

Climate change and stratospheric ozone depletion

Early effects on our health in Europe



WHO Regional Publications, European Series, No. 88

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stratospheric ozone depletion
Early effects on our health
in Europe

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and Colin Soskolne

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Contents

	<i>Page</i>
Foreword	vii
Preface	ix
Executive summary	xi
Introduction	1
Initiatives on climate change and human health	3
1. Climate change in Europe	7
Climate in Europe	7
Observed changes in climate	9
Projections of future climate change	13
Rise in sea level	14
Impact of climate change on water resources	15
Stratospheric ozone depletion	17
2. Effects on health of climate change in Europe	21
Thermal stress	24
Climate change and urban air pollution	28
Aeroallergens	29
Extreme weather	30
Foodborne diseases	33
Water-related diseases	34
Vector-borne diseases	36
Rodent-borne diseases	49
Pest species	50
Effects on food supply	50

3. Health effects of stratospheric ozone depletion	53
Skin cancer	53
Damage to the eye	56
The immune system	56
4. Early effects of climate change on human health	59
5. Action to reduce the health effects of climate change	63
Mitigation to reduce or prevent climate change	63
Secondary health benefits of mitigation policies	66
Adaptation strategies to reduce the potential effects on health of climate change in Europe	67
Monitoring and surveillance	68
Intersectoral issues.....	77
Research and policy	77
6. Conclusions	79
References	81
Annex 1. Policy document prepared for the Third Ministerial Conference on Environment and Health, London, 16–18 June 1999	97
Annex 2. Members of the Working Group on the Early Human Health Effects of Climate Change and Stratospheric Ozone Depletion in Europe	115

Foreword

Many people in Europe are concerned about the impacts of climate change and stratospheric ozone depletion on human health. A warming trend and stratospheric ozone depletion have been observed in Europe over the last four decades. The European Environment and Health Committee identified the need to assess these topics in 1997, as part of the lead-up to the Third Ministerial Conference on Environment and Health, held in London in June 1999. This review is the result. It is based on the deliberations of technical experts at two meetings in 1998, a review of current available science on the health effects of climate change and stratospheric ozone depletion within the European Region, and further technical input since the Conference.

Understanding what effects environmental changes could have on the health of the European population was the principal driving force behind the review. It clearly points out that there is still substantial scientific uncertainty and a need for more research on these topics. Some evidence shows, however, that recent warming trends in Europe may have already affected health. Some health effects are related to climatic and weather variability, while others are connected to climatic changes. Changes in the frequency of temperature extremes and stagnation periods increase episodes of thermal stress and air pollution. The impact of these episodes on mortality and morbidity, especially among the elderly, is well documented. Extreme weather events, such as floods, have caused nearly 500 deaths

and the evacuation of nearly 500 000 people in Europe in recent years. Outbreaks of Cryptosporidium infection have been related to extreme weather events that overwhelmed the public water supply system. The risk of the reappearance of malaria in some areas of southern Europe is another cause for concern. Some seasonal patterns are observed, with cases of foodborne disease peaking in the summer months. Inappropriate food handling in combination with warmer springs and summers, and milder winters, may contribute to the increased incidence of foodborne diseases.

The evidence presented in this review drove the recommendations made by the health and environment ministers at the London Conference. They agreed that there is an urgent need to consider how these global changes will affect the health of European populations, how to minimize adverse health impacts, how to improve monitoring and research, and how to facilitate all such action through Europe-wide coordination, sharing of information, and wider international cooperation.

I believe that this publication is a first step towards gaining more knowledge of the health effects of these major environmental threats and that it will contribute to the achievement of the objectives and recommendations of the London Conference.

Finally, I would like to thank the editors for their valuable contribution, in particular Professor Anthony McMichael and Ms Sari Kovats, from the London School of Hygiene and Tropical Medicine, for their continuous assistance.

Marc Danzon
WHO Regional Director for Europe

Preface

The Third Ministerial Conference on Environment and Health, held in London in June 1999, defined the agenda for action on environment and health in Europe for the beginning of the 21st century. The bulk of this publication was prepared as a background document by the Working Group on the Early Human Health Effects of Climate Change and Stratospheric Ozone Depletion in Europe, convened by the Rome Division of the WHO European Centre for Environment and Health at the request of the European Environment and Health Committee. The Working Group comprised representatives of national governments, international organizations and the European Commission as well as academics. The areas of expertise represented included biology, climatology, epidemiology, geology, infectious diseases, mathematics and public health.

Annex 1 was prepared as a separate policy document for the Conference and contains the recommendations of the Working Group on action to reduce or prevent the effects of climate change on the health of populations in Europe. These recommendations were agreed on at two meetings of the Working Group in May and October 1998. The members of the Working Group are listed in Annex 2.

The evidence comprising the substance of this publication is predominantly based on reductionist science. Consequently, the interaction or synergistic or harmful effects across species or their component parts and across disciplinary lines have not been taken into

account as a whole. Further, the analysis includes only what has been reported in the accessible literature. Many questions relating to climate change and population health remain unanswered and have yet to be investigated scientifically. Publication bias may have affected the literature to reflect only the results from positive studies. The focus in future should be on more holistic approaches for understanding the effects of the problems already identified.

The editors would like to offer special thanks to the following individuals who supplied text or data, reviewed early drafts or provided assistance in other ways, thereby contributing much to the present substance of this publication: Simon Hales (Wellington School of Medicine, New Zealand), Mike Hulme (Climatic Research Unit, University of East Anglia, United Kingdom), Marco Jermini (WHO European Centre for Environment and Health, Rome Division), Katrin Kuhn (London School of Hygiene and Tropical Medicine, United Kingdom), Tim Lack (Water Research Centre, United Kingdom), Matthew Livermore (University of East Anglia, United Kingdom), Kathy Pond (WHO European Centre for Environment and Health, Rome Division), Francesca Racioppi (WHO European Centre for Environment and Health, Rome Division), Gerreth Rees (Director, Robens Centre for Public and Environmental Health, United Kingdom), Geoffrey Tiernay (Directorate-General for Environment, Nuclear Safety and Civil Protection (DG XI), European Commission) and Alistair Woodward (Wellington School of Medicine, New Zealand).

Executive summary

Human effects on the environment now include unprecedented changes at the global level in the atmosphere and the stratosphere. Climatologists project that the accumulation of greenhouse gases in the lower atmosphere will change the world's climate, and this has apparently already begun. Stratospheric ozone has been depleted in recent decades. The relationship between the two phenomena is complex, and new knowledge is emerging. Authoritative international reviews have concluded that these global environmental changes will affect human health, mostly adversely. At the global level, some of the ongoing changes in patterns of human disease are compatible with the advent of climate change. However, further research is needed to clarify these and future relationships.

Climate change and stratospheric ozone depletion are anticipated to have a range of health effects. Some will be direct effects, such as deaths related to heat waves and skin cancer induced by ultraviolet radiation. Others will result from disturbances to complex physical and ecological processes, such as changes in patterns of infectious disease, drinking-water supplies and agricultural yields. Some health effects may become evident by 2010; others would take longer. Further, failure to reduce fossil fuel combustion, as the principal means of reducing greenhouse gas emissions, will result directly in a continuing (and increasing) avoidable burden of mortality and disease from exposure to local air pollution.

There is a need to consider how these global change processes will affect the health of European populations, how to minimize adverse health effects, how to improve monitoring and research and how to facilitate all such actions through Europe-wide coordination, sharing of information and cooperation in wider international efforts.

The 1992 United Nations Conference on Environment and Development recognized, in Agenda 21, that the unavoidable uncertainties associated with forecasting the potentially serious effects of global environmental change do not justify a wait-and-see approach. Rather, in such circumstances there is a strong case for prudent and precautionary action. This precautionary principle is manifestly relevant to global climate change and stratospheric ozone depletion because irreversible changes in the world's environment and climate systems may occur and because the associated health outcomes are potentially serious.

This report reviews the scientific evidence and policy implications for the potential effects of climate change on human health. The introduction describes the initiatives carried out on climate change and human health at both the global and European levels. The first chapter gives an overview of climate change and scenarios for the 21st century for Europe. The second chapter addresses the health effects of climate change, with particular attention to potential effects on thermal stress and vector-borne diseases. The third chapter reviews the health effects of stratospheric ozone depletion, particularly the effects of ultraviolet radiation on the immune system. Climate change may already be affecting human health, and a chapter on the early health effects of climate change is therefore included (early effects in this context are defined as effects anticipated within the next 10–30 years). The final chapters describe the actions necessary to reduce the health effects of climate change. Action includes the benefits for population health of policies to reduce climate change (mitigation) and of preventive action to reduce potential health effects of climate change (adaptation).

Introduction

The aggregate environmental impact of humanity has begun to change some of the earth's great biophysical systems. Such human-induced systemic environmental change is unprecedented. In particular, humans are altering the composition of the atmosphere. Changes in the lower atmosphere will cause long-term global climate change. Changes in the stratosphere increase the amount of harmful ultraviolet irradiation at the earth's surface.

The global environmental changes now taking place have common origins in the scale and type of both ongoing and escalating human economic activities. Population growth, the spread of industrialization and modern transport systems, increased consumerism and the emergence of a global economy are affecting the environment in ways that might not have been thought possible several decades ago. Concerted, coordinated action will be required to adapt to and mitigate the environmental and health consequences arising from these activities.

The natural world and the human economy are fundamentally connected. There can be no sustained economic development without an intact natural environment. In turn, human wellbeing and health depend fundamentally on those same two entities: nature's "goods and services" provide the world's life-support systems. Hence, the potential health consequences of global environmental changes need to be assessed. However, the links between these global change

processes and between their joint effects and the unknown future course of human social and technical development make estimating such effects complex and uncertain.

This report addresses the effects of both climate change and stratospheric ozone depletion on health. Both processes are linked by virtue of various chemical and physical relationships in the atmosphere, and these provide sufficient reason for considering stratospheric ozone depletion in the overall assessment of the health effects of climate change (Box 1 and Fig. 1).

Nevertheless, the essential difference between greenhouse gas accumulation and stratospheric ozone depletion should be borne in mind. Greenhouse gas accumulation increases the effect of radiative forcing on climate, whereas the destruction of stratospheric ozone by chemicals, including chlorine radicals, leads to increased ultraviolet radiation at ground level. These two distinct phenomena are members of a wider-ranging family of global environmental changes.

Box 1. The relationship between climate change and stratospheric ozone depletion

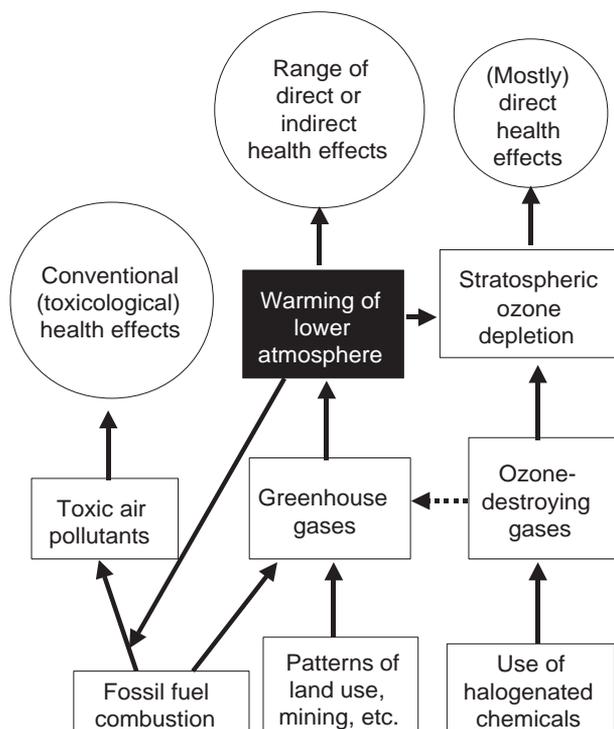
Climate and weather are often thought to be a product of the lower atmosphere, that is, the troposphere. Hence, including a section about the depletion of ozone in the stratosphere (middle atmosphere) in a report about global climate change may seem inappropriate. Stratospheric ozone destruction is essentially a separate process from greenhouse gas accumulation in the lower atmosphere, but there are several links between the two processes (1,2).

Several greenhouse gases, especially chlorofluorocarbons, also destroy ozone. Ozone is itself a greenhouse gas. Thus, ozone depletion has caused the stratosphere to cool since the 1970s. Ozone depletion in the lower stratosphere may have offset some of the positive radiative forcing that has occurred in recent decades (3).

Tropospheric warming apparently induces stratospheric cooling, which exacerbates ozone destruction (4). Climate change may therefore delay the recovery of the ozone layer.

Further, in a warmer world, patterns of personal exposure to harmful solar radiation (such as sunbathing in temperate climates) are likely to change. Ground-level ultraviolet radiation, while primarily determined by the extent of stratospheric ultraviolet absorption, is reduced by clouds and air pollution in the troposphere. As both depend on temperature, climate change may affect ground-level ultraviolet radiation.

Fig. 1. Interaction among climate change, stratospheric ozone depletion and air pollution



Source: McMichael, A., personal communication, 1998; WHO Regional Office for Europe (5).

INITIATIVES ON CLIMATE CHANGE AND HUMAN HEALTH

Growing awareness of climate change has stimulated several assessments of its likely effects on human population health. In particular, the Intergovernmental Panel on Climate Change has comprehensively reviewed the scientific literature on this topic in its Second Assessment Report (6,7) and the Third Assessment Report due out in 2001. The Intergovernmental Panel on Climate Change regional assessment also addressed the health effects for Europe (8). A task group convened by WHO, the World Meteorological Organization and the United Nations Environment Programme has comprehensively assessed the health effects of climate change (9). Because of

the scale of the analysis, the global and Europe-wide reviews do not provide insight into the extent of health effects related to climate change at the national or local level.

Countries that are signatories to the United Nations Framework Convention on Climate Change are obliged to undertake national assessments of the effects of climate change. However, few countries have conducted reviews of the potential health effects of climate change. These include Australia (10), Canada (11), Japan (12,13) and the United States (14). The Canadian Global Change Program, set up in 1992, also had a wider remit to identify and set priorities among research themes in health sciences related to global change.

Within Europe, national impact assessments covering various sectors such as agriculture and industry have been published for some countries (15–26). Only the United Kingdom's Climate Change Impacts Review Group (18), the Netherlands' national research programme on global air pollution and climate change (27) and the Czech Republic's climate change country study (22,28) have addressed the potential consequences for human health in any depth. A pilot study carried out by the Potsdam Institute about the potential effects of climate change on the Brandenburg area in Germany also addressed the health effects (21).

The European Commission has funded a project entitled A Concerted Action towards a Comprehensive Climate Impacts and Adaptation Assessment for the European Union (ACACIA). ACACIA reviews current knowledge of the potential effects of climate change in all European Union countries and specifies research needs for policy-making. ACACIA addresses environmental consequences as well as human health (29).

Research programmes on climate change and human health are limited in Europe. Projects are currently distributed unevenly between countries, with most of the recent scientific activity coming from the Netherlands and the United Kingdom. The Netherlands' national research programme has sponsored some research on climate change and health involving scientists from several other countries.

Government agencies and research institutions in the United States have taken a more active approach than those in Europe. In 1989, the Agency submitted a report to Congress addressing climate change and the health effects for the United States (14). The Agency is supporting a comprehensive research programme (Integrated assessment of public health effects of climate change for the US) that also supports policy development and analysis (30). The multi-agency US Global Change Research Group has finalized the US National Assessment: Potential Consequences of Climate Variability and Change. A national assessment synthesis team has integrated the results of regional and sectoral assessments. The health sector assessment addressed the following questions (31,32):

1. What is the current status of the nation's health, and what are current stresses on our health?
2. How might climate change affect (exacerbate or ameliorate) the country's health and existing or predicted stresses on health?
3. What is the country's capacity to adapt to climate change and variability, for example, through modifications to the health infrastructure, behavioral changes, or by adopting specific coping mechanisms? What are the negative health impacts, if any, of adapting? What are the co-benefits, if any? What are the economic and social costs/benefits?
4. What essential research gaps must be filled?

In 1996, WHO, the World Meteorological Organization and the United Nations Environment Programme tentatively established a collaborative network on climate change and human health, which was endorsed in 1997 by the United Nations Inter-Agency Committee on the Climate Agenda (a joint programme of international agencies concerned with climate issues). In May 1998, the World Health Assembly approved these initiatives and, in resolution WHA51.29, requested the Director-General to formalize these agreements and start collaborative actions in support of Member States.

Other international bodies are also developing a range of health-related interests and activities. For example, the International Human Dimensions of Global Change Programme coordinated several workshops in 1999 on the links between environment and health, in conjunction with the International Council of Scientific Unions and the International Geographical Union Commission on Health and Development.

In conclusion, no current activity on climate change by agencies in Europe is systematically addressing the human health effects of climate change in Europe. In particular, the issues of monitoring for early effects on health and the identification of specific public health action are not being addressed. In addition, a forum needs to be created to bring together the scientists working on research on health effects, so that they can benefit from shared knowledge and experience.

Climate change in Europe

Since the beginning of the Industrial Revolution (between about 1750 and 1800), emissions of greenhouse gases have been rising as a result of increased industrial and agricultural production and greater use of fossil fuel for domestic heating. The atmospheric concentration of carbon dioxide, the main greenhouse gas, has increased by 30% since pre-industrial times (3). Ice-core studies indicate that the atmospheric carbon dioxide concentration is now higher than at any other time in the past 160 000 years, that is, most of the lifetime of the modern human species.

The main effect of increased concentrations of greenhouse gases has been enhancement of the troposphere's heat-trapping capacity, a process known as radiative forcing. This results in the enhanced greenhouse effect, or global warming (Fig. 2). Greenhouse gas emissions are thus a matter of global rather than local concern.

CLIMATE IN EUROPE

Climate is determined by latitude or altitude and by a country's proximity to the ocean or an inland sea. In Europe, the annual temperature variation ranges from some 10 °C in coastal regions of Ireland and the United Kingdom to about 30 °C in Finland and the Russian Federation. Annual precipitation totals range from as low as 200 mm per year in Greece and southern Spain to over

Fig. 2. The greenhouse effect

Source: Houghton et al. (32).

2000 mm in coastal regions of Norway and at some locations in the Alps (8).

Although much of Europe lies in the northern latitudes, the relatively warm seas that border the continent give most of central and western Europe a temperate climate, with mild winters and summers. In the Mediterranean area, the summer months are usually hot and dry, with almost all rainfall occurring in winter. In eastern Europe (from central Poland eastwards), moderating drier conditions prevail, accompanied by a greater amplitude of annual variation in temperature: hot summers and cold winters. Northwestern Europe is characterized by relatively mild winters with abundant precipitation along the Norwegian coast and mountains, and much colder winters and generally drier conditions in Finland and Sweden.

The natural variability of climate is becoming better understood. There are natural oscillations within the climate systems, such as the North Atlantic Oscillation and the El Niño Southern Oscillation, which affect interannual variability. El Niño prominently influences weather patterns in much of the world but has only very weak effects in Europe. The North Atlantic Oscillation is characterized by changes in ocean circulation in the Atlantic and is a possible determinant of interdecadal and interannual variability in Europe (34).

OBSERVED CHANGES IN CLIMATE

There has been a clear worldwide warming trend. Spatially resolved reconstruction of annual surface temperature patterns over the past six centuries shows that, of the mean Northern Hemisphere temperatures, the years 1990, 1995 and 1997 were warmer than any other years since at least 1400 (35). Climatologists of the Intergovernmental Panel on Climate Change have confirmed that “the balance of evidence suggests a discernible human influence on global climate” (6).

Global temperatures have increased by about 0.6 °C in the last 100 years. In Europe, the warming trend is slightly greater, 0.8 °C (36,37). There have been clear differences within the European Region, and the warming trend has not been continuous throughout the century (38). In Greece and parts of eastern Europe, some stations show a cooling trend.

Warming over most of Europe was especially great between 1981 and 1990, with increases in annual mean temperature from 0.25 °C to 0.5 °C compared with the long-term average. The warming is most apparent in a band extending from Spain over central Europe into the Russian Federation. At some high-elevation sites in the Alps, temperature increases have been even more marked, exceeding 1 °C in the 1980s (39,40). Increases in minimum temperatures have been far larger than changes in maximum temperatures, and the observed temperature rise has been most marked during the winter period. This is consistent with evidence from other regions of the world, such as the United States (41).

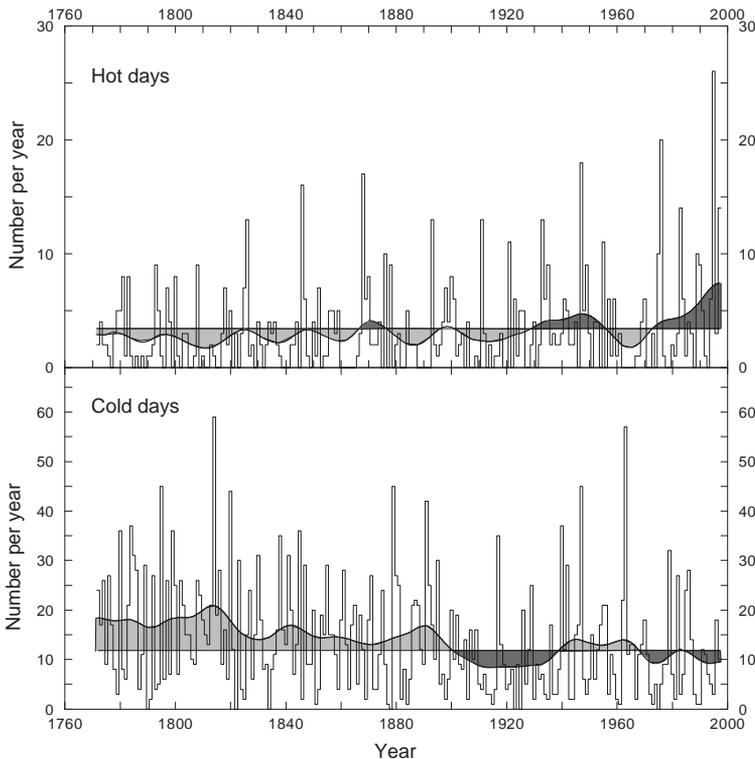
Precipitation has increased in the northern half of Europe, with increases ranging from 10% to 50%. By contrast, the region stretching from the Mediterranean through central Europe into the European part of the Russian Federation and Ukraine has experienced decreases in precipitation by as much as 20% in some areas (8). However, precipitation trends show complicated patterns in time and space.

Extreme events (such as heat waves, drought, heavy precipitation and storms) are, by definition, rare. A regional assessment for Europe concluded that there were insufficient time-series data to find trends in the frequency of extreme events (38). An assessment in the United States found that the frequency of extreme precipitation

events has increased in recent decades (42). The United Kingdom has one of the longest climate data series in the world – the Central England Temperature, which dates back to 1659. Daily data are available from 1772 and indicate that there has been a significant reduction in the number of “cold” days and a more modest increase in the number of “hot” days per decade, especially the last decade (Fig. 3). No long-term trends in annual precipitation or in the frequency of severe gales in the United Kingdom were found.

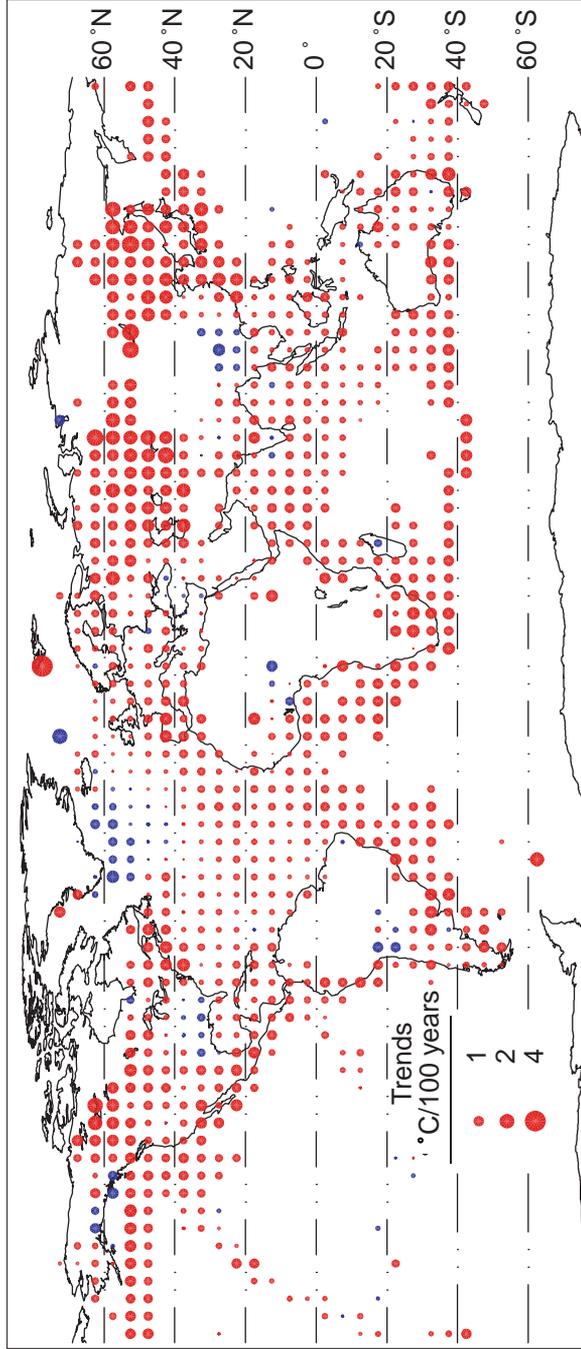
Ecological effects of the observed changes in climate have also become apparent in Europe (Fig. 4 and 5). Terrestrial plant growth

Fig. 3. Annual number of “hot” (mean temperature above 20 °C) and “cold” (mean temperature below 0 °C) days extracted from the Central England Temperature record for the period 1772–1997. The horizontal lines are the average temperature for 1961–1990, and the smooth curves emphasize 30-year time-scale variability.



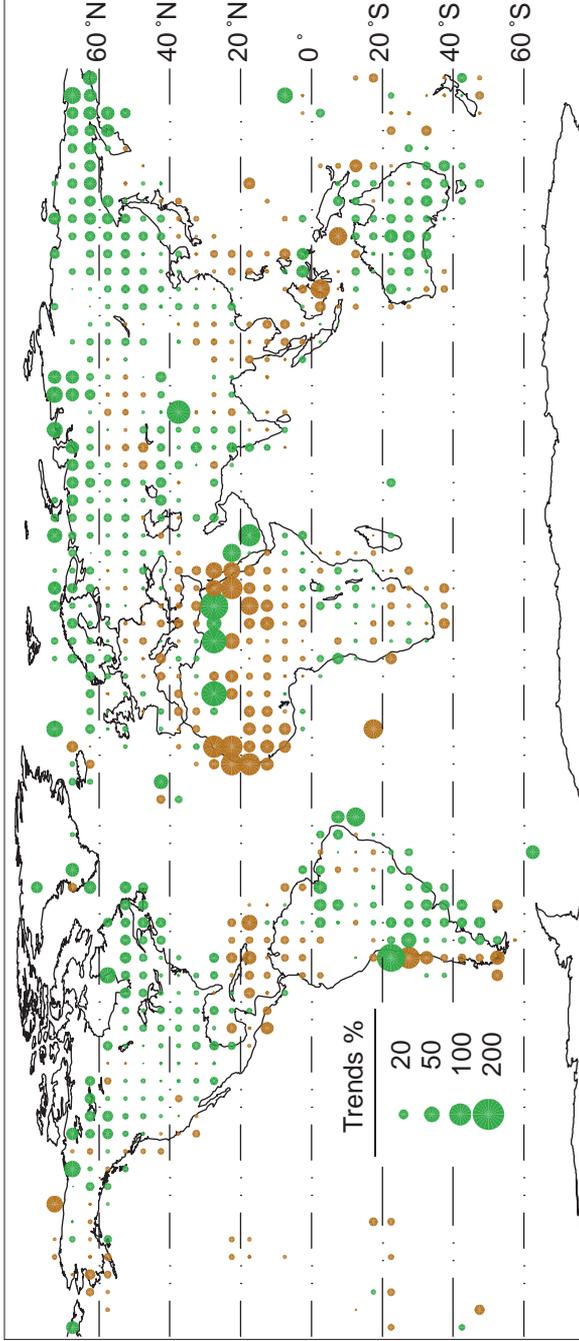
Source: Hulme & Jenkins (43).

Fig. 4. Magnitude of observed trends in annual average temperature for 1901 to 1996.
Red circles indicate increasing trends and blue circles indicate decreasing trends



Source: Beniston & Töl (8).

Fig. 5. Magnitude of observed trends in annual precipitation, expressed as the percentage change from the average annual precipitation for 1901–1995 relative to the average for 1961–1990. Green circles indicate increasing trends and brown circles indicate decreasing trends



Source: Beniston & Tol (8).

as measured by satellite (which gives an indication of photosynthetic activity) has increased in the past decade owing to the extension of the growing season associated with warmer summers (44). The greatest increase lies between 45 °N and 70 °N, which corresponds to most of Europe, where marked warming has occurred in the spring (45). An advance of the seasonal cycle by 7 days was observed between 1960 and the early 1990s. In northern latitudes (> 45 °N), the advance of spring is, on average, 12 days. The impact of climate change on mountain regions has also been observed. Increased species richness in plants at lower altitudes and an upward expansion of the species range at higher altitudes have been observed in the Alps (46).

PROJECTIONS OF FUTURE CLIMATE CHANGE

Projections of future climate change in Europe are derived from global climate model experiments. Climatologists of the Intergovernmental Panel on Climate Change have reviewed the results of these experiments for the recent global and regional assessments (6,8). The main findings for the European Region are summarized below.

An overall increase in average annual temperatures is projected, and this increase is likely to be greater in high (boreal) latitudes than in mid-latitude Europe. Summer temperatures will increase more than winter temperatures. Annual mean warming may be greater in eastern Europe than in southwestern Europe. Projected precipitation patterns are more uncertain. In general, continental regions may become dryer while maritime regions may become wetter. Models show an increase in precipitation for Europe as a whole due to a higher content of water vapour in the atmosphere. Winter precipitation will increase in high latitudes of Europe as well as at higher elevations in mountain regions such as the Alps. Precipitation is expected to decrease in the Mediterranean region and in central and eastern Europe.

A major source of uncertainty in these projections is the future concentration and distribution of aerosols. Aerosols are suspensions of particles in the atmosphere that occur naturally and as a result of human activities. By reducing solar radiation at ground level,

aerosols may offset some climate warming. The regional “negative” effect of sulfate aerosols in central Europe could offset some of the time-dependent “positive” effect of carbon dioxide on climate warming (47). The local effects of aerosols on precipitation patterns are also highly uncertain.

The output of the global climate model has very coarse geographical resolution. Climate scenarios that are more locally or nationally relevant are therefore produced via downscaling, whereby local climatological data are linked to the global climate model output. Several regional climate scenarios have been constructed for Europe, often for assessing the impact on one sector such as agriculture (48). The climate change scenarios that have been developed for the ACACIA project are presented in the context of natural climate variability (29).

The possibility of rapid climate change must also be considered. The climate system is not sufficiently understood to rule out a non-linear response to increasing greenhouse gas concentrations. An example is rapid change in the thermohaline circulation of the world’s oceans. The collapse of the thermohaline circulation in the North Atlantic (the “Gulf Stream”) would cause cooling over northwestern Europe, especially the United Kingdom. It has been suggested that, under certain climate regimes, the thermohaline circulation could switch from an “on” state to the colder “off” state, and there is some evidence that thermohaline circulation has weakened in recent years. Global climate model experiments in general show a weakening of the thermohaline circulation, but none indicates a dramatic collapse (43).

RISE IN SEA LEVEL

Global eustatic sea level is forecast to rise by 13–94 cm by 2100 due to climate change (3). In Europe, the regions vulnerable to increased flooding include areas already close to or below mean sea level. Vulnerable regions include:

- the coastline of the Netherlands
- the North Sea coast of Germany

- the Po River delta in Italy
- the Black Sea coast.

Areas with low intertidal variation are also more vulnerable to a rise in sea level. Such areas include the coastal zones of the Baltic Sea, the Mediterranean Sea and the North Sea/Atlantic coast. Many of Europe's largest cities are built on estuaries and lagoons (for example, Hamburg, London, St Petersburg, Salonica and Venice) and are therefore vulnerable to a rise in sea level (49).

Most low-lying areas in Europe are already protected from coastal flooding, and it is anticipated that countries will maintain and strengthen coastal defences, as it has been shown to be cost-effective to do so. However, changes in the nature and frequency of storm surges, especially in the North Sea, are likely to be of considerable importance for many low-lying coastal areas (8).

Nicholls & Mimura (50) have evaluated the policy implications of sea-level rise. The slow but steady degradation of the coastal fringe in much of Europe has gone largely unnoticed until recently. This trend is likely to continue and accelerate with a rise in the sea level. Some studies have estimated that future populations are at risk of flooding under the projected rise in sea level. Table 1 illustrates some assessments for Germany, the Netherlands and Poland.

The collapse and loss of most of the land-based ice of the West Antarctic Ice Sheet in a short time would entail a much more rapid rise in sea level than is currently forecast. Complete disintegration would raise sea levels by 4–6 metres (51). In addition to the possibility of rapid climate change, the potentially catastrophic risks of a rise in sea level must be considered.

IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Water is one of the main integrating factors for many environmental and economic systems in Europe. Under current climatic conditions, many areas have problems with water supply. Climate change is likely to enhance water-related stresses in these areas (8).

Table 1. Assessment of European population at risk of a rise in sea level^a

Country	Scenario for rise in sea level (metres)	People affected		People at risk ^b		Capital value loss		Land loss		Wetland loss		Adaptation and protection costs	
		No. of people (thou- sands)	Percent- age of total	No. of people (thou- sands)	Percent- age of total	Millions of US \$	Percent- age of gross national product	km ²	Percent- age of total	km ²	Millions of US \$	Percent- age of gross national product	
Germany	1.0	3 200	3.9	309	0.3	7 500	0.05	13 900	3.9	2 000	23 500	2.2	
Netherlands	1.0	10 000	67	3 600	24	186 000	69	2 165	6.7	642	12 300	5.5	
Poland	0.1	NA ^c	NA	25 (18) ^d	0.1 (0.05)	1 800	2	NA	NA	NA	700±4	2.1±0.01	
Poland	0.3	NA	NA	58 (41)	0.1 (0.1)	4 700	5	845	0.25	NA	1 800±8	5.4±0.02	
Poland	1.0	235	0.6	196 (146)	0.5 (0.4)	22 000	24	1 700	0.5	NA	4 800±400	14.5±1.2	

^a The results are for the existing coastal defences, and all costs have been adjusted to US dollars in 1990. The numbers of people affected and at risk, capital loss, land loss and wetland loss assume no human response. The adaptation and protection costs assume that protection is implemented in all areas except those with low population density. The adaptation and protection costs for Poland include capital and annual operating costs, whereas % of gross national product assumes that the costs are all incurred in one year.

^b People at risk are the number of people flooded by storm surges in an average year.

^c NA = not available.

^d Results in parentheses are people who will be flooded more than once a year.

Source: Nicholls & Mimura (50).

Areas vulnerable to water stress include:

- the Mediterranean region
- the Alps
- northern Scandinavia
- certain coastal zones
- central and eastern Europe.

In a warmer climate, water availability will be reduced by increased evapotranspiration. However, the response of hydrological systems depends on many factors, such as the distribution of precipitation and storage capacity. Many regions will experience a general decrease in runoff, although the change in runoff may range between -5% and $+12\%$. More droughts are expected in southern Europe (8). The potential for winter and springtime flooding may be greater in northern, northwestern and central Europe.

STRATOSPHERIC OZONE DEPLETION

Stratospheric ozone is thought to have begun forming several billion years ago as a result of the solar-powered destruction and recombination of oxygen. The natural concentration of stratospheric ozone is now maintained through the dynamic equilibrium existing between the production and destruction of ozone. The destruction is catalysed by trace amounts of hydrogen, nitrogen and halogen free radicals (especially chlorine and bromine). These free radicals occur naturally but, in recent decades, their concentration has been increased greatly by industrial activities. This has upset the equilibrium and led to a sustained decline in stratospheric ozone concentrations (2,52).

Stratospheric ozone depletion, as with greenhouse gas accumulation in the lower atmosphere, entails changes in the global climate. That is, although the gaseous emissions arise from diverse localized sources, in all continents, their environmental impact is of a diffuse globalized kind. Local emissions thus contribute to an integrated global change that has potentially serious consequences for human health.

Significant stratospheric ozone has been depleted, mainly at middle and high latitudes. Ozone depletion is more pronounced in winter and spring than in summer (53). These seasonal differences are more marked in the Northern Hemisphere, although, in general, ozone depletion is more pronounced in the Southern Hemisphere. The ozone over Europe has been depleted at approximately 3% per decade (54).

Stratospheric ozone shields the earth's surface from incoming solar ultraviolet radiation, which is harmful to all animals and plants. Increases in ground-level ultraviolet radiation are presumed to have occurred, especially at higher latitudes. However, such trends are difficult to ascertain because ultraviolet radiation has only recently begun to be measured at specific wavelengths. In addition, local factors such as clouds, aerosols and tropospheric ozone pollution can absorb or reflect ultraviolet radiation before it reaches the ground.

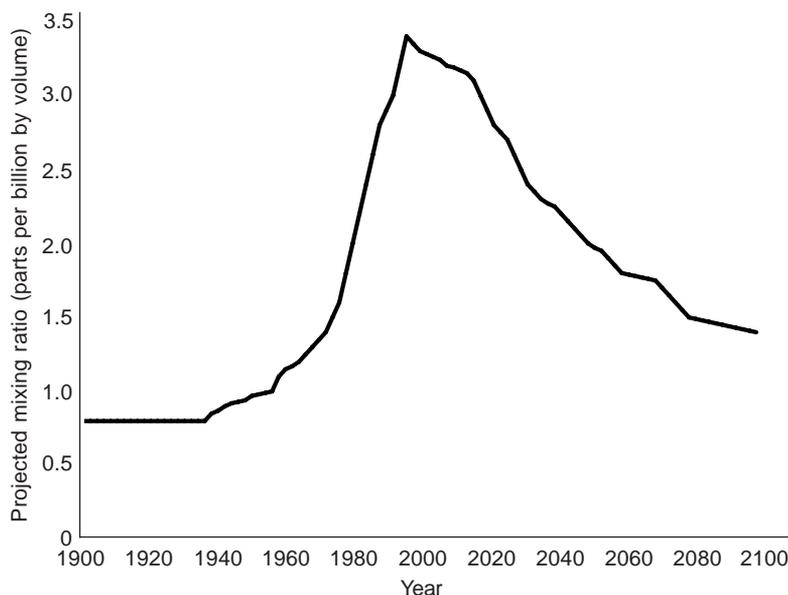
The United Nations Environment Programme (54) estimates that, from 1979 to 1992, biologically active radiation (the ultraviolet band that causes erythema) increased by the following:

- latitude 40–50°N: 3.5% per decade
- latitude 50–60°N: 5% per decade
- latitude 60–70°N: 4% per decade.

A phasing out of chlorofluorocarbons and other halocarbons was agreed to internationally in the Montreal Protocol on Substances that Deplete the Ozone Layer (1987), in its London (1990), Vienna (1995) and Montreal (1997) Amendments, and in the Copenhagen adjustment. Nevertheless, the concentration of stratospheric ozone is not expected to return to its normal level until the second half of the 21st century (Fig. 6). There is also evidence that some countries are not observing the global ban on chlorofluorocarbons, and illegal trade in these substances would compromise the recovery of the ozone layer.

Some recent evidence indicates that global warming may alter the atmospheric heat distribution so as to increase the cooling of the stratosphere (3). If such stratospheric cooling continues, the risk of

Fig. 6. Projections of ozone layer recovery under the Montreal Protocol and its Amendments



Note: The curve shows the projected mixing ratio (frequency of occurrence) of equivalent effective chlorine. It is based on the Protocol scenario in the 1998 World Meteorological Organization/United Nations Environment Programme ozone assessment, where one assumes the maximum emissions allowed within the protocols. Thus, a lower concentration in the figure means a higher projected concentration of ozone.

Source: preliminary data from the World Meteorological Organization 1998 ozone assessment (Velders, G., personal communication, 1999).

ozone depletion could continue to increase even after chlorine and bromine loading starts to decline. Shindell et al. (4) have estimated that the projected increase in greenhouse gas concentrations, and subsequent tropospheric heat-trapping, may increase polar ozone losses and thus delay the eventual recovery of the ozone layer.

2

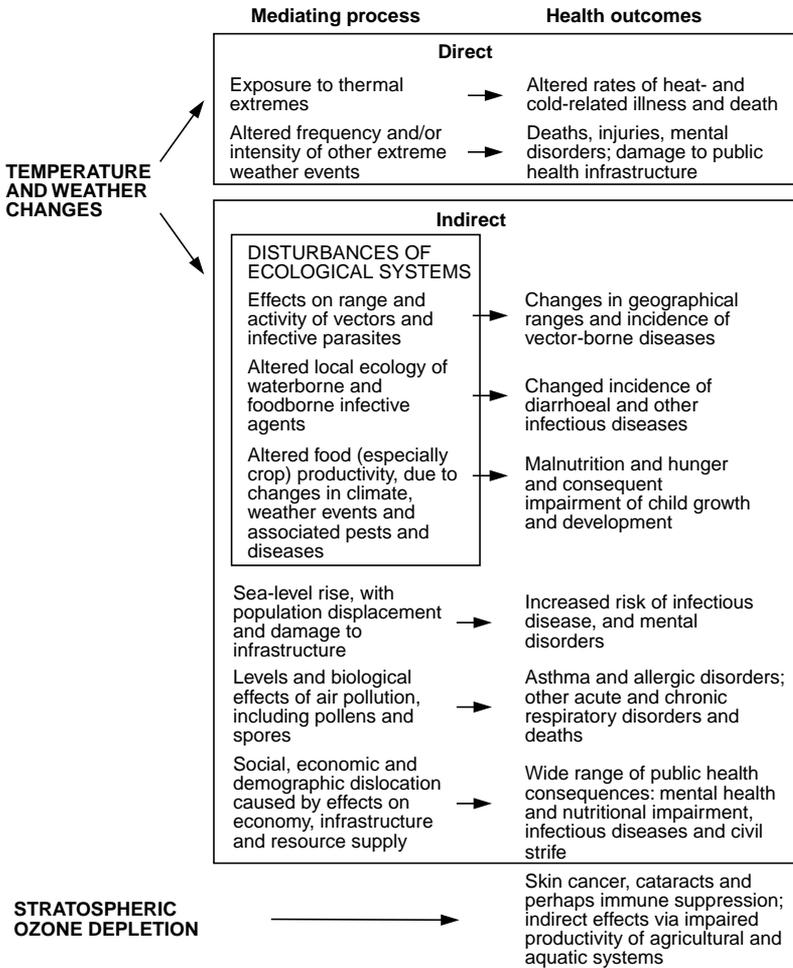
Effects on health of climate change in Europe

The major types of effect on human health of climate change and stratospheric ozone depletion are shown in Fig. 7.

A major problem with assessing future effects on health is the lack of research on most questions related to weather, climate and health. Indeed, the European Science Foundation has identified the effects of climate change as a research priority for environment and health in Europe (55).

The health impact assessment of global climate change has three distinctive features: (a) the large spatial scale; (b) the timing and the potentially long temporal scale; and (c) the level of complexity in the systems being studied. Further, health impact assessment must accommodate multiple uncertainties that compound across antecedent environmental and social changes (56). Some health effects of global climate change can be estimated by reasonable extrapolation of relatively simple models of cause and effect. For example, a change in ambient temperature is expected to change the number of temperature-related deaths. However, this may not be appropriate if the health risk concerned is linked to an ecological process. Infectious diseases are the most obvious example of a category of health problem with complex, ecologically based dynamics. Climate change effects on population health will reflect the conditions of the ecological and social environments in which humans live. Our health is profoundly affected by various natural systems such as the ecology

Fig. 7. The major effects of climate change and stratospheric ozone depletion on human health



Source: McMichael et al. (9).

of pests and pathogens, food supplies, water supplies, climatic conditions and weather patterns. In addition, climate change will not affect human health in isolation but will do so simultaneously with other ecological and demographic changes.

The most important research methods for forecasting future health effects are listed in Box 2.

Box 2. Most important research methods for forecasting future health effects

Analogue studies

- Analogue of a warming trend such as increased malaria in highlands, correlated with a trend in warming
- Analogue of extreme events such as assessment of the mortality impact of a heat wave
- Description of a basic or recurrent relationship between climate and health, such as interannual variation in malaria correlated with minimum November temperature (time-series data)

Predictive models

Empirical–statistical models

- Extrapolation of simple relationships between climate and disease, using univariate regression such as daily temperature and mortality
- Extrapolation of relationships between climate, vector and disease, using multivariate regression such as change of distribution of mosquitos with change in climate
- Extrapolation of relationships between climate and disease, using geographical information systems and statistical methods with spatially correlated data (generalized linear mixed model), such as mapping tick abundance with climate and other variables

Process-based models

- Models derived from accepted theory can be applied universally, such as vector-borne disease risk forecasting with a model of vectorial capacity

Integrated assessment models

- Multidisciplinary process-based models linked together horizontally or vertically, such as the effects of climate change on food supply and the risk of hunger

Source: McMichael et al. (57).

In epidemiological terms, the exposure to climate is either a direct measure of climate or weather (such as precipitation or temperature) or an indirect measure of the effects of climate on ecological or social systems that affect health. Such climatic exposures can be described in three broad temporal categories: long-term changes in means or norms; interannual or interdecadal variability; and isolated extreme events such as floods, droughts or storms. These categories are not independent. Extreme events are a function of variability in climate; for a given distribution, any shift in the mean will affect the frequency of extreme events.

Further, impact assessment of climate change must consider both the sensitivity and vulnerability of populations to specific health outcomes from climate change. In particular, the following aspects must be considered (6).

- How sensitive is a particular system to climate change: that is, how will the system respond to a given change in climate?
- How adaptable is the system: that is, to what degree are adjustments in practices, processes or structures of systems likely to affect either actual or projected climate change? Adaptation can be spontaneous or planned and can be carried out in response to or in anticipation of changes in conditions.
- How vulnerable is a system to climate change: that is, how susceptible is it to damage or harm? Vulnerability depends on both sensitivity and adaptability.

Given the uncertainty regarding the potential effects on human health, focusing on describing and reducing population vulnerability is essential.

THERMAL STRESS

Global climate change will be accompanied by an increase in the frequency of heat waves as well as warmer summers and milder winters. Even with no change in climate variability, an increase in mean temperatures would increase the number of summer heat waves (as currently defined) and reduce the number of cold spells in winter, for any given location. It has been projected that the equivalent of the extremely hot summer of 1976 in the United Kingdom, very unlikely in today's global climate (occurring once every 310 years), would occur every 5–6 years under the anticipated warmer climate of 2050 (58).

Although the mean annual temperature in Europe has increased (see Chapter 1), there is very little information on historical trends in extreme temperature episodes (heat waves or cold spells). An analysis of mean daily temperature records for Athens from 1983 to 1995 found no trend in the frequency of extreme events (59), but this is consistent with the lack of an observed warming trend in Greece.

The Central England Temperature series, however, does indicate an increase in the number of days with mean temperature over 20 °C in recent decades in central England.

Analyses of daily meteorological and mortality data in cities in Germany, Greece, the Netherlands and the Middle East show that, overall, mortality rises as summer temperatures increase (9,60–62). A U-shaped relationship has been widely observed between daily temperature and mortality in these cities and others in temperate regions. Thus, mortality is lowest within an intermediate “comfort” temperature range. In Greece, the relationship between temperature and mortality is a J-shaped curve, with lowest mortality observed when daily temperature is approximately 23 °C (59). A similar shape has been observed in the Netherlands, where average temperatures are lower than in Greece: the lowest mortality is at about 16 °C (62). The rate of increase in deaths as daily winter temperature decreases appears to be considerably less steep than that accompanying increasing temperatures in summer. Thus, mortality appears to be more strongly associated with temperature for heat-related deaths than for cold-related deaths, although the latter occur over a much greater temperature range.

For temperatures above the intermediate comfortable range, there is sometimes a threshold above which mortality increases markedly (63). The threshold temperature is related to population location. No threshold effect has yet been shown in any European population.

Episode or time-series analyses have been used to determine the acute effects of hot weather on populations. Daily mortality from all causes has been shown to increase during heat waves. Several episode studies have estimated the excess mortality associated with heat waves or acute heat episodes in Europe. Extremes of temperature cause physiological disturbance and ill health. Much of the excess mortality attributable to heat waves is from cardiovascular, cerebrovascular and respiratory disease, and these deaths are not certified as heat-related. It is therefore likely that, during hot weather, people suffering from such diseases experience additional health problems. Several studies have observed that elderly people are especially vulnerable to heat-related illness (64).

Many countries in Europe and elsewhere have an aging population. The European Commission has estimated that, by the year 2025, the population of adults aged 60 years and older in the European Union will increase by 37 million (50%) (65). The population vulnerable to thermal stress will therefore increase, and climate change will represent an additional burden on this population.

The effects of some heat episodes have been documented. For example, a heat wave in London in July 1976 was associated with a 15% increase in mortality, approximately 520 excess deaths (66). Another heat wave, in Belgium in 1994, was associated with a 13.2% increase in mortality in elderly people (67). A heat wave in July–August 1995 in London (immediately following the severe heat wave in Chicago in July 1995) was associated with a 15% increase in mortality (68).

A heat wave in Greece in July 1987 was associated with 2000 excess deaths in Athens (69). In all urban areas except Athens, a 32.5% increase in mortality was observed compared with the average mortality in July for 1981–1986 (61).

The magnitude of these effects still needs to be established in terms of years of life lost. The public health significance of the “harvesting” phenomenon needs to be determined. Harvesting means that a proportion of the deaths occur in susceptible frail or sick people who were likely to have died in the near future. More formal analysis and quantification of the harvesting effect is needed. Similarly, many questions about the interaction between high temperature and high concentration of air pollutants need to be resolved. Some of the heat waves described above were associated with major pollution episodes.

Physiological or “autonomous” adaptation will clearly mitigate some of the effects of future increases in the frequency or intensity of heat waves. People can become physiologically acclimatized to hot environments over a few days, but complete acclimatization to an unfamiliar thermal environment may take several years. There is some evidence of acclimatization to hot weather at the population level. For example, the impact of the first heat wave on mortality is often greater than that of subsequent heat waves in a single summer (9).

This effect can also be explained in part by the accumulating deaths of susceptible individuals: that is, towards the end of the summer there are fewer vulnerable people alive to die in a heat wave.

Much of the published research on climate change, temperature and mortality has focused on urban populations in North America (70). The knowledge base needs to be expanded by studying populations in Europe and the rest of the world.

Decreased mortality as a result of milder winters

In cold and temperate locations, the daily number of deaths increases as the daily wintertime temperature decreases (71,72). However, this rate of increase appears to be considerably less steep than the relationship between mortality and increasing temperature in the summer. Thus, countries in northern Europe have a clear seasonal variation in mortality, with death rates during the winter 10–25% higher than those in the summer (73). A study in Germany suggests that the increased use of central heating contributed to a steady decline in winter mortality from 1946 to 1995 (74).

In Europe, excess winter mortality is especially high in the United Kingdom (75,76). Indeed, relative excess winter mortality in the United Kingdom is approximately twice that in Scandinavian countries (72) and the Russian Federation (77). Social and behavioural adaptation to cold weather plays an important role in preventing winter deaths in high-latitude countries (78). The social or behavioural causes of the large excess mortality in winter in the United Kingdom are not well understood. Seasonal patterns of respiratory infections such as influenza are a significant cause of winter deaths, especially in epidemic years.

A direct increase in mean summer and winter temperatures associated with global climate change would mean fewer cold spells. Many countries with a high proportion of deaths in winter, such as the United Kingdom, are likely to experience a reduction in total winter mortality from milder winters under climate change. Langford & Bentham (79) estimated that 9000 wintertime deaths per year could be avoided by the year 2025 in England and Wales if the average winter temperature increased by 2.5 °C. A meta-analysis by Martens (80,81) estimated that an increase in global temperature of 1 °C could reduce winter cardiovascular mortality in Europe.

The recent Eurowinter Study (82) indicates that southern European populations are more vulnerable than their northern counterparts to short-term cold spells. Northern European countries may therefore be more vulnerable to an increase in heatwaves.

CLIMATE CHANGE AND URBAN AIR POLLUTION

Air pollution in urban areas is a major concern for environmental health in Europe, especially the effects of particulates (83). The dissemination and concentration of air pollutants (both particles and gases) depend on the prevailing weather conditions – air currents, temperature variation, humidity and precipitation. Large, slowly moving anticyclones may cover an area for several days, or a week or more, and give rise to conditions that readily allow pollutants to accumulate. Predicting the impact of climate change on average local air pollution concentrations is therefore very difficult. However, forecasts of climate change in the United Kingdom indicate an increase in anticyclonic conditions in summer (with a decrease in anticyclonic conditions in winter and spring), which would tend to increase air pollution concentrations in cities (43).

Secondary air pollutants, such as ozone, form through photochemical reaction. The rate of reaction therefore increases at higher temperatures and increased levels of sunlight. Other things being equal, climate change is expected to increase the average ambient concentrations of ozone and to increase the frequency of ozone pollution episodes.

The relationship between ambient temperature and ozone concentration is not linear. The US Environmental Protection Agency (14) estimated, based on data from the United States, that a 4 °C rise in mean annual temperature would cause a 10% increase in peak ozone concentrations. This would double the number of cities in the United States that currently exceed the national air quality standards for this pollutant. The model assumed that precursor vehicle emissions and other weather factors (such as the frequency of anticyclonic conditions) were unchanged. Increased ground-level ultraviolet radiation from stratospheric ozone depletion would also increase the concentration of tropospheric ozone.

Particulate matter and acid aerosols seem to be the main agents of acute effects of air pollutants on daily mortality. Ozone also adversely affects all-cause mortality in European cities (84). High temperatures also have acute effects on mortality, as discussed above. In most epidemiological studies of air pollution effects, temperature is treated as a confounder. Few studies have addressed the need to quantify and describe the separate effects on mortality and morbidity of air pollution and thermal stress. There is some evidence of a physiological synergistic effect between high temperatures and pollutants (61).

AEROALLERGENS

The production of many aeroallergens in the air, especially pollen, depends on the season of the year. The start of the grass pollen season in the United Kingdom can differ by about 32 days according to the weather in the spring and early summer. However, trends in pollen abundance are more strongly linked to land-use change and farming practices than to climate (85). Hay fever consultations have been shown to coincide with the onset and duration of the pollen season. Climate change is likely to change the seasonality of pollen-related disorders such as hay fever. However, it is not yet known whether this would entail a season of longer duration in addition to an earlier onset. There are local differences in sensitivity to different pollens, and this makes forecasting future health effects difficult.

As with many atopic diseases, the prevalence of hay fever is rising in Europe; the reasons are not clear but do not include climate change. Small changes in seasonality associated with climate change in the future may affect many people, and the aggregate impact of climate change on health might be significant.

The relationship between climate change and respiratory diseases is complex. Beggs & Curson (86) have developed an integrated environmental model of asthma. Climate change is likely to affect (indoor) cockroaches, moulds and fungi, damp in modern building materials, dust mites and (outdoor) pollen and air pollutants.

The seasonality of asthma is complex and not well understood. In the United Kingdom, for example, seasonal peaks vary between

age groups, suggesting different causative factors. Only about 10% of admissions to hospital due to asthma are estimated to be related to pollen allergens (87). Climate change may therefore affect the seasonality of some asthma cases.

EXTREME WEATHER

Climate change is likely to substantially affect human health by changing the magnitude and frequency of extreme weather events (88). Climate change projections are based on the anticipation of increasing means or norms. Global or regional climate models are not well able to forecast future climate variability, whether daily, interannual or interdecadal. Changes in extreme events are forecast by estimating changes in probability distributions.

The effects of natural disasters are increasing, both in Europe and globally (Table 2). An analysis by a reinsurance company (91) found a three-fold increase in the number of natural catastrophes in the previous 10 years compared with the 1960s. This trend primarily results from global trends, which affect population vulnerability rather than changes in the frequency of extreme events. The reasons for the observed increase in the effects of disasters in Europe are:

- increasing concentrations of people and property in urban areas;
- settlement in exposed or high-risk areas such as flood plains and coastal zones; and
- changes in environmental conditions, such as deforestation increasing the risk of flooding.

Several assessments for Europe have concluded that the risk of river flooding will increase. The hydrological cycle will be more intense in a warmer climate. This will entail more episodes of heavy rainfall and an increased risk of flooding and landslides. Droughts may increase in arid and semi-arid regions, where higher rainfall is not able to compensate for the greater evapotranspiration. The increased risk of flooding under climate change has been assessed regionally and nationally (8). Coastal flooding will also increase if the sea level rises unless sea defences are upgraded appropriately (50).

Table 2. Serious floods in Europe in the 1990s

River(s)	Year	Fatalities	Damage costs	Remarks
Tazlau (Romania)	1998	107	€ 50 million	Breakdown of the Tazlau dam
Ouveze (France)	1992	Nearly 100	Not known	Camp site
Rhine/Meuse	1993/1994	10	€ 1100 million	
Po	1994	63	€ 10 000 million	Catchment area covered by up to 60 cm of mud
Rhine	1994/1995	None	€ 1600 million	Evacuation of 240 000 inhabitants in the Netherlands
Glomma and Trysil River Basins (Norway)	1995	None	€ 300 million	Largest flood since 1789
Pyrenean River	1996	85	Not evaluated	Camp site
Oder, Labe, Vistula and Morava	1997	95	€ 5900 million	195 000 people evacuated; great material loss
Lena (Sakha, Russian Federation)	1998	15	1300 million roubles	51 295 people evacuated, complete disruption of transport system, great material loss

Source: European Environment Agency (89), adjusted by Menne et al. (90).

Floods are the most common trigger for a natural disaster. Recent devastating floods in Europe affected the Czech Republic, France, Germany, Italy, the Netherlands, Norway, Poland, Romania and the Russian Federation.

Except for those generated by dam failure or landslides, floods are climatic phenomena influenced by geology, geomorphology, relief and soil and vegetation conditions (92). Floods may also be intensified by human alteration of the environment such as the drainage patterns from urbanization, agricultural practices, deforestation and the use of improper construction techniques. Weather and hydrological processes can be fast or slow and can produce flash floods or more predictable, slowly developing river floods.

Flash floods have two characteristics. First, they follow a causative event (such as excessive rainfall in a catchment system or sudden release of water in a dam) within minutes or hours and with high velocity flows and great volumes of water. Second, with flooding commonly lasting less than 24 hours (93), they are accompanied by an extremely short warning and response time, with potential for great loss of life (94). Riverine floods usually result from rainfall or the melting of snow and ice, and the levels rise more slowly.

The effects of floods on health

The effects of floods on human health may be divided into direct effects or indirect contributory effects as a result of being flooded. Direct effects on health are those caused by the floodwaters. Indirect effects are those caused by other systems damaged by floods.

The primary cause of death due to floods is drowning. It can also be caused by various combinations of trauma and hypothermia with or without submersion. The proportion of those surviving floods who require emergency medical care is reported to vary between 0.2% and 2%. Most injuries requiring urgent medical attention are minor, and include lacerations, skin rashes and ulcers. Nevertheless, flood-associated lacerations are frequently contaminated by the flood water (95).

Much of the effect of flooding on mortality and ill health may be attributable to the distress and the effects of the event on people's mental state. Following flooding in Bristol in the United Kingdom, primary care attendance rose by 53% and referrals and admissions to hospital more than doubled (96). Similar mental health effects were found following floods in Brisbane in 1974 (97). An increase in mental symptoms and post-traumatic stress disorder, including 50 flood-linked suicides, was reported in the two months following the major floods in Poland in 1997 (98).

During and following both catastrophic and noncatastrophic flooding, health is at risk if the floodwaters become contaminated with human or animal waste. In industrialized countries, like many in Europe, the risks of disease due to flooding are greatly reduced by a well maintained sanitation infrastructure. In addition, public health measures undertaken during a flood have often been successful in

preventing outbreaks. Such measures include monitoring and surveillance activities to detect and control outbreaks of infectious disease.

From a public health viewpoint, floods may disrupt water purification and sewage disposal systems, cause toxic-waste sites to overflow, or dislodge chemicals stored above ground. In addition, make-shift evacuation centres with insufficient sanitary facilities may become substantially overcrowded. The combination of these events may contribute to increased exposure to highly toxic biological and chemical agents. Examples include the potential for waterborne disease transmission of such agents as enterotoxigenic *Escherichia coli*, *Shigella*, *Salmonella* and hepatitis A virus.

An epidemic of leptospirosis was associated with floods in Ukraine in 1997, and flood-related outbreaks of epidemic nephropathy have also been reported in the territory of the former Socialist Federal Republic of Yugoslavia (99). Analysis of surveillance data following the major floods in 1997 suggests that the number of cases of leptospirosis increased in the Czech Republic (100). Flooding in Lisbon in 1967 was linked with a small outbreak of leptospirosis; a total of 32 cases was estimated on the assumption that only one third of cases are reported (101).

A number of studies have established a link between dampness in the home, including occasional flooding, and a variety of respiratory symptoms. For example, a study in Canada found that flooding was significantly linked to the occurrence of coughing, wheezing, asthma, bronchitis, chest illness, upper respiratory symptoms, eye irritation and nonrespiratory symptoms in childhood (102). In 1998, the river Lena in the northeastern republic of Sakha in the Russian Federation flooded massively, and one of the most serious problems reported was respiratory tract infection. Very little is known about the occurrence of other diseases, such as skin diseases, and links to flooding.

FOODBORNE DISEASES

The epidemiology of foodborne diseases is rapidly changing as newly recognized pathogens and well recognized pathogens increase in prevalence or become associated with new kinds of food. Different

factors contribute to these changes, one being the fluctuation in ambient temperature (103). The pattern is often seasonal, with cases of foodborne disease peaking in the summer months. Another risk factor is incorrect food-related behaviour, such as inadequate refrigeration, the use of unsafe raw materials and inadequate handling (103). However, inappropriate food-related behaviour combined with warmer springs and summers and milder winters may contribute to the increasing incidence of foodborne diseases.

A study of reported cases of foodborne illness in the United Kingdom for the period 1982–1991 found a strong relationship between incidence and temperature in the month preceding the illness, but not between rates of foodborne illness and temperature in the month in which illness occurred (104). This relationship was subject to a threshold effect: below 7.5 °C no relationship was observed but above this temperature the relationship was very strong. Assuming maintenance of current systems, it would appear that the incidence of food poisoning will rise in the United Kingdom during the next half century in response to temperature change. Increases in cases of food poisoning are estimated to be between 5% and 20% per month by 2050, with the highest proportional monthly increases predicted to occur in spring and autumn (104).

WATER-RELATED DISEASES

Water-related diseases can be divided into four categories (105).

- Faecal–oral diseases can spread via water or food contaminated with faecal material. They include diseases transmitted by direct ingestion of the pathogen and those spread because of a lack of water for personal hygiene. Examples include cholera, typhoid, hepatitis A and diarrhoeal diseases.
- Certain diseases that spread from one person to another can be exacerbated by lack of water for personal hygiene. These include infections of the skin and eye (such as scabies and trachoma) and those carried by lice (such as epidemic typhus).
- Water-based diseases can be caused by pathogenic organisms that spend part of their life cycle in aquatic organisms and are often associated with standing water. In Europe, an example of such a disease would be cercarial dermatitis.

- Diseases can be spread by water-related insect vectors. These vectors breed in water and include mosquitos, which transmit malaria and dengue.

Waterborne outbreaks of disease are widespread throughout the WHO European Region. Since the early 1980s, organisms that had not previously been regarded as waterborne agents have been identified in outbreaks in the European Region: *Campylobacter*, Norwalk virus, *Giardia* and *Cryptosporidium*. In about 60% of the outbreaks, the causative agent is not identified (106).

Faecal–oral diseases are still a major public health problem in Europe. More than 12% of the population in the WHO European Region does not have access to safe drinking-water (83). The majority of these people live in countries in the eastern part of the Region, where acute diarrhoeal diseases are still a major cause of childhood sickness. Two thirds of infant deaths in Azerbaijan, Armenia, Belarus, Georgia and the Republic of Moldova are caused by acute respiratory infections and diarrhoeal diseases. Cholera outbreaks continue to be reported from Albania, the Russian Federation and Ukraine. Hepatitis A is endemic and has a high prevalence in central and eastern Europe and the countries of the former USSR.

The most significant waterborne disease associated with the public water supply in western Europe is cryptosporidiosis. *Cryptosporidium* is an intracellular parasite of the gastrointestinal and respiratory tracts of numerous animals. *Cryptosporidium* oocytes can survive several months in water at 4 °C and are among the most chlorine-resistant pathogens. When contamination occurs, it has the potential to infect very large numbers of people. This is illustrated by an outbreak in 1993 in Milwaukee, which affected more than 400 000 people (107). About 5000 cases of cryptosporidiosis are reported each year in the United Kingdom. A study in the United States has suggested a link between episodes of heavy rainfall and outbreaks of this disease, as the capacity of conventional filtration plants is often exceeded under such conditions (108).

Cercarial dermatitis is a water-based parasitic disease that is emerging in Europe (109). The intermediate hosts are snails of the genus *Lymnaea*, the abundance of which may increase in a warmer climate.

Controlling the disease is difficult, requiring strict maintenance of water bodies and the use of molluscicides.

The complex relationships between human health and problems of water quality, availability, sanitation and hygiene are extremely difficult to quantify. For example, there are multiple routes of faecal–oral transmission. Predicting the potential effects of climate change on water-related diseases therefore becomes even more difficult. Further, any attempt to do so must take into account water-management practices, the growth in demand for water and a number of other factors not related to climate.

Climate change could have a major impact on water resources and sanitation in situations in which water supply is effectively reduced. This could in turn reduce the water available for drinking and bathing and lower the efficiency of local sewage systems, leading to an increased concentration of pathogenic organisms in raw water supplies. In addition, water scarcity may necessitate using poorer-quality sources of fresh water, such as rivers, which are often contaminated. All these factors could result in an increased incidence of diarrhoeal diseases.

VECTOR-BORNE DISEASES

Several important diseases are transmitted by vectors such as mosquitos, ticks or rodents. These vector organisms are sensitive to climatic conditions, especially temperature and humidity. Thus, the distribution of vector-borne diseases is restricted by the climatic tolerance limits of their vectors. Further, biological restrictions that limit the survival of the infective agent in the vector population also determine the absolute limits for disease transmission.

Climate plays a role in determining the distribution and abundance of insect species, either directly or indirectly through its effects on host plants and animals. Climate change is therefore expected to affect the geographical range and seasonal activity of many vector species (9). This sensitivity is reduced, however, if the vector is adapted to an urban or domestic environment. In addition, land-use change is also likely to be the major factor in future changes in vector distribution and abundance in Europe.

The effect of climate change on actual human cases of disease is much harder to forecast than changes in the distribution of the vectors. The life-cycle stages of the infecting parasite within the vector are also limited by temperature. A minimum temperature threshold is required to complete the extrinsic incubation period. These limits will expand northwards with climate change.

The current main vector-borne diseases in Europe can be classified as:

- formerly widespread, such as malaria, which is currently epidemic in Armenia, Azerbaijan, Tajikistan, Turkey and Turkmenistan;
- locally endemic, such as leishmaniasis in southern France, Italy, Portugal and Spain, and tick-borne encephalitis in southern Scandinavia and central and eastern Europe; and
- emerging diseases, such as Lyme disease, which is prevalent over much of Europe.

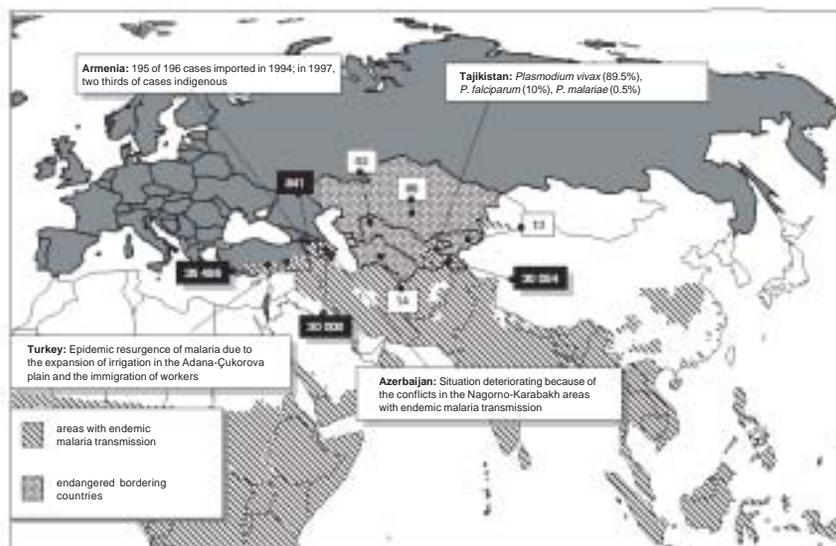
These diseases are addressed in more detail below.

Malaria

Malaria is the most important vector-borne disease worldwide, and has also become a growing problem in Europe in recent years (Fig. 8 and 9, Table 3). Five of the 51 countries in the WHO European Region currently have epidemics: Armenia, Azerbaijan, Tajikistan, Turkey and Turkmenistan. In 1994, the population of these countries was estimated at 82 million, and 88 313 cases of malaria (passive case detection) were reported. A recent assessment in Tajikistan found that the incidence of malaria was 22 per 1000 population, and in one district about 15% of these cases were caused by *Plasmodium falciparum* (110). This incidence is 10 times that reported using routine or passive surveillance.

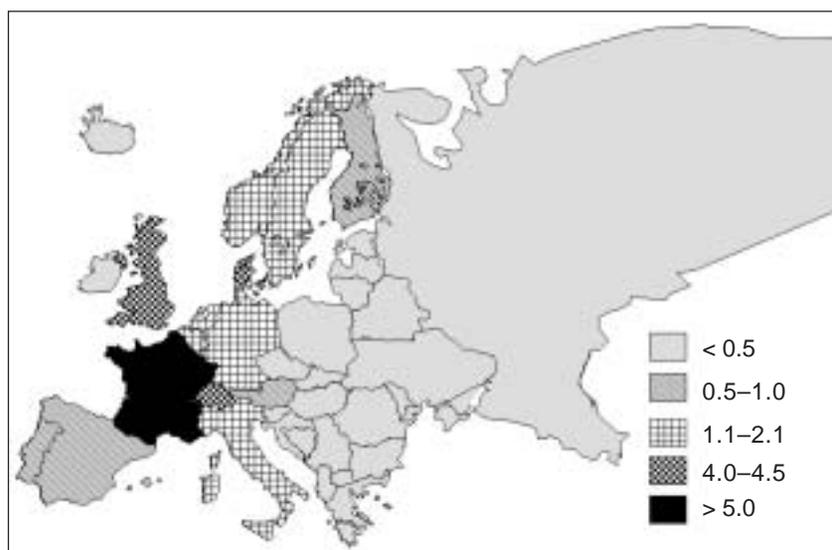
Control measures, both before and during the global effort by WHO to eradicate malaria, sharply reduced the incidence of the disease in Turkey. By 1971, *P. falciparum* had been eradicated and only 2046 cases of *P. vivax* were recorded, most of which were found in a small area in southeastern Anatolia. From the late 1960s, however, vigorous expansion of irrigation in the Adana-Çukorova plain allowed the main vector, *Anopheles sacharovi*, to proliferate. Extensive

Fig. 8. Cases of malaria in the WHO European Region in 1997



Source: WHO Regional Office for Europe.

Fig. 9. Imported malaria cases per 100 000 population in nonendemic countries in Europe in 1997



Source: WHO Regional Office for Europe.

Table 3. Malaria outbreaks in the European Region

Country	Year	Total no. of cases	No. of cases with confirmed local vector transmission	Main vector	Parasite
Azerbaijan	1996	13 135	13 135	<i>An. sacharovi</i>	<i>P. vivax</i>
Tajikistan	1997	30 054	30 054	<i>An. superpictus</i> <i>An. pulcherrimus</i>	<i>P. vivax</i> <i>P. falciparum</i>
Turkmenistan	1998	137	129	<i>An. superpictus</i>	<i>P. vivax</i>
Ural Mountains (Russian Federation)	1996	12	2	<i>An. messae</i>	<i>P. vivax</i>
Uzbekistan	1983–1992	755	39	<i>An. superpictus</i> <i>An. pulcherrimus</i>	<i>P. vivax</i>
Turkey	1997	35 456	35 446	<i>An. sacharovi</i>	<i>P. vivax</i>

Source: WHO Regional Office for Europe.

agricultural development also attracted a steady flow of migrant labour from the areas of southeastern Anatolia that had malaria. Inevitably, malaria transmission quickly increased and, by 1977, more than 100 000 cases of *P. vivax* malaria were reported from Adana and the adjacent provinces of Hatay and İçel (88.1% of all cases). Concentrated efforts entailing considerable cost succeeded in reducing the number of cases countrywide to 15 000 by 1989. This could not be sustained, however, and the malaria situation deteriorated once more, the vast majority of cases being reported from southeastern Anatolia.

One of the largest development projects in the eastern Mediterranean area is under way in this region. The Southeastern Anatolia Project involves the construction of 13 dams, 19 hydroelectric power plants and an irrigation network for 1.7 million hectares of land. This irrigation project and social changes in the region have contributed to the increased risk of malaria now facing Turkey. In 1990, only 8886 cases were reported from the entire country versus 12 218 in 1991, 18 676 in 1992, 47 210 in 1993 and 84 345 in 1994. In recent years, the Government has renewed its efforts to fight malaria, incorporating them into the Southeastern Anatolia Project with support from the United Nations

Development Programme and WHO. In 1998, 36 461 cases were reported, 87.1% from southeastern Anatolia, 8.7% from the Adana area and 4.2% from other areas of Turkey.

Local transmission has been reported recently in Turkmenistan, Uzbekistan and the Ural Mountains (Russian Federation) and is thought to have originated from cases imported from nearby Afghanistan, Azerbaijan or Tajikistan (111). Malaria was probably imported into the countries of the former USSR as a result of war in Afghanistan and Azerbaijan and the associated population movements across national borders.

Governments were unable to afford insecticides or to manage appropriate vector control programmes. Consequently, mosquito densities increased and enhanced the probability of local malaria transmission of imported parasite strains. There is now a risk that malaria may be introduced to surrounding countries where potential malaria vectors are present. The importation of cases into Bulgaria and Romania from the countries of the former USSR is now increasing, and this increases the risk of local transmission. This risk of the reintroduction of malaria to the eastern part of the European Region could be increased by climate change.

Concomitant with increases in the volume of international travel, the number of imported cases of malaria has increased steadily in all countries in Europe. It has been estimated that, in the period 1985–1989, 16 000 people living in Europe were infected with malaria while travelling, but this number is likely to be an underestimate (112). In 1994, 17 deaths from malaria were recorded among European travellers.

Data from the United Kingdom (113) show that cases of imported malaria rose from 66 in 1966 to 2500 in 1996 – nearly a 40-fold increase, some of which is explained by the increase in the volume of international travel. The majority of imported cases originated in Africa. Most imported cases are caused by *P. vivax*, but the prevalence of imported falciparum malaria increased by some 15% during 1977–1986 in the United Kingdom (114). Since 1988, *P. falciparum* has accounted for more than half the cases (113). In 1997, a rise in cases imported from East Africa was noted from the malaria epidemics triggered by heavy rains in Kenya and Uganda. Other European countries with imported malaria are France, Germany and Italy.

Airport malaria occurs when vectors that have arrived on aircraft transmit the disease to people. People who work and live in or near airports are most at risk. Since 1969, 63 cases of airport malaria have been reported in western Europe, and most were caused by *P. falciparum*. Some tropical vectors can survive in the low temperatures of a luggage compartment and are therefore ideal for overseas transportation. For example, *An. arabiensis* from Madagascar overwinters in altitudes above 1500 m (115). Six cases of airport malaria were described in and around Charles de Gaulle Airport in Paris during the very hot summer of 1994 (116). Consequently, aircraft are now sprayed regularly with residual pyrethroids.

The six major vectors of European malaria – *An. atroparvus*, *An. labranchiae*, *An. maculipennis*, *An. messeae*, *An. sacharovi* and *An. superpictus* – are distributed throughout the continent. Jetten & Takken (114) have reviewed the published data on vector distribution, but many of these are probably out of date. The current distribution of malaria vectors in Europe needs to be mapped.

Transmission has been reported from Greece, Italy, Portugal and Spain (114). The population of *An. labranchiae* has recently increased in Italy because of large-scale rice cultivation. The prevalence of *An. messeae* has increased in the Russian Federation (Russian Plains, lower Volga, Crimea and the Ural Mountains) as a result of environmental changes such as eutrophication of lakes and ponds and warmer springs. Consequently, local transmission of *P. vivax* malaria has occurred in these regions (111).

Introduced, indigenous or autochthonous malaria is defined as an infection transmitted by a local *Anopheles* mosquito in a country that has achieved eradication (117). This is only possible when the following conditions are fulfilled:

- a sufficient density of local *Anopheles* mosquitos;
- a sufficient incidence of imported malaria;
- compatibility between the local vectors and the imported *Plasmodium* strain; and
- optimal climatic factors allowing a complete sporogonic cycle in the vector.

In western Europe, several cases of local transmission have also been reported. In Corsica in 1970–1971, *P. vivax* caused an autochthonous outbreak of malaria that infected both tourists and local residents (117). In 1997, a woman with no history of travel or blood transfusion, living far from the nearest airport, was diagnosed with *P. vivax* infection in Maremma, Italy. Investigations revealed that the parasite had been transmitted by *An. labranchiae*, the previous vector of malaria in Italy. The vector had acquired the parasite from a neighbour infected with *P. vivax* during a trip to India (118). This case illustrates the ease with which malaria can be transmitted when the above conditions are fulfilled.

There is concern that imported cases may lead to the reintroduction of *P. falciparum* malaria in Europe. Some local mosquitos were clearly once vectors of the European strain of *P. falciparum*, but it is not known whether they also are capable of transmitting its tropical strains. It has been shown that *An. atroparvus*, *An. messeae*, *An. sacharovi* and *An. labranchiae* are refractory to strains of *P. falciparum* from India, Kenya and the Malayan peninsula (119–122). However, the suspected vector of malaria in the United Kingdom, *An. plumbeus*, has been infected with *P. falciparum*, although it is not yet clear whether the mosquito is able to transmit the parasite (121). These studies therefore suggest that, in general, European vectors of malaria are not able to transmit tropical *P. falciparum* malaria. Only after a long period of selection would the tropical parasites become adapted to transmission by *Anopheles* spp. in Europe.

The risk of reintroduction of vivax malaria in western and central Europe under conditions of climate warming must be addressed. *P. vivax* is present in the eastern part of the European Region and has been responsible for recent local cases (described above). The vectors *An. atroparvus*, *An. sacharovi* and *An. messeae* are susceptible to *P. vivax* from Africa, Asia and South America (119). There is a risk that *P. vivax* is homogeneous in its adaptation to vectors. This would mean that the parasite could be imported from any endemic country.

Although climate warming is predicted to continue, it is unlikely to have more than a very limited role in the countries of the European Region. Milder winters could increase the potential for malaria

transmission in a season, but they would negatively affect the geographic distribution of most palaeartic malaria vectors by reducing the extent and presence of their breeding places. Nevertheless, more research and accurate models are needed to predict the effects on malaria of climate change.

Leishmaniasis

Leishmaniasis occurs in two forms, both of which are present in Europe (123). Both the visceral and the cutaneous form are caused by *Leishmania donovani infantum*. Cutaneous leishmaniasis cases have been reported from France, Italy, Spain and countries in central Asia. Zoonotic visceral leishmaniasis (also known as kala-azar) is endemic in all countries bordering the Mediterranean Sea. It has become an important co-infection with HIV in France, Italy and Spain (124).

Leishmaniasis is transmitted by sandflies, which inhabit semi-arid regions. Sandflies are very susceptible to DDT and were significantly reduced in Europe following malaria eradication campaigns in the 1960s and 1970s. As vector control declined, however, vector densities increased. The reservoirs or intermediate hosts of the pathogen are rodents, foxes and domestic or stray dogs. In endemic urban areas, the black rat may play a role in transmission.

There are two sandfly vectors of leishmaniasis in Europe. *Phlebotomus perniciosus* is distributed throughout the Mediterranean region (France, Portugal, Spain, Tunisia and Turkey). *Ph. perfiliewi* has more of a northern distribution, extending from Cyprus, Greece and Malta (but not North Africa) to eastern Europe (Azerbaijan, Hungary, Romania and the Federal Republic of Yugoslavia).

Sandfly vectors are not actively controlled in Europe. Cutaneous leishmaniasis and zoonotic visceral leishmaniasis are controlled by treating human cases. In Europe, canine leishmaniasis is a major veterinary problem, and a dog vaccine is considered highly desirable. A vaccine is currently being developed for use in humans.

The distribution of zoonotic visceral leishmaniasis in Europe is probably limited by the distribution of the sandfly vectors. Climate change is likely to extend the range of the sandfly vectors northwards.

One study on leishmaniasis in Italy (125) indicates that climate change may extend the range of *Ph. perniciosus* but reduce that of *Ph. perfiliewi*. Higher temperatures would accelerate the maturation of the protozoal parasite, thereby increasing the risk of infection (126). An important vector in southwestern Asia (including Israel), *Ph. papatasi*, has been mapped using climate and satellite data (127). It has been estimated that a rise in temperature of 3 °C would greatly increase both the geographical and seasonal distribution of *Ph. papatasi* in this region (128).

There is a risk that zoonotic visceral leishmaniasis will extend further northwards in Europe with climate change. Several imported cases of canine leishmaniasis are reported in Austria, Germany and Switzerland every year (129). Thus, imported cases are a potential source of the pathogen if the vectors expand northwards with climate change.

Dengue

Dengue is the most important arboviral disease of humans. Dengue and the related syndromes of dengue haemorrhagic fever and dengue shock syndrome are a leading cause of child mortality in Asia. The incidence and geographical distribution of dengue have increased dramatically since the late 1950s and, in particular, over the last decade. The reasons include the combined effects of several factors: unprecedented population growth and unplanned and uncontrolled urbanization producing a large at-risk population; increased air travel resulting in the rapid spread of dengue viruses to new areas by the movement of infected people; and a lack of effective control of *Aedes aegypti* mosquitos that have flourished under these conditions (130). *Ae. albopictus* has been successfully introduced to areas where it was never present before.

Dengue is not now present in Europe, although in the late nineteenth century and up until 1948 it was reported from Crete, Egypt, Greece, Lebanon, Palestine, Syria and Turkey (131). In the past decade, cases have been reported from Djibouti, Saudi Arabia and possibly Yemen. Dengue is included in this report because there is a risk it may be re-introduced into the European Region.

The principal vector of dengue is the mosquito *Ae. aegypti*, which is adapted to urban environments. Historically, *Ae. aegypti* has been

recorded in several European and North African countries in the Mediterranean region, including France and Portugal. The distribution of *Ae. aegypti* closely follows the 10 °C winter isotherm (132), and currently includes sub-Saharan Africa and some countries bordering the Persian Gulf.

Another dengue vector, *Ae. albopictus*, is currently extending its range in Europe. It was introduced into Italy in 1990 and has been reported from 10 regions and 19 provinces since. It has also been separately reported from Albania since 1979. The climatic limits to the distribution of *Ae. albopictus* are a monthly mean winter temperature below 0 °C, a mean annual rainfall exceeding 50 cm and a mean summer temperature exceeding 20 °C. Countries in the European Region that currently meet such criteria include Albania, France, Greece, Portugal, Spain, Turkey and the Federal Republic of Yugoslavia (133).

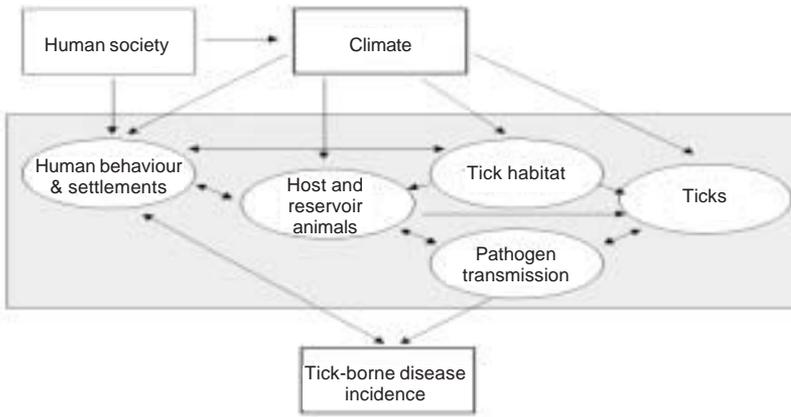
Epidemiological studies have shown that temperature is a major factor in dengue transmission in urban areas (9). An increase in global mean temperature of 2 °C by 2100 can potentially increase the latitudinal and altitudinal range of transmission of the disease. In temperate locations, climate change would increase the length of the transmission season (134).

Focks et al. (135) have developed and validated a mathematical model of dengue transmission. The model indicates that dengue transmission could occur in Athens for a short period in late summer under current climate conditions if the vector and virus were introduced (134). This is consistent with observed transmission, as Athens experienced a large outbreak of dengue in 1928. An increase in mean temperature would only result in seasonal dengue transmission in southern Europe if the vector and virus were to be established.

Tick-borne diseases

Ticks transmit several bacterial, rickettsial and viral pathogens to humans (Fig. 10). Ticks are ectoparasites, and their geographical distribution depends on the availability of suitable habitat vegetation and host species, usually rodents and large mammals such as deer. The distribution and population density of ticks is also limited

Fig. 10. Interactions between tick-borne disease and the environment



Source: Lindgren (136).

by climatic factors. Tick vectors are long-lived and are active in the spring, summer and early autumn. The temperature must be sufficiently high to complete the tick's life cycle during the warmer part of the year and high enough in winter to maintain the life cycle. The humidity must be sufficient to prevent both eggs and ticks from drying out. Higher temperatures enhance proliferation of the infectious agent within the ticks, although temperatures above the optimum range reduce the survival rate of both ticks and parasites.

The northern limit of the distribution of ticks in Sweden changed between 1980 and 1994 (137). In regions where ticks were prevalent in the 1980s, population density increased between the early 1980s and mid-1990s. Changes in distribution and density over time are correlated with changes in seasonal daily minimum temperatures (138).

Ixodid ticks such as *Ixodes ricinus* and *I. persulcatus*, which are widely distributed in temperate regions, transmit tick-borne diseases in Europe. Most at risk of infection are those who spend time in the countryside or come into contact with the ticks in vegetation in periurban areas. People have also been infected in city parks. Tick populations are difficult to control directly using pesticides. Controlling the host animal populations is also difficult because many

species can provide ticks with a blood meal. Tick populations may be controlled indirectly by modifying the type of local vegetation, but this can only be done on a small scale. Currently, the most effective public health measure is to raise public awareness about tick-borne diseases and how to avoid infection.

Lyme borreliosis or Lyme disease is prevalent over much of Europe. The disease agent was described in 1975 after an outbreak in the United States, and the disease is therefore considered as an emerging infection. It is now the most prevalent arthropod-borne disease in temperate zones. The disease incidence has increased in several European countries, such as Finland, Germany, the Russian Federation, Scotland, Slovenia and Sweden. This may partly be due to increased reporting as well as a real trend. For example, an increase in Lyme disease during the last decade has been serologically confirmed in Sweden (139).

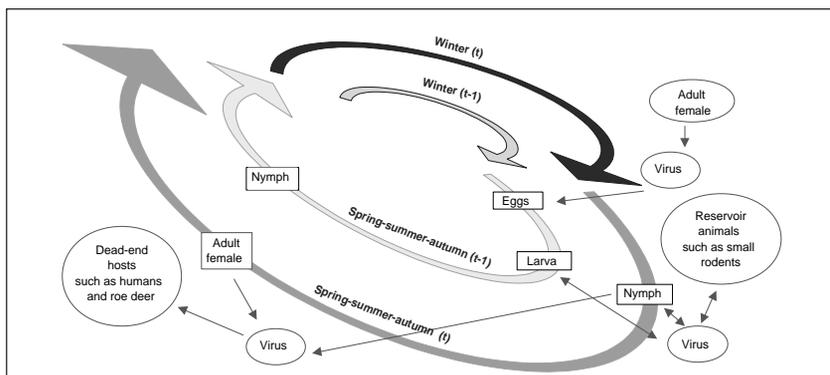
The risk of contracting the pathogen, *Borrelia burgdorferi*, from a single tick bite is 1 in 100–150 in endemic regions (140). Lyme borreliosis is a complex multisystem disorder and includes cardiac and nervous system disorders and arthritis. Most infections are asymptomatic and self-limiting, but the disease can be fatal if left untreated. Transmission occurs during the spring, summer and early autumn when the ticks are active. Climate change is likely to lengthen this transmission period. A vaccine has recently been developed in the United States, but this would not be applicable to Europe because the pathogen structures are more heterogeneous.

Tick-borne encephalitis is present in southern Scandinavia and central and eastern Europe. Tick-borne encephalitis is caused by a flavivirus with at least two subtypes: the central European type – prevalent in Europe – and the Russian spring–summer encephalitis subtype. The latter comprises other subtypes that cause diseases worldwide: louping-ill in Ireland, Norway and Scotland, Omsk haemorrhagic fever in Siberia, Kyasanur Forest disease in India and Powassan encephalitis in North America. The risk of contracting the disease from a single tick bite is 1 in 600 in endemic regions (140). The mortality rate for tick-borne encephalitis is 1%, and 10% of cases lead to permanent paralysis. Mortality rates are higher for the Russian spring–summer encephalitis subtype. A vaccine for tick-borne

encephalitis is available, and persons at high risk of infection (such as those who live or work in endemic areas) are vaccinated in Sweden and other countries.

Tick-borne encephalitis virus is transferred mainly from small rodents to humans by ticks (Fig. 11). The virus has also been shown to infect humans via unpasteurized goat's milk, leading to some rare localized outbreaks in the eastern part of the European Region. A study lasting nearly four decades in a highly endemic region in Sweden found that the incidence of tick-borne encephalitis increased after

Fig. 11. Schematic overview of a 2-year tick life cycle in relation to the transmission of tick-borne encephalitis



Source: Lindgren (136).

Table 4. Numbers of tick-borne encephalitis cases diagnosed annually from 1991 to 1997 in selected European countries

Year	Austria	Czech Republic	Estonia	Germany	Hungary	Latvia	Lithuania	Poland	Slovenia
1991	128	356	68	44	288	227	14	4	245
1992	84	337	163	142	206	287	17	8	210
1993	102	621	166	118	329	791	198	249	194
1994	178	619	177	306	258	1 366	284	181	492
1995	109	744	175	226	234	1 341	426	270	260
1996	128	558	177	114	224	716	309	259	406
1997	99	416	404	160	99	874	645	200	274

Source: Baxter Immuno, personal communication, 1998.

milder winters (fewer days with temperatures below -7°C) combined with extended spring and autumn seasons for two successive years (136). The range of tick-borne encephalitis in Europe may significantly contract, however, as well as shift to higher latitudes and altitudes (141), as its transmission depends on a particular pattern of tick seasonal dynamics, which may be disrupted by climate change.

Table 4 shows the numbers of tick-borne encephalitis cases diagnosed annually from 1991 to 1997 in selected European countries. The increase in the number of cases observed in many countries is largely likely to result from an increase in serological diagnostic capacity as well as an increase in awareness of the disease.

RODENT-BORNE DISEASES

Rodents are reservoirs of a number of human diseases. Rodents can act as both intermediate infected hosts or as hosts for arthropod vectors such as fleas and ticks. Rodent populations are affected by weather conditions. In particular, warm, wet winters and springs increase rodent populations. Under climate change, rodent populations could be anticipated to increase in temperate zones, resulting in greater interaction between humans and rodents and a higher risk of disease transmission, especially in urban areas. Rat populations have increased significantly in recent years. In some European countries, breakdown in sanitation controls and inadequate hygiene are contributing to serious problems of rat infestation.

Hantaviruses and their rodent hosts are present in Europe and cause haemorrhagic disease. Epidemic haemorrhagic fever (also called haemorrhagic fever with renal syndrome) is a major problem in the Balkans. The Puumala strain caused an outbreak of more than 20 000 cases of epidemic haemorrhagic fever in the west of the Russian Federation (142). In Finland, studies have shown that the number of cases is linked to the population density of the host vole.

Rats are carriers of *Leptospira interrogans*, the causal agent of leptospirosis or Weil's disease. Human infections can occur after direct contact with soil or water contaminated with rat urine or faeces. Thus, flooding increases the risk of human infection (see p. 33).

PEST SPECIES

Many organisms that are considered pests are involved in the transmission of infectious diseases in Europe. However, information about the potential response of these species to climate change is very incomplete.

Higher mean temperatures and damp winters arising from climate change may increase fly (*Musca*) and blowfly (*Calliphora*) populations. Populations of other fly species may also increase, especially given the trend towards more intensive animal farming, which produces large quantities of manure. All species in these groups are capable of breeding at temperatures of 10 °C, and larvae will continue to develop at temperatures as low as 3.5 °C. Thus, if average temperatures rise, contamination of food with enterobacteria or enteroviruses could increase and become prevalent for a greater part of each year.

In common with flies, cockroaches of the family Blattidae are potential “mechanical” carriers of foodborne pathogens and are considered to be major threats to hygiene in the domestic environment. In Europe, higher temperatures might encourage cockroaches to venture from dwellings into sewers. Higher temperatures would also facilitate the movement of cockroaches and other insects between dwellings, making control of infestations more difficult (143).

EFFECTS ON FOOD SUPPLY

During the past 10 000 years – which have been relatively stable in climatic terms – farming methods have evolved and improved, enabling more food to be produced. Local climatic limitations on crop growth have been overcome through irrigation, fertilization, mechanization and the breeding of varieties adapted to local conditions. During the past five decades, the food requirements of a rapidly expanding population, combined with a worldwide shortage of new tracts of arable land, have led to an unprecedented reliance on yield improvement.

Climate change could affect food production through:

-
- geographical shifts and yield changes in agriculture;
 - a reduction in the quantity of water available for irrigation;
 - loss of land through a rise in sea level and associated salinization; and
 - effects on the productivity of fisheries through a rise in sea level and changes in water temperatures, currents, flows of fresh water and nutrient circulation.

Predicting the effects of climate change on crop and livestock yields is complex. Agricultural production is sensitive to the direct effects of climate, especially extreme weather events. It is also sensitive to the indirect effects of climate on soil quality, on the incidence of plant diseases and on weed and insect (including pest) populations. In particular, irrigated agriculture would be affected by changes in water resources. The Intergovernmental Panel on Climate Change has reviewed assessments of the impact of climate change on agricultural productivity (6).

The modelling exercises reported to date have often not attempted to incorporate social and economic responses. It is assumed that farmers will adapt to changes in climate by, for example, changing crop varieties or dates of planting. Human societies would clearly respond to significant changes in food supplies by such means as migration. The complex political, economic and technological influences on world food production are difficult to quantify. These influences include the rapid commercial and political changes that have encouraged the production of standardized crops for unseen, remote markets using large-scale, heavily mechanized agricultural production methods. This has occurred to the extent that food has gradually become an international commodity rather than a source of nutrition for local populations.

In Europe, the regional assessment by the Intergovernmental Panel on Climate Change concludes that crop mixes and production zones will be redistributed (8). Subsequent changes in food prices are highly dependent on world markets and the adaptive actions taken by producers. Relatively few studies, however, have addressed vulnerability to food shortages in Europe, and the assessment of the Intergovernmental Panel on Climate Change does not identify vulnerable groups. Several regional assessments for Europe have also been

undertaken (48). These studies focus on model simulations for changes in crop yield and agricultural risk.

The political implications of climate change must also be considered. As land areas suitable for the cultivation of key staple crops or productive fishing grounds undergo geographical shifts in response to climate change, they may become the subject of political conflict. Conflicting demands for water may also cause problems, especially in Israel, Turkey and other semi-arid countries (106).

Health effects of stratospheric ozone depletion

The amount of ultraviolet radiation that may reach a given part of the earth's surface at any time is determined by a great variety of factors, including latitude, season, time of day, altitude, local atmospheric conditions (smog, cloudiness, haze, smoke, dust, fog, altitude and aerosol particles), variation in the thickness of the ozone layer and the angle of the sun above the horizon. Ultraviolet radiation may damage the skin and the eyes and influence the immune system (Table 5). The effects of ultraviolet radiation on the skin can be acute or chronic. The acute effects are erythema and sunburn, and the chronic effects can be freckles, solar lentigines, melanocytic nevi, solar keratosis, photo-aging and cancer (145). We report here only skin cancer and the effects on the eyes and immune system.

SKIN CANCER

Many epidemiological studies have implicated solar radiation as a cause of skin cancer (both melanotic and non-melanotic) in fair-skinned humans (146,147). Non-melanotic skin cancers are of two major histological types: basal cell carcinoma and squamous cell carcinoma. The risk of these cancers has generally been thought to correlate with cumulative lifetime exposure to solar radiation. Nevertheless, recent evidence suggests that the relationship is more complex. At least for basal cell carcinoma, childhood exposure may be important (148–150). These types of cancer usually develop on the

Table 5. The main effects of solar ultraviolet radiation on the health of humans

Nature of effect	Direction of effect	Strength of evidence
<i>Effect on immunity and infection</i>		
Suppression of cell-mediated immunity	Harmful (?)	Sufficient
Increased susceptibility to infection	Harmful	Sufficient
Impairment of prophylactic immunization	Harmful	Inadequate
Activation of latent virus infections	Harmful	Sufficient
<i>Effects on the eye</i>		
Acute photokeratitis and photoconjunctivitis	Harmful	Sufficient
Climatic droplet keratopathy	Harmful	Limited
Pterygium	Harmful	Limited
Cancer of the conjunctiva	Harmful	Inadequate
Lens opacity (cataract)	Harmful	Limited
Uveal melanoma	Harmful	Limited
Acute solar retinopathy	Harmful	Sufficient (?)
Macular degeneration	Harmful	Inadequate
<i>Effects on the skin</i>		
Malignant melanoma	Harmful	Sufficient
Non-melanocytic skin cancer	Harmful	Sufficient
Sunburn	Harmful	Sufficient
Chronic sun damage	Harmful	Variable
Photodermatoses	Harmful	Sufficient
<i>Other direct effects</i>		
Vitamin D production	Beneficial	Sufficient
Other types of cancer	Beneficial	Inadequate
General wellbeing	Beneficial	Inadequate
<i>Indirect effects</i>		
Effects on climate, food supply, disease vectors, air pollution, etc.	Probably harmful	Inadequate

Source: Armstrong (144).

parts of the body most often exposed to sunlight (such as the face, neck, scalp, hands and arms) (151,152).

Malignant melanoma, a cancer of the pigment-producing cells of the skin, usually develops on an already pigmented patch such as a mole (153–155). The relationship between melanoma skin cancer and ultraviolet radiation is complex. Overall, 60–90% of melanoma cases in fair-skinned populations are estimated to involve sunlight

exposure (156). Repeated severe sunburn episodes in early life are considered important for the development of melanoma. The incidence of melanoma in fair-skinned populations has risen by 3–7% every year since at least the 1960s, which probably reflects a progressive increase in the average levels of personal exposure to solar radiation, owing to changes in the patterns of settlement, recreation, clothing and occupation that are unrelated to stratospheric ozone depletion (157).

Estimates have been made of how ozone depletion may affect the rate of skin cancer in certain countries. The model developed by Slaper et al. (158) takes into account the production and emission of ozone-depleting substances, the global stratospheric concentrations of chlorine, the local depletion of stratospheric ozone, the resulting increases in ultraviolet B levels and, finally, the effects on skin cancer rates. Several delay mechanisms in the effect of ozone depletion on skin cancer rates are important, such as the time taken to develop tumours. In the case of ozone depletion, the separate scenarios modelled are related to the Montreal Protocol, the international agreement restricting the production of ozone-depleting substances. Thus, full compliance with the Montreal Protocol and all its amendments and adjustments would lead to a peak in stratospheric chlorine concentration and ozone depletion by about 2000 (Fig. 6) and to a peak in skin cancer by about 2050. The latter is mainly delayed because skin cancer incidence depends on the cumulative ultraviolet B exposure.

The most recent assessment by the United Nations Environment Programme (54) has updated the above projections for total skin cancer for a “European” population living at a latitude around 45 °N. It estimates that, under the amended Montreal Protocol, an excess incidence will peak at about 5% during the third quarter of the 21st century. This means an extra 100 cases of skin cancer per million population per year from stratospheric ozone depletion. The current background rate of skin cancer is about 2000 cases of skin cancer per million population per year. If the moderate aging of the “European” population were factored into the modelling, the excess incidence would become, proportionally, a little higher. The calculations by the United Nations Environment Programme assume that behavioural and demographic risk factors do not change and that

the current rate of ozone depletion and increases in exposure to ultraviolet radiation are sustained during the next several decades.

DAMAGE TO THE EYE

The external epithelial layer of the eye, the cornea and conjunctiva, absorbs virtually all ultraviolet radiation with a wavelength of less than 290 nm. Excessive exposure to ultraviolet radiation is known to cause damage to the eye's outer tissue. The condition most directly linked to ultraviolet radiation exposure is corneal photokeratitis ("snow blindness"). This is caused by acute exposure and is the ocular equivalent of sunburn. Chronic exposure to ultraviolet radiation is linked to conditions such as pterygium (*145*). The role of ultraviolet B in cataract formation is complex and unclear. Some cataract subtypes are associated with ultraviolet radiation exposure, but others are not.

THE IMMUNE SYSTEM

There is good evidence both in humans and experimental animals that ultraviolet radiation causes local (that is, occurring only at the site of irradiation) and systemic immunosuppression. Although the mechanisms of ultraviolet radiation-induced immunosuppression are better understood, many questions remain to be answered. The consequences of immunosuppression for patterns of infectious disease in human populations are less clear.

Cellular immunity and the activity of natural killer cells have been shown to be affected by ambient doses of ultraviolet radiation (*159*). Ultraviolet radiation-induced suppression may therefore play a role in reduced resistance to skin tumours. Immunosuppression may also lead to diminished resistance to viral and bacterial infections because, in addition to the activity of natural killer cells and cellular immunity, phagocytic activity is also reduced. All these mechanisms are involved in immune resistance to infections. Such effects have been shown in experimental laboratory animals. Animal data can be extrapolated to humans with information from studies that compare species. The results from such extrapolation studies indicate that

ambient doses of ultraviolet radiation reduce the resistance to infectious diseases in humans (160). The effect of ultraviolet radiation on herpes simplex infection is well known and confirms the effects found in animal studies.

Further epidemiological studies are required to fully understand the impact on the incidence and prevalence of infections. Even a modest effect on the immune system that may result in a moderate depression of resistance to an infection, or affect its duration or severity, may have a significant aggregate social and economic impact at the population level for very common diseases (such as the common cold and gastroenteritis).

Ultraviolet radiation-induced changes in immune response may also affect autoimmune diseases. Increases in ultraviolet radiation may either suppress or aggravate the disease depending on the type of immune response that underlies the disease. It has recently been proposed, based on epidemiological and laboratory evidence, that increased exposure to ultraviolet radiation is associated with a lower prevalence of multiple sclerosis (161). It is also known that ultraviolet radiation aggravates lupus lesions when used as a medical treatment (54).

It is now generally accepted that allergic respiratory disease (such as asthma) is associated with the enhanced expression of the Th2 cell pathway immune response (162). Ultraviolet radiation has been shown to preferentially suppress the Th1 component of the cellular immune response and to enhance the Th2 component. It has also been suggested that production of immunoglobulin E (IgE) – the immunoglobulin involved in the immediate hypersensitivity immune (allergic) response – is stimulated by ultraviolet radiation in experimental animals (159,163). The detrimental effect of ultraviolet radiation on lupus, which is a Th2-type phenomenon, supports the argument for this mechanism in humans. The stimulation of the Th2 response by ultraviolet radiation, and hence stimulation of IgE production, may result in respiratory allergy. Increased exposure to ultraviolet radiation, such as from lifestyle and personal behaviour, may thus play a role in the as yet unexplained increase in the prevalence of respiratory allergy in many countries.

By affecting the immune system, an increase in ultraviolet radiation may have important effects on the incidence and prevalence of infectious diseases. It may also have important effects on autoimmune and atopic diseases. Climate change may also affect the distribution of pathogens and allergens as well as other factors that affect the immune system, such as natural toxins from moulds that contaminate wheat. Such phenomena may well interfere with and influence the consequences of immunosuppression.

4

Early effects of climate change on human health

The detection and attribution of the early effects of climate change on the health of human populations is a priority. A range of anticipated health effects from climate change and depletion of stratospheric ozone have been described. Some of the direct-acting effects are likely to become evident within the coming decades. For example, an increase in heat wave-related deaths and an increase in ultraviolet radiation-induced skin cancer in some populations may occur soon or are already occurring.

There is good evidence that anthropogenic climate change is already affecting plant growth and distribution. There is also good evidence of climate-related changes in the distribution and behaviour of animal species both within Europe and elsewhere. A study of Edith's checkerspot butterfly in North America found that the species had extended its range north and reduced its range to the south (164). This study also confirmed that the changes were consistent with observed shifts in climatic bands.

At the global level, patterns of changes in human disease are compatible with the advent of climate change. In particular, increases in vector-borne diseases have been observed in highland regions (165). It is not possible, however, to attribute these increases directly to observed climate warming, because of the many other environmental changes that have occurred in these regions over recent decades, which affect malaria distribution and incidence (166). An analysis

of recent historical malaria data in the highland region of Ethiopia demonstrated an increasing trend in malaria mortality and morbidity over the last two decades (167). Analysis of data indicates that increases in malaria outbreaks in Ethiopia during the past decade were mainly a result of the observed increase in night-time temperatures. Thus, regional climate change appeared to cause the extension of malaria transmission to higher altitudes. In Europe, changes in the northern limit of the European tick, *Ixodes ricinus*, in Sweden over the last two decades have recently been attributed to observed warming (136).

The time frame for the emergence of the health effects of climate change would depend on several factors. The “incubation” period (delay between environmental event and onset of ill health) ranges from almost zero (storm-induced injury, for example) to weeks or months (vector-borne infections) and to years and decades (ultra-violet radiation-related malignancies).

In addition, some factors influence the ability to detect whether change really is occurring. The extent and quality of information and variability in the background or pre-existing level of disease must be considered. The time when the health effects of climate change can first be detected will depend on two primary determinants:

- the sensitivity of response (the steepness of the rate of increase); and
- whether there is a threshold.

The first detectable changes are likely to be in the geographical range (latitude and altitude) of certain vector-borne infectious diseases and/or in the seasonality of these diseases. For example, summer-time foodborne infections (such as salmonellosis) may show longer-lasting annual peaks.

If extreme weather events become more frequent (such as heat waves, floods and droughts), then detectability will refer mainly to whether the frequency of such events or exposure has increased. If such events become more or less severe, then changes in the magnitude of the health effects associated with such events could be detected.

Any changes in the levels of nutrition and hunger will be difficult to attribute to climate change *per se*. Many complex factors influence food production. Temporal trends in production policies, soil degradation and variety of genotypes and phenotypes, along with trends in transport, storage, distribution and marketing, ensure that it remains difficult to discern any influence of climate change on food production.

5

Action to reduce the health effects of climate change

Action to reduce the health effects of climate change can be thought of in terms of the classical categorization of preventive measures in public health (McMichael, A., personal communication, 1998):

- primordial prevention: preventing climate change itself (mitigation);
- primary prevention: action taken to prevent the onset of disease from environmental disturbances in an otherwise unaffected population (such as early weather watch/warning systems and supplying bednets to all members of a population at risk of exposure to encroaching malaria);
- secondary prevention: preventive action taken in response to early evidence of health effects (such as adaptation and strengthening disease surveillance); and
- tertiary prevention: health care action taken to lessen the morbidity or mortality caused by the disease (such as improved diagnosis and treatment of cases of malaria).

Secondary and tertiary prevention are both, in general, relatively less effective than primordial and primary prevention. They are both ethically and socially undesirable when primary action could be taken.

MITIGATION TO REDUCE OR PREVENT CLIMATE CHANGE

Mitigation refers to actions that are taken to reduce the emissions or enhance the sinks of greenhouse gases. Mitigation can be achieved

in several ways. National and international policies (including those of the European Union) centre around reducing emissions of greenhouse gases. Few policy measures address strategies to reduce the actual or projected effects of climate change.

Scientific evidence linking greenhouse gas emissions caused by human activities with the risk of global climate change began to arouse public concern in the 1980s. Governments held a series of international conferences that issued urgent calls for a global treaty to address this problem. The United Nations General Assembly responded in 1990 by establishing the Intergovernmental Committee for a Framework Convention on Climate Change. The United Nations Framework Convention on Climate Change was adopted at the 1992 United Nations Conference on Environment and Development (the Earth Summit) and came into force on 21 March 1994.

As of December 1999, 181 countries had ratified or accepted the Convention, including the European Union and its 15 members. Several countries in the eastern part of the European Region have accepted but not ratified the Convention. The ultimate objective of the Convention and any related legal instruments that the Conference of the Parties may adopt is to stabilize, in accordance with the relevant provisions of the Convention, greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human interference with the global climate system.

The Third Session of the Conference of the Parties was held in Kyoto in December 1997. For the first time, governments of industrialized countries committed themselves to legally binding restrictions on emissions by adopting the Kyoto Protocol. Industrialized countries that are Parties to the United Nations Framework Convention on Climate Change agreed to reduce their emissions of six greenhouse gases, including carbon dioxide, by 5% from the 1990 levels in the commitment period, 2008–2012 (168–170). Of the 84 countries that signed the Kyoto Protocol, only 22 had ratified it by January 2000. The European Union as a whole is committed to reduce emissions by 8%, the countries of central and eastern Europe are committed to reductions of 5–8%, and the Russian Federation and Ukraine are committed to stabilizing their emissions at 1990 levels.

Some countries have also set voluntary targets for reducing emissions that are in excess of their obligations under the Framework Convention. The United Kingdom, for example, has set a domestic target of reducing emissions by 20% by 2010. Global economic mechanisms need to change before greenhouse gas concentrations can be effectively stabilized. Many countries that have no incentives for legally or voluntarily reducing their emissions also have a supply-driven energy market that is opposed to the use of energy sources other than fossil fuels.

The Fourth Session of the Conference of the Parties took place in Buenos Aires, Argentina, in November 1998. The Conference agreed on a two-year deadline for strengthening the implementation of the Convention and preparing for the future entry into force of the Kyoto Protocol (171).

A total of 165 countries and 3000 other participants attended the Fifth Session of the Conference of the Parties in Bonn, Germany, in October and November 1999. The Fifth Session focused mainly on the issues relevant to preparing the entry into force of the Kyoto Protocol, such as the clean development mechanism, joint implementation, emission trading, compliance, technology transfer and capacity-building, carbon sinks, and emissions from international air and maritime traffic.

The long lifetime of greenhouse gases and the latency in the climate system mean that action taken now will have little effect on future warming before 2050. Further, the Kyoto commitments are insufficient to avert serious effects from climate change. The Intergovernmental Panel on Climate Change expects the mean global temperature to rise by 1.4 °C by 2050, assuming a standard non-interventionist scenario for greenhouse gas emissions (6). About 0.25 °C of this warming had already been realized by the 1990s. Parry et al. (172) have estimated that full implementation of the Kyoto targets would reduce the anticipated global warming by only 0.05 °C and would not significantly reduce the effects of climate change on populations at risk of hunger, coastal flooding or water shortage (Table 6). This means that governments must take action to adapt to the potential or actual health and other effects of climate change.

Table 6. Worldwide effects of climate change, estimated for the year 2050 under different scenarios for the emission of greenhouse gases, for Annex I countries of the United Nations Framework Convention on Climate Change

Emissions scenario	Global warming compared with 1961–1990 (°C)	Additional population (millions) at risk from the effects of climate change on:		
		water shortage	coastal flooding	hunger
No mitigation	1.39	1053	23	22
Kyoto targets	1.33	1053	22	20
20% reduction	1.22	909	21	17
30% reduction	1.19	891	20	16

Source: Parry et al. (172).

Since local emissions of greenhouse gases and ozone-destroying gases contribute to processes of global atmospheric change, preventive policies must be part of a coordinated international effort. Mitigation is not possible on a local or regional basis. European countries, like all other countries, have a moral obligation to contribute to this preventive effort on behalf of human wellbeing and health everywhere. Taking local action to reduce effects, in the absence of such mitigation attempts, entails an unethical decision to protect local populations from the effects when more distant populations may be less able to protect themselves.

SECONDARY HEALTH BENEFITS OF MITIGATION POLICIES

The ongoing negotiations to reduce emissions of greenhouse gases present an important opportunity to improve population health. Many mitigation policies and technologies in Europe and beyond can have substantial near-term health benefits. Such win–win policies can reduce greenhouse gas emissions and provide other social or environmental benefits. For example, restricting the circulation of private motor vehicles in urban areas would decrease the burden of mortality and morbidity from road traffic accidents and reduce both local and global pollution. A significant shift in road transport towards more environmentally sound modes of transport, such as public transport, walking and cycling, would improve air quality and population health.

The secondary benefit of the reduction in air pollutant concentrations can be substantial, especially for the effects of particulates, nitrogen oxides and sulfur dioxide. The Working Group on Public Health and Fossil-Fuel Combustion (173) estimates the global impact of reduced exposure to particulate matter smaller than 10 μm (PM_{10}) as 700 000 fewer premature deaths per year by 2020 under a mitigation scenario. This indicates the likely magnitude of the health benefits of a mitigation policy.

Cities in China and India have the worst air quality in the world (174,175). Reductions of greenhouse gas emissions in these countries will have a greater health benefit per unit of reduction than in the industrialized countries that have strict controls. Thus, governments can directly improve health in poorer countries by supporting the use or introduction of climate-friendly technologies. The specific mechanism for this under the United Nations Framework Convention on Climate Change is the clean development mechanism.

ADAPTATION STRATEGIES TO REDUCE THE POTENTIAL EFFECTS ON HEALTH OF CLIMATE CHANGE IN EUROPE

Adaptation refers to action taken to lessen the effects of the anticipated changes in climate. The ultimate goal of adaptation interventions is to reduce diseases, injuries, disabilities, suffering and death from climate change at the least cost.

Public health programmes should anticipate the health effects of climate change such as those on infectious diseases. For example, surveillance systems could be improved in sensitive geographical areas. Such areas include those bordering areas of current distribution of vector-borne diseases that could themselves experience epidemics under certain climatic conditions. Vaccination programmes could be intensified, and pesticides for vector control and drugs for prophylaxis and treatment could be stockpiled.

Countries in Europe will be able to adapt to some of the health effects of climate change, either by maintaining existing health and other services or by adopting new policy measures. Little is known about the biological or passive adaptation of humans to climate

change. Although most assessments of the health effects of climate change have not addressed adaptation explicitly, assessments of the effects of thermal stress have modelled the modulating effect of acclimatization at the population level.

Irrespective of climate change, breakdowns in public health measures have been responsible for many recent outbreaks of disease. Climate change therefore presents an additional burden on health. Both existing and future potential environmental health problems share many of the same underlying causes related to poverty and inequality.

MONITORING AND SURVEILLANCE

The early effects of climate change on human population health have not yet been identified. Systematic assessment of the adequacy of data collection and monitoring systems is therefore urgently needed in relation to this task in Europe and elsewhere (*176,177*).

The detection and attribution of the health effects of climate change were recently discussed at the First Interagency Workshop on Climate Change and Human Health Monitoring sponsored by WHO, the Medical Research Council in the United Kingdom and the United Nations Environment Programme (*178*). The main objectives of the Workshop were to set priorities for research and monitoring and to identify opportunities for collecting new data and integrating both climate and health data. The workshop recommendations include:

- inventory and assessment of relevant climate, environment and health data sets;
- identification of unmet data needs;
- free and easy access to data for research purposes; and
- new monitoring initiatives that build on monitoring and surveillance systems and their current strengths.

A more concerted public health approach is needed, starting with the identification of the most appropriate methods for monitoring to detect the early effects of climate change in Europe. Table 7 describes a

Table 7. Summary of monitoring needs for detecting the early human health effects of climate change in Europe

Health effects	Location	Data needs
Vector-borne diseases such as malaria and dengue	Margins of distribution, both latitude and altitude, such as the highlands of East Africa for malaria Areas with sporadic or seasonal epidemics	Mortality data Primary care data Communicable disease surveillance centres Vector data from local field surveys Land-use and vegetation data (remote sensing) Current data sets need to be standardized
Water-borne diseases such as cholera and cryptosporidiosis	Current endemic areas and areas with sporadic disease	Mortality data Data on communicable disease surveillance
Diseases related to marine ecosystems such as cholera	Oceans Coastal populations	Disease surveillance, such as cholera cases Sampling of phytoplankton for pathogens, biotoxins, etc. Remote sensing for algal blooms, etc.
Heat-related mortality	Urban populations in developing and industrialized countries	Daily mortality and morbidity (chronic cardiorespiratory) data
Extreme-weather events such as floods and storms	All regions	Mortality data Disease surveillance, such as gastrointestinal diseases Data on the effects of disasters
Sea-level rise	Vulnerable populations, such as on low-lying islands	Groundwater quality Diarrhoeal disease surveillance
Malnutrition and food supply	Critical regions	Population nutritional status Land-use data Socioeconomic data

Source: Haines & McMichael (176).

broad monitoring scheme for this purpose. Data are needed to provide information for policy-makers on the magnitude of climate change effects. In addition, as part of monitoring systems, such data can help to determine the requirements for and the effectiveness of preventive or adaptive actions. There is an important mutual interaction

between research and the development of data collection systems. Indicators of early effects of climate change need to be developed. Such indicators need to be climate-sensitive: that is, respond to climate variability on natural scales of days, weeks, months (seasons) and years.

Cause-specific mortality is continuously monitored in most countries in Europe, but the data are of variable quality. Infectious disease surveillance varies widely depending on the locality, the country and the disease. The long-term collection of morbidity data and primary care consultation data could give a more sensitive indication of the health effects of climate change (176).

It is important to detect the early effects of climate change on heat-related mortality. Comprehensive databases of (daily) all-cause mortality are available in several countries and cities, especially within the framework of existing European studies on the acute effects of air pollution (such as the APHEA (Air Pollution and Health – a European Approach) database). However, data on cause-specific mortality are less easily available, and standardization is a problem if one wishes to compare effects between countries. It needs to be determined whether there are time trends in heat wave-attributable mortality in association with documented background warming.

Table 8 lists the set of priorities and criteria that have been developed to assist in selecting the infectious diseases that should be monitored. Many climate-sensitive diseases are subject to passive surveillance in Europe. The WHO Regional Office for Europe collects surveillance data on some diseases, such as malaria, from Member States. European networks for surveillance are already in place for several infectious diseases that may be affected by climate change. These include:

- the European Working Group on Legionella Infection – a network for the surveillance of diseases caused by *Legionella*; and
- Enter-net – an international network for the surveillance of infections caused by *Salmonella* and also *Escherichia coli* strain O157.

Table 9 shows a list of criteria that are essential in deciding which diseases would be suitable for monitoring.

Table 8. Criteria for a monitoring scheme for the early health effects of climate change in Europe

Why monitor?	To detect early effects To promote better research To assist in building integrated assessment models To improve and evaluate adaptation strategies To inform policy-makers and the public
What should be monitored?	Climate-sensitive diseases Potential confounders (migration, lifestyles, land use, etc.) Adaptation strategies
What criteria are used to select the climate-sensitive diseases?	Strength of the evidence and climate sensitivity Potential magnitude of effect (economic considerations) Current availability of data, including feasibility and cost of collection Short-term benefit of the monitoring process (for example, uses for other health activities and preventive work)
How should the monitoring be carried out?	Minimum data set Arrangements for exchange and coordination of data

Source: WHO Regional Office for Europe (5).

Table 10 lists four infectious diseases identified as likely to be affected by climate change and includes some characteristics of the surveillance system. These diseases were selected because they are sensitive to climate and because Europe-wide surveillance is already in place. A definite list has still to be developed and further discussed.

The added value of Europe-wide surveillance is very important. The observed climate change signal may not be detectable at the national level. Regional or continent-wide impact assessment studies of climate change are therefore needed. In addition, the various effects of climate change are not likely to be confined to national borders.

Climate and environmental monitoring

The health and environment sectors collaborate little on research in global change. Many global change research and monitoring organizations are interested in health impact assessment and have

Table 9. Criteria for selecting potential diseases for climate change surveillance in Europe

Criterion	Reason for importance	Notes
Suitable for continuous surveillance	Need time series for comparison with climate factors	Infrequent infections suitable for detailed outbreak surveillance such as <i>Legionella</i>
Established causation	Need to distinguish direct climate effects from other known factors	Causation established for most prevalent infections
Environmental sources	Infections with strong environmental causation most likely to be affected by climate factors, such as thermal or rainfall variation, and extreme events, such as floods and heat waves	Especially waterborne diseases and those sensitive to temperature changes
Low or no case-to-case transmission	Strengthens association with environmental exposure	Such as malaria, <i>Campylobacter</i> and tick-borne encephalitis
Sustainable	Surveillance unlikely to be considered cost-effective for infections that are not routinely measured or those with low clinical importance; sentinel surveillance methods may be considered	Need to agree on surveillance priorities and to examine the feasibility of using existing surveillance systems
European network already in existence	Increases sustainability	Such as Enter-net for <i>Salmonella</i> and <i>Escherichia coli</i> and the European Working Group on Legionella Infection for <i>Legionella</i> . The European Parliament is considering integrating existing European Union networks; the WHO Regional Office for Europe will associate
Disease occurs naturally in Europe	Increases feasibility	Travel-associated or infrequent infections may be suitable, such as cholera
Public health and preventive measures available	Justifies effort	Such as vaccination or control measures, including improved sanitation and temperature control of foods

Source: WHO Regional Office for Europe (179).

requested feedback from health researchers. Conversely, many health researchers are unaware of the best sources of climate and environment data (both ground-based and remotely sensed data).

The aspects of local environmental conditions that may affect health are already being monitored. Air and water pollution levels are measured regularly by the Global Environment Monitoring System of the United Nations Environment Programme. Monitoring levels of pollutants in air, water and food and identifying emission sources are the most important means of evaluating and regulating such exposure. The coordinated approach of the Global Environment Monitoring System provides a model for the type of multicentred monitoring that is now essential in monitoring the effects of climate change.

The WHO European Centre for Environment and Health is developing a Health and Environment Geographical Information System (HEGIS). HEGIS is to be used to identify areas and issues of priority for environment and health. Initially, it will focus on demographic and air quality data. There is potential to expand HEGIS to include data relevant to climate change and health effects.

Environment and climate monitoring is also coordinated through the global observing systems (Fig. 12).

The Global Climate Observing System (GCOS) is an international effort to provide the scientific and technical framework for documenting the present state of the earth's climate, monitoring its condition and developing an understanding of its evolution (180). GCOS coordinates the systematic and comprehensive global observation that will lay the foundation for improving the detection of climate change and predicting climate variability.

The Global Ocean Observing System (GOOS) will provide the essential observations to underpin predictions of El Niño and other climatic events. GOOS coordinates efforts to fill the many gaps in the current ocean observing systems and to make it fully comprehensive and fully global. The scientific and technical design of the GOOS will address climate, coastal zones, health of the oceans and living marine resources (181).

Table 10. Assessing potential diseases for surveillance for climate change: high-priority infections

Disease	Continuous, frequent or regular surveillance	Active surveillance component	Clear definition and diagnostic criteria	Causation established	Significant association with the environment	Minimum core data set including epidemiological factors	Sustainable network?	Sensitive areas	Public health approach established
<i>Campylobacter</i> infection	Yes, but mainly just counting	Only in some areas or regions	Typing system developed: more information needed on clinical syndromes	Yes, for food; lack of information on the importance of environmental sources. Very low case-to-case transmission	Yes	Incidence, prevalence, travel history, water exposure	Yes	Common in all countries	Only for outbreaks plus some case-control studies
<i>Cryptosporidium</i> infection	Only in some countries	No – except the United Kingdom	Yes, plus a typing system to distinguish human and zoonotic strains	For aquatic and zoonotic sources, case-to-case transmission in children	Yes – widely prevalent in water and resistant to chlorination	Incidence, prevalence, travel history, water and agricultural exposure	Yes	Northern Europe plus may increase after floods	Only in some countries

Table 10 (contd)

Disease	Continuous, frequent or regular surveillance	Active surveillance component	Clear definition and diagnostic criteria	Causation established	Significant association with the environment	Minimum core data set including the epidemiological factors	Sustainable European network?	Sensitive areas	Public health approach established
Malaria	Yes	Information on travel etc. collated	Yes	Yes	Yes – aquatic breeding sites; also association with temperature and rainfall	Incidence, prevalence, travel history, vector surveillance	Yes – could be enhanced for climate	Mediterranean south-eastern Europe, airport areas	Mainly clinical and laboratory surveillance; prophylaxis for travellers
Tick-borne encephalitis	In some countries	In some countries	Yes	Yes	Yes – vector patterns changing but also influence of behavioural factors	Incidence, prevalence, morbidity, vector surveillance	Yes – for hospitalized cases	Endemic areas where vectors are expanding	Vaccination, public health advice on avoiding bites

Source: WHO Regional Office for Europe (179).

Fig. 12. The global observing systems

	Atmosphere	Land	Oceans
	World Weather Watch	Global Atmosphere Watch	Global Ocean Observing System
Global Climate Observing System	Climate	Climate	Climate
	Weather	Air pollution Ozone	Marine services Coastal zone management Ocean ecosystem Living marine resources
		Land degradation Pollution Biodiversity Anthropogenic effects on natural systems	

Source: McMichael et al. (9).

The Global Terrestrial Observing System (GTOS) will be used to calibrate and validate ecosystem models, to detect and monitor the responses of terrestrial ecosystems to global change and to observe changes in agro-ecosystems caused by new patterns of land use (182). GTOS focuses on five issues: changes in land quality; availability of freshwater resources; loss of biodiversity; climate change; and pollution and toxicity. GTOS coordinates interaction between monitoring networks, research programmes and policy-makers, especially for data exchange and application.

The information provided via GCOS, GOOS and GTOS would help countries in meeting the requirements of global conventions, including the United Nations Framework Convention on Climate Change. Currently, most monitoring and assessment is targeted at specific issues (such as food security and deforestation) and, like health data, monitoring is only for a limited duration. However, technological advances are allowing more investment in and use of decision-support tools. Some policy-makers are also recognizing the value of investing in environmental data and information systems.

GTOS does not yet include health indicators. Socioeconomic data are being incorporated, however, and social scientists have now become involved at several levels. Data can be used to validate the models that are being developed to forecast effects of global change, including health effects. GTOS is open to new ideas about monitoring and early warning of global change.

INTERSECTORAL ISSUES

Intersectoral issues are those that involve collaboration between health and other sectors. Effective intervention for many threats to public health requires thinking more broadly than the health sector. Intersectoral collaboration should be strengthened so that public health considerations are addressed in implementing adaptation strategies.

Many adaptation strategies require collaboration across sectors, for example:

- water quality and water supply
- agriculture
- urban development and building design
- demographic change and the aging of populations
- climate monitoring and short-term (weather) and medium-term (seasonal) forecasting.

In some areas, the health sector could use information from seasonal climate forecasts or historical climate data in its programmes, enabling more proactive health care planning.

RESEARCH AND POLICY

Collaboration across research disciplines is fundamental to global change research. Barriers to global change research have been identified in Canada and include: lack of national strategic research plans; lack of communication between disciplines; single-discipline funding agencies that do not fund interdisciplinary research; and lack of public concern (11).

Research on the health effects of global environmental change requires a network of scientists within Europe and should be conducted within an international framework. It requires an exploratory and multi-pronged approach, with the maximum exchange of information and cross-fertilization of ideas and techniques among scientists, agencies and institutes. Systematic information on climate change and health in the European Region is seriously lacking. Several groups in Europe have already begun working on aspects of this topic (such as in the Netherlands, Sweden and the United Kingdom), but there is no forum for communication or dissemination of results.

The European Commission, the European Science Foundation and WHO have identified priorities for environment and health research for Europe by consensus. Climate change and stratospheric ozone depletion were identified as one of five specific research areas (55). The recommended research task is: "to improve the epidemiological and mechanistic science base and develop predictive methods for the assessment of future health risks of human-induced climate change and increased exposure to [ultraviolet] radiation".

Policy-making under conditions of uncertainty

The precautionary principle is most often taken to be that stated in Principle 15 of the 1992 Rio Declaration on Environment and Development: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

Much has been written on the interpretation and use of the precautionary principle, with debate often around "how much" damage is relevant and what constitutes full scientific certainty. These questions are sharper when uncertainty is substantial.

Many unavoidable types of uncertainty are attached to forecasting the potentially serious effects of global climate change. The world's environment and climate systems may change irreversibly. Thus, the precautionary principle is manifestly relevant to global climate change and stratospheric ozone depletion because of the potentially serious nature of their effects on health.

6

Conclusions

Human-induced changes in the global climate system and in stratospheric ozone pose a range of health risks. Irrespective of actions that might soon be taken to reduce or halt these environmental changes, human populations will be exposed to some degree of climate change and increased ultraviolet irradiation over the coming decades.

Climate change is likely to have wide-ranging and potentially serious health consequences, including various risks to the health of European populations. Some health effects will be direct-acting (such as heat wave-related deaths and ultraviolet radiation-induced skin cancer); others will result from disturbances to complex physical and ecological processes (such as changes in the patterns of infectious disease, in freshwater supplies and in agricultural yields). Effects on the health of the human population are likely to become evident within the coming decade. Capacity must therefore be enhanced for the detection of the early health effects of climate change and stratospheric ozone depletion. This can only be achieved by supporting research, monitoring and assessment.

Failure to reduce fossil fuel combustion (as the principal means of reducing greenhouse gas emissions) will result directly in a continuing burden of mortality and disease from exposure to local air pollution.

Climate change is likely to have serious implications for human health in many countries in Europe. Vulnerable populations need to

be identified and adaptive actions taken. For example, countries in northern Europe are vulnerable to an increased incidence of tick-borne encephalitis, and countries in southern Europe are vulnerable to an increased local transmission of malaria. Beyond Europe, effects on food and water supplies and a rise in sea level could be catastrophic. Climate change may, therefore, exacerbate current problems in areas near the European Region, such as North Africa and western Asia, and indirectly lead to population displacement.

Managing risks to health requires several steps: awareness that the problem exists; an understanding of what causes the problem; capacity to deal with the cause; a sense that the problem is important; and political will (*183*). We now need to redefine as unacceptable many of the personal and industrial practices that contribute to the burden of greenhouse gases and thereby pose risks to the health of present and future generations.

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**EARLY HUMAN HEALTH EFFECTS OF CLIMATE CHANGE AND
STRATOSPHERIC OZONE DEPLETION IN EUROPE**

Executive summary

Human-induced changes in the global climate system and in stratospheric ozone pose a range of health risks. Irrespective of any actions that might soon be taken to reduce or halt these environmental changes, human populations will be exposed to some degree of climate change and increased ultraviolet irradiation over the coming decades. There is therefore a need to consider how these global change processes will affect the health of European populations, how to improve research and monitoring, how to minimize adverse health impacts, and how to achieve Europe-wide coordination, sharing of information, and participation in wider international efforts in this area.

To this end, a WHO working group has made a number of recommendations, which are summarized below.

- A. Support the establishment of a Europe-wide interagency network for monitoring, researching and reviewing the early human health effects of climate change and of stratospheric ozone depletion, developing and advocating prevention, mitigation and adaptation policies, and identifying specific research priorities in that field. The WHO European Centre for Environment and Health

should act as a coordinator of this network, as part of the global programmes under the Inter-Agency Committee on the Climate Agenda endorsed in 1998 by the World Health Assembly, and link it to other relevant global programmes such as those arising from the United Nations Framework Convention on Climate Change and the Montreal Protocol on Substances that Deplete the Ozone Layer.

- B. Support interdisciplinary research into the study and forecasting of health impacts of climate change and stratospheric ozone depletion, focusing particularly on health outcomes relevant to European populations, and ensure that funding is available for this purpose. Related disease monitoring and research networks should be strengthened. Professional education and training should also be strengthened, with emphasis on acquisition of the necessary interdisciplinary understanding and research skills.
- C. Support the identification, development, standardization, evaluation and broad use of systems for monitoring and assessing changes in environmental indicators, bio-indicators of health risk and impacts on health, and indicators of population health status across Europe. These systems must be coordinated with global monitoring activities.
- D. Develop capacities, as necessary, to undertake national health impact assessments, with the aim of identifying the vulnerability of populations and subgroups, and ensure the necessary transfer of know-how among countries. These assessments will be made available for possible consideration in the forthcoming Third Assessment Report of the Intergovernmental Panel on Climate Change.
- E. Carry out ongoing reviews of the social, economic and technical prevention, mitigation and adaptation options available to reduce the adverse impacts of climate change and stratospheric ozone depletion on human health. Support the implementation of prevention, mitigation and adaptation strategies, taking into account national impact assessments (e.g. by strengthening surveillance activities), with appropriate public education and with special reference to vulnerable groups.

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- F. Orient the activities of bilateral and international donor agencies and other interagency bodies to provide resources and technical assistance to countries in need, for the implementation of both mitigation and adaptation strategies. These strategies should be designed to reduce the short- and long-term health impacts of climate change, fossil fuel combustion and stratospheric ozone depletion.

Background

1. This policy document contains the recommendations of the Working Group on the Early Human Health Effects of Climate Change and Stratospheric Ozone Depletion in Europe. The recommendations address actions to identify, reduce or prevent the impacts of climate change and stratospheric ozone depletion on the health of populations in Europe. The Working Group was convened by the WHO European Centre for Environment and Health (WHO-ECEH), Rome Division, at the request of the European Environment and Health Committee (EEHC). The Group was fully aware of the worldwide initiatives on climate change and stratospheric ozone depletion and the other proposals being submitted to the Third Ministerial Conference on Environment and Health, such as the European Commission/European Science Foundation/WHO research initiative and the Charter on transport, environment and health. These proposals were taken into consideration when developing the recommendations contained in this document, in order to avoid overlaps and duplication.

Synopsis of the issue

2. Human environmental impacts now include unprecedented changes at global level in the atmosphere and the stratosphere. Climatologists project that greenhouse gas accumulation in the lower atmosphere will change the world's climate and has apparently already begun to do so. Depletion of stratospheric ozone has occurred in recent decades. The relationship between the two phenomena is complex and new knowledge is emerging. Authoritative international reviews have concluded that these global environmental changes will affect human health, mostly in adverse ways. At global level, some of the ongoing changes in patterns of human disease are compatible with the advent of climate change. However, further research is needed to clarify these and future relationships.

3. It is anticipated that climate change and stratospheric ozone depletion will have a range of health impacts. Some will result from direct effects (e.g. heatwave-related deaths and skin cancer induced by ultraviolet radiation); others will result from disturbances to complex physical and ecological processes (e.g. changes in patterns of infectious disease, drinking-water supplies and agricultural yields). Some health effects may become evident within the coming decade; others would take longer. Furthermore, failure to reduce fossil fuel combustion (as the principal means of reducing greenhouse gas emissions) will result directly in a continuing (and increasing) avoidable burden of mortality and disease from exposure to local air pollution.

4. There is a need to consider how these global change processes will affect the health of European populations, how to minimize adverse health impacts, how to improve monitoring and research, and how to facilitate all such actions through Europe-wide coordination, sharing of information, and cooperation in wider international efforts.

5. The 1992 United Nations Conference on Environment and Development (UNCED) recognized, in Agenda 21, that the unavoidable uncertainties attached to forecasting the potentially serious impacts of global environmental change do not justify a wait-and-see approach. Rather, in such circumstances there is a strong case for prudent and precautionary action. This “precautionary principle” is manifestly relevant to global climate change and stratospheric ozone depletion, because of the possible occurrence of irreversible changes in the world’s environment and climate systems and because of the potentially serious nature of the associated health outcomes.

European and global initiatives on climate change, stratospheric ozone depletion and health

6. In 1997, governments that are parties to the United Nations Framework Convention on Climate Change (UNFCCC) (initiated at UNCED) agreed to reductions in greenhouse gas emissions under the Kyoto Protocol. Consequently, national and European Union policies are centred on mechanisms to achieve these mitigation targets. However, few policy measures address strategies for reducing the actual or projected impacts of climate change (adaptation).

7. In Europe there are several research-related initiatives which address climate change and its impacts. However, few of these initiatives address the impacts on human health, reflecting the fact that this topic is in the early stages of development. Furthermore, those initiatives are currently distributed unevenly between European countries. Very few countries have conducted national assessments of the potential effects of climate change on human health. None the less, a regional review of health impacts in Europe was recently conducted for a regional assessment report compiled by the Intergovernmental Panel on Climate Change (IPCC). Because of the scale of the analysis, this Europe-wide review cannot provide insight into the extent of health effects related to climate change at national and local levels.

8. At global level, a few initiatives have been taken to address the health impacts of climate change. In 1996, WHO, the World Meteorological Organization and the United Nations Environment Programme tentatively established a collaborative network on climate and human health, which was endorsed in 1997 by the Inter-Agency Committee on the Climate Agenda, a joint programme of international agencies concerned with climate issues. In May 1998, the World Health Assembly approved these initiatives and requested the Director-General to formalize the agreements and begin collaborative actions in support of Member States (resolution WHA 51.29). Other international bodies, including the World Bank, the International Council of Scientific Unions and IPCC, are also developing a range of health-related interests and activities, with which European initiatives should be coordinated wherever possible.

9. The international community has started to take action to prevent further large-scale depletion of stratospheric ozone since the Vienna Convention for the Protection of the Ozone Layer, in 1985. In 1987 countries agreed on the Montreal Protocol on Substances that Deplete the Ozone Layer, under which world consumption of specified chlorofluorocarbons (CFCs) and halons would be frozen and total CFC consumption would be reduced by 50% by the year 2000, relative to the base year 1986. Since then four amendments (London, Copenhagen, Vienna and Montreal) have been made to the original Protocol.

Recommendations

Implications and needs

10. The prospect of adverse health impacts from climate change and stratospheric ozone depletion has two main implications.

- It strengthens the argument for taking preventive action to halt these global environmental change processes. Protection of the public's health is a fundamental objective of social policy. In this particular context, primary preventive action will require coordinated international action to reduce gaseous emissions.
- Because these global environmental change processes are already occurring and will continue over successive decades, adverse health impacts should be minimized through adaptive interventions that may reduce population vulnerability and minimize local exposure.

11. The discussion and recommendations set out below emphasize four basic needs:

- to acknowledge the potential seriousness of the issue of health impacts and its policy relevance;
- to enhance understanding and disseminate information;
- to adopt a plan of action;
- to implement a plan of action.

12. The recommendations are arranged in the following categories: (i) coordinated European action; (ii) research needs; (iii) development of monitoring and assessment; (iv) preventive strategies to minimize health impacts from unavoidable climate change and stratospheric ozone depletion; and (v) international perspectives.

Coordinated European action

13. The physical and temporal scales of global change processes and of their likely health impacts mean that they cannot be primarily addressed at local level. Rather, there is a need for a pan-European approach that links environmental and health data collection and research transnationally, taking into account all the research efforts already made. Many informative comparisons can be drawn across the geographic and climatic gradients of the European Region.

14. The health sector should support mitigation policies by widely disseminating relevant evidence- and science-based messages on the human health consequences of climate change among policy-makers, representatives of private enterprises and the general public. It is within the mandate of WHO to strengthen this advocacy work in Member States by all possible means.

15. Integrated regional data collection activities are increasingly being carried out in relation to environmental indices and health outcomes. These include remote sensing of environmental data and formal networks collecting standardized health data (such as WHO's European infectious disease monitoring system and multinational networks for certain specific diseases).

16. At present, however, there is no international mechanism for securing an overview of the emerging threats to human health posed by climate change. This situation requires the presence of a central, pan-European coordinating body to facilitate the several multinational efforts being made and to provide Member States with the necessary information and insight to support policy-making. Such a coordinating centre should:

- (a) provide support to Member States and develop their capacity to assess the impacts on human health of climate change and stratospheric ozone depletion;
- (b) strengthen the advocacy role of the health sector in support of ongoing UNFCCC negotiations and national mitigation policies, as well as in support of implementation of the Montreal Protocol and its subsequent amendments;
- (c) strengthen the dissemination of information on health impacts within the health sector, in other sectors and among the general public;
- (d) assist with national impact assessments, in order to assess national vulnerabilities and priorities for preventive action;
- (e) support interdisciplinary research into the study and forecasting of the health impacts of climate change and stratospheric ozone depletion;
- (f) assist in the development of national health response (adaptation) strategies;

- (g) build strategic partnerships between policy-makers, the research community, monitoring and surveillance networks, and other relevant institutions and agencies;
- (h) in partnership with regional health and environmental monitoring and surveillance networks, develop indicators and review data periodically to detect early health impacts of climate change and stratospheric ozone depletion.

RECOMMENDATION A

Support the establishment of a Europe-wide interagency network for monitoring, researching and reviewing the early human health effects of climate change and of stratospheric ozone depletion, developing and advocating prevention, mitigation and adaptation policies, and identifying specific research priorities in that field. WHO-ECEH should act as a coordinator of this network, as part of the global programmes under the Inter-Agency Committee on the Climate Agenda endorsed in 1998 by the World Health Assembly, and to link it to other relevant global programmes such as those arising from the United Nations Framework Convention on Climate Change and the Montreal Protocol on Substances that Deplete the Ozone Layer.

Research

17. The relative newness of this topic means that there has been little formal research into the health impacts of climate change. Nevertheless, the topic has begun to be clarified by a combination of literature reviews, epidemiological studies, laboratory studies and predictive modelling. Much of the research cannot be done within a simple empirical framework. In order to forecast the likely health outcomes of exposure to future environmental scenarios, predictive models need to be developed that integrate disparate systems. This requires unusual reliance on an interdisciplinary approach. There is now an urgent need to focus research capacities and efforts more sharply.

18. This need has also been recognized in the recommendations being proposed to the Ministerial Conference by the European

Science Foundation, the European Commission and WHO (see document EUR/ICP/EHCO 02 02 05/7). Consonant with those recommendations, it was judged appropriate to reaffirm here the need for:

- epidemiological studies of ongoing climatic variations and trends in relation to health;
- development of mathematical models to forecast likely health outcomes in relation to the projected climatic/environmental changes;
- development of monitoring methods and systems to detect early evidence of health-related changes and to further inform the epidemiological and predictive modelling studies.

19. Within the foreseeable future, certain types of early health effects are likely to become detectable by means of epidemiological studies. Examples include:

- changes in the geographic range or seasonality of particular infectious diseases;
- time trends in health outcomes related to thermal extremes;
- increases in some types of skin cancer and infectious diseases commensurate with latitude-specific changes in ambient ultraviolet radiation exposure.

20. The European Region exhibits several characteristics that can enhance the informativeness of epidemiological research:

- a broad variety of environmental conditions, including gradients in geography, climate, culture and socioeconomic conditions;
- a variety of diseases occurring in diverse environments; studies of infectious diseases in relation to climatic influences could focus, for instance, on leishmaniasis around the Mediterranean, tick-borne encephalitis in Scandinavia and central Europe, and waterborne infectious diseases in countries throughout Europe;
- the distribution of malaria vectors in Europe and population dynamics in relation to climate;
- pre-existing regional networks for the recording of certain diseases.

Capitalizing on these research opportunities within Europe will, in turn, strengthen the information base for policy-making.

21. In addition, there are as yet few formal courses available for the instruction and training of a cadre of researchers. Therefore support is needed to ensure that short courses and other modular teaching components are provided for scientists wishing to address research work on health impacts associated with climate change and stratospheric ozone depletion.

RECOMMENDATION B

Support interdisciplinary research into the study and forecasting of health impacts of climate change and stratospheric ozone depletion, focusing particularly on health outcomes relevant to European populations, and ensure that funding is available for this purpose. Related disease monitoring and research networks should be strengthened. Professional education and training should also be strengthened, with emphasis on acquisition of the necessary interdisciplinary understanding and research skills.

Development of monitoring systems and health impact assessments

22. Monitoring the potential impacts of climate change and stratospheric ozone depletion on health is important for a number of reasons. This includes the provision of epidemiological data to inform policy-makers about the magnitude of effects. As a part of surveillance systems, such data can help to determine the requirements for and the effectiveness of preventive actions.

23. A number of infectious diseases are likely to be affected by climate change. These include vector-borne diseases (such as malaria, tick-borne encephalitis, Lyme disease, leishmaniasis and dengue) and other infectious diseases (such as legionellosis, salmonellosis, cholera, leptospirosis, cryptosporidiosis, campylobacter

disease). Monitoring networks exist for some of these diseases in Europe: Salmonella infections are monitored through the Enter-net network and Legionella infections by the European Working Group on Legionella Infection. WHO/EURO is monitoring the occurrence in Europe of other infectious diseases. However, more coordinated and intense monitoring efforts are needed for cryptosporidiosis, campylobacter disease, tick-borne encephalitis and Lyme disease.

24. Current systems for monitoring related indicators of exposure, e.g. local air pollutants and ground-level ultraviolet radiation, need to be expanded and strengthened. Bio-indicators of health risk also need to be developed, to detect early or unanticipated health impacts of climate change and stratospheric ozone depletion. For example, the monitoring of vector species could be strengthened in order to detect early changes in their distribution in Europe associated with climate change.

25. Monitoring systems are currently being developed for climate (the Global Climate Observing System), oceans (the Global Ocean Observing System) and land surface (the Global Terrestrial Observing System). These systems will coordinate measurement of a range of variables relevant to climate change and its impacts, but they lack indicators related to human health.

26. Populations vary in their vulnerability to health impacts, and they also vary in the resources available for adaptive responses. These differences in vulnerability, between and within populations, reflect a wide range of demographic, cultural, political, socio-economic and technological circumstances. National impact assessments should be undertaken, to describe and identify the means by which the vulnerability of populations and subgroups could be reduced and to select priorities for monitoring. It would be extremely valuable to include national health impact assessments for European countries in the forthcoming Third Assessment Report of the IPCC, to be completed in the year 2000. This report is expected to become the primary source of information on regional and sectoral impacts of climate change for policy-makers, the scientific community and stakeholders in the early years of the next century.

RECOMMENDATION C

Support the identification, development, standardization, evaluation and broad use of systems for monitoring and assessing changes in environmental indicators, bio-indicators of health risk and impacts on health, and indicators of population health status across Europe. These systems must be coordinated with global monitoring activities.

RECOMMENDATION D

Develop capacities, as necessary, to undertake national health impact assessments with the aim of identifying the vulnerability of populations and subgroups, and ensure the necessary transfer of know-how among countries. These assessments will be made available for possible consideration in the forthcoming Third Assessment Report of the Intergovernmental Panel on Climate Change.

Prevention

27. There are two basic strategies for preventing or minimizing the human health impacts of climate change and stratospheric ozone depletion. These are to slow down or halt environmental change processes by cutting down gaseous emissions, and to make adaptations that reduce the health impacts of those environmental changes. The former requires coordinated international action; the latter could be tackled on a local basis.

28. Authoritative scientific assessments have concluded that the world is already committed to experiencing these two environmental changes over at least the next few decades, even if radical reductions in emissions were achieved immediately. It is therefore important to assess how best to minimize adverse health impacts. IPCC has, during 1997–1998, reviewed the options for adaptation to reduce health impacts.

29. Adaptation strategies span a wide spectrum, from long-term efforts to reduce social and economic disparities, to the more immediate

provision of local information, incentives to behavioural change, and the use of technical protective devices. A simple example is that of reducing the extra deaths and episodes of serious illness experienced by urban populations during extremes of heat. Adaptations could include “weather-watch” warning systems, better housing design, climate-related urban planning (to reduce the “heat island effect”), and greater access to emergency medical care. As far as possible, such interventions should be undertaken on the basis of evidence that demonstrates their effectiveness.

30. The success of these strategies will rely on the involvement of local and national communities in the decision-making process, which in turn is dependent on an effective programme of information sharing and dissemination.

RECOMMENDATION E

Carry out ongoing reviews of the social, economic and technical prevention, mitigation and adaptation options available to reduce the adverse impacts of climate change and stratospheric ozone depletion on human health. Support the implementation of prevention, mitigation and adaptation strategies, taking into account national impact assessments (e.g. by strengthening surveillance activities), with appropriate public education and with special reference to vulnerable groups.

International perspectives

31. Since local emissions of greenhouse gases and ozone-destroying gases contribute to processes of global atmospheric change, preventive policies must be part of a coordinated international effort; it is not possible to mitigate their effects on a local or regional basis. Thus European countries have a moral obligation to contribute to this preventive effort on behalf of human wellbeing and health everywhere. The corollary to this is that taking local adaptive action, in the absence of such mitigation attempts, entails an unethical decision to protect local populations when more distant populations may be less able to protect themselves.

32. Climate change is likely to entail serious implications for human health in many countries through its impacts on food and water supplies and rises in sea levels. Climate change may therefore exacerbate current problems in regions around Europe (e.g. north Africa, western Asia) and indirectly lead to population displacement.

33. Countries in Asia, Africa and Latin America may equal or exceed the greenhouse gas emissions of developed countries within the next two decades. Fossil fuel combustion is associated with both greenhouse gas emissions and local air pollution. The latter also has a serious impact on human health. It is therefore important that European and other developed countries embark on cooperative activities with developing countries to adopt mitigation measures to reduce both the effects of future climate change and the direct health burdens associated with fossil fuel combustion.

RECOMMENDATION F

Orient the activities of bilateral and international donor agencies and other interagency bodies to provide resources and technical assistance to countries in need, for the implementation of both mitigation and adaptation strategies. These strategies should be designed to reduce the short- and long-term health impacts of climate change, fossil fuel combustion and stratospheric ozone depletion.

Conclusions

34. Human-induced changes in the global climate system and in stratospheric ozone pose a range of health risks. Irrespective of actions that might soon be taken to reduce or halt these environmental changes, human populations will be exposed to some degree of climate change and increased ultraviolet irradiation over the coming decades.

35. Global change processes are likely to have wide-ranging and potentially serious health consequences, including various risks to the health of European populations. Some health impacts will result from direct-acting effects (e.g. heatwave-related deaths, and ultraviolet-induced skin cancer); others will result from disturbances to

complex physical and ecological processes (e.g. changes in patterns of infectious disease, drinking-water supplies and agricultural yields). Effects on the health of human populations are likely to become evident within the coming decades. Furthermore, failure to reduce fossil fuel combustion (as the principal means of reducing greenhouse gas emissions) will result directly in a continuing (and increasing) avoidable burden of death and disease from exposure to local air pollution.

36. It is therefore important to enhance the capacity to detect the early health impacts of climate change and stratospheric ozone depletion. This can be achieved only by supporting monitoring, research and assessment activities.

37. Specific actions to be taken include:

- (a) the support of interdisciplinary research into the study and forecasting of health impacts of climate change and stratospheric ozone depletion, focusing particularly on health outcomes relevant to European populations (relevant disease-recording and research networks should be strengthened accordingly);
- (b) national health impact assessments to identify the vulnerability of populations and subgroups and the appropriate health impacts to be monitored (with the enhancement of national capacity to undertake such monitoring and assessment as necessary);
- (c) the development and evaluation of monitoring systems for the collection and assessment of information on changes in environmental indicators, bio-indicators of health risk, and population health status across Europe, including liaison with global monitoring activities;
- (d) adaptation strategies to reduce the health impacts of climate change, based on national impact assessments (which may entail strengthening surveillance methods), with appropriate public education and with special reference to vulnerable groups.

38. To ensure that these actions are carried out, it is proposed to establish a Europe-wide interagency network, to coordinate a broadly-based programme of monitoring, research, review, advocacy and development of adaptation policies. This network, which should have a coordinating centre (e.g. within the WHO European Centre for

Environment and Health), would facilitate the sharing of information and participation in wider international efforts and would help to protect the health of European populations from the effects of climate change and of stratospheric ozone depletion.

The need for this document was identified by the European Environment and Health Committee (EEHC) in 1997. A working group was established, consisting of representatives of national governments, international organizations and the European Commission, and academics. The areas of expertise represented included biology, climatology, epidemiology, geology, infectious disease, mathematics and public health. Two meetings were held; the working group reviewed draft texts with assistance from experts of the London School of Hygiene and Tropical Medicine, and comments were received from the EEHC.

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People are concerned about the impact on their health of the climate warming and stratospheric ozone depletion that Europe has been experiencing for the last century. This publication attempts to clarify what early effects these environmental changes are having on our health, and what further effects they may have in the future.

What is certain is that more frequent thermal stress, associated or not with air pollution, causes illness and death, especially among the elderly; extreme weather events such as floods cause death, illness and material damage; some water- and foodborne diseases increase during extreme weather conditions, such as heavy rainfall and heatwaves; malaria could increase with climate warming; and ozone depletion increases skin cancer and weakens the immune system. While much is still uncertain about the precise relationship between changes in the climate and changes in disease patterns, the need for action is clear: action either to reduce the climate change itself, or to reduce its harmful effects.

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