslide in Uttarkashi (2003) and a series of landslides and flash floods in the Satluj valley during 2000 and 2005. The landslide and other mass movement activities are essentially periodic, generally limited to the monsoon rainfall which acts as trigger for inducing the slope instability. The number, frequency and damage due to landslides are determined mainly by geological, geo-morphological, hydrological, land use, climatic and anthropogenic factors. In the IHR the damage caused by the landslides is estimated to be more than Rs. 50 every year, causing more than 200 deaths annually which is


ISBN: 978-81-930585-3-4

about 30% of the total such losses worldwide .The atmospheric temperature increase brought about by global climate change has resulted in the shift of monsoon pattern accompanied by an increase in intensity of rainfall and cloudbursts and heavy landslides during recent years (Sah and Mazari, 1998). Earthquakes are also responsible for generating landslides on an extensive scale and further augmentation of the same during the monsoon period, as is evident in many parts of the Garhwal Himalaya during recent earthquakes. Among the four belts in the IHR, rock falls and avalanches are common in the Higher Himalaya due to high relief. On the other hand, the Lesser Himalaya, a belt of medium-high relief features comprising sedimentary rocks overlain by nappes of crystalline rocks, is prone to landslides and other mass movements.

The IHR is also susceptible to hazards like glacial lake outburst floods (GLOF). The occurrence of GLOF in high mountains poses many problems for inhabitants and their infrastructure such as heavy loss of human life, damage to agricultural crops and property and destruction of hydro-electric projects. GLOF also causes rapid filling of reservoirs. Damage to settlements and farmland can take place at very great distances from the outburst source. Avalanches are other glacial hazards. Although the avalanche zone lies in the snow-clad Higher Himalayan belt which is sparsely populated, nevertheless this hazard poses dangers on highways which pass underneath. R exerts a considerable influence on weather patterns throughout the South Asia.

**Apparent and Potential Impacts of Climate Change on the Mountain Ecosystems**

The mountain ecosystems not only influence the atmospheric circulation significantly, but also exhibit a great deal of variation in local climatic patterns. Hence, they are likely to get affected most by the global climate change. However, the impacts of climate change on mountain ecosystems cannot be predicted with reasonable accuracy due to lack of long term and time – line studies. In the mountain regions even small changes have the potential to produce significant effects, particularly in the marginal environments that are under stress. Various Ecosystems within the IHR have evolved under certain climatic regimes. Some of the ecosystems are more susceptible to climate change, compared to others, due to extreme sensitivity of constituent elements.

Some of the apparent changes in the IHR due to climate change include shrinking of glaciers, glacial lake outburst floods, and shifts in the boundary of certain ecosystems (e.g., treeline).

**Some of the major impacts are taken up for consideration, which deserve urgent attention**

## I. Impact on Glaciers

- Himalayan glaciers cover approximately 23,000 $km^2$, being one of the largest concentrations of glacier-stored fresh water apart from the Polar Regions. Glaciers are the products of climate and climate change; truly reckoned as veritable thermometers of global warming.
- Surveys based on satellite images and ground investigations by ISRO's Space Application Centre (SAC) Ahmedabad have established that in Himachal Pradesh alone, the glaciers have reduced from 2,077 $km^2$ to 1,628 km2 – an overall deglaciation of 21 % in four decades. According to SAC as many as 127 glaciers of less than 1 km2 size have lost 38 per cent of their geographical area since 1962. The larger glaciers, which are progressively getting fragmented, have receded by as much as 12 per cent which is truly alarming.
- Data on glacial recession from the IHR are available only for last 150 years. These reveal that the Himalayan glaciers are retreating at an average rate of 18-20 m yr-1(Mazari 2006).
- Such a rapid depletion of ice caps and faster glacial melts in the IHR is bound to adversely affect India's freshwater balance which could have catastrophic consequences for, consumptive and non – consumptive users of water.


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**The rate of retreat of some important Himalayan glaciers is presented below:**

**Table 5: Snout recession of Himalayan glaciers***

| Name of glacier | Period of Measuring | Period (in years) | Recession (in m) | Average rate (m/yr.) |
|---|---|---|---|---|
| Milam glacier | 1849-1957 | 108 | 1350 | 12.50 |
| Pindari glacier | 1845-1966 | 121 | 2840 | 23.40 |
| Gangotri glacier | 1962-1991 | 29 | 580 | 20.00 |
| Tipra bank glacier | 1960-1986 | 26 | 325 | 12.50 |
| Dokriani glacier | 1962-1991<br>1991-2000 | 29<br>09 | 480<br>161.15 | 16.5<br>18.0 |
| Chorabari | 1962-2005 | 41 | 238 | 5.8 |
| Shankulpa | 1881-1957 | 76 | 518 | 6.8 |
| Poting | 1906-1957 | 51 | 262 | 5.13 |
| Glacier no-3 Arwa | 1932-1956 | 24 | 198 | 8.25 |
| Bara Shigri | 1956-1963 | 07 | 219 | 31.28 |
| Chhota Shigri | 1987-1989 | 03 | 54 | 18.5 |
| Sonapani | 1909-1961 | 52 | 899 | 17.2 |
| Kolai | 1912-1961 | 49 | 800 | 16.3 |
| Zemu | 1977-1984 | 07 | 193 | 27.5 |

(*The Department of Science and Technology, GOI, under the Himalayan Glaciology Programme (HGP) has been carrying out a multidisciplinary study on the mass balance, recession, ice thickness, glacial discharge, sediment transfer, isotopic and chemical characteristic of snow, ice and melt water and geomorphology mapping under the leadership of Wadia Institute of Himalayan Geology since 1986. During the first phase information has been generated on Chhota Shigri glacier in Himachal Pradesh, Dokhriani in Bhagirathi Valley and Chorabari in the Alaknanda basin of Uttaranchal. These glaciers are being monitored regularly to detect the changes).

**II. Disturbances in hydrological functions**

- Increase in ambient temperature can have strong influence on local weather pattern. It is predicted that there would be an upward shift in various climatic zones with slight rise in temperature. Also, there is increasing evidence that winter precipitation in the form of snow fall has declined over the years.
- Increase in glacier melting is likely to increase runoff and glacial lake outburst floods Reduction in the Crysphere can also alter upstream hydrology, stream flow, primary productivity and mountain farming. Other consequences of reduced hydrological functions include shortage of drinking water, reduction in agricultural and hydropower production.
- Impacts of reduced catchment capabilities in IHR is likely to be far more serious on cities, towns and villages downstream including Himalayan foothills that depend completely (or partially) on mountain streams and rivers.
- Increased atmospheric temperature would mean higher rainfall and reduction in snow fall leading to more erosion, increased run-off and loss of surface soil on steeper mountain slopes which would accelerate the rates of siltation and flash floods.
- Water provided by the hill aquifers in the form of springs is responsible for sustaining domestic livestock and agricultural activity since the ancient times. Already access to safe potable water is limited in the IHR. Under the changed precipitation conditions, leading to increased run-off and less infiltration; coupled with removal of forest cover, has already started showing signs of depleted hill aquifer regimes in the IHR.

**III. Impact on crop and livestock productivity**

- Shifts in precipitation patterns coupled with elevated temperature would have direct impact on crop productivity. As the glaciers disappear and summer runoff diminishes, much of the catchment areas are likely to face aridity.


ISBN: 978-81-930585-3-4

- Changes in climate would affect the quality of horticultural crops such as apple and apricots. There may be shifts in fruit belts but there exists very little scope for expansion.
- Flowering and fruiting phenology of many species would alter. It is known that late snowfall affects the processes of pollination indirectly. Relative immobilization of bees is triggered due to low temperatures brought about by late snowfall.
- Rangeland and pastoral production system is likely to get affected likewise. Positive factors such as carbon dioxide fertilization and better water use efficiency are contrasted by negative feedback such as deficiency in water and higher fluctuation in temperature. Rangeland forage quality and quantity would be seriously affected, suggesting an increased requirement for feed supplements for livestock.
- At higher altitudes increased temperature and heat stress may influence livestock production. As livestock diseases are much influenced by climate change, transmission of wind borne Foot and Mouth Disease viruses may increase.
- There is a strong correlation between the climate change, failure of crops and deforestation inducing clearing of more areas for Jhum in the NEHR.

**IV. Effect on forests and biodiversity**

- Climate change is likely to enhance the frequency and intensity of forest fires in the mountains, exacerbating problem of carbon emissions, haze and habitat destruction. The factors listed for plants and crops in general also largely apply to forests.
- A depletion of soil moisture may cause productivity of major species to decline. Productivity of moist deciduous forests could also be reduced.
- Global climate change has prompted serious concern over the potential consequences to the world's ecological systems and wildlife. Changes in habitat will have an impact on indigenous flora and fauna, and their ability to adapt to changing climatic conditions. Climate-related hydrological changes to a species habitat are likely to become more and more pronounced as the global mean temperature of the earth rises; resulting in changes in salinity, water temperature, increase in sun exposure in areas due to evaporation, melting ice, and various other interconnected ramifications.

**V. Implication for human health**

Understanding of the impacts of climate variability and change requires information at multiple levels. As in case of several other sectors, data on health surveillance in IHR are not readily available, making predictions and comparisons difficult. Some of the widely accepted implications for human health are perceived as follows:

- Increased ambient temperature is likely to cause thermal stress, resulting in discomfort, physiological stress, and ill health.
- The existing problem of water quality is likely to be further exacerbated by climate change. The risk of water-borne diseases will increase. Already access to safe water is quite limited in the IHR.
- Climate change will also affect infectious diseases transmitted by insects, i.e. vector-borne diseases such as malaria, dengue, and schistosomiasis. These diseases are sensitive to temperature as well as to land-use changes.

**VI. Impact on other aspects of Human Society**

Climate change is likely to have direct impact on forestry, agriculture and other land use practices in the IHR. For example, a change in precipitation and species composition could enhance the frequency and intensity of forest fires in the mountains, exacerbating problem of emissions, haze and habitat destruction. Similarly, with changed hydrology and cropping pattern the agricultural production is likely to be affected. Due to lower discharge of the river systems generation of hydropower will become more expensive, particularly as concept of run-of-the-river schemes is being preferred over big dams. More energy is going to be required for refrigeration and cooling, to combat discomfortable temperature regimes. It may appear to be a scenario not inherent to the mountain systems, but a changeover is already witnessed in many parts of the IHR.

Climate change is predicted to severely affect the tourism industry in view of shorter duration winter snow and lower river discharge in summer. High temperatures are also likely to affect the tourist trend leading to crowding of smaller resorts having comfortable temperature levels, but its consequences on the environment are likely to be substantive .This is already witnessed in many parts of the IHR and is likely to aggravate further.

The poorer sections of the society in the IHR are less prepared to address the impacts of climate change as compared to richer brethren. This, coupled with inequities being caused by economic globalization, is likely to enhance gaps between 'haves' and 'have-nots' further. Malnutrition due to reduction in food quality and quantity is likely to increase in IHR.

## 9. MIGRATION AND CONFLICT

The costs and consequences of climate change on our world will define the 21st century. Even if nations across our planet were to take immediate steps to rein in carbon emissions—an unlikely prospect—a warmer climate is inevitable. As the U.N. Intergovernmental Panel on Climate Change, or IPCC, noted in 2007, human-created "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." As these ill effects progress they will have serious implications for U.S. national security interests as well as global stability—extending from the sustainability of coastal military installations to the stability of nations that lack the resources, good governance, and resiliency needed to respond to the many adverse consequences of climate change. And as these effects accelerate, the stress will impact human migration and conflict around the world. It is difficult to fully understand the detailed causes of migration and economic and political instability, but the growing evidence of links between climate change, migration, and conflict raise plenty of reasons for concern. This is why it's time to start thinking about new and comprehensive answers to multifaceted crisis scenarios brought on or worsened by global climate change. As Achim Steiner, executive director of the U.N. Environment Program, argues, "The question we must continuously ask ourselves in the face of scientific complexity and uncertainty, but also growing evidence of climate change, is at what point precaution, common sense or prudent risk management demands action."

In the coming decades climate change will increasingly threaten humanity's shared interests and collective security in many parts of the world, disproportionately affecting the globe's least developed countries. Climate change will pose challenging social, political, and strategic questions for the many different multinational, regional, national, and nonprofit organizations dedicated to improving the human.

### Migration

Migration adds another layer of complexity to the scenario. In the 21st century the world could see substantial numbers of climate migrants—people displaced by either the slow or sudden onset of the effects of climate change. The United Nations' recent Human Development Report stated that, worldwide, there are already an estimated 700 million internal migrants—those leaving their homes within their own countries—a number that includes people whose migration is related to climate change and environmental factors. Overall migration across national borders is already at approximately 214 million people worldwide, with estimates of up to 20 million displaced in 2008 alone because of a rising sea level, desertification, and flooding. One expert, Oli Brown of the International Institute for Sustainable Development, predicts a tenfold increase in the current number of internally displaced persons and international refugees by 2050.

It is important to acknowledge that there is no consensus on this estimate. In fact there is major disagreement among experts about how to identify climate as a causal factor in internal and international migration. But even though the root causes of human mobility are not always easy to decipher, the policy challenges posed by that movement are real. A 2009 report by the International Organization for Migration produced in cooperation with the United Nations University and the Climate Change, Environment and Migration Alliance cites numbers that range from "200 million to 1 billion migrants from climate change alone, by 2050," arguing that


ISBN: 978-81-930585-3-4

"environmental drivers of migration are often coupled with economic, social and developmental factors that can accelerate and to a certain extent mask the impact of climate change."

The report also notes that "migration can result from different environmental factors, among them gradual environmental degradation (including desertification, soil and coastal erosion) and natural disasters (such as earthquakes, floods or tropical storms Clearly, then, climate change is expected to aggravate many existing migratory pressures around the world. Indeed associated extreme weather events resulting in drought, floods, and disease are projected to increase the number of sudden humanitarian crises and disasters in areas least able to cope, such as those already mired in poverty or prone to conflict.

**Conflict**

This final layer is the most unpredictable, both within nations and transnationally, and will force the United States and the international community to confront climate and migration challenges within an increasingly unstructured local or regional security environment. In contrast to the great power conflicts and the associated proxy wars that marked most of the 20th century, the immediate post Cold War decades witnessed a diffusion of national security interests and threats. U.S. national security policy is increasingly integrating thinking about non state actors and nontraditional sources of conflict and instability, for example in the fight against Al Qaeda and its affiliated groups. Climate change is among these newly visible issues sparking conflict. But because the direct link between conflict and climate change is unclear, awareness of the indirect links has yet to lead to substantial and sustained action to address its security implications. Still the potential for the changing climate to induce conflict or exacerbate existing instability in some of the world's most vulnerable regions is now recognized in national security circles in the United States, although research gaps still exists in many places. The climate-conflict nexus was highlighted with particular effect by the current U.S. administration's security-planning reviews over the past two years, as well as the Center for Naval Analysis, which termed climate change a "threat multiplier," indicating that it can exacerbate existing stresses and insecurity. The Pentagon's latest Quadrennial Defense Review also recognized climate change as an "accelerant of instability or conflict," highlighting the operational challenges that will confront U.S. and partner militaries amid a rising sea level, growing extreme weather events, and other anticipated effects of climate change. The U.S. Department of Defense has even voiced concern for American military installations that may be threatened by a rising sea level. There is also well-developed international analysis on these points. The United Kingdom's 2010 Defense Review, for example, referenced the security aspects of climate change as an evolving challenge for militaries and policymakers. Additionally, in 2010, the Nigerian government referred to climate change as the "greatest environmental and humanitarian challenge facing the country this century," demonstrating that climate change is no longer seen as solely scientific or environmental, but increasingly as a social and political issue cutting across all aspects of human development.

As these three threads—climate change, migration, and conflict—interact more intensely, the consequences will be far-reaching and occasionally counterintuitive. It is impossible to predict the outcome of the Arab Spring movement, for example, but the blossoming of democracy in some countries and the demand for it in others is partly an unexpected result of the consequences of climate change on global food prices. On the other hand, the interplay of these factors will drive complex crisis situations in which domestic policy, international policy, humanitarian assistance, and security converge in new ways.

**Areas of Concern**

Several regional hotspots frequently come up in the international debate on climate change, migration, and conflict. Climate migrants in northwest Africa, for example, are causing communities across the region to respond in different ways, often to the detriment of regional and international security concerns. Political and social instability in the region plays into the hands of organizations such as Al Qaeda in the Islamic Maghreb. And recent developments in Libya, especially the large number of weapons looted from depots after strongman Moammar Qaddafi's regime fell—which still remain unaccounted for—are a threat to stability across North Africa.

Effective solutions need not address all of these issues simultaneously but must recognize the layers of relationships among them. And these solutions must also recognize that these variables will not always intersect in predictable ways. While some migrants may flee floodplains, for example, others may migrate to them in search of greater opportunities in coastal urban areas.

Bangladesh, already well known for its disastrous floods, faces rising waters in the future due to climate-driven glacial meltdowns in neighboring India. The effects can hardly be over. In December 2008 the National Defense University in Washington, D.C., ran an exercise that explored the impact of a flood that sent hundreds of thousands of refugees into neighboring India. The result: the exercise predicted a new wave of migration would touch off religious conflicts, encourage the spread of contagious diseases, and cause vast damage to infrastructure.

India itself is not in a position to absorb climate-induced pressures—never mind foreign climate migrants. The country will contribute percent of global population growth and have close to 1.6 billion inhabitants by 2050, causing demographic developments that are sure to spark waves of internal migration across the country.

Then there's the Andean region of South America, where melting glaciers and snowcaps will drive climate, migration, and security concerns. The average rate of glacial melting has doubled over the past few years, according to the World Glacier Monitoring Service.

Besides Peru, which faces the gravest consequences in Latin America, a number of other Andean countries will be massively affected, including Bolivia, Ecuador, and Colombia. This development will put water security, agricultural production, and power generation at risk—all factors that could prompt people to leave their homes and migrate. The IPCC report argues that the region is especially vulnerable because of its fragile ecosystem.

Finally, China is now in its fourth decade of ever-growing internal migration, some of it driven in recent years by environmental change. Today, across its vast territory, China continues to experience the full spectrum of climate change related consequences that have the potential to continue to encourage such migration. The Center for a New American Security recently found that the consequences of climate change and continued internal migration in China include "water stress; increased droughts, flooding, or other severe events; increased coastal erosion and saltwater inundation; glacial melt in the Himalayas that could affect hundreds of millions; and shifting agricultural zones"—all of which will affect food supplies.

These four regions of the world—northwest Africa, India and Bangladesh, the Andean region, and China—will require global, regional, and local policies to deal with the consequences of climate change, migration, and conflict. Alas, such policies that might be effective in these complex crisis environments cannot be designed within the existing global institutional framework. There are many reasons for this.

In the United States, as in many other developed nations, the defense, diplomacy, and economic and social development silos are not adept at analyzing the input of a broad range of policy fields in combination with direct dialogue with the people of the affected regions. From Europe's perspective, the fragmented nature of the continent's reaction to rising climate migrants from Africa stands out. From the perspective of regional powers such as India, China, Brazil, and South Africa, there are yet again different sets of policy priorities that block action. And from the perspective of multilateral organizations, there is another set of policy disconnects.

Yet action is critical. Environmentally induced migration, resource conflicts, and unstable states will not only have an impact upon the nations where they occur, but also on the United States and the broader international community.

**Moving Forward**

The interplay of migration, climate change, and conflict is complex and will be with us for the long term. Nevertheless, the uncertainty surrounding the exact causality should not be a reason for ignoring this key nexus. And while the causal relationship may not always be clear, the lines of inquiry moving forward are becoming apparent. To understand this nexus, we will need to ask, for example, what role mediating factors


ISBN: 978-81-930585-3-4

such as economic opportunity, levels of development, health indicators, and legal status will play in the relationship between climate change and migration. It will be equally critical to determine whether there is a threshold at which the effects of climate change could be significant enough to cause migration directly, or at what level of climate change it will become the most important of several migration "push" factors.

Additionally, we should ask whether climate change will alter the composition of migrant communities. Migrants, after all, are not necessarily the most desperate or destitute of their countrymen and women. Migrations, particularly across international borders, often require means. Could a significant increase in extreme weather events or long-term shifts in climate norms alter this dynamic, and what would be the implications of that shift? Some instances of the complete climate, migration, and conflict nexus exist to guide the examination of these questions. Consider, for example, the Second Tuareg Rebellion in Mali in 1990. British economist Nicholas Stern argues that drought in Mali in the decades preceding the conflict contributed to local and international migration. Those who later tried to return found a "lack of social support networks for returning migrants, continuing drought, and competition for resources between nomadic and settled people," all of which were among the factors that sparked the rebellion.

Jeffrey Mazo at the International Institute of Strategic Studies adds that the forced migration ultimately pushed some young men into Algeria and Libya, "where many were radicalized"—a dangerous development in an already unstable region.

Imagine similar migration-fueled conflicts in India and Bangladesh, the Andean region, and in China. We can't know how they might develop but we do know the three ingredients—climate change, migration, and conflict. From the perspective of a forward-looking policymaker, situations like this suggest that the uncertainty that still surrounds the climate, migration, and conflict nexus requires greater attention when it comes to security solutions, not less.

**Sustainable security situation to deal with climate change, migration, and conflict. Specifically they must**

- Conduct federal government institutional reform in the United States that addresses the development-security relationship and that prioritizes planning for long-term humanitarian consequences of climate change and migration as a core national security issue
- Develop strategies to strengthen intergovernmental cooperation on transboundary risks in different regions of the world
- Increase funding for the Global Climate Change Initiative
- Ensure better information flows and more effective disaster response for earlywarning systems
- Support the best science to expand our understanding of specific circumstances such as desertification, rainfall variability, disaster occurrence, and coastal erosion, and their relation to human migration and conflict
- Identify regions most vulnerable to climate-induced migration, both forced and voluntary, in order to target aid, information, and contingency-planning capabilities
- View migration as a proactive adaptation strategy for local populations under pressure due to increased environmental change

A truly sustainable approach to security, then, requires us not only to look at the traditional security threats posed by the interaction between states, but also to understand that the security of the United States is advanced by promoting the individual well-being of people across the developing world, and by embracing collective responses to shared threats posed by climate change. We turn first to understanding the dynamics of those threats.

## 10. TOURISM

According to the System of Tourism Statistics (STS), 'Tourism' is defined as the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited".


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‘Tourism’ refers to all activities of visitors, including both ‘tourists (overnight visitors)’ and ‘same-day visitors’. This concept can be applied to different forms of tourism. Depending upon whether a person is travelling to, from or within a certain country the following forms can be distinguished:

- **Inbound Tourism,** involving the non-residents received by a destination country from the point of view of that destination;
- **Outbound Tourism,** involving residents travelling to another country from the point of view of the country of origin;
- **Domestic tourism,** involving residents of a given country travelling within that country.

Therefore, tourism covers not only international travel (i.e. inbound tourism from the point of view of destinations, or outbound tourism from the point of view of generating markets); it also covers tourism inside one’s country of residence (i.e. domestic tourism). As an economic activity, tourism is defined on the one hand by the demand and consumption of visitors, whether by tourists (i.e. overnight visitors) or by same-day visitors; on the other hand, tourism refers to the goods and services produced to meet that demand. As such it comprises a whole range of different activities, e.g., transport to and at the destination, accommodation, catering, entertainment, shopping, services of travel agencies, outgoing and incoming tour operators, etc.

The extent to which climate change may affect the environmental systems of a range of international tourist destinations worldwide and the potential impacts these changes may have on tourism. International tourism is the largest and most rapidly expanding economic activity in the world today. As reported by the World Tourism Organisation, travel and tourism involved 625 million people internationally and generated $US 445 million in receipts in 1998 (WTO, 1999). Tourism is an important contributor to the economies of most countries and in some can represent up to one fifth of GDP. The global tourism industry is expected to grow significantly in the future as personal incomes and leisure time increase, and transportation networks improve.

The climate system is dynamic and varies on all time scales. However, over the last century we have seen an increase of over 0.6°C in the average temperature of the Earth. The warming this century has been more rapid than any other period for which we have data. The 1990s will be the warmest decade this millennium with 1998 the warmest year and August 1998 the warmest month.

Since the start of the industrial revolution vast quantities of carbon dioxide and other so-called greenhouse gases have been released into the atmosphere by the burning of fossil fuels, most notably coal and oil, and to a lesser extent, gas. This has led to an increase in the atmospheric concentration of carbon dioxide from 280ppm (parts per million) to its present level of 355ppm. Carbon Dioxide is one of the main greenhouse gases, along with water vapour and methane. As a result of the increasing concentration of these gases, more long wave radiation from the Earth is absorbed, thus reducing the energy lost to space and so altering the natural balance between incoming and outgoing radiation. Continued use of carbon-based fuels will further increase the atmospheric concentrations of carbon dioxide and other greenhouse gases. The most recent estimates of how this will change over the next century have been produced by the IPCC Special Report on Emissions Scenarios. These estimates of future emissions are used in mathematical climate models (Wigley *et al,* 1997) to explore how this will effect global temperatures and regional climates

Detailed analysis of the output from these climate models provides further evidence of the impacts of the enhanced greenhouse effect upon our climate. For example, we can now say with increasing confidence that the average global rainfall will increase. However, this will not be experienced everywhere, and for some regions there will be decreases in rainfall. Extreme climate events (such as droughts and prolonged 'hot' periods) may increase in frequency. For example, in the UK, what is perceived as a hot year or month (e.g. August, 1997) may become the norm by the middle of the next century, and what we might consider to be an exceptional period in the future will lie outside our present sphere of experience. Changes in the frequency of other extreme weather events such as severe windstorms (tornadoes and hurricanes) are more difficult to determine, but any increase in these would certainly have profound regional impacts.


ISBN: 978-81-930585-3-4

Many aspects of our lives are influenced by the weather and the climate, from the crops we grow to the social activities we engage in. The natural environment and climate conditions are very important in determining the attractiveness of a region as a holiday destination. In the UK, summer weather conditions are classified as 'comfortable' (not too hot, not too humid, not too cold) yet millions of Britons each year fly the relatively hot (2-3 hours) distance to Southern Europe in search of better weather. In turn, tourism is having an effect on the environment and climate. For example, the expansion in air travel is itself increasing emissions of greenhouse gases and enhancing the risk of continued global warming (IPCC, 1999).

Holidays have become an essential part of our lives in the latter stages of the twentieth century. They account for one of our most costly items of expenditure with an average package holiday costing £0.70 per household per week for a package holiday in the UK, and £8.10 per household per week for a package holiday overseas (Office of National Statistics). As well as the more frequently visited short-haul destinations, eg Spain, Greece and Turkey, the accessibility of far-flung exotic holiday destinations is now increasing. International tourism is one of the most important and rapidly growing service industries in the world. However, its continued success is closely and symbiotically related to the preservation and enhancement of environmental resources. The environment is one of the most basic resources for tourism; yet unchecked growth in tourism inevitably leads to modification of the environment.

**How Climate Change Affects Tourism**

There are four complicated interactions between tourism development and climate change, ranging from natural, external phenomena to those resulting from human behaviors:

- Direct impact from weather phenomena caused by warming: destruction wrought by floods, storms, fires and drought, glacial lake overflows, the disappearance of beaches and so on.
- Indirect, long-term impacts resulting from a substantial and lasting alteration of the environment of a tourist destination that reduces its attractiveness (polluted waters, receding forests, decreased biodiversity, retreating glaciers and snow caps, etc.).
- Lifestyle changes, causing, for example, the reorientation of tourism flows both in winter and summer.
- Induced impacts, which include the efforts of individuals and public policies aimed at attenuating the effects of warming that produce a series of consequences for tourism activity: for example, the adoption of new, more energy-efficient technologies, increased transport costs, product-diversification efforts aimed at prolonging a season and reducing vulnerability, etc.

**Lessons for the Tourism Sector**

- Shift mindset and create a corporate culture that actively seeks to develop business approaches that expand economic opportunity throughout the value chain;
- Focus on employment and training to support local economies;
- Improve procurement practices to grow business with local farmers and small enterprises;
- Link tourists to local cultural products and experiences;
- Pay attention to the distribution patterns of tourism-related economic opportunities so that they reach smaller local enterprises;
- Collaborate with others to maximize economic development impact and to enhance efficiency; and
- Share best practices with others in the tourism industry.

**Lessons for Governments**

- Encourage inclusive business models through regulatory and fiscal policy and public contracts;
- Build public-private partnerships to increase training capacity;
- Partner with the national tourism sector to facilitate the shift to inclusive business models and greater development impact;
- Create a conducive environment for small and micro enterprises; and
- Engage at local and provincial levels, not just national.

**Mitigation Potential**

Tourism has the responsibility to minimise harmful GHG emissions and there are many technological, behavioural, managerial and policy initiatives that can bring tourism to a more sustainable emissions pathway. For tourism transport, technological improvements are unlikely to be enough to compensate for the rapid growth in demand, in particular for air travel. Large potentials for emission reductions also exist in land transport, accommodation and activities. In particular the energy needed for heating and cooling can be reduced significantly (e.g., through solar heating of water, better insulation, and optimising the use of air-conditioning). The climate change mitigation potential is thought to be relatively high in the tourism sector because efforts to reduce energy consumption and GHG emissions in the sector are still largely in their infancy and thus far have been taken without any vision of a coordinated sector-wide strategic response. 738 The Mitigation Scenarios developed suggest that emissions of the 2035 'business-as-usual' trajectory could be reduced by 38% with the 'technical-efficiency' scenario and 44% with the 'modal-shift' and 'length-of-stay' scenario. Importantly, when these scenarios are combined emissions were able to be reduced to 16% below the 2005 baseline, which is consistent with the desired emissions pathway of the international community, as discussed at the "Vienna Climate Change Talks". ** This study shows that with combinations of strong mitigation effort significant emission reduction is possible by 2035 versus a 'business-as-usual' trajectory, without jeopardizing the growth of world tourism in number of trips or guest nights. Achieving this desirable alternative scenario will not be easy and concerted action by the entire tourism sector must commence in the very near term. Climate change mitigation policies within tourism will have to find a balance between potentially conflicting objectives. Clearly, decisions on climate change and tourism have implications for local, national and global, as well as inter-generational equity and all these aspects need to be taken into account to arrive at an effective policy mix. For example, the most effective mitigation option for tourism would be to reduce the growth in the demand for flying (e.g., by increasing taxation and/or including the aviation sector in emissions trading schemes). However, such policy options must be weighed carefully against the other socio-economic benefits of tourism, including the needs of developing countries in terms of poverty alleviation and other Millennium Development Goals, and the support of protected areas and biodiversity, especially because long-haul travel from the industrialized countries causes most emissions, while only a minor share of this long-haul travel is directed to poor regions.

**Mitigation Policies and Measures**

Climate change mitigation relates to technological, economic and socio-cultural changes that can lead to reductions in greenhouse gas emissions. Tourism-related emissions are projected to continue to grow rapidly under 'business-as-usual' conditions in contrast to the substantial emission reduction targets the international community agreed was required in the latest round of UNFCCC negotiations ("Vienna Climate Change Talks 2007"), where it was recognized that global emissions of GHG need to be reduced to well below half of the levels in 2000 by mid-century. * Mitigation is thus of particular importance in tourism; however, mitigation policies need to consider a number of dimensions, such as the need to stabilize the global climate, the right of people to rest and recover and leisure **, and attaining the United

Nations Millennium Development Goals: As the emission reductions required for tourism to contribute meaningfully to the broader emission reduction targets of the international community are substantial, mitigation should ideally combine various strategies, such as voluntary, economic, and regulatory instruments. These can be targeted at different stakeholder groups, including tourists, tour operators, accommodation managers, air lines, manufacturers of cars and aircraft, as well as destination managers. Instruments could also be applied with different emphasis in different countries, so as not to jeopardize the development and poverty reduction opportunity offered by tourism in developing countries. It is clear that for those actors being pro-active in addressing climate change, mitigation offers a range of business opportunities. Given current societal trends, it seems that there will be new, permanent and growing markets for environmentally oriented tourists and many opportunities to develop new low carbon tourism products .


ISBN: 978-81-930585-3-4

## 11. ENROLLMENT OF WOMEN IN CLIMATE CHANGE MITIGATION

The gender dimension of climate change, and in turn climate justice, must be highlighted. The impacts of climate changes are different for women and men, with women likely to bear the greater burden in situations of poverty.

Women's voices must be heard and their priorities supported as part of climate justice. In many countries and cultures, women are at the forefront of living with the reality of the injustices caused by climate change. They are critically aware of the importance of climate justice in contributing to the right to development being recognized and can play a vital role as agents of change within their communities.

It is important to remember, however, that women are not only vulnerable to climate change but they are also effective actors or agents of change in relation to both mitigation and adaptation. Women often have a strong body of knowledge and expertise that can be used in climate change mitigation, disaster reduction and adaptation strategies. Furthermore, women's responsibilities in households and communities, as stewards of natural and household resources, positions them well to contribute to livelihood strategies adapted to changing environmental realities.

Women are more vulnerable to the effects of climate change than men—primarily as they constitute the majority of the world's poor and are more dependent for their livelihood on natural resources that are threatened by climate change. Furthermore, they face social, economic and political barriers that limit their coping capacity. Women and men in rural areas in developing countries are especially vulnerable when they are highly dependent on local natural resources for their livelihood. Those charged with the responsibility to secure water, food and fuel for cooking and heating face the greatest challenges. Secondly, when coupled with unequal access to resources and to decision-making processes, limited mobility places women in rural areas in a position where they are disproportionately affected by climate change. It is thus important to identify gender-sensitive strategies to respond to the environmental and humanitarian crises caused by climate change.

Historically climate policy has not addressed the differing ways in which climate change affects men and women. Mary Robinson Foundation –Climate Justice (MRFCJ) is working to contribute to the development of gender-informed climate policy. At the international level this is policy which sets out commitments to address the gender dimensions of climate change and which provides guidance on how best to do this.

MRFCJ aims to strengthen references to gender and gender equality and women's leadership in international policy in order to facilitate more gender responsive action on the ground.

The Women Leaders' High Level Summit on 21 June gathered women Heads of State and women leaders, and called on global leaders to accelerate actions and policies for a sustainable future. Ms. Michelle Bachelet, Under-Secretary General and Executive Director of UN Women said that when women enjoy equal rights and opportunities, poverty, hunger and poor health decline and economic growth rises.

**Incorporating gender perspectives and involving women as agents of change in responses**

The active participation of women in the development of funding criteria and allocation of resources for climate change initiatives is critical, particularly at local levels. Gender analysis of all budget lines and financial instruments for climate change is needed to ensure gender-sensitive investments in programmes for adaptation, mitigation, technology transfer and capacity building.

**Technological developments** related to climate change should take into account women's specific priorities, needs and roles, and make full use of their knowledge and expertise, including indigenous knowledge and traditional practices. Women's involvement in the development of new technologies can ensure that they are user-friendly, affordable, effective and sustainable. Gender inequalities in access to resources, including credit, extension services, information and technology, must be taken into account in developing activities designed to curb climate change. Women should also have equal access to training, credit and skills-development programmes to ensure their full participation in climate change initiatives.

Governments should thus be encouraged to incorporate gender perspectives into their national policies, action plans and other measures on sustainable development and climate change, through carrying out systematic gender analysis; collecting and utilizing sex-disaggregated data; establishing gender-sensitive benchmarks and indicators; and developing practical tools to support increased attention to gender perspectives.

The consultation and participation of women in climate change initiatives must be ensured, and the role of women's groups and networks strengthened. Currently, women are underrepresented in the decision-making process on environmental governance. They should be equally represented in decision-making structures to allow them to contribute their unique and valuable perspectives and expertise on climate change. Women can make substantive contributions through their knowledge and experience on issues related to the management of natural resources. For example, women in leadership positions— at national, local and community levels— have made a visible difference in natural disaster responses, both in emergency rescue and evacuation efforts and in post-disaster reconstruction, as well as in the management of essential natural resources, such as fresh water.

## 12. SOCIAL STRATEGY TO COMBAT CLIMATE CHANGE

Communicating the climate message to different people may require different strategies, especially if you want people to go beyond awareness. The common objective for all people would be awareness, understanding what climate change is and what impact it has.

But different people may have other goals. The other goal for the farmers is how to minimize the risk of crop failure. For community women and youth, the accompanying goal would be to create income-generation opportunities. For public officials, one goal would be the design of regulations appropriate to local climate conditions. Another goal would be building capacity, for instance, in how to reduce carbon emissions

If the dry season is longer than normal, for instance, farmers should not plant rice due to the lack of water; instead, they should switch to non-staple food crops like soybeans, peanuts and cassava. In this way, the farmers adapt to the weather.

The village of Cisalopa, south of Bogor in West Java, the Komunitas Greena, founded by high-energy IPB graduate Nina Nuraniyah, organizes trainings to reduce global warming and create jobs for local women and youth. The women make exquisite bags, purses and pencil boxes from otherwise discarded food wrappers, while the young people are employed to sell at nearby schools ice cream made from locally-grown ubi ungu (purple edible sweet-potato-like tubers). Their activities amount to climate mitigation at the local level.

Algae growing around Antarctica are short on iron. For decades, scientists have theorized that iron dumped in the oceans there could help fertilize the algae—and that algae could in turn absorb carbon dioxide, thus battling global warming. While tests have shown that iron can, in fact, fuel algae blooms, only now have scientists discovered what happens next—and the results look promising.

Researchers fertilized the algae and waited weeks to see where it would end up. As hoped, after the algae died, it sank to the ocean floor. The study, which was conducted eight years ago but whose results have only just emerged, suggests that algae can carry carbon dioxide to the bottom of the sea, apparently safely. But some experts are skeptical. "At best, this technology appears to be speculative," says an environmental advocate. "At worst, it could turn out to be a disastrous experiment that could have major impacts on the ocean ecosystems."

The bottom line for a climate communication strategy is an intended outcome common for all stakeholders: Behavioural change. People must change their behaviour before.

## 13. PEOPLE'S ORGANISATION AND CLIMATE CHANGE MITIGATION

Climate change organisations have grown rapidly in number, size and influence over the past decade.Given that people in modern societies try to respond to challenges by thinking, talking, debating, or arguing about the problem, then such profusion is expected.


ISBN: 978-81-930585-3-4

To add weight to their arguments people tend to get together and form groups. This happened even before the advent of social media that simply makes the process swift and mollifies the tyranny of distance. Forming organisations is the way we have learned to tackle issues that affect more than our immediate kin.

**Climate change organisations cover the full spectrum of types**

- **Multi-national agency**, most notably the UNFCCC, that are created by and for the benefit of many nations.
- **Technical organisations** that are primarily involved with the science or engineering, such as the IPCC.
- **Non-government organisations** (NGOs) who use the freedom of not being tied to the public purse to advocate a particular position. Many of the well-known conservation NGOs such as Greenpeace and WWF are included but many climate change specific NGOs have also emerged.
- **Lobby groups** are usually created by and for commercial interests. They are often small organisations but can be highly influential as they are often well funded.
- **Private sector companies** in their own right can be big enough or influential enough to be loud voices in the debate.
- **Activists** make the organisations list because although often started or fronted by an individual, they sometimes gather together a group voice and in the internet age can become quite lively.

**Here are some of the top climate change organizations**

1. **Pew Center on Global Climate Change** : The Pew Center on Global Climate Change brings a new cooperative approach and critical scientific, economic and technological expertise to the global debate on climate change.
2. **Climate Institute** :Working to "to protect the balance between climate and life on earth."
3. **US Global Change Research Program :**The USGCRP provides the foundation for increasing the skill of predictions of seasonal-to-inter-annual climate fluctuations (which can bring excessively wet and dry periods) and long-term climate change.
4. **United Nations World Meteorological Organization (WMO)** :World Meteorological Organization coordinates global scientific activity in several areas, including: air pollution research, climate change and ozone depletion studies.
5. **Encyclopedia of the Atmospheric Environment:** A project of the Atmosphere, Climate, & Environment Information Programme at the Manchester Metropolitan University.
6. **EPA Global Warming Page**: “Explains climate change science, U.S. climate policy, greenhouse gas emissions, environmental effects, and what you can do.”
7. **Climate Change Solutions**: An online resource centre of success stories, opportunity areas, tools, and resources on how to reduce greenhouse gas emissions.
8. **Earth System Research Laboratory:** Identifies the nature and causes of climate variations on scales ranging from months to centuries.
9. **Hadley Centre for Climate Prediction and Research:** Provides the UK government with up-to-date assessments of both natural and man-made climate change.
10. **What's Up With the Weather**?: NOVA and Frontline examine the issues of global warming and its link to the burning of fossil fuels.

**There are two broad camps, those who would**

- Keep our economic, social and resource use systems humming along as we shift to energy and production that release less greenhouse gas, indeed we use the power of this system to achieve the transition – the market will do it for us.
- Shift to clean energy and production because we must curb emissions but we must also decrease consumption to tread more lightly on the earth – the market is the root of the problem.


ISBN: 978-81-930585-3-4

One camp assures us that our economic system has delivered wealth, consistently, so why not harness its power to extend the benefits to all and to fix any challenge we face. Solutions for global warming can be found if we unleash the power of the markets and its proven mechanisms.
The other camp is convinced that consumption, epitomized by excess, will be our downfall. We must satisfy need not want and ease ourselves back to the simpler life.

These are caricatures for sure; exaggerated for the sake of simplicity and yet hide many critical subtleties. What has happened, and will continue, is that the debates over the philosophy will consume much of our emotional energy even before we get to debate the merits of specific technical solutions. We risk ‘fiddling while Rome burns’.

Here though, both approaches, and their innumerable variants, are touted as solutions for global warming on the premise that we can actually stop, even reverse, a warming trend.

## 14. COMMUNICATION STRATEGY TO MITIGATE CLIMATE CHANGE

As climate change is a global problem with wide-ranging impacts, it is essential that the climate change messages are communicated successfully with many different groups including residents, partners, opinion formers, and stakeholders.

Action on climate change consists of two complementary elements. Mitigation is concerned with the causes of global warming and calls for the reduction of greenhouse gas emissions. Whilst adaptation is concerned with the impacts of a changing climate on society, the economy and the environment, and promotes activities to reduce vulnerability to extreme weather events and other longer term changes in our climate. This strategy looks to how to communicate both the mitigation and adaptation agendas. This strategy provides a framework for delivering key messages on climate change issues to target audiences. This strategy discusses the actions recommended to raise awareness of climate change and its impacts, and the communication of these actions. this strategy will also look at the communication of mitigation.

The effects of climate change are not instantaneous and easily observable by ordinary people and businesses. It is also accepted that reversing climate change will take a long time, even after action is taken. These issues make it difficult to engage people in action to combat climate change. . In the roll out this strategy, particular attention will be paid to understanding the audiences’ mentality, level of understanding of climate change, interests, values, and concerns. Accordingly, the message content, and language will be tailored to address their specific information needs, pre-existing knowledge, and concerns.

Given the technical nature of Climate it is crucial that climate change messages both for information and action, are communicated effectively and successfully to all stakeholders so as to influence and guide the necessary or relevant policies, actions and solutions for both mitigation and adaptation at all levels.

**Comhar recommends that the communications strategy must:**

- Fulfil a dual role of raising awareness of the necessity to reduce greenhouse gas emissions and of providing information on greenhouse gas emissions associated with our daily choices;
- Recognise the urgency of taking action;
- Promote individual responsibility;
- Be sustained over a period of at least five years;
- Have significant, dedicated resources, including major additional funding, assigned to it;
- Be integrated and exploit synergies with other relevant campaigns and activities across Government departments and with Northern Ireland;
- Have a full-time communications coordinator appointed, with a specific brief to ensure that the communications strategy is developed, disseminated, monitored and evaluated;
- Involve all of the target sectors identified in the National Climate Change Strategy, identify the agencies responsible for coordinating climate change measures in each sector and be designed to make the best use of the key actors and media available within each sector;


ISBN: 978-81-930585-3-4

- Identify and develop the institutional framework to implement carbon labelling of products across all sectors and provide assistance with a consistent design;
- Involve central government and local authorities leading by example, requiring green procurement where possible and an ex-ante climate impact assessment of Government policies and measures;
- Facilitate feedback from citizens and stakeholders to assess the efficacy of climate-related policies and measures;
- Recognise and incorporate the potential of key groups such as the media, NGOs and Professional institutions in communicating climate change;
- Integrate climate change messages throughout the education system;
- Tap innovative channels/media to extend coverage of the message;
- Look beyond the timescale of the Kyoto Protocol and the National Climate Change Strategy to the medium- and longer-term goals (e.g. 2020 and 2050) that have been identified by the European Union to meet the ultimate UN objective of avoiding dangerous climate change.

## 15. AGRICULTURAL EXTENSION STRATEGY IN CLIMATE CHANGE MITIGATION

The global increases in CO2 concentration are due primarily to fossil fuel use and land use change, while those of CH4 and N2O are primarily due to agriculture (IPCC, 2007). Agriculture is therefore the main culprit of climate change producing significant effects through the production and release of GHGs.

Agricultural extension has key roles to play in initiating this change. This is because adaptations to climate change impacts require changes in knowledge, attitudes, resilience capacities, and skills of the people and agricultural extension can bring this change.

Agricultural extension according to Leeuwis (2006) is a series of embedded communicative interventions that are meant, among other things, to develop and/or induce innovations which supposedly help to resolve (usually multi-actor) problematic situations. It has been observed that agricultural extension is involved in public information and education programmes that could assist farmers inmitigating the effects of climate change. According to them, such involvements include awareness creation and knowledge brokerage on the issues of climate change; building resilience capacities among vulnerable individuals, communities and regions; encouragement of wide participation of all stakeholders in addressing climate change issues; and developing appropriate frameworks for coping/adapting to climate change effects/impacts.

Organic agriculture, as an adaptation strategy to climate change and variability, is a concrete and promising option for rural communities and has additional potential as a mitigation strategy. Adaptation and mitigation based on organic agriculture can build on well established practice because organic agriculture is a sustainable livelihood strategy with decades of use in several climate zones and under a wide range of specific local conditions. The financial requirements of organic agriculture as an adaptation or mitigation strategy are low. Further research is needed on yields in organic agriculture and its mitigation and sequestration potential. Other critical points are information provision and institutional structures such as market access.

### Role of agricultural extension

Research without extension is a luxury and extension without research is a mockery. Agricultural extension has a defining role in mitigating the effect of climate change. Research and extension strategies need to be devised to change the practices so that rising temperatures can be controlled to some extent.

Extension personnel need to be equipped with the technologies to combat the climate change and be trained in techniques to motivate the peoples for adoption of environmental technologies. Extensional personnel can be trained and deployed to identify the target areas which are likely to be affected more by temperature rise. The problems of these areas can then be referred to the research stations for suitable research interventions. The technology that comes out of the research houses needs to be disseminated further to the ultimate users. An extension worker is an important asset in the whole identification, research and dissemination process as illustrated in the model below:


ISBN: 978-81-930585-3-4

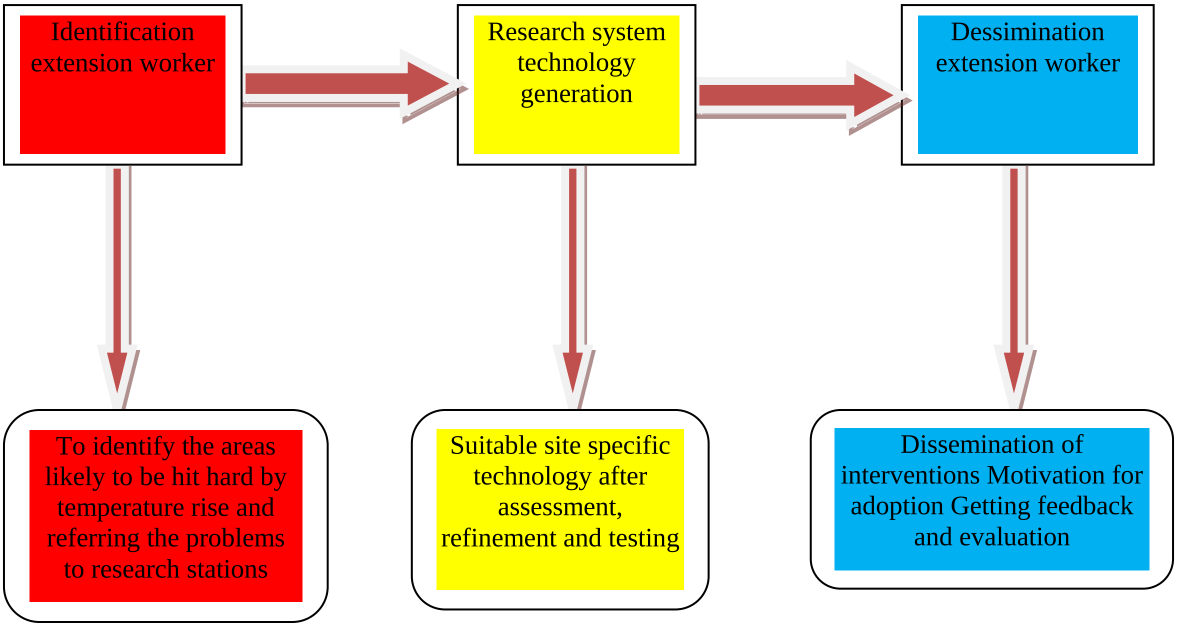



**Fig. 8: Global Warming and Agriculture: Issues and Strategies Parveen Kumar and M S Nain*Research Journal of Agricultural Sciences 2010, 1(3): 298-301**

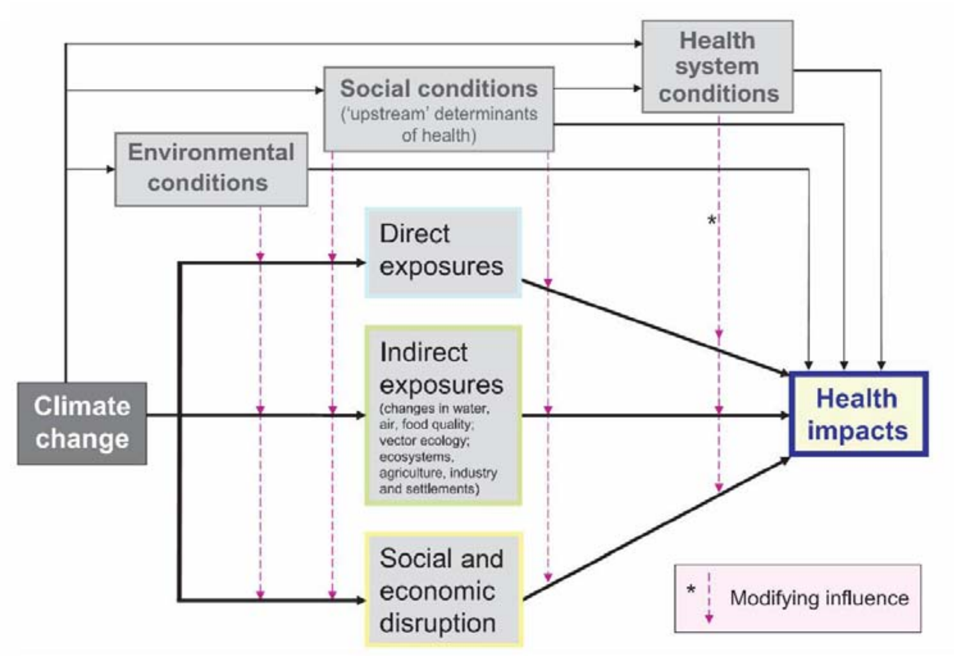
## 16. IPCC OBSERVATION ON PUBLIC HEALTH AND GLOBAL WARMING

The health of millions of people globally is projected to be affected through changes in climate discussed above. In the South and South-East Asia regions, some of the key changes and projected health impacts include (IPCC, 2007; Confalonieri et al., 2007):

- Increase in the number and severity of heat waves contribute to premature deaths from heat stress and exacerbate respiratory diseases and cardiovascular illnesses related to increased ground-level ozone in urban areas; most affected would be children, the elderly and chronically sick persons.
- Change in average temperatures and rainfall patterns affect the distribution of infectious disease vectors such as malaria and dengue; specific outcomes would vary locally since reduced rainfall could also reduce mosquito-breeding ranges.
- Increase in heavy-precipitation events increase the risk of water- and food borne diseases, diarrhoea and cholera, including through disruption of waste disposal systems; during episodes of severe flooding, there would also be increased direct risk of injuries and death.
- Increased drought risk could lead to more frequent crop failures, increasing the risk of malnutrition especially for poor children, and to heightened emotional stress and community tensions in drought affected areas.
- Increases in tropical cyclone intensity bring increased risk to human life, property and public infrastructure, and increase post-traumatic stress disorders.
- Sea-level rise, where combined with extreme events such as storms and floods, poses challenges to livelihoods particularly of poorly protected low-lying settlements and farm land; in the longer term, sea level rise could force significant relocation of populations with attendant stresses on community cohesion and well-being. The specific impacts and numbers of people affected will depend not only on future climate change but also on socioeconomic development and specific factors that directly shape the health of populations.

These include education, health care systems, public health initiatives, infrastructure and economic development, and the ability of these factors to respond to the changing pressures of a changing climate (IPCC, 2007). Fig. 3 shows these links schematically.


ISBN: 978-81-930585-3-4




*Source*: Confalonieri et al., 2007)

**Fig. 9: Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of environmental, social and health-system factors**

## 17. IPCC OBSERVATION ON BIODIVERSITY LOSS AND GLOBAL WARMING

There is high confidence that climate change will result in extinction of many species and reduction in the diversity of ecosystems, Vulnerability of ecosystems and species is partly a function of the expected rapid rate of climate change relative to the resilience of many such systems. However, multiple stressors are significant in this system, as vulnerability is also a function of human development, which has already substantially reduced the resilience of ecosystems and makes many ecosystems and species more vulnerable to climate change through blocked migration routes, fragmented habitats, reduced populations, introduction of alien species and stresses related to pollution.

There is very high confidence that regional temperature trends are already affecting species and ecosystems around the world (Parmesan and Yohe, 2003; Root et al., 2003; Menzel et al., 2006) and it is likely that at least part of the shifts in species observed to be exhibiting changes in the past several decades can be attributed to human-induced warming (Root et al., 2005). Thus, additional climate changes are likely to adversely affect many more species and ecosystems as global mean temperatures continue to increase. For example, there is high confidence that the extent and diversity of polar and tundra ecosystems is in decline and that pests and diseases have spread to higher latitudes and altitudes.

Each additional degree of warming increases disruption of ecosystems and loss of species. Individual ecosystems and species often have different specific thresholds of change in temperature, precipitation or other variables, beyond which they are at risk of disruption or extinction. Looking across the many ecosystems and thousands of species at risk of climate change, a continuum of increasing risk of loss of ecosystems and species emerges in the literature as the magnitude of climate change increases, although individual confidence levels will vary and are difficult to assess. Nevertheless, further warming is likely to cause additional adverse impacts to many ecosystems and contribute to biodiversity losses. Some examples follow:

- About half a degree of additional warming can cause harm to vulnerable ecosystems such as coral reefs and Arctic ecosystems.


ISBN: 978-81-930585-3-4

- A warming of 1°C above 1990 levels would result in all coral reefs being bleached and 10% of global ecosystems being transformed.
- A warming of 2°C above 1990 levels will result in mass mortality of coral reefs globally, with one-sixth of the Earth's ecosystems being transformed (Leemans and Eickhout, 2004), and about one-quarter of known species being committed to extinction. For example, if Arctic sea-ice cover recedes markedly, many ice-dependent Arctic species, such as polar bears and walrus, will be increasingly likely to be at risk of extinction; other estimates suggest that the African Succulent Karoo is likely to lose four-fifths of its area. There is low confidence that the terrestrial biosphere will become a net source of carbon.
- An additional degree of warming, to 3°C, is likely to result in global terrestrial vegetation becoming a net source of carbon, over one-fifth of ecosystems being transformed (Leemans and Eickhout, 2003), up to 30% of known species being committed to extinction (Thomas et al., 2004; Malcolm et al., 2006)estimate that 1 to 43% of species in 25 biodiversity hotspots are at risk from an approximate 3 to 4°C warming) and half of all nature reserves being unable to meet conservation objectives . Disturbances such as fire and pests are very likely to increase substantially.
- There is very high confidence that warming above 3°C will cause further disruption of ecosystems and extinction of species.

## 18. IPCC OBSERVATION ON MIGRATION AND GLOBAL WARMING

In 1990, the Intergovernmental Panel on Climate Change (IPCC) noted that the greatest single impact of climate change could be on human migration—with millions of people (the most common estimate is 200 million by 2050) displaced by shoreline erosion, coastal flooding and agricultural degradation. But with so many other social, economic and environmental factors at work, establishing a linear, causative relationship between anthropogenic climate change and forced migration has, to date, been difficult.

Predicting future flows of climate migrants is complex; stymied by a lack of baseline data, distorted by population growth and reliant on the evolution of climate change as well as the quantity of future emissions. Nevertheless the available science, summarized in the latest assessment report of the IPCC, translates into a simple fact: on current predictions the "carrying capacity" of large parts of the world will be compromised by climate change.

Climate change will cause population movement by making certain parts of the world much less viable places to live; by causing food and water supplies to become more unreliable and increasing the frequency and severity of floods and storms.

Recent reports from the IPCC and elsewhere set out the parameters for what we can expect:

- By 2099 the world is expected to be on average between 1.8 and 4ºc hotter than it is now. Large areas are expected to become drier—the proportion of land in constant drought expected to increase from 2 percent to 10 percent by 2050.
- Meanwhile, the proportion of land suffering extreme drought is predicted to increase from 1 percent at present to 30 percent by the end of the 21st century.
- Rainfall patterns will change as the hydrological cycle becomes more intense. In some places this means that rain will be more likely to fall in deluges (washing away top-soil and causing flooding). Changed rainfall patterns and a more intense hydrological cycle mean that extreme weather events such as droughts, storms and floods are expected to become increasingly frequent and severe. For example, it is estimated that the South Asian monsoon will become stronger with up to 20 percent more rain falling on eastern India and Bangladesh by 2050.
- Conversely, less rain is expected at low to mid-latitudes; by 2050 sub-Saharan Africa is predicted to have up to 10 percent less annual rainfall in its interior. Less rain would have particularly serious impacts for sub-Saharan African agriculture which is largely rain-fed: the 2007 IPCC report of the Second Working Group estimates that yields from rainfed agriculture could fall by up to 50 percent by 2020.


ISBN: 978-81-930585-3-4

- "Agricultural production, including access to food, in many African countries and regions is projected to be severely compromised by climate variability and change" the report notes. According to the same report crop yields in central and south Asia could fall by 30 percent by the middle of the twenty-first century.
- Some fish stocks will migrate towards the poles and colder waters and may deplete as surface water run-off and higher sea temperatures lead to more frequent hazardous algal blooms and coral bleaching.
- Compounding this, climate change is predicted to worsen a variety of health problems leading to more widespread malnutrition and diarrhoeal diseases, and altered distribution of some vectors of disease transmission such as the malarial mosquito.
- Meanwhile, melting glaciers will increase the risk of flooding during the wet season and reduce dry season water supplies to one-sixth of the world's population, predominantly in the Indian subcontinent, parts of China and the Andes. Melting glaciers will increase the risk of glacial lake outburst floods particularly in mountainous countries like Nepal, Peru and Bhutan.
- Global average sea level, after accounting for coastal land uplift and subsidence, is projected to rise between 8cms and 13cms by 2030, between 17cms and 29cms by 2050, and between 35cms and 82cm by 2100 (depending on the model and scenario used).
- Thermal expansion of sea water accounts for nearly two-thirds of this rise with glacial melt providing the rest.
- Large delta systems are at particular risk of flooding.

According to Nicholls and Lowe, using a mid-range climate sensitivity projection, the number of people flooded per year is expected to increase by between 10 and 25 million per year by the 2050's and between 40 and 140 million per year by 2100's, depending on the future emissions scenario.

The area of coastal wetlands is projected to decrease as a result of sea level rise. For a high emissions scenario and high climate sensitivity wetland loss could be as high as 25% and 42% of the world's existing coastal wetlands by the 2050's and 2100's respectively.

The avalanche of statistics above translates into a simple fact—that on current trends the 'carrying capacity' of large parts of the world, i.e. the ability of different ecosystems to provide food, water and shelter for human populations, will be compromised by climate change.


ISBN: 978-81-930585-3-4