CLIMATE CHANGE AND THE MEDITERRANEAN REGION

by Jacqueline Karas

EXECUTIVE SUMMARY

Water shortages and poor harvests during the droughts of the early 1990s exposed the acute vulnerability of the Mediterranean region to climatic extremes. Against this backdrop, the prospect of a major climate change brought about by human activities is a source of growing concern, raising serious questions over the sustainability of the region.

This report examines the potential implications of global climate change for the Mediterranean region. Drawing on the results of recent studies, it reviews possible changes in climate together with recent trends, the potential impacts of climate change and the implications for sustainable development.

One key finding is that future climate change could critically undermine efforts for sustainable development in the Mediterranean region. In particular, climate change may add to existing problems of desertification, water scarcity and food production, while also introducing new threats to human health, ecosystems and national economies of countries. The most serious impacts are likely to be felt in North African and eastern Mediterranean countries.

The report concludes that while there is some scope for adaptation, ensuring the long-term sustainability of the region requires urgent action to cut global emissions of greenhouse gases.

Specific findings are summarised below.

Hotter and drier times ahead?

If current trends in emissions of greenhouse gases continue, global temperatures are expected to rise faster over the next century than over any time during the last 10,000 years. Significant uncertainties surround predictions of regional climate changes, but it is likely that the Mediterranean region will also warm significantly.

The outlook for precipitation is much less certain, but most projections point to more precipitation in winter and less in summer over the region as a whole. A common feature of many projections is declining annual precipitation over much of the Mediterranean region south of 40 or 45° N, with increases to the north of this. Even areas receiving more precipitation may get drier than today due to increased evaporation and changes in the seasonal distribution of rainfall and its intensity.

As a consequence, the frequency and severity of droughts could increase across the region. Changes in large-scale atmospheric circulation - as represented by the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) - would further effect the occurrence of extreme events.

An indication of the scale of possible changes is given by one scenario based on the output from four climate models. This suggests that temperatures could rise by over 4°C by 2100 over many inland areas and by over half of this over the Mediterranean Sea. Over the same period, annual precipitation is projected to decline by 10 to 40% over much of Africa and southeastern Spain, with smaller - but potentially significant - changes elsewhere.

Aerosol emissions may counter some of the effects of greenhouse gases in some areas. But, in the long term prospect remains one of hotter, drier conditions throughout the Mediterranean region as the relative influence of greenhouse gases increases over time.

Coastal flooding and erosion

As the world warms, global sea levels will rise as oceans expand and glaciers melt. Around much of the Mediterranean basin, sea levels could rise by close to 1 m by 2100. As a consequence, some low-lying coastal areas would be lost through flooding or erosion, while rivers and coastal aquifers would become more salty. The worst affected areas will be the Nile Delta, Venice and Thessaloniki where local subsidence means that sea levels could rise by at least one-and-a-half times as much as elsewhere.

Climate shows possible signs of change

On a global scale, there is increasing evidence that climate is changing and of a discernible human influence. The high natural variability of the Mediterranean climate make both the detection of climate change and attribution of its cause very difficult. Nevertheless, observations suggest that climate may already be changing in the region.

Land records for the western Mediterranean show slight trends towards warmer and drier conditions over the last century. In contrast, parts of the eastern Mediterranean have experienced cooler, wetter conditions in recent times than earlier this century. Surface water temperature records for the last 120 years show little overall trend but deep water records for the western Mediterranean show a continuous warming trend since 1959.

During the period 1952 to 1992, the number and frequency of heat waves affecting the region has increased. The early 1990s were notable for recurrent droughts and for periods of intense rainfall in the western Mediterranean and for extreme cold events and rainfall in the east. Recent climatic extremes are linked with the exceptional behaviour of ENSO and of the NAO. Record-breaking NAO values occurred in 1983, 1989 and 1990, while the prolonged 1990 to 1995 El Niño event was the longest on record.

While all such trends and extremes could have occurred naturally, they are broadly consistent with the potential effects of greenhouse gas emissions and aerosol emissions to-date.

Increase in extent and severity of desertification

While much desertification is attributed to poor land use practices, hotter and drier conditions would extend the area prone to desertification northwards to encompass areas currently not at risk. In addition, the rate of desertification would increase due to increases in erosion, salinisation and fire hazard and reductions in soil quality. As a result, the process of desertification is likely to become irreversible.

The economic and human costs of an increase in desertification would be tremendous - even today, the annual costs of desertification in Tunisia and Spain are US$100 million and US$200 million, respectively.

Increased frequency of water shortages and decline in water quality

It is likely that the first impacts of climate change will be felt in the Mediterranean water resource system. Reductions in water availability would hit southern Mediterranean countries the hardest. In Egypt, Libya, Tunisia, Algeria, Morocco, Syria, Malta and the Lebanon, water availability already falls below, or approaches 1,000 m3 per person per year - the common benchmark for water scarcity.

Even relatively well-endowed countries, such as Spain, Greece and Italy, could suffer ever-more frequent regional water shortages due to the twin problems of climate change and rising demand. Crete, for example, could experience serious water shortages in five out of six years by 2010.

Some water supplies could become unusable due to the penetration of salt water into rivers and coastal aquifers as sea level rises. Water pollution already a major health hazard in the region - would become still worse as pollutants become more concentrated with reductions in river flow.

Food security threatened by falls in production and world price rises

Livestock production would suffer due to a deterioration in the quality of rangeland associated with higher concentrations of atmospheric carbon dioxide and to changes in areas of rangeland as climate boundaries move northwards. In the European Mediterranean, the area of unproductive shrubland is expected to expand, while in North Africa and the Near East, most of the steppe rangeland could give way to desert by 2050 or earlier.

Yields of grains and other crops could decrease substantially across the Mediterranean region due to increased frequency of drought. While losses may be partially offset by beneficial effects from carbon dioxide, crop production would be further threatened by increases in competition for water and the prevalence of pests and diseases and land losses through desertification and sea level rise.

Climate change effects combined with wider socio-economic factors could cause cereal production over much of southern Europe to become untenable. At Kardista in central Greece, for example, the chance of obtaining current yields of maize could drop to close to zero by 2050, while in Spain, irrigation problems could force maize out of production.

In North Africa and the Near East, changes in average climate associated with a doubling of carbon dioxide could cause yield losses of over 20% for wheat, corn and other coarse grains - even before allowance is made for losses through other causes. In coastal areas, large areas of productive land may be lost through flooding, saline intrusion and waterlogging. In Egypt, for example, agricultural production may cease altogether over an area extending 20 km inland.

World prices for many key commodities such as wheat, maize, soybean meal and poultry could rise significantly as a result of global climate changes. Not only might Mediterranean countries loose substantially in economic terms, but the combination of higher prices and crop losses would lead to a deterioration in levels of food security in, particularly, southern countries.

New, widespread risks to public health

Reductions in food security would increase the risks of malnutrition and hunger for millions in the south. The combination of heat and pollution would lead to an upsurge in respiratory illness among urban populations, while extreme weather events could increase death and injury rates. Water shortages and damaged infrastructure would increase the risk of cholera and dysentery. Higher temperatures would increase the incidence and extent of infectious diseases, such as malaria, dengue fever, schistosmaisis and yellow fever.

Many valuable ecosystems would be lost

Many valuable ecosystems could be lost as species fail to keep up with the shift in climate boundaries and/or find their migration paths blocked by human activities. Wetland sites will face the dual threats of drying out and sea level rise. Up to 85% of wetland sites in southern Europe could disappear with a 3 to 4°C rise in temperatures. In Tunisia, for example, rising temperatures could contribute to the loss of all food plants and breeding waterfowl and the disappearance of nationally important fisheries.

Economic activity undermined in coastal zones

Industries, infrastructure and heritage sites in the coastal zone would be threatened by inundation or erosion due to sea level rise. For example, a rise in sea level of just 0.5 m would flood the western part of Kastala Bay (Croatia) harbour and cause serious degradation to the historic cities of Cres (Croatia) and Venice (Italy). Hydroelectric power output could be constrained by water shortages, with potentially serious knock-on implications for both domestic and industrial users.

Serious social disruption as the livelihood of millions is threatened and international tensions over resources mounts.

Serious social disruption could occur as millions are forced from their homelands as a result of desertification, poor harvests and sea level rise, while international disputes over shared water resources could turn into conflict in the face of declines in water availability and increased demand.

Losses to national economies

National economies would be adversely affected not only by the direct impacts of climate change, but also through the cost of adaptive measures and the knock-on implications of changes elsewhere. Quantitative estimates of financial costs are unreliable but in general, developing countries are expected to suffer larger relative economic damages than developed countries.

Sustainable development hinges on international action to cut greenhouse gas emissions

Future climate change could critically undermine efforts for sustainable development in the Mediterranean region through its impacts on the environment and social and economic well-being. While in many respects climate change exacerbates existing problems rather than creates new ones, the sheer magnitude of the potential problem means it cannot be ignored.

There is some scope for adaptation, but the fact that many measures would be beneficial irrespective of climate change suggests that radical changes in policies and practices will be needed. It is also vital that developed countries meet their obligations to assist adaptation in developing countries through access to know-how and financial assistance.

Ultimately, however, the long-term sustainability of the Mediterranean region requires keeping climate change within tolerable bounds. Current understanding of safe limits points to the need for prompt international agreement - and action - to make the drastic cuts in emissions of greenhouse gases required to stabilise atmospheric concentrations of these gases.

1. INTRODUCTION

In 1993, tourists from Malaga to Athens and from St. Tropez to Malta were confronted by exhortations to "Save it" as the region was hit by its fifth year of drought after winter rains failed to replenish the reservoirs and aquifers (Pearce, 1993). Serious as such events were, they pale in comparison with the potential impacts of a human-induced climate change.

Atmospheric concentrations of greenhouse gases1 are rising as a result of human activities and, in particular fossil-fuel use, land-use changes and agriculture. Greenhouse gases occur naturally in the atmosphere, where they allow solar radiation to reach the Earth unhindered but trap a proportion of outgoing radiation. In this way, greenhouse gases play a critical role in maintaining the heat balance of the Earth. But as concentrations rise, scientists believe the world will warm.

In 1986, the Scientific Committee of Problems of the Environment proclaimed that global warming "should be considered one of today's most important long-term problems" (Bolin and others, 1986). Research over the last 10 years has reaffirmed the magnitude of the looming threat. In 1996, the Intergovernmental Panel on Climate Change (IPCC)2 reported for the first time that past emissions appear to have had "a discernible influence on global climate" (IPCC, 1996a). The IPCC further found that, if current trends in emissions continue, this could cause a rate of warming over the next century "probably greater than any seen in the last 10,000 years".

The magnitude, and possible immediacy, of a major change in climate has alarming implications for countries world-wide as both ecological and human systems are fundamentally dependant on climate. The Mediterranean region3 is particularly vulnerable to climate change as over much of the region, summer rainfall is virtually zero. Water scarcity is endemic and changes in the water balance would have substantial implications for, amongst other things, agriculture and water supplies. This vulnerability is compounded by the ongoing desertification of much of the region, together with population growth and poverty in, particularly, the southern Basin.

Over the last five years, a number of studies have assessed how climate change may affect the Mediterranean region. From these, it is clear that while many uncertainties remain, climate change will have profound and far-reaching implications for the 350 million or so people who live in the Mediterranean region today - and for generations to come. This report draws on recent work to examine, first, how climate may change and what recent observations show. It then moves on to describe some of the potential impacts of future climate change and their significance in light of recent trends and, finally, discusses the implications for sustainable development in the region.

Figure 1: The Mediterranean region.

2. FUTURE CLIMATE CHANGE

Climate varies naturally on all timescales from decades to millennia due to changes in atmospheric and ocean circulation, solar output and volcanic activity. However, future climate change will be dominated by human influences unless and until the composition of the atmosphere is stabilised.

Stabilisation of concentrations of carbon dioxide - a key greenhouse gas - requires cuts in emissions of between 50 and 70%. Emissions of other gases would also have to be reduced significantly - or even stopped completely - if atmospheric concentrations are to be stabilised and the risk of climate change reduced. This section, examines the potential implications for both global climate and climate in the Mediterranean region if cuts of this magnitude are not achieved.

Global Changes in Climate

The magnitude and rate of future climate change will depend on the amount of greenhouse gases emitted, the sensitivity of climate to these gases, and the degree to which the effects are modified by aerosol emissions. The IPCC present six scenarios of future emissions, based on widely differing assumptions of future population and economic growth, energy consumption, technological developments and land use. These all show that atmospheric concentrations of greenhouse gases will continue to rise throughout the 21st century unless there is concerted action to curb emissions (Houghton and others, 1996).

The climatic impact of this rise in greenhouse gases will be modified by the influence of aerosol emissions (Box 1). Unlike greenhouse gases, the effects of aerosols are localised and short-lived. Thus, their overall effect is likely to be to mask - rather than to offset - the much more fundamental, long-term influence of greenhouse gases on climate at some locations. Nevertheless, aerosols could exert a strong influence on the climate experienced at some locations and the IPCC make a range of different assumptions over future aerosols in their various emissions scenarios.

Box 1: The Aerosol Effect

Aerosols are microscopic airborne particles. Natural sources include dust storms, fires and volcanic eruptions. Human sources include the combustion of fossil fuels and the deliberate burning of forests and fields. The climatic impact of aerosols depends on their size and composition. Some aerosols, such as soot, may have a warming effect. Others, such as sulphate aerosols, are believed to have a cooling effect. The dominant effect is, however, currently thought to be one of cooling, although some uncertainty surrounds even this because of uncertainties over the indirect effects of aerosols.

In any case, the cooling effect is not, according to the IPCC, "...a simple offset to the warming effect of greenhouse gases" (Houghton and others, 1996). Aerosols tend to have a much shorter lifetime in the atmosphere than greenhouse gases. While greenhouse gases may stay in the atmosphere for centuries, volcanic aerosols tend to stay in the atmosphere for months to years. The atmospheric lifetime of most aerosols of human origin is still shorter - only a few days.

The short lifetime of aerosols of human origin means that their effects will be fairly localised and that, unlike greenhouse gases, aerosols do not constantly build up in the atmosphere. This has two important implications.

- The relative impact of aerosols is expected to become less as time passes.
- If all emissions from fossil fuel burning were stopped tomorrow, the cooling from aerosols would end within a week, while greenhouse warming would continue for decades to centuries.

Sulphate aerosols are also major contributors to acid rain and emissions subject to controls. If, and when, emissions are reduced, their climate effect will decrease also. Not controlling acid emissions to try and mitigate the effects of greenhouse gases is not considered an option due to their devastating effect on crops, ecosystems and materials.

Under the IPCC's "mid-range" emissions scenario (IS92a), concentrations of greenhouse gases reach the equivalent of double pre-industrial levels of carbon dioxide by 20304 - and continue to rise thereafter (Carter and others, 1994). As a result of this, and allowing for potential increases in aerosol emissions, the IPCC calculate that global temperatures will climb by between 1.4 and 2.9°C by the year 2100, with a best-estimate of 2°C (Kattenberg and others, 1996). This range in values reflects scientific uncertainty over the sensitivity of the climate system to changes in greenhouse gas levels. Even values at the low end of this scale suggest a rate of warming greater that any seen in the past 10,000 years.

Even this may be an under-estimate of changes to come. The IPCC's emissions scenario assumes that emissions of aerosols increase markedly, creating a strong cooling effect. This is unrealistic. No account is taken of the Second Sulphur Protocol or of amendments to US car emissions. Moreover, as the World Energy Council point out, if emissions were to increase as projected, then this "would cause deposition levels that exceeded the 'critical loads' for most ecosystems in South and East Asian regions" (WEC, 1996).

Given this, emissions of aerosols are likely to be controlled much earlier than envisaged in the IPCC's main scenario and the global warming will be consequently greater. Figure 2 compares projected changes in global mean temperature under the IPCC's mid-range scenario with increasing aerosols and using the same greenhouse gas scenario but with constant 1990 aerosols. Assuming constant 1990 aerosols, global temperatures would increase by between 1.6 and 3.5°C by 2100, with a best-estimate of 2.4°C. If greenhouse gas emissions conformed to the highest of all the IPCC's scenarios then temperatures would rise still further - by up to 4.5°C by 2100 (Kattenberg and others, 1996).

Figure 2: Global mean temperature changes from 1990 to 2100 under the IPCC's mid-range emission scenario (IS92a) and different climate sensitivities (Kattenberg and others, 1996). The full line shows temperature changes assuming aerosol emissions increase, while the dashed line is for constant 1990 aerosols.

As the world warms, global precipitation is expected to increase on average and other aspects of climate will change. The process of climate change will, however, not be a smooth, gradual process. Rather, the IPCC state, "[as] future climate extends beyond the boundaries of empirical knowledge, the more likely outcomes will include surprises and unanticipated rapid changes." (IPCC, 1996a).

Increasing temperatures will cause sea levels to rise as glaciers melt and the water in the oceans expands. Under the IPCC's mid-range emissions scenario, global sea levels could rise by 20 to 86 cm by 2100, with a best estimate of 59 cm (Warrick and others, 1996). If aerosol emissions are held constant at 1990 levels, then sea levels could rise more - between 23 and 96 cm by 2100, with a best-estimate of 55 cm. A rise of 50 cm is between two and five times the rise in the past century. Time lags in the onset of melting mean that sea levels would continue to rise many centuries after 2100, even if concentrations of greenhouse gases were stabilised by then.

Significant uncertainty surrounds the projections of sea level rise. This is largely because of uncertainty over how much ice will melt. A particular concern is the fate of the West Antarctic ice sheet - this would cause a rise in sea level of up to 6 m. This threat is generally considered as uncertain and remote in time compared with the more immediate threat posed by the potential rise in sea levels over coming decades. However, the relatively recent discovery that ice shelves in Antarctica may be melting from beneath due the presence of warm water from the deep oceans adds to concern over the stability of the continental ice sheets (Jenkins and others, 1995).

Climate Change in the Mediterranean Region

As the world warms, climate will change in the Mediterranean region. However, considerable uncertainty exists over just what form these changes may take. This is primarily because of the acknowledged weaknesses of global climate models (GCMs) in assessing regional climate changes (Box 2).

While such uncertainties are frustrating, the option of ignoring the prospect of a major change in climate is no more acceptable. Scientists are confident that global warming due to current trends in emissions will be accompanied by significant changes in local climate. Decisions must be taken on the basis of the best information available, taking account of the uncertainties, and not on the simply-wrong assumption that future climate will be the same as in the past.

The following sections draw on the results of variety of studies to give an impression of how climate may change in the Mediterranean region as we move into the 21st century. Where possible, the results from several studies are compared to give a sense of a range of possible outcomes.

Box 2: Climate Models and their Limitations

Most regional studies of future climate change use output from global circulation models (GCMs) of the atmosphere and ocean. In these models, the physical laws and empirical relationships that describe atmospheric and oceanic systems are represented by mathematical equations. The many complex processes - such as the melting of sea ice and formation of water vapour - that influence climate are taken into account.

By changing the inputs to GCMs, scientists can assess the effects of increasing concentrations of greenhouse gases on the climate system. The majority of experiments to-date are 'equilibrium response' experiments and assess the ultimate impact of a sudden doubling of concentrations of carbon dioxide. Recently, attention has focused on more realistic 'transient response' experiments. These experiments measure real-time climate changes in response to progressive increases (typically 1% per year) in carbon dioxide concentrations.

All climate models have a number of limitations:

- The coarse resolution of global climate models means they do not adequately depict many geographic features and the interactions between the atmosphere and the surface;
- Natural variations in local climate are much greater than those in climate averaged over continental or larger scales;
- The uneven spatial impact of aerosols - not only have few model experiments taken aerosols into account, but those that do include only very simplified effects ; and
- Land-use changes - such as deforestation and desertification - are currently seldom allowed for, but will substantially affect local climates.

Despite these limitations, scientists are confident in GCM results for large-scale changes in climate. Confidence in local and regional predictions is, however, lower as most models do not represent current climate well on this scale and projections vary widely. But, as climate scientist Tom Wigley observes, "[in] spite of the problems that plague current GCMs, they are the best tool we have for projecting future changes in climate at a regional level." (Wigley, 1992). Nevertheless he cautions, model results "should be treated strictly as scenarios of possible future climate and not as predictions."

Changes in Temperature

Rising concentrations of greenhouse gases alone could cause warming over the Mediterranean region similar in magnitude to the global increase. Results from four equilibrium experiments indicate that temperatures over the region as a whole could rise by about 3.5°C between now and the latter half of the 21st century in response to a doubling of carbon dioxide (or its equivalent) (Wigley, 1992). According to three transient model runs, about half of this rise - between 1.4 and 2.6°C - could occur by the 2020s (Rosenzweig and Tubiello, 1997). There is no evidence of marked seasonal differences in response.

These results are towards the high end of expectations as the models used have middle to high sensitivities5. An impression of the full range of possible outcomes is given by an analysis of output from nine transient models for southern Europe and Turkey6 (Kattenberg and others, 1996). This points to temperature increases of 1 to 4.5°C (with a mid-point of about 2.5°C) during the winter and summer by the latter half of the 21st century. Even if emissions of greenhouse gases were stabilised by then, temperatures would continue to climb for several decades due to time lags in the response of the oceans.

There will be marked regional differences in the rate of temperature increase experienced at different locations - although there is wide disagreement between the patterns of change projected by the various models (Wigley, 1992 and Cubasch and others, 1996). A picture of possible changes is given by an average of the output from four equilibrium experiments, statistically down-scaled for further local details (Figure 3; Palutikof and Wigley, 1996)7. The results show that temperatures across the region could rise between 0.7 and 1.6°C for every degree rise in global mean temperature.

Figure 3: Model average temperature changes (°C) over the Mediterranean region for every °C rise in global mean temperature resulting from rising concentrations of greenhouse gases (Palutikof and Wigley, 1996). The map values can be seen as broadly indicative of conditions which may exist around 20308. Areas where temperatures are projected to rise less than the global mean are shaded.

The greatest rates of temperature increase occur over Africa, the Ukraine and eastern Turkey, while the lowest rates of change occur over the Mediterranean Sea. The coastal zones are areas of rapid transition. Between now and 2100, temperatures could have risen by up to 2.5 to 3°C over the Mediterranean Sea, 3 to 4°C over coastal areas and 4 to 4.5°C over most inland areas, with increases of up to 5.5°C over Morocco9. This general pattern of change suggested by these results is physically reasonable as warming over the sea is likely to lag behind that over land areas. Also, these findings are broadly similar to those from more detailed model experiments (Cubasch and others, 1996)10.

These results do not take account of possible increases in aerosol emissions which could mask some of this warming. One transient experiment suggests that aerosols may reduce warming over the Mediterranean region by 1-2°C over a period from 1795 to 2030-2050 (Mitchell and others, 1995). The net effect may even be to give an impression of cooling over the central Mediterranean in summer over the next few decades (Hasselmann and others, 1995). Given the likely exaggeration of aerosol effects discussed earlier, such results probably over-estimate the potential for local cooling. But, in any case, the long-term prospect remains one of warming throughout the Mediterranean region as the relative influence of greenhouse gases increases over time.

Changes in Precipitation

The prospects for precipitation over the Mediterranean region in a warmer world are highly uncertain due to the general weakness of GCMs in predicting regional precipitation. Models offer conflicting evidence over how precipitation may change on average over the Mediterranean region. Two out of three equilibrium experiments presented in one study suggest an overall increase in precipitation across the region (Rosenzwieg and Tubiello, 1997). However, recent transient model runs for the 2020s suggest an overall decrease of between 1.5 and 7.3% (Rosenzwieg and Tubiello, 1997).

Most equilibrium and transient experiments show a widening in the seasonal precipitation gradient with more precipitation in winter and less in summer. An average of four equilibrium model results for the whole Mediterranean region suggests an increase in winter precipitation of 10% and a decrease in summer precipitation of 10% between now and 210011 (Palutikof and others, 1992). This finding is broadly supported by a more recent comparison of nine transient model runs for southern Europe and Turkey (Kattenberg and others, 1996). In this case, most models suggest increases in winter precipitation of up to 10% and reductions in summer precipitation of 5 to 15% by the latter half of the 21st century.

The patterns of precipitation produced by different model runs are so divergent that it is difficult to have confidence in any single projection. Nevertheless, a common feature of many model runs is decreasing annual precipitation over much of the Mediterranean region south of 40 to 45oN, and increasing precipitation north of this (see for example, Cubasch and others 1996, Barrow and Hulme, 1995 and Palutikof and Wigley, 1996). This is illustrated by a scenario based on the average results from four equilibrium models, statistically down-scaled to give a sense of more localised changes12 (Figure 4, Palutikof and Wigley, 1996).

Figure 4: Model average precipitation changes (%) over the Mediterranean region for every °C rise in global mean temperature resulting from rising concentrations of greenhouse gases (Palutikof and Wigley, 1996). The map values can be seen as broadly indicative of conditions which may exist around 203013. Areas where precipitation is projected to decrease are shaded.

In this scenario, annual precipitation changes across the region range from 12% to +13% per °C rise in global mean temperature. This translates into annual precipitation decreases of between 10 and 40% over much of Africa and southeast Spain, and of up to 10% over central Spain, southern France, Greece and the Near East by 210014. There is also the suggestion of possible increase in precipitation of up to 20% over central Italy. However, as the authors stress, confidence in these scenarios is low because of the uncertainty associated with GCM results for regional precipitation.

In the short-term, aerosol effects may counter the effect of rising concentrations of greenhouse gases in some areas. Results from transient experiments for around the middle of the 21st century suggest that once aerosol effects are allowed for precipitation over southern Europe and Turkey as a whole may increase slightly (Kattenberg and others, 1996). These changes are far from certain as they depend critically on both the aerosol scenario used and how aerosols are represented in the models. In any case, a long-term model run for the Mediterranean region suggests that from 2050 onwards precipitation would decrease markedly as the relative influence of greenhouse gases grows (Palutikof and others, 1996b).

Clearly, there remains considerable uncertainty over how precipitation will change over the Mediterranean region in response to the changing composition of the atmosphere. However, the balance of evidence seems to suggest reductions in precipitation over much of the region, with a possible transitional period for some areas due to aerosol effects.

Changes in Moisture Availability

In terms of the ecological and social impacts of climate change, changes in moisture availability are more important than changes in precipitation or temperature alone. Low levels of moisture availability are associated with droughts.

Moisture availability is determined both by water gains from precipitation and water losses through runoff and evapotranspiration15. As temperature increases, evapotranspiration will also increase (all other things being equal). This means that even where precipitation is projected to increase, actual moisture availability could go down if the gains are outweighed by losses. The projected widening of the seasonal precipitation gradient is also likely to reduce water availability during the growing season (Kattenberg and others, 1996; Wigley, 1992). This is because extra precipitation in winter may not be stored in the soil, but lost as runoff. The occurrence of precipitation in intense episodes has a similar effect (Segal and others, 1994).

GCMs are particularly weak at determining moisture availability. This is partly because potential evapotranspiration is not properly assessed by GCMs due to crude treatment of the hydrological cycle (Rind and others, 1992) and partly because of the huge uncertainties over future precipitation. Despite this, there is a high level of consistency in model results for southern Europe and Turkey, with models showing an overall reduction in summer moisture availability in response to rising concentrations of greenhouse gases (Kattenberg and others, 1996). Results from three equilibrium experiments for southern Europe and Turkey suggest that soil moisture would decrease over the whole region by 15 to 25% during the summer (IPCC, 1992). A preliminary assessment of changes in the water balance over the eastern Mediterranean from Turkey through to Egypt also found a tendency for a northwards shift of the desert line (Segal and others, 1994).

Evidence of reductions in water availability over much of the Mediterranean region during both winter and summer comes from a recent transient experiment (Gordon and O'Farrell, 1996). This is supported by work for the region using average temperature and precipitation output from four equilibrium experiments (Palutikof and others, 1994 and 1996b)16. This study indicates an unfavourable shift in the ratio of precipitation to evapotranspiration throughout the whole Mediterranean region in every season17. The greatest effects are over the north of the region, extending over the Italian mainland, Sardinia and Corsica, in spring and autumn. The impact on human activities may, however, be most acute in the south of the region where water is in particularly short supply even now.

Again in the near-term, the effects of increased concentrations of greenhouse gases may be mitigated in some areas by the effects of aerosols. Two transient experiments show that if aerosol effects are included, then soil moisture over southern Europe and Turkey as a whole could increase, rather than decrease (Kattenberg and others, 1996). However, exaggeration of aerosol effects and the localised nature of their impacts means that some areas may still experience drier conditions. Moreover, these findings are only relevant to around the middle of next century. Beyond this, the relative influence of greenhouse gases is expected to grow and the long-term prospect is one of a drying out of the whole Mediterranean region.

Changes in Extreme Events

As climate changes the frequency of extreme events in the Mediterranean region will change in response to changes both in average climate and in climate variability. Warmer conditions over the Mediterranean region should lead to an increase in the occurrence of extremely high temperatures and a decrease in extremely low temperature events. One study finds that by around the middle of the next century, current maximum temperatures in Athens could be exceeded in most months (Barrow and others, 1995).

Similarly, in areas experiencing a general decrease in precipitation, droughts are likely to become more frequent as the probability of dry days and the length of dry spells increases. The converse is true for areas where precipitation increases. One study reports that the probability of a dry spell lasting more than 30 days in summer in southern Europe would increase by a factor of between two and five on a doubling of carbon dioxide (Gregory, 1996). A study for Naxos (Greece) further suggests that a 10% reduction in winter precipitation could increase the length of dry spells by up to 21 to 45%, while a 10% increase in summer precipitation could increase the length of wet spells by 15% (Palutikof and others, 1992)18.

In general, scientists expect more heavy rain events in a warmer world due to an intensification of the hydrological cycle. Most models suggest a general increase in the intensity of precipitation of between 10 and 30% at most latitudes for a doubling of carbon dioxide (Kattenberg and others, 1996). Storminess may also increase, although this is less certain.

On a wider scale , changes in climate variability will be influenced by changes in general atmospheric circulation. A major source of year-to-year variability world-wide is the El Niño-Southern Oscillation (ENSO) phenomenon)19. ENSO is renowned for bringing climatic disruption world-wide (Glantz and others, 1991). In the Mediterranean region, El Niño events have been linked with low rainfall over much of the western and central basins (Arkin and Xie, 1997, Lamb and Peppler, 1991 Rodó and others, 1997; Rodó and Comins, 1996).

As yet, scientists are uncertain how ENSO will change in a warmer world - models do not simulate the phenomena very well and under-estimate the variability. Nevertheless, a number of models indicate that ENSO events will continue to occur in a warmer world and there is some evidence that precipitation anomalies will increase in tropical areas (Kattenberg and others, 1996). However, a number of papers reviewed by the IPCC suggest that “much of the effects of global warming may be modulated through a change in the magnitude and regularity of the warm and cold phases of ENSO” (Dickinson and others, 1996).

Of still greater significance to the Mediterranean region is the fate of the North Atlantic Oscillation (NAO))20 although as yet little indication has been given of likely changes in a warmer world. The state of the NAO critically affects storm tracks, temperatures and precipitation across Europe and eastern North America. High values have been linked with low winter rainfall throughout much of the Mediterranean and cold conditions in the east (Hurrell, 1995; Palutikof and others, 1996b; Trenberth and Shea, 1997).

Despite these uncertainties over exactly how climate variability and extremes will change in the Mediterranean region, the overall picture does suggest an increase in the frequency of extreme events and, in particular, of droughts in the western Mediterranean.

Sea Level Rise

Locally, the apparent rise in sea level will critically depend on local land movements. Most of the Mediterranean region currently appears to be stable and is likely to experience a sea level rise comparable with the global mean - up to about 96 cm by 210021 (Milliman, 1992; Warrick and others, 1996). The Near East and Alexandria may, however, experience slightly lower rates of sea level rise - up to 90 cm by 2100 - as the land appears to be rising slightly.

The worst affected regions seem likely to be the larger river deltas of the Nile, Thessaloniki and Venice, which are currently subsiding. In these areas, sea levels could rise by up to 150 cm, 140 cm and 175 cm, respectively by 2100. Rising sea levels would, in all areas, bring the risk of inundation, higher rates of erosion and increased saline intrusion into rivers and aquifers.

3. OBSERVED CLIMATE CHANGES: SIGNS OF CHANGE

Past emissions of greenhouse gases have already affected the Earth’s energy balance and the effects on global and regional climates will become more marked over time (Santer and others, 1996). This raises two key questions: is climate changing? And, if so, can the observed changes be attributed to the changing composition of the atmosphere?

Globally, at least, scientists appear to have detected the first signs of climate change. Since 1860, mean global temperatures have risen by between 0.3°C and 0.6°C. Warming since the mid-1970s has been particularly rapid with all eight of the warmest years on record occurring since 1983 (WMO, 1997; CRU, 1997). Early signs are that 1997 may also prove to be a record-breaking year (Tiempo, 24 Jun 1997).

In 1996, the IPCC announced that the observed warming “is unlikely to be entirely natural in origin” (IPCC, 1996a). On the basis of further detailed assessments of patterns of atmospheric and oceanic temperatures and changes in the hydrological cycle, the IPCC further concluded that the “balance of evidence suggests a discernible human influence on global climate” .

As global climate appears to be changing, we would expect the Mediterranean climate also to have changed. Detection of climate change on this scale is, however, extremely difficult as the high variability in local climates masks trends in the ‘noise’ of natural fluctuations. Moreover, the short period of observations makes the identification of clear trends difficult and creates uncertainty over the scale of natural variability.

Proving that any observed changes are the result of the changing composition of the atmosphere is still more difficult due to the weakness of models in predicting the regional effects of climate change. The picture is further complicated by the influence of other human activities on climate (Box 3) which may not only mask underlying trends but could either accentuate or mitigate the effects of global warming.

For all this, observational records do suggest marked changes in the climate of the Mediterranean region over recent years. While it is impossible to be certain if these trends are "real" or if they can be attributed to atmospheric pollution, a number of aspects of the observed changes are consistent with a human influence. In either case, absolute proof will only be available with hindsight - by which time significant impacts will already be occurring.

Box 3: Human Influences on Regional Climates

Human activities can substantially affect regional climates. The cooling effects of sulphate aerosols are discussed earlier, but other significant impacts arise from urbanisation and other land use changes. These effects complicate the detection of more fundamental climate changes.

- Urbanisation and the associated pollution have the effect of increasing both temperature and precipitation (Cotton and Pielke, 1995). Warmer conditions result from a number of processes, including: the slowing of winds by high buildings, heat released as energy is used and a reduction in evaporation as rain runs off into drains rather than being retained in soils. Precipitation increases as air rises and cools over what is effectively a man-made hill.

The combined effects of urbanisation on local climates can be significant. In Athens, urbanisation is held responsible for a 1°C rise in maximum temperatures over the last 20 years which occurred despite a fall in minimum temperatures (Metaxas and others, 1991). Similarly, rainfall over the last 70 years has been higher than expected given trends in other nearby regions (Amanatidis and others, 1993). Over the period 1970 to 1989, the number of automobiles increased from about 200,000 to over a million, but also many more, and higher, buildings were constructed between the Athens National Observatory and the coast.

- Desertification acts to increase maximum daily temperatures and reduce precipitation. (Cotton and Pielke, 1995). While desertification is in part a product of climate change, there are also important feedbacks on local climate. Land degradation tends to reduce soil moisture and this in turn reduces evaporation resulting in increased maximum temperatures and lower rainfall. Reductions in vegetation have a similar effect as this reduces the amount of water captured and then recycled through evapotranspiration to create rain. Both processes also increases the reflectively - or "albedo" - of the ground causing higher temperatures in the day and reducing them at night.

Analysis of temperature data for this century shows that warming was nearly 0.2°C greater over dryland areas than over land areas as a whole (Jones, 1994). It is unclear, however, how much of this difference is due to recent desertification and how much is due to the existing arid state of many dryland areas. Desertification is a major, long-term problem in the Mediterranean region and it is possible that this accounts for, at least in part, the observed decrease in rainfall in some areas.

- Deforestation can increase maximum daily temperatures and reduce precipitation in much the same way as desertification (Cotton and Pielke, 1995). Experiments in both the Amazon and in southern Nigeria reveal a much greater range in temperature over cleared ground (Ghuman and Lal, 1986; Salati and others, 1978). The role of forests in enhancing rainfall is also well-established - an estimated 50% of rainfall in the Amazon is from local evaporation and transpiration (Salati and others, 1978). In the Mediterranean region, deforestation has occurred over many centuries and the effects are unlikely to distort the recent record - although, of course, the effects of past deforestation will be ever-present.

- Irrigation and Man-made Lakes have the opposite effect on climate than desertification as rainfall increases due an increase in local water availability and day-time temperatures are lowered with an increase in albedo (Cotton and Pielke, 1995). Few definitive studies of the scale of these effects have been done but estimates of the possible effects of a proposal to flood depressions in the Chott region in Algeria and Tunisia suggest that, as a consequence, local precipitation could increase by up to 150 mm every year (Enger and Tjernström, 1991). The impact of existing irrigation in, say, Egypt and Israel is unknown, but may have offset some of the general decrease in precipitation observed locally.

While the effects of such activities on regional climates can clearly be large, the effects on global climate are very small. Globally, urbanisation accounts for only an estimated 0.05°C of the observed warming over land areas this century (Jones and others, 1990). The global impact of desertification is thought to be still smaller - only a few hundredths of a degree (Nicholls and others, 1996).

Trends in Temperature

Sea surface temperature records for the Mediterranean region show clear fluctuations in climate over the last 120 or so years, but little overall trend (Figure 5). This record shows that temperatures were at a minimum around 1910 and then rose sharply to a maximum around 1940 after which they stabilised for around 20 years. After this, while global temperatures continued to rise to unprecedented levels, the Mediterranean region experienced a decade of rapid cooling. Warming resumed in the late 1970s, but still temperatures remained below those experienced in the 1930s and 1940s up until 1989 at least.

Figure 5. Variations in annual sea surface temperatures across the Mediterranean between 1873 and 1989, as represented by frequency differences of warm minus cold months. The jagged line shows annual values while the smooth line highlights variations over decadal and longer timescales. (Source: Metaxas and others, 1991).

This basic pattern is also evident in sea surface temperature records for both the eastern and western basins and in the seasonal records, but with one potentially important difference. The cooling in the east of the region during the 1970s was much more marked than in the west (Metaxas and others, 1991). As a result, temperatures remained substantially below average in the east until at least the end of the 1980s. It is also notable that deep water records for the western Mediterranean show a continuous warming trend from 1959 (Bethoux and others, 1997).

Land records for the western and central Mediterranean do, however, suggest a long-term warming trend. While all show a similar pattern of warming and cooling, the 1970s minimum is much less pronounced at many locations, for example, Cairo, Marseille, Perpignan and Athens (Metaxas and others, 1991;

Repapis and Philandras, 1988). While this may in part be attributable to increasing urbanisation over the last 30 to 40 years, the overall impact is an appearance of warming comparable with that seen in the global record. This contrasts with Jerusalem (Israel) where annual temperatures in the mid-1970s were lower than during any other time during the previous 100 years (Repapis and Philandras, 1988).

This east-west difference in temperature trends also shows up clearly when average conditions for the period 1975 to 1994 are compared with average conditions during the previous twenty years (Nicholls and others, 1996). This shows that temperatures were, on average, higher during the recent period over south-west Europe and north-west Africa. In contrast, average temperatures in the eastern Mediterranean were lower than during the previous 20 years. The area of colder conditions is centred on Turkey and extends west as far as Italy in the north and Libya in the south.

Recent changes in temperature across the Mediterranean clearly fall within the range of natural variability. But, the general pattern of change is also broadly consistent with a GCM simulation of temperature changes over the region associated with the combined effects of present-day carbon dioxide levels and sulphur emissions (IPCC, 1996a). This being the case, then it is possible that the warming over the last decade experienced over much of the region may be a sign of things to come. Only time will tell.

Trends in Precipitation

Since 1900, precipitation decreased by over 5% over much of the land bordering the Mediterranean Sea, with the exception of the stretch from Tunisia through to Libya where it increased slightly (Nicholls and others, 1996a). Within these overall trends, regular alternations between wetter and drier periods are discernible. Records for both the western Mediterranean and the Balkans indicate major moist periods sometime during the periods1900 to 1920, 1930 to 1956, and 1968 to 1980 with intervening dry periods (Maheras, 1987; Maheras and Kolyva-Machera, 1990). Records for the period 1951 onwards show a slight tendency towards decreasing rainfall in almost all regions and in all seasons (Figure 6; Palutikof and others, 1996b). The only clear positive trend is in the eastern Mediterranean in the autumn.

Figure 6: Yearly rainfall anomaly index for the northern Mediterranean from Portugal to Syria, and including the islands north of 35°N (Palutikof and others, 1996b). The index is for the hydrological (rainfall) year from September in one year to August in the following year.

Such regional trends underplay the scale of changes in precipitation experienced locally. Over the period 1975 to 1994, precipitation was on average more than 17% lower than during the preceding 20 years over much of north-western Africa, Spain, Italy and Greece (Nicholls and others, 1996). The recent dryness in the western Mediterranean contrasts with the conditions elsewhere in northern Africa and the eastern basin. Here, precipitation was generally higher over the last couple of decades compared with the previous 20 years. (Nicholls and others, 1996).

Events took an abrupt about-turn in 1996, with drying areas suddenly experiencing extreme wet conditions and vice versa (WMO, 1997). It is not clear if this is just a temporary “blip” in overall trends, the start of a new trend or a return to more “normal” conditions experienced earlier this century. If the models are broadly correct about precipitation changes in response to increases in greenhouse gases, the droughts over the western Mediterranean could be symptomatic of a growing human influence on climate in the region. Wetter conditions in the east might reflect the stronger influence of aerosols in this area.

Occurrence of Extreme Events

During the period 1952 to 1992, the number and frequency of heat waves affecting the Mediterranean region has increased (Geeson and Thornes, 1996), while the early 1990s were notable for a number of extreme events (Box 4). It is impossible to gauge if the frequency and magnitude of extremes has increased without a thorough analysis. Nevertheless, records of ENSO and NAO - both of which are linked with the occurrence of extreme events in the

Mediterranean region - do show exceptional behaviour. This may, in turn, suggest that the recent history of extremes in the Mediterranean is unusual.

Box 4: Recent Climatic Extremes in the Mediterranean Region

- The early 1990s were characterised by extreme drought over much of this region. In 1995, precipitation was less than 75% of normal (1961-1990) over much of the western Mediterranean (CRU, 1997). Over 1994 and 1995, Spain received less than 50% of normal at some locations (CRU, 1997).
- In the winters of 1991/2 and 1992/3, rarely seen snowfall fell in many areas of north Africa and the eastern Mediterranean, while average temperatures from December to March 1991/2 were the coldest on record in Turkey (from 1930) and at Jerusalem (from 1865) (WMO/UNEP, 1994).
- Between late September and early November 1993 large sections of south-eastern France, western Spain, central Portugal, Corsica and northern Morocco recorded 2 to 3 times the usual precipitation (WMO/UNEP, 1994). In this period, Madrid had the highest amount of precipitation since records began in 1854 while in mid-November 1993, Greece and Israel experienced major floods (WMO/UNEP, 1994).
- In 1995, some interior parts of Egypt saw rainfall for the first time in nearly half a century. Similarly, conditions in Tunisia and Libya were exceptionally wet (CRU, 1997).

Both the unusual coldness of over the eastern Med-iterranean over the last decade and the dry conditions afflicting most of the region have been linked with exceptionally high values in the NAO (Hurrell, 1995, Palutikof, 1996; Trenberth and Shea, 1997). From the 1940s to the early 1970s, NAO values decreased markedly. This trend re-versed sharply 25 years ago, resulting in largely un-precedented positive values of NAO values from 1980 onwards (with the notable exception of the 1995-6 winter). NAO values for 1983, 1989 and 1990 winters are the highest since records began in 1894.

Changes in parts of the western and central Med-iterranean have been connected to the ENSO the phenomenon. The behaviour of ENSO has changed mark-edly since 1976/1977, with the record being dominated by El Niño events and showing only rare instances of La Niña events (Trenberth and Shea, 1997). The prolonged 1990 to 1995 El Niño event is the longest on record and would be expected to occur less than once every 2000 years (Trenberth and Hoar, 1996). La Niña conditions returned abruptly in 1996 but, at the time writing, early signs of an imminent El Niño event have been observed (Tiempo, 24 June 1997).

The extent to which observed changes in NAO and ENSO are due to increases in greenhouse gases is not clear. Evidence exists that persistent ENSO events, at least, may have occurred prior to the period of instrumental data (Allan and D'Arrigo, 1996). But, as climate scientists Kevin Trenberth and Dennis Shea point out: "the observational evidence is suggestive that climate change, for whatever reason, is contributing to [these] changes in circulation, which in turn alter the distribution of storm tracks and rainfall." (Trenberth and Shea, 1997).

4. IMPACTS OF CLIMATE CHANGE

Climate change will have diverse and far reaching consequences for the Mediterranean region (Figure 7). An immediate concern is the potential to exacerbate existing problems of desertification, water resources and food production. But ultimately, the impacts will be much wider as the effects cascade through the social and economic system. While all areas will be affected, the type and extent of impacts experienced will vary markedly depending on local circumstances.

Figure 7: Impact of climate change on environment and society (Milliman and others, 1992).

While there has been an upsurge in impacts studies in recent years, it remains difficult to be precise over the scale of impacts likely to occur. This is partly due to fundamental uncertainties in modelling regional climate change. Most studies focus on the possible impacts of hotter, drier conditions. However, while current evidence suggests this is the most likely response to increasing concentrations of greenhouse gases, it must be noted that confidence in particularly the precipitation scenarios is low (see Section 2). Also, other activities - and in particular aerosol emissions - could have an important influence on climate in some areas, at least in the short term.

Assessment of the impacts of climate change is further complicated by the need to consider not only the nature of the climate change, but also the sensitivity of ecological and social systems to change, the degree to which adaptation is possible and the vulnerability of any given system (Box 5). The extent to which existing studies take these factors into account varies. But, common weaknesses include failures to consider: how systems may evolve under progressive long-term climate change; the interactions between different sectors; and/or the implications of multiple stress factors. As a result, it seems likely that the potential impacts of climate change are understated in many studies.

Nevertheless, there is clear evidence of potentially serious impacts throughout the Mediterranean region, with the most acute impacts being felt south of the socio-economic divide in Africa and the Near East. The following sections, like most of the studies they draw on, focus on the potential implications on hotter, drier conditions over much of the Mediterranean region.

Box 5: Assessing the Impacts of Climate Change

The impacts in any particular area will depend on four key factors.

- The magnitude and rate of climate change. This will critically affect both the extent to which ecological and social systems can withstand stress and their ability to adapt. The impacts of climate change will be mediated through not only the direct effects of changes in temperature and other climate variables, but also the associated rises in atmospheric concentrations of carbon dioxide and in sea level. The rapid rate of change anticipated under all but the lowest scenarios of climate change poses a particular threat.
- The sensitivity of ecological and social systems to climate change. Low-lying coastal areas are obviously sensitive to changes in sea level, while the droughts and floods of the 1990s clearly exposed the sensitivity of, in particular, water supply and food production systems to climate variations. Other key concerns such as desertification and the degradation of natural ecosystems probably more immediately impacted by demographic change and land use practices than by climate - although, even in these areas, the fundamental change in underlying conditions suggested by climate change has significant long-term implications.
- The scope for adaptation. Both the rate of climate change and the uncertainty over the nature of the expected changes makes adaptation difficult, particularly in the many areas, such as infrastructure development, where planning timescales are long in relation to the timescales of the predicted changes.
- The vulnerability of areas. This is determined both by the system's sensitivity to change and by its ability to adapt. It is likely that vulnerability will be dictated by as much by economic circumstances and institutional infrastructure as by inherent sensitivity to climate change.

Finally, it is vital to assess potential impacts of climate change in the context of other environmental and socio-economic trends. Many countries of theMediterranean region are already under pressure due desertification, population growth, tourism, pollution and (legitimate) aspirations to improve economic well-being. Climate change is just one further stress. But, the dependence of most human activities on the environment means that changes can either enhance or undermine development in the region.

Desertification

In the Mediterranean region, future climate change is likely to aggravate significantly the existing problem of desertification and critically undermine the effectiveness of efforts to combat the problem.

The threat posed by desertification to human welfare is internationally recognised and was the stimulus behind agreement on an International Convention to Combat Desertification in 1992. UNEP define desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (ICCD, 1994). In the process of desertification, biologically and economically productive land becomes less productive and less able to support the communities that depend on it.

Desertification is considered one of the most serious problems facing the Mediterranean region today (Table 1). The area affected extends across northern Africa into the Near East and across large parts of Europe, including Greece, southern Italy, Sicily, Corsica, and the Iberian Peninsula (UNEP, 1992; Imeson and Emmer, 1992). Every year, Turkey, Tunisia and Morocco lose around 54237, 18000 and 2200 hectares of land through erosion, respectively (UNEP, 1987).

Table 1: Extent of desertification (%) in the early 1980s (Mabutt, 1984).

The economic and human costs of desertification are enormous. Tunisia alone spends US$100 million on efforts to combat desertification (Kharrat, 1997). Desertification in Spain causes an estimated 30,000 million pesetas (US$200 million) economic damages every year (La Mundo, 13 October 1993; La Vanguardia, 7 January, 1994). Human costs often include malnutrition, the risk of famine and dislocation of people who are forced abandon their lands.

Much desertification is attributed to human activities going back over millennia. Human impacts arise from overstocking, over-cultivation and deforestation and, to a lesser degree, irrigation and urbanisation. Past degradation is held responsible for decline ancient civilisations within the region and elsewhere (Box 6). However, drylands are inherently vulnerable to water stress and drought and as the United Nations Framework Convention on Climate Change (UNFCCC) points out, "countries in arid and semi-arid areas or areas liable to floods, drought and desertification ... are particularly vulnerable to the adverse effects of climate change" (preamble).

Box 6: Lessons of the Past - Desertification and the Decline of Civilisations

The devastating consequences of desertification are evidenced by the destruction of ancient civilisations. Six thousand years ago in Mesopotamia (the Middle East), food production and Sumerian culture declined as poor irrigation practices led to huge tracts of land becoming salinised (WRI/IIED/UNEP, 1989). The political, military and economic decline of Assyria and Babylonia some three thousand years ago coincided with a notable period of warming and drying in the region (Neumann and Parpola, 1987). Climate change could explain this aridity - but so could desertification. Elsewhere, in Rajastan in north-west India, archaeological evidence tells of a well-developed civilisation existing at around the same time in an area that is now tropical desert. (Cotton and Pielke, 1995) This transformation is thought to be as much the consequence of overpopulation and denudation of the local vegetation as of natural climate change. Around the Mediterranean region, areas covered today by Maquis vegetation (scrub, oak, heath and so on) were once productive forests (WRI/IIED/UNEP, 1989).

Climate change would both affect the extent of areas prone to desertification and the severity of desertification in existing drylands. At a fundamental level, the conditions for desertification are dictated by climatic factors since the process occurs mainly in arid, semi-arid and dry sub-humid zones22. The reduction in moisture availability projected under climate change would both increase the aridity of existing drylands and progressively shift the boundaries of areas susceptible to desertification northwards in the Mediterranean region to encompass areas currently not at risk.

The particular vulnerability of ecosystems in semi-arid and arid areas to climate change is highlighted by the IPCC which points out that "[whereas] most terrestrial ecosystems have some built-in ability to buffer the effects of climate variability, this is not so true of those in arid and semi-arid lands - where even small changes in climate can intensify the already high natural variability and lead to permanent degradation of the productive potential of such lands." (Bullock and Le Houérou, 1996).

The potential for desertification is still further enhanced through the direct effects of climate change on erosion, soil quality, salinisation and fire hazard. Key processes include the following (Rosenzweig and Hillel, 1993; Imeson and Emmer, 1996).

- As soils dry they become more susceptible to wind erosion, especially where there is no vegetation cover or the area is cultivated - this could ultimately generate "dust bowl" conditions in some areas. The hazard of water erosion would also be made worse by any accompanying increase in rainfall intensity.
- Higher temperatures could result in a reduction in soil fertility due to higher rates of decomposition and losses of organic matter, and could affect nutrient cycling.
- A general decrease in precipitation or increase in evaporation will cause an increase in the area affected by saline conditions. Spain and Italy, in particular, could experience an increase in the area affected by low permeability, shrinking and swelling and waterlogging. Coastal areas could be more directly affected by salinisation due to the increased penetration of salt water into the groundwater.
- Increasing temperatures and drier conditions could give rise to more forest fires, although the extent to which land degradation results will vary. In Sardinia (Italy), forest fires are the most important cause of severe soil erosion (Aru, 1984). A Spanish newspaper in October 1994 suggested that soil erosion resulting from forest fires and torrential rain cost Spain more than 55 000 million pesetas (US$360 million) per year (López-Bermúdez, 1995).

There could also be important feedback effects. For example, a reduction in surface moisture or vegetative cover would increase temperatures and reduce rainfall as less energy is used in evapo-transipiration and less water is recycled. Where vegetation cover is lost completely, soil surfaces become sealed and encrusted, reducing water intake and resulting in a still drier environment (Bullock and Le Houérou, 1996).

For all this, it is impossible to quantify the combined impact of climate change on desertification. Much will depend not just on the climate change but also of coincident pressures arising from other human activities and the effectiveness of responses to the problem of desertification in general. However, as the IPCC warns: "[desertification] is likely to become irreversible if the environment becomes drier and the soil becomes further degraded through erosion and compaction" (Bullock and Le Houérou, 1996). Thus, in a very fundamental way climate change threatens to undermine all current efforts to reduce desertification in the Mediterranean region.

Water Resources

Climate change could further exacerbate existing problems over water scarcity in many Mediterranean countries and cause a decline in water quality through increased concentrations of pollutants, salinisation and increased salt water intrusion in coastal aquifers.

Water scarcity is endemic in many parts of the Mediterranean, making these countries particularly vulnerable to any reduction in supplies. The common benchmark for water scarcity is 1,000m3 per person per year. Water availability either already falls below this level or is expected to within two to three decades in southern Mediterranean countries including Egypt, Libya, Tunisia, Algeria, Morocco, Syria, Malta and the Lebanon (WRI/IIED/UNEP, 1997). Even in the generally well-endowed countries of the northern Mediterranean such as Spain, Italy and Greece, regional water problems exist.

The reduction of moisture availability anticipated in the climate change scenarios would inevitably add to the problem of water scarcity throughout the Mediterranean region. The changes in precipitation combined with increased evaporation would directly reduce runoff and ground water levels throughout the Mediterranean region. The acute sensitivity of water resources to rainfall reductions is illustrated by estimates that a 20% decrease in rainfall in Acheloos basin (Greece) would increase the risk of water system failure (inability to provide targeted supplies) from less than 1% at present to 38% (Mimikou and others, 1991)

Other processes would further damage water supplies. Poorer infiltration due to soil degradation would reduce aquifer recharge, while reservoirs could be seriously affected by an increase in sedimentation due to erosion. Such sedimentation problems are already anticipated in the Apollakia reservoir in Rhodes (Perissoratis and others, 1996).

The problem of reduced water availability will be compounded by increases in demand driven by both socio-economic factors and climate change itself. In Crete, it has been estimated that increases in urban demand alone could increase the likelihood of water shortages from 20% in 1980 to 85% in 2010 (MEDALUS II, 1996). As climate changes, demand for irrigation water is likely to increase. This is significant, as irrigation accounts for about 72% of all water consumption in the Mediterranean region (Blue Plan, 1988). Experiments for Lesotho point to an increase in demand of 7% with a 10% decrease in runoff and of more than 20% with a 2°C rise in temperature (Arnell and Piper, 1995).

Water quality could also be adversely affected by climate change. Higher temperatures and evaporation would cause rises in the salinity of lakes and reservoirs, while in coastal areas, rises in sea level would increase saline intrusion into aquifers and estuaries. In Malta, a 1 m rise in sea level could reduce water from the main reservoir by 40% (Attard and others, 1996), while in France, the Vaccares and lower lakes of the Camargue are anticipated to become hyper-saline (Corre, 1996). Problems of saline intrusion would be further exacerbated by reductions in runoff and by increased withdrawals in response to higher demand. Excessive demand already contributes to saline intrusion problems in many coastal areas of Italy, Spain, Greece and North Africa (Aru, 1996).

Pollution concentrations would also increase with a reduction in river and lake levels. Dumping of a whole variety of wastes in seasonal channels around the Mediterranean is already a major health hazard and the problem could become more acute with climate change (MEDALUS II, 1996). Similarly, the situation could become critical in Venice where there are already massive inflows of urban, industrial and agricultural waste (Sestini, 1992).

There is no doubt that many opportunities exist to improve supply through demand side management and increasing the efficiency of water use, for example through improved irrigation systems, changes in crops and so on (Kaczmarek, 1996). In the Syrian coastal area alone, it has been estimated that 40% of water supplied is lost through poorly constructed and maintained mains and illegal tapping (Al-Shalberi and others, 1996). Increasing the amount of fresh water available through desalinisation processes is less attractive as it is both very expensive and highly intensive in the use of fossil fuels (although renewable energy sources can be used).

However, as the IPCC point out, “[it] remains uncertain whether water supply systems will evolve substantially enough in the future to compensate forthe anticipated negative impacts of climate change on water resources and for potential increases in demand.” (IPCC, 1996b). It is therefore not surprising that, as early as 1990, UNEP warned “[it] is likely that the impact of climate change will first be felt in the Mediterranean water resource system.” (UNEP, 1990).

Agriculture

Future climate change would affect food production in the Mediterranean region in a number of ways. Direct effects would be incurred through the change in climate itself and the associated increase in carbon dioxide levels and sea level rise. But, in many areas, food production would be further affected by other climate impacts such as desertification, increased fire risk, spread of pests and diseases and changes in the global markets.

The full impact of climate change on food production remains uncertain. As yet, no fully integrated studies of the overall impact of these various changes have been undertaken. Moreover, most studies focus on a limited range of foodstuffs and consider changes in yield under present-day cultivation conditions and even then often only double carbon dioxide conditions. Nevertheless, the available evidence suggests that climate change will have a deleterious impact on food production throughout the region, increase prices and add to food insecurity in the southern basin.

Rangelands

Future climate change is likely to both reduce the productivity of rangelands and change the areas amenable to livestock production. The most serious impacts on livestock production would be in the southern Mediterranean, where the rangelands are already under pressure from land use changes and population growth.

Rangelands sustain a large number of people in the Mediterranean region through their support for livestock and forage crops. They are currently receding across the region, but particularly in the south where some 50% of arid steppe rangeland has been cleared for crops over the last 30 years (Le Houérou, 1992). This ever-increasing clearance is also a major cause of desertification in northern Africa and the Near East (Le Houérou, 1988). This fragmentation of rangeland may add to their vulnerability to climate change (Archer, 1994). As the IPCC point out, "[with] the addition of climate change to existing impacts, rangelands may be more susceptible to extreme events such as drought, 100-year floods, and insect outbreaks" (Allen Diaz, 1996).

Higher levels of carbon dioxide will worsen conditions for grazing across the region as this will increase the carbon to nitrogen ratio in forage, thus reducing its food value (Allen Diaz, 1996). Moreover, a reduction in moisture availability would change the species composition in favour of woody, less palatable, plants. A further effect of a shift of carbon storage from soil to biomass is that it is likely to adversely affect soil stability and increase erosion.

As climate changes, the areas suitable for rangeland will change in response to changes in the water balance. A doubling of carbon dioxide (or its equivalent) would shift the climatic limits for grass and dwarf shrub steppes 300 to 500 km polewards at the expense of shrubland (Allen-Diaz, 1996). In European Mediterranean countries, a northwards expansion of unproductive shrubland is expected due to the abandonment of agricultural land for climatic and wider socio-economic reasons, increases in wildfires and a decrease in livestock grazing (Allen-Diaz, 1996).

The potential effects of climate change on rangelands in North Africa and the Near East are much more serious. The projected reduction in moisture availability alone would mean the encroachment of desert further north. Decreases in plant cover may also increase erosion and lead to a nearly irreversible loss of productive potential (Parton and others, 1993). It is likely that this "natural response" will be compounded by desertification due to over-grazing and the current trend towards conversion of rangeland to agriculture. The net result is that by 2050 (or earlier), most of the steppe rangeland is expected to have given way to desert (Le Houérou, 1992;

Allen-Diaz, 1996).

Desertification of the North African and Near Eastern steppes would have significant implications for the livestock industry and the wider economy in these areas. Over 50% of the sheep industry is in the arid-steppe zone and increasingly this would have to depend on imported feed and the international cereal market to survive (Le Houérou, 1992). Thus, national economies could be hit twice-over: first, by a decline in the contribution of the livestock industry to the economy; and second, by the cost of importing more feed. As the IPCC point out, the losses to the national economy would "have serious implications for the food policies of many underdeveloped countries and on the lives of thousands of pastoral people" (Allen-Diaz, 1996).

Crop Production

Future changes in climate would significantly affect both crop yields and what it is possible to grow. The overall impact on crop production will, however, be determined by the ability of farmers to adapt as existing problems over land and water use are ex-acerbated. There will be marked north-south differences in both the impacts and the re-sponses, with the most serious problems being faced in the south.

Crop production remains important for both domestic food con-sumption and the gen-eration of export income in the Mediterranean region. Currently, Med-iterranean agriculture accounts for nearly all the olive oil production world-wide, 60% of wine production, 45% of grape production, 20% of citrus production and about 12% of total cereal production (FAO, 1993). Today, the northern Mediterranean is self sufficient in food production, while the southern Mediterranean countries produce less than 60% of their food (Rosenzweig and Tubiello, 1997). Even in the absence of climate change, basic food security in southern countries is likely to deteriorate due to a combination of population growth, land use changes and water problems. Water use has also become a problem in Spain, Greece and southern Italy.

Increasing levels of atmospheric carbon dioxide may increase the yield of major food crops as a result of higher rates of photosynthesis and improvements in water use efficiency. Under controlled conditions, yields of C3 plants - such as wheat, rice, soybean and barley - increase by about 30% with a doubling of present-day carbon dioxide levels (Cure and Acock, 1986; Rogers and Dahlman, 1993). The measured response for C4 plants - such as maize, sugarcane, millet and sorghum - is much less. There is, however, considerable debate about whether or not these benefits would occur in the real world.

Climate change is likely to result in a northward shift of crop growing zones, with some areas becoming progressively less suitable for growing certain crops and more suitable for others. Crop response models are commonly used to assess the potential effects of both increased carbon dioxide and changes in mean climate. Result from these models generally show yields of grains and other crops could decrease substantially in Mediterranean areas due to an increased frequency of drought (Reilly, 1996).

Regional results from a global crop-response modelling study suggest that yields of a number of major crops could decrease markedly in North Africa and the Near East, under three equilibrium climate scenarios (Table 2, Rosenzweig and others, 1993; Reilly and others, 1993)23. Estimated yield losses are over 20% for wheat, corn and other coarse grains in some scenarios, even allowing for effects of carbon dioxide. The largest losses of up to 51% in the case of wheat - are anticipated in Egypt. The potential for large reductions in Egyptian wheat and maize yields is also supported by more recent modelling work (El-Shear and others, 1997). Even allowing for some adaptation, yield losses may occur throughout the southern and eastern Mediterranean region24.

Table 2: Estimated yield changes of major crops by region. The range takes account of results under three equilibrium GCM scenarios for a doubling of carbon dioxide and includes thedirect carbon dioxide effects. Estimates derived by Rosenzweig and others, 1993 and extracted from Reilly and others, 1993.

- Yields decrease under at least one climate scenario if no account is taken of carbon dioxide fertilisation effects.

** Yields decrease under at least one climate scenario even allowing for carbon dioxide fertilisation effects and some adaptation.

The European Community region includes: Portugal, Spain, France, Italy and Greece
The Eastern Europe region includes: Former Yugoslavia, Albania
The Middle East/North Africa - oil producers region includes: Syria, Algeria, Tunisia and Libya
The Middle East/North Africa - other countries region includes: Turkey, Cyprus, Lebanon, Israel, Morocco

The global crop modelling study suggests more promising prospects for European countries as a whole, but detailed country studies for southern European suggest the outlook for cereal production is poor in these countries. Experiments for Spain, southern Italy and Greece all show a decline in maize yields, even allowing for the potential benefits of carbon dioxide fertilisation (see review by Rosenzweig and Tubiello, 1997).

- One study found that under the IPCC's mid-range reference scenario, yields at Kardista (central Greece) may drop by about 8% by 2030 and that by 2050 the probability of obtaining current yields could be close to zero (Kapetanaki and Rosenzweig, 1997). Yield reductions of almost twice this amount were calculated for a site in northern Greece.
- A study of the implications of climate change for maize production in Spain suggests that "the yield reductions and the exacerbated problems of irrigation water availability ... may force the crop out of production in some regions" (Iglesais and Minguez, 1997). The same situation could arise in many other parts of the Mediterranean region.

The prospects for wheat in southern Europe are less certain. Crop-climate experiments for a number of different climate scenarios suggest that wheat yields may increase in northern Mediterranean countries (Harrison and Butterfield, 1995; Igelais and Minguez, 1997). This may, however, be over-optimistic as the yield increases are largely attributable to higher carbon dioxide levels and thus must be open to question. Indeed, results of another experiment in which carbon dioxide effects are not included suggest that yields in northern and central Italy would decline (Bindi and others, 1993).

Overall, the outlook for cereal production is probably significantly worse than suggested by the crop-climate models. This is because the models have a number of inherent limitations which suggest that they may be over-optimistic in the yields predicted (Box 7). Uncertainties surrounding the effects of carbon dioxide have already been described. Aside from this, their failure to consider the impact of extreme events, soil conditions, competition for water supplies, changes in the prevalence and distribution of pests and diseases and sea level rise could be particularly important.

Box 7: False Optimism? Crop-Climate Experiments

Crop-climate modelling experiments make a number of highly optimistic assumptions, including:

- The CO2 fertilisation effect works to the full - the effects of carbon dioxide on yields may be overestimated as the experimental results used to calibrate the models may not be replicated in variable, windy, pest-infected field conditions (Körner, 1990).
- Climate variability will not alter - changes in the frequency and magnitude of extreme events (for example, extended periods of high temperatures, droughts, and so on) could have a greater impact than changes in mean climate alone (Semenov and Porter, 1994).
- Nutrients are not limiting and diseases and insect pests are controlled - ensuring these conditions are met could require the use of expensive agrochemicals and may make farming uneconomic.
- Irrigation water is available in unlimited supply (sometimes, but not always, assumed) - in reality, reductions in water availability would increase competition between sectors for water supplies.
- There are no problem soil conditions - there are.
- No account is taken of land degradation or sea level rise on production - this could be particularly important in the southern Mediterranean.

Taken together, these limitations suggest that crop-climate experiments may give substantially higher yields than would be achieved in reality. Thus, while such experiments do provide a useful idea of the sensitivity of particular crops to mean climate change, their results should be treated with caution.

Crop production in all areas could be adversely impacted by changes in the incidence of plant diseases and insect pests. Milder winters could increase the incidence of outbreaks of, for example, powdery mildew, brown leaf rust of barley, strip rust of cereals (Meier, 1985), while also reducing incidence of most fungal diseases. Higher temperatures could also cause a proliferation of insect pests as warmer and longer growing seasons provide time for pests to reproduce more often (Pimentel and Pimentel, 1978). Ironically, responses to such outbreaks, could actually damage agricultural production in the long term. For example, an increased use of pesticides will enhance soil degradation and thus soil erosion (Baric and Gasparovic, 1992).

The anticipated increase in the frequency of high temperature and drought events could further undermine agricultural production in many regions. This effects of just a short period of extreme conditions is illustrated by the drought in 1993 when more than half the harvest was lost to drought in some areas of Spain. In the Segura river basin (southeast Spain), 10,000 hectares could not be irrigated and 400,000 tons of green products were lost (Revista del MOPT, January, 1994). Ultimately, the viability of crop production would be jeopardised by an increase in the frequency of such events. One study suggests that the anticipated reduction in moisture availability would simply make soils unsuitable for cereal growing throughout large parts of Spain, southern Italy and Greece (Le Houérou, 1992).

As conditions deteriorate for cereals, opportunities for other crops may open up. Warmer climates and a longer growing season would extend the scope for olive and citrus throughout much of the northern Mediterranean region. One study suggests that a 3°C warming could extend the area of citrus crops in Europe by a factor of three and effectively close the European market for this product (Le Houérou, 1992). However, a study for the Kastela Bay region (Croatia) is more pessimistic finding that “citrus and kiwi fruits are already impossible to grow without irrigation” (Baric and others, 1996). Similarly, another study points out that warmer winters could lead to the loss of adequate winter chilling for crops such as peaches, nectarines and kiwi fruits (Reilly, 1996).

In the southern Mediterranean, the scope for olive production may also increase in some areas. Moreover, increases in temperature may, however, open the way for the more tropical species such as avocado, mango, banana, paw paw and sugar cane (Le Houérou, 1992) - assuming there is an adequate supply of water.

Crop production of all types in coastal areas will be vulnerable to sea level rise. While the extent of inundation may be limited, problems of increased saline intrusion and waterlogging due to the higher water table are expected. The most vulnerable, and most studied, area at risk is the Nile Delta (Egypt). If sea level rises by 1m, then 12 to 15% of existing agricultural land in the Delta may be lost (Nicholls and Leatherman, 1995). Even a 0.2 to 0.4 m rise in sea level could eventually cause agricultural land in Egypt to be withdrawn from production over an area extending 20 km inland (El-Shaer and others, 1997).

The actual impact of climate change on the agricultural production will depend, not just on the nature of the change, but also on demographic and socio-economic factors. These factors mean there are likely to be large north-south differences in the impacts of climate change on production. Cereal production is already marginal over much of southern Europe and could according to one study “become untenable with a worsened water balance, particularly if, as expected the price of cereals in the EEC countries progressively declines to world market prices.” (Le Houérou, 1992). As a result the land devoted to cereals in the northern Mediterranean seems likely to shrink as climate changes, with marginal lands being converted to other uses.

This contrasts markedly with the situation in North Africa and the Near East where it is anticipated that cereal production may continue despite ever-increasing risks (Le Houérou, 1992). Reductions in moisture availability could cause crop expectancy in semi-arid areas to drop by 20% to around 50 or 60%. In arid areas - where crop expectancy is only one-fifth or less today, cereal growing would become more of a gamble than it is today. Despite this, demographic pressures mean that cereal production in semi-arid and arid areas is likely to continue and the area devoted to it may even expand despite the crop losses (Le Houérou, 1992). Such an expansion would bring its own problems, as the IPCC note, “[in] Afro-Asian Mediterranean countries, extension of agriculture and overgrazing in marginal areas, ... will probably lead to further degradation of plant cover and soil loss” (Allen-Diaz, 1996).

It is unclear whether or not countries on both sides of the socio-economic divide would be able to take advantage of the opportunities for new crops that may arise. One study suggests that in the northern Mediterranean “olive cultivation will inevitably shrink in spite of more favourable conditions, because of increasing costs of labour and the difficulty in developing mechanised harvesting” (Le Houérou, 1992). While, a study for Tunisia suggests, “[a] great increase in olive cultivation could be anticipated in the plain of Mateur except that the expected EEC olive products import quotas will limit this change” (Hollis, 1992).

Clearly, radical changes in agricultural practice and policies may be required as climate changes. The key question is: could these adaptations be made? The IPCC is far from optimistic, highlighting firstly “there are significant uncertainties about the capacity of different regions to adapt successfully to the projected climate change” (IPCC, 1996a). The IPCC goes on to suggest that “[during] water shortages, allocations to agriculture will most likely decline before allocations to other uses”. For the developing countries of the south, the extent to which they can adapt will also depend critically on the affordability of appropriate measures and access to both know-how and technology.

Food Security

More important than food production is the question, will people have enough to eat? And if so, at what cost? Vulnerability to hunger or malnutrition depends on a range of factors, of which local food production is only one. These factors include: changes in the world market for agricultural products, population trends, national economic well being and income distribution. Experience tells us it is not enough just to produce enough food globally, people must be able to access it.

Even today, there are significant differences in the vulnerability of countries in the Mediterranean region to hunger. Most European countries currently enjoy high levels of food security while Morocco and Algeria have only moderate food security (Downing, 1992)25. Even in the absence of climate change, it seems probable that food security in southern countries will go down due to population growth, their low level of economic development and ongoing land degradation.

Assessing the impacts of climate change on food security is immensely complex. To do so, requires not just climate and crop modelling, but also economic modelling of the world's trading system - thus adding yet another level of uncertainty. Nevertheless, results from initial studies suggest potentially serious implications for southern Mediterranean countries. World trade models have been used to examine the implications of three equilibrium GCM climate scenariosand associated crop yield changes (with-or without-carbon dioxide effects and with- or without-adaptation) for food prices and national welfare (Reilly and others, 1993)26.

The results show virtually all commodities could become more expensive, if no allowance is made for carbon dioxide fertilisation effects and adaptation. Under all climate scenarios the price of wheat, rice, groundnuts, cotton, sugar and tobacco at least doubles, with one scenario suggesting price hikes of over 500% for rice and tobacco. Even if allowance is made both carbon dioxide effects and adaptation, then prices of key commodities such as wheat, maize, sorghum, rice, soybean meal, sugar, beef, pork and poultry rise in at least two out of three climate scenarios The effect of the price rises means that agricultural exporters may gain even though their supplies fall, but some food-importing countries may suffer economic losses even if they manage to increase food production. Assessments of net welfare change for regions encompassing Mediterranean countries suggest that all regions may loose substantially in economic terms, although there is a chance of a small gain under more optimistic scenarios (Table 3).

Table 3: Economic welfare implications of the impact of climate change on global agricultural production. The range takes account of results under three equilibrium GCM scenarios for a doubling of carbon dioxide and includes direct carbon dioxide effects. Data extracted from Reilly and others, 1993.

- Yields decrease in at least one climate scenario if no account is taken of carbon dioxide fertilisation effects.

** Yields decrease in at least one climate scenario even allowing for carbon dioxide fertilisation effects and some adaptation.

For country coverage, see table 2.

For developed countries, such losses may be simply financial, but in poorer developing countries, there is a risk of malnutrition, starvation or hunger. In the Mediterranean region, the most at risk seem likely to be Albania, Algeria, Egypt, Lebanon, Morocco, Syria and Tunisia - all of which has a Gross Domestic Product below US$2,000 per person, closely followed by Croatia and Turkey (1993 data from WRI/IIED/UNEP, 1997).

Wider Socio-Economic Implications

Almost all aspects of human society are dependant on climate and most would be affected by climate change either directly or as the effects cascade through the socio-economic system. The combined impacts could be a much more serious risk to human well-being than the effects on any individual sector.

As yet, there are few fully integrated studies of the impacts of climate change in the Mediterranean region and this makes it is impossible to gauge the full ramifications of climate change. Nevertheless, even a brief assessment of four areas: human health, natural ecosystems, industry and infrastructure and social disruption illustrates the potential seriousness and diversity of threats posed by climate change.

Human Health

In a 1995 WHO/UNEP report, Anthony McMicheal declares, "[in] destabilising the world's climate and its dependent ecosystems, we are posing new and widespread risks to public health" (WHO/UNEP, 1995). This finding is further supported by the work of the IPCC (McMichael, 1996). Direct effects will arise from increases in the frequency and severity of heat waves and other extreme weather events. But, the most significant impacts are likely to come indirectly through the effects of climate change on, for example, the distribution and prevalence of infectious diseases, water quality, food security and sea level rise.

Quantifying the full impact of climate change on health is extremely difficult. This is partly because many modelling techniques are still in their infancy, but partly because impacts will depend on numerous interacting factors including other environmental trends, social resources and pre-existing health status. Nevertheless, sufficient understanding exists to identify some of the major pathways by which the health of the population of the Mediterranean region may be at put atrisk by climate change.

An increase in the frequency and severity of heat waves would both increase illness and death rates. Some of the most serious effects may be felt in large cities, where extreme heat could aggravate local pollution problems and increase the incidence of respiratory illness. The sensitivity of populations in the Mediterranean region to such an outcome is highlighted by conditions in Athens in June to August 1993 where a combination of pollution and high temperatures during a heat wave caused more than a thousand people to seek medical attention in Athens (WMO/UNEP, 1994).

Increases in extreme weather events, such as storms or intense rainfall would increase death and injury rates. Torrential rain and the floods and/or destruction associated with it is already responsible for deaths in Mediterranean countries. For example, torrential rain in September 1991 led to one of the deadliest floods on record in southern France as 32 people drowned (WMO/UNEP, 1994). Events such as this could become more common if rainfall intensifies as climate changes.

Warmer conditions could increase the incidence and extent of infectious diseases such as malaria, dengue fever, schistosomiasis and yellow fever. In recent years, the prevalence of the schistosome-spreading snails has increased world-wide due to the spread of irrigation. Climate changes could, however, increase the incidence of schistosomiasis in Egypt at least (Gillet, 1974; WH0, 1990). Currently, snails lose their infections in the winter, but with higher temperatures, they could cause infection throughout the year. Climate change will also increase the extent of potential malarial areas.

Climate change is already playing a part in the recent resurgence of infectious diseases world-wide. Even with the minor increase in temperature experienced to-date, malaria and dengue are now being reported at higher latitudes in Africa, Asia and Latin America than at any time this century (WHO/UNEP, 1995). How great an impact climate change has on human health will ultimately depend, however, on finding ways to tackle the ongoing growth in pesticide and drug resistance.

Some of the most important impacts are likely to come, however, through the deteoriation of social and economic circumstances in areas affected by desertification and sea level rise. Falls in food production and higher prices could significantly increase the risk of widespread malnutrition and hunger in countries with little, or inadequate welfare support mechanisms. Water shortages and increased concentrations of pollutants could, together with the higher temperatures, increase the risk of cholera, salmonella and dysentery. This problem could be compounded by damages to drainage and sewerage infrastructure through sea level rise (Attard and others, 1996).

The health impacts on populations in the Mediterranean region will vary significantly both in terms of the risks individual countries are exposed to and still more critically, health services available and economic well-being. The most severe problems are likely to be faced by those countries which already have the biggest problems today - notably those in North Africa and the near East. In these areas, child mortality rates among under-fives are already average six times higher than rates in southern European countries (WRI/IIED/UNP, 1989). Climate change could further increase this divide.

Natural Ecosystems

Future climate change and the associated environmental changes would directly threaten natural ecosystems in the Mediterranean region, including biosphere reserves and wetland sites of recognised international importance (Figure 8; Milliman and others, 1992). Ecosystems have both an intrinsic value and a value to humanity as they provide a variety of goods and services - from fire wood to soil retention and from filtering pollution to recreation.

Figure 8: Wetland sites of international importance, MAB biosphere reserves and UNESCO World heritage sites (UNEP, 1987).

Despite some legal protection, natural ecosystems throughout the Mediterranean region are being lost or damaged as a result of, for example, land co

nversion, pollution and infrastructure developments. Climate change will, however, pose a still more fundamental threat to the integrity of ecosystems and the activities they support.

Climate change will directly affect ecosystems though the associated increase in carbon dioxide levels, sea level rise and changes in temperature and other climate variables. But there will also be secondary impacts, for instance, an increase frequency of drought might decrease the ability of trees to resist pests.

The ability of natural ecosystems to respond to changes in climate boundaries will highly dependent on the rate of change itself. While animals and birds can respond fairly swiftly it is, as the IPCC point out, “unlikely that future rates of [tree] species migration could match those required by the currently expected rates of climate change" (Kirschbaum and others 1996). In theory, some other plant species could keep up with the rate of change, but in practice their ability to establish themselves elsewhere will be constrained by the extent of desertification and by human land uses. As a result many valuable species and habitats may be lost.

Wetland sites would be affected both by the drier conditions and by the effects of sea level rise. The acute sensitivity of wetland sites to higher temperatures is illustrated by the results of one study that suggests that an increase of 3 to 4°C would decrease the aerial extent of hydrophyte wetland in southern Europe by 70 to 85% (Brock and van Vierssen, 1992). The IPCC observe that sea level rise in combination with human activities could threaten half the world's coastal wetland sites, including those around the Mediterranean sea (Warrick and others, 1996).

The potentially devastating impact of climate change when combined with other pressures is illustrated by a study on the Ichkeul National Park (Tunisia) (Hollis, 1992). This shows that the combination of rise in temperature and a dam scheme would cause the loss of all food plants for wintering and breeding waterfowl and the disappearance of nationally important fisheries. Some groups of birds, notably flamingos and waders, may benefit but only marginally.

In the case of natural ecosystems, the scope for adaptation through human intervention is limited as yet there is no way of maintaining species diversity and ecosystem integrity artificially in the face of long-term environmental change.

Industry and Infrastructure

Impacts on industry will vary, with some benefiting - and others losing - from climate change. Food processing industries could clearly suffer if food production goes down, while one soft drinks industry could be a potential winner - during the first six months of 1993, Seville inhabitants drank 11,000 million pesetas (almost US$80 million) in bottled water (Revista del MOPT, January 1994). However, the soft drinks and other industries could all be adversely affected by irregularities in both water and energy supplies.

Supplies of hydroelectric power would be significantly reduced if the frequency of droughts increases and/or there is an overall reduction in runoff and increase in evaporation. This risk has already been identified in Greece, where one study points to a very large increase in the probability of being unable to generate the design power from hydroelectric reservoirs (Mimikou and others, 1991). The extent, and possibly the immediacy, of this problem was highlighted in 1993 when restrictions on irrigation and hydroelectric output were imposed in Morocco during a prolonged dry spell (WMO/UNEP, 1994).

The anticipated increase in rainfall intensity could also cause havoc. In July 1991, exceptionally heavy showers and thunderstorms in Turkey led to widespread flooding, several deaths and extensive material damage from Istanbul to Samsum, including the demolition of several bridges and toppling of power lines (WMO/UNEP, 1994).

The most serious impacts on both industry and infrastructure are likely to be caused by rising seal levels. The coastal zone is host to both thermal and nuclear power-plants (Figure 9) and host of other industries: including 73 petrochemical plants, 28 metallurgic plants, and 56 chemical industry plants (Baric and Gasporavic, 1992). Located in the coastal zone for easy access to transportation and water supplies, they are particularly vulnerable to sea level rise. The extent to which any particular facility is affected will depend on local conditions and as yet no full assessment has been undertaken, although a number of case studies have highlighted some industries which may be adversely affected.

Figure 9: Thermal power-plants located in the coastal zones (Baric and Gasporavic, 1992).

In the Inner Thermaikos Gulf (Greece) region, low-lying areas such as the developing industrial zone of Sindos and the Micra airport have been identified as totally exposed to even a minor rise in sea level (Georgas and Perissoratis, 1992). In the Kastela Bay region (Croatia), sea level rise would directly affect the ship yards, chemical plants and ferro-alloy plants, while a rise of just 0.5 m would flood the western part of the city harbour (Baric and others, 1996). In the Cres-Losinj Islands, 5-10% of the total water supply network is close to the shore and would risk inundation at high tides (Randic and others, 1996)

Rising sea levels would also have serious implications for many heritage sites of national and/or international importance (Figure 8) and popular beach resorts. For example, a rise in sea level of just 0.5 m would cause serious degradation to Venice (Italy) and threaten neighbouring towns of artistic and historical significance (Sestini, 1996). Similarly, in the Cres Losinj Islands (Croatia), the 4000 year old city of Osor and the historic city of Cres would be directly at risk from rising sea level (Randic and others, 1996). Beach resorts throughout the region would be affected by loss of their key attraction - the beach. In Crete, for example, many regions could lose at least half their current extent of beach with only a 50 cm rise in sea level (Georgas and others, 1996).

The loss of some of the regions natural and historical heritage, combined with enhanced beach erosion and growing water scarcity could have serious implications for the tourist industry. Tourism is a major industry in Mediterranean countries - in 1984, there were 100 million tourists in coastal areas. In the absence of climate change, this number is projected to grow to 170-340 million by 2025 (UNEP, 1987). But, with the loss of some of the attractions this growth may not be realised, despite possible benefits arising from an extension of the tourist season due to warmer weather. In any event, climate change combined with a growth in tourism would add to water scarcity problems in the region.

Social Disruption

Serious social disruption could arise due to tensions arising from reductions in water availability and both internal and external migrations of displaced people. Examples of minor disruptions exist even today. For instance, protesters blocked Istanbul's international airport to highlight the failure of the government to deal with the countries worst water problem in 40 years (Toronto Star, 5 August, 1993). Desertification is also known to exacerbate political instability as it contributes significantly to water scarcity, famine, displacement of people and social breakdown. This is, according to UNEP, a recipe for political instability and tensions between countries (UNEP Fact Sheet 10).

International conflicts could arise over rights to shared river and aquifer resources as a result of both climate change and population and development pressures (Gleick, 1993). There are already disputes between, for example, Syria and Turkey over shares in the waters of the Euphrates and between Egypt, Sudan and Ethiopia over the Nile. Existing regional agreements will become still more strained, if water availability declines or as demand increases as a result of climate change or regional developments.

Environmental refugees could become a still greater problem as millions are uprooted by shoreline erosion, coastal flooding and agricultural disruptions" (IPCC, 1990, Myers, 1993). Desertification inevitably leads to migration to cities as the land cannot support the original inhabitants (El-Karouri, 1996), while in Egypt alone it has been estimated that a sea level rise of only 0.5 m would permenantly displace 16% of population (Broadus and others, 1986). Northward migration flows across the Mediterranean Sea are already increasing as people are attracted into the newly prosperous southern European countries (King, 1996). As climate changes, European countries are likely to come under still greater pressure from hungry multitudes to the south.

National Economy

Adverse impacts on national economies will arise from a number of directions, including:

- Direct impacts of climate change. These could range from possible negative impacts on the balance of payments due to changes in agricultural production and relative food prices, increased health problems and to opportunity costs arising from irreversible damage.
- Responses required to mitigate the impacts of climate change. These could range from increases in the cost of efforts to reduce desertification to welfare payments for displaced people. These can be expensive, for example, the cost of combating desertification, even a decade ago, was estimated to range from US$25 per hectare for rangeland to around US$750 per hectare of irrigated land (Dregne, 1983).
- Knock-on implications from changes elsewhere. The impacts of climate change will be felt world-wide and this could significantly affect both import and export markets. On another level, the cost of accommodating environmental refugees could be substantial.

Quantifying such costs is extremely problematic, however, studies do point to substantial economic costs for Mediterranean countries. A study for Greece, for example, found that the total cost of climate change could be an estimated US$2.6 to US$5.9 billion per year (Dalianis and Petassis, 1993). This includes estimated annual losses equivalent to: US$2.3 to US$3.9 billion due to lost agricultural production; US$35.6 to US$71.2 million to ameliorate the impacts of sea level rise; a minimum of US$8.4 million for preservation of biodiversity at risk from climate change.

Past efforts to cost the global impacts of climate change have generally met with controversy owing to several factors, including: the relative economic value assigned to lives in developed and developing countries and the discounting of future impacts. Economists assign a much lower monetary value to life in developing countries, which is inappropriate when dealing with a global problem. Even so, these estimates show that developing countries will suffer larger relative damages in economic terms than developed countries.

While economic assessments may provide some insights into the nature of economic impacts, they are ultimately misleading. Many aspects of human and ecological welfare simply cannot be measured in monetary terms. Moreover, a perverse characteristic of economic studies is that some attempts to mitigate adverse impacts of climate change could increase Gross Domestic Product (GDP) as they increase cash flow through the economy. To simply count this as a plus is, of course, too simplistic since money spent on tackling problems produces only marginal and short-term benefits and, in the absence of climate change, could be more constructively used to benefit human well-being.

5. IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

The UN Conference on Environment and Development - the "The Earth Summit" - in 1992 signalled international recognition of both the inherent unsustainability of current development paths and the pressing need to reorientate social and economic policies accordingly. Climate change and its consequences threatens to undermine all such attempts to do so in the Mediterranean region unless action is taken to both reduce adverse impacts and emissions. Achieving this will require fundamental changes to social and economic policies and significant international support for developing countries.

Linking Climate Change and Sustainable Development

The most widely accepted definition of sustainable development is that adopted by the World Commission on Environment and Development:

“development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987). Three basic principles underlie this objective: environmental sustainability, development and equity (Karas, 1995). Climate change and its consequences may cut against all three.

- Environmental sustainability - recognises that sufficient resources need to be retained or renewed to allow both current and future generations to meet their needs. Climate change in the Mediterranean region may reduce the capacity of the environment to support human activity in future by exacerbating problems of desertification and water scarcity in the region.
- Development - is a broad concept that encompasses improvements in not merely economic terms, but also in social and environmental welfare. The sheer magnitude of the potential problems created by climate change seriously undermine the ability of countries to improve conditions for their people.
- Equity - with a particular stress on meeting the needs of the poor today and of future generations. The fact that poorer southern Mediterranean regions are likely to be hardest hit by climate change goes directly against this principle, as does the prospect of permanent degradation of the environment.

Even without climate change, current developments in the Mediterranean region are wholly unsustainable. The most fundamental problem is that human activities are already seriously degrading the environment as a life support system, through their key role in desertification, over-extraction of water from aquifers and pollution. Problems are further exacerbated in the south where population growth presents the ever-more challenging prospect of improving quality of life while also accommodating more people.

In this sense, climate change will largely exacerbate existing problems rather than create new ones. But, there are three key dimensions to the problem of climate change which mean that it cannot be ignored. First, the near-inevitability of impacts over the next few decades due to time lags in the climate systems response to past emissions; second, the irreversibility on human timescales of, in particular, the impacts on desertification, water resources and sea level rise; and third, the need for international action to cut emissions of greenhouse gases if the threat of climate change is to be reduced.

In view of these factors, ensuring sustainable development in the Mediterranean region will require action both to adapt to the impacts of climate change and to minimise emissions of greenhouse gases.

Tackling the Impacts

The commonalties between the possible adverse impacts of climate change and existing problems of environmental degradation, food and water insecurity, and so on suggest a variety of common solutions. These range from improvements in land use and water management, through to technical fixes and better social support systems.

Mediterranean countries are already signed up to a number of international and regional agreements which effectively establish a policy framework for actions that would mitigate many of the impacts of climate change. These include: the Agenda 21, the Framework Convention on Climate Change, the International Convention to Combat Desertification, the Convention on Wetlands of International Importance and the Biodiversity Convention, the Mediterranean Action Plan, and the European Union’s (EU) Fifth Action Programme on the Environment “Towards Sustainability”.

Climate change adds to the need for the effective implementation of these agreements. However, at the moment, the prospects do not look good. While the agreements have stimulated significant research and a range of small-scale innovative projects, the pace of environmental degradation continues to increase.

The root of the problem is that the principles of sustainable development have yet to be reflected in wider social and economic policies. The consequences of this have been noted by the IPCC: “[many] current agricultural and resource policies - already a source of land degradation and misuse ... will discourage effective adaptation measures” (IPCC, 1996b). For example, the EU’s Common Agricultural Policy has been shown to actively contribute to the ongoing problem of desertification (MEDALUS II, 1996). Similarly, there seems little prospect of improving water security in Syria while free water is handed out to industry (Al-Shalabei and others, 1996).

Clearly, radical changes in both policies and practices are needed if countries are going to successfully reduce existing problems, let alone the adverse impacts of climate change. Furthermore, it is widely recognised that climate change will add to the costs of appropriate responses and, as the IPCC note in the case of agriculture, “[the] incremental costs of adaptation strategies could create a serious burden for developing countries (Watson and others,1996). In view of this, it will be vital that developed countries meet their obligations under the Climate Convention to, “assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptations to those adverse effects” (Article 4, paragraph 4).

Reducing the Problem

Ultimately, sustainable development in the Mediterranean region could hinge critically on getting international agreement - and the action to back it up - to curb emissions of greenhouse gases. The Framework Convention on Climate Change is clear in its objective, which is:

“...stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (Article 4)

Achieving this objective will require stopping and then reversing the current global growth in emissions by deep cuts (Alcamo and Kreileman, 1996; Karas, 1991). But, while the signing of the Convention at the Earth Summit in June 1992 was an important landmark, emissions continue to escalate.

Clearly, it is in the interests of Mediterranean Countries to push for international action to cut emissions of greenhouse gases particularly by countries with the greatest per-capita emissions. However, the deep cuts in emissions required to stabilise atmospheric concentrations of greenhouse gases means that all countries need to find ways of meeting their development requirements while also minimising greenhouse gases emissions.

The IPCC highlights the feasibility achieving this goal, stating, “[the] consequences of different technological choices and strategies to date demonstrate that different industrial development paths - with substantially lower emissions are possible” (Kashiwagi, 1996). The IPCC further points out, A[if] carried out with care ..... responses would ... enhance the prospects for sustainable economic development for all peoples and nations” (Watson and others, 1996).

Reorientating development along more a more sustainable path requires fundamental changes in sectoral and fiscal policies, particularly with regard to transport and energy. A central plank of any response strategy in Mediterranean countries, as elsewhere, must be to find ways of meeting growing demand for energy while minimising greenhouse gas emissions. While the possible reduction of the viability of hydroelectricity is unfortunate, other renewable sources of energy - solar, biomass and wind - are of proven value. Of these, solar power is particularly promising in the Mediterranean region.

As in the case of adaptation strategies, major obstacles to the adoption of appropriate strategies include limited technical knowledge and financial resources. Here again, it will be vital that developed countries meet their obligations under the climate convention to “take all practical steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how” (Article 4, paragraph 5).

6. CONCLUSIONS

Scientists are confident that if current emissions of greenhouse gases continue, the world will warm, sea levels will rise and regional climates will change. However, large uncertainties remain over how climate in the Mediterranean region will change and over its likely impacts. Nevertheless, after reviewing recent work in the area, a number of conclusions can be drawn.

- The Mediterranean region is likely to warm significantly over the next century and beyond in response to rising concentrations of greenhouse gases. It is impossible to be certain over the precise pattern or scale of warming, but it is likely that warming rates over some inland areas will be much greater than the global average, while rates elsewhere may be slightly lower than average.
- Warming will be accompanied by changes in precipitation, moisture availability and the frequency and severity of extreme events. Significant uncertainties remain over future precipitation patterns in the region, but the balance of current evidence suggests annual precipitation may decline over much of the Mediterranean region. Moisture availability may go down even in areas where precipitation goes up due to higher evaporation and changes in the seasonal distribution of rainfall and its intensity. As a consequence, the frequency and severity of droughts could increase.
- Aerosols and other human influences on climate may mask more fundamental changes in climate. In some areas, the effects of these other influences may be sufficient to give an illusion either of no underlying trend, or an opposite tendency to that expected. But, in the longer-term the effects of greenhouse gases are expected to dominate future climate changes in the Mediterranean as their influence grows over time.
- It is likely that the changing composition of the atmosphere is already influencing climate in the Mediterranean region. Climate records for the region suggest a number of unusual characteristics to recent climate behaviour.

These fluctuations could all have occurred naturally. But, it is notable that some aspects of recent climate variations are consistent with changes that climate models suggest could occur.

- Sea level rise and a reduction in moisture availability would exacerbate existing problems of desertification and water scarcity and substantially increase the risks associated with food production. Coastal areas are directly threatened by rising sea levels, but the risks arising from changes in moisture availability and the intensity of rainfall remain difficult to quantify because of the large scientific certainties and the concurrence of ongoing trends in land degradation.
- Climate change would have far-reaching consequences affecting, for example, peoples health, the integrity of ecosystems and the services they support, industry, the risk of social disruption and national economies. Again the most greatest adverse impacts would arise from rising sea levels and the possible reduction in moisture availability.
- The most serious impacts are likely to be experienced North African and the eastern Mediterranean countries where ongoing desertification, poverty and demographic change are already major problems. Adaptation could be impeded in many areas by anticipated rate of climate change, limited access to technical expertise and wider social and economic circumstances and policies.
- The impacts of climate change could seriously undermine efforts to reorientate societies towards sustainable development. The unsustainability of existing trends in the Mediterranean region is already widely recognised. However, the irreversible character of some of the possible impacts of climate change threatens to undermine all efforts to reorientate societies along more sustainable paths.

Finally, Mediterranean countries have little choice but to try and adapt as best they can to the almost inevitable changes in climate arising from past emissions of greenhouse gases. But, the long-term sustainability of the region could hinge critically on prompt international agreement, backed up by action, to substantially cut emissions of greenhouse gases. Developing countries of the southern and eastern Mediterranean are likely to need international support to enable them both to adapt and to keep their own emissions of greenhouse gases to a minimum.

GLOSSARY

Acronyms

CO2	Carbon dioxide
EEC	European Economic Community
ENSO	El-Niño-Southern Oscillation
EU	European Union
GCM	Global Circulation Model
ICCD	International Convention on Combating Desertification
IPCC	Intergovernmental Panel on Climate Change
IPCC92a	The IPCC's "baseline" or "reference" scenario of future emissions
of	greenhouse gases
FCCC	Framework Convention on Climate Change
MEDALUS	Mediterranean Desertification and Land Use
NAO	North Atlantic Oscillation
UNEP	United Nations Environment Programme
US	United States of America
WHO	World Health Organisation

Units

cm	centimetres
m	metres
mm	millimetres
°C	degrees centigrade/Celsius
km	kilometres
m	cubic metres
ppbV	parts per billion by volume
ppmV	parts per million by volume
%	percent

REFERENCES

Alcamo, J. and Kreileman, E., 1996. The Global Climate System: Near Term Action for Long Term Protection. RIVM Report no. 481508001. Bilthoven, The Netherlands; Rijkinstitut voor Volkesgezonheid en Milieu.

Allan, R. J., and D'Arrigo, R. D., 1996. Persistent ENSO sequences: how unusual is the recent El Niño? Holocene. Submitted. Cited in: Nicholls and others, 1996.

Allen-Diaz, B., 1996. Rangelands in a changing climate: impacts, adaptations, and mitigation. In: Watson, R.T., and others (eds). Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp.130-158. Cambridge, Cambridge University Press.

Al-Shalaberi, N. M. and others, 1996. Implications of expected climate changes for the Syrian Coast. In: Jeftic, L., Keckes, S., and Pernetta, J. C. (eds). Climate Change and the Meditterranean. Volume 2, pp. 251-321.

London: Arnold.

Amanatidis, G. T. and others, 1994. Decreasing precipitation trend in the Narathon area, Greece. Int. J. of Climatol., 13, 191-201.

Archer, S. 1994. Woody plant enchroachment into Southwestern grasslands and savannas: rates patterns and proximate causes. In: Vavra, M. and others (eds), Ecological Implications of Livestock Herbivory in the West., pp. 13-68. Denver, Society for Rangeland Management. Cited in: Allen-Diaz, 1996.

Arkin, P. A. and Xie, P., 997. ENSO-related internnual variabiliity in large-scale precipitation during 1979-1995. Paper presented to: Seventh Conference on Climate Variations, Long Beach, California, February 2-7, 1997, pp. 170-173. Boston: American Metorological Society.

Arnell, N. W. and Piper, B. S., 1995. Impact of Climate Change on an Irrigation Scheme in Lesotho. Working Paper. Laxenburg, International Institute for Applied Systems Analysis. Cited in: Kaczmarek, 1996.

Aru, A., 1984. Aspects of desertification in Sardinia - Itlay. In:

Desertification in Europe. Proceedings of the Information Symposium in the EEC Programme on Climatology, Mytilene, Greece. Cited in: Imeson and Emmer, 1992.

Aru, A., 1996. The Rio Santa Lucia site: an integrated study of desertification. In: Brandt, C. J. and Thornes, J. B. (eds). Mediterranean Desertification and Land Use, pp. 189-206. Chichester: John Wiley and Sons.

Attard, D. J. and others, 1996. Implications of expected climatic changes for Malta. In: Jeftic, L., Keckes, S., and Pernetta, J. C. (eds). Climate Change and the Meditterranean. Volume 2, pp. 323-430. London: Arnold.

Baric, A. and Gasparovic, F., 1992. Implications of climate change on the socio-economic activities in the Mediterranean coastal zones. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 129-174. London: Edward Arnold.

Baric, A. and others, 1996. Implications of expected climatic changes for the Kastela Bay region of Croatia. In: Jeftic, L., Keckes, S., and Pernetta, J. C. (eds). Climate Change and the Meditterranean. Volume 2, pp. 143-249. London: Arnold.

Barrow, E. and Hulme, M., 1995. Construction of regional scenarios. In:

Harrison, R. A., Butterfield, R. E. and Downing, T. E. Climate Change and Agriculture in Europe. Assessment of Impacts and Adaptations. Research Report No. 9, pp. 21-30. Oxford: Environmental Change Unit, University of Oxford.

Barrow, E., Semenov, M. A. and Hulme, M., 1995. Construction of site-specific scenarios. In: Harrison, R. A., Butterfield, R. E. and Downing, T. E. Climate Change and Agriculture in Europe. Assessment of Impacts and Adaptations. Research Report No.9, pp. 30-50. Oxford:

Environmental Change Unit, University of Oxford.

Bethoux, J. P. and others, 1990. Warming trend in the Western Mediterranean deep water. Nature, 347, 660-662, 18 October.

Bindi, M., Maracchi, G. and Miglietta, F. 1993. Effects of climate change on the ontomorphogenic development of winter wheat in Italy. In: Kenny, G. J. and others. The Effects of Climate Change on Agricultural and Horticultural Potential in Europe. Oxford: Environmental Change Unit. Cited in: Rosenzweig and Tubiello, 1997.

Blue Plan, 1988. Futures of the Mediterranean Basin: Environment Development 2000-2025, Sophia, Antipols. Cited in: Baric, A. and Gasparovic, F. 1992.

Bolin, B. and others (eds), 1986. The Greenhouse Effect, Climate Change and Ecosystems. SCOPE 29. Chichester: Wiley and Sons.

Brandt, C. J. and Thornes, J. B. (eds), 1996a. Mediterranean Desertification and Land Use. Chichester: John Wiley and Sons.

Broadus and others, 1986. Rising sea level and damming of rivers: possible effects in Egypt and Bangladesh. In: Titus, J. G. (ed). Effects of Changes in Stratospheric Ozone and Global Climate. Volume 4: Sea Level Rise. Washington DC, US Environmental Protection Agency/United Nations Environment Programme.

Brock, T. C. M. and van Vierssen, W. 1992. Climate change and hydrophyte-domminated communities in inland wetland ecosystems. Wetlands Ecology and Management, 2, 37-49. Cited in: Öquist and Svensson, 1996.

Bullock, P. and Le Houérou, H. (eds), 1996. Land degradation and desertification. In: Watson, R. T., and others (eds). Climate Change 1995:

Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp. 170-189. Cambridge, Cambridge University Press.

Carter, T. R., and others, 1994. IPCC Technical Guidelines for Assessing

Climate Change Impacts and Adaptations. IPCC Working Group II. Available from Department of Geography, University College, London.

Corre, J-J., 1992. Implications des changements climatiques etude de cas:

Le Golfe du Lion (France). In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 328-427. London: Edward Arnold.

Cotton, W. R. and Pielke, R. A., 1995. Human Impacts on Weather and Climate. Cambridge: Cambridge University Press.

CRU, 1997. Annual 1995. Climate Monitor, 24 (5). Norwich: Climate Research Unit.

Cubasch, U. and others, 1996. Estimates of climate change in southern Europe derived from dynamical climate model output. Clim. Res., 7, 129-149.

Cure, J. D. and Acock, B., 1986. Crop responses to carbon dioxide doubling:

a literature survey. Agric. and For. Meteor., 38, 127-145. Cited in:

Reilly, 1996.

Dalianis, D. and Petassis, D. 1993. Social Cost of Electric Energy Production in Greece. University of Athens. (Information from S. Psomas, Greepeace Greece).

Dickinson, R. E. and others, 1996. Climate processes. In: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I. Cambridge, Cambridge University Press.

Downing, T. E., 1992. Climate Change and Vulnerable Places: Global Food Security and Country Studies in Zimbabwe, Kenya, Sengal and Chile. Oxford: Environmental Change Unit.

Dregne, H. E., 1983. Desertification of Arid Lands. New York: Harwood Academic Publishers. Cited in: WRI/IIED/UNEP, 1987.

El-Karouri, M. O. H., 1986. The impact of desertification on land productivity in Sudan. In: El-Baz, F. and Hassan, M. H. A. Physics of Desertification, pp. 52-58. Dordrecht, Martinus Nijhoff. Cited in: Bullock and Le Houérou, 1996

El Shaer, H. M. and others, 1997. Impact of climate change on possible scenarios for Egyptian agriculture in the future. Mitigation and Adaptation Strategies for Global Change, 1 (3), 233-250.

Enger, L. and Tjernström, M., 1991. Estimating the effects on the regional precipitation climate in a semi arid region caused by an artificial lake using a mesoscale model. J. Meteor., 30, 227-250. Cited in: Cotton and Pielke, 1995.

FAO, 1993. FAO Production Year Book 1993. Cited in: Rozenweig and Tubiello, 1997.

Geeson, N. A. and Thornes, J. B., 1996. MEDALUS II. Executive Summary Phase II. Commissions of the European Community DG XII.

Georgas, D. and Perissoratis, C., 1992. Implications of future climatic changes on the Inner Thermaikos Gulf. In: Jeftic, L. , Milliman, J. D. and Sestini, G. (eds), 1992. Climatic Change and the Mediterranean, pp. 495-534. London: Edward Arnold.

Georgas, D. and Perissoratis, C. and Armbariotis, P., 1996. Climate Impacts Report for Crete. Athens, Greenpeace Greece.

Gillet, J. D., 1974. Direct and indirect influences of temperature on the transmission of parasites from insects to man. In: Taylor, A. E. R. and Muller, R. (eds). Effects of Meteorological Factors on Parasites, pp. 79-95. Oxford: Blackwell Publications. Cited in: McMicheal, 1996.

Glantz, M. H., Katz, R. W. and Nicholls, N. (eds), 1991 Teleconnections Linking Worldwide Climate Anomalies. Scientific Basis and Societal Impacts. Cambridge: Cambridge University Press.

Gleick, P. H., 1993. Water in Crisis. Oxford: Oxford University Press.

Cited in: Kasczmarek, 1996.

Gomez, M. J. M., 1995. New tourism and the future of Mediterranean Europe.

Tidjschrift Voor Economische en Sociale Geografie, 86 (1), 21-31.

Gordon, H. B. and O'Farrell, S. P., 1996. Transient climate change in the CSIRO coupled model with dynamical sea-ice. Mon. Wea. Rev. (in press). Cited in: Kattenberg and others, 1996.

Ghuman, B. S. and Lal, R., 1986. Effects of deforestation on soil properties and microclimate of a high rain forest in Southern Nigeria. In:

Dickenson R. E. (ed), 1986. The Geophysiology of Amazonia, pp. 225-244. New York: John Wiley and Sons. Cited in: Cotton and Pielke, 1995.

Greenpeace International, 1997. Polar Meltdown. The Changing Climate in Antarctica. Amsterdam: Greenpeace International.

Gregory, 1996. Personal Communication. Cited in: Kattenberg and others, 1996.

Harrison, P. A. and Butterfield, R. A., 1985. Results from site and regional scale integration. In: Harrison, R. A., Butterfield, R. E. and Downing, T. E. Climate Change and Agriculture in Europe. Assessment of Impacts and Adaptations. Research Report No.9, pp. 401-407. Oxford:

Environmental Change Unit, University of Oxford.

Hasselman and others, 1995. Detection of anthropogenic climate change using a fingerprint method. In: Ditlesven, P. (ed). Proceedings of "Modern Dynamical Meteorology", Symposium in Honour of Askel Winn-Nielson. ECMWF Press. Cited in: Kattenberg and others, 1996.

Hollis, G. E., and others, 1992. Implications of climatic changes in the Mediterranean Basin: Garaet el Ichkeul and Lac de Bizerte, Tunisia. In Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 602-679. London: Edward Arnold Houghton, J. T., and others (eds), 1996. Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I. Cambridge, Cambridge University Press.

Hurrell, J. W., 1995. Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation. Science, 269, 676-679.

Iglesais, A. and Minguez, M. I., 1997. Modelling crop-climate interactions in Spain: vulnerability and adaptation of different agricultural systems to climate change. Mitigation and Adaptation Strategies for Global Change, 1 (3), 272-288.

Imeson, A. C., and Emmer, I. M., 1992. Implications of climate change on land degradation in the Mediterranean. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, 95-128. London:

Edward Arnold.

ICCD, 1994. Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.

IPCC, 1990. Climate Change: The IPCC Scientific Assessment: Final Report of Working Group 1. Cambridge: Cambridge University Press. Cited in Myers, 1993.

IPCC, 1992. Climate Change: The 1990 and 1992 IPCC Assessments. IPCC First Assessment Report. Overview and Policymakers Summaries and 1992 IPCC Supplement. WMO/UNEP.

IPCC, 1996a: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I. Cambridge, Cambridge University Press.

IPCC, 1996b: Watson, R. T., and others (eds). Climate Change 1995:

Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II. Cambridge, Cambridge University Press.

Jenkins, A., Jacobs, S. S. and Keys, J. R., 1995. Is the little PIG in hot water. Ant. J. of US, in press. Cited in: Greenpeace International, 1997.

Jones, P. D., 1994. Hemispheric surface air temperature variations: a reanalysis and an update to 1993. J. Climatol., 7, 1794-1802. Cited in:

Nicholls and others, 1996.

Jones, P. D. and others, 1990. Assessment of urbanisation effects in the time series of surface air temperature over land. Nature, 347, 169-172. Cited in: Nicholls and others, 1996.

Kaczmarek, Z., 1996. Water resources management. In: Watson, R. T., and others (eds). Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp. 469-486. Cambridge, Cambridge University Press.

Kapetanaki, G. and Rosenzweig, C., 1997. Impact of climate change on maize yield in central and northern Greece: a simulation study with Ceres-maize. Mitigation and Adaptation Strategies for Global Change, 1 (3), 251-271.

Karas, J. H. W., 1991. Back from the Brink. Greenhouse Gas Targets for a Sustainable World. London: Friends of the Earth.

Karas, J. H. W., 1995. New Directions for Structural Funds. Indicators for Sustainable Development in Europe. London: New Economics Foundation.

Kashiwagi, T., 1996. Industry. In: Watson, R. T., and others (eds). Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp. 651-677. Cambridge, Cambridge University Press.

Kattenberg, A. and others, 1996. Climate models - projections of future climate. In: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I, pp. 289-357. Cambridge, Cambridge University Press.

Kellogg, W. W. and Schware, R., 1981. Climate Change and Society. Colorado:

Westview Press.

Kharrat, M, 1997. Personal communication. From Greenpeace Tunesia.

King, R., 1996. Migration and development in the Mediterranean region.

Geography, 81 (350 Pt 1), 3-4.

Kirschbaum, M. and Fischlin, A., 1996. Climate change impacts on forests. In: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I, pp. 95-130. Cambridge, Cambridge University Press.

Körner, C., 1990. CO2 fertilistation: the great uncertainty in future vegetation development. In: Saloman, A. and Reidal, D. (eds). Global Vegetation Change. Mass: Hingham. Cited in: Iglesais and Minguez, 1997.

Lamb, P. J. and Peppler, R. A., 1991. West Africa. In: Glantz, M. H., Katz, R. W. and Nicholls, N. (eds). Teleconnections Linking Worldwide Climate Anomalies. Scientific Basis and Societal Impacts, pp. 120-187. Cambridge:

Cambridge University Press.

Le Houérou, H. N., 1988. Considerations biogéographiques sur les steppes Nort-Africaines. Cpte-Rend. Ve Coll. Intern. de l’Assoc. Franç. de Géogr. Phys. Biogéographie, Environnement, Aménagement. Paris: CNRS, Univ. Cited in: Le Houérou, 1992.

Le Houérou, A. N., 1992. Vegetation and land-use in the Mediterranean Basin by the year 2050: A prospective study. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 175-232. London: Edward Arnold.

López-Bermúdez, F., 1995. Desertifcation/degradation. Is this important research for the European Mediterranean countries? Unpublished paper to:

MEDALLUS Conference on Mediterranean Desertification, Myth or Reality, Almeria, November 1994. Cited in: Thornes, 1996.

Mabutt, J. A., 1984. A new global assessment of the status and trends of desertification. Env. Consv., 11 (2), 106. Cited in: WRI/IIED/UNEP, 1989.

Maheras, P., 1987. Temporal fluctuations of annual precipitation in Palma and Thessaloniki. J. Meteorol., 12, 305-308.

Maheras, P. and Kolyva-Machera, F., 1990. Temporal and spatial characteristics of annual precipitation over the Balkans in the twentieth century. Int. J. Climatol., 10, 495-504.

McMicheal, A. J., 1996. Human population health. In: Watson, R. T., and others (eds). Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp. 563-584. Cambridge, Cambridge University Press.

MEDALUS I, 1993. Final Report. CEC Contract No. EPOC-CT90-0014-(SMA).

Commission of European Communities DG XII.

MEDALUS II, 1996. The MEDALUS II. Mediterranean Desertification and Land Use. Executive Summary Phase II. Commission of European Communities DG XII.

Meier, W., 1985. Pflanzenschutz im Feldbau. Tierische Schädlinge und Plflanzenrankheiten, 8 Auflage, Zurich-Reckenholz, Eidgenössiche Forschungsanstalt fur Landwirtschaftlichen Pflanzenbau. Cited in: Reilly, 1996.

Metaxas, D. A., Bartzokas, A. and Vitsas, A., 1991. Temperature fluctuations in the Mediterranean area during the last 120 years. Int. J. Climatol., 11, 897-908.

Milliman, J. D., 1992. Sea-level response to climate change and tectonics in the Mediterranean Sea. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 45-57. London: Edward Arnold.

Milliman, J. D., Jeftic, L. and Sestini, G. (eds), 1992. The Mediterranean Sea and climate change - an overview. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 1-14. London:

Edward Arnold.

Mimikou, M. and others, 1991. Regional climate change impacts: impacts on water management works. Hydrol. Sci. J., 259-270. Cited in: Kaczmarek, 1996.

Mitchell, J. F. B. and others, 1995. On surface temperatures, greenhouse gases and aerosols: models and observations. J. Climate, 10, 2364-2386. Cited in: Kattenberg and others, 1996.

Myers, N., 1993. Environmental refugees in a globally warmed world.

BioScience, 43 (11), 752-761.

Neumann, J. and Parpola, S., 1987. Climatic change and the eleventh-tenth-century eclipse of Assyria and Babylonia. JNES, 46, 161-182. Cited in: Cotton and Pielke, 1995.

Nicholls, R. J. and Leatherman, S. P., 1995. Sea level Rise. In: Strzepek, K. M. and Smith, J. B. (eds). As Climate Changes: International Impacts and Implications. Cambridge: Cambridge University Press. Cited in: El-Shaer and others, 1997.

Nicholls, N. and others, 1996. Observed climate variability and change. In:

Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I, pp. 137-192. Cambridge, Cambridge University Press.

Palutikof, J. P., Goodess, C. and Guo, X., 1994. Climate change, potential evapotranspiration and moisture availability in the Mediterranean Basin. Int. J. Climatol., 14.

Palutikof, J. P., Trigo, R. M and Adcock, S. T., 1996b. Scenarios of rainfall over the Mediterranean: is the region drying. Presentation to:

International Conference on Mediterranean Desertification, 29 October-1 November 1996, Crete Greece. Available from: Climate Research Unit, UEA, Norwich, UK.

Palutikof, J. P. and Wigley, T. M. L., 1996. Developing climate change scenarios for the Mediterranean Region. In: Jeftic, L., Keckes, S. and Pernetta, J. C. (eds). Climatic Change and the Mediterranean. Volume 2, pp. 27-55. London: Edward Arnold.

Palutikof, J. P. and others, 1992. Regional Changes in Climate in the Mediterranean Basin Due to Global Greenhouse Gas Warming. MAP Technical Report Series. Athens: UNEP.

Palutikof, J. P. and others, 1996. Climate and climate change. In: Brandt, C. J. and Thornes, J. B. (eds). Mediterranean Desertification and Land Use, pp. 43-86. Chichester: John Wiley and Sons.

Parton, W. J. and others, 1993. Observations and modeling of biomass and soils organic matter dynamics for the grassland biome worldwide. Global Geochem. C

ycles, 7 (4), 785-805. Cited in Allen-Diaz, 1996.

Perissoratis, C. and others, 1996. Implications of expected climate changes for the island of Rhodes. In: Jeftic, L., Keckes, S., and Pernetta, J. C. (eds). Climate Change and the Meditterranean. Volume 2, pp. 57-142. London:

Arnold.

Pimentel, D. and Pimentel, M., 1978. Dimensions of the world food problem and losses to pests. In: Pimentel, D. (ed), World Food, Pest Losses, and the Environment, pp. 1-16. Boulder: Westview Press. Cited in: Kellogg and Schware, 1981.

Randic, A. and others, 1996. Implications of expected climate changes for the Cres-Losinj Islands. In: Jeftic, L., Keckes, S., and Pernetta, J. C. (eds). Climate Change and the Meditterranean. Volume 2, pp. 431-548.

London: Arnold.

Reilly, J., 1996. Agriculture in a changing climate. In: Watson, R. T., and others (eds). Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II, pp. 429-167. Cambridge, Cambridge University Press.

Reilly, J., Hohmann, N. and Kane, S., 1993. Climate Change and Agriculture:

Global and Regional Effects Using an Economic Model of International Trade.

Report MIT-CEEPR 93-012WP. Cambridge: Massachusetts Institute of Technology.

Repapis, C. C. and Philandras, C. M., 1988. A note on the air temperature trends of the last 100 years as evidenced in the eastern Mediterranean time series. Theor. Appl. Climatol., 39. 93-107. Cited in: Metaxas and others, 1991.

Rind, D. and others, 1990. Potential evapotranspiration and the likelihood of future drought. J. Geophys. Res., 95 (D7), 9983-10004. Cited in:

Palutikof and others, 1994.

Rodó, X., Baert, E. and Comin, F. A., 1977. Variations in seasonal rainfall in southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation. Clim. Dynamics, 13, 275-284.

Rodó, X., and Comin, F. A., 1996. Recent ENSO signals in southern Europe: a consequence of climate change? Submitted. Cited in Rodó and others, 1997.

Rogers, H. H. and Dahlman, R. C., 1993. Plant responses to atmospheric CO2 enrichment. Vegetatio, 104/5, 117-131. Cited in: Reilly, 1996.

Rosenzweig, C. and Hillel, D., 1993. Agriculture in a greenhouse world.

National Geographic Research and Exploration, 9 (2), 208-221.

Rosenzweig, C. and others, 1993. Climate Change and World Food Supply.

Research Report No. 3. Oxford: Environmental Change Unit.

Rosenzwieg, C. and Tubiello, F. N., 1997. Impacts of global climate change on Mediterranean agriculture: current methodologies and future directions. An introductory essay. Mitigation and Adaptation Strategies for Global Change, 1 (3), pp. 219-232.

Salati, E., Marques, J. and Molion, L. C. B., 1978. Origem e distribuicão das Chuvas na Amazônia. Interciencia, 3, 200-205. Cited in: Cotton and Pielke, 1995.

Santer, B. and others, 1996. Detection of climate change and attribution of causes. In: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I, pp. 411-443. Cambridge, Cambridge University Press.

Segal, M. and others, 1994. Some assessments of the potential 2 x CO2 climatic effects on water balance components in the eastern Mediterranean. Clim. Change, 27, 351-371.

Semenov, M. A. and Porter, J. R., 1994. The implications and importance of non-linear responses in modelling of growth and development of wheat. In:

Grasman, J. and van Straten, G. (eds). Predictability and Non-Linear Modelling in Natural Sciences and Economics. Wageningen. Cited in: Barrow and others, 1995.

Sestini, G., 1992. Implications of climatic changes for the Po Delta and Venice Lagoon. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 429-494. London: Edward Arnold.

Thornes, J. B., 1996. Introduction. In: Brandt, C. J. and Thornes, J. B. (eds). Mediterranean Desertification and Land Use, pp. 1-12. Chichester:

John Wiley and Sons.

Trenberth, K. E. and Hoar, T. J., 1996. The 1990-1995 El Niño-Southern Oscillation event: longest on record. Gephys. Res. Lett., 23, 57-60. Cited in Trenberth and Shea, 1997.

Trenberth, K. E. and Shea, D., 1997. Atmospheric circulation changes and links to changes in rainfall and drought. Paper presented to: Seventh Conference on Climate Variations, Long Beach, California, February 2-7, 1997, pp. J14-J17. Boston: American Metorological Society.

UNEP, 1987. Environmental Data on the Mediterranean Basin (Natural Environment and Resources). Provisional version. Blue Plan, Sophia Antipolis. Cited in: Milliman and others, 1992.

UNEP, 1990. High and Dry: Mediterranean Climate in the Twenty-First Century. UNEP.

UNEP, 1992. World Atlas on Desertification. Seven Oaks: Edward Arnold.

Cited in: WRI/IIED/UNEP, 1987 and Brandt and Thornes, 1996.

Warrick, R. and others, 1996. Changes in sea level. In: Houghton, J. T., and others (eds). Climate Change 1995: The Science of Climate Change. Report of IPCC Working Group I, pp. 363-405. Cambridge, Cambridge University Press.

Watson, R. T., and others (eds), 1996. Climate Change 1995: Adaptations and Mitigation of Climate Change, Scientific-Technical Analyses of Impacts. Report of IPCC Working Group II. Cambridge, Cambridge University Press.

WEC, 1996. Climate Change 1995. The Inregovernmental Panel on Climate Change Second Assessment Report Reviewed. Report No. 5. London: World Energy Council.

WCED, 1987. Our Common Future. Oxford: Oxford University Press.

WHO, 1990. Potential Health Effects of Climate Change. Report of a WHO Task Force.

WHO/PEP/90.10. Geneva: World Health Organisation. Cited in: McMicheal, 1996.

WHO/UNEP, 1995. Climate Change and Human Health. Personal communication from Athena Ronquillo of Greenpeace Southeast Asia.

Wigley, T. M. L., 1992. Future climate of the Mediterranean Basin with particular emphasis on changes in precipitation. In: Jeftic, L., Milliman, J. D. and Sestini, G. (eds). Climatic Change and the Mediterranean, pp. 15-44. London: Edward Arnold.

WMO, 1997. WMO Statement on the Status of the Global Climate in 1996.

WMO-No. 858. Geneva: World Meteorological Organisation.

WMO/UNEP, 1994. The Global Climate System Review. Climate System Monitoring June 1991 - November 1993. Geneva: World Meteorological Organisation.

WRI/IIED/UNEP, 1987. World Resources 1987. New York: Basic Books.

WRI/IIED/UNEP, 1989. World Resources 1988-89. New York: Basic Books.

WRI/IIED/UNEP, 1997. World Resources 1996-97. New York: Basic Books.

1 The main greenhouse gases are carbon dioxide, methane, nitrous oxide and chlorofluorocarbons.

2 The IPCC was formed in 1988 to advise world leaders on current scientific understanding of climate change issues and represents pre-eminent scientific opinion of climate change. Its most recent assessment involved over 2,000 scientists from government, universities, industry and environmental groups world-wide and was published in early 1996.

3 The Mediterranean region is loosely defined in this report as countries bordering the Mediterranean Sea (plus Portugal) between about 27° to 47°N and 10°W to 37°E.

4 The time taken for carbon dioxide levels to reach double the pre-industrial level is generally used as a bench mark in assessing the rate of change in atmospheric composition. Carbon dioxide concentrations are projected to reach double their pre-industrial levels by 2060. Translating emissions of other greenhouse gases into carbon dioxide equivalents allows the warming effect of all greenhouse gases to be considered. The doubling date for equivalent carbon dioxide will be earlier than that for carbon dioxide alone.

5 Rosenzweig and Tubiello give no indication of the climate sensitivity of the various models, but results from the same models presented elsewhere (Kattenberg and others, 1996) suggest sensitivities in the middle to high range.

6 Together, these areas make up the IPCC's "Southern Europe" region.
This region is defined as 35-50°N, 10°W-45°N (IPCC, 1992; Kattenberg and others, 1996).

7 The model output was first standardised to give expected change per °C to remove biases produced by models of differing climate sensitivity. It was then statistically downscaled on the basis of existing relationships between large scale changes and station observations to provide more local detail.

8 Based on the IPCC's mid-range emissions scenario (IS92a), assuming high climate sensitivity and constant aerosols (see Figure 2). If climate sensitivity proves to be at the low end of the scale, then this chart would represent possible conditions in 2060. The chart can also be scaled to represent any other time in future by multiplying the value for a location with the expected rise in global mean temperature.
9 Based on the IPCC's mid-range emissions scenario (IS92a), assuming high climate sensitivity and constant aerosols (see Figure 2).
10 In these experiments, greater spatial detail was gained by inputting changes in greenhouse gases and results from a transient model into a high-resolution regional atmospheric model.
11 The original report indicates that precipitation could change by plus or minus 3% depending on season for every 1°C rise in global mean temperature. In this report, changes for 2100 are based on temperature projections under the IPCC's mid-range emissions scenario (IS92a), assuming high climate sensitivity and constant aerosols (see Figure 2).
12 See note 7.
13 See note 8.
14 See note 9.
15 Evapotranspiration is defined as the discharge of water from the Earth's surface to the atmosphere by evaporation from bodies of water, or other surfaces, and by transpiration from plants.
16 The temperature data is used to calculate changes in evapotranspiration - a method that is likely to give more reliable results than model estimates of this parameter.
17 These results are still only a rough guide to changes which may actually occur because no account is taken of the reservoir of soil moisture, nor of differences in soil type and crop type across the Mediterranean region.
18 According to composite scenarios of future climate changes presented in Palutikof and others, 1992, such conditions could occur sometime after the middle of the next century.
19 The ENSO phenomenon describes a periodic warming of the Pacific Ocean and related shifts in atmospheric circulation. ENSO is often represented by the Southern Oscillation index which describes the difference in mean sea level pressure between Tahiti and Darwin (Australia). Negative values indicate El Niño (or warm) events, while positive values indicate La Niña (or cold) events.
20 The NAO is described by the winter mean sea level pressure differences between Ponta Delgada (Azores) and Akureyi (Iceland).
21 Sea level rises are calculated on the basis on of past trends given by Milliman (1992) and projected global increases given by the IPCCs mid-range scenario for constant aerosols and high climate sensitivity.
22 The relative dryness of areas is defined by the ratio of precipitation-to-potential evapotranspiration. True climatic deserts are defined by hyper-arid zones. Drylands susceptible to desertification - in ascending order of dryness - are classed as: dry sub-humid, semi-arid and arid. As moisture availability goes down, dry sub-humid areas may become semi-arid conditions while semi-arid areas may become arid. In the extreme, deserts may be created.
23 The study assumes a high climate sensitivity and takes no account of aerosols - both of these factors imply less severe impacts in the near term than suggested. But, perhaps more significantly, no account is taken of the effects of sea level rise, changes in climate variability, increases in pests and diseases or land losses through desertification - all of which could mean more severe impacts.
24 Adaptations considered here consist only of those measures that would not generally increase costs, for example, shifting in planting dates.
25 According to a food security index composed of: national food shortage (food availability per person), household food poverty (Gross National Product per person) and national food deprivation (childhood mortality).
26 The results of this study can only be taken as a first approximation of possible impacts on food security. The study assumes a high climate sensitivity and takes no account of aerosols - both of these factors imply less severe impacts in the near term than suggested. But, perhaps more significantly, no account is taken of the effects of sea level rise, changes in climate variability, increases in pests and diseases or land losses through desertification- all of which could mean more severe impacts.

Beni Ghedach, Tunisia. Severe wind erosion, resulting from clearing of vegetation, now affects more than 75% of Tunisia.

Beni Ghedach, Tunisia. Severe wind erosion, resulting from clearing of vegetation, now affects more than 75% of Tunisia.

The first signs of severe erosion are now evident at Jeffra Mountains.

Farmers rely increasingly on water from man-made reservoirs (Cherichira, Tunisia).

Charabat, Tunisia. Olive groves are being inundated with encroaching sand.

Local people spend a lot of time building fences to protect roads, farms and communities from the progress of erosion.

ACKNOWLEDGMENTS

This report is written by Jacqueline Karas. Jacqueline Karas is a freelance consultant on climate change and sustainable development. Prior to this, she was a senior researcher with the Climate Research Unit (CRU) and Environmental Appraisal Unit at the University of East Anglia (UEA), Friends of the Earth, and the New Economics Foundation. The report further benefits from the expert advice of Jean Palutikof, a Reader at CRU. Jean Palutikof has worked extensively on the science and impacts of climate change. Recent work includes the development of climate scenarios for the Mediterranean region.

The author thanks David Lye for his support during the writing of this report and staff of Greenpeace for their constructive comments on drafts and producing this report. Greenpeace staff include: Karen Brouwer (International), Bill Hare (International), Hannoun Guizani (Mediterranean), Mustapha Kharrat (Tunisia), Juan Lopez de Uralde (Spain), Athena Ronquillo (Southeast Asia). She also thanks Phil Jones and Mike Hulme of CRU for their assistance in identifying pertinent materials and Phil Judge of School of Environmental Sciences at the UEA for drafting two of the diagrams presented here.

The author also acknowledges the work of the many researchers upon which this study draws, in particular, those involved in the Intergovernmental Panel on Climate Change and UNEP’s Mediterranean Action Plan and European Commission’s MEDALUS Project. Responsibility for the content of this report remains, as always, with the author.