



Earth System
Science Partnership

DIVERSITAS IGBP IHDP WCRP

Global Environmental Change and Human Health

Science Plan and Implementation Strategy

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ESSP JOINT PROJECT ON GEC AND HUMAN HEALTH

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Table of contents

| | |
|---|----|
| Executive Summary | 01 |
| Preamble: Science Plan and Implementation Strategy | 03 |
| 1. Introduction | 07 |
| 1.1. General comments | 07 |
| 1.2. Global Environmental Change: Definitions | 08 |
| 1.3. Pathways by which GEC can affect human health | 10 |
| 1.4. Why a project on GEC and human health | 11 |
| 1.5. Training Component | 12 |
| 1.6. The human dimensions of the research | 14 |
| 2. Conceptual Framework and Major Science Issues | 16 |
| 2.1. Goals and Objectives | 16 |
| 2.1.1. Assess the past, current and future health impacts of GEC | 17 |
| 2.1.2. Enrich the policy discourse on adaptation and mitigation | 18 |
| 3. Scientific Themes | 20 |
| 3.1. Atmospheric composition changes and health | 21 |
| 3.1.1. Impacts of climate change on health | 21 |
| 3.1.2. Stratospheric ozone depletion and health | 34 |
| 3.2. Land Use/Land cover changes and human health issues | 37 |
| 3.2.1. Ecosystem functions and services | 38 |
| 3.2.2. Traditional, pharmaceutical and industrial uses of biodiversity resources | 40 |
| 3.3. Global environmental changes and infectious diseases | 41 |
| 3.3.1. Land use/land cover changes and vector and rodent-borne infectious diseases | 42 |
| 3.3.2. Changes in human-animal relationships and the emergence and spread of zoonotic pathogens | 46 |
| 3.3.3. Food-related, water-related and other infectious diseases | 48 |
| 3.4. Food-producing systems and health | 50 |
| 3.5. Urbanisation and health | 57 |
| 3.5.1. Extreme climate events, thermal stress and air pollution | 58 |
| 3.5.2. Urban sprawl and exposure to vector-borne diseases | 58 |
| 3.5.3. Water quality and disease outbreaks | 59 |
| 3.5.4. Population mobility | 60 |
| 3.5.5. Crowding, concentration and the diffusion of disease | 61 |
| 3.6. Vulnerability, social representation and resilience building | 63 |
| 3.6.1. Vulnerability | 63 |
| 3.6.2. Social representation and resilience building | 65 |
| 4. Implementation Considerations | 68 |
| 4.1. Interdisciplinary methods and data needs | 68 |
| 4.1.1. Methods and data | 68 |
| 4.1.2. Human health and GEC scenarios | 70 |
| 4.2. Integrative activities | 71 |
| 4.2.1. Multi-site approach to integrate monitoring and surveillance | 71 |

| | |
|---|-----------|
| 4.2.2. Population health surveys | 71 |
| 4.2.3. Data linkage | 72 |
| 4.3. Collaboration with other programmes and networks | 73 |
| 4.4. Expectations and project timeline | 75 |
| 5. Concluding remarks | 77 |
| 6. References | 78 |
| 7. Acknowledgements | 86 |
| 8. Acronyms and Abbreviations | 87 |

Executive Summary

This Joint Project, *Global Environmental Change and Human Health*, is the fourth within the Earth System Science Partnership (ESSP). It is being developed as a logical complement to the three ongoing ESSP projects. Those three projects address the global carbon cycle (Global Carbon Project, GCP), the global water system (Global Water System Project, GWSP), and Global Environmental Change and Food Systems (GECAFS). Changes in each of those three systems influence, via diverse pathways, human wellbeing and health.

It is widely, often intuitively, understood that human societies and the wellbeing and health of their populations depend on the flow of materials, services and cultural enrichment from the natural world. Nevertheless, to date there has been little formal description and study of the relationships between global environmental changes (GEC) and human health, and of the ways in which social institutions and processes modulate those relationships. For several human-induced global environmental changes, particularly changes to the world's climate system and to the ultraviolet radiation-filtering functions of the stratosphere, there has been a recent increase in research into the main health risks. But for most other GECs little formal research on the risks to human health has been carried out. Indeed, among the practitioners of the various scientific disciplines engaged in studying the processes and impacts of GECs – including environmental sciences, ecology, geography, economics, etc. – there has been relatively little recognition that ecosystem disruptions, species extinctions, degradation of food-producing systems, the perturbation of cycling of elements and nutrients, and prevailing forms of urbanisation pose risks to the wellbeing and health of human populations.

Against this background the need has now been recognised within the Earth System Science Partnership for a Joint Project to increase, strengthen, and then support and coordinate the (now slowly evolving) international research network in relation to this topic.

The Project's main research goals are:

1. Identify and quantify health risks posed by GEC, now and in the reasonably foreseeable (scenario) future:
 - a. Develop methods of modelling/understanding tradeoffs between economic development, environmental change and human health.
 - b. Take account of the roles of culture, social institutions and technology choices in modulating health risks, affecting vulnerability and influencing policy responses.
2. Describe spatial (geographic, intra/inter-population) and temporal differences in health risks, to better understand vulnerabilities and priorities for interventions.
3. Develop adaptation strategies for reducing health risks, assess their cost-effectiveness, and communicate results (especially to decision-makers).
4. Foster research training programs, to boost networked international research capacity in GEC and Human Health.

The **Science Plan** incorporates a review of the scientific literature about the context and nature of various major GECs and the pathways by which they do, or are likely in future to, affect human health. Important questions and priority topics for research are identified, for each of the following major GEC domains:

1. Atmospheric composition changes and their health impacts
 - a. Climate change and health
 - b. Stratospheric ozone depletion and health

2. Land Use/Land Cover changes and human health issues
 - a. Ecosystem functions and services
 - b. Traditional, pharmaceutical and industrial uses of biodiversity resources
3. Infectious disease and Global Environmental Changes
 - a. Land use/land cover change and vector/rodent-borne infectious diseases
 - b. Changes in human-animal relationships and emergence/spread of zoonoses
 - c. Food-related, water-related and other infectious diseases
4. Food-producing systems and health
5. Urbanisation and health
 - a. Extreme climate events, thermal stress and air pollution
 - b. Urban sprawl and exposure to vector-borne diseases
 - c. Water quality and disease outbreaks
 - d. Population mobility
 - e. Crowding, concentration and the diffusion of disease
6. Vulnerability, social representation and resilience building
 - a. Vulnerability
 - b. Social representation and resilience building

The **Implementation Strategy** for the above Science Plan is then addressed in relation to: (i) the need to develop systems-based thinking and analytic methods; (ii) the need for stronger interdisciplinarity, highlighting the human dimensions of the problem; (iii) the need for enriched collaborative networks (regionally and globally – and including collaboration among the ESSP projects); and (iv) various key aspects of project management, encompassing the location and operation of the IPO, the role and function of the Scientific Steering Committee, and the training and capacity-building activities that should be developed and promoted.

A three-stage Project Timeline is proposed, along with the intended outcomes of the research.

The information in the report is also intended for the information of policy-makers, to enrich understanding of how these modern-day global environmental issues bear on human societies, wellbeing and health. The information should also prove useful for fund-raising activities for implementing this ESSP Joint Project on Global Environmental Change and Human Health.

Preamble

Science Plan

The Chairs and Directors of the ESSP (Earth System Science Partnership) charged DIVERSITAS at its 2002 annual meeting with convening a scoping meeting on *Global Environmental Change and Human Health*. The meeting occurred on 27 February - 1 March 2003 in Paris. It was funded by all ESSP partners, with additional support from the French Institute for Biodiversity (IFB).

The meeting was co-chaired by Professor Tony McMichael, Director of the National Centre for Epidemiology and Population Health, the Australian National University, Canberra, Australia and Professor Ulisses Confalonieri, from the National School of Public Health in Rio de Janeiro, Brazil. Both Co-Chairs participate in the work of the Intergovernmental Panel on Climate Change (IPCC) and of the Millennium Ecosystem Assessment (MA) on health-related issues. Participants came from 15 countries, representing the four ICSU global environmental change programmes (DIVERSITAS, IGBP, IHDP, and WCRP), various research programmes and academic institutions, and a representative from the UN's World Health Organisation, Dr. Carlos Corvalan (Department of Protection of the Human Environment, WHO, Geneva).

The meeting participants agreed that a new joint (networked) project on human health impacts was a priority – and that it would logically complement the three ongoing ESSP projects on the global carbon cycle (Global Carbon Project, GCP), the global water system (Global Water System Project, GWSP), and Global Environmental Change and Food Systems (GECAFS), each of which systems influences human wellbeing and health.

The ESSP launched the Science Plan and Implementation Strategy for its fourth Joint Project on Global Environmental Change and Human Health in November 2006 at the ESSP Open Science Conference (Beijing, China). IHDP was not a full sponsor of the project at the time, as the IHDP Scientific Committee decided that the Science Plan would need more input from the human dimensions side. The IHDP Scientific Committee, therefore, approved the creation of an IHDP Task Force on Global Environmental Change and Human Health, under the leadership of Professor Manuel Cesario (UNIFRAN, Brazil), during the IHDP - IGBP Joint Scientific Meeting in March 2007 (Angra dos Reis, Brazil), in order to organize and formulate the IHDP contribution to the project. It was agreed at the ESSP Chairs and Directors level that the contribution of the IHDP Task Force would be merged into the GECHH Science Plan, and that IHDP thereafter would become a sponsor of the project. As a result this ESSP joint project on Global Environmental Change and Human Health is now co-sponsored by all four partner programmes: DIVERSITAS, IGBP, WCRP, and the IHDP.

In naming this new project, the phrase “Global Environmental Change” was preferred to the wider-ranging, more open-ended, term “Global Change”. The former phrase reflects directly the terminology of the ESSP (especially that of GECAFS). It also captures the important fact that the still-enlarging human population, with its increasingly intense economic activities, is now creating a range of global or worldwide environmental risks to wellbeing and health, of unprecedented scale and systemic nature. This reflects humankind's unintended transformation of several of Earth's great natural biogeophysical systems – a transformation that is occurring in concert with various “globalising” transformations in the economic, social, cultural, demographic, communication, trade and political realms. As the world undergoes increasing urbanisation, the process of the growth, spread and environmental impact of cities

sits at the interface of today's environmental, demographic and social changes. Hence, the topic of urbanisation is included in this project.

There has been little systematic research on this complex topic of global environmental change (GEC) and human health, and there is not yet a well-established international research community addressing the topic. Meanwhile, it has become evident, including through the recent work of the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, and formal assessments of the health consequences of biodiversity losses, that there is an urgent need to understand better how these large-scale changes affect human well-being, health and survival around the world – and how they are likely to do so in future.

Hence, the Science Plan is prepared for information and, especially, to facilitate awareness and engagement of researchers in this new ESSP joint project on *Global Environmental Change and Human Health*. The Plan also provides information for national and international policy-makers, and a basis for fund-raising activities for implementation.

Implementation Strategy

A follow-up meeting, organised by DIVERSITAS on behalf of the ESSP, occurred on 14-16 January 2004. The meeting was, again, co-chaired by Professors McMichael and Confalonieri. Participants reconsidered briefly the Science Plan and developed an implementation strategy for the plan. Participants discussed the implementation strategy for six scientific themes, which variously cut across the main goals of the Science Plan:

1. Atmospheric composition changes and health
2. Infectious disease risk (including emergence) in response to GEC
3. Biodiversity changes and health
4. Food-producing systems (including land use/cover and fresh-water systems) and health
5. Urbanisation and health
6. Vulnerability and adaptation

It was recognised that these themes are not independent of one another. They often affect one another, and they often combine interactively in their impacts upon human health. Further, while some GECs are of a “primary” kind, resulting directly from excessive human pressure on the natural environment (e.g., greenhouse gas accumulation and resultant climate change, stratospheric ozone depletion; disruption of global elemental cycles; land clearance), others (e.g., biodiversity changes) occur substantially in response to those primary changes. Food-production both affects and is affected by land use/cover; freshwater systems and biodiversity changes. Likewise, urbanisation both contributes to GEC and the urban environment is often affected by GEC. (See also Figure 1, page 10.)

International Project Office

The Planning Team discussed possibilities for an International Project Office. Suggestions in relation to Brazil, Canada, China, and India were initially made with later additions of Austria, Germany, Mexico and the UK. At time of printing, IPO opportunities were being explored with several parties.

Key perspectives underlying this initiative

Two key points underlying this international research coordination initiative were agreed to in these two initial meetings:

1. Population health is a crucial “bottom-line” indicator of the impacts of Global Environmental Changes (GEC) on human societies. Health outcomes are affected, directly or indirectly, by changes in water and food supplies, the integrity of terrestrial and coastal ecosystems, biodiversity, microbial environment and climate. Therefore, in principle, trends in population health should provide critical information about society’s success in attaining sustainable development – since sustainable development is, in the last analysis, primarily about maximizing and maintaining positive human experiences: wellbeing, health and survival.

(However, impacts on health are often time-lagged because of the intrinsic buffering of health risks by culture and technology. A further technical difficulty is that of identifying initial, often marginal, impacts of GEC against a complex background of other non-GEC influences on human health.)

2. The potential population health impacts of GEC extend into future decades, and are likely to increase if environmental conditions deteriorate further. This underscores the profound ecological significance of today's ongoing, and generally escalating, human-induced changes in the Earth System. Recognition of this dimension of the problem will enrich the policy discussion and should thereby help to motivate policy responses, including both mitigation and adaptation measures.

This new ESSP joint project therefore seeks to identify, characterise, and quantify the health impacts of GEC and to forecast the trends in future health impacts. In doing so, it will explore the roles of social institutions, culture and human behaviour as modulators of these relationships and as determinants of the scope and nature of both mitigation and adaptation responses.

This internationally coordinated research on global environmental changes and their consequences for human wellbeing and health will form a new, dynamic, and integrative node in the developing domain of Earth System Science. They will help focus on policy options that ensure a healthier and more sustainable future.

1. Introduction

1.1. General comments

Human population health depends, fundamentally, on the conditions of the social and natural environments. In other words, viewed in ecological and population-level terms, the limits to, and characteristics of, a population's health profile are determined in the medium-to-longer term by the adequacy of environmental conditions. This viewpoint differs from the usual day-to-day perspective that dominates popular discussion about health and disease – and which focuses on how individual behaviours, circumstances and (increasingly) genes affect who, within a population, is most likely to develop a particular disease.

The challenge, here, is to understand how environmental conditions and changes – especially, now, global environmental changes – influence, perhaps determine, the health outcomes for whole communities and populations over a longer time frame. The related need is to understand how social, cultural and political conditions, structures and processes influence, first, the vulnerability of the community or population to adverse impacts on health, and, second, their capacity to make adaptive responses that lessen the risks to health.

Over the past half-century there has been a growing awareness of health risks arising from environmental exposures, including from modern industrial practices. This spectrum of health hazards encompasses toxicological, physical and microbiological exposures, all usually confined within a localised setting. Local air pollution, environmental tobacco smoke and pesticide residues in local food produce are familiar examples. Such localised environmental hazards remain important public health issues, particularly in many developing countries.

Today, however, as the scale of human impact on the world's environment increases, larger-scale and more complex changes in ecological and biogeophysical systems portend potentially greater, and longer-lasting, risks to human health and survival. These global environmental changes are unprecedented in human experience, at least at this scale, and some of them (such as climate change, stratospheric ozone depletion, and the global amplification of activated nitrogen) are new at any scale. They require serious, immediate and internationally coordinated research attention.

The category **“Global Environmental Change”** (GEC) refers to the set of biophysical transformations of land, oceans and atmosphere, driven by an interconnected complex of socio-economic and natural processes (Gobel, 2005), see Box 1, page 9. Concurrent with the modern phenomenon of “globalisation” (i.e., the growing and accelerated interconnectedness – cultural, economic, physical, electronic, etc. – of the world), and to some extent as a consequence, humans have recently begun to induce much larger-scale changes in Earth's biogeophysical life-support systems. This reflects the huge aggregate environmental impact of human population size, economic activity, prevailing technologies and consumption patterns.

For example, human actions are increasing the atmospheric concentration of several energy-trapping gases, thus amplifying the natural “greenhouse effect” that keeps Earth comfortably above freezing-point. In its Third Assessment Report, the UN's Intergovernmental Panel on Climate Change (IPCC, 2001) stated: “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.” The other major types of GEC include stratospheric ozone depletion, biodiversity loss and changes, land and sea use changes, disruption of elemental cycles (e.g., nitrogen, sulphur and phosphorus),

depletion of freshwater supplies, urbanisation and the global dissemination of persistent organic pollutants. These all pose serious health risks to current and future human societies.

Periods of disruptive social and environmental transition have often been accompanied by setbacks in human health and survival. In particular, there are well-known historical examples of infectious disease outbreaks that were caused by social and environmental transitions and which, in turn, generated social, economic and geopolitical changes. Emerging infectious diseases like SARS, HIV/AIDS, H5N1 Avian Influenza and West Nile Virus – joining a growing list of over 30 infectious diseases new to biomedical science since the mid-1970s – show the power of infectious diseases to arise suddenly, spread rapidly, and affect trade, travel, tourism and livelihoods. Sometimes a single serious epidemic infectious disease arrives, as with influenza at the end of World War I or the Black Death (bubonic plague) in fourteenth-century Europe. Infectious diseases can also arrive in groups, as with the tuberculosis, smallpox and cholera epidemics of Charles Dickens' England. In the past three decades, new infectious diseases have surfaced at an historically unprecedented pace.

The advent of these GECs signifies that, today, we have begun to live beyond Earth's capacity to supply, absorb and replenish. Meanwhile, many developing countries bear a "double-burden": poverty and large-scale environmental degradation, driven by both local and global factors. There is therefore an urgent need to understand the range of possible consequences of global environmental change for human societies, especially health consequences – and how these will affect the pursuit and attainment of the UN's Millennium Development Goals.

1.2. Global Environmental Change: Definitions

The definition of Global Environmental Change (GEC) is based on the principles of the "Amsterdam Declaration on Global Environmental Change" – which led to the creation of the ESSP.

Earth System

The Earth System behaves as a self-regulating system, comprising physical, chemical, and biological components and is affected by, and affects, the social, economic and political dimensions of human societies – their social structures, economic activities and institutions. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability. The understanding of the natural dynamics of the Earth System has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.

Global Environmental Change

Human-induced changes to the structure, composition or function of large natural biogeophysical and ecological systems entail changes in the complex array of forcings and feedbacks that characterise the internal dynamics of the Earth System (Steffen & Elliott 2004). These planetary-scale environmental changes are of great significance because they are diminishing the capacity of Earth's natural environment to supply and replenish resources, and to absorb and recycle the waste products of the activities of humans and their domesticated animals. Increasingly, these Global Environmental Changes are equal to some of the great forces of nature in their extent and impact. Some of the changes are accelerating.

Global Environmental Change cannot be understood in terms of a simple cause-effect paradigm. Nor can any one of the changes be considered in isolation of the other coincident changes. These effects interact with each other and with local- and regional-scale changes in ways that are difficult to describe and predict. Earth System dynamics are characterised by

critical thresholds and abrupt changes. The Earth System has operated in different states over the last half million years, sometimes undergoing abrupt transitions (within a decade or less). Human activities can switch the Earth System to alternative modes of operation that may prove irreversible and less hospitable to humans and other life.

These changes are “global” in the sense of either being globally integrated (i.e., entailing a systemic change to a global system, such as the climate system) or occurring by worldwide aggregation of widespread local changes (e.g., land degradation, species extinctions).

Box 1. The main types of human-induced Global Environmental Change

Changes to atmospheric composition (and, therefore, function)

- Greenhouse gas accumulation, leading to climate change
 - Warming
 - Altered precipitation
 - Altered patterns of extreme events
 - Sea level rise
- Stratospheric ozone depletion (allowing increasing flux of ultraviolet radiation)

Changes in land-use, land cover changes and sea-use changes

- Infrastructure development (roads, etc.), Water projects (dams, irrigation, etc.), and Agriculture
 - Deforestation and reforestation
 - Habitat fragmentation
 - Land conversion and loss of soil fertility
- Aquaculture
 - Depletion of coastal- and marine ecosystems stocks

Desertification

Biodiversity changes

- Loss of genes, species and ecosystems
- Human-driven species redistribution (biological invasions)
- Structural and functional changes in ecosystems

Changes to biogeochemical cycles (nitrogen, phosphorus, sulphur, carbon)

Changes to the hydrological cycle, and depletion of freshwater supplies and quality

World-wide dissemination of persistent organic pollutants (POPs)

Urbanisation

- Sanitation (waste disposal, water supply)
- Air pollution (local and, increasingly, regional)
- Housing conditions and location
- Enhanced “microbial traffic”: crowding, poverty, networks, mobility, behaviours

1.3. Pathways by which GEC can affect human health

Figure 1 (below) illustrates the main pathways by which GEC can affect human health. The categories of health impacts shown are not exhaustive. For example, many of the impacts shown would be associated with mental health problems (e.g., post-traumatic stress disorders, suicides) and other environmental changes would result in conflicts over depleted resources or would cause the diverse health risks typically associated with migration and environmental refugee status.

The figure also does not attempt an overlay that portrays the many important conditioning and determining influences of cultural, social, behavioural and institutional factors.

The area that now requires particular research development is shown within the grey-shaded rectangle. There is, of course, still much research to be done in relation to the health consequences of stratospheric ozone depletion and global climate change. However, that research domain is already attracting substantial attention and does not need as much “affirmative action” as do the relationships shown in the grey area – many of which are intrinsically complex, entailing perturbations of ecosystems and feedbacks between concurrent environmental change processes (Sieswerda et al., 2001).

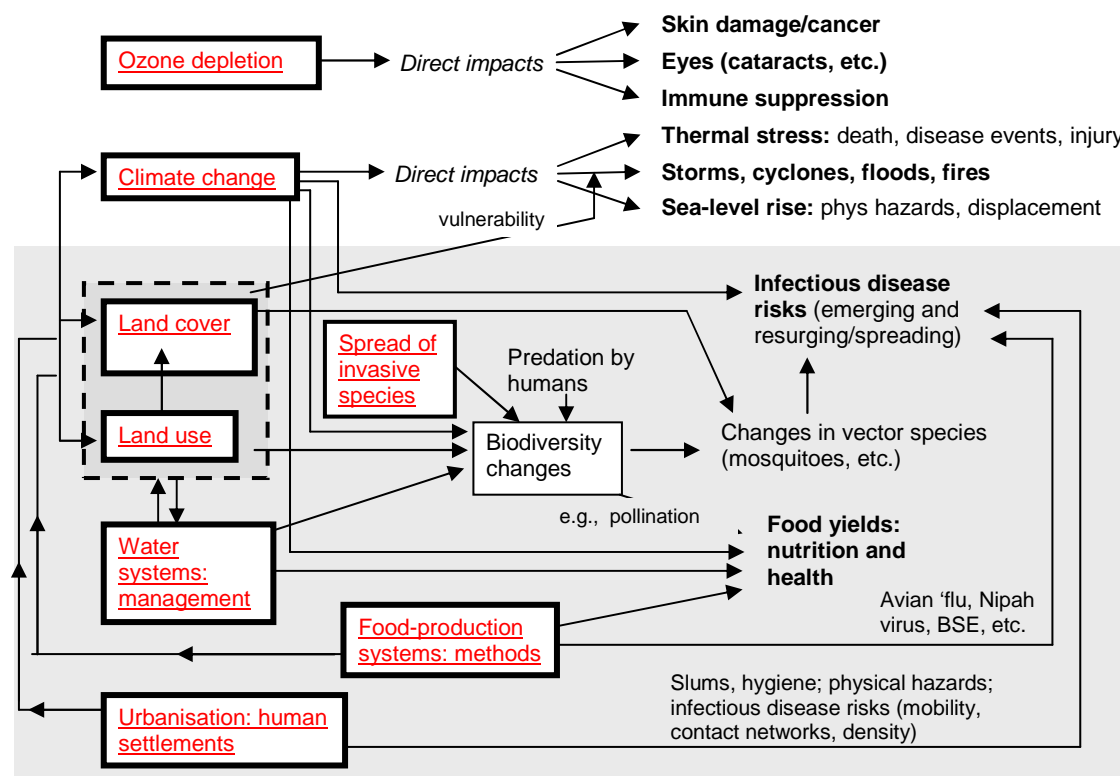


Figure 1. Schematic diagram of the main types of bio-geo-physical pathways by which Global Environmental Changes (boxed underlined text) can affect human health

The section above the grey area refers to the “direct” health impacts of global atmospheric changes. The grey area refers to the more complex, multivariate, paths by which GEC can affect risks of infectious diseases and nutrition. This project is likely to pay particular attention to developing research and risk assessment in relation to the grey area. That area poses substantial, and increasing, risks to health, but is difficult to study via conventional research strategies and methods.

1.4. Why a project on GEC and Human Health?

Our increasing recognition that humankind is now imposing great changes and stresses on global environmental systems, the biosphere's "life-support systems", necessarily draws attention to the substantial and increasing risks to human wellbeing and health. This will particularly threaten health and survival in many disparate vulnerable populations around the world (see examples in Table 1 below).

Table 1: The estimated numbers of people, globally, at risk from selected major examples of the adverse health impacts of global environmental changes.

| Category of health risk | Size/proportion of populations at risk | Types of GECs involved |
|--|---|--|
| Malaria | 40% of world population | Climate change and land use change |
| Dengue fever | 3 billion | Climate change, urbanisation, world trade |
| Diarrhoeal diseases (associated with water quality/quantity) | 1 billion people | Climate change, land cover change, pollution, irrigation and freshwater shortage, urbanisation |
| Malnutrition (especially food shortages) | 840 million | Climate change, land use, freshwater shortage, biodiversity change |
| Health consequences of desertification: malnutrition; respiratory diseases; impacts of population displacement | 250 million people | Climate change, land use, land cover change |
| Skin cancer, eye disorders, immune system depression | Mid-high latitude populations (1-2 billion) | Stratospheric ozone depletion |

This topic is complex and still relatively new to researchers in the world of health sciences. There are, currently, relatively few persons, groups and institutions around the world undertaking formal research in this topic area. Nevertheless, those parties already comprise an

informal network, much reinforced by participation in two major international scientific review-and-assessment exercises over the past decade – the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MA). Several other more recent international initiatives have contributed to this emergence of an international constituency for this proposed new ESSP Project. They include recent initiatives by the World Health Organization to nurture an international network of research centres in developing and developed countries and to collaborate in the Biodiversity and Health Project, and the carrying out of the “Climate Change Futures: health, biodiversity and economic dimensions” Project (based at Harvard University).

A recurring difficulty has been the imbalance in numbers of researchers in developing and developed countries. Not surprisingly, the world’s lower-income countries have fewer trained researchers working in the population health arena, and they also have differing priorities because of the enormity of some of the public health problems that press immediately upon them. (This, despite the emerging recognition that, in general, the adverse health impacts of GEC in both the near- and longer-terms will be greater in those lower-income countries – in part because of geographical location and in part because of the higher vulnerability of their populations.)

There has also been an imbalance in the GEC topic areas addressed. Much of the recent new research effort has focused on studying the influence of climatic changes upon human health. This effort has been greatly stimulated by the work of the IPCC, with its ongoing documentation of knowledge gaps and research needs. The IPCC process has also created an interdisciplinary milieu within which health impacts research could thrive and has helped to create a funding environment wherein at least some agencies and government funding bodies have begun to support research on climate change health impacts.

The same stimuli are now beginning to operate in the wake of the Millennium Ecosystem Assessment (MA), with its focus on the current and future consequences of human-induced changes to ecosystems and biodiversity. The MA process revealed a generalised paucity of well-documented research into how human-induced changes to ecosystems actually affect human wellbeing and health. This is beginning to change, as some of the researchers who have been actively studying climate change health impacts now broaden their research agenda, and as new (often younger) researchers, aware of the emerging importance of this topic, enter the arena. Further, there is an increasingly receptive interdisciplinary environment, as researchers in cognate disciplines better appreciate that much of the real (and politically persuasive) importance of their work derives from the potentially serious implications for human societies.

A further consequence of this evolution of research engagement is the recognition that much of the research needs to be conducted within a systems context, and to draw upon a wide spectrum of natural and social sciences. Many of the modifications of (for example) infectious disease transmission, or of local food production, or of local environmental stability (e.g., against flooding) are the result of coexistent, and often interacting changes. This means that there is an increasingly recognised need for the development of systems-based modelling and analytic techniques. This will require a closer integration of disciplines – and this should include a close working relationship between the component projects of the ESSP.

1.5. Training Component

The other obvious requirement of the project is that of capacity-building. This project will provide an important contribution to the emerging international research and policy

development effort if it can support and stimulate the participation and training of researchers in less well-resourced countries.

Objectives

The main objective of the training component in this Project is, in the short term, to stimulate the interest of young scientists in the relationships between the GECs and human health and well being, as a primary focus for their professional work. In the long term, it aims to contribute to the formation of a critical mass of professionals – especially in the health sector – able to develop investigations on the health impacts of GECs. The very few scientists currently involved with these important issues worldwide is a clear indication of the existing gap in terms of prepared manpower to address GEC-Health problems.

The training of these scientists would facilitate the formation of new research groups concerned with GEC/health issues as well as expand and consolidate the few existing ones. It would also give feedbacks to the Project itself.

The main target of training should be health scientists with an adequate background in epidemiology and human population health. Their training would enable them to become familiar with the large-scale global environment changes and how research methods could address the associated health impacts and responses of populations.

Strategies

An annual two-week long course for international trainees (10-15 people) will be offered, using specific funds raised for that purpose. The existing GEC and human health research groups in Universities and Research Institutes in a few countries – and informally recognized by the Program for the Protection of the Human Environment of the WHO - should take a leading role in the organization of the courses, in the indication of the instructors and also in the provision of infrastructure for the course, on a rotational basis (every year in a different country). The Project's Scientific Steering Committee will be responsible for the selection of the candidates. Priority will be given to young candidates enrolled in PhD Programs who wish to use these themes as a subject for their dissertation.

Course content

The detailed curriculum will be developed by the Scientific Steering Committee of the Project and should include the following:

1. Introduction to Earth System Science: drivers and biophysical aspects of the GECs.
2. Issues of scale in GEC and human health research and data. Methodological approaches, including systems-based analyses, the development and use of scenario-based risk forecasting, and the role of interdisciplinary research.
3. Large-scale changes to atmosphere: possible health impacts and their measurement.
4. Large-scale changes in terrestrial/marine systems: conceptual framework, health impacts.
5. Assessment of vulnerability of populations to the health impacts of GECs.
6. Consideration of modulating and contributory roles of culture, technology, social institutions and human behaviour to GEC impacts and to the response to perceived and anticipated health risks.

1.6. The Human Dimensions of the research

Climate change can affect human health directly [e.g., thermal stress, floods and storms] and indirectly through changes in the ranges of disease vectors (e.g., mosquitoes), water-borne pathogens, water quality, air quality, and food availability and quality.

The actual health impacts will be strongly influenced by local environmental conditions and socio-economic circumstances, and by the range of social, institutional, technological, and behavioural adaptations taken to reduce the full range of threats to health.

(IPCC, 2001)

A guiding principle of the ESSP is that the topics under investigation span natural and human-induced environmental processes and conditions – and the human behavioural, social and institutional contexts that influence: (i) those human impacts on the Earth System, (ii) human vulnerabilities to the consequences of those impacts, and (iii) human policies and actions as both drivers and responses to those perceived consequences. Nevertheless, it is important to note here that the aim of this fourth ESSP project is not to look at the primary effects of socioeconomic, cultural and political circumstances on population health - although the role of those circumstances in influencing the genesis of GECs, their impacts and the coping responses to them will be an important part of this research program.

Each of the four ICSU Global Environmental Change programmes should therefore have a clearly identifiable interest in, and a reasonable level of engagement with, each of the ESSP joint projects. At the same time, it can be expected that there will be some ‘discomfort’ between the joint projects and their sponsoring programmes, such that mutual learning necessarily results. This should be the added value of working within this overall ESSP programmatic context.

Any conceptual and methodological discomforts aside, it is axiomatic that inter-disciplinary approaches will be widely necessary, bringing together the earth sciences, the biological sciences, health sciences, social sciences and others. Those relationships are extremely important. The task here, as part of the process of identifying, assessing and forecasting risks to health, is to integrate consideration of the “human dimension” concepts, variables and processes that initiate and modulate the main relationships of interest.

There is a further practical consideration. Since the topic area of GEC and Human Health is relatively under-developed as a formal research arena, there will be some wisdom in the early stages in “learning to walk before learning to run”. It has taken a decade of determined work by a small number of epidemiologists and related health, social and natural scientists to establish the importance, and feasibility, of research in this domain. Therefore, before embarking on wholesale “horizontal integration” of all human, social and institutional variables into analyses of causal relationships, health risks, adaptive impacts and forecasting-models, there is much still to be learnt about the basic relationships between environmental changes and human health risks. A rational staging of the science will be needed – perhaps with selected demonstration projects that highlight different configurations of inter-disciplinarity. (This type of staging has characterised the development of research methods and concepts in the domain of climate change and health.)

In 2005, the WHO established a new Commission to review evidence and promote action on Social Determinants of Health (http://www.who.int/social_determinants/en/). The

commission's aims are to address the gross inequities in health between countries and among social groups within countries. These inequities are dramatic and demand attention. Within countries, too, there are large inequities; evidence shows a twenty-year gap in life expectancy between the most and least advantaged groups in some countries. As another important issue, social determinants of health come from across the social and economic spectrum that affects the circumstances in which people live and work. Poverty in its various manifestations, inequity, food insecurity, social exclusion and discrimination, inappropriate housing, shortcomings in safeguarding early childhood development, unsafe employment conditions, and insufficient quality of health systems account for most of the global burden of disease and death, and for the bulk of existing health inequities between and within countries. These influences are socially determined and can and must be addressed also in the context of GEC.

Particular attention should be paid to social institutions and their role(s) in minimising adverse health impacts of GEC. That stated, there is again need for an appropriate staging of some such research. For example, in order to know in which communities (and their vulnerable sub-groups) to concentrate warnings and social-support efforts in order to reduce deaths from heatwaves, we need first to determine which subgroups are at greatest risk.

For some adaptation modalities, such as sea-walls and better water-engineering in relation to storm surges and floods, and the use of bed-nets to protect against malaria, the safety and health benefits are well known. Therefore the project should embrace development of policy recommendations on that type of adaptive strategy.

Nevertheless, in the overall development and management of this ESSP joint project, it must be generally borne in mind that, in order to influence policies to protect population health and safety, there must be an evidence base in relation to the actual risks to health. The experience of the recently-completed MA was that very little research has yet been done on how changes in ecosystems affect risks of physical hazards, stability of infectious disease transmission, micronutrient content of crops and their likely effects in young children, etc. In the absence of some "baseline" understanding of the types, sources and magnitudes of risks to health from environmental changes, the next, more integrated, generation of research questions often cannot easily, or rationally, be framed.

This project should also include research into how best to address the wider penumbra of secondary health effects, flowing from the primary impacts of GEC. Indeed, the recent scientific assessments within the IPCC and the Millennium Ecosystem Assessment (MA) have discussed how these disruptive changes, via physical population displacement, loss of livelihood and conflict situations, will increase the flow of "environmental refugees". This will, inevitably, cause a wide spectrum of (mostly adverse) health consequences. Although these are intrinsically difficult to study and to quantify in formal fashion, the project should, nevertheless, find ways by which they can be addressed, assessed and communicated.

2. Conceptual Framework and Major Science Issues

2.1. Goals and Objectives

Goals

The project has four primary goals:

1. Identify, characterise and quantify health risks due to GEC, now and in the reasonably foreseeable (scenario-based) future:
 - a. Develop methods of modelling/understanding tradeoffs between economic development, environmental change and human health.
 - b. Take account of the roles of culture, social institutions and technology choices in modulating health risks, affecting vulnerability and influencing policy responses.
2. Describe spatial (geographic, intra/inter-population) and temporal differences in health risks, to better understand vulnerabilities and priorities for interventions.
3. Develop adaptation strategies for reducing health risks, assess their cost-effectiveness, and communicate results (especially to decision-makers).
4. Foster research training programs, to boost networked international research capacity in GEC and Human Health.

An over-arching goal is to elucidate the spectrum and magnitude of risks to human wellbeing and health, consequent upon human-induced global environmental changes, in order that society at large has a fuller understanding of the actual and likely consequences of the ways in which, collectively, human societies are changing the Earth System.

Research objectives

As corollary to the above project goals, the two main research objectives are:

1. Assess past, current and future health impacts of GEC

Assess the relationships, and where possible the mechanisms, by which GEC affects health outcomes. The research results should then be applied to the development of adaptation (impact-lessening) measures, such as improvements in living and working conditions, strengthening of relevant social institutions, and the use of Health Early Warning Systems.

2. Enrich the policy discussion about the need for, and methods of, mitigation and adaptation

Communicate the results of the above research to the wider public policy arena. This should facilitate the development of strategies and policies for both mitigation (hazard reduction or elimination) and for increasing the knowledge levels, preparedness, adaptive capacity and resilience of local populations.

An important additional research task is to develop new methods of modelling population health risks and burdens, and of clarifying the tradeoffs between economic development, environmental change and human health. This in turn will require an expanded range of data-sets and an extension of ways of using existing data-sets.

Further, the development of networked international research will make an important contribution to capacity-building. This will be important at many levels of both science and its translation into social policy. It will be of particular importance in low-income countries in strengthening the evidence base and implementation capacity for adaptive strategies to lessen health risks. Hence, this becomes an important corollary-objective of the Science and Implementation Plan.

The following two sections examine these two objectives in more detail.

2.1.1. Assess the past, current and future health impacts of GEC

Compared to conventional environmental health risks (mostly direct-acting and local), the topic area of GEC-and-health relationships entails relatively few such simple exposure-response relationships. In general a population-level, systems-based, ecological approach will be needed.

Priority research areas should be selected according to appropriate criteria. Four relevant criteria are:

- Settings in which GEC “exposures” impinge on a sufficiently large number of people.
- The specified GEC “exposure” is likely to have substantial (i.e., detectable) impacts on health.
- Settings where there is high vulnerability of population/community to the specified environmental change (e.g., low capacity to adapt to the hazards).
- Research should focus on situations where there is preliminary evidence of a relationship – and, preferably, where plausible causal mechanisms exist.

Carrying out research where there are sufficient and good data will generally ensure an informative result. So, if there is a strong hypothesis or apparent relationship to be investigated but there are only sparse data available, then special priority should be assigned to data collection. If data collection is very expensive it can sometimes be “piggy-backed” onto data collection already occurring for other reasons – for example, by integrating surveillance of diseases and key biological indicators (e.g., insects, rodents, algae, etc.) into existing programs for monitoring environmental conditions. Alternatively, in research sites that are rich in health data collections, it may be possible to integrate environmental surveillance parameters.

GEC-and-health relationships very often entail complex causal pathways. Further, some particular health impacts are often influenced by several different concurrent pathways. For example, deforestation increases the potential for flooding after heavy rains and can also affect the emergence of infectious disease clusters. The relationship is often further complicated by the presence of various non-GEC confounding factors that may partly or even fully explain the apparent GEC-and-health relationship. Study site selection and data collection should therefore seek to minimise these sources of background noise in the research or adjust for them in assessing impacts on health.

A cross-disciplinary approach will be required. A broad range of disciplines – including economists, medical and biological scientists, climatologists, ecologists, geographers, demographers, sociologists and anthropologists, environmental scientists and engineers, development program designers and managers, commercial representatives, and service providers – is required to work on these multifaceted problems. Further, the communities ‘at risk’ should be involved in problem definition, solution development and intervention testing.

2.1.2. Enrich the policy discourse on mitigation and adaptation

Elucidating the risks to population health from GEC will facilitate better informed social policy responses, spanning:

- Mitigation policies aimed at stopping detrimental environmental change. (Indeed, concern over health risks is what motivates most people to address the behavioural and political choices that GEC demands. Research that extends and strengthens the evidence of health risks can therefore be expected to add important rationale and stimulus to the mitigation debate.)
- Adaptive strategies, policies and measures to reduce current and future adverse health impacts of GEC.
- ‘Portfolio’ solutions to GEC that combine mitigation and adaptation (such as solar power for home, clinics, schools, agriculture and small businesses; water purification; pumping and crop irrigation; desalination).

For many environmental changes, inertia in the affected systems means that changes today may continue to affect the systems for decades or even centuries. A well-known example is the centuries-long rise in sea level that will follow from this century’s global warming. As corollary, the consequences of efforts to reduce the drivers of these changes may not become apparent for decades to centuries.

While GECs occur at global/worldwide scale, many of the health impacts will be site-specific and path-dependent; that is, they will depend on local circumstances. For example, malaria epidemics occur following rainy seasons in some regions, but during droughts (with local stasis of water) in others. Therefore, public health interventions must be designed at a scale and of a kind that is appropriate to the health outcome of concern.

Interventions should, where possible, be directed at local, national, regional and global scales. This means that research will have its greatest translational impact if processes and relationships are studied at some or all of these levels.

Vulnerability

The vulnerability of a particular population to the potential health impacts of GEC will depend on the degree to which individuals and systems are susceptible to, or unable to cope with, these environmental changes. Vulnerability is a function of: (i) exposure magnitude, (ii) target system sensitivity, and (iii) adaptive resources and capacity. In a little more detail:

1. The magnitude of the exposure to environmental change: this includes changes in both average environmental conditions and in the extent of their variability. Repeated weather extremes (e.g., repeated heavy rains) or sequential extremes (such as prolonged drought followed by heavy rains and flooding) can deplete a community’s coping mechanisms and resources thereby increasing vulnerability to stresses.
2. The extent to which health status, or the natural or social systems on which health community outcomes depend, are sensitive to the environmental change. In simple terms, this refers to the form of the exposure-response relationship. The sensitivity of ecosystems (e.g., agroecosystems) may be important if the environmental stresses are likely to alter essential health-supporting functions such as water supplies, food production, carbon sinks, and stabilisation of infectious disease transmission.
3. The adaptation measures, both potential and those already in place to reduce the burden of a particular adverse health outcome (e.g., the prevalence of air-conditioning within an urban area will help to reduce the impacts of heat extremes). The effectiveness

of any existing adaptive interventions partially determines the aforementioned exposure-response relationship.

In general, the vulnerability of a population depends on the level of material resources, effectiveness of governance and civil institutions, quality of public health infrastructure, access to relevant local information and pre-existing burden of disease. Indeed, a mix of individual, community, political, social, economic, cultural and geographical factors determines vulnerability. These factors are not uniform across a region or nation; rather, there are geographic, demographic and socio-economic differences. Hence, the effective targeting of prevention or adaptation strategies requires understanding which demographic or geographic sub-populations may be most at risk.

One particular challenge in the development of adaptation strategies is the issue of scale. The drivers of, and hence the potential for response to, GEC can operate at international, national and local levels. Ozone depletion is a global issue, with chlorofluorocarbons (CFCs) produced locally affecting global stratospheric concentrations. Deforestation, international trade and travel have local, national, regional and international environmental and social impacts. These can influence the emergence of infectious diseases across these scales. Infectious diseases emerging in one part of the world can affect nations throughout the world (e.g., the brief pandemic of SARS in 2003).

Clearly, then, the choice of effective interventions also requires understanding of the scale at which the drivers of change and health outcomes occur.

3. Scientific Themes

Introduction

The six scientific themes of this GEC and Human Health joint project were chosen in relation to the four most important large-scale human-induced changes in the world's environment that result in hazards to human health:

- Atmospheric changes
- Land use/Land cover changes
- Changes associated with food-producing systems
- Urbanisation

In addition to these four themes, the issue of infectious disease persistence, emergence and spread due to environmental changes, although it is a cross-cutting issue (intersecting with each of the above issues), is accorded a separate thematic section because of its importance, complexity and current global relevance.

The sixth science theme is also a cross-cutting issue: the vulnerability/adaptation of human societies to the health risks posed by GECs.

This six-themed approach facilitates the definition of research questions. However, overlaps are unavoidable in light of the multifactorial environmental, social, economic and cultural determinants of human health.

In this section on Scientific Themes the standardised hierarchical structure is as follows:

- Themes
- Issues and research goals
- Specific research foci
- Research priorities
- Topics

3.1. Theme 1: Health risks due to changes in global atmospheric composition

Introduction and Rationale

The increasing, global, energy-intensiveness and scale of human economic activities over the past two centuries has greatly increased the rate of release of industrial, automobile, land-clearing and agricultural gaseous emissions to the atmosphere. This process has progressively changed the composition of the lower atmosphere (the troposphere) and the middle atmosphere (the stratosphere). These two processes are largely (but not entirely) independent of one another: the former entails an increased tropospheric concentration of energy-trapping “greenhouse gases” (especially carbon dioxide), and the latter entails an increased stratospheric concentration of ozone-destroying halogenated gases (especially the chlorofluorocarbons, CFCs).

The atmospheric accumulation of anthropogenic (human-induced) greenhouse gas emissions influences the world’s climate. The depletion of stratospheric ozone allows more of the incoming solar ultraviolet radiation to reach Earth’s surface. Both these changes have important consequences for human health, as discussed in the following two sections.

3.1.1. Issue 1 – Impacts of Climate Change on Health

State of the Science

a. Global climate change: the process

Earth’s naturally-occurring greenhouse gases (GHG) in the troposphere, especially carbon dioxide, cause warming of the planet’s surface. Indeed, during the pre-industrial the natural CO₂ concentration in the troposphere (275 ppm) raised Earth’s average surface temperature by 32°C. The concentration of CO₂ is currently 380 ppm, representing an increase of almost 40% over the past two centuries. Although some uncertainties remain about the sensitivity of the climate system to changes in GHG concentrations, and about the future trajectories of those concentrations, there is now near-unanimous scientific agreement that the rising GHG concentration will cause additional warming and other climatic changes (including a change in climatic variability) over coming decades.

Further, there is now a strong scientific consensus that most of the warming that has occurred over the past half-century (0.6°C increase in global average surface temperature), especially in light of various temporal-spatial ‘finger-print’ characteristics, is attributable to anthropogenic GHG emissions (IPCC 2001).

Global climate change will have diverse, escalating impacts on human health. No matter how much mitigation of GHG emissions might be undertaken in the immediate future, health impacts will occur because of the great inertia inherent in the climate system. Hence, alongside mitigation actions, adaptation policies and strategies will need to be developed to lessen the potential adverse health impacts (and to take best advantage of any local/regional beneficial effects of climate change).

Beyond the major contribution of fossil fuel combustion to climate change, the full life-cycle of fossil fuels also entails a range of risks to health. Environmental damage from the mining,

refining and transport of fossil fuels poses risks, as do the subsequent hazards of air pollution and acid precipitation from fossil fuel combustion. These chemical and physical exposures, while strictly not ‘global environmental changes’, represent a source of widespread collateral damage. Indeed, by acting in concert with climate change (and compounded by large-scale land use, land cover changes and other GEC), some of these more ‘classical’ environmental health hazards have begun to affect biological systems.

b. Approaches

Just as it now appears that we have underestimated the rate of GHG-induced climate change, we may well have underestimated the sensitivity of biological systems to small changes in temperature and to the instability in climate accompanying those changes. A wide range of changes in physical systems (glaciers, sea-ice, jet-stream location, ocean currents) and in non-human biotic systems has now been observed in association with regional warming (Root, Schneider et al).

Climate change is unlikely to cause any novel category of health impacts. (Although, plausibly, it may contribute to the entry of new species or strains of infectious agents in human populations. See the Nipah Virus disease example in section 3.3., page 41) Rather, it will exacerbate the population burden of climate-sensitive diseases, injuries and premature deaths.

The three main categories of health risks from climate change are shown in Figure 2.

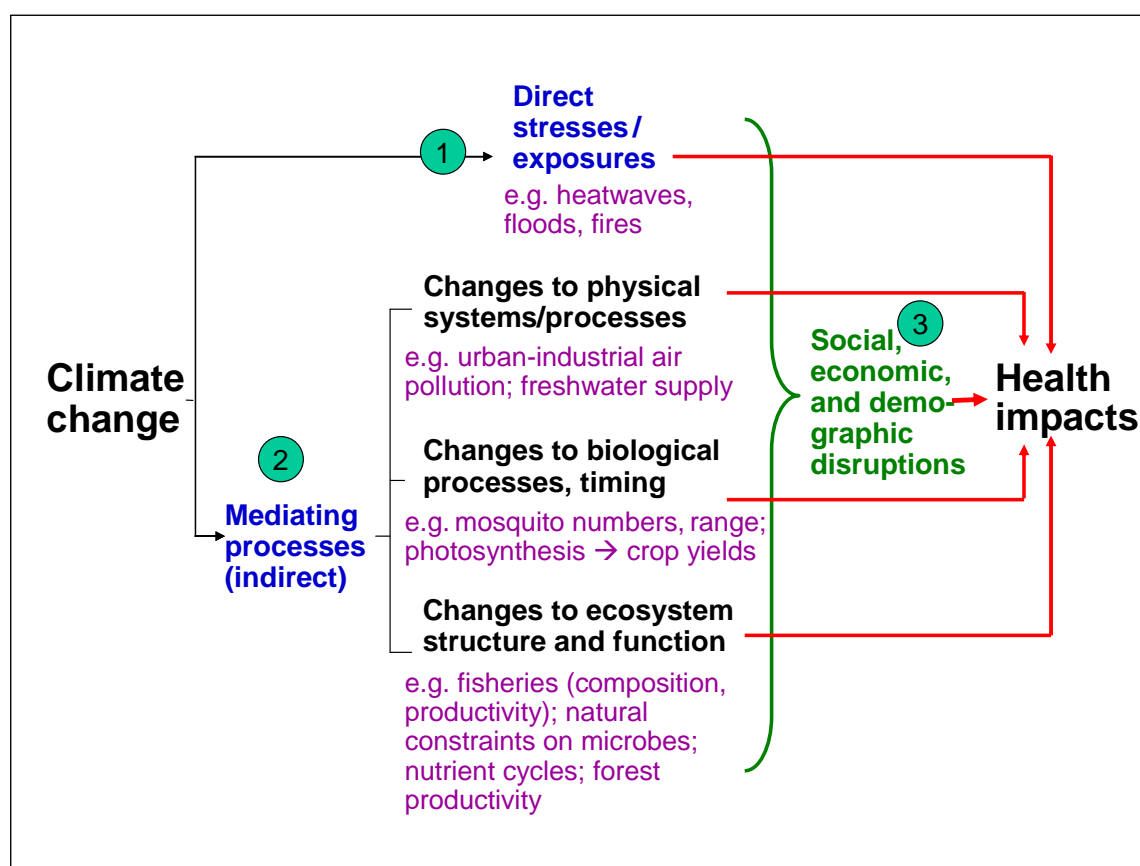


Figure 2. Schematic representation of the three main causal pathways by which changes in climatic conditions impinge on human health

Currently there are four main difficulties in assessing the likely health impacts of climate change:

1. Knowledge of how (natural) variations in climatic conditions affect risks to health is incomplete. Over past decades, epidemiologists have had rather little interest in studying these relationships (although that is now changing under the stimulus of anticipated climate change.)
2. The forecasting of climate change in response to likely scenarios of future GHG emissions has some important limitations. Higher-resolution geographic modelling is gradually being achieved; and increasing attention is now being paid to modelling future changes in climate variability.
3. There is little information about how adaptive strategies (both spontaneous and planned) will modify the health impacts of climate change. Further, there are unavoidable uncertainties about the future level of vulnerability in regional populations, and about their adaptive capacities.
4. A common approach to assessing the health risks of climate change is reductionist, addressing an itemised list of likely risks and specific health outcomes. This approach ignores or discounts the many different secondary health impacts that follow climatic-environmental changes to livelihoods, food and water supplies, coastal safety, and so on. Social, economic and demographic disruptions due to the regional impacts of climate change have a myriad of health consequences (as was also evident in the wake of the Asian Tsunami of December 2004). These consequences, obviously, cannot be quantitatively estimated in advance. Besides, climate change does not act in isolation; other large-scale environmental changes interact with climate change such that, for example, the flood consequences of heavy rainfall are exacerbated by deforestation and land degradation, and the impacts on agricultural yields are also conditioned by agroecosystem changes due to biodiversity loss, soil erosion and aquifer depletion.

Research Goals

- Develop, through collaborative networking, a more systematic approach to the detection and documentation of climate change-attributable changes in population health risks (especially the occurrence of infectious diseases, the impacts of thermal stress, and injury/death rates due to extreme weather events).
- Improve the estimation of current and future health impacts at regional and national scales, taking into account projections of changes in both climatic mean conditions and variability.
- Develop better ways of estimating (and communicating) future health impacts, preferably for decadal (even half-decadal) time-slices. Where possible (as a function of both available information and methodological capacity) seek to incorporate estimates of modulating influences by social conditions and institutions.
- Develop quantitative or semi-quantitative approaches to those health impacts that, currently, are not amenable to conventional quantitative risk assessment. This includes acquiring better insight into how climate change will contribute to the disruption and displacement of local communities, generating migrant/refugee flows (and attendant health risks).

The following sections consider the main categories of health risks posed by global climate change (named as **Focus A to F of Issue 1**):

- A Thermal stress
- B Extreme weather events
- C Air pollutants and aeroallergens
- D Infectious diseases
- E Food yields, human nutrition and health
- F Demographic and socio-economic disruption

Focus A. Adverse health impacts of thermal stress

Over many millennia, regional human populations adapted to diverse climates via physiological, behavioural and other cultural-technological responses (such as housing). For most populations, there is an optimal temperature at which the daily/weekly death rate is lowest; and departures in daily/weekly temperatures outside this “comfort zone”, to higher or lower temperatures, are associated with increased mortality.

Severe and sustained episodes of summer heat are associated with increased morbidity and mortality. The death toll in an unprepared region can be substantial. For example, there were approximately 30,000 excess deaths due to the extreme August 2003 heat-wave in Europe. In most countries, relatively few deaths are reported as directly attributed to “heat” (International Classification of Diseases, ICD9=992.0). Heat stroke, often fatal, is the only syndrome specifically attributable to temperature extremes. Most deaths from heat-waves are due to fatal culminations of pre-existing cardiovascular disease (heart attack and stroke) and chronic respiratory diseases, particularly in older persons. The World Meteorological Organization (WMO) is reviewing bio-climatological indices to determine an appropriate measure of thermal stress in humans for use in climate-health research.

The adverse health impacts of heat-waves can be reduced by an effective early warning system. The World Meteorological Organization has, over the past decade, supported the development of these systems in several major urban population settings.

Research priorities

Better data are needed on both the morbidity and mortality associated with thermal stress (extremes of both hot and cold weather). Studies should be conducted in various settings of developing countries, both urban and rural. That relationship apparently varies greatly between populations presumably reflecting socio-economic conditions, culture, population health profile, and geography. There are also individual-level risk factors that influence vulnerability to thermal extremes, including age, health status, housing, institutional care, and social support networks. Research is needed at these multiple levels to understand why populations, communities and individuals respond differently to thermal extremes.

There is an unresolved question about the *net* mortality impact of a shift in the annual distribution of daily temperatures. To what extent might a reduction in cold-related deaths offset any increase in heat-related deaths? A first-order answer can be estimated for any given population for which the curvilinear temperature-mortality relationship is already documented, by simply shifting the temperature distribution to a higher range and also using linear extrapolation in relation to the high temperature sub-range. However, if daily

temperatures are likely to be more variable in a warmer world, then this will make the modelling exercise more difficult.

Better documentation is needed of the relationship of thermal extremes to *cause-specific* health outcomes, and to better understand the underlying mechanisms. For cause-specific mortality studies, especially in relation to heat-waves, this should include elucidating how much of the statistically excess mortality is due to mortality displacement (“harvesting”) following the event and how much is “preventable mortality” due to the failure of local health care systems to respond adequately to high risk groups.

Research is needed to identify the characteristics of the most vulnerable populations. Other research should determine the information required, and how it should be communicated, to motivate appropriate behaviour changes during heat-waves – especially in vulnerable populations. The effectiveness of interventions needs to be evaluated. People perceive risks differently, and have different responses to perceived risks. Longer-term strategies need to be developed to reduce morbidity and mortality due to heat-waves, such as improved housing design and measures to reduce urban heat islands. For cold spells, effective interventions need to be developed to prevent cold-related morbidity and mortality, particularly among vulnerable populations such as the homeless.

In modelling the future impacts of thermal stress, under specified climate change scenarios (e.g., in 2025, 2050), it will be important to take account of the following population characteristics (as far as possible): (i) future age distribution, (ii) future prevalence of cardiovascular and respiratory disease, (iii) any future changes in extrinsic determinants of vulnerability.

Topics

Study the relationships between thermal stress and human morbidity and mortality at different demographic and geographical scales: individual, population, community.

- Study the *net* mortality impact of a shift in the annual distribution of daily temperatures.
- Study the mechanisms of the relationship of thermal extremes to *cause-specific* health outcomes.
- Develop models of effects of thermal stress on human health taking into account population characteristics (future age distribution, future prevalence of cardiovascular and respiratory disease, any future changes in extrinsic determinants of vulnerability).

Focus B. Adverse health effects of extreme weather events

Extreme weather events are low probability events that can have major adverse impacts on human communities or society at large. Important attributes of extreme events include their rate (frequency), intensity, volatility (shape), and spatial and temporal clustering. Every year extreme weather events cause substantial morbidity and mortality worldwide. From 1992 to 2001, there were 2,257 reported disasters due to droughts, extreme temperature, floods, forest/scrub fires, cyclones and windstorms (OFDA/CRED International Disaster Database, www.cred.be). Future changes in the average climatic conditions would affect the pattern of occurrence of extreme weather events. If, as is now widely anticipated by climate scientists, weather also becomes more variable in a warmer world, this would further affect the pattern of extreme events.

Climate related diseases

Well known examples include malaria and cholera as well as cardiovascular disease associated with heat waves (Patz. *et al.*, 2005). However, as the climate changes, a much wider range of vector borne diseases will have to be considered as their distributions alter (for example, Leishmaniasis and Lyme Disease). The migration of environmental refugees may exacerbate the problem with the spread of disease and challenges to health care systems that are not equipped to manage patients with unfamiliar illnesses.

The contamination of the food supply with infectious agents and a wide variety of natural and anthropogenic toxic agents will also need to be considered. This is especially important given reliance on the global distribution of food since contamination occurring in one region of the world may give rise to impacts in other regions.

Adverse effects of heat waves, especially in relation to increased incidents of food poisoning and also in relation to the effects of urban air pollution, should be considered. With regard to the latter, the urgency of the case is supported by approximately 30,000 deaths across Europe in 2003 due to the combined effects of the heat wave and air pollution, particularly on the elderly.

The Food Supply and Malnutrition

A very serious threat to health is posed by increasing levels of malnutrition resulting from climate impacts on crop and seafood production. Crop failures appear to be related to changing patterns of rainfall and to air pollution, especially rising concentrations of ground level ozone. The latter is expected to reduce crop production globally by approximately 10% by 2050. It should be noted that this is occurring over a period when the global population is expected to increase to 8 to 8.5 billion people, with 90% of this increase occurring in developing countries. Simultaneously, there appears to be a progressive collapse of capture fisheries worldwide while the threat posed by climate change to aquaculture is also increasing. At present 1 to 2 billion people are highly dependent on seafood as their major source of protein. In the future, this number is set to increase to between 3 and 4 billion. Capture fisheries only account for 90 million tonnes of the 180 millions tonnes of fish eaten each year; the remainder is produced by aquaculture, usually in the coastal zone. This is where climate change impacts will occur as sea levels rise, coastal flooding proceeds, storms intensify and ocean acidification develops.

Human well-being and security

With the spread of droughts, flooding and agricultural decline, one can easily understand why fears of reduced access to drinking water, cereal crops and the threat of infectious diseases affect our sense of wellbeing. One might also predict a dramatic rise in the incidence of stress-related psychiatric disorders and depression, as well as physical manifestations of stress such as asthma and hypertension, as living conditions deteriorate.

The spread of infectious disease, and reduced access to sufficient food and water is expected to provoke mass migrations to safer areas. We already know that migrant populations display different patterns of disease to those of endemic populations. People who, for whatever reason, are forced to remain in their own locality may simply feel increasingly disorientated, depressed and unwell. Their ability and motivation to work may decline. In India, for example, 25,000 farmers have committed suicide since 1997, as crops have failed and they

have been forced into grinding poverty. Effects on workforces in different parts of the world will often have important global consequences, not only for food production, but in other areas such as the manufacture of clothing, electronics and chemical products, and in the oil and gas industries of the energy sector. This subject warrants detailed investigation.

The most frequent natural weather disaster during the decade 1992-2001 was flooding (43% of 2,257 disasters). Floods killed almost 100,000 people and affected more than 1.2 billion people over the decade. Floods have recently become more destructive, and projections show that this trend may become more pronounced over the coming decades (Schar & Jendritzky, 2004). Relatedly, Stott and colleagues (2004) have estimated that the underlying human-induced global warming trend in the past 2-3 decades doubled the probability of occurrence of the August 2003 extreme heat-wave in Europe.

The health consequences of extreme weather events are complex and far-reaching, with some effects occurring during or immediately after the event (such as injuries, and an increase in communicable diseases) and others occurring during the recovery period (such as mental health disorders), or as a consequence of the secondary effects of the event. Extreme weather events adversely affect human health both directly and indirectly. For example, the *direct* physical health effects of floods include: mortality (injuries, infectious diseases, poisoning, and diseases related to the physical and emotional stress). *Indirect* effects result from the extreme events affecting other systems in ways that cause human injury and disease.

Examples of indirect effects are: reduced nutritional status (especially among children); increases in respiratory and diarrhoeal diseases (including cholera) because of the crowding of survivors; mental health problems (often protracted); and, for floods, increases in water-related diseases from disruption of water supply or sewage systems and exposure to hazardous chemicals or pathogens released from storage sites and waste disposal. Health hazards resulting from damage to infrastructure (water and sanitation) will hit the poorly prepared societies of LDCs most severely. The health effects of drought in poor populations are primarily associated with food insecurity, risk of famine, and increases in the prevalence of waterborne diseases. Regular water shortages will particularly affect society's poorest, with the least reliable water supply, as they will experience the sharpest increases in water prices as well as the most time consuming adaptations to provide their families with potable water. The latter will predominantly affect women and children (www.unicef.org/wes/index_womenandgirls.html). In all drought-affected populations there are losses of livelihood, social and economic disruption, and increases in mental health problems (including, usually, suicide rates). As a result, the full health burden of a major extreme weather event is likely to be much larger than that initially estimated.

There are also adverse health effects associated with forest fires or wild-fires, and regardless of how they are started, they are an ongoing concern, particularly in regions and seasons where the weather is dry and hot. During a wild-fire, residents in stricken areas are subject to smoke effects. Among them, the most common respiratory problems are asthma, emphysema, and bronchitis that can affect, for example, chronic heart disease patients who should monitor their breathing and exposure to airborne matter.

For all extreme weather events there is anxiety about recurrence of the event. Factors affecting the perceived risk of recurrence include a perceived failure on the part of relevant institutions to alleviate risk or to provide adequate warnings of that risk. These additional sources of stress and anxiety can have significant impacts upon the overall health and well-being of victims.

Projections of extreme events under future climate change scenarios are uncertain. Global average water vapour concentration and precipitation are expected to increase further during the 21st century, with precipitation extremes projected to grow. Adverse consequences include increased risk of floods, landslides, avalanches, and mudslides; increased soil erosion; and increased pressure on flood insurance systems and disaster relief. Other anticipated changes include an intensification of the El Niño climate cycle, changes in the frequency and severity of storms and cyclones, and more severe droughts and wild-fires (Webster et al., 2005).

Research priorities

Floods, droughts, and other consequences of extreme weather events are natural occurrences. A fuller documentation and understanding is required of the human health impacts of these events, of the population sub-groups and areas at particular risk, and of effective response strategies. The health impacts of extreme weather events are poorly characterized, as is understanding of the recovery process. More and better quantitative data are needed, including better registration of injuries and deaths. The available morbidity data are limited, which limits our understanding of both the impacts and the possible effective response options.

Topics

- Improved knowledge about impacts and vulnerability is a prerequisite to understanding how extreme weather events will affect the demands on the emergency management system and the loads on the health-care systems.
- Determine the extent of post-event social and mental care necessary for those affected by an extreme weather event (visits to identify problems, assistance with recovery work phases, financial assistance and advice, and medical/social advice).
- Research on information dissemination for those especially vulnerable to suffer health impacts during extreme weather events (elderly, those with prior-event health problems, the poor, and those with dependents).
- Research to improve early warning systems, particularly for floods, along with better arrangements for response to those warnings (longer warning lead times, more accurate warnings, more advisory warning messages).

Focus C. Adverse health effects of air pollution and aeroallergens due to climate change

Air pollutants have a range of well-documented adverse health effects. Based on a great diversity of epidemiological studies around the world in urban-industrial settings, it is evident that long-term exposure to elevated levels of physico-chemical air pollution (especially sulphur and nitrogen oxides, volatile organic compounds, ozone and particulates) causes a greater increase in premature mortality than does acute exposure.

Meteorological conditions can influence air quality via the formation and/or transport of air pollutants. For example, there is evidence that the formation of ozone (known to have adverse effects on the respiratory tract and associated with increase mortality risk), from precursor chemical air pollutants, proceeds more rapidly at higher temperatures and in conditions of bright sunlight. There are as-yet unanswered questions as to whether the biological health impacts of air pollutants are modified by meteorological conditions.

Airborne biological particles such as pollen, spores and moulds also affect health, especially allergic disorders of the respiratory tract (asthma, hay fever). Some species, such as ragweed and mugwort, present particular risks for health and require land-use controls or eradication.

However, relatively little research has been done on climatic influences on the health impacts of aeroallergens. In Europe, it appears that the average length of the plant-growing season has increased by 10–11 days over the last 30 years. The pollen season is now starting and peaking earlier, particularly in species that start flowering earlier in the year. The duration of the pollen season has been extended in some summer and late-flowering species. Warming is likely to further cause an earlier onset and may extend the duration of the flowering and pollen season for some species (such as grasses and weeds). There is also evidence that climate change facilitates the geographical spread of specific plant species to new areas as they become climatically suitable (Root et al., 2003; Williams et al., 2005).

Air pollution, from industrial activity and biomass burning, has become an important issue affecting many parts of the world and across international boundaries over the past decade. However, discussions of "global environmental change" have usually not treated *local* air pollution as part of the GEC, for the following reasons:

1. Air pollution is usually localised within and around urban-industrial-transport sites (e.g., many of China's big cities).
2. The impacts are predominantly of the conventional toxicological kind, acting directly on the human respiratory and cardiovascular systems.
3. Biomass burning is usually localized within rural areas, but the plumes from the fires can be transported over great distances. They can impact urban areas, leading to respiratory and cardiovascular problems there.

The primary source of greenhouse gas emissions (fossil fuel combustion) is also, directly, a major source of environmental health hazard. This raises the companion research questions as to how to design an energy path for developing countries so that the decoupling of economic growth from reliance on fossil fuels actually works. This is an urgent and complex issue requiring serious research (see www.wbgu.de Whitebook "Transforming energy systems").

Research priorities

Uncertainties persist about the type, direction and magnitude of changes in air quality that could result from climate change. Research is needed on how climate change could affect exposures to air pollutants, aeroallergens, and particulate material from fire-agricultural burning:

- Climate change may affect natural sources of air pollution. The documented seasonal variations in natural emissions of volatile organic compounds suggest that warmer temperatures could increase those emissions.
- Climate change may change the geographic distribution and type of aeroallergens. Research is needed into how weather and climate variability affect:
 - amount and timing of seasonal releases of aeroallergens.
 - density and allergenicity of pollen.

Topics

- Study impacts of weather/climate on the incidence, prevalence, distribution, and severity of allergic disorders as well as respiratory diseases.

Focus D. Climate and Infectious diseases

Infectious disease transmission is influenced by many factors, including extrinsic social, economic, climatic and ecological conditions and the intrinsic level of human immunity. Many infectious agents, vector organisms, non-human reservoir species, and the rate of pathogen replication within the vector organism are sensitive to climatic conditions (Reeves et al., 1994; Kovats et al., 2001; Pascual et al., 2005). For example, salmonella and cholera bacteria, both non-vector-borne diseases (VBDs), proliferate faster at higher temperatures. In regions where low temperature, low rainfall or lack of vector habitat limit VBD transmission, climatic changes may tip the ecological balance and trigger epidemics. Epidemics can also result from climate-related migration of reservoir hosts or human populations.

There have been many studies on the relationship between short-term climatic variation and infectious disease, especially VBD. Studies in South Asia and South America have documented the association of malaria outbreaks with the ENSO cycle. (Bouma & van der Kaay, 1996; Bouma, Dye, van der Kaay, 1996; Bouma et al., 1997; Bouma & Dye, 1997; Poveda et al., 2001; Gagnon et al., 2002). In the Asia-Pacific region (Hales, Weinstein & Woodward, 1996; Hales et al., 1999; Corwin et al., 2001; Hopp & Foley, 2003) and in South America (Gagnon et al., 2001), El Niño and La Niña events appear to have influenced the occurrence of dengue fever outbreaks. Similarly, inter-annual (especially ENSO-related) variations in climatic and environmental conditions in Australia influence outbreaks of Ross River virus disease. (Maelzer et al., 1999; Woodruff et al., 2002; Tong et al., 2004). Many of these associations between infectious diseases and El Niño events are reasonably attributable to the higher temperatures, which affect both vector and pathogen, and to the influence of changes in rainfall, surface-water and water vapour pressure.

Increased notifications of (non-specific) food poisoning in the UK (Bentham & Langford, 2001; 1995) and of diarrhoeal diseases in Peru and Fiji (Singh et al., 2001; Checkley et al., 2000) have accompanied short-term increases in temperature. Further, strong linear associations have been found between temperature and notifications of salmonellosis in European countries (Kovats et al., 2004) and Australia (D'Souza et al., 2004), and a weaker seasonal relationship exists for campylobacter (Kovats et al., 2005; Nichols, 2005).

Climate change is presumably already affecting some infectious diseases. However, no one study is conclusive. Tick-borne (viral) encephalitis in Sweden has reportedly increased following a succession of warmer winters over the past two decades, (Lindgren, 1998; Lindgren et al., 2000) although this interpretation is contested. (Randolph & Rogers, 2000). The geographic range of the ticks that transmit Lyme borreliosis and viral encephalitis has extended northwards in Sweden (Lindgren, Talleklint & Polfeldt, 2000) and increased in altitude in the Czech Republic (Danielova, 1975; Daniel et al., 2004) in association with recent trends in climate (Lindgren, Talleklint & Polfeldt, 2000; Zeman, 1997).

Elsewhere, there have been reports of a recent strengthening of the relationship between El Niño events and outbreaks of cholera in Bangladesh (probably reflecting the influence of warmer coastal and estuarine waters on the proliferation and spread of the cholera vibrio within the base of the marine food chain), and of changes in the altitudinal range of malaria in parts of Sub-Saharan Africa in association with local warming trends (Bonora et al., 2001; Githeko & Ndegwa, 2001; Zhou et al., 2004).

Climate change will affect the incidence, seasonal transmission and geographic range of various vector-borne diseases. These would include malaria, dengue fever and yellow fever (all mosquito-borne), various types of viral encephalitis, schistosomiasis (water-snails),

leishmaniasis (sand-flies: South America and Mediterranean coast), Lyme disease (ticks) and onchocerciasis (West African river blindness, spread by black flies) (McMichael et al., 2003).

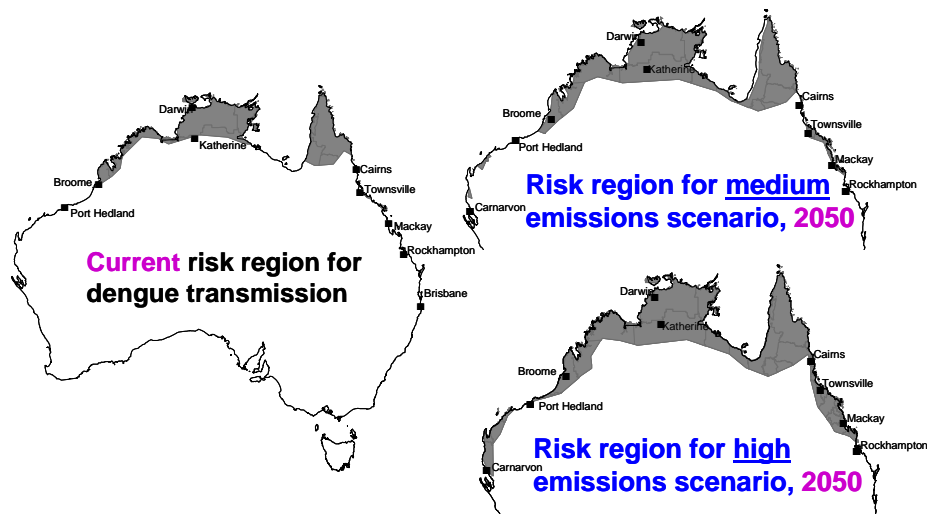


Figure 3. Dengue fever transmissibility in Australia, now and by 2050: Modelling of the receptive geographic region for the dominant mosquito vector, *Ae. Aegypti*, under alternative climate-change scenarios for 2050

The formal modelling of climate change impacts on vector-borne diseases has focused on malaria (van Lieshout et al., 2004) and dengue fever (Hales et al., 2002). Modelling the latter is conceptually simpler (see, for example, Figure 3). While malaria entails two main pathogen variants (*falciparum* and *vivax*) and relies on several dozen regionally dominant mosquito species, dengue fever transmission depends principally on one mosquito vector, *Aedes aegypti*. Both statistical and biologically-based (mathematical) models have been used to assess how a specified change in temperature and rainfall pattern would affect the transmission potential of these and other vector-borne diseases.

Approaches

- Some infectious diseases display *relatively* less complex relationships to climatic variations/trends – e.g., salmonellosis, dengue fever – than do others. For many of those others, the relationship is mediated by more complex changes in ecosystems and non-human host species – e.g., malaria, Ross River virus disease, Lyme disease and Leishmaniasis. There is a need to undertake studies of the latter category, to elucidate the mediating ecological processes.
- This decade, it is near-certain that there will be a pattern of changes in climate-sensitive infectious diseases that, collectively, signal that climate change is beginning to affect this aspect of health in human populations. Coordinated research is needed to gather, from diverse sources around the world, systematic information pertaining to this question.
- The modelling of future ranges and risks of infectious disease, under climate change scenarios, should increasingly be enriched by inclusion (‘horizontal integration’) of credible estimates of changes in other factors that would modify those risks.

- Because of the complex of biological, ecological and environmental influences on infectious disease occurrence, there is a need to document situations in which multiple environmental changes act concurrently, and to elucidate the net impact on risk of infectious disease transmission. We need to build up a 'library' of experience and knowledge about these more complex situations.

Topics

- Systematic studies of recent trends in incidence, seasonality and geographical distribution in selected infectious diseases (and, where appropriate, their vectors) in relation to associated climatic trends.
- Critical comparison of alternative approaches to scenario-based modelling of future risks of infectious disease. What are the distinctive attributes, purposes and uses of process-based (biological) modelling versus statistical (empirical) modelling?

Focus E. Food yields, human nutrition and health

As is well-known to human societies everywhere, food sources display seasonal variations and the yields from natural and managed ecosystems (agriculture, animal husbandry, aquaculture) are affected by climatic conditions and events. This topic area is discussed much more fully in the Science Plan of the ESSP joint project on Global Environmental Change and Food Systems (GECAFS).

Climate change will affect basic plant physiology, especially photosynthesis, in a well understood way. Plants are generally sensitive to temperature and soil moisture; the germination of some plants is dependent on critical low temperatures being attained. Other ways in which climate change would affect plant yields are:

- CO₂ "fertilisation" effect (especially in the C3 plants that evolved when CO₂ levels were higher)
- Influences on plant diseases
- Influences on pest species (crop losses)
- Extreme weather events: floods, droughts, etc
- Sea-level rise: salination and inundation of coastal land

The herding and husbandry of livestock for human consumption is also at risk from climatic vicissitudes and trends. The geographic range of various parasitic and other infectious diseases in mammals and birds is sensitive to climatic conditions. For example, there has been a recent report of the cattle viral disease, blue-tongue, moving to higher latitude in Europe in association with the recent warming trend (Purse et al., 2005).

The geographic location of some ocean fisheries is now being affected by warming of the water (Perry et al., 2005), and the increasing acidification of the world's oceans, as carbon dioxide is absorbed at an increasing rate from the atmosphere, poses a threat to the (pH-sensitive) calcification of diverse organisms at or near the base of the marine food web (UK Royal Society, June 2005).

Approaches

Because of the indirect nature of the connections between climatic impacts on food yields and the flow-on to food availability/affordability, nutritional status and health (pregnancy

outcome, infant/child development, growth, adult health and function, deficiency-related disorders), this is a difficult topic to study in systematic, quantitative fashion. Perhaps for this reason there has been little research on this relationship. One manifestation of this is the limited extrapolation, to humans, of the modelling of (physiologically-mediated) climate change impacts on regional food yields: the exercise has been limited to estimating future changes in the number of hungry/underfed persons in the world (Parry et al., 2004). There have been no attempts yet to estimate how threshold-based or stochastic consequences of climate change (downturn in CO₂ fertilisation effect at higher temperature, occurrence of pests and diseases, damage due to extreme events) might affect food yields.

Research priorities:

This is a complex area in which to study health impacts and risks. Environmental influences on food production are rarely univariate, and there are always concurrent social, political, technological and economic forces at work.

It is important that the health research sector promote realisation that food production is, ultimately, about feeding humans and maintaining their health. Much public discussion treats agriculture and livestock production as principally a commercial activity, geared at generating domestic and national income. Increasingly, world food production is controlled by powerful transnational companies whose obligation is to shareholders, not to local communities who produce the food or to those who most need the food for health and survival.

Research priorities cannot be forged exclusively in relation to climate change. Hence the issue needs to be considered further in section 3.4., page 50.

Focus F. Adverse health effects of demographic and socio-economic disruption

Demographic and socioeconomic disruption is likely to result from several interrelated environmental trends, including climate change and other changes that are increasing water stress, land degradation, coastal and marine ecosystem damage, pressure on food supply systems in many areas of the world, and tensions and conflicts over access to limited resources. These trends are already contributing to the growing numbers of 'environmental refugees'. Population migrations are associated with a large range of adverse health impacts resulting from the disruption of family life, poor health prior to migration, the consequences of living in crowded and often unsanitary conditions, etc. This applies particularly to refugee populations who are confined to transit or settlement camps, often in squalid, crowded and degrading conditions.

Research priorities

Little research has been conducted on the role of climate change as a current and future contributor to socio-economic disruption, loss of livelihoods, resource conflicts, and population out-migration. More generally, the many adverse health impacts of the consequences of living in resettlement camps are well documented and could serve as a basis for studies on other socio-economic disruptions.

Storm surges and sea level rise may necessitate the abandonment of some small island nations. (The Pacific-island population of Tuvalu has already begun plans to relocate, primarily to New Zealand.) Little research has been done to understand how to preserve communities and their cultural heritage in the face of such a radical relocation. Many studies have shown the importance of cultural integrity and social cohesion to long-term behavioural patterns, levels of social capital, and, in consequence, population health.

Topics

- Study the health consequences of climate change on socio-economic disruptions resulting from resource conflicts and large-scale population migrations.
- Assess the risks to community/population health from the threats to culture and ways of living posed by climate change (e.g., rising sea levels making Pacific islands uninhabitable).

3.1.2. Issue 2: Stratospheric Ozone Depletion and Health

State of the Science

a. Overview of environmental process

Stratospheric ozone depletion gathered pace during the latter stages of the twentieth century because of the accumulation of various human-made ozone-destroying industrial and agricultural gases. Most of the ozone-destroying gases are halogen-containing, the main ‘culprit’ being the chlorofluorocarbons (CFCs). The process was formally identified in the 1970s, and coordinated international remedial action was initiated in the 1980s via the Montreal Protocol, 1987. The subsequent cut-back in the release of ozone-destroying gases means that stratospheric concentrations of chlorine and bromine compounds (the main source of the ozone-destroying chemical reaction) are expected to peak during this decade, with full restoration of stratospheric ozone within a half-century. This will require continued international commitment and monitoring.

There is some interplay between the otherwise separate processes of climate change (troposphere) and ozone depletion (stratosphere). First, most of the ozone-destroying gases also exert a “greenhouse” effect while passing through the troposphere. Second, the warming of the troposphere induces cooling of the stratosphere (i.e. some of the infrared radiation is precluded from reaching the stratosphere), and that cooling actually amplifies the ozone-destroying chemical reactions.

Ozone first began to appear in Earth’s atmosphere around two billion years ago. Oxygen (O_2) produced by photosynthesis in water-based plants spilled over into the atmosphere and was converted by incoming solar ultraviolet radiation to ozone (O_3). Because this stratospheric ozone filtered out the biologically harmful short wavelengths of UVR, life forms were able to move, and evolve, from the aqueous to the terrestrial environment.

Ultraviolet radiation (UVR) is part of the solar electromagnetic spectrum, with wavelengths just shorter than the violet component of visible light. UVR comprises longer wavelength UVA, intermediate wavelength UVB, and shorter wavelength UVC. The shorter the wavelength the potentially more biologically damaging is the radiation. Ambient UVR consists of: (i) most of the incident solar UVA, which penetrates almost fully to reach the Earth’s surface, (ii) less than 10% of the incoming solar UVB, most of which is filtered out by stratospheric ozone, and (iii) no short-wave UVC, which is completely absorbed in the atmosphere. The health effects of stratospheric ozone depletion will thus be largely confined to those associated with increased exposure to UVB radiation.

Ninety percent of Earth’s ozone is in the stratosphere, with the remaining 10% being in the troposphere. Total ‘column’ ozone is least at the equator and increases at higher latitude, with greater overall column amounts at high latitudes in the northern hemisphere than in the

southern hemisphere. There are seasonal and interannual fluctuations in total column ozone as a result of wind transport and the stratospheric circulation of ozone.

b. Summary of biological and health impacts

Ultraviolet radiation is biologically active, particularly at its shorter wavelengths. The main risks to human health are skin cancer, ocular damage, and suppression of immune system activity (Lucas et al., in press).

Action spectra for biological responses indicate that it is radiation in the UVB range that is absorbed by DNA. Subsequent damage to DNA appears to be a key factor in causing some skin cancers, eye disorders, and may have effects on the immune system. UVA may play an important role in photo-ageing of the skin and there is some evidence that it plays a role in the causation of malignant melanoma. The most obvious, perhaps main, health risk of increased exposure to UVR is that of increased incidence of skin cancer, especially in fair-skinned populations. This relationship has been well studied by epidemiologists, in relation to natural (geographic and personal behaviour-based) variations in UVR exposure. Other than estimating (modelling) the future risks of skin cancer for given scenarios of ozone depletion, there is no real need for new information about the basic UVR-skin cancer relationship.

Exposure to UVB enhances endogenous production of vitamin D within human skin and thus helps prevent bone weakness: rickets and osteomalacia.

The eye is the only part of the human body not shielded from harmful UVB radiation by skin. The vulnerability of the eye to environmental hazards is a consequence of the ability to see. Each part of the eye may be affected by UVR. The cornea and conjunctiva can be affected by acute high dose UVB resulting in acute photo-conjunctivitis and photo-keratitis as well as by a chronic lower dose exposure that may lead to pterygium. There is strong epidemiological and biological evidence of a causal relationship between certain types of “senile” cataract and UVR exposure, with exposure to UVB being of prime importance. Cataracts occur mainly in older age groups, causing various levels of visual impairment up to complete blindness. They are extremely common and may be associated with an increased risk of mortality in developed as well as developing countries.

UVR exposure suppresses the immune system, both systemically and locally. It is likely that it therefore suppresses autoimmune activity (which is, in essence, normal immune activity that is directed at the wrong target), and therefore decreases the risk of a number of autoimmune disorders. This effect could be mediated either through enhanced levels of vitamin D (known to play an important role in immune modulation) or via direct effects of UVR on immune activity. UVR may also have beneficial (protective) effects on the cardiovascular system, and various cancers (breast, prostate, non-Hodgkin’s lymphoma).

Approaches

There are two underlying difficulties in studying the association between UVR exposure and human health:

(i) *Difficulties in estimating human exposure:* Season, latitude and the “column” of stratospheric ozone determine the UVR level at Earth’s surface. An individual’s dose of UVR is determined by this ambient level and by individual differences in sun exposure habits. An additional factor is human skin pigmentation (e.g., deeply pigmented skin has a natural sun protection factor [SPF] of 13). For any level of UVR exposure, the biologically damaging effect will be much greater on fair skin than on more deeply pigmented skin.

(ii) *The complexity of the dose-response relationships for the various health outcomes:* Diseases associated with UVR exposure generally appear in mid- to late-adulthood, and are likely to be caused by either chronic exposure over many years or a critical exposure early in life. Epidemiological studies of the association between UVR and diseases such as skin cancer and eye disease are based on recalled lifetime patterns and amounts of sun exposure, including sunburns and hours in the sun. Ideally, prospective studies could be carried out on individuals wearing personal UVR monitors for several decades to clarify both exposure and dose-relationships.

Research Needs

There is a need to clarify the questions about how increased UVR exposure will affect the human immune system and, hence, the occurrence and manifestation of various immune (and autoimmune) disorders, and the efficacy of vaccination.

Research is also needed to understand how climate change itself will affect patterns of solar exposure in different populations, cultures and geographic locations.

Topics

- Studies of population-level ambient UVR exposure, by location
- Research to elucidate the effects of ultraviolet radiation on the immune system:
 - Animal and human health studies of UVR impact on immune indices
 - Assess impact of UVR on autoimmunity and autoimmune disorders
 - Assess the potential link between UVR and susceptibility to infectious diseases
 - Compare vaccination efficacy, by season and by latitude
 - Studies of above in relation to levels of skin pigmentation
- Clarify relationship of UVR to different categories of cataract and other ocular effects

It will also be relevant to consider, in light of the up-to-date science, whether there is need to assess the magnitude and relevance of the impacts of increased UVR exposure upon plant growth, crop yields, and the reproduction of fish and frogs. These have potential bearing on human wellbeing and health, especially in agrarian populations in low-income countries at mid-high latitude.

3.2. Theme 2: Land Use/Land Cover Changes and Human Health Issues

Introduction and Rationale

Land Use activities convert natural landscapes for human use or change management practices on human-dominated lands. Their ultimate goal is the acquisition of natural resources and use of ecosystem services for immediate human needs (Foley et al., 2005).

Global environmental impacts of Land Use range from changes in atmospheric composition to the extensive modification of Earth's ecosystems, with consequences for the decline of biodiversity, especially through the loss, fragmentation and modification of habitats (Foley et al., 2005).

The Land Cover is defined by the attributes of the Earth's land surface and immediate subsurface, surface and ground water and human structures (Lambin et al., 2003). Land cover conversions are the complete replacement of one cover type by the other (e.g., deforestation); land cover modifications are more subtle changes that affect the character of the land cover without changing its overall classification (Lambin et al., loc cit).

LUCC relationships to Human Health can be best approached by considering its impacts mediated via Biodiversity changes (see Figure 1, page 10).

Human health issues related to biodiversity changes

Biodiversity is the variability within and among living organisms (plants, animals and micro-organisms) and the systems they inhabit (habitats, biomes, ecosystems). Biodiversity loss is defined as the long term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services (CBD).

One of the most pressing of the GECs is "Biodiversity Change", not only because of the rapid rate of loss and disruption of the world's biodiversity stocks but also because of the frequent irreversibility of the processes. Biodiversity changes involve the interactions of many processes, biological and abiotic, at different scales, and are caused by multiple social and economic pressures. The Millennium Ecosystem Assessment acknowledged the existence of five major drivers of biodiversity loss: (i) Habitat change, loss or degradation; (ii) Invasive alien species; (iii) Overexploitation; (iv) Climate Change and (v) Introduced pathogens (MEA, 2005). Knowledge of the mechanisms and outcomes of biodiversity loss and their effects on human health is still poor. Yet, biological diversity and ecosystem functioning is part of the vast "web" that supports human life through the services they provide, such as clean water and air, climate regulation, provision of food, fibre and other essential materials, detoxification, pollination, carbon sequestration and many others.

The linkages between biodiversity change and human health may depend on other components of GEC and hence there are multiple pathways by which changes in biodiversity can influence human health. For example, biodiversity can influence human health through competitive interactions among reservoir hosts or vectors for the agents of infectious diseases. In aquatic ecosystems, nutrient loading and loss of filtering bivalves may lead to outbreaks of cholera (*Vibrio cholerae*), but these effects may be mediated by changes in the biodiversity of the plankton community with which *Vibrio* symbiotically associates. In forests, the effects of

land-use changes such as deforestation and habitat fragmentation on reservoir hosts and vectors for infectious diseases will depend on the species composition and richness of these communities (biodiversity) as well as on the types of land use practices and associated demographic phenomena and the magnitude and pattern of land cover changes. Land use can also affect health by altering water quality and quantity via anthropogenic changes in ecosystems since more than three quarters of the world's accessible freshwater comes from forested catchments.

The emergence and re-emergence of infectious diseases among humans, wildlife, livestock, crops, forests and marine life in the final quarter of the 20th century can be viewed as a primary symptom that integrates the many aspects of global environmental and social changes. Contemporaneous changes in greenhouse gas concentrations, ozone levels, the cryosphere, ocean temperatures, land use and land cover threaten the stability of our epoch, the Holocene – a remarkable 10,000-year period that has followed the retreat of ice sheets from temperate zones. The impacts of deforestation and climatic volatility are a particularly potent combination creating conditions conducive to infectious disease emergence and spread. Any changes in the density, distribution, population dynamics or ecological interactions of host animal or insect vector species may result in new patterns of infectious disease incidence.

The theme “Biodiversity Change” can be approached at different levels of organization: (i) ecosystems; (ii) species/populations, and (iii) genetic variation. The relationship between biodiversity and infectious diseases will be described in section 3.3, along with the effects of other GEC.

3.2.1. Issue 1 - Studies of ecosystem functions and services as related to overall health

Ecosystems are defined as a complex of plant, animal and micro-organism communities and their non-living environment interacting in a functional unity (CBD). Over the past 50 years, at a global level, humans have changed natural ecosystems more rapidly and extensively than in any comparable period in human history (MEA, 2005).

Ecosystem services are the benefits that people derive from ecosystems (MEA, 2005) and can be classified as:

- Provisioning services: fresh water; food; new products from biodiversity, etc.
- Regulating and supporting services: climate stability, detoxification, etc.
- Cultural services: amenity and leisure.

The following ecosystem services have a more direct relationship with human health:

1. Regulation of infectious diseases (see section 3.3)
2. New products from biodiversity (see issue 2, this section)
3. Provision of food (see section 3.4)
4. Waste processing and detoxification
5. Provision of fresh water (see section 3.3.3.)
6. Regulation of natural hazards (see section 3.1.1. B)

The multiple biological symptoms of GEC include amphibian declines on six continents, the alteration of the reproductive and migratory phenology of plant and animal species (Root et al., 2003; Walther et al., 2003; Parmesan & Yohe, 2003), a decline in pollinators, the proliferation of harmful algal blooms along coastlines worldwide and emerging infectious diseases (EIDs) across a wide taxonomic spectrum. There are multiple social, ecological and global factors lying behind these shifting worldwide patterns of infectious diseases (Weiss & McMichael, 2004). There are diverse plausible mechanisms and pathways by which these factors and changes in biodiversity, in particular, influence the emergence of infectious diseases. One general example is that declining biodiversity and the impacts of climate change on habitat and biodiversity can decouple important biological control systems that otherwise limit the emergence and spread of pests and pathogens.

Population explosions of nuisance organisms and disease carriers may be viewed as signs of ecosystem disturbance, reduced resilience and resistance. Rodents, insects and algae represent key biological indicators, rapidly responding to environmental change. The increasing rate of species extinctions assumes additional significance in this respect: periods of mass extinctions – punctuations in evolutionary equilibrium – are followed by the emergence of new species. Will the current human-induced loss of biodiversity favour opportunistic species?

In the marine environment, altered composition of communities and change in keystone species can affect the emergence and spread of diseases and biotoxin-producing algae. Wetlands have important detoxification functions and are called “nature’s kidneys” due to the filtering of nitrogenous wastes from agriculture, livestock, humans and fossil fuel combustion by-products. They are also nurseries for several species, carbon sinks, sinks for contaminants (water and air), and buffers for shorelines against tides, storms and rising sea levels.

Research priorities

The pathways and mechanisms that need to be elucidated include:

1. Monocultures and habitat simplification and the potential for infectious disease spread among agricultural crops and forest plants and consequences for food.
2. Habitat loss and human penetration into disrupted wilderness areas, bringing humans in contact with previously "isolated" pathogens.
3. Declines in predators that release prey from natural biological controls, and small prey can become pests and carriers of pathogens.
4. Loss of competitors (that carry pathogens less efficiently than primary animal hosts), removing these buffers against pathogen abundance and spread.
5. Diseases of wildlife (like West Nile virus) can, themselves, alter animal biodiversity, and cause extinctions, increasing vulnerability to emerging infectious diseases (see Daszak *et al.*, 2000).

Goal

Study, at the community and ecosystem scales, the consequences of biodiversity changes on ecosystem functions and services (e.g., water quality and availability, crop yields, local climatic control, and air contaminants), and their attendant impacts, directly or indirectly, on human wellbeing and health.

3.2.2. Issue 2: Health implications of impairments to traditional pharmaceutical and industrial uses of biodiversity resources

Historically, biodiversity has been the major source of pharmaceuticals, and today natural sources are relied on by 85% of the world's population for primary health care. Biodiversity products are still important sources of novel compounds for pharmaceuticals. An average of 62% of new small molecule, non-synthetic chemical entities developed for cancer research over the period 1982-2002 were derived from natural products (MEA, 2005). Malaria, one of the world's most important infectious diseases, has been treated historically with drugs derived from natural products (quinine, etc.) and today, artemisinins, derived from the herb *Artemisia annua* is an important therapeutic resource. (MEA, 2005). Innovative programs of biodiversity research, such as the search for novel small molecules from marine and soil micro-organisms, have been greatly facilitated by innovative new technologies. High-throughput screens and bioassay-guided fractionation have led to remarkable new techniques in which thousands of plant or animal extracts can be rapidly screened for hundreds of new disease targets.

Such research, however, has been hampered by habitat loss and species extirpations, which have particularly impacted sessile organisms in tropical rain forests and coral reefs. The Convention on Biological Diversity (CBD) aims to provide incentives for the sustainable use of biodiversity, facilitate and encourage international collaborations between biodiverse-rich countries and technologically-rich countries.

Global threats to biodiversity, and especially species losses, may affect the development of valuable new products for humanity. The current decline of biodiversity may affect bioprospecting for drugs and these losses may go undetected because many commercially important species are either small or microscopic (MEA, 2005).

Indigenous knowledge of biodiversity is also rapidly disappearing from the world (Cox, 2000).

Research priorities

One of the most pressing issues is to study the threats and opportunities of bioprospecting to species loss. A fuller documentation is required of the range and extent of human dependence on natural compounds and materials for economic and pharmaceutical purposes.

Activities to be undertaken:

- Multi-stakeholders (pharmaceutical industries, local populations) conflict resolution analysis relating to biodiversity exploitation for medical purposes, through high-quality contracts and transparent institutional policies that result in benefit-sharing.
- Intensification of efforts in the use of new technologies to the exploration of currently unidentified majority of species and their potential products.

3.3. Theme 3: Global environmental changes and infectious diseases

Introduction and Rationale

Infectious diseases account for 29 of the 96 major causes of human morbidity and mortality listed by the World Health Organization, representing 24% of the global burden of disease (WHO, 2004).

The emergence, rise, spread, modulation, and (sometimes) disappearance of infectious diseases in humans reflect a long-running narrative of cultural and environmental changes. Over the past ten millennia or so, human communities have created a succession of new ecological niches and opportunities for mutant microbes to jump species barriers and become human pathogens. The more intense the intrusion into, or reshaping of, the natural environment by humans, the greater is the probability of encountering such microbes and initiating a human infectious disease. An estimated 30-40 such “new” infectious diseases have appeared in the past three decades as a result of intensified human pressures on, and movements within, the wider environment.

The main contemporary, widespread, influences on this accelerated emergence/resurgence of infectious diseases are these (Murphy, 1999; Daszak, et al., 2000; Patz et al., 2000; Taylor et al., 2001; Wilson, 2003; IOM, 2003; Molyneux, 2003; Burroughs et al., 2001):

- Globalisation (distance and speed) of travel and trade
- Land Use and changes to ecosystems (deforestation, biodiversity loss, etc.)
- Intensified livestock production and live animal markets
- Bush-meat hunting
- Population growth, density, and concentrations of urbanised poverty
- Human behaviour and susceptibility to infection (now includes population ageing,
- HIV, IV drug use, transplantation, transfusion)
- Biomedical exchange of human tissues (transfusion, transplantation, injection)
- Food-processing technologies
- Breakdown of public health measures

Infectious agents, and their vectors, are typically very sensitive to environmental conditions (Weiss and McMichael 2004). As “r species” they can take quick advantage of a change in environment, occupying niches and multiplying exponentially. The past decade has seen a succession of new infections resulting from intensified food production methods, in disparate circumstances around the world. This includes Mad Cow Disease (bovine spongiform encephalopathy) and its human equivalent (variant CJD) in the UK and beyond; Nipah virus infection in pig farmers in Malaysia, and the ongoing concern about H5N1 avian flu in Southeast Asia (associated with intensified crowded methods of production and marketing of poultry).

3.3.1. Issue 1: Land Use/Land Cover Changes and vector-borne and rodent-borne infectious diseases

State of the Science

Vector-borne diseases (VBD) cause a significant burden of disease worldwide. Diseases that are considered to be sensitive to the different forms of GEC include malaria, filariasis, dengue fever, yellow fever, West Nile fever, leishmaniasis, Lyme disease, mosquito-borne and tick-borne encephalitis and other arboviral diseases in the tropics. Climate is an important factor that sets limits, spatial and seasonal, on the incidence and geographic distribution of these diseases. Within those limits, the prime determinants of occurrence are usually non-climatic factors, such as land cover changes and human demographics and behaviour. The Millennium Ecosystem Assessment has recently reviewed the evidences of the influences of global ecosystem changes on the distribution and dynamics of infectious diseases (MEA, 2005).

Tropical forest ecosystems are recognized as rich sources of plant and animal biodiversity and there is a significant overlap between the distribution of the majority of important vectors and agents of human and animal diseases and the tropical rain forest ecosystems, woodland savannas and the edges of these ecosystems (Molyneux, 2002).

The following are the major mechanisms relating the process of deforestation/reafforestation to the incidence of VBD (Molyneux, 2002):

1. Changes in the adaptive behaviour of animal reservoir hosts, vectors and humans (including their immune status) such as the capacity of animals to live in closer proximity to humans and the ability of insect vectors to use human hosts as sources of blood meals.
2. Forest-related activities increase and change exposure to human infective vector-borne infections.
3. The destruction of forest habitat may result in the change of distribution patterns, removal, displacement or eradication of vector and animal reservoir species.
4. Reforestation may be associated with the rapid capacity of vectors to adapt to new habitats in frequently non-indigenous climax vegetation.

Land Use and Land cover changes as drivers

The diversity of species provides resilience and resistance to ecosystems in the face of perturbations and invasions, while the mosaics of habitat support that diversity, providing generalized defences against the spread of opportunists. Human-induced changes such as deforestation, habitat fragmentation, hunting pressures and the local manifestations of climate change now contribute significantly to disrupting relationships among species that help to prevent the proliferation of pests and pathogens.

The influence of biodiversity change and habitat fragmentation upon infectious disease occurrence is well illustrated by the process of deforestation that increases the “edge effect”. This process takes place at the boundaries (or ecotones) between ecological systems (e.g., forest/plantation) where some vector and host species are confined to or occur in higher densities. Deforestation creates every year thousands of kilometers of anthropogenic ecotones, due to the patches formed. These changes in boundary architecture influence its permeability

to materials, energy and organisms and may lead to novel species interactions, thereby promoting pathogen–vector–host interaction. The resulting alteration in the risk of focal infectious diseases is greater in the tropics due to the existence of more forests, more biological diversity and more human exposure.

This process has contributed, in recent decades, to the emergence of the various viral haemorrhagic fevers in South America. These viral infections are caused by arenaviruses that have wild rodents as their natural hosts. They have been described especially in Argentina (Junin virus), Bolivia (Machupo virus) and Venezuela (Guanarito virus) (Maiztegui 1975; Simpson 1978; Salas et al., 1991). These haemorrhagic fever infections typically occur in outbreaks ranging from a few dozen to thousands of cases. Outbreaks have mostly occurred in rural populations, when individuals also become infected by contact with contaminated rodent excretions. The Machupo virus provides a good example. Forest clearance in Bolivia in the early 1960s, which was accompanied by blanket spraying of DDT to control malaria mosquitoes, led, respectively, to infestation of cropland by *Calomys* mice and to the poisoning of the rodents' usual predators (village cats). The consequent proliferation of mice and their viruses resulted in the appearance of a new viral fever, the Bolivian (Machupo) haemorrhagic fever, which killed around one seventh of the local population.

For vector-borne diseases, recent investigations have shown that deforestation may cause shifts in mosquito species composition, relative density and occurrence; alterations in the duration of their gonotrophic cycles and survivorship and also exert new evolutionary pressures and genetic shifts in the pathogens they transmit (Chang et al., 1997; Brault et al., 2004; Afrane et al., 2005; Vittor et al., 2006).

The complex multi-faceted processes of ecosystem changes and changes in human behaviour that led to the emergence of Nipah virus disease in Malaysia in the late 1990s, and those leading to the rise of Lyme disease (borreliosis) in northeast USA in the 1970s, provide instructive illustrations (Weiss & McMichael, 2004). These are discussed in more detail below.

Loss of biological diversity from agriculture can also increase the risk of infectious disease. Agricultural practices often promote rodent populations (potential disease-carrying vectors) by reducing their natural predators and supplementing their food supply (Daily and Ehrlich 1996). Forest fragmentation and subsequent biodiversity loss in the eastern U.S. may have promoted the abundance of the primary reservoir hosts for Lyme disease (deer and white-footed mice). Fragmented forests lack alternative mammalian hosts for the tick, who would otherwise “dilute” the effect of the more competent mice reservoir (Schmidt and Osterfeld 2001; Loguidice et al., 2003).

Climate Drivers

Disease-transmitting insect vectors do not regulate their internal temperatures and are thus sensitive to external temperature, humidity, rainfall, and soil moisture. Climate change may alter the distribution of vector species depending on whether conditions become more or less favourable for their breeding places and their reproductive cycle. Changes in climatic conditions also affect vector survival, which can influence disease transmission. Ambient temperature can also influence the reproduction and maturation rate of the infective agents within the vector species.

It is expected that ecosystem responses will be one mediator of the potential effects of changes in climate on infectious diseases, especially vector-borne diseases. A wide variety of ecological trends are associated with the long term climatic warming trend that has been occurring over the past century (Hughes, 2000; McCarty, 2001; Walther et al., 2003; Parmesan & Yohe, 2003; Root et al., 2003).

The extent and magnitude of climate-driven changes in human and animal infectious diseases mediated by ecological systems will be determined by two major factors (Confalonieri, 2006):

1. The nature (functional, structural); type, extent and magnitude of the ecosystem responses to climate change.
2. The degree of association between the components of the cycle of the disease (infectious agents; arthropod vectors; invertebrate intermediate hosts and vertebrate animal reservoirs) to the natural biological systems.

Climate change may induce in a given region, the replacement of an entire ecological system by another adapted to the new condition of temperature and rainfall. One example would be the “savannahization” of the tropical forests in South America.

Less radical changes in ecosystems would involve alterations in community composition; geographical distribution of a species; in abundance or seasonality of reproduction or migration of species. All these may be relevant to a specific disease dynamics and the more complex a disease cycle is (e.g., involving arthropod vectors and vertebrate reservoirs) the more likely is it to be affected. But even changes limited to the abiotic elements of an ecosystem, such as the water cycle, can change the dynamics of water-borne infections (no other animal species involved).

A drastic change in the abundance and or distribution of a given species of reservoir of natural infections can affect the maintenance of the cycle of pathogens which depend on a few species of vertebrate to persist in endemic form in a natural system. This is the case of yellow fever virus which is maintained by mosquitoes and monkey species in tropical forests of the Americas.

Some infectious disease agents such as influenza A viruses; West Nile Fever viruses and *Borrelia sp* causing Lyme disease are maintained in wild birds. Hence, changes in migration of bird species, induced by climatic and ecosystem changes (Sillet et al., 2000; Mills, 2005) may have an impact in the epidemiology of these diseases.

Another example is the indirect influence of climate on the amplification of arbovirus infections which have wild birds as reservoir hosts, such as the encephalitides (Saint Louis; Eastern Equine and West Nile). Enzootic amplification is necessary to achieve mosquito infection rates sufficient to cause human epidemics and it is facilitated by extended droughts which make mosquitoes and susceptible birds congregate in selected refuges (water bodies), thereby increasing transmission (Shaman et al., 2003). Climate change-induced modifications in wetland ecosystems and on the frequency/timing of droughts could significantly affect the dynamics of these diseases.

In regard to the differences in the cycles of infections, two basic situations can be found (Confalonieri, 2006):

1. Disease cycles that are intimately tied to the natural environment in its entire distribution range and which have not adapted to anthropic environments.

2. Diseases that are more ubiquitous and have cycles in both natural biological systems and anthropic landscapes, such as agricultural systems or even urban areas.

In the former case (diseases confined to natural systems) the cycles are more vulnerable to climate-driven changes in ecosystems and infections may die out if the pathogen is not able to adapt to the new conditions. For the more ubiquitous disease cycles drastic changes in habitats and ecological niches may cause disease extinctions on a local or regional scale due to changes in populations of vectors or reservoirs but human risks may persist in anthropic environments.

Ultimately, however, actual infections in human populations will be linked to specific exposures which may be driven by a wide range of factors, especially social, economic and behavioral factors.

The following changes in VBD transmission are likely to result from future GEC:

1. In particular regions the overall incidence and the length of the transmission season may increase or decrease. Small changes in seasonality may be important because transmission rates tend to increase exponentially rather than linearly during the transmission season.
2. The geographic distribution of disease transmission may increase or decrease when vectors take advantage of changed climatic conditions to move into new areas, or changing conditions decrease the ability of vectors to reproduce and survive long enough for disease transmission to occur. Even small increases in the range of a vector can result in the exposure of new populations; and, because new populations often lack acquired immunity, more serious clinical disease can result.

Research priorities

- Malaria is clearly a high-priority topic. This VBD is not receding in the world, despite massive efforts and expenditures over several decades. Debate persists as to whether there is any recent evidence that regional climate trends have affected malaria occurrence. While there has been an initial concentration on studying highland malaria in eastern Africa, there will be merit in extending the research to studies of the altitudinal and latitudinal spread of malaria in many regions of the world (Southeast Asia, South Asia, southern China, northern South America, Central America).
- The investigation of pathogen and host dynamics in anthropogenic ecotones to elucidate the mechanisms involved in altered infectious disease risks.
- Much remains to be learnt about how climatic conditions affect the range, seasonality and intensity of VBDs. This information is needed to: (i) develop effective public health responses, and (ii) make high-quality forecasts of future impacts of GEC. Research into associations between temporal and spatial variations in climate and the transmission of VBD can be categorized into three conceptual areas:
 - Evidence, from the recent past, about the associations between short-term climate variability (e.g., monthly or inter-annual temperature differences) and infectious disease occurrence.
 - Evidence about longer-term trends of climate change and infectious disease occurrence.

- Evidence about how meteorological variables influence components of the vector-pathogen-host relationship – necessary for the development of ‘biological’ (process-based) models for estimating the future burden of infectious disease under projected climate change conditions.

Where there is a sufficient knowledge base (e.g., the recurring influence of El Niño events on malaria occurrence in certain parts of the tropical/subtropical world), early warning systems should be developed and evaluated.

The increasingly long-distance, rapid and high-volume trading activity around the world, including more informal trading practices (e.g., wild animal trade in East and Southeast Asia), is increasing the probabilities of dissemination of infectious diseases. West Nile Fever (1999 arrival, from Eurasia, in New York), trans-Pacific spread of SARS to Canada, the cargo ship-borne spread of *Aedes albopictus* (vector mosquito for dengue) and the ready global dissemination of influenza viruses all attest to the importance of these physical facilitating factors in the modern world.

Goals

- Study the many potential drivers (e.g., conversion of natural lands into agricultural ones, climate change, biodiversity loss) of the abundance and distribution of vectors, their competence to transmit disease, the requirements for the pathogen, infection rate, etc.
- Develop models to estimate future driver-induced changes in (potential) transmission of VBDs. Specification is needed as to whether actual or potential transmission is being estimated. Often, statistical/empirical models are better suited to the former (i.e., assuming the actual climate-VBD relationship observable today will apply in a future climate-altered world). Biologically-based models (where achievable) can estimate how transmissibility would, in principle, be affected by climate change; but, without linkage to other modules, the model will not allow for any constraining effects of non-meteorological variables.
- Determine pathways to improve the capacity of individuals, communities, and nations to better develop response options to address the projected VBD impacts of climate change, and the efficacy of interventions aimed at improving response.

3.3.2. Issue 2: Changes in Human-Animal relationships and the emergence and spread of zoonotic pathogens

State of the Science

a. Intensified livestock/poultry production

Both modern industrial agricultural practices and some longstanding cultural traditions have caused health problems, as exemplified by the emergence of BSE, SARS and avian influenza.

The background to the BSE epidemic is well-known. To improve the protein content in the diet of cattle, ground-up remains of slaughtered sheep and cattle, including remnants of brain and spinal cord, were fed to cattle. In time, the causal agent of BSE, an unusual protein called a prion, was transmitted to humans, causing a rapidly progressive and still untreatable brain disease, called new variant Creutzfeldt Jacob Disease (nvCJD). Documented cases have been low in number, but with a long latency period the risk of nvCJD remains.

Severe acute respiratory syndrome (SARS) gained international attention during an outbreak that began during November of 2002 in China. Wet markets, a known source of influenza viruses since the 1970s, were found to be the source of the bulk of the infections (Webster 2004). Live-animal markets are common in most Asian societies, specializing in many varieties of live small mammals, poultry, fish, and reptiles. Survey data show that the live markets and restaurants in Guangzhong sold various small carnivore species that were captured in China, Laos, Viet Nam and Thailand, and were then brought into close proximity with one another. Most early cases of SARS were in people who worked with the sale and handling of wild animals. The species at the centre of the SARS epidemic were palm civet cats, raccoon dogs, and Chinese ferret badgers. The SARS outbreak may be viewed as a disease emerging from a new type of livestock production, because civets had become domesticated and raised as a farm animal.

Other pathogens have used livestock as an intermediate stage in emergence from wildlife reservoirs to humans. In Malaysia and Singapore, during 1998-9, an outbreak of a novel paramyxovirus (Nipah virus) affected primarily pig farmers and abattoir workers, causing death in 39% of the 263 people infected (Chua et al., 2000). The virus is carried by fruit bats (flying foxes) which fed close to pig pens at an intensively-managed farm in peninsular Malaysia. Recent work has shown that the intensity of the farm management system allowed the virus to persist and cause a cascade of human cases, leading to a largescale outbreak (Daszak et al., In press).

Avian influenza virus has caused fatalities in humans, highlighting the potential risk that this type of infection poses to public health. Genetic reassortment within a person co-infected with human and avian strains of influenza virus, could potentially link the high transmissibility associated with human-adapted viruses with the high rates of mortality observed in the avian cases, thus triggering a potentially devastating pandemic (Ferguson et al., 2004). The “Spanish” influenza pandemic of 1918-19 was the largest infectious disease event in recorded history, killing over 20 million people. Recently a single gene coding for the viral haemagglutinin (HA) protein from the 1918 pandemic influenza was identified and produced extraordinary virulence in a mouse model (Kobasa et al., 2004). Such highly virulent recombinant viruses will continue to pose a threat through agricultural practices.

b. Encroachment into wildlife habitats, and bushmeat consumption

Cultural practices such as hunting of bushmeat is sometimes driven by failed agriculture, population increases and hunger. Invasion and penetration of forest habitat by humans exposes them to viruses, such as *simian foamy virus* (Wolfe et al., 2004). There are implications for the emergence of other SIVs, including HIV, as well as other viral diseases such as SARS. Within many cultures, the predilection for eating meat of various exotic species exacerbates the risk of exposure to infectious agents not previously encountered. This issue will be addressed in more detail in section 3.4.

Research Priority

- Influenza remains a global public health major concern. In light of its apparently complex ecological basis, including the role of viral transmission and genetic mixing within the bird-duck-pig-human complex in the crowded farming conditions in southern China and the possible transcontinental spread of the virus via migratory birds. The emergence and spread of new strains may be sensitive to GEC conditions, such as the effects of climate change on bird migration phenology.

Goals

- Assessment of the health risk of trade in wildlife
- Surveillance of wildlife trade for zoonotic and other infectious agents
- Study of how these drivers – and others, like road building for exploration and extraction of minerals – contribute to zoonotic emerging diseases and transfer of animal viruses to humans
- Monitor hunters for wildlife pathogens

3.3.3. Issue 3: Food-related, water-related and other infectious diseases

The centrality of water and sanitation for human life and health is widely acknowledged. Water is used directly for drinking, cooking, washing and growing food but about one third of the world's population live in countries experiencing moderate to high water stress; about one billion people globally do not have access to safe freshwater supplies and 2.4 billion people lack access to adequate sanitary infrastructure (WHO & UNICEF 2000). Roughly 10% of the global burden of disease as measured by the Disability Adjusted Life Years (DALYs) is caused by health problems associated to water (UNESCO, 2006). Global change of the hydraulic cycle is expected to contribute significantly to the enhancement of these figures. This may prompt individual, local, regional and international conflicts about water rights and properties.

Adverse health effects related to water are regularly organized into four categories: water-borne diseases ('dirty water diseases', e.g., cholera, toxic substances), water-based diseases (e.g., schistosomiasis), water-related vector-borne diseases (e.g., malaria), and water scarce diseases ('water washed diseases', e.g., trachoma).

Some important endemic diseases are transmitted through direct contact with water contaminated by pathogens and parasites or chemicals, such as schistosomiasis, guinea worm infections and skin lesions caused by arsenic.

Water-based diseases are caused by pathogenic organisms that spend part of their life cycle either in the water or in aquatic organisms. Water-related diseases depend on water bodies for transmission (e.g., malaria mosquitoes, avian influenza reservoirs, onchocerciasis). Water shortage is a critical determinant of both malnutrition and poor sanitation in several parts of the developing world.

Water-borne diseases are usually considered to be those diseases that are spread via water that is contaminated with faecal material or toxic substances. Diseases caused by pathogenic organisms (water-based diseases) that spend part of their life in aquatic organisms are often associated with standing water, and therefore often promoted by water management projects, which have been launched by societies to mitigate consequences of water scarcity (dams, irrigation). Food-borne illnesses are defined as diseases, usually either infectious or toxic in nature, caused by agents that enter the body through the ingestion of food. There are a number of important emerging food-borne pathogens, such as *Escherichia coli* serotype O157:H7 infection of beef. Many food-and water-borne diseases show strong seasonal patterns that reflect their mode of transmission.

Diseases transmitted through food and water primarily are the primary causes of infectious diarrhoea; these diseases cause significant morbidity and childhood mortality worldwide. Water-borne infectious diseases claim 3.2 million lives each year (6% of all deaths globally). Some faith-based and bequeathed water-related behavioural patterns may not be neglected in

their role to promote water-related disease and to inhibit new, health-promoting water technologies and management schemes, e.g., nutrient cycles.

Some infectious diseases, such as *Salmonellosis*, are relatively common and self-limiting infections. Others, such as cholera, can be life threatening. Food- and water-borne diseases have a large economic impact in both developed and developing countries. In developed countries, economic impacts are through treatment costs and loss of working time. Laboratory studies have shown that, in general, the proliferation of organisms such as bacteria increases with increasing temperature, providing other conditions are met. Therefore, if all else is unchanged, an increase in ambient temperature will increase the number of cases of infectious diarrhoea.

Research priorities

Although temperature and precipitation are known to affect the incidence of various food- and water-borne diseases, only a few studies have been conducted of the temperature-disease relationship across the full range of ambient temperatures for specific pathogens. These relationships depend on the prevailing types of pathogens and modes of transmission, which means that they vary according to local circumstances.

It is important to promote studies both to provide more accurate scientific information on the water-associated disease burden and to demonstrate the effectiveness of integrated water resources management schemes for disease control and health protection.

Goals

- Demonstrate, from the recent past, about the associations between short-term and long-term climate variability (e.g., monthly or inter-annual temperature differences) and infectious disease occurrence. These relationships will vary considerably between countries and communities at different stages of socio-economic development. Therefore, these studies need to account for the various other factors related to the incidence of food- and water-borne diseases, including socioeconomic variables that measure economic development and levels of sanitation.
- Study how to improve the capacity of individuals, communities, and nations to better develop response options to address these projected impacts.

Linkages with other projects

This Theme (GEC and infectious diseases) should develop direct linkages with the IGBP/IHDP Global Land Project as well as with the ESSP Global Water System Project and the DIVERSITAS cross-cutting network, bioHEALTH.

3.4. Theme 4: Food-producing systems and health

Introduction and Rationale

Together, croplands and pastures have become one of the largest terrestrial biomes on the planet, occupying approximately 40% of the ice-free land surface (Foley et al., 2005). Today, cultivated lands cover nearly 18 million km², roughly the size of South America, and pastures and rangeland comprise another 33 million km², approximating the size of Africa (Ramankutty & Foley 1999; Asner et al., 2004; Foley et al., 2003). Populations across the globe have altered the landscape to improve their well-being, either for nutrition, energy (hydro-electric dams), economic gain or shelter. Nevertheless, current practices are depleting resources at unsustainable levels and land-use practices have also led to many serious, unintended health consequences.

By definition, agriculture alters ecosystems and the biogeophysical environment. In the views of some commentators, ongoing trends in agricultural activity may cause more global environmental damage over coming decades than will ‘new’ changes such as global climate change (Greenland et al., 1998; Trewavas, 2002).

The main health-impact issues – which will also be noted within the GECAFS framework – are:

- The adequacy and quality of food supplies for human consumption, against a background of widening and intensifying demands on the natural resource base (soil and freshwater).
- The consequences of freshwater diversion into irrigated agriculture, in relation to water availability for drinking, cooking and domestic hygiene.
- The contribution of food-production practices to the generation of greenhouse gases (especially fossil fuel combustion, nitrous oxide emissions, and methane from wet agriculture) and ozone-destroying gases (especially brominated soil fumigants).
- Local and regional chemical pollution, including toxic exposures (pesticides, heavy metals) and eutrophication of waterways.
- The impacts of land-use practices (including dams and irrigation) on infectious disease occurrence (e.g., schistosomiasis in Africa’s Great Lakes; generation of Nipah Virus disease in Malaysia in wake of bat feeding deprivation via forest clearance and exacerbation by El Niño of 1997-98).
- The health consequences, direct and indirect, of the dominant influence of nitrogenous fertilisers to the human-induced nitrification of the global environment.

Land-cover change for food production involves road and dam construction, irrigation, and deforestation. These incursions can all modify the transmission of infectious disease (McMichael 2001; Patz et al., 2004). For example, increasing tropical deforestation (often for livestock production) has increased the risk of malaria in Africa, Asia and Latin America, and Leishmaniasis in Latin America. In another example, irrigation in tropical areas often increases the habitat and breeding sites for schistosomiasis (involving snails as an

intermediate host), and mosquito-borne Japanese encephalitis, malaria and filariasis (or elephantiasis).

Denuding the landscape of trees (for agriculture or any reasons) also can exacerbate flood risks. For example, Hurricane Mitch, a devastating storm that hit Central America in 1998, killed almost 10,000 people, widespread illness from water- and vector-borne diseases followed, and one million people were left homeless. Areas with extensive deforestation with settlements on degraded hillsides or floodplains suffered the greatest morbidity and mortality (Cockburn et al., 1999). This event along with others, such as the subsequent Yellow River flood catastrophe in China in 1998, demonstrate the importance of land cover features as a buffer that can prevent injury/fatality from floods.

The agriculture sector uses a very great amount of fresh water, accounting for ~85% of global consumption (Gleick, 2003). Roughly 40 percent of food crops are derived from irrigated lands. Additional benefits of water projects may include draining wetlands with resulting reduction in mosquito breeding sites; however, the wetland services of filtering, detoxifying, or providing species habitat will be lost. In addition, some irrigated lands have become heavily salinized and useless for crop production.

Intensive agriculture also affects water quality by increased sediment load and leaching of nutrients and agricultural chemicals and toxics into streams and rivers. In the last 40 years, there has been a 7-fold increase in fertilizer application and a 70% increase in irrigated cropland area (Rosegrant et al., 2002; Gleick 2003). Agriculture is the largest source of excess nitrogen and phosphorus in waterways and coastal zones (Carpenter et al., 1998). Indeed, humans now generate as much biologically activated nitrogen as do all of Nature's pathways – volcanoes, lightning, vegetation, and others. The Millennium Assessment (2005) estimates that our contribution, especially from nitrogenous fertilizers, may increase by a further 65% by 2050. We are changing the chemistry of soils and waterways around the world. This poses risks to human health, both direct and indirect, including those shown here:

- Diminished crop yields (soil nitrification and acidity), and hence impaired nutritional sufficiency
- Eutrophication (nitrates and phosphates) of waterways, potentiating cholera outbreaks (via planktonic blooms)
- Stomach cancer (nitrate ingestion)
- Nitrogen oxides (air pollutants)
- Methaemoglobinaemia (babies)

Concentrated and intensive animal production (either in agriculture and aquaculture) carry both ecosystem and human health risks. Antibiotics are routinely used for prophylaxis and growth promotion in high-production livestock agriculture, rather than being used sparingly for medical purposes. Such subtherapeutic levels exert selective pressure on the emergence of resistant bacteria (Patz et al., in press). For example, *Campylobacter* bacteria and *E. Coli* strains cultured from piggeries show widespread resistance to multiple antibiotics. Livestock have also been shown to be reservoirs of drug-resistant *Salmonella* bacteria and other *E. Coli* that are resistant even to newer generation antibiotics, like cephalosporins. See also the following box.

Box 2: Livestock production

The domestication of animals as a food source, millennia ago, made them easier to catch and kill, and to exploit their reproductive cycle (eggs and milk). This greatly helped to ensure supply. But human culture and technology rarely stand still and, under the modern stimuli of industrialisation and competitive free-trade, the breeding and growing of livestock has much intensified. This generates four major problems: (i) seriously impaired animal welfare, including heightened disease incidence; (ii) heightened pressures on the environment; (iii) substantial energy-losses due to the diversion of cereal grains from humans to animals; and (iv) diverse (and often unexpected) risks to human health – including the generation of antibiotic-resistant bacteria and the mobilisation of infectious disease agents (e.g., new influenza virus strains and other avian viruses from pig-duck-human contacts in southern China and high-density chicken farming in Southeast Asia,¹ and the UK's "Mad Cow Disease" episode and consequent variant Creutzfeldt-Jakob Disease in humans.²

Globally, as the per-person production of cereal now appears to be declining, the per-person production of meat is continuing its four-decades-long 60% rise.³ Meat is widely viewed as a desirable, high-quality, component of diet, and hence an increase in meat consumption is a central feature of the "nutrition transition".⁴ However, producing sufficient, not to mention excessive, meat for a future global urban population of 5-6 billion poses major challenges to environmental sustainability. Modern "industrial" meat production requires very high inputs of energy, water, cereal grains and ("growth-promoting") antibiotics, and it does much damage to local environments (effluent, chemical runoff) while also contributing to global climate change (via methane release from livestock, from both ends). In Australia, where the English culinary culture was transplanted two centuries ago without reference to local environment, cattle and sheep farming has done widespread damage to soils, pastures and waterways. It would be both environmentally beneficial and health-promoting if those cloven-hoofed domesticates were substantially replaced by kangaroos (a plentiful source of low-fat meat).⁵

The statistics for food-energy losses and water requirements for production of feed-lot and factory-farmed livestock are impressive.^{6,3} To produce a kilogram of feed-lot beef requires around nine kilograms of cereal grain (e.g., corn); for pork the approximate ratio is 4:1, for chickens 2:1. Beyond those statistics is the issue of *who* bears the losses. The answer is that they are mostly borne by poorer populations in lower-income countries striving to generate foreign exchange by exporting feed-grains – rather than growing food-grains for local consumption.

Events in East and Southeast Asia in recent years have highlighted some other health-endangering aspects of the rearing, capture and sale of animals for food. For millennia, small farms accommodated mixed species living closely with humans – goats, pigs, cattle, ducks, geese, chickens, and perhaps a water buffalo or a donkey – and accordingly there was much animal-to-animal and animal-to-human transfer of (often novel) infectious agents. As mentioned above, the widespread duck-pig-human small-farm complex in Southern China is implicated in the generation of variant influenza virus strains. Cross infection also occurs when animal species are raised separately but are sold together in the market place. The 1997 outbreak of avian influenza in Hong Kong occurred in mixed markets, where live chickens, quail and ducks were stacked together in close quarters with humans.⁷ The liking, widely evident in that part of the world, for eating exotic animal species also exacerbates the risk of exposure to infections not previously encountered. Indeed, this situation probably triggered the Severe Acute Respiratory Syndrome (SARS) epidemic, in which (wild) palm civet cats,

traded across national borders, were the prime suspect as the source of the new corona virus that caused SARS.¹

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Loss of biodiversity, invasion and food yields

Invasion of exotic species can affect biodiversity within agroecosystems, which in turn affects vulnerability to invasions of parasites, pests and weeds. Hence, reducing invasions and pest and pathogen emergence will decrease the need for both pesticides, some of which are persistent organic pollutants (POPs) that have direct human impact, and fertilizers that often cause eutrophication of lakes and marine coastal ecosystems, harming fisheries and leading to seafood-borne toxins.

One way to reduce the effect of invasive species on food-producing systems, as well as to decrease the impacts of damaging insects, is to increase temporal and spatial biodiversity (between years, within the field, and between adjacent fields).

Trends in world food production

Global food production has almost tripled since the 1960s, while the world population has approximately doubled. This increase in globally-averaged per capita yield mostly reflects gains in cereal grain yield, especially via the Green Revolution. That “revolution” depended on higher-yield dwarf strains and more intensive inputs of energy and chemicals. Those inputs were often at the expense of soil and water resources. Meanwhile, globally, the annual rate of expansion of cropland has declined, and around the world little additional good land remains to be recruited.

On any reasonable analysis, however, there *must be* limits (at least in the absence of remarkable advances in food production methods). Some commentators now wonder if we are starting to see evidence of over-use of agro-ecosystems for grain farming. Improvements in yield, especially for cereal grains, have slowed over the past decade (UN Environment Program, 2002; WEHAB, 2002; Tilman et al., 2001) and globally, the annual increase in grain harvest has been falling behind annual population increase during 1996-2003 (see Figure 2, page 22).

Cereal grains (rice, wheat, maize) are an important index of food adequacy since, worldwide, they account for around half of all food energy. While much grain is consumed directly, an

increasing proportion (currently about one third) is consumed via its rather inefficient conversion to meat (chicken, pork and, especially, beef), eggs and dairy products.

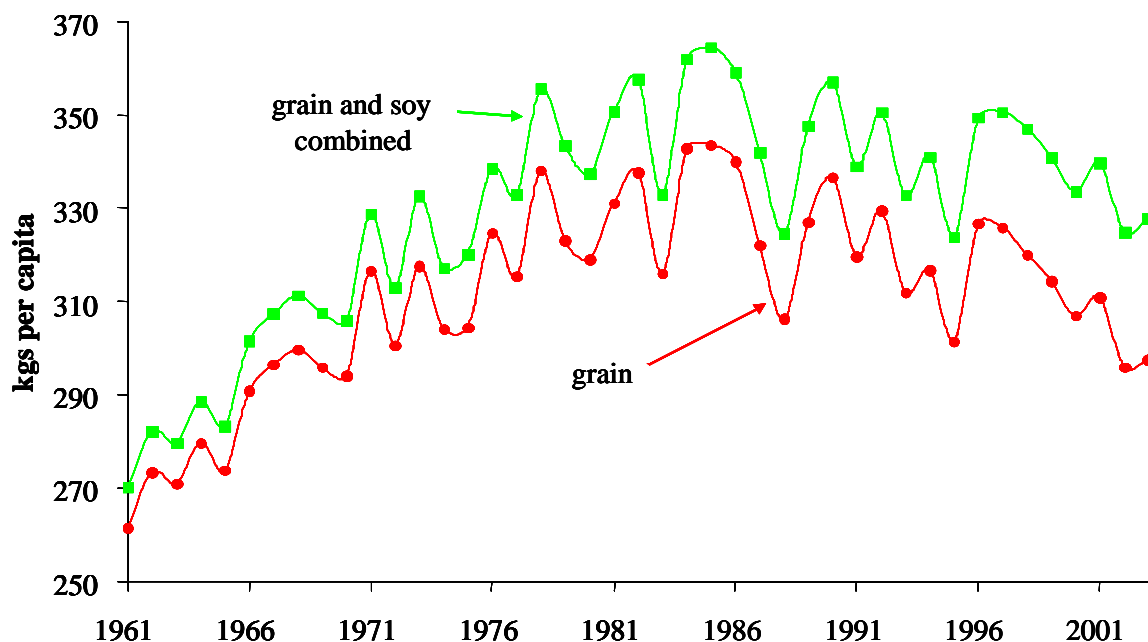


Figure 4. Per capita grain and soy production 1961-2003. Raw data from the FAO and UN Population Division. Peak production occurred in 1985. Since then the decline in per capita grain production has been partly compensated by increased soy production. Soy is an increasingly important form of animal feed. (Source: C Butler, see figure 4.3 in Lang & Heasman, 2004) (Note: preliminary figures for grain-plus-soy in 2004 indicate a rebound, perhaps to around the 1997-8 level.)

The downturn in per capita yield during 1996-2003 is undoubtedly multi-causal. The main likely contributors include regional switches from grain to other crops, government-subsidised idling of grain-farming land in USA and some European countries, the downturn in agriculture in Russia and former USSR countries since 1990, the widespread decline in soil fertility and productive land area over the past several decades (UN Environment Programme, 2002), and, perhaps, the early impacts of climate change (Peng et al., 2004).

While the *proportion* of hungry and malnourished people in the world is slowly declining, in *absolute* terms there remain an estimated 840,000,000 under-nourished people (FAO, 2004). Of these, 95% of under-nourished persons are in middle- and low-income countries (and around 60% of these are in Asia). Meanwhile – a distasteful irony – the prevalence of obesity is now increasing in middle-class urban populations everywhere.

Research priorities

Food production is a necessity for human survival. However, current agricultural practices in many parts of the world are increasingly looming as unsustainable, and thus pose both direct and indirect health risks. Priority areas requiring research focus include:

- Determination of the environmental and health costs and benefits (immediate and deferred) of modern agricultural practices.

- Study the balance between near-term human population nutrient and energy requirements and the long-term sustainability of natural resources for meeting future food and nutrition needs.
- Comparative study of response options at all scales, from local to global, and develop understanding of coupled human-environment systems (including both the impacts and responses to impacts).
- Studies of the relationship between biodiversity in and around agricultural systems (polycultures, mixed habitats) and the invasion and spread of pests and pathogens – with detrimental impacts on food yields.
- Research on the introduction of agricultural practices necessary to increase temporal and spatial biodiversity.

See also the research priorities under 3.1.1. Focus E, page 32.

Topics

- Optimization modelling studies to identify “best practices” to maximize food yields while simultaneously (i) maintaining the natural resource base for sustainable use, and (ii) maintaining stability of the microbial world, to minimise changes in risks of infectious diseases to humans (and other species).
- Carry out integrated assessments of the environmental impacts and the health consequences of food production systems, studied across all sectors and at multiple spatial-temporal scales.
- Develop a more sophisticated understanding of the interplay among soils, waterways, climate, plants, insects and other species as interacting factors and systems that bear on the current and future prospects for human population health.
- Mainstream “food and nutrition” as a central issue for population health. (It is all too often not visible to either clinical medicine or to public health as a “health” issue.)

Marine Ecosystems

Box 3. Environmental changes and the productivity of ocean fisheries

Fish are a major source of high-quality protein for many populations around the world, including many coastal communities in developing countries. The several current major threats to the sustainability of the world's fisheries therefore present a direct threat to the nutritional adequacy of local and regional diets, and, hence, to the nutritional status and health (including child physical and intellectual development) of many communities.

Modern industrial fishing fleets are putting great pressures on ocean fisheries. The best-known case example is the dramatic collapse of the Grand Banks cod fishery, North-west Atlantic, in the 1970s and 1980s. Despite the resultant 1992 moratorium, that fishery now appears unlikely to recover because the whole ecosystem has undergone a state-change with a re-positioning of species (MA 2005).

Two other recent reports indicate the additional pressures, at global level, that humankind is now placing upon the world's fisheries.

The UK Royal Society (2005) released a detailed report, documenting how the increasing atmospheric carbon dioxide concentration is acidifying the ocean. The chairman of the report team said: "the rising ocean acidity is yet another reason for us to be concerned about the carbon dioxide we are pumping into the atmosphere. Failure to cut carbon dioxide emissions may mean that there is no place in the oceans of the future for many of the species and ecosystems that we know today." The reason for that statement is that calcification of zooplankton, crustaceans and shellfish is very sensitive to pH. This poses a serious threat to the productivity of the base of the marine food web.

At about the same time a physical shift was reported in various fish populations in the North Sea in association with ocean warming over the past several decades. Almost two-thirds of fish species had either moved to higher latitudes or to deeper levels. The authors forecast that global climate change will affect fish populations similarly in many parts of the world.

This combination of three great human-induced pressures on the world's ocean fisheries threatens their future productivity – and hence jeopardises a very important source of human food (particularly protein), nutrition and health.

Linkages with other projects

This Theme (food-producing systems and health) should develop direct linkages with ESSP-Global Environmental Change and Food Systems (GECAFS), IGBP- Global Ocean Ecosystem Dynamics (GLOBEC), and IHDP-Global Environmental Change and Human Security (GECHS).

3.5. Theme 5: Urbanisation and human health

Introduction

Over the past two centuries, the proportion of humans living in cities or large towns has increased from approximately 5% to 50%. This process of urbanisation entails radical changes in social organization, family relations, housing conditions, transport choices, recreational opportunities, dietary patterns, occupational environments, access to educational and healthcare services, and, of course, the transmission of infectious disease agents (McMichael 2000). The inevitability and impact of urbanisation forces at the global level, in particular within the developing countries, in the next 25 years is going to further exacerbate the above changes and add new environmental and health impacts.

Some health risks may be overt, as with road trauma or the increase in asthma hospitalisations during air pollution crises. Others are more insidious – for example, sustained exposure to environmental lead blunts young children's intelligence. The material quality of housing is also important, and, in many countries, affects seasonal patterns of morbidity and mortality. Housing quality, including dampness, may contribute to early-life exposure to fungal spores and to house dust mites, both likely initiators of asthmatic predisposition in children. Another "health risk" related to houses is their stability (construction) especially in the case of flooding.

Urban air pollution has, in recent decades, become a worldwide public health problem. The earlier industrial/domestic air pollution from coal-burning has been largely replaced by pollutants from motorised transport. These form photochemical smog in summer and episodes of heavy haze of particulates and nitrogen oxides in winter.

As modern cities expand, transport systems become increasingly prominent. Car ownership has escalated over the past half-century in much of the world. In many Asian cities, rapid growth in private vehicle ownership, without commensurate growth in road capacity, has created serious environmental problems (including increased lead pollution). As well as the problem of exhaust gas emissions - causing local air pollution, contributing to acid rain and to greenhouse gas emissions - the other major public health impacts of car-based systems include: (i) injuries, (ii) reduced physical activity (and resultant obesity), (iii) disruption of neighbourhoods and social relations (mental health problems), and (iv) increased noise levels (sleep disturbance, raised blood pressure).

Further, cities have increasingly large "ecological footprints" – i.e., the amount of land, sea and atmosphere needed to supply the city's material and energy needs and absorb its wastes (Rees 1996). There are undoubted ecological benefits of urbanism, including economies of scale, shared use of resources, and opportunities for reuse and recycling. Equally, though, there are great "externalities". Urban populations depend on food grown elsewhere, on raw materials (timber, metals, fibre, etc.), surface water and energy sources (especially fossil fuels) extracted from elsewhere, and on disposing their voluminous wastes elsewhere. For example, the estimated consumption of resources by 29 cities of the Baltic Sea region – wood, paper, fibres and food (including seafood) – requires a total area several hundred times greater than the combined area of the 29 cities. This will have consequences on the "natural environment" by its modification and more often its destruction leading to other health and well-being problems tackled in other sections of this implementation plan.

Therefore, urbanisation can be seen as both causing much of the environmental-change problem, but also providing opportunities for many solutions. Indeed, one aim of the ESSP is

to make a contribution to the development of "sustainable" health care systems which will be able to deal with most of the issues raised within this section. Health care systems in this context are viewed from a broad public health perspective but also include the medical performance and economic capability of health care systems.

3.5.1. Issue 1 – Extreme Climate Events, Thermal Stress and Air Pollution

The most obvious place where GEC and health intersect is in cities when extreme heat/cold events and pollution interact to cause increased morbidity and mortality among vulnerable populations (e.g., the elderly, children, the poor and the homeless). In the hottest and coldest months of the year, extreme events at the local level appear to be increasing in number, occurrence, duration and intensity as the result of global climate change.

More intense and erratic storms will redesign vulnerability maps, and heavy rains may flood streams not affected earlier. Extreme weather (cold/heat) events affect vulnerable populations in the largest urban centres of both developed and developing countries, although with variations. The mortality excesses associated with heatwaves in France and India in the summer of 2003 illustrate this sub-theme.

Research priorities

While the evidence is mounting that GEC leads to more and intense extreme heat/cold events, contributes to urban air pollution and results in increased morbidity and mortality among vulnerable populations, the ability to forecast extreme events, the interactions with prevalent urban air pollution and the resulting health impacts remains limited.

Research gaps also exist in: (i) attributing the differential and exclusive impacts of extreme weather events on morbidity and mortality in the short term; (ii) exclusive health impacts of urban air pollution in the longer term; and (iii) the inadequate preparedness of local health and social services to respond effectively to these events.

Topics

- Studies to improve regional forecasting of extreme heat/cold events including the interface with prevailing air pollution levels to produce likely enhanced health impacts on vulnerable and marginal population groups.
- Emergence of heat island occurrence in the megacities of developing countries and their likely health impacts.

3.5.2. Issue 2 - Urban Sprawl and Exposure to Vector-Borne Diseases

When future historians reflect upon the major trends of the 20th century, it will be recognized as the century of urbanisation. In virtually every part of the world and in every country, populations increasingly moved from rural to urban places, leading to the physical expansion of cities everywhere. The 21st century will witness the consolidation of this process. Intense population mobility (also a factor in multiplying the health consequences of GEC), including commuting and intra-metropolitan migration, has gone hand-in-hand with urban expansion, which increasingly takes the form of urban sprawl. Peri-urbanisation, or *in situ* urbanisation, an important phenomenon in Asia, results from the growth and transformation of rural villages to city dimensions. Such quasi-urbanized areas are more exposed to vector-borne diseases and are worst served by health and sanitary infrastructure.

When residential and economic land uses are extended to previously rural areas, the emergence and spread of vector-borne diseases are facilitated; biodiversity is threatened; atmospheric pollution from increased automobile use is increased; water use is increased; and the economies of scale from concentration, in terms of adaptation and mitigation measures in the face of GEC, are lost.

Research priorities

Linking residential patterns to exposure to vector-borne diseases and to other health consequences of GEC is a key gap in our knowledge. The examples of Hurricane Katrina in New Orleans and the Asian tsunami are evidence that the income-related effect may occur in both rich and poor countries. Marginalized population groups, whether in degraded, dense city centres or in distant, poorly serviced peripheries, are most likely to be affected.

Topics

- Studies of the role of urban sprawl in the emergence of urban malaria, Dengue Fever, Lyme Disease, and other vector borne diseases.
- Studies of respiratory illnesses aggravated by higher air pollution levels promoted by urban sprawl.
- Identify best practice in comprehensive public health strategies to prevent/control the spread of vector borne diseases under the conditions of rapid urban growth.

3.5.3. Issue 3 - Water Quality and Disease Outbreaks

The growth in urban populations results in the growth in demand for water. In both DCs and LDCs, cities face periodic water shortages and even water stress situations. The periods of water shortage are growing in frequency as a result of GEC and the growing demand for water. The lack of water in general and safe drinking water in particular places populations at increasing risk of exposure to disease from either the use of contaminated water or the debilitating effects of dehydration. An important concern is that 13 percent of the world's urban population live in low elevation coastal zones (LECZ), ranging from 7 percent in Latin America to 18 percent in Asia. Flooding and salinization of already inadequate water supplies will deteriorate health conditions. Large cities are especially vulnerable: 65% of cities with more than 5 million inhabitants are in these zones, compared to 13% of cities with fewer than 100,000 (UNFPA, 2007).

Research priorities

While the basic science underlying the links between contaminated water or dehydration and exposure to disease are generally well understood, the magnitude of the problem of declining water resources and their impacts on the health of urban populations are not well-known nor understood.

Topics

- Studies of ground water levels, reservoir capacity, risk of salinization and increased risk of exposure to disease (e.g., fluorosis).
- Assess the health impact of dumping urban waste-water in water bodies for consumption in down stream communities (city health footprints).

3.5.4. Issue 4 – Population Mobility

Global environmental, political and economic changes mean that people are constantly on the move. Counted in these moves are people displaced by war and disaster, people moving to seek employment on a temporary or permanent basis and people travelling from place to place either for business or leisure. Arguably, the dominant trends in migration have been from rural to urban places, among urban places and to a lesser extent reverse migration from urban to rural places. Other forms of short-term mobility are growing, including movements across national borders. These movements are not well documented for their health impacts and their potential for mixing vulnerable populations must be assessed.

The urban transition is further advanced in some regions than others (Latin America as compared to most of Asia and Africa, for example), which implies that mitigation and adaptation measures will have to be tailored to regional circumstances. In the predicted urban growth of Asia and Africa, there is room for anticipating GEC in the design of city growth, while Latin America faces major adaptation challenges.

The scale and rapidity with which long distance travelling takes place now means that exposure of vulnerable populations is taking place at unprecedented rates (e.g., the spread of SARS). This greater mixing may also mean that immunity against genetic strains of infectious agents acquired in the rural area of origin may no longer protect against different strains in the urban destination of the migrant.

In some cases, the migration is triggered by climatic phenomena, especially droughts. ENSO-associated droughts in the semi-arid Brazilian northeastern region caused rural-urban migration and visceral leishmaniasis outbreaks in large cities, the parasite being carried by infected migrants (Franke, 2002; Confalonieri, 2003).

Research priorities

While disease surveillance systems provide some ability to track the spread of a disease like SARS, the role that large scale migration (e.g., rural to urban migration) especially to urban centres plays in the mixing of vulnerable populations or the spread of diseases linked directly to GEC have not received systematic attention and need to be analysed. Furthermore the experience with SARS has highlighted some significant deficiencies of health care systems to react in a timely and appropriate way to outbreaks of new highly infectious diseases (e.g., the spread of SARS among health care workers in its early stages).

Topics

- Studies of the role that migration to large urban centres and reverse migration play in the mixing of vulnerable populations.
- Studies of the role that migration to large urban centres and reverse migration play in the spread of diseases directly connected to GEC.
- Studies of the role of health care systems in controlling the spread of newly emerging diseases.
- Studies of the role that international migration (rural-urban, urban-urban and return) plays in the mixing of vulnerable populations.
- Studies of the dynamics of intra-urban mobility and the shifting vulnerabilities to disease vectors, flooding and landslides associated to GEC.
- Studies of institutional responses to large-scale rural-urban migration designed to attenuate the vulnerability of migrants.

3.5.5. Issue 5 - Crowding, Concentration and the Diffusion of Disease

Concentration of the population and crowding are common phenomena within the world's largest cities. Human crowds provide easy routes for communicable diseases. In many cities, concentration and crowding is not only about human concentration and crowding, but also about human concentration and crowding in conjunction with animal concentration and crowding. The strains of social disintegration in rapidly growing urban areas are an important factor driving the burden of disease that is influenced by the proximity of large numbers of susceptible individuals. In the context of GEC, this is creating the conditions not only for the rapid diffusion of newly emergent diseases from person to person but the rapid diffusion of disease from animal to person (e.g., SARS and potentially Avian Flu).

Crowding and concentration also means that people are living in areas that are most vulnerable to extreme events. In South Asia every year people face the prospect of losing their homes, death, and disease resulting from cyclones. Simultaneously, the human systems (e.g., the health care system, the emergency service systems, the food system and infrastructure) essential for the mitigation of these events are also under severe stress or even collapse. For example, it is common for there to be major outbreaks of cholera and diarrhoeal diseases in the aftermath of a major cyclone and significant lag time in response to the major challenges. Another issue to consider related to high population densities in which the association of crowding, poverty, residence in areas subject to flooding and landslides, and recent migration intensifies social and environmental vulnerability.

Research priorities

It has been long recognized that the concentration of population and crowding, especially when combined with extreme poverty, create the conditions for the rapid spread of diseases such as tuberculosis, influenza, and dengue fever. More recently, the introduction of diseases such as SARS and the Avian Flu represent new challenges for researchers focusing on the origin, transmission, diffusion, and control of disease.

The morbidity and mortality resulting from the concentration and crowding of populations in vulnerable places is well documented. What is missing is research that can lead to improvements in how human systems can become more resilient. What is also needed are studies that take into account the dynamics of human settlement in vulnerable urban areas, the potential health risks exacerbated by overcrowding and concentration providing the basis for improved public health strategies and urban design.

Goals

- Study how urban systems can be better prepared and organized to respond to the aftermath of extreme events.
- Analyse the relationships between settlement patterns, social and service infrastructure, human vulnerability and the implications for human health and human systems.
- Analyse consequences of indoor air pollution and its consequences on human health.
- Studies of the ways in which crowding, mobility, housing and poverty affect infectious disease transmission patterns in urban settings; and studies of how urban populations act as sources or critical masses for the generation and amplification of infectious disease outbreaks and spread.

- Studies of institutional preparedness and connections between governmental agencies and the networks mobilized by vulnerable populations to respond to extreme climate events.

Research priorities

The development of conceptual models and their empirical testing is required to analyze the links between GEC, urbanisation and health.

One important question is whether there are critical thresholds beyond which the interactions among urban population growth and the impacts on the natural (e.g., sources of water) and built (e.g., the urban infrastructure required to deliver water) environment lead to ecological changes that have major health impacts. If so, what role does GEC play in the build up to these thresholds?

Topic

- Develop models of urban population growth, ecological change and consequences on health.

Linkages with other projects

This Theme (urbanisation and human health) should develop direct linkages with the IHDP core project on Urbanisation and GEC and the IGBP core project on International Atmospheric Chemistry (IGAC), the Global Carbon Project activity - Urban and Regional Carbon Management, and ICSU's initiative on Health and Wellbeing in the Urban Environment.

3.6. Theme 6: Vulnerability, social representation and resilience building

3.6.1. Issue 1 - Vulnerability

Vulnerability has been described as “exposure to contingencies and stress, and the difficulty in coping with them” (Chambers, 1989). In relating the notion of **Vulnerability** to the broader framework of **Risk**, three major dimensions are involved (Kasperson & Dow, 2005):

1. Exposure to stress/perturbations.
2. Sensitivity of people/places to these perturbations, including their capacity to anticipate and cope with stress.
3. Resilience of exposed people/places, in term of their capacity to absorb shock, while maintaining function.

Several regions and populations that are and will be affected by GEC are highly vulnerable, in the sense that they are poorly equipped to cope with these changes; many are already exposed to multiple stresses arising from socioeconomic forces. As a consequence their health will be at an increased risk. However, human population health vulnerabilities to the impacts of GECs did not receive substantial past analysis in vulnerability research and assessment; only general aspects related to global climate change having received some attention (Kovats et al., 2003; Fussl & Klein, 2004).

Adaptation strategies to protect human health need to be developed even if the best possible mitigation measures were implemented today. Since there is a huge lead time between the anthropogenic “causes” of environmental change (e.g., CO₂ emissions) and their effects (e.g., global warming) there is both the time and the obligation for the scientific community to generate the evidence for better human adaptation policies.

Impacts of Global Environmental Change on human health are modulated by the ability of individuals and social systems to adapt. Exposure leads to initial impacts given a sensitivity function. Initial impacts prompt spontaneous or autonomous adaptation measures, which may not entirely eliminate the adverse health effects. A residual net impact remains, which in turn can stimulate planned adaptation measures as a policy response. As Figure 1 (page 10) shows, such policies can be aimed to reduce the impact of a given exposure (vulnerability) or at reducing the human interference with the earth system in the first place (mitigation, left side of the graph).

Before proposing a research agenda, it is useful to look at adaptation from different angles (see Figure 5, overleaf). It can happen spontaneously or as a consequence of planned individual or collective action. It can be biological (e.g., by developing antibodies against a climate-sensitive infectious disease), behavioural (e.g., by avoiding exposure to sunlight), or societal, (e.g., by building storm drains in mega-cities). It is further useful for research to distinguish the level at which adaptation occurs (individual, group, national or international). Further, following the public health paradigm, it can be seen at different stages of prevention: primary (e.g., building dams to avoid flooding); secondary (e.g., early recognition of potential damage) and tertiary that is dealing with the impacts (e.g., preparedness on the part of health services to treat diseases likely to be exacerbated by GEC early).

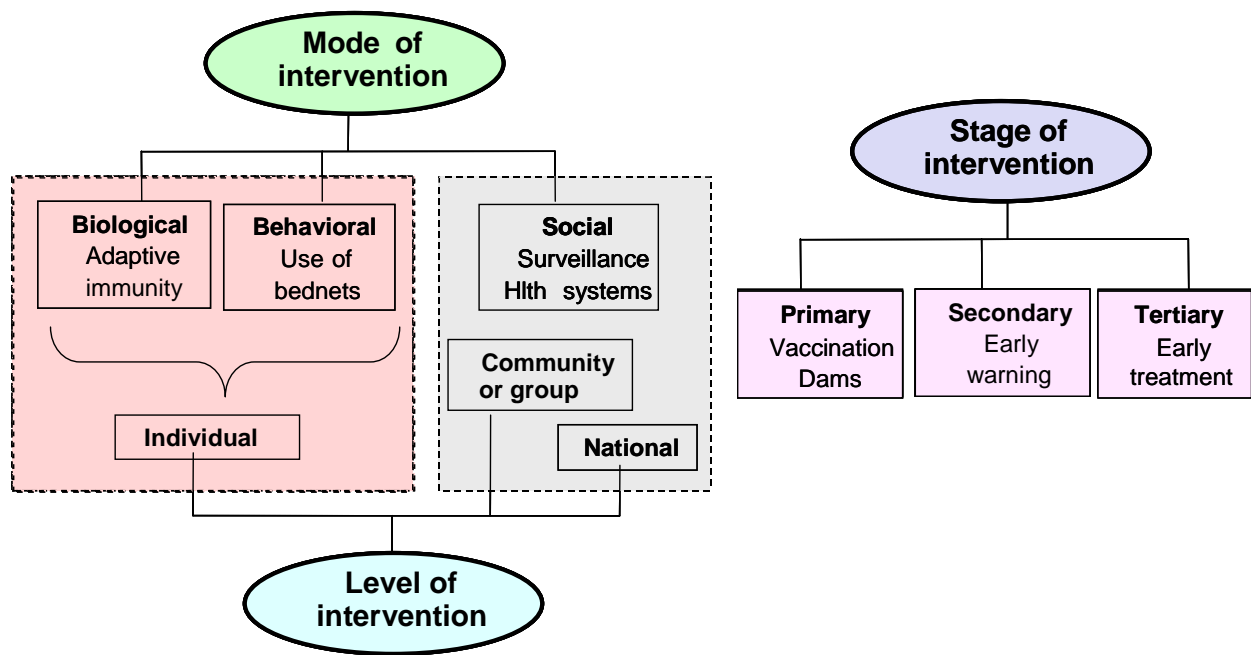


Figure 5. Three key dimensions of adaptation (mode, level and stage), showing malaria-related examples in each box (modified after McMichael and Kovats 2000)

Research priorities

Few studies of adaptation to health impacts go beyond identifying policy options that are intuitively obvious. We lack an understanding of the process of adaptation, the decision making process, the roles of various stakeholders in it, potential barriers and constraints. Further, we lack a clear idea of the effectiveness and costs of adaptation measures. Without such information, it is impossible to design appropriate adaptation policies.

Research Activities

- **Adaptive capacity** - to identify the adaptation capacity / vulnerability of different population sub-groups to adverse health impacts; analyzing which population groups will be affected most, or above average given a specific exposure (vulnerability); to review current measures, technologies, policies and barriers to improving the adaptive capacity of human populations to global environmental change.
- **Adaptation measures** - to identify and scientifically evaluate, where possible, the most appropriate and effective measures, technologies and policies to successfully adapt to global environmental change:
 - *Information:* indicators for early recognition of specific health effects should be identified, validated and the respective data collected in a systematic spatial (in specific hot spots) and temporal (longitudinal prospective) pattern.
 - *Technology:* research and development for drugs and vaccines against diseases likely to be more frequent under scenarios for Global Environmental Change. Studies into the use of information technology for fast early warning systems.

- *Risk sharing*: How can informal networks be strengthened, how can formal risk sharing tools, such as community-based or social insurance, microcredit be developed? How can income generating activities of households be diversified?
- *Health services*: They are the main, though not only, conduit through which the measures of three preventive stages will have to be delivered. Unfortunately health services are quite ineffective particularly where they are needed most (a new facet of the “inverse care” law). Improving health systems is not a matter of material resources, managerial skill and political will alone. Health system research should aim at the double issue of access to (e.g., through innovative financing policies) and quality of health services at the peripheral and district levels. At the central level the management and information processing capacity should be assessed and cost-effective ways of improving it tested in intervention studies.
- *Infrastructure*: What is the optimal mix of health and other infrastructure needed to improve the adaptive capacity, particularly in developing countries?
- *Equity*. Exposure, sensitivity and adaptive capacity are likely to vary substantially among population subgroups and over time. This has been stated frequently, but rarely taken into account in study designs. The geographic, economic, gender and age differentials in exposure, sensitivity, adaptive capacity, should be an integral part in studies of adaptation and vulnerability.
 - *Economics resources*: What are the costs of adaptation measures, at the individual, household, group, national and international levels? What cost sharing regimes could be devised to spread those costs?
- Estimates of the health benefits in relation to costs of specific strategies or combinations of strategies for adaptation for vulnerable populations under different scenarios for change in the nine dimensions depicted in Figure 5.

Such studies should be carried out in several different settings (different exposure profiles, different adaptive capacity) using the same research protocol. For countries in Africa and Asia, the data-rich sites should be used where appropriate, since they collect reliable health data (impact) as well as socio-economic data as a starting point.

3.6.2. Issue 2 - Social Representation and Resilience Building

Current social science vulnerability assessments usually employ the notions of:

1. Multiple stressors (direct/indirect; environmental/anthropogenic).
2. Socially and spatially varying exposures to health-related stressors (with scale dependencies).
3. Socially and spatially differential sensitivities to health risks.
4. Broad ranges of coping capabilities and adaptation potentialities, particularly those of the affected populations themselves.
5. Health outcomes, as a continuum along the lines between health vulnerability and health security.

A people-centred perspective of what vulnerable groups themselves perceive as health risks, how they endeavour to build resiliencies, how they organise their daily lives around health

issues, what they themselves value as health security is required. Social vulnerability, in this context, has to be conceptualized as a day-to-day struggle for health security, whereby the vulnerable seek to develop risk-prone livelihood portfolios. As empirical research has shown, the non-tangible assets are frequently the most important ones such as social networks/social capital. The vulnerable spend much time and effort to “invest” in such assets. The term “adaptation” which is central to this science plan has to be viewed from this perspective, and a special emphasis has to put on the multiplicity of institutional relations and processes involved. Health security is not just an outcome of political, technical, infrastructural, etc. intervention, but is constantly negotiated and contested, it is highly conflictual, and the successful adaptation of some groups may also imply health vulnerabilities for others.

This points to the fact that health vulnerability is socially and spatially highly differential, and that the determinants of the relative vulnerability of human groups to the health implications of GEC is an integral part of the social and spatial structures and processes in which health vulnerability is imbedded. From this perspective, health vulnerability is a reflection of larger processes of marginalization and deprivation, of mechanisms that disempower and disentitle the vulnerable from health entitlement. Socially and locally differential human health has to be viewed, first and foremost, as an outcome of inequities and injustices that the most vulnerable face. Under the impact of health privatisation, health transitions and major transformations of the health care and social security systems in virtually all societies, health security has also become a highly politicised arena. From a social science perspective, the impacts of GEC on the vulnerable have to be viewed from these angles.

Another strand of discussion around social/health vulnerability points to its recursive character. Much empirical work has shown that today’s vulnerabilities are the result of former impacts, and that today’s coping mechanisms and adaptive measure will lay the foundation for tomorrow’s health vulnerabilities/securities. However, coping and adaptation, in this context, have to be conceptualized as social and political processes in which vulnerable people are both victims and agents.

A more systematic vulnerability assessment framework as indicated above might serve to offer entry points into an interdisciplinary integration where particular disciplines can work on specific components of health vulnerability to GEC, and then integrate these within a conceptual framework.

Complex social networks sustain humans in normal times. Human vulnerabilities during change, hazard, disaster or conflict reinforced by GEC, are usually a matter of disruption or failure of these networks. Vulnerability is determined by physical, social, economic, cultural and environmental factors, resulting in inequities in material and intangible consumption. It increases the elements at risk; limits genuine coping strategies; and restricts the learning processes from previous disasters and further capability-building. Therefore it represents a trigger for preventive and adaptive capacity, and creative resilience building for self-protection.

Socialization processes can improve coping and adaptive capacities and resilience-building, enabling threatened societies to deal better with unknown situations caused by GEC and to guide decision making on health care reforms and public health strategies.

Research Priorities

- To understand the construction processes of social representation and identity among different social, gender and age groups, enabling people, policy makers, and international organizations to improve resilience, reinforcing the existing adaptive potential among different social groups.
- Deepening the interlinkages between top-down institutional action and bottom-up resilience behaviour to reduce social vulnerability and therefore to reinforce risk reduction processes for short term emergency and middle and long-term responses to health and other social vulnerability issues.
- A central challenge for research and practical policies is that present formal data banks on extreme events and epidemic outcomes overlook social vulnerability and do not account for social and, particularly, gender identity differences during normal time, leaving highly vulnerable groups isolated in crisis situations. Social vulnerability analysis needs to be developed to reduce vulnerability in the most isolated groups at the time of extreme events.
- More accurate understanding and training would facilitate creating support networks that underlie a resilient society, and enable societies to deal with new dangers and threats resulting from GEC.

Research activities

- Research on situated knowledge which relates formal with informal behaviour. It affects attitudes (doubts, certainty) and justifies deepness. It questions policy makers, creates confidence, and empowers citizens as acting subjects. Differences between the perception of objects and persons create different socio-cognitive representations, enabling people and policy to understand the complexity of the world and to reinterpret and rethink integrally the complex relations between GEC, new risks in health conditions and public health strategies.
- For an effective response to health hazards and threats, the understanding of social vulnerability is crucial. In turn, research is needed that leads to the design of effective processes of resilience-building and coping strategies to avoid the “survival dilemma.”
- A deeper understanding of gender, which plays a crucial role in health issues due to women’s complex roles and social identity (in reproductive, productive, social, psychological and cultural terms) is required. Improved understanding of objective and subjective stability during dangers and threats related to GEC can also increase the efficiency of public health and social programmes for preventive actions, early warning and adaptive capacities.
- The analysis of complex risk emergencies has to be linked to the prevention of conflicts with health and environmental threats. For example, there is no doubt in Africa that drought, malnutrition, famine and HIV/AIDS triggered by undemocratic governments and warlord governance, create complex emergency patterns with high death tolls and wide population movements.

Linkages with other projects:

This Theme (vulnerability, social representation and resilience building) should develop direct linkages with the WHO Healthy Cities Programme, IHDP-GECHS and the Metropolis Program.

4. Implementation Considerations

This section addresses the implementation of the ESSP joint project on GEC and Human Health from two different perspectives: scientific (4.1. and 4.2.) and organizational/administrative (4.3. and 4.4.).

4.1. Interdisciplinary methods and data needs

4.1.1. Methods and Data

Research on this topic often requires linking diverse disciplines, as mentioned above. Examples are:

- Spatial mapping, remote sensing and weather satellite images in relation to disease distribution, incidence and forecast, such as meningitis and malaria in Africa, malaria in Latin America and South Asia, and onchocerciasis (river blindness) in West Africa.
- Classical outbreak investigation combined with knowledge of recent environmental and commercial-practice changes, climate and meteorological data, and knowledge of forest ecology for elucidation of infectious disease emergence such as Nipah virus disease and its causal agent in Malaysia (1997-1999).
- Spatial mapping of the migration patterns of birds and the spread of pathogens and vectors carried by them such as West Nile virus in the USA since 1999.
- Field survey methods to understand food production, land use, resource extraction, and variable vulnerabilities.
- Social analysis and health systems research to understand the limitations of public health strategies in the context of GEC and to identify options for overcoming health inequalities.

A wide range of research methods and various data sets are needed for the study of GEC-human health relationships. Traditional methods in epidemiology and health sciences research will be an important part of this effort. However, many new research concepts and methods are needed.

To address more integrative approaches to studying GEC-human health relationships, international seminars and courses should encourage exchanges of new ideas and concepts from the many disciplines and sub-disciplines involved.

There is also need for new types of data-sets, in addition to extending the use of various existing data-sets. Currently, research in the area of health and the global environment is frequently constrained by the lack of appropriate data and available data are not often fully accessible or exploitable. More research is needed to improve the methods for the compilation, integration and standardisation of health and environmental data. This should involve a dialogue between users and collectors of data to ensure that data are collected on the most useful variables and with the most appropriate spatial and temporal resolution.

Biologically-relevant indices that reflect changes due to GEC need to be developed. Examples include: drought severity indices, against 30-year averages (available for USA); multi-day heavy rain events (in development); sequential extremes, such as periods of drought interrupted by heavy rains and flooding (not yet in development). Similarly, measures are required to characterise the socio-economic and other material factors that affect the

vulnerability of a population to GEC. For example, income is not a very useful measure of poverty in the slums of Asian cities or the *favelas* of Brazilian cities. Poverty is better measured by indices of food scarcity or housing quality.

Although some large data-sets are available, improvements in the following areas are needed:

- Availability of high-quality health time series data, in different scales. Excellent quality longitudinal health data sets on entire contiguous populations have existed for up to 50 years in sites cooperating in the INDEPTH network. (www.indepth-network.org).
- Monitoring (collection of data), especially in connection with programs with monitoring of environmental conditions and animal populations. Remotely sensed data can overcome some of the problems of lack of ground-based data. They can provide vital information on diverse variables, including vegetation, land cover, flood events, coastal algal blooms, etc. There is also a need for expanded resources for interpretation of satellite-derived data.
- Integration of large data sets from national and international statistical agencies in the form of demographic and health surveys with environmental change data.
- Development of better ways of data linkage and data dissemination.
- Historical data on factors involved in promoting the spread or initial emergence of diseases. For example, historical data on expansion of agriculture could be useful to determine the reasons for the emergence of a new foodborne disease.
- Data that are appropriately geographically scaled. Geographical information systems (GIS) can overcome some of the problems of the mismatch among geographically scaled data sets, but the failure to include measures of location (e.g., postal codes) retards matching of health data series with environmental, socio-economic and demographic data.
- Maps of health risk areas or regions.
- Development of more robust analytic methods capable of overcoming data limitations. Meta-analyses and Bayesian analyses will help this field to progress.

Box 4. Modelling Environmental and Social Systems: Dealing with Complexity and Uncertainty

Today's large-scale environmental problems are characterised by complexity. They entail non-linearities, time delays, feedback loops, and system interconnectedness. Small events can have unexpectedly big effects; causal influences are multiple and separated in time; and the problems to be studied transcend disciplines. This makes prediction, and hence management of risks, particularly difficult.

Computer models enable us to structure our understanding of complex systems. A model constitutes an abstraction of an actual real-world system. It is useful because it can be manipulated, developed and analysed in place of the real system. However, the uncertainty and indeterminacy of complex systems requires us to make subjective decisions about the behaviour of various aspects of the system. This implies embedding a series of assumptions in the model, thereby incorporating uncertainty at various levels.

The complexity of systems has several major consequences for modelling:

First, it inevitably affects how models are developed and applied. The modelling requires an iterative ("trial and error") process, where modules at different levels of detail are considered in conjunction with different assumptions and hypotheses about how the real system works.

This iteration typically occurs over time, as new knowledge and ideas are generated and subsequently used to modify existing models.

Second, complexity precludes any attempt to create an exact replica that is free of uncertainties. Instead, it nurtures a creative process in which the different sources of uncertainties are explored. Model development and application may thus be perceived as part of a learning process. Models are useful for more than prediction; they can be used for exploratory analyses, communication and learning.

All too often, however, complexity gets simplified during model development, and uncertainties are minimised because they are seen as undesirable – indeed, as perhaps invalidating inference about a real problem. Yet complexity, treated as an asset, enables a different way of viewing and understanding systems. To fully realise this opportunity will require modelling that incorporates a more comprehensive approach to handling complexity and uncertainties.

4.1.2. Human health and Global Environmental Change scenarios

Models and data with regard to health outcomes have become an integral part of the scientific review work of the Intergovernmental Panel on Climate Change (IPCC). The Global Environmental Outlook process of the United Nations Environmental Programme (UNEP) assesses the state of the environment, trends and progress in policy development, including multilateral environmental agreements; and the future, with a focus on emerging environmental issues and region-specific alternative policies. Health consequences of biodiversity loss is a key issue for the Millennium Ecosystem Assessment (MEA) and these issues have taken a front row seat with deliberations of the Scientific Body of the Convention on Biological Diversity (CBD-SBSTTA). Absent from these assessments, however, are future health scenarios (Martens & Huynen, 2003).

Scenario development is one way to look at what the future might bring, allowing a deeper understanding of the potential health risks and encouraging the implementation of policies and processes for prevention and increase future adaptive capacity to what the future does bring.

International agreements and conventions regarding environmental, energy and socio-economic issues need to be informed by the most comprehensive information regarding model predictions, data and scenario projections for the future – and health should be an integral part of this information. Health scenarios for a wide range of spatial and temporal scales are thus needed by scientists and policy-makers to more accurately project the true consequences and societal costs of various future pathways and policy responses.

Research priorities

Long-range, integrated scenarios based on a comprehensive, interactive set of factors and choices driving the global environment can help inform policy makers. Scenarios have been generated concerning global climate, water utilization, availability, distribution and quality, and ecosystem composition, structure and function. But, to date, “future health scenarios” have not been generated. There is a need to combine the fields of Global Environmental Change and scenario analysis with the field of health. To do this, we need to organize and implement an international, multidisciplinary, participatory process to formulate health futures.

4.2. Integrative Activities

4.2.1. Multi-site approach to integrate monitoring and surveillance

In order to assess the health outcome of Global Environmental Change, disease surveillance systems need to be linked to monitoring of relevant environmental data for defined geographical locations. Since substantial infrastructure is required for accurate disease surveillance, it makes sense to capitalise on surveillance systems already in operation, such as a series of INDEPTH sites, largely but not entirely in Africa.

Existing surveillance sites will need to be assessed with regard to whether they are representative of locations where impacts of Global Environmental Change are particularly strongly experienced. These include high altitude sites, tropics and sub-tropics, coastal zones, desert fringes and locations, which are experiencing extensive land use change such as deforestation accompanied by population movements.

Outcomes of interest include vector borne diseases such as malaria and dengue, rodent borne diseases such as hantavirus infections, water related diseases (e.g., cholera), morbidity and mortality associated with extreme weather events (e.g., accidents); cancer, malformations and reproductive problems linked to the accumulation of POPs, temperature sensitive food related diseases (e.g., salmonella and toxic *Escherichia coli*), and conditions, especially malnutrition, which of course depends on socio-economic factors as well as on the productivity of agro-ecosystems. As far as possible disease surveillance and environmental data should be complemented by other relevant data on potential confounding factors such as public health programmes and patterns of resistance to anti-infective agents depending on the disease in question. Where possible, bio-indicators relevant to human health should also be monitored, for example insect vector species, rodents, the presence of *Vibrio cholerae* in plankton in coastal marine ecosystems, etc. Some sites where the terrestrial or marine environment is being monitored may also be suitable for inclusion of indicator species.

As much as possible field data collection activities should adopt an intersectoral integration approach in which study and monitoring efforts includes the survey of environmental processes, their health impacts and the regionally relevant social drivers. Thus, from the science perspective, interdisciplinarity would be promoted and, from the practical aspect, resources and efforts would be optimised. One model for this is the NSF (US National Science Foundation) program of Long Term Ecological Research Stations (LTERS), upon which a human health component might be added and the other way around, adding biological and meteorological data collection to health surveillance sites (www.INDEPTH-NETWORK.ORG). Another model is the new initiative Global Earth Observation System of Systems (GEOSS).

4.2.2. Population Health Surveys

To take into account the impacts of GEC at the local and individual levels, an effort should be made to develop a common international protocol for carrying out population health surveys. To date population health surveys such as the Canadian Community Health Survey collect information on a statistically and geographically representative sample of individuals and households measuring the socio-economic characteristics of the individuals, health status, health behaviours (e.g., tobacco and alcohol consumption), activities of daily living, use of health services and other measures of everyday activity that either enhance or detract from the individual's likelihood of health.

There are three directions in which population health surveys might be extended to contribute to our understanding of GEC and human health. First, through address information (e.g., GIS, postal codes), individual level data can be linked to environmental data (e.g., local air pollution measures) at various geographic scales to determine the relative contributions of individual characteristics, health behaviours, etc., and environmental stressors have on human health. The development of statistical techniques such as multi-level modelling have shown great promise as a way forward in taking advantage of these types of data linkage.

A second direction would see the incorporation of environmental exposure data into population health surveys. For example, asking questions about the sources of drinking water used by an individual on a daily basis and knowing where the individual lives would allow researchers to link measures already found in population health surveys to measures of water quality.

The third direction is to develop population health surveys as longitudinal surveys to allow researchers to track individuals over time and in various locations, for example through demographic surveillance sites. Beyond the immediate impacts of extreme environmental events, human health is going to be affected slowly by GEC in most places. Over exposure to ultraviolet radiation as a child only manifests itself later in life as skin cancer. Using a longitudinal approach would allow researchers to determine how human behaviour and vulnerability are affected by changing levels of exposure to environmental factors over time.

Research priorities

There is need for modelling and development of health scenarios, with global and regional resolution. This could be developed by reference to the current IPCC assessment endeavours.

4.2.3. Data Linkage

In virtually every country, data are collected on mortality, morbidity, various aspects of the population and the environment. The data are, however, collected separately through various government departments. For example, mortality and morbidity data might be collected by a ministry of health, population information might be collected by a ministry of labour and environmental data might be collected through a ministry of the environment.

In addition, UN-sponsored demographic and health surveys feature the largest global data set on human health. These should be leveraged in relation to current data on GEC. The integration of environmental change and vulnerability data into demographic and health surveys should also be a priority.

Research priorities

Optimally, developing a common international protocol for data linkage would facilitate the sharing of data within countries and between countries to allow for more comprehensive analyses of GEC. The greatest challenge to such a goal is to take into account the differences among countries in their approaches to confidentiality. In the absence of such an approach, geographical information systems (GIS) provide great potential for data integration to support research on GEC and human health.

4.3. Collaboration with other programmes and networks

In addition to the ESSP, the World Health Organization (WHO) was represented at project planning meetings and expressed an interest in becoming involved. Other partners such as the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) may be approached as appropriate.

There is also a great need to integrate this type of research into the ongoing and future research, being done by natural scientists, on changes in ecosystem structure and function. It became very clear during the Millennium Ecosystem Assessment (MA) that many of the “sub-global assessments” were impoverished by the lack of prior engagement of epidemiologists, environmental health scientists and social scientists in the research.

Adaptation and vulnerability are concepts germane to all biological and human systems. In the context of Global Environmental Change, the ESSP joint project on GEC and Human Health can and should therefore build on work carried out by existing ESSP joint projects (GCP, GECAFS, and GWSP); IHDP core projects (GEC and Human Security; Urbanisation and Global Environmental Change) as well as the IGBP-IHDP Joint Project (Global Land Project and the Land-Ocean Interactions in the Coastal Zone) and others, including the global change SyTem for Analysis, Research, and Training (START) and the Monsoon Asia Integrated Regional Study (MAIRS).

Collaborations with the other three ESSP joint projects

This new ESSP joint project on GEC and Human Health would be linked to the already existing ESSP joint projects, the Global Carbon Project (GCP), the Global Environmental Change and Food Systems (GECAFS), and the Global Water System Project (GWSP) via multiple pathways. The following examples show illustrative relationships between this new project and the existing three ESSP projects.

Global Carbon Project (GCP) and Health

- Carbon dioxide increases weed and tree pollen production disproportionately over biomass growth (thereby possibly increasing the incidence of asthma and allergies).
- The life-cycle of fossil fuels (oil, coal and natural gas) entails multiple health and ecological impacts, including:
 - Exploration and extraction: fires, blowouts and accidents; river delta degradation (e.g., Nigeria); cadmium, arsenic, cyanide, PAHs and mercury contamination of fish.
 - Transport: leaks and spills affecting wildlife health, fisheries and livelihoods.
 - Refining: benzene release into air causes leucopenia.
 - Burning: contributes to air pollution (with respiratory and cardiovascular impacts); acid rain affecting water quality and food production, human and wildlife health, and ecosystem degradation (eutrophication of freshwater and coastal marine ecosystems (HABs) and climate change: multiple direct and indirect health impacts.

Global Environmental Change and Food Systems (GECAFS) and Health

Terrestrial

- Agricultural pests, pathogens and weeds account for 44% loss of growing and stored crops, with possible impacts on human nutrition.
- Livestock zoonotic diseases (such as Nipah virus in pigs, Malaysia) can be transferred to humans. Non-zoonotic diseases of livestock such as BSE in cattle (United Kingdom) and H5N1 avian influenza in poultry can affect human health, influenced by cultural practices, economics (livelihoods, tourism), food production and distribution processes, and human mobility.
- Widespread use of antibiotics in livestock feed and aquaculture exerts enormous selective evolutionary pressure on micro-organisms and affects the emergence of antibiotic resistance of human pathogens.

Marine

- Biotoxins produced by harmful algal blooms (HABs or "red tides") can cause illness in humans (e.g., paralytic fish poisoning, diarrhetic fish poisoning), harm marine mammals, sea birds and fish (thus resources for human nutrition).
- Human pathogens such as hepatitis A or *Vibrio parahaemolyticus* can contaminate shellfish and *Vibrio cholerae* and other *Vibrio* species, and other genera of bacteria can contaminate finfish for human consumption.
- Coral-reef diseases affect nurseries for reef and shell fish (important for human consumption), habitat for reef dwellers (cone snails, sponges) that provide medicines for humans, buffer coastlines against storms, and prevent salinization of water that can affect human health directly (hypertension) and via agricultural productivity.

Global Water System Project (GWSP) and Health

- Adequate quantities, availability and quality of water are all essential for maintaining hygiene and preventing waterborne disease outbreaks.
- Changes in the water cycle, weather patterns, distribution and timing of precipitation have implications for agriculture and human health.
- Extreme weather events affect the timing and intensity of infectious disease outbreaks, can directly cause trauma and damage infrastructure (e.g., water systems, health care infrastructure).
- Prolonged droughts increase vulnerability to fires, haze and respiratory disease;
- Marine coastal ecosystems are affected by warming seas and changing ocean currents. (Alley *et al.*, 2003).
- Toxic *Cyanobacteria* in bodies of freshwater can cause skin rashes, liver and neurological toxicity.

4.4. Expectations and Project Timeline

Important steps in planning, implementation, and management of the project include the following:

1. The establishment of an administrative infrastructure
2. Finding sources of funding
3. Dissemination of the work of the core project
4. Organisation of a broadly-based scientific steering committee
5. Identification of key stakeholders
6. Establishing a significant number of individual projects within this core project
7. Defining the project's long term strategic objectives
8. Strengthening the links with other international projects and networks
9. Contributing to the consolidation of existing research groups on GEC and Human Health, and fostering the formation of new ones
10. Establishing mechanisms for the periodical reassessment of the goals, core questions and methods for the ESSP joint project on GEC and Human Health

The objectives to be achieved should be considered on a staged basis: short-term (3 years); medium-term (6 years) and long-term (10 years) basis:

Short-term (2006-2008):

1. Present the Science Plan and Implementation Strategy at the ESSP Open Science Conference in Beijing (November, 2006)
2. Incorporate IHDP's contribution (October 2007).
3. Identify and approach major stakeholders for the Project (2008).
4. Establish the Scientific Steering Committee for the Project (2008).
5. Establish its International Project Office (2008).
6. Implement actions to enhance visibility and outreach.

Medium term (2009-2011):

1. Consolidate interactions with other Global Environmental Change Projects.
2. Have at least 20 individual projects within the framework of the GEC and Human Health project.
3. Form a global network of at least 10 research groups on GEC and Human Health associated with the projects.
4. Present scientific products to the end users of the research (decision makers, etc.).

Long term (up to 2015):

1. To be defined by the Scientific Steering Committee.

Governance

The project will have a Scientific Steering Committee (SSC). This will comprise up to sixteen members, with representation of all major regions of the world, high- and low-income countries, and major scientific disciplinary areas.

There will be an Executive Committee, comprising the Chair of the SSC, Executive Officer, Deputy Executive Officer (if appointed), and 1-2 other member(s) of the SSC (on some rotating basis).

International Project Office

The International Project Office (location to be determined) will be responsible for the day-to-day management of the GEC and Human Health Project. Working with the SSC, the Executive Officer will develop plans for the implementation of Project activities and ensure that plans are carried out.

5. Concluding remarks

Around the world, human health is, and will be, affected by Global Environmental Changes. These constitute a major new category of environmental health hazard, arising predominantly from human-induced systemic changes to the natural systems and processes that underpin health and life.

This project would be part of the ESSP program of research, and would provide a logical “bottom line” for the other ongoing research in relation to changes in water systems, food systems and the carbon cycle. It will also establish direct linkages with other GEC Programme core and joint projects such as the “Urbanisation and Global Environmental Change”; the “Global Land Project” and others. If humankind collectively mismanages the Earth System, by perturbing the carbon cycle and the world’s climate, by changing the availability and quality of freshwater, by impairing the world’s food-producing ecosystems and by depleting the stocks of biodiversity, then there will inevitably be costs to human biology, health and survival.

There is a need to develop research methods and research capacity, internationally, in order to elucidate these risks and to achieve their reduction. The setting is a challenging one, entailing changes in various complex, non-linear natural- and anthropogenic systems, and encountering many coexistent and interacting environmental stresses on human societies.

The GEC-and-health task for the international health research community is urgent and large. However, with the advent of parallel initiatives in cognate “Earth System Science” domains, and with an evident trend towards the development and funding of inter-disciplinary approaches to these research issues, we should be optimistic that this great topic can now be tackled in a timely and effective fashion.

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8. Acronyms and Abbreviations

| | |
|-------------|---|
| BSE: | Bovine Spongiform Encephalopathy |
| CBD: | Convention on Biological Diversity |
| CDJ: | Creutzfeldt-Jakob's Disease |
| CFCs: | Chlorofluorocarbons |
| CRÉD: | Centre for Research on the Epidemiology of Disasters |
| DALYs: | Disability Adjusted Life Years |
| DCs: | Developing Countries |
| DDT: | Dichlorodiphenyltrichloroethane |
| DIVERSITAS: | International programme of biodiversity science |
| DNA: | Deoxyribonucleic acid |
| EID: | Emerging Infectious Disease |
| ENSO: | El Niño - Southern Oscillation |
| ESSP: | Earth System Science Partnership |
| FAO: | Food and Agriculture Organization |
| GCP: | Global Carbon Project |
| GEC: | Global Environmental Change |
| GECAFS: | Global Environmental Change and Food Systems |
| GECHS: | Global Environmental Change and Human Security |
| GEOSS: | Global Earth Observing System of Systems |
| GHG: | Greenhouse Gas |
| GIS: | Geographical Information System |
| GLP: | Global Land Project |
| GWSP: | Global Water System Project |
| HABs: | Harmful Algal Blooms |
| HIV/AIDS: | Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome |

| | |
|----------|---|
| H5N1: | Influenza A virus subtype H5N1 |
| ICSU: | International Council for Science |
| IGBP: | International Geosphere-Biosphere Programme |
| IHDP: | International Human Dimensions Programme on Global Environmental Change |
| INDEPTH: | International Network of field sites with continuous Demographic Evaluation of Populations and their Health in developing countries |
| IPCC: | Intergovernmental Panel on Climate Change |
| LDCs: | Least Developing Countries |
| LOICZ: | Land-Ocean Interaction in the Coastal Zone |
| LTERS: | Long Term Ecological Research Stations |
| LUCC: | Land Use and Land Cover Change |
| MA: | Millennium Ecosystem Assessment |
| MAIRS: | Monsoon Asia Integrated Regional Study |
| OECD: | Organisation for Economic Co-operation and Development |
| OFDA: | The Office of U.S. Foreign Disaster Assistance |
| PAHs: | Polycyclic Aromatic Hydrocarbons |
| POPs: | Persistent Organic Pollutants |
| SARS: | Severe Acute Respiratory Syndrome |
| SBSTTA: | Subsidiary Body on Scientific Technical and Technological Advice |
| SCOPE: | Scientific Committee on Problems of the Environment |
| SIV: | Simian Foamy Virus |
| START: | global change System for Training, Analysis, Research, and Training |
| UGEC: | Urbanisation and Global Environmental Change |
| UNEP: | United Nations Environment Programme |
| UNESCO: | United Nations Educational, Scientific and Cultural Organization |
| VBD: | Vector Borne Disease |
| WCRP: | World Climate Research Programme |
| WEHAB: | Water, Energy, Health, Agriculture and Biodiversity |
| WHO: | World Health Organization |
| WMO: | World Meteorological Organization |

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