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# BIOLOGICAL EFFECTS OF CLIMATE CHANGE

An introduction to the field and a survey of current research

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## Preface

This project was motivated by difficulties for scientists to familiarize with the complex network of institutions, organizations and research programs of climate change, combined with the obvious need for more biologists to direct their efforts towards the field of climate change impact studies.

I am greatly indebted to CICERO by its director Ted Hanisch and research coordinator Kjell Arne Hagen, who took an immediate interest in the project idea and provided me with an excellent place to work as well as the necessary finacial resources. CICERO is primarily a center for the social sciences, yet with the few natural scientists connected to CICERO, this is one of the few institutions were the concept of interdisciplinarity actually seems to give results.

Shortly after the initiation of this project, which originally was planned for half a year, the GCTE by its chairman Dr. Brian Walker and officer Dr. Will Steffen expressed their great interest . After a meeting with Will Steffen it was decided to broaden the scope of the project, which mainly resulted in the addition of a survey of the national level research together with the already planned overview of international programs. This demanded a prolongation of the time-period as well as additional financial resources. The funding for a three months extention of the project was provided by the Royal Ministry of Finance, the National Committee for Environmental Research (Norwegian Research Council, Div. NAVF), and the Steering Committee for the Environment and Development (Norwegian Research Council, Div. NAVF).

In order to map *current* research, this study could not be based on existing literature. Rather, it has depended upon the cooperation of the more than a hundred people who have been requested for information on the on-going research of their institute or on individual projects. Without the positive response and solid support from those requested, this report would not exist.

For this report to present up-to-date information the work had to be performed within a very strict time frame. The flexibility and goodwill of CICERO allowed me to hire *Cand. scient.* Nina Trandem to help me through the final spurt. She provided excellent scientific as well as editorial help, for which I am most grateful. Furthermore, Will Steffen has contributed significantly by his comments on an earlier draft on the manuscript.

Last, but not least, I am utterly grateful for the excellent comments, ideas and inspiration from my scientific supervisor prof. Nils Christian Stenseth.

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## Foreword by Brian Walker

Climate change heads the list of global environmental problems that have, over the last several years, become firmly entrenched on the international political agenda. Until very recently, much of the emphasis in the climate change debate has focussed on changes to the atmosphere itself, and what they might mean in terms of rising temperature. Increasingly, however, the focus is shifting to the impacts of climate change (which includes not only mean temperature, but changes to rainfall intensities and patterns, extremes in temperature, and changes to the severity and paths of storms). Governments, non-governmental organizations, and the public want to know what will happen to the production systems upon which they depend for food and fibre and to the ecosystems which support the rich diversity of life on Earth.

The newcomer wanting to learn more about the biological implications of climate change is confronted with a complex array of scientific issues and a bewildering tangle of organizations, institutions, international research programs and national- and regional-level studies that deal, in one way or another, with climate change impacts on biological systems. This survey aims to familiarize biologists with both the major issues and the relevant programs.

Part I of the survey deals with the scientific issues involved with climate change impacts in a clear and concise way. It serves as a good introduction to the field, and provides enough references for those who wish to learn more about particular topics.

The importance of the potential impacts on biological systems of changes in climate has spawned a plethora of international and national research programs. This survey gives brief descriptions of the major international programs, and gives examples of national projects from countries around the world. The list of contact points for the various programs and the list of project titles, given in the appendices, are particularly useful.

Studying the impacts of climate change on biological systems is a rapidly expanding field, and this survey is an excellent starting point for those wishing to learn more about the topic.

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## Summary

This report presents a survey of international (Chapter 2) as well as national research activities within 13 selected countries (Chapter 3) in the field of biological effects of climate change. In addition, a brief overview of potential changes within natural ecosystems in response to climate change is given (Chapter 1). This part is intended to serve as a quick introduction for biologists who lack previous experience with the whole or parts of the field of climate change impact studies. The ultimate goal of this work is, through the information in this report, to contribute to the avoidance of unnecessary research duplication and promote scientific cooperation.

The overview in Chapter 1 is based on a projected doubling in atmospheric $CO_2$ and a temperature elevation of approx. 0.3°C per decade over the next century. The exact magnitude of these changes is of less importance than the highly probable fact that they will occur.

At the level of individual plants, well documented *responses to $CO_2$ increase* include an enhanced photosynthetic rate, a higher water use efficiency, increased relative root size, and increased tolerance to air pollutants. Elevated *temperature* will affect all living individuals. The immediate responses are likely to be most pronounced among plants and poikilothermic animals, because their physiological processes proceed at a rate dependent on ambient temperature. The relation between plant and animal physiology and temperature is a classical field of study, and today we benefit from the vast amount of literature which has been produced in the field. There is, however, a general lack of long-term studies.

The ultimate fate of individuals and species depends upon the responses of other organisms. Among second order effects related to elevated $CO_2$, it is focused on interactions between herbivores and plants. High $CO_2$-grown foliage may be consumed at higher rates due to a lowered N-content. Furthermore, it is well documented that $C_3$ and $C_4$ plants react differently to elevated atmospheric $CO_2$. This illustrates the very important point that the responses to climate change differ between species. The concept of differential reactions from changes in climate in general is discussed in relation to effects on ecological interactions, with particular reference to competition, predation and parasitism. The ultimate outcome of climate changes at the ecosystem level depends upon the system´s ability to adapt and the species´ dispersal ability. Most studies suggest that time and genetic variability are insufficient for evolution to occur, and that the major response will be migration. It is likely that the already alarming rate of extinction that we for several reasons experience today, will be magnified.

Plant material grown at elevated $CO_2$ is likely to decay slowly because of its high lignin and low N-content. On the other hand, the overall turnover rate of organic material generally increases with temperature.

Throughout Chapter 1, indications of the terrestrial plants as an important dynamic element in the carbon cycle are made. Whereas some factors tend to enhance biomass accumulation (e.g. increased photosynthetic rate due to elevated $CO_2$), others indicate the opposite (e.g. increased herbivore load due to lowered nutritional value of high $CO_2$ grown foliage). There

are indications that the terrestrial biosphere may act as a sink for carbon. This is still a controversy, however.

Chapter 1 ends with a brief discussion regarding potential effects on marine ecosystems. It should be noted that the major biological effort within marine climate change research apparently has been directed towards the potential feedbacks to the climate system, rather than on impact studies. The general mechanisms discussed for terrestrial ecosystems also apply for oceans. This section concentrates on potential effects of changes in surface temperature and ocean circulation and mixing pattern, with particular reference to productivity and community composition. Special attention is paid to the arctic ecosystem, because the changes are likely to be most pronounced at high latitudes, and because of the particular importance of the dynamics of sea ice.

Altogether, this report, together with several other recent studies, emphasizes the need for long-term whole-ecosystem studies.

The major international programs which include studies related to potential biological effects of climate changes are presented in *Chapter 2*. The largest collective effort on the terrestrial side is probably within Global Change and Terrestrial Ecosystems (GCTE, an IGBP Core Project). Apart from the GCTE it seems that biological effects are commonly included in programs with broader scopes, often with emphasis on the physical aspects of the climate system. This is particularly true for programs addressing marine ecosystems. The descriptions of individual programs are generally introduced by their overall objectives and aims, before emphasis is put on the parts relevant for biological effects. The general impression of the undersigned may thus not be reflected, namely that the biological sciences lag behind the other natural sciences in terms of general effort and resources. However, the attention devoted to biological impact studies appears to be increasing.

An overview of research on biological effects in 13 selected countries is given in *Chapter 3*. All in all, due to the high number of programs/projects presented in this report, each description is quite brief. Therefore, an extensive list of contacts is given in Appendix B (for *both* Chapters 2 and 3). With the purpose of providing a quick reference, a complete list of project titles from the national survey is given in appendix C. Altogether, Chapter 3 presents more than two hundred projects. The majority of these have not yet resulted in published articles. Hence, there should be strong probabilities of locating new, interesting activities.

## Introduction

The phenomenon of climate change is by now widely accepted among scientists. Severe effects on our natural ecosystems are anticipated, yet great uncertainties are associated with the magnitude and direction of these effects. The complexity and global nature of the problems connected to biological effects of climate change demand cooperation between several scientific disciplines as well as across national borders. Although biology seems to be lagging behind the other natural sciences as far as resources and general effort are concerned, in recent years there has been a significant increase in the research effort directed towards an improved understanding and predictive ability with respect to biological effects of climate change. The growing number of research programs and projects within this field makes it difficult and time consuming for individual scientists to keep informed about current activities. The primary objective of this report is to present a survey of activities within the field, international as well as within selected countries (Chapters 2 and 3). An additional objective is to provide a brief overview of the likely responses of the living organisms within natural ecosystems (Chapter 1). The ultimate goal is to, through the information in this report, contribute to the avoidance of unnecessary research duplication and the promotion of scientific cooperation.

Within the broad field of climate change, the main emphasis of this report is placed on the possible responses of elevated atmospheric $CO_2$ and altered temperature and precipitation regimes, including possible feedback mechanisms. Furthermore, *natural ecosystems* are discussed; intensively managed ecosystems such as agricultural areas or forest plantations are not included. However, when collecting information on current research within individual institutions or projects, it proved very difficult to draw distinct lines regarding what should be included and what should not. For instance, often research on greenhouse gases other than $CO_2$ constitutes parts of larger projects on effects of greenhouse gases in general. In such cases, these were included for the sake of being thorough. Another difficulty has been distinguishing between managed and unmanaged ecosystems. If a very conservative definition for unmanaged systems is applied, for instance "ecosystems not utilized by man", practically all of the European forests would be excluded. Another example is research on direct effects of elevated $CO_2$ on plants, where the model species is a crop plant. The overall strategy has been to include rather than exclude projects when in doubt. Hence, the term biological effects on natural ecosystems in this context also encompasses research directly related and of obvious relevance to this issue.

This report draws heavily on the work performed by the Intergovernmental Panel on Climate Change (IPCC). In 1990, the IPCC produced scenarios for future emissions of greenhouse gases, and these were interpreted in terms of future changes in greenhouse gas concentrations, global mean temperature and global mean sea-level (Houghton et al. 1990). The basic conclusions relevant for this report were as follows:

* Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide.

* Future warming is estimated to be about 0.3°C/decade (range 0.2-0.5°C) over the next century.

* Global mean sea level is expected to rise (estimated to 8-29 cm by the year 2030).

In 1992, the same panel produced an update for the 1990 assessment (Houghton et al. 1992), including a new and more comprehensive set of scenarios. The basic conclusions regarding future atmospheric $CO_2$ concentration and temperature were not significantly changed from the first IPCC scientific assessment. Yet, it is stated that "because General Circulation Models (GCMs) do not yet include possible opposing anthropogenic influences, including the forcing from sulphate aerosols and stratospheric ozone depletion, the net rate of increase in surface temperature may be less than previously predicted" (Houghton et al. 1992). Changes in sea level may also be less severe than previously estimated (Wigley and Raper 1992). Although there are still large uncertainties connected to predicting the future climate, the scenarios made generally serve the purpose for research on biological effects.

The report is not meant to be read from the first through the last page; it is meant to serve as background information and to be used as a reference book. In order to keep the size of this report down to a sensible level, only brief summaries of individual programs/projects are given. However, the importance of easy access to additional information is acknowledged; an extensive list of contact points is given in Appendix B. Furthermore, the titles of all the projects described in Chapter 3 (national research) are listed in Appendix C for quick reference.

# I Altered atmospheric composition - an introduction to the issue of potential biological responses

This chapter provides information on some of the major recent studies connected to biological effects of climate change. It is written with the purpose of providing a quick introduction for biologists relatively inexperienced in the field of climate change.

The predicted climate changes are not unique in the Earth's history regarding the magnitude of the changes. The rate at which the predicted changes may occur, however, far exceeds any natural fluctuations in the past. Hence, natural ecosystems may respond in ways similar to those in the past, but the effects are likely to be far more severe.

Increasing atmospheric concentrations of greenhouse gases (GHGs) introduces two different stresses to natural ecosystems. Firstly, it may in itself affect ecosystem processes and thereby influence ecosystem health and composition. The matters discussed here regard effects of elevated $CO_2$, only. Secondly, the projected changes in global climate are expected to severely alter natural ecosystems. The first part of this chapter deals with potential responses of plants to the $CO_2$ increase (1.1) and to altered temperature and moisture regimes (1.2), at the level of individuals and species and interactions between species, - in that order. Interactions between species are, for clarity, dealt with by explicitly discussing responses to $CO_2$ first (1.1.2), and then responses to climate change in general (1.3). Large scale manifestations of the responses are discussed (1.4) in terms of adaptation, migration and extinction (biodiversity). Finally, the possibility that the terrestrial biosphere acts as a carbon sink is briefly dealt with (1.5). As for studies concerned with freshwater communities, the literature is comparably scarce. It seems as though the threat of global warming has provoked relatively few new experimental studies; rather, the general ecological knowledge has been used to try to predict possible responses. Brief mention of freshwater organisms are included in the terrestrial part.

The general mechanisms for ecological interactions discussed for terrestrial systems are also true for marine ecosystems. Some of the specific characteristics of the marine ecosystems are discussed separately (1.6).

## 1.1 Effects of increased atmospheric $CO_2$ concentrations.

It is estimated that even if man-made emissions of $CO_2$ could be kept at present rates, atmospheric $CO_2$ would increase (from present level of approx. 350 ppm) to about 450 ppm by the year 2050, and to about 520 ppm by the year 2100 (Houghton et al. 1990). Because $CO_2$ is the substrate for photosynthesis, it is self-evident that this will have major impacts on plants.

The nature of plant responses to elevated $CO_2$ concentrations is quite complex with first and second order effects. First order effects (sec. 1.1.1) include potential effects on photosynthesis, respiration, water use efficiency, reproduction, tolerance to salinity, growth rates, and form. Second order effects (sec. 1.1.2) include plant-to-plant interactions (e.g. competition and symbiosis), plant-to-animal interactions (e.g. herbivory, pollination and shelter) and plant-to-microbial interactions (e.g. disease and decomposition) (Bardecki et al. 1990).

### 1.1.1 First order effects

Botanists have long known some of the effects of elevated $CO_2$ levels, and greenhouse growers have used $CO_2$ fertilization to increase plant growth. Enhanced $CO_2$ levels usually increase photosynthetic rate, at least in short-term experiments. In some species this effect levels off with time, and sometimes there is even a decline in photosynthetic rate (Bazzaz 1990). This reduction may occur because other factors, such as low nutrient availability, eventually limit $CO_2$ uptake (Melillo et al. 1990).

Photorespiration, which is closely associated with photosynthesis is greatly reduced at high $CO_2$ levels. There is less information available regarding the effects of $CO_2$ concentration on dark respiration rates (i.e. all plant respiration except photorespiration), and conflicting reports indicate a poor understanding of this issue. In simple terms, dark respiration is the negative side of net primary production and is therefore of high global importance when it comes to global change (Woodward et al. 1991).

Other general features accompanying the effects of increased $CO_2$ levels are a decrease in stomatal density, a reduction in stomatal opening and thus reduced transpiration rates, and a higher water use efficiency (Allen 1990, Bazzaz 1990, Parry 1992). Therefore, it is expected that in a water-limited environment, growth will be stimulated by enhanced $CO_2$ concentrations through improved water conservation. Yet, the total water used by a community is unlikely to alter with $CO_2$ alone, because plants tend to develop leafier canopies (Woodward et al. 1991). Furthermore, the energy balance could cause foliage temperature to rise and prevent full expression of the reduction in stomatal conductance at elevated $CO_2$ (see Allen 1990 for review).

It has also been argued that elevated $CO_2$ changes the pattern of assimilates to different parts of the plants. This may merely reflect a changed timing of development (Eamus and Jarvis 1989). The many different responses of partitioning to elevated $CO_2$ prevents any generalization, however, although there is widespread evidence that there is an increased relative root size at elevated $CO_2$ (Woodward et al. 1991).

There are a number of distinct differences in the response to elevated $CO_2$ between $C_3$ and $C_4$ plant species, of which perhaps the most pronounced difference regards the photosynthesis where $C_3$ plants usually show a larger response. On the other hand, regarding for instance water use efficiency, the response applies equally to $C_3$ and $C_4$ species (Woodward et al. 1991). Most of the Earth's plant biomass (about 95%) is accounted for by $C_3$ species, but a number of plants important to humans, such as maize, are $C_4$ species. The general responses described in this chapter apply to $C_3$ species unless otherwise mentioned.

The ultimate effect on individual plants due to enhanced $CO_2$ level depends on the interaction of other environmental factors, like temperature, light levels, soil moisture, and nutrient availability (see Bazzaz 1990 for review). In particular, the presence of gaseous pollutants would affect the response to high $CO_2$ levels. To a large extent, the penetration of phytotoxic gases is presumed to occur through stomata and to be taken up in dissolved form. Thus, as it is well known that stomata tend to close in response to $CO_2$, this may indicate that plants gain tolerance to some air pollutants. For instance, Carlson and Bazzaz (1982) found that fumigation with $SO_2$ caused reduced growth of three different $C_3$ species at 300 ppm $CO_2$, but not at higher concentrations of $CO_2$.

Air pollutants in nature are likely to be found in combination rather than alone, and this complicates experimental work on this issue. Allen (1990) points out the importance of directing research towards the questions: 1) Will increased atmospheric pollutants regionally or locally reduce the positive response of rising global atmospheric $CO_2$ on vegetation productivity? and 2) Will rising global atmospheric $CO_2$ counteract in part the regional or local detrimental effects of atmospheric pollutants on vegetation? This illustrates a very critical issue that deserves further attention, namely the interaction between $CO_2$ and other factors. It represents a serious gap in our knowledge and is a major stumbling block to the development of mechanistic, whole-plant models of carbon dynamics (Melillo et al. 1990).

Finally, we need more knowledge on the long-term effects of elevated $CO_2$. Although a large number of studies have been performed at tissue and individual plant levels, the majority have been short-term experiments (and most often they terminated before reproduction). Bazzaz (1990) summarized the research needs as follows: a) How long does the enhancement of growth continue? b) How do the allocational relationships in the plant change with time under elevated $CO_2$ levels? and c) How will tissue quality change over time and what are the consequences of this to herbivores, pathogens and symbionts? (See also the following on "second order effects").

All in all, these research needs illustrates the principal lack of knowledge for the whole issue of biological effects of climate change, the key words being *long-term whole-ecosystem studies* (e.g. Mooney 1991, Körner and Arnone 1992). Although interactions between $CO_2$, temperature and other environmental factors are major contributors to complicating the experimental work, it seems now that more effort is being directed towards multivariate experiments as opposed to the earlier works mainly performed with varying single factors. This contributes to a more realistic approach to the problems of predicting the effects on ecosystems.

### 1.1.2 Second order effects

First and second order effects are closely interrelated, since nearly all first order effects may influence upon the second order effects of elevated $CO_2$. For instance, when the direct response to elevated $CO_2$ varies between species (Zangerl and Bazzaz 1984, Bazzaz and Garbutt 1988), this would alter plant-plant interactions and shift population dynamics and competitive relationships of plants growing under field conditions. This is exemplified by $C_3$ and $C_4$ species in the first part of this section. Following are consequences of changes in plant tissue quality considered, as related to herbivory, symbiotic relationships, and soil processes such as decomposition and nutrient cycling.

Some ecosystems, such as temperate zone grasslands, can contain a mixture of $C_3$ and $C_4$ plants. It would be expected that as the $CO_2$ increases the $C_3$ plants should do progressively better than the $C_4$ plants, unless there is water stress (Melillo et al. 1990). For instance, Bazzaz and Carlson (1984) studied the competition between $C_3$ and $C_4$ herbaceous plants under two moisture regimes and three levels of $CO_2$. The $C_3$ species grew progressively more rapidly than the $C_4$ species as the $CO_2$ and moisture levels increased. The increased competitive ability of a $C_3$ species, grown together with a $C_4$ species under elevated $CO_2$, was also demonstrated by Carter and Peterson (1983), Bazzaz and Garbutt (1988), and Wray and Strain (1987).

These studies of $C_3$ and $C_4$ groups of species show that plants respond differently when isolated and when in competitive environments. This is most often the case in *intraspecific* competition as well. For instance, the interaction of $CO_2$ with plant density may show different responses than when varying $CO_2$ alone. The picture is further complicated when additional factors (nutrients, temperature, pollutants etc.) are taken into consideration. Zangerl and Bazzaz (1984) demonstrated that $CO_2$ enrichment affects annual plant communities both in terms of productivity and species composition, and that the effect of $CO_2$ on such systems may depend upon other resources such as light and nutrients. Thus, the ultimate manifestation of increased $CO_2$ at the community level is likely to be altered species composition.

Studies on the effects of increased $CO_2$ on plant-animal interactions are limited, yet some work has been done on herbivory. The main conclusion is that herbivores may indirectly be affected due to changes in tissue quality of plants grown at high $CO_2$. Lincoln et al. (1986) found that larvae of the soybean looper (*Pseudoplusia includens*) fed at increasingly higher rates on plants from elevated $CO_2$ atmospheres. The reason for this was probably the lowered N (protein) content of the leaves and the increased feeding rate was to compensate for this. The larvae also grew less (5%), however, and the food conversion efficiency was lower (32%). Growth responses of early and late instar larvae to lower nitrogen, high $CO_2$ grown foliage may differ, due to the inability of younger larvae to efficiently process the increased flow of food through the gut caused by additional consumption of high $CO_2$ foliage (Fajer 1989). Similar results were found for larvae of a specialist insect herbivore, *Junonia coenia*. (Fajer et al. 1989). The adult pupal weight and female fecundity were not affected by the $CO_2$ environment of the host plant, however. Fajer et al. (1989) concluded that foliage-feeding herbivores may confront poorer quality host plants in the future, which may induce both lengthened larval periods and greater mortality. Delayed rates of development could lead to increased susceptibility to predation and parasitism. Some plants may thus experience a reduced herbivore load, thereby further increasing their yield under elevated $CO_2$. However, those insect herbivores that do survive will probably consume significantly more foliage and thereby negate the plants´ increased growth. Increased herbivory could affect plant growth as well as feed back to ecosystem-level phenomena, like accelerating nutrient cycling (Melillo et al. 1990).

The relationships between plants and microbes may also be affected by elevated $CO_2$. Symbiotic relationships between plants and nitrogen fixing organisms are well-known phenomena. For many ecosystems, high rates of productivity are linked to nitrogen fixation, and the $CO_2$ concentration is an important controller of the symbiotic relationships. Plants grown with supplemented $CO_2$ have exhibited a five-fold increase in nitrogen fixation over untreated controls (Hardy and Havelka 1975, as cited in Melillo et al. 1990).

Finally, decomposition rate may be altered with changing atmospheric composition. This prediction is based on the findings that the C/N ratio of tissues grown under elevated $CO_2$ levels decline and on experimental evidence that tissue with high lignin and low nitrogen content decays slowly (Bazzaz 1990). However, the few community experiments performed at elevated $CO_2$ suggest little changes in the rate of nutrient cycling (Woodward et al. 1991). Furthermore, decomposition is clearly related to climatic factors, with rates generally increasing with temperatures and precipitation in well drained areas. On the other hand, low temperatures and excessive moisture (waterlogging) would generally limit decomposition rates (Melillo et al. 1990). This exemplifies the risk when considering the effects of different factors separately. For several reasons this is commonly done, one of them being for practical purposes - as with the organization of this report.

### 1.2 Direct effects of changes in temperature and moisture

Effects of climate change will not be manifested as responses to temperature changes alone. Global precipitation characteristics, the frequency of extreme events (fire etc.), the sea level and soil chemistry, all interrelated factors, are also expected to change (Houghton et al. 1990). This section focuses on the effects of temperature and moisture, and other mechanisms are briefly discussed.

All living organisms are affected by temperature in one way or another. The physiological processes of all plants and poikilothermic animals (together comprising the vast majority of living things) proceed at a rate dependent upon ambient temperature. Homotherms (birds and mammals), on the other hand, are able to maintain a high and approximately constant internal body temperature and are, for physiological processes, *relatively* independent of the prevailing environmental temperatures (but see below). Yet, as discussed in the next section, the responses of other organisms naturally have severe impacts on their lives as well.

Through the physiological processes of plants and poikilothermic animals, temperature and moisture exert a strong influence upon important life history traits like birth, growth, and death rate. In general, hydrological relationships will affect living organisms directly by altered levels of precipitation, runoff, soil moisture, snow cover, snowmelt and evapotranspiration, as well as indirectly by transforming sea and lake levels, which influence coastal and shoreline ecosystems (Bardecki et al. 1990). This section does not cover all these issues but concentrates on a few important processes. It is subdivided into two subsections, each considering direct impacts of changes in temperature and moisture on plants and animals respectively.

### 1.2.1 Plants

The carbon budget of plants is important for the global carbon cycle. Net photosynthesis, for which the response is broadly similar to that of overall growth, is the difference between gross photosynthesis and respiration. Photosynthesis and respiration respond differently to temperature, with the latter being the most responsive at higher temperatures. This could result in a reduction in net carbon uptake by plants (Woodwell 1987).

On the other hand, different kinds of stress can reduce photosynthesis, and so is it with water stress. This can be alleviated, at least in the short term, when plants are exposed to elevated $CO_2$ (section 1.1.1). The effect of water stress on respiration is more complex. One plausible effect of reduced moisture level would be reduced respiration if plant growth is reduced (Hanson and Hitz 1982, as cited in Melillo et al. 1990).

Temperature and moisture can also affect the timing of development and senescence, a common example would be the abscission of the leaf canopy of deciduous trees in autumn. In drier tropical ecosystems, moisture can function as the primary controller of canopy development (Melillo et al. 1990). This means, depending on the organisms involved, that either temperature or moisture can function as the primary determinant of the length of the growing season.

Correlations between climate and vegetation has traditionally been a research field of high interest, which has proven highly useful in the context of the new challenge of global warming and the attempts to model the effects. The interaction between plant physiology and climatic variables is reflected in present-day distribution of vegetation. Such correlations that have well-founded explanations at the physiological level are those between plant distribution and, respectively, growing season length, absolute lowest annual temperature, and total precipitation (Woodward 1992). The growing season for different plant species is usually measured in day-degrees. The minimum day-degree total necessary for species of differing vegetation types to complete their vegetative and reproductive cycle varies largely (see Woodward 1987), exhibiting a direct dependency on temperature for the existence of a species in a certain area. Not only do plants need sufficient warm days during the year for growth and reproduction, they are also restricted by absolute low temperatures at the poleward or upper altitudinal boundaries of a species range. While so-called chilling sensitive species (e.g. tropical vegetation) are killed by temperatures in the range of 0°C to 10° C, boreal needleleaved trees may be resistant to all temperatures (Woodward 1987). Finally, plant biomass is clearly correlated with total precipitation. Averaging observations on the global scale indicates that biomass is greater where there is more precipitation. As precipitation increases from less than 50 mm/year, vegetation changes from desert to sparse shrub or herbaceous vegetation to parkland with scattered trees and finally to full forest (Schulze 1982, as cited in Woodward 1992).

### 1.2.2 Animals

The direct effects of temperature on animal biology is a classical field of study and a huge amount of literature exists in this field. It should be noted though, that the major part of this literature tells us about the short-term effects on individual physiological processes, rather than the survival of a particular species during a projected warming trend in nature.

As stated above, all physiological processes in poikilothermic animals are affected by ambient temperature. Generally, the overall metabolic rate increases with temperature, and hence the required intake rate of energy and materials like protein also increases (Dawson 1992). On the other hand, a higher temperature may improve the efficiency by which energy and materials are obtained. For example, the digestion of herbivorous food may require a certain minimum temperature (Tracy 1992). A higher metabolism also increases the oxygen demand, and in aquatic systems this coincides with the lowered oxygen solubility of warmer water. Both these factors may aggravate problems for aquatic species living in places with oxygen depletion, e.g. near the bottom of stratified lakes. One such species is the freshwater crayfish *Astacus astacus*. On the other hand, if oxygen is not a limiting factor a temperature rise could be favorable for this species because it limits the frequency of molting (e.g. Westin and Gydemo 1986; Gydemo and Westin 1987).

The effect of temperature on rate of development in many poikilothermic animals may bring about changes in the number of generations per year. In the case of rapidly reproducing animals, such as aphids, where population number increases exponentially, the fitting in of one or more extra generations in a climatically good year may produce a very dramatic increase in the population density (Ford 1982).

Although fairly independent of temperature as far as physiological processes are concerned, homothermic animals have to regulate their body temperature according to their environments. Mechanisms for such regulations include, for instance, adjustments of the insulation provided by fur or feathers. At ambient temperatures exceeding body temperature, birds and mammals may prevent over-heating by evaporative cooling such as sweating or bathing (Dawson 1992), i.e. processes that increase the demand for water. In regions were the anticipated warming is likely to be accompanied by reduced precipitation, it may thus represent a direct threat to homothermic animals as well.

In general, animals may use several modes of response to higher temperatures: behavior serving to minimize stress, physiological thermoregulation, hyperthermia or dormancy involving a relaxation of thermoregulatory control. Although such mechanisms enhance the immediate chance of survival, they cannot eliminate subtle effects of warming on animal biology (Dawson 1992). An important consequence of the different responses to increasing temperatures is that they most probably vary among species. Hence, as with plants, the outcome is likely to be alterations in the community composition.

A feature of particular concern in this context is the reproductive biology, which is highly sensitive to altered temperature regimes. As reproductive patterns are very diverse, it is very difficult to generalize concerning the anticipated effects. Dawson (1992) specifies some areas in vertebrates of special importance: i) the behavioral pattern of the parents, appearing especially critical for birds nesting in exposed situations or depending on food and water sources distant from the nesting sites; ii) embryos and chicks, and the urgency of the adult birds´ ability to maintain proper temperatures for them; iii) reproductive processes, including fertility and fecundity, intensity and duration of estrus, and egg production; and iv) sex determination in reptiles, where temperature has been shown to be a key factor for several species.

### 1.3 Effects on ecological interactions between species

Within an ecosystem all organisms are connected to one another either in a direct (e.g. predator-prey) or an indirect manner (e.g. primary producer - secondary consumer). Hence, a major determinant of the fate of an individual or a species may in fact be the response of other organisms within the same system. Such relations are discussed in this section, with a focus on competition, predation and parasitism. Finally, there is a brief mention of the fire-vegetation system.

The principal outcome of competitive interactions has been illustrated above in the case of differential reactions between $C_3$ and $C_4$ plant species as a consequence of elevated $CO_2$ concentrations in the atmosphere. In general, some species may be able to adjust to and utilize the changes in climate better than other species, and thus the outcome of a competition between two species may be different than it would without the predicted changes in climate. Furthermore, many species will face "exotic" competitors for the first time. Factors favoring exotics on land include the increased mortality of natives, creating gaps for colonization of sun-loving annuals, and the relative lack of native herbivores for the new species (Bardecki et al. 1990). Thus, one major outcome of climate change could be new associations of species in previously well defined communities. The concept of a shift in community composition may be illustrated by the well-known phenomenon of eutrophication in freshwater lakes. A temperature rise could lead to increased mineralization of organic matter stored in soils which could release nutrients such as nitrogen and phosphorus and affect trophy status of lakes (Hessen and Wright 1991). Increased nutrient loads will, under certain circumstances, lead to the blooming of undesirable blue-green algae, due to their high ability to utilize phosphorus.

Of crucial importance to plant community functioning is the synchronous operation of life cycles of interacting plants, animals and soil organisms. Such synchronisms may be disrupted, for instance, as a result of that species respond differently to environmental changes and a shift in competitive ability. A well known example is the synchronism found between the life cycles of plants and the animals which they depend upon for pollination or seed dispersal. Another example is the migration of waterbirds from their wintering to their breeding grounds. These migrations are timed to match the emergence of food resources in the wetlands along the migration route (Myers and Lester 1992).

Climatic influences may affect the duration of time over which individuals of poikilothermic species may be available as a prey to their predators, because at higher temperatures developmental rate may be accelerated and thus stages of their life cycles shortened. Moreover, the increased locomotory activity and faster movements made possible by higher temperature could make a poikilothermic prey species inaccessible to those predators dependent on its sluggishness. On the other hand, increased prey activity may be advantageous for predators which only attack moving prey (Ford 1982).

If a direct response of a prey species is a change in distribution (sec. 1.4), its predators would probably follow and the response of the prey would thus be translated up the food chain. By analogy, in the case of herbivory, we can substitute the term "prey" with the term "food". As plant nutritional value also may be affected by climate change (sec. 1.1), both the quality and quantity of an herbivore´s food resources may be changing. Relationships between pathogens and their hosts may in many ways manifest similar responses to climate change as that of the predator prey relationship, although the analogy is further complicated by the fact that, in the former situation, the "host" (the organism being preyed upon) is several orders of magnitude larger than the attacking organism, the pathogen. In consequence, it is not always the case that the direct climatic response is manifested by organisms lower in the food chain followed by an indirect response by individuals at the next trophic level (Ford 1982).

Climate related stresses may increase plant susceptibility to insect attacks. (Melillo et al. 1990). Under water stress, for example, the biochemical composition of plants changes, and concentrations of amino acids, alcohols and other potential insect attractants tend to rise (Rubenstein 1992). With regard to temperature, parasites and diseases may do well in a warming world. In temperate regions, the distribution of pests is often limited by low temperatures and particularly by cold conditions during winter. Therefore, warmer conditions in such regions are likely to extend the potential geographic range of some pests and also increase their abundance where decreased development times will enable extra generations to occur (Cammell and Knight 1992). Warmer temperatures may thus enable the invasion of pathogens with which the native potential hosts have no previous evolutionary history, i.e. the opportunity to develop resistance has not been present. This may be illustrated by several historical events where man has brought new species and their associated natural parasites into areas where related host species are non-resistant. One such example is the introduction of an American crayfish species (*Pasifastacus leniusculus*) to Europe and the rapid spread of the crayfish plague and the almost complete elimination of the native *Astacus astacus* throughout the region (e.g. Unestam 1973). On the other hand, if population size of the host species declines because of climate change, their rare species of parasites may become extinct. However, in some cases the presence of a parasite can be important, as some species of hosts may become pests in the absence of pathogens that normally regulate their number (see Dobson and Carper 1992).

Climate induced changes in vegetation may involve changes in overall vegetation flammability, which in turn alters fire frequencies and intensities (Brubaker 1986). Despite the complexity of the fire-vegetation system, the effects of fire on a population are often easy to predict. For instance, fire should increase the rates of range expansion and local population growth for shade-intolerant species, which require large openings for establishments. On the other hand, the spread of shade tolerant, late successional species may be slowed if fires are frequent enough to keep most stands in early successional stages (Brubaker 1986). However, when species no longer are centered in their climatic range, the response for individual species after a fire may be different than without the projected climate change.

### 1.4 Adaptation, migration or extinction? Broad scale manifestation of responses to climate change.

What will be the main manifestation of the response to climate change? For simplicity, we could first consider the natural flora and fauna to be immobile. Hence, the organisms can either adapt to the changes or die. On an individual level, the ability to adjust to the changes would depend upon the physiological plasticity, whereas, on a population level, this ability would also be determined by the potential for rapid evolution of new traits, depending on, e.g., genetic heterogeneity and generation time. As discussed above (1.2.1) plants and animals use several modes of response to cope with environmental stresses like increased temperature, reflecting various levels of physiological plasticity. The possibilities for such adjustments would be expected to be best for individuals that normally experience large environmental changes, for instance in regions with large seasonal variations. The potential for evolution is commonly regarded as insufficient. Paleoecological evidence of the response, especially of plants, to past climate changes, indicates that evolutionary adaptation has played no more than a minor role as a response to climate change (Huntley 1991). Adding to this is the fact that the rate of the forecasted changes is much larger than those in the past. Yet, such rapid evolutionary changes *may* take place, as concluded by Bradshaw and McNeilly (1991). Where such evolution does occur however, they say that "..there appear to be definite limits to what takes place. Similar evidence is forthcoming from situations where artifical selection has been applied. The explanation appears to be that all evolution depends on the occurrence of appropriate variability, and for various reason this is not always present in natural populations." This is also supported by Dawson (1992), who, in addition to the time aspect and the probable insufficient variability, points out that ".. any contemporary organism already represents a highly evolved entity in which any possible evolutionary developments are likely to be constrained by ontogeny and tradeoffs involving other functional requirements."

To sum up, there seems to be a general agreement that individual adjustments and short-term evolution may occur to some extent, but this will not be the major manifestation of plant and animal response to climatic change. Historic evidence for changes in species distribution in relation to past climatic changes indicates that, generally, species have responded to climate changes not by evolution, but by *migration* (Bradshaw and McNeilly 1991, Huntley 1991).

So, if we are to expect widespread migration of species, how will this take effect? One hypothesis, a static community model, proposes that large groups of species (i.e. communities) shift as tightly linked and highly coevolved assemblages. The other hypothesis, an individualistic or dynamic community model, suggests that individual species respond differentially. The paleological evidence clearly demonstrates that the individualistic model is closer to the truth (Graham and Grimm 1990). Also, examples of differential responses of species or groups of species (e.g., $C_3$ vs. $C_4$ species) and different ecological interactions described above provide present-day support for the latter hypothesis.

To what extent migration can be realized depends upon a number of factors including environmental conditions and the inherent ability to disperse. The ability to disperse varies greatly between species. Clearly, animals are generally more mobile than plants and so their distributional limits manifest a more rapid response time. In contrast, terrestrial plants are usually mobile at one stage of their life cycle, i.e. when their seeds or other propagules may be dispersed by wind or ocean currents (Ford 1982), - or animals. In general, for wind- or current- driven dispersal, one could say that the smaller and lighter the seed, the greater the species´ facility for rapid extension of range. Typically, a plant species will extend its range in a series of waves or leaps. The expansion of its distribution range will be determined by the mobility of the species propagules but also the generation time of the plant. Thus, trees, with their long generation time, would be rather slow in responding to climatic change (Ford 1982).

The sensitivity to climate change varies largely between species and between biota. On a global scale, it is predicted that the effects will be pronounced in temperate and arctic regions, where temperature increases are projected to be relatively large. It is unclear how affected the tropical biota would be by the relatively low temperature increases projected for the lower latitudes, because little is known about the physiological tolerance of tropical species. However, substantial disruption may occur due to precipitation changes (Peters 1991, Hartshorn 1992). Organisms inhabiting relatively unvarying environments exhibit a narrow tolerance range whilst those inhabiting environments with, for instance, considerable seasonal changes in climate exhibit a much wider range of environmental tolerance. The former would naturally be far more vulnerable to environmental changes than the latter (Ford 1982). Changes in local species composition will be most rapid at the boundaries between vegetation types, where noticeable changes in response to a warming of 1° to 2°C may occur within a decade (Woodward 1992). If populations are fragmented and small, they are more vulnerable to the new stresses brought about by climate change (Peters 1991). In mountainous areas, species may respond to climate change by migrating vertically over relatively short distances; boreal habitats may only have to ascend around 500 meters to compensate for a three degree temperature rise. However, migration to higher altitudes leads to a concomitant reduction in the total area of any habitat type, so species with larger area requirements may go extinct (Dobson et al. 1989).

A major obstacle for dispersal is caused by human activities. Population reduction and habitat destruction due to human activities will prevent many species from colonizing new habitats when their old ones becomes unsuitable. The synergy between climate change and habitat destruction would threaten many more species than either factor alone (Peters 1991).

Estimates of annual global rate of species extinction range from 100-10,000 times of that before human intervention (Bardecki et al. 1990). The basic issue that drives all concerned about biological diversity is the accelerated and irreplaceable loss of genetic material, species, populations and ecosystems. Associated with this loss are the loss of products obtained from nature (presently and potentially), possible disruption of essential ecological processes and service, and loss of options for biological and cultural adaptation to an uncertain future.

Loss of key species, such as primary producers which play a critical role in the support of other species, could trigger a domino effect, leading to further extinctions and perhaps demise of an ecosystem. The greatest concentration of species diversity in the world is found in tropical rain forests. These forests account only for 7% of the land area, yet contain at least 50% of all species. Current estimates indicate that annually, approximately 1% of this biome is being deforested and another 1% is being degraded (Bardecki et al. 1990).

### 1.5 Is the terrestrial biosphere a carbon sink?

Throughout this chapter, indications of terrestrial plants as an important dynamic element in the carbon cycle have been made. Whereas some factors tend to enhance productivity and biomass accumulation (e.g. increased photosynthetic rate due to elevated $CO_2$), others indicate the opposite (e.g. increased herbivore load due to lowered nutritional value of high $CO_2$ grown foliage). Furthermore, the discrepancy between studies on the individual and community level (and the general lack of studies at this level) further complicates this issue. Altogether, the effect on productivity is likely to differ between regions, and it is still a controversy whether the terrestrial biosphere acts as a source or a sink both today and in the future. However, there are indications that the terrestrial biosphere in fact acts as a sink today due to the $CO_2$ buildup that we already experience.

The atmospheric accumulation of $CO_2$ is the balance between anthropogenic emissions and the uptake due to biospheric sinks. The world oceans are generally considered as major sinks for carbon, although the magnitude of their uptake is somewhat uncertain. Yet, there seems to be general agreement that it cannot account for the budget imbalance, i.e. the measured accumulation of $CO_2$ is less than would be expected from current $CO_2$ emission estimates. Thus, the "missing sink" may be accounted for by terrestrial vegetation.

All in all, the IPCC argued that the likeliest terrestrial biospheric processes contributing to large sinks are enhancements in productivity due to atmospheric $CO_2$, together with N-fertilization from atmospheric deposition and forest regrowth. Yet, it is stated that ".. while the individual effects of $CO_2$ enhancement on plant growth and physiology are well documented, the net ecosystem consequences of $CO_2$ under natural conditions depend on many other factors and cannot currently be estimated. Nevertheless, in models with active biospheres, global accumulation from the physiological effects of increased $CO_2$ are often made in order to account for a missing sink."

Once again, the need for long-term whole ecosystem studies is emphasized.

### 1.6 Marine ecosystems

Aquatic systems are fundamentally different from terrestrial ones because of the physical properties of water. Water is denser than air, has a higher specific heat, is a better heat conductor, and is less subject to rapid temperature change. At elevated temperatures water becomes less dense, and this may affect stratification and circulation (Ray et al. 1992). All of these factors have an influence on living organisms in aquatic environments.

A significant proportion of the international research effort regarding climate change concentrates on marine ecosystems. Yet, only a small fraction of this effort is directed towards the *effects* of climate change. Rather, the attention has, apparently, to a large extent been focused on the way the oceans (including biological communities) may affect the climate system. Judging from available literature, very few predictions can be made. Hence, it is worth noting, as pointed out to me by several marine biologists, that this report only represents a very small part of the marine climate change research.

When considering biological effects of climate change, it seems appropriate to begin with a brief introduction of the processes collectively called the "biological carbon pump". This is because these processes are of particular importance in assessing the influence of climate change on marine biota (and vice versa), and also because they illustrate some important features of the ocean ecological system. The driving force of the biological carbon pump is the photosynthesis of planktonic algae. Marine photosynthesis is responsible for a worldwide annual conversion of 30-50 Gt of carbon from dissolved, inorganic substrates to organic material. The algae are either eaten by marine heterotrophic organisms or they sink down towards the deep sea. This latter process represents a carbon transport away from the surface waters. Because of the very slow subsurface physical mixing and circulation, it may be hundreds or thousands of years before $CO_2$ resulting from the breakdown of organic material in mid and deep waters is returned to the upper ocean for exchange with the atmosphere. And for the small proportion (0.05-0.5%) of photosynthetically fixed carbon that becomes incorporated into the sediments, the time scale for its remobilization, through geological processes, is many millions of years (Williamson and Holligan 1990).

Thus, the biological pump lowers the partial pressure of $CO_2$ in surface waters and enhances the partial pressure of $CO_2$ not in contact with the atmosphere. The functioning of the biological pump involves the supply of nutrients to surface waters, food web dynamics, and sinking losses of particulates to the deep sea. It may be expected to respond to changes in both the strength of the overall thermohaline circulation and to variations in the abundance of nutrients, primarily nitrogen and phosphorus (Melillo et al. 1990).

Physical-chemical parameters are the primary determinants of the distribution of marine habitats, communities, and ecosystems. A change in these parameters (including surface water temperature, ocean circulation and mixing pattern, and upwellings) will have broad impacts on basic ecological structures and processes (Tsyban et al. 1990). To make concrete predictions of the magnitude and direction of the changes is not possible, based on our limited knowledge of the dynamics of the systems' components. Rather, we can generally approach the problem by discussing the recognized interactions between the climate system and the biological communities and indicate processes and components that are likely to be affected.

The productivity of the global ocean in the new climatic conditions would be determined by changes in functioning of the ecosystems in the most productive region, namely the upwelling zones and high latitude regions, and near shore waters. Circulation and mixing control nutrient availability to the ocean primary producers (phytoplankton) and their access to solar radiation required for photosynthesis. Changes in distribution and intensity of upwellings would thus be an important determinant of productivity, but there seems to be no clear predictions regarding magnitude and direction of such changes. In polar and sub-polar regions, light and temperature are the basic limiting factors. An important effect would thus be in the duration of the growing season, ultimately affecting bioproductivity. On the global scale, however, there are no clear indications of increased primary productivity. Fogg (1991) considered possible effects on ocean productivity of a 2°C rise in average sea surface temperature accompanied by a 30 cm rise in mean sea level over the next 30 years, and concluded that it seems unlikely that there will be any perceptible changes in total primary productivity. There have been few clear demonstrations that increased primary production actually promotes reproductive success and population growth of commercial fishes, which makes it difficult to draw conclusions about total ocean productivity (Tsyban et al. 1990).

In general terms, the temperature increase may cause a poleward spreading and deepening of warm oceanic waters. Biological communities may reflect this by poleward translocation. But since the rate of change is expected to be very rapid, questions immediately arise regarding the potential of biota to accommodate these rates of change (Melillo et al. 1990). Some life forms that are relatively immobile or genetically less adaptable may, in the worst case, be threatened by extinction. Yet, widespread extinctions are not likely (see below), but widespread changes in community distributions and composition are probable (Ray et al. 1992). The phytoplanktonic community may serve as an example of potential changes in community composition. Some species are confined to using undissociated forms of carbon while others are able to utilize bicarbonate. The pH changes in sea water associated with a doubling of atmospheric carbon dioxide concentration would be of the same order of magnitude as existing temporal and spatial variations and could cause a shift in the $CO_2$/bicarbonate ratio sufficient to have a significant effect on competition (Fogg 1991). Another example, of obvious importance to man, is the potential changes in commercially important fish stocks. Annual climate changes are considered one of the major factors determining the size of fish stocks (Hamre 1991). Each population within a species is adapted to the specific temporal and spatial features of its habitat. A temperature rise of 2°C may have substantial impact on the distribution, growth and reproduction of the fish stocks. Fish may take new spawning areas and their distribution patterns may thus change considerably (Tsyban et al. 1990). Thus, the changes in ecosystem composition and biodiversity due to rising temperature and more $CO_2$ in the atmosphere described for terrestrial ecosystems, also apply to marine systems. Altogether, effects may be less pronounced due to the mobility, large ranges, high fecundity, and rapid growth rates of most marine organisms, contrary to the long lag times that may occur in, for instance, forests (Ray et al. 1992).

Probably the largest changes in distribution of species will result from changes in the pattern of water movement. On the largest scale, we have the phenomenon known as *El Niño*. *El Niño* is a change in the circulation pattern of the equatorial Pacific in which southward flowing currents bring warm water to the normally cold coasts of Ecuador and Peru (Fogg 1991). The spreading of warm waters from north to the south is accompanied by a rise of sea surface temperature of 5° to 8°C, strengthening of water mass stratification and, consequently, by a sharp weakening of the intensity of coastal upwellings. These processes lead to serious changes in the structure of the phytoplanktonic community, a sharp reduction in the productivity in the coastal zone, mass mortality of fish and birds feeding on them, as well as to secondary contamination of the ecosystem with organic matters (Tsyban et al. 1990). Global warming is likely to affect the occurrence of *El Niño*. More generally, we can expect that the shifting of isotherms as a result of global warming will affect the pattern of air/ocean interactions and that changing current flows will have consequences for marine life on the large scale (Fogg 1991). Geographic variations should result in numerous and perhaps episodic regional and mesoscale perturbations as well (McGowan 1990). Several of the commercially important fish stocks (e.g. capelin and cod) rely on ocean currents during pelagic stages with passive migration. A disruption of such currents could bring about serious disturbances on the life cycles of fish as we know them today.

Global warming is expected to be largest at high latitudes and thus have especially strong impacts in these regions. One important consequence could be a reduction in the extent and persistence of sea ice. Ice plays a major role in the development and sustenance of arctic ecosystems, including all levels in the trophic web. The low light in winter limits primary production in the water column, and the relatively high concentrations of algae living on and actually in the ice, are important sources of food for herbivores both while sea ice is in place and when it breaks up in the spring (Melillo et al. 1990). For instance, the seasonal melting and freezing of ice in the Barents sea is the basis for massive algal blooms. The immediate mechanisms behind this event is that nutrients accumulate under the ice cover and when the ice retracts in the summer there is, at this latitude, continuous light during the day and night. The capelin (*Mallotus villosus*) feeds on the consequent immense zooplanktonic production, whereas the capelin itself is a major food source for several fish and whale species, including the commercially important cod, *Gadus morhua*. (Hamre 1991). Furthermore, polar mammals use ice in particular ways to support their feeding and reproduction needs. Animals like seals and walrus would be left vulnerable by the loss of their habitat (Ray et al. 1992, Alexander 1992). An extreme case is the polar bear. This bear would not exist today had it not been for the ice habitat which it relies upon for hunting its primary prey, the seal.

Probably the most important aspect of climate change on the world oceans and coastal zones will be the impact of sea level rise on coastal residents and on marine ecosystems. Global mean sea level may rise about 8-29 cm by the year 2030 and 21-71 cm by 2070, mainly due to thermal expansion of the oceans and increased melting of mountain glaciers (Warrick and Oerlemans 1990). For each centimeter of rise in sea level beaches may erode a meter landward. Flooding and erosion of soil could lead to substantial increases in the flow of nitrogen, phosphorus and sulfur in the coastal zones, creating the potential for severe eutrophication (Tsyban et al. 1990). Moreover, this would entail increased turbidity, which is detrimental to many marine organisms, particularly filter feeders (e.g. economically important shellfish) (Ray et al. 1992). The effects on biodiversity are likely to be larger in coastal areas than in the open sea. Organisms living in the open sea are relatively free to move to new geographic areas, while near shore organisms are more constrained by the physical features of the shore.

## II International programs

In this chapter, some major international research programs are presented. It does not cover all relevant programs which may be classified as multinational, in fact the next chapter contains projects which include several nations as well. However, the two chapters differ in that the activities described in chapter 2 are coordinated or funded within the framework of an *established* international organization, whereas multinational projects in the next chapter are coordinated through an interim body like, for instance, a scientific steering group. Programs aimed strictly at environmental monitoring are not included[1]. The first sections (2.1-2.4) deals with programs coordinated by ICSU-related units. Then activities within the framework of the United Nations are described (2.5-2.6) followed by some Europe-based programs (2.7-2.8). Finally, there is a brief introduction to the NATO Science Program (2.9), merely to point out that their activities include more than political and military dimensions.

The overview is generally quite brief, with the aim to give basic information and to indicate where additional information may be obtained. Contacts for each section are given in Appendix B.

### 2.1 IGBP - International Geosphere-Biosphere Programme

The IGBP is an interdisciplinary research endeavour, carried out within the framework of the International Council of Scientific Unions (ICSU). Along with the World Climate Research Programme (WCRP) and other international research efforts, it addresses critical unknowns related to global environmental change. The Intergovernmental Panel on Climate Change (IPCC) has identified IGBP and WCRP as the two major research programmes devoted to decreasing our uncertainty in relation to global climate change. The WCRP is concerned with the physical aspects of the climate system and is thus not included in this report.

The ICSU initiated detailed planning for IGBP in the late 1986 and appointed a Special Committee to guide the planning and implementation of the programme. In order to provide for joint planning and coordination with bodies of the United Nations, an Interagency Coordinating Committee has been formed

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[1]For a survey of monitoring programmes, I would suggest to the following publication: " A survey of Environmental Monitoring & Information management Programmes of International Organizations". Published by the UNEP-HEM office in April 1991 (second edition).

with the participation of the United Nations Environment Programme (UNEP), The United Nations Educational, Scientific, and Cultural Organization (Unesco) and the World Meteorological Organization (WMO).

A secretariat for the IGBP has been established at the Royal Swedish Academy of Sciences to support the planning and implementation process and to provide a focal point for communication and coordination. The Secretariat publishes the findings of planning group deliberations in a series of IGBP reports, as well as the Global Change Newsletter.

Objective of IGBP:

> *To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are ocurring in this system, and the manner in which they are influenced by human activities.*

For practical reasons, the research is based on several Core Projects. The IGBP initially defined a number of research priority questions, within which the Core Projects were developed (see IGBP 1990). The Core Projects are organized into a hierarchy of foci, activities and tasks.

The IGBP-programme is truly interdisciplinary in nature, and most core-projects includes biological research to some extent. The GCTE (Global Change and Terrestrial Ecosystems) core project is however, the most important core project in this regard, and it is given a broad presentation below. Other relevant Core Projects include JGOFS, BAHC, IGAC, GOEZS, LOICZ, and, GAIM These are briefly introduced in the subsequent section.

### 2.1.1 GCTE - Global Change and Terrestrial Ecosystems

The information in this section was drawn from the GCTE Operational Plan (IGBP 1992).

The objectives of the GCTE are:

- *To predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems;*

- *To determine how these effects lead to feedbacks to the atmosphere and the physical climate system.*

The following introduces the four foci, and their activities and tasks.

1: Ecosystem Physiology
2: Change in Ecosystem Structure
3: Global Change Impact on Agriculture and Forestry
4: Global Change and Ecological Complexity (Proposed).

The first two foci are designed to provide a fundamental understanding of the impacts of global change on ecosystem function, composition and structure, and their feedback effects. The third and the proposed fourth foci, are designed to examine the more specific impacts of global change on systems of great importance to humans - for the production of food and for the earth's biological diversity and complexity. *Focus 3* is however, beyond the scope of the present report and *is excluded from the following description*. However, it should be noted that Focus 3 is closely related to the work on more "natural" ecosystems. The modelling component of this Focus is closely linked to the rest of the GCTE modelling, through LEMA (Long-term Ecosystem Modelling Activity - see "Focus 2 Integrating Activities").

**Focus 1: Ecosystem Physiology**

The primary aim of is to understand and model the effect of global change on primary ecosystem processes, such as the exchange of energy, water and trace gases with the atmosphere, element cycling and storage, and biomass accumulation or loss.

Activity 1.1: Effects of elevated $CO_2$

This activity recognizes the critical need for information concerning ecosystem-level interactions between $CO_2$ and other resources, especially nitrogen and water, and for experiments that explore the suite of ecosystem feedbacks, including changes in soil nutrient availability and herbivory.

Long term objective:

- *To determine and predict the effects of elevated $CO_2$, interacting with other environmental factors, on ecosystem physiology at the patch scale (10-100m), and to investigate potential feedbacks to the atmosphere.*

Short-term objectives:

- *To assess whether terrestrial ecosystems will serve as a source or a sink of carbon under elevated $CO_2$ alone and in combination with other environmental changes.*

- *To determine, through case studies, how $CO_2$ enhancement will affect ecosystem productive capacity through alterations of such processes as plant-pest interactions, nitrogen mineralization and water-use efficiency.*

Task 1.1.1: Whole-Ecosystem FACE Experiments
Task 1.1.2: Integrating Experiments on Ecosystem $CO_2$ response

Activity 1.2: Changes in Biogeochemistry

The overall emphasis of the biogeochemistry activity is the terrestrial regulation of element pools, transformations, gains, and losses as they are altered by the components of global change.

Long-term objective:
*To determine the interactive effects of land use, altered atmospheric composition, and climate change on the biogeochemical cycles of carbon, nitrogen, and other elements.*

The more immediate objective are specific to each of the three regions, identified in the following three tasks.

Task 1.2.1: Humid Tropical Forests Undergoing Land-Use Change

Short-term objective:
*To determine the effects of land clearing and agricultural intensification on quantities and pathways of carbon and nutrient loss (and their regulation) in several humid tropical regions.*

Task 1.2.2: High Latitude Systems

Short-term objective:
*To determine the interactive effects of increased temperature and changes in nutrient availability on carbon and nutrient pools and fluxes across the transition from boreal forest to tundra.*

Task 1.2.3: Semi-Arid Tropical Ecosystems

Short-term objective:
*To determine the interactive effects of altered precipitation pattern and changes in land use (especially grazing and fire frequency) on the biogeochemistry of semi-arid tropical systems along a moisture gradient.*

Activity 1.3: Effects of Changes in Vegetation on Water and Energy Fluxes
(To be conducted jointly with the BAHC)

Modelling evaporation from land surfaces in the context of General Circulation Models, (GCMs) requires knowledge of the bulk surface conductance for water vapour transport, which determines the partitioning of energy into sensible and latent heat. This strongly affects continental hydrological cycles, including evaporation, exchange between surface and ground water and the runoff of surface water. The bulk surface conductance is determined by both the structure and the stomatal properties of the vegetative cover, together with the evaporative properties of the soil surface. The vegetation canopy responds readily to changes in climate and to soil water availability. Evaporation from land surfaces can be modelled in SVAT (soil-vegetation-atmosphere-transfer) models as a submodel of GCMs only if the bulk surface conductance is taken into account. Knowledge of bulk surface conductance is also important for the water balance of ecosystems and its nutrient and carbon fluxes, which in turn feed back to influence vegetation structure and stomatal conductance. The aim of activity 1.3 is to quantify bulk surface conductance which combines stomatal regulation and physical structure of the vegetation to determine terrestrial evaporation.

Task 1.3.1: Bulk Surface Conductance

Long-term objective:

*To develop the capability to predict the effects of vegetation changes on water and energy fluxes between land surfaces and the atmosphere, and in particular the changes in bulk surface conductance with season, succession and long-term $CO_2$ increase.*

Short-term objectives:

- *To quantify, as far as possible, bulk surface conductance from the major biomes of the earth, from data in the literature*
- *To assess the requirements in terms of accuracy and spatial representativeness for current and foreseeable models of bulk surface conductance, for the purpose of (i) parameterizing land surfaces in GCMs, and (ii) investigating ecosystem responses to climate or composition changes*
- *To develop a patch-scale model of bulk surface conductance, based on plant physiological mechanisms and the physics of transfer through the soil-plant-atmosphere continuum, accounting for the responses of bulk surface conductance to climate factors (light, vapour pressure deficit), soil water availability and nutrition*

- *To extend the available data on bulk surface conductance by means of appropriate ground-based measurements*
- *To develop the capability for inferring bulk surface conductance from remotely sensed data.*

Activity 1.4: Integrating Activities

Global change will lead to the simultaneous alteration of a number of environmental variables. The whole-system $CO_2$ enrichment studies, the gradient studies in critical regions, and the water and energy flux studies to be conducted in focus 1 are designed to provide insights into how global change will affect key ecosystem processes involved in the carbon balance, nutrient dynamics and hydrologic cycling. The final requirement in Focus 1 is to bring these changes together so that we can predict the net effect of their simultaneous actions. Task 1.4.1. undertakes this integrating effort, while task 1.4.2. develops one of the important products of integrating models - a better understanding of terrestrial ecosystems in the global carbon cycle.

Task 1.4.1: Integrated Models of Ecosystem Physiology under Global Change

Long-term objective:

*To develop (and/or improve) integrated carbon, nutrient and water models at the patch scale to predict how global change will affect the physiology of terrestrial ecosystems in the decades to century time-frame.*

Short-term objectives:

- *To develop linked plant-soil models of carbon, nutrient and water interactions at the patch scale to operate at time scales of days to decades*
- *To use the models to predict the consequences of resource changes ($CO_2$, nutrients, water) for carbon fluxes and storage in conjunction with (i) $CO_2$ enrichment experiments, and (ii) gradient studies in the critical regions identified by the GCTE - semi-arid tropics, wet tropics and tundra/boreal regions*
- *To incorporate the multiple-resource patch-scale models into the development of Activity 2.1's patch scale models of change in ecosystem structure and composition.*

Task 1.4.2: Carbon Pools and Fluxes in Terrestrial Ecosystems

The major goal of this task is a better understanding of terrestrial ecosystems as sources and sinks for atmospheric $CO_2$.

Objective:

*To understand and model the emissions and sequestration of $CO_2$ by terrestrial ecosystems for global carbon models*

**Focus 2: Changes in Ecosystem Structure**

Of the driving forces of global change, the most important for determining the distribution and performance of organisms are the range and seasonality of temperature, precipitation, and other environmental factors; the intensity and frequency of severe episodic events, such as fires and hurricanes; and, for much of the earth, the group of demographic, economic and social pressurses related to human activities. These factors, combined, with physiological responses such as sensitivity to high $CO_2$, longevity and ability to disperse, will determine the future structure of the world's ecosystems.

The goal of focus 2 is to model this complex suite of impacts and responses so that the pattern of change in ecosystem composition can be predicted.

The ability to predict changes in ecosystem structure and composition is being developed for two distinct purposes:

(i) The first, and more important, purpose is to predict the impacts of global change on terrestrial ecosystems in their own right (i.e. independent of their feedback to the atmosphere). If human societies are to adapt and perhaps benefit from global change, then we must be better able to predict what will happen to the terrestrial ecosystems on which we depend. Thus, much of the emphasis of focus 2 will be on the development of a nested set of "impacts" models to predict changes in ecosystem structure at a wide range of scales, from patch to landscape to region. In addition it is essential that models are developed for all the major biomes on earth.

(ii) The second purpose is to build a dynamic global vegetation model that will capture the feedback effects that changes in ecosystem structure and function will have on further atmospheric changes, and which can be linked to the general circulation models (GCMs) that predict future climate. At present the only global models predicting vegetation distributions are static and thus not capable of forming an interactive component in GCMs. GCTE aims to produce a mechanistically-based dynamical model of global vegetation for incorporation in GCMs.

<u>Activity 2.1: Patch Scale Dynamics</u>

A mechanistically-based prediction of the effects of global change on structure and composition of communities can be achieved only by understanding processes. Central to this predictive ability will be the development of one or more models of patch dynamics, which will be both the nucleus of this activity and the basis for integrating over large areas such as landscapes and regions.

Task 2.1.1: Global Key of Plant Functional Types

It will not be feasible to develop models for every ecosystem of the globe nor represent every species within those ecosystems. Thus the concept that the complexity of nature can be reduced in models by treating a smaller number of "functional types" (FTs) is central to the work of Focus 2.

Long-term objective:

*To develop a general classification system of plant (and eventually animal) functional types appropriate for predicting the dynamics of change in ecosystem structure due to the impacts of global change.*

Short-term objectives:

- *To review the current state of knowledge of the FT approach at a global scale*
- *To elucidate the ecological constraints and trade-offs in morphological and physiological attributes which define morphological types*
- *To initiate case studies where a FT approach can be tested and assessed.*

Task 2.1.2: Experiments on Ecosystem Structure and Function

Objective:

*To identify (and, so far as possible, quantify) the important mechanisms that link change in ecosystem function to change in ecosystem structure, and* vice versa.

Task 2.1.3: Patch Models of Ecosystem Dynamics

Long-term objective:

*To develop patch models of ecosystem dynamics for global application, incorporating mechanistic information on the responses of plant processes to global change and the influence of these responses on ecosystem structure.*

Short-term objective:

*To develop models of patch dynamics for two study sites, based on the FT approach and the experiments on ecosystem structure and function.*

Activity 2.2: Models from Patch to Region

The goal of this activity is to build on experimental and modelling efforts elsewhere in GCTE to develop a suite of models, from patch through landscape to region. These models will be specifically designed to understand and predict the impact of global change on ecosystems.

Task 2.2.1: Ecosystem Dynamics From Patch to Region, based on Change in Climate and Atmospheric Composition

Long-term objective:

*To develop a suite of models of climate- and atmosphere driven ecosystem dynamics, based on patch models and incorporating landscape effects, on scales relevant to management decisions.*

Short-term objective:

*To establish, via LEMA (Long-term Ecosystem Modelling Activity), a core of modelling groups operating at the landscape level, and develop agreed model protocols to meet GCTE requirements.*

Task 2.2.2: Ecosystem Dynamics from Patch to Region, Based on change in land Use

Objective:

*To develop in collaboration with Focus 3 and HDGEC (Human Dimensions of Global Environmental Change), spatially explicit models of land-cover change; and to determine the effects of these land-cover changes on ecosystem structure, composition, and function.*

Activity 2.3: Regional-to-Global Models of Vegetation Change for Element Cycles and Climate Feedback

At present there is no mechanism for incorporating the feedback of a changing land surface in a dynamic, interactive way into global models of the physical climate system or of the biogeochemical or hydrological cycles. Global vegetation is assumed to be static. However, as a result of global change, the earth's distribution of vegetation will change, and this will lead to feedbacks to climate. The ultimate goal of this activity is to develop appropriate dynamic models that can be used to calculate direct feedbacks through changes in surface conductance, albedo and surface roughness and indirect feedbacks through changes in biogeochemical cycles.

Task 2.3.1: Static Models of Global Vegetation Change

Objective:

*To improve methodologies for directly scaling up predictions of vegetation distribution from patch to globe.*

Task 2.3.2: Dynamic Global Vegetation Model (DGVM)

Objective:

*To develop a dynamic model of change in global vegetation that can be linked to GCMs.*

**Focus 2 Integrating Activities**

GCTE will establish a network of modelling centres called LEMA (Long-term Ecosystem Modelling Activity). Its goals are to:

(i) facilitate collaborative research, particularly in the development and improvement of models essential to the GCTE programme

(ii) focus the international modelling effort on a coherent and mutually agreed set of objectives

(iii) synthesize GCTE results into a set of robust models designed to meet GCTE objectives

(iv) provide feedback to experimental efforts as priorities for model parameters, investigation of additional phenomena, and needs for model testing information arise

Although LEMA is formally placed with Focus 2 it will facilitate the entire GCTE modelling effort, across all Foci.

**Focus 4: Global Change and Ecological Complexity (Proposed)**

Complexity is viewed as the suite of species interactions within an ecosystem. It includes the diversity of species, their connectivity and spatial diversity (patchiness). Connectivity, unlike species diversity, is considered to change with scale because it incorporates such effects as variations in landscape structure and migration. This Focus is therefore designed to understand and determine the importance of species diversity and ecosystem complexity on the dynamic responses of ecosystem function to environmental change. It is also necessary to consider the reverse response, the influence of changes in ecosystem function on diversity and complexity, both to achieve this overall understanding, and because it forms the basis of applied interest groups such as the International Union for the Conservation of Nature and Natural Resources (IUCN).

A specific issue to be considered is the vulnerability of species diversity in reserves to environmental change. Reserves for species conservation are typically isolated landscape units and will be vulnerable to environmental change because of disrupted networks of migration.

Global change and ecological Complexity was originally proposed as a separate IGBP core project (IGBP 1990) and has only recently been incorporated within GCTE as a proposed Focus 4. The operational plan for Focus 4 will be developed in detail in 1993 and published in 1994. A draft operational plan was made available at an IGBP Conference in January 1993 (SAC III, Ensenada, Maxico) from which the following information was drawn. Although the deviding into activities and tasks has been discussed, i.e. some activities may be combined and new tasks may be developed, the brief summary below illustrates the main questions to be addressed in this Focus.

Activity 4.1: Relationships between Ecological Complexity and Ecosystem Function

The aim is to define relationships between species diversity, complexity, and connectivity and selected processes for a range of major ecosystems. The final structure of this and Activity 4.2 will evolve in collaboration with the SCOPE component of the Diversitas programme.

Task 4.1.1 Manipulative experiments on Compexity/Function

Objective:

*To determine through manipulative experimentation the effect of changing complexity on function, and vice versa, for a number of ecosystems.*

Task 4.1.2: Models of Complexity and Function

Objective:

*To construct theoretical models that simulate the complexity (diversity and connectivity) of real ecosystems and relate change in complexity to change in function.*

Activity 4.2: Interactive Effects of Global Change on Ecological Complexity and on the Relationship Between Complexity and Ecosystem Function

The aim is to examine how the interactive effects of global change will alter ecological complexity, and how this in turn will lead to changes in function, directly and through changes in the relationship between complexity and function.

Task 4.2.1: Experimental and Observational Studies

Objective:

*To determine by experimentation and observation the impacts of various kinds and combinations of global change on ecological complexity and on the relationships between complexity and ecosystem function.*

Task 4.2.2: Modelling Impacts of Global Change on Complexity/Function

Objective:

*To develop predictive models of the complexity/function relationship under conditions of global change*

Task 4.2.3. Complexity/Function under Global Change: Feedbacks to Further Change

Objective:

*To determine and quantify whether global change impacts on ecological complexity and on the relationship between complexity and ecosystem function will lead to feedbacks to further global change.*

Activity 4.3: Consequences of Global Change for the viability of Isolated Populations

Task 4.3.1: Habitat Fragmentation, Land-Use/Cover Change and Population Viability

Objective:

*To develop, refine and verify models to predict the viability of isolated plant and animal populations containing different total number of individuals, with different life histories, on isolated habitat fragments; and to explore the role of inter-patch migration by biota in maintaing biodiversity in rapidly changing landscapes.*

Task 4.3.2: Interactive Effects of Habitat Fragmentation and Climate Change

Objective:

*To examine and model the implications of climate change for maintenance of biological diversity and connectivity in isolated habitat patches set in a variaty of landscapes.*

Activity 4.4; Complexity, Function and Global Change: Regional and Global Synthesis

The other three Activitites of Focus 4 emphasize the fundamental relationships betwen complexity and function, and the impacts of global change both on complexity and on this relationship at the process level. The aim of this activity is to extend this information geographically to build up scenarios of change in ecological complexity, and its implications, at regional and global scales.

Task 4.4.1: Identification of Areas of Functional Sensitivity

Objevtives:
- *To develop and promulgate general methodologies for identifying areas, functional types, and species most at risk from global change.*
- *To determine and map the regions of the world were loss of ecological complexity is most likely to lead to significant changes in ecosystem function.*

### 2.1.2 Other IGBP Core Projects

This section briefly introduces other relevant IGBP Core Projects: JGOFS, BAHC, IGAC, GOEZS, LOICZ, and, GAIM. For further information, consult IGBP-reports (mainly no. 12 1990) or see app. B for contact persons.

**JGOFS** (Joint Global Ocean Flux Studies, an established Core Project) is primarily concerned with assessing and understanding how carbon flows in the ocean and across its boundaries, both now and in the future. "In principle, this would include understanding the biological effects of climate change in the ocean, because there is potential for a strong biological feedback on oceanic carbon transport. However, within its constraints of people, money and ideas JGOFS will concentrate on assessing the present carbon fluxes and their first-order (physical-chemical) changes. It is quite possible, though, that individual research projects within JGOFS will address biological responses and feedbacks as well, and such extensions are to be welcomed when they occur". (G.T. Evans, JGOFS Executive Scientist, pers. comm.).

Another established core-project, the **BAHC** (Biospheric Aspects of the Hydrological Cycle) expresses the biological relevance through the objective:

> *How do plant communities and ecosystems in combination with the topographic structure of the land surface affect the cycle of water on Earth?*

Sub objectives:

- *To determine the biospheric controls of the hydrologic cycle through field measurements for the purpose of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales ranging from vegetation patches to GCM grid cells*
- *To develop and implement a long-term commitment to observations designed to test the results of global change modelling of the interactions between the biosphere and the physical Earth system in relation to the hydrological cycle.*

**IGAC** (International Global Atmospheric Chemistry project - an established core project) was initiated by the IAMAP Commision on Atmospheric Chemistry and Global Pollution (CACGP) and its science plan was developed by an extensive group of atmospheric scientists at a workshop in 1988. It was later accepted and incorporated as an IGBP core project. While there was a strong perception at the workshop that biological interactions with the atmosphere would have to be an essential component of the research activities of the IGBP, it was felt that the biological and ecological community was not sufficiently well represented to formulate the biological component of the overall research program. Effort has therefore been put into establishing close linkages to biological reserach by, for instance, arranging joint workshops (see e.g. IGBP report no. 13).

Objectives:
- *To develop a fundamental understanding of the processes that determine the chemical composition of the atmosphere.*
- *To understand the interactions between atmospheric chemical composition and biospheric and climatic processes.*
- *To predict the impact of natural and anthropogenic forcing on the chemical composition of the atmosphere.*

Regarding marine and coastal ecosystems, it is expected that **GOEZS** (Global Ocean Euphotic Study) and **LOICZ** (Land Ocean Interactions in the Coastal Zone) will provide major contributions to our understanding of these biological systems in relation to global change. These Core Projects' objectives are, respectively:

- *To develop a predictive understanding of the basic relationships among the physical, chemical and biological properties of the oceanic euphotic zone.*

- *To develop a predictive understanding of the effects of changes in climate, land use and sea level on the global functioning and sustainability of coastal ecosystems, with emphasis on the interactions between changing conditions* *on land and sea, and on possible feedback effects on the physical enivironments.*

A science plan for LOICZ has recently been developed, and it will be published in the near future as IGBP Report no. 23. GOEZS still has status as "Proposed Core Projects". The main implementation phase is planned to commence in 1998. Active planning, including the development of models and instruments may be initiated already in 1994.

The proposed Core Project **GAIM** (Global Analysis, Interpretation and Modelling) has been developed into a so-called task force, supervised directly by the Scientific Committee of IGBP and undertaking a series of specific tasks. The GAIM Action plan for 1993-1995 will be published shortly as IGBP Report no. 26.

The broadly defined objective is:

*With the aid of models, synthesize a fundamental quantitative understanding of the global physical, chemical and biological interactions in the Earth system during the last 100,000 years and assess possible effects of future natural and/or man-induced changes.*

## 2.2 SCOPE Scientific Programme

The SCOPE (Scientific Committee on Problems of the Environment) scientific programme for 1992-1995 is highly concerned with global change issues. It consists of four separate components:

- Sustainable development
- Biogeochemical cycles
- Health & ecotoxicology
- Global change & ecosystems

In addition there is one component interacting with all the others:

- Sustainable biosphere.

The global change & ecosystem component includes four streams of study:

* climate change and coniferous forests and grasslands
* UV-B effects on biological systems
* ecosystem function of biodiversity
* dynamics of woody plant-grass systems (to be launched in 1994)

It should be noted that SCOPE is not primarily a body for coordination or funding of operational research programmes. Rather it functions as a body for evaluation and assessment of current knowledge. This work includes producing updated reports and books as well as arranging workshops on environmental issues (Véronique Plocq-Fichelet, SCOPE Executive Director, pers. comm.). This also means a close cooperation with other research programs; for instance are the SCOPE synthesis and analysis used by GCTE in developing its research program.

SCOPE is involved in two specific programmes which is relevant for biological effects of climate changes:

### 2.2.1 ISBI - International Sustainable Biosphere Initiative

The programme was initiated by an ecological research agenda for the 1990's, the *Sustainable Biosphere Initiative* proposed by the Ecological Society of America. A further development of this agenda established the *International Sustainable Biosphere Initiative* (ISBI), which is now adopted by SCOPE. The research priorities are defined within three facets of sustainability: Diversity and sustainability; sustainability in a changing biosphere; and in human dimensions of sustainability. Following are the research questions of Sustainability in a changing atmosphere. It should be noted that the research questions are given by way of example only and indicate that new information is needed to answer problems related to global change that include studies at levels from responses of individuals to those of entire regions (see Huntley et al 1991).

**1.** The state of the biosphere

Goal: *To document the present state of the Earth's biotic systems and the factors controlling the rate and direction of change*.

1) How can we monitor the status of the Earth's biotic resources through time?
2) What are the climatic controls of the growth of organisms at regional scales, and of interactive controlling elements including salinity, pollutants, $CO_2$, and so forth, and how can these be quantified?

**2.** Responses and feedbacks of biotic systems to change

Goal: *To develop the information needed to assess the responses and feedbacks of biotic systems to global change.*

1) What are the responses of organisms and whole ecosystems to multiple stress factors, including UV-B, enhanced $CO_2$, elevated temperature, climate change and pollutants, and how will these responses influence atmospheric projections?
2) How will the controls of distributions, abundance, and productivity of organisms be altered in the context of rapidly changing environment?
3) What are the effects of ecosystem degradation or eutrophication in the past and present, and how can this knowledge guide habitat management and restoration measures?

**3.** Synthesis and modelling

Goal: *To develop approaches for synthesizing information from various disciplines and taken at different scales in order to understand the functioning of the Earth system.*

1) What new approaches are available to improve the linkage of information from various scales of research (for example, ecosystem change models linked with global circulation models)?
2) What methods can be used to interpret patterns at broad scales (e.g., remote sensing) in terms of processes operating at finer scales?
3) What new approaches can be used for integrating information from the level of the individual organism with that of the ecosystem?

### 2.2.2 IUBS[2] - SCOPE - Unesco Programme on Ecosystem Function of Biodiversity - Diversitas.

The general objectives of this programme are to identify scientific issues and promote research projects that require international cooperation in the following areas:

1) The ecosystem function of biodiversity.

The basic questions addressed here are as follows:

- How is sytem stability and resistance affected by species diversity and how will global change affect these relationsips? and,

- What is the role of biodiversity (species and landscapes) in ecosystem processes (e.g. nutrient retention, decomposition, production, etc.) including feedbacks, over short and long term spans and in face of global change (climatic change, land use change, and invasions)?

This component will be undertaken by SCOPE, and will be linked directly to the Focus 4 of GCTE. The Operational Plan for Focus 4 will rely strongly on the SCOPE analysis (Will Steffen, pers. comm.).

2) The origins and maintenance of biodiversity.

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[2]IUBS - International Union of Biological Sciences is an International Scientific Union member of ICSU.

The conceptual framework and research hypotheses for this theme have been identified by a workshop (the "Havard Forest Workshop") and will serve as a basis for the development of this theme. The study of biodiversity at the intraspecific genetic and population levels, including research on and processes of speciation and extinction, represents an important step for understanding diversity at higher levels. Also, it is very important to make a clear distinction between local and global extinctions, and their management implications.

3) Inventorying and monitoring biodiversity

In dealing with the question of inventorying and monitoring of biodiversity on Earth, we are faced with formidabel technical and material problems relating to estimating the number of species and their distribution. These problems are compounded by the acute shortage of trained taxonomists all over the world, but especially in the tropical countries where much of the world´s biodiversity is found.

The actual sites for study will be chosen from - but not limited to - a selected number of Biosphere Reserves as identified by the Unesco´s MAB-programme.

4) Biodiversity of wild relatives of cultivated species.

Within the framework of the programme, four sets of priority hypotheses and recommendations have been developed at a) genetic, b) species to community, and c) ecosystems levels, and d) to deal with the problem of inventorying and monitoring species diversity and their changes around the world.

For more information, see Younes 1991 and 1992. The description given in this section was drawn directly from those two publications.

## 2.3 The Role of Antarctica in Global Change (SCAR)

SCAR (Scientific Committee on Antarctic Research - an interdisciplinary ICSU body) has, in consultation with several interested international groups, developed an international plan for a regional research programme on the Role of Antarctica in Global Change. This work has been closely linked to the IGBP through an IGBP-SCAR Steering Committee, and the programme is planned to constitute the Antarctic[3] research contribution of the IGBP. This Committee

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[3]The IASC (International Arctic Science Committe), is, although not an ICSU-associated body, the Arctic counterpart of SCAR. The IASC is currently planning a global change programme for the Arctic, corresponding to the SCAR Antarctic programme. A Planning

identified four major, interdisciplinary themes to define and encompass the research priorities of an Antarctic component of the IGBP:

- detection of global change in Antarctica
- study of the critical processes linking Antarctica to the global system
- extraction of paleoenvironmental information
- assessment of ecological effects.

A draft version of the programme implementation plan was finished in March 1992, from which the following information was drawn.[4] Six Antarctic core projects have been identified:

1. The Antarctic sea-ice zone: interactions and feedbacks within the global geosphere-biosphere system.
2. Global paleoenvironmental records from the Antarcic ice sheet and marine and land sediments.
3. The mass balance of the Antarctic ice sheet and sea level.
4. Antarctic stratospheric ozone, tropospheric chemistry and the effect of UV on the biosphere.
5. The role of the Antarctic in biogeochemical cycles and exchanges: atmosphere and the ocean.
6. Detection and monitoring of global change in Antarctica.

Naturally, in Antarctica, the emphasis is more on biota in the ocean than on land. Although it appears that biology is not a field of priority in this programme, sub areas of core project 1 and 6 were identified to be relevant to this survey:

One of eight objectives within **core project 1** is:

*To determine the role of Antarctic sea ice in marine biotic systems.*

The Antarctic sea-ice zone is a key habitat for marine biota. The biological activity has a strong annual cycle with a very productive spring/summer period which represents a crucial part of the life cycle of marine biota and marine food chains from phytoplankton to fish, birds and mammals. Changes in the timing

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Workshop on a Regional Research Programme in the Arctic on Global Change was held by the IASC in Reykjavik, Iceland 22-25 April 1992.

[4]At the time of this writing the Implementation Plan was a draft document, not to be cited, quoted or reproduced. The information above is, however, given with the approval of Dr. Gunter Weller, the lead author of the document. The Implementation Plan will be published in the near future. The reader should turn to this for more detailed information.

and periodicity of the cycle as a result of climate and sea-ice changes would have impact on the food chain and marine living resources. In particular, the presence and dynamics of sea-ice influence: 1) the biological habitat and distributions of populations of organisms at all trophic levels; 2) plant and animal populations and food web dynamics; and 3) the flux of carbon from the atmosphere to the deep ocean and its sequestration there by physical and biological processes.

To determine the biological role of sea-ice, we need to understand how major changes in sea-ice thickness, structure and extent may affect physical, chemical, and biological relationships between atmosphere, water column, benthos, and sediments at both short-term and long-term scales. Two topics in the Antarctic sea-ice zone system which need priority attention are:

- the factors controlling population dynamics, life cycles, and survival of the biota; and
- the nature of biogeochemical cycles of carbon, nitrogen, phosphorus, and silicon in the sea ice, water column, and benthos.

Within **core project 6** there is one sub area specifically addressing biologically relevant questions, which is headed "Ecosystem sensitivity and indicator species". It puts emphasis on the sensitivity of communities in Antarctic ecosystems which may be manifested as a response in their physiology, life cycle, productivity, or as an influence on ecological processes.

The primary objective of this part of the programme will be to identify key organisms, biological processes, and interactions that are most likely to be influenced by changes in the climatic regime of Antarctic marine and terrestrial ecosystems.

## 2.4 GLOBEC - Global Ocean Ecosystem Dynamics (SCOR/IOC/ICES)

GLOBEC is a programme jointly sponsored by SCOR (Scientific Committee on Oceanic Research, - an interdisciplinary ICSU body), IOC (Intergovernmental Oceanographic Commission, - a Unesco Commission) and ICES (International Council for the Exploration of the Sea, -an Intergovernmental Organization).

The programme is motivated by the need to understand how changes in the global environment will affect the abundance, diversity, and production of animal populations comprising ocean ecosystems, and also by the fact that there is no focus on the role of zooplankton in the IGBP. Zooplankton is a critical component in our understanding of biogeochemical cycling in addition to their general importance in the ecosystem; variations in zooplankton dynamics may affect biomass of many fish and shellfish stocks.

GLOBEC will consist of initiatives undertaken directly by the international programme; initiatives undertaken by regional and national programmes as part of GLOBEC; and associations with long-standing programmes that are oriented towards the GLOBEC goal statement that wish to develop scientific communication links and interaction with GLOBEC, but are not directly related to the GLOBEC organic structure.

The goal of GLOBEC is:

*To understand the effects of physical processes on predator-prey interactions and population dynamics of zooplankton, and their relation to ocean ecosystems in the context of the global climate system and anthropogenic change .*

The strategy for building the GLOBEC Core Program (GCP) is oriented toward the goal of investigating global-ocean issues in zooplankton dynamics, the relation between zooplankton and primary production, and the relation between fish production and zooplankton in the context of understanding the effects of physical processes on population dynamics of zooplankton.

## 2.5 MAB - Man and the Biosphere (Unesco)

MAB is an International Unesco research programme, based upon national research initiatives. The program emphasises multidisciplinary approaches in order to attain an improved understanding of the interrelationships between ecological and social systems. Generally speaking, MAB's objectives are to further research in order to:

- *develop a basis for rational use and preservation of biospheric resources*
- *develop a basis for improving the interaction between man and the environment*
- *predict the consequences of today's actions upon tomorrow's world and thereby improve man's ability to effectively manage biospheric resources.*

There are several networks and sub-projects within the framework of MAB, some of which are relevant for global change. Regarding the more narrow issue of biological effects of climate changes, the following (ITEX) seems to be the most relevant activity. Mentioning of other MAB related activities, i.e. projects in cooperation with the International Union of Biological Sciences (IUBS) also seems appropriate in this context (2.5.2).

**2.5.1 ITEX - International Tundra Experiment**

In December 1990, forty-seven reseachers from nine countries (Canada, Denmark, Finland, Great Britain, Iceland, Norway, Sweden, United States, USSR) with polar interest participated in a workshop to develop an International Tundra Experiment (ITEX). The workshop was held after the MAB/NSN (Northern Sciences Network) recommended that MAB committees in all countries with expertise in tundra research should identify experts who could contribute to, and support, the development of ITEX. The NSN of the Unesco MAB Programme was established in 1982 to help stimulate national and international MAB-type interests in northern regions.

ITEX is a long-term arctic research programme. Its objectives are to monitor over the next several decades shifts in arctic climate and vegetation due to on-going global change, and to predict the direction and magnitude of such responses in the entire holarctic realm. The project was designed to obtain ecological evidence about expected or already on-going changes in arctic ecosystems due to global anthropogenic influences.

Large permanent plots are planned to be established in selected Canadian, Alaskan, Scandinavian and Russian tundra ecosystems. Field manipulations will be constructed to simulate expected climatic changes: Shelters to increase tundra temperatures, and snow fences to increase snowcover. Plant population demographics and response variables including phenological traits, morpho-logical traits and performance measures will be monitored in control and experimental sites.

**2.5.2 Unesco/MAB and IUBS cooperative projects.**

There are two other MAB programmes of relevance in this context, which have been undertaken in cooperation with IUBS (M. Skouri, Director of the Division of Ecological Sciences, Unesco, pers. comm.):

*Soil Fertility and Global Change* was initiated in 1984 and is now in a transition phase. A new research agenda is being formulated to address the interaction between soil and the atmosphere. Organizationally it is within the framework of Unesco and the Tropical Soil Biology and Fertility Programme (TSBF) of the IUBS. Its aims are to stimulate research in the tropics, and in particular on the poorly understood topic of biological processes in the maintenance of soil fertility.

*Savanna Modelling for Global Change* is a proposed continuation of the Unesco/IUBS ten year project entitled "Responses of Savannas to Stress and Disturbance" which started in 1983. The project aims at developing an understanding of the way tropical savannas respond both to natural and to human stresses and disturbances.

*The IUBS-SCOPE-Unesco Programme on Ecosystem Function and Biodiversity, see 2.2.2.*

## 2.6 IPCC - Intergovernmental Panel on Climate Changes (UN)

The IPCC is an intergovernmental panel of scientific and technical experts tasked to assess the current understanding of the scientific aspects of climate change; the environmental consequences and social and economic impacts as well as response options and strategies. Strictly speaking, it does not belong within this context of research programme descriptions. However, the IPCC plays a very central role in the overall climate research effort. As a result of the IPCC work, a number of researcher and research organizations have initiated programmes and projects. For one thing, chapter 1 of this report draws heavily on their results, as well as most of the programmes/projects presented in chapters 2 and 3. Because of this, a brief description of the Panel's work and structural organization is appropriate.

The Panel was appointed in 1988 by the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO). Almost 1, 000 researchers from sixty countries have taken part in the IPCC's work.

The IPCC has undertaken a global assessment of which the results were presented in three volumes (one for each working groups) which comprise the First IPCC Assessment Report (Houghton et al. 1990). (The volumes are available commercially, se appendix B):

Working Group I: "Climate Change - The IPCC Scientific Assessment"

Working Group II: "Climate Change - The IPCC Impact Assessment"

Working Group III: "Climate Change - The IPCC Response Strategies"

The reports were discussed at the second World Climate Conference in Geneva at the beginning of November 1990. The Conference stressed in its statement the special need for increased research in general and the importance of intensifying activities in the WCRP (World Climate Research Programme) and IGBP (International Geosphere-Biosphere Programme).

In order to produce an update of the First Assessment Report, the IPCC decided at its fifth session (Geneva, March 1991) the six following tasks:

1: Assessment of net greenhouse gas emissions:
   Sub-section 1: Sources and sinks of greenhouse gases;
   Sub-section 2: Global warming potentials;

2: Predictions of the regional distributions of climate change and associated impact studies, including validation studies:
   Sub-section 1: Update of regional climate models;
   Sub-section 2: Analysis of sensitivity to regional climate change:
3: Energy and industry related issues;
4: Agriculture and forestry related issues;
5 Vulnerability to sea-level rise:
6: Emission scenarios.

The publication of the 1992 IPCC Supplement (Houghton et al. 1992) completed the short-term work on these six task. Long term work on the same Tasks continues.

## 2.7 ENVIRONMENT (CEC)

The Environment programme (1991-1994) is aimed at contributing to the scientific and technical basis for the implementation of the EC environmental policy. As such it constitutes an extension and expansion of the current STEP (Science and Technology for Environmental Protection) and EPOCH (European Programme on Climatology and Natural Hazards) programmes.

The programme is subdivided into four areas, of which "Participation in global change programmes" is the first. Only this area is presented here. It is specifically expressed that the effort directed to global change problems will be greatly expanded.

The selection procedure for projects under the different topics has not yet been terminated, hence it is impossible to give any details about the exact subjects to be covered. For further information, see appendix B for a list of contact persons of the CEC Environment Programme.

**Participation in global change programmes**

The goal is to contribute to understanding the processes governing environmental change and to assess the impacts of human activities. The programme will specifically address the following:

• The reduction of ozone concentration in the stratosphere as a consequence of the release of persistent, chlorine containing molecules, such as chlorfluoro-carbons;

• the increasing concentrations of some trace gases and aerosols in the troposphere (volatile organic compounds - VOCs), photo oxidants, nitrogen oxides, sulphur containing molecules), which overload the mechanisms for cleaning the atmosphere, in particular the oxidation pathways, thus enhancing the long-range transport of pollution;

• the perturbations of biogeochemical cycles through man-made emissions to soil and waterbodies, direct or through atmospheric deposition, enhanced by other factors, like land use.

Consequences for human health and ecosystems are included by addressing problems such as:

- health and ecological effects of UV-irradiation.
- dynamics and vulnerability of ecosystems under stress.

The research topics are naturally closely related to major international programmes, in particular the WCRP and IGBP. Thus the present programme provides a basis for the European contribution to these global programmes. In addition it focuses on topics of more specific European interest, in particular in the field of climate change impacts.

*The following gives the programme* outline *including a more detailed description of the components relevant to this report:*

A) CLIMATE CHANGE AND CLIMATIC IMPACTS

**A.1 Natural climate change**

**A.2 Anthropogenic climate change**

The objectives are to provide:
- *understanding and prediction of anthropogenic climate change with a focus on regional change of climate statistics, including understanding and simulation of natural climate variability*
- *monitoring of ongoing changes of the global environment and climate system, and, with special emphasis on the European continent and surrounding oceans, monitoring of all climate related quantities, including land surface state, i.e. the conditions of soils and vegetation cover.*

<u>A.2.1 Climate change impacts</u>

Objectives:

- *Forecasting and understanding the impacts of the foreseen climate change upon selected sectors of the European environment*
- *Quantitative assessments of impacts on sectors of socio-economic relevance such as human settlement and activities, taking account of both physical and human factors.*
- *Guidelines for risk management and for the development or rehabilitation of areas damaged or at risk.*

Research tasks

**1.** Prediction of future sea level change
**2.** Changes in storm surge risk in Europe from climatic change and sea level rise
**3.** Potential impacts of sea level rise on natural ecosystems and coastal land-use within Europe

Assessment of environmental and land-use impacts on European coastal areas by conduction of case studies on particularly vulnerable locations, suitable for the integrated analyses of the impacts arising from the interaction of sea level, natural systems and human occupancy.

Two types of case studies may be envisaged. The first is the "analogue" case study which focuses on areas where impacts are already being experienced because of relative rise of sea level due to land subsidence. The second type of case study should focus on areas such as deltas and coastal plains, where an increase in the rate of sea level rise would threaten to exceed the natural rates of rejuvenation, leading to degradation of the natural resource base and endangering human habitation.

**4.** Impacts of sea level rise on surface and ground water supplies.

**5.** Land resources

a) Bioclimatic shift of crops
b) Impacts of increasing $CO_2$ and climatic change on European forests and other natural plant ecosystems.

Study of possible changes in productivity, mixture of species, and spatial extent of forests and other natural ecosystems. Expertise from a range of disciplines across Europe should be brought together. The purpose is to provide a strong, rigorous methodological foundation for estimating the potential effects of $CO_2$ and climatic change, and for evaluating strategies for future management.

c) Sensitivity of European crop yields to increased $CO_2$ and climatic change

**6.** Water resources
**7.** Physical factors, monitoring and prevention [Connected to "Instability and erosion of natural slopes"]
**8.** Flood hazards development and testing of theoretical and instrumental methods for the study, forecast and control of floods, and for flood hazard assessment
**9.** Land-use practices favouring or hindering floods

B) GLOBAL CHANGES IN ATMOSPHERIC CHEMISTRY AND BIOGEOCHEMICAL CYCLES AND THEIR CONSEQUENCES FOR LIFE ON EARTH

**B.1 Stratospheric ozone**

**B.2 Tropospheric physics and chemistry.**

**B.3 Biogeochemical cycles and ecosystem dynamics**

Objectives

- *To increase the understanding about sources, pathways and chemical/biological transformations of natural and anthropogenic compounds including the processes controlling the cycling and exchanges of these substances in terrestrial, aquatic, wetland, estuarine and coastal ecosystems in order to*
- *develop a comprehensive scientific basis for pollution control and habitat protection policies for terrestrial, aquatic, wetland, estuarine and coastal ecosystems;*
- *define indicators of environmental change and damage at different ecosystem levels, suitable for the analysis and prediction of the effects of natural and anthropogenic perturbations;*
- *develop or modify existing process-based models to predict the response of ecosystems to such perturbations*

The results should ultimately allow recommendations of normative measures and appropriate management and protection practices enabling soil fertility, water regime, environmental quality and biological diversity to be preserved and restored.

Research will emphasize investigations at the ecosystem or catchment scale, and will address in particular processes and pathways at *transition zones* between different ecosystem types (e.g. terrestrial/aquatic, land/ocean interfaces etc.)

Subareas:

**1.** Biogeochemical cycles and hydrology

- Changes in the carbon cycle (quantification of uptake by vegetation, allocation into different compartments of ecosystems and release to neighbouring ecosystems or to the atmosphere) with particular attention to modifications of primary production and decomposition of organic matter;
- Changes in the cycles of mineral nutrients, allocation to the different compartments of ecosystems, and losses to surface water and the atmosphere;
- Changes in ecosystem hydrology (mainly due to changes in land use), partitioning of precipitation, evapotranspiration and water use, circulation within ecosystems, and effects of changes in snow cover;
- Identification and quantification of sources and pathways of organic and inorganic matter, and of selected contaminants, and input-output balances at the land-sea interface;
- Mechanisms and rates of processes triggering the fluxes and cycles of natural and anthropogenic compounds in the estuary and the coastal area, and the coupling mechanisms between water column, sediment and biota;

**2.** Plant physiology

- Tree physiology, in particular the role of hormones, the partitioning and transport of assimilates, remobilisation and translocation of nutrients and senescence processes;
- Effects of pollutants and of combination between pollutants and other environmental stresses (temperature, drought, biotic factors) on physiological processes in plants, in particular forest trees;
- Effects of abiotic changes (increase of temperature and $CO_2$ levels) on physiological functions (primary and secondary metabolisms), vegetation phenology, rooting patterns and tree ring thickness.

**3.** Impacts of pollutants on soils and rhizosphere

- Impact of pollutants on biotic processes below ground (decomposition, nitrification/denitrification and other physico-chemical transformations involving mycorrhiza and soil microflora);
- Acidification neutralizing mechanisms, in particular the weathering of parent materials in order to define critical deposition thresholds.

**4.** Biodiversity

- Impacts of abiotic changes on species composition and biological diversity, vegetation structures and spatial distributions, density and successions.
- Impact on genetic diversity, in particular in forest trees focusing also on the assessment of human influences on genetic diversity and on population/ecosystem stability and adaptability.

**2.7.1 CLIMEX - Climate Change Experiment**

CLIMEX is a international, interdisciplinary research project (Germany, the Netherlands, Norway, U.K.). It is partly (about 50%) financed by the EEC (the Environment programme) and partly by the participating institutions. Preliminary studies will start in the near future, whereas the intensive experimental phase will commence in April 1994. The project will focus on the ecosystem response to climate change, in particular the plant-soil-water linkages and processes. Plant physiology, soil fauna, nutrient cycling, turnover of organic matter, soil and soil solution, hydrological flowpaths, and runoff water quality will be investigated. The results will aid in development of process-oriented models to predict the response of forests and freshwaters in Europe to future changes in atmospheric $CO_2$ and climate.

CLIMEX will experimentally enrich with $CO_2$ and raise the temperature of two entire forested headwater catchment ecosystems. It will make use of the two enclosures (1200 $m^2$ and 650 $m^2$) located at Risdalsheia in southernmost Norway. Eight years of background data are available from this site, collected as part of the RAIN project (Reversing Acidification In Norway). The project will use greenhouses to study the impact of the greenhouse effect.

Objectives:
*The objectives of CLIMEX are by means of large-scale manipulation with* $CO_2$ *enrichment and elevated temperature*

- *to measure changes in* $CO_2$ *uptake, gas exchange and plant phenology*
- *to measure changes in forest growth and nutrient status*
- *to measure changes in ground vegetation and nutrients*
- *to determine change in mineralization of soil organic matter*
- *to determine changes in soil fauna and biologically mediated processes*
- *to measure the effects on runoff water quality and quantity*
- *to develop a process-oriented model of effects linking terrestrial and aquatic response.*

Experimental design:
*Climate changes alone:* Ambient acid precipitation has been collected by the roof in the KIM catchment since 1984. This has been filtered and cleaned by ion-exchange, natural levels of seasalts re-added and then reapplied beneath the roof and above the forest canopy by a sprinkling system. This treatment will continue in CLIMEX, augmented by increased levels of atmospheric $CO_2$ and increased ambient temperature (by 5° C) by means of $CO_2$ dosing and hot air equipment conventionally used in agricultural greenhouses. As untreated

reference for the biological studies, a small portion of the KIM catchment will be sectioned off to receive clean precipitation but not elevated $CO_2$ or temperature.

*Interaction between climate changes and acid deposition:* At the EGIL catchment ambient acid precipitation collected by the roof is simply recycled beneath the roof without cleaning. For CLIMEX, levels of atmospheric $CO_2$ will be increased and ambient temperature raised by 5°C. The adjacent ROLF catchment (no roof, ambient acid deposition) serves as a reference for present climatic conditions. At both enclosed catchments, there will be a step change in $CO_2$ and temperature, starting at the beginning of the growing season.

## 2.8 ICAT -Impacts of Elevated $CO_2$ Levels, Climate Change and Air Pollutants on Tree Physiology (COST)

COST is an acronym for the French equivalent of "European Cooperation in the Field of Scientific and Technical Research". It is, principally a framework for R&D cooperation, allowing for both the coordination and national research projects and/or the participation of third countries in Community programmes, taking the form of precompetitive or basic research or activities of public utility.

COST cooperation involves 23 countries: the twelve EC Member States plus six of the EFTA (European Free Trade Association) countries (Austria, Finland, Iceland, Norway, Sweden, Switzerland), Czechoslovakia, Hungary, Poland, Turkey and Yugoslavia.

All COST projects are funded nationally, and fall within one of fourteen defined scientific or technical areas. "Environment" is one of these areas, and herein is one project relevant for the present survey, namely ICAT.

The information below on ICAT was drawn from a "Technical Annex of the Memorandum of Understanding of COST project 614".

Natural populations will partially have the ability to adapt to a relatively fast changing atmosphere and altered climatic conditions by ecotypic differentiation through selection. However, the significance of this adaptation depends on the genetic variation within the population and the length of the plant life cycle. In plants with a long life cycle, such as trees, ecotypic differentiation will be slow and will hardly have any adaptive value. Here the availability of phenotypic plasticity will be the important factor in the adaptation and survival of the species in a reltively fast changing atmosphere.

Objectives:

- *The primary aim of the project is to co-ordinate cooperative European research on the impact of the so-called greenhouse effect and air pollutants and its combination on trees functioning in the different European climate regions. The specific objectives are:*

- Tree functioning and adaptation: *To promote, integrate and intensify cooperative interdisciplinary research on the impact of a combination of elevated $CO_2$ levels, the consequences of an altered climate (drought, temperature stress) and a polluted atmosphere, also in the various combinations, on the physiological functioning and phenotypic plasticity of trees. To expand the present knowledge of the impact of multiple environmental stress factors on the biophysics, biochemistry and physiology of trees.*

- Forests: *To assess the role of forests as a sink for $CO_2$. To develop a system analysis for the forests of the various European regions in which the effects of combinations of elevated $CO_2$ levels and air pollutants on forest functioning can be simulated.*

- Forest fitness and wood production: *To obtain parameters which will be essential in the modelling and prediction of the consequences of the so-called greenhouse effect on forest fitness and commercial wood production in general.*

Participating countries in ICAT are: Austria, Belgium, Finland, France, Germany, Italy, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

## 2.9 Science of Global Environmental Change (NATO)

NATO (North Atlantic Treaty Organization) has, in addition to its better known political and military dimensions, a "Third Dimension", which seeks to encourage interaction between people, to consider some of the challenges facing our modern society and to foster the development of the scientific potential of Alliance countries. The NATO Science Programme (Scientific affairs division), established in 1958, plays a major role in this Third Dimension. Research projects are not funded or coordinated within this framework. Rather it provides support for activities which foster scientific mobility and interchange between scientists.

One programme of the NATO Science Committee is the *Science of Global Environmental Change*. The objective is to promote research dealing with potential global changes within the Earth's environmental system, using the means available to the NATO Science Committee. Its particular aim is to describe and understand the interactive physical, chemical and biological processes that regulate the total earth system. Its primary goal is to advance our capability to predict changes in the global environment, in particular those which result from human impact on the climate. Five thematic areas have been identified for special consideration:

- The climate system and the hydrological cycle
- Biogeochemical processes and dynamics
- Ecosystems and global environmental change
- Global environmental changes of the past
- Human dimensions of global environmental change

## III Research on biological effects of climate changes in some selected countries

In this chapter an overview of research on biological effects in 13 selected countries is given. Naturally, the magnitude of the collective research effort varies largely within this highly diverse sample of nations. Accordingly, this overview differs in the level of detail among countries. This, as well as the criteria for selection of projects to be included, calls for a few comments on the manner of which information was compiled.

Initially, the national IGBP chairman or the leader of specific nationally coordinated climate change programs was approached. This usually resulted in the identification of relevant research projects or scientists. Within national climate change programs, there was often an inventory of either scientists or project titles available. Consequently relevant activities were identified, often with the aid of national coordinators, and indiviual scientists were requested for description of their projects. As a rule, such descriptions were included without revision, due to time constraints[1]. This procedure naturally applies for the smaller countries and where national inventories of some sort were available. The other alternative was to try and identify the major relevant research centres and request information from local coordinators. In any case, the results of the inquiries, as presented in this chapter, ultimately depended upon the goodwill of numerous program directors, coordinators and individual scientists.

Regarding the selection of activities to be included, the overall criteria was that it should include studies of living organisms and explicitly relate to effects of climate change. The latter may be interpreted in both a very wide and a narrow sense, which is reflected in the scope of biological projects placed within the framwork of national climate change programs. For instance, an arbitrary project entitled "Ecology of reptiles" would not be included in this report, unless, of course, it was defined as part of a national climate change program.

The dependency upon the cooperative will of so many individual scientists as well as the difficulties encountered when selecting projects to be presented in

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[1]This means that each description has different authors. This is also true whenever the information was drawn from an already existing document; the words and content were not altered. If a description was unduly long, whole subsections were omitted instead of rewriting and summarizing. The result is a very heterogenous collection of project presentations, in terms of language, organization etc., but this was considered of minor importance for the present purpose.

this report, indicate how this information should be used. It is not meant to provide a measure of the total research effort on biological impacts for a specific country. Rather, it may serve as a point of departure for individual scientists who wish to locate additional activities within their own field of interest, - activities which have not yet resulted in published articles. Furthermore, it should provide valuable information for coordinators as well as funding units of international programs. Finally, anyone who wishes to initiate new projects may benefit from consulting this overview.

Within each country, the terrestrial projects are presented first, followed by freshwater and marine projects, respectively. Contact persons for each project or activity described in this chapter are given in appendix B.

## 3.1. Belgium

A survey of the IGBP-related research in Belgium was published in 1991 (Vanderborght 1991), with concise presentations of the research effort of 58 Belgian IGBP-related scientific teams including more than 200 scientists. The present information was drawn from that compendium, and includes brief presentations of the relevant research projects.

### 3.1.1 An investigation into the impact of elevated $CO_2$ upon the response of European forests

The species-specific (Norway spruce and poplar) and clonal specific (poplar clones) effects of increased carbon dioxide level on tree development and functioning will be determined. Biochemical, morpho-anatomical and ecophysiological responses will be examined and fractal modelling will be used to simulate high $CO_2$ effects on whole-tree growth.

### 3.1.2 Global change effects of elevated atmospheric $CO_2$ levels and increased air temperature on grassland ecosystems

In this 4-year cooperation between the Universities of Antwerp and Gent, the long term interaction is studied between elevated atmospheric $CO_2$ content, increased growth temperature, and soil nitrogen and water availability in grassland ecosystems. Plant reactions are examined on a leaf as well as on a canopy scale and canopy responses will be modelled for prediction of seasonal productivity changes. A second goal is the acquisition of data on the response of mixed vegetation to increased $CO_2$ and temperature, to identify and to estimate possible consequences of competitive shifts due to different responses in a species mixture. The cooperation is extended to V.I.T.O (Dept. Energy and Environment), who will focus on the carbon-fixing capacity of the entire Belgian territory through remote sensing.

### 3.1.3 Ecophysiological study of the effects of high atmospheric $CO_2$ concentration on a forest ecosystem in open top chambers

Since 1987, both 3 year old clones and seedlings of spruce (*Picea abies* (L.) Karst.), maple (*Acer pseudoplatanus* L.) and Beech (*Fagus sylvatica* L.) are grown in OTC surrounding an undisturbed forest ecosystem. Four experimental blocks installed under a mature forest canopy, are each composed of two OTC (3 m h and 3 m d) and one control plot (without chamber). The air changes inside the chamber five times a minute. Since May 1989, $CO_2$ is injected at concentrations of 450 and 550 ppmv and the temperature is rised by 1.5°C. We intensively monitor microclimate, precipitation and air pollution. The project is planned for four more years. We will study changes in assimilation $CO_2$ at three different levels of investigation:

At the infra-cellular level we will study the various channels of the carbon metabolism (in collaboration with Prof. P. Dizengemel, University of Nancy, France). We will take routine measurements of 9 enzymes between April and August 1991, adjusting the frequency of the measurements to the pace of the plant growth.

At the level of leaves on the branch, we will measure gaseous exchange of the plant with the atmosphere. We will use a LiCor 6200 to take the measurements and adapt our experimental procedure to try to eliminate certain physiological and environmental constraints (low photosynthesis activity under luminosity). To make up for the shortcomings of the LiCor, we are developing a porometer prototype. The method used is comparable to the one used in "WALTZ" porometers. The frequency of the measurements will also be adapted to the growth rates of the trees. The chemical make-up of the leaves will be analysed at the end of the leafy period every year, and after the growth periods in May and August every other year. The first chemical analysis of foliage in 1991 will show whether continuing research along this channel is advisable.

At the level of the ecosystem of the entire tree, we will study various overall parameters which characterize the growth and development of the plant: dry weight, leaf surface, stem/root ratio, dendrological parameters, nutritive status, etc. These are destructive tests, so the results of these measurements will only be available when all manipulations have been completed.

The data obtained at each level of investigation will be incorporated progressively into a calculation model which should include the general principles governing assimilation of $CO_2$ by forest trees. In view of the contribution of the individual to the development of the ecosystem, we will try to predict the potential of the entire forest ecosystem to cope with an increase in atmospheric $CO_2$.

### 3.1.4 Effects of increased atmospheric $CO_2$ content on primary productivity and carbon allocation in typical Belgian forest ecosystems

The object of this programme is the study of the greenhouse effect on net $CO_2$ uptake, growth and net primary productivity in deciduous and coniferous forest ecosystems. The programme follows a research strategy composed of three different steps:

1: The fundamental analysis of the greenhouse effect based on photosynthesis and growth measurements on young poplar, oak and pine plants in a $CO_2$ enriched and non-enriched greenhouse (the "model system").

2: The collection of similar field data from measurements on young and adult trees of photosynthesis rate, growth rate and total biomass accumulation in three typical Belgian forest ecosystems: an indigenous oak forest of the Atlantic type (the Experimental Forest "Aelmoeseneie" of the Faculty of Agricultural Sciences, University of Gent, located at Gontrode); a man-made monoculture of Scotch pine (State Forest "Pijnven", located at Hechtel) and a man-made poplar plantation (also located at the Experimental Forest "Aelmoeseneie").

3: The evaluation of the results from the model system and the field experiments will be related to each other. This will allow the extrapolation of the effects from $CO_2$ enrichment in the model-system to the level of primary productivity in typical Belgian ecosystems. This way the future evolution of the productivity and the carbon cycle will be predicted when the $CO_2$ concentration doubles in the middle of the next century.

### 3.1.5 Changes in the biogeochemistry of carbon in terrestrial ecosystems

A) Organic matter turnover in a West European climatic transect of coniferous forests

B) Interpolation of litter decomposition between forest stands in relation to climate, soil condition, tree species and forest management in order to construct an ecotechnological expert system.

A: The presented project is the Belgian contribution to the EZSF/FERN project on organic matter turnover in a West European climatic transect of coniferous forests. In a transect from Sweden to Portugal, the rate of litter decomposition in coniferous forests is measured.

### 3.1.6 Thermal biology of European reptiles: Toward a prediction of climate change effects

Predictions of responses of ecosystems to climate change require knowledge of the ecophysiological relationships between the component species and their biotic and abiotic environments. Research focuses on the thermal biology of European lacertid lizards (genera *Lacerta, Podarcis, Psammodromus* and *Acanthodactylus*) and snakes (genera *Vipera* and *Natrix*).

Past and current studies have focused on:

- Experimental determination of thermal preferences, thermal tolerance limits and the range of body temperatures wherein ecological performance is maximised .
- Experimental determination of the thermal dependence of egg development.
- Mechanisms of thermoregulation and flexibility of thermal requirements under changing ambient conditions.
- Estimation of the amount of evolutionary changes of thermal physiology (preferred and optimal body temperatures), by analysing both intra- and interspecific variation.

Our present results indicate that the rate of evolutionary adaptation will be small or non-existent. In contrast, reptiles might cope with changing climatic conditions through their flexible thermoregulatory behaviour. However, the effects of incubation temperature on embryonic development and life history traits of the newborns seem to be stringent. This may have important consequences for the distribution and abundance of populations and species.

### 3.1.7 Detectability of land systems by classification of Landsat Thematic Mapper data, Virunga National Park, Zaïre

The Virunga National Park lies in the province of Kivu, Eastern Zaïre, and is a part of the intramontaineous trench opened in the tertiary times, known as the

African Rift region. The studied area covers the plains of the Rwindi and Rutshuru rivers, flowing into the lake Edward (1400 $km^2$). The mapping of landsystems and vegetation of the Virunga National Park was performed with the aid of aerial photographs and field studies during a regional survey in 1978-1982. The study is based on the morphopedological approach, focused on the landform (morphology), the nature of the soil, the vegetation and their mutual relationships. The use of this method was imposed by the necessity of giving a diagnostic of soils and land units to be finalised in relation with wildlife management. The main factors controlling the pattern of landsystems were studied: geology, tectonic control of the sedimentation in the rift basin, and climate.

For large and relatively little known areas as the one we study, the imagery issued from the Thematic Mapper sensor of the Landsat earth observation satellite appears to offer considerable potential as data source. It provides multispectral information in the visible and infrared with a ground resolution of 30x30 m, and may be repeated to study the evolution of the land system. The digital format of the data allows the use of a statistical classification of "spectral signatures" of the observed objects. A false colour composite was produced by displaying the three infrared channels of Thematic Mapper in Red/Green /Blue. This image was the basis of statistical grouping and ordering of the landscape by methods of unsupervised and supervised classification. The objects of the landscape are classified in a limited number of classes, according to their similar spectral characteristics, on a fully automatic procedure (unsupervised) or according to pre-determined classes (supervised). The supervised classification gives the best results and leads to the production of a map containing 17 classes related to the thematic units. The procedure may be easily reproduced for data acquired at different dates, and is an adequate tool to monitor changes in the protected zones of the park and in the surrounding densely populated areas. Integrated with other information (economic data, climatic data) in a Geographical Information System, it provides a technical basis for the best economical and political decisions for the local and international authorities concerned with mankind and nature welfare.

### 3.1.8 $N_2O$ production through biological denitrification in soils

Under anaerobic soil conditions nitrate is biologically reduced either to $N_2O$ and $N_2$ (denitrification) or to $NH_4^+$ (dissimilatory nitrate reduction or DNR). Nitrogen losses from soil are suspected to constitute various environmental hazards; $N_2O$ as a probable "greenhouse gas", and NO as an important factor governing $O_3$ levels in the stratosphere. The main objectives of the studies are:

- The determination of the quantitative influence of the main factors (temperature, $NO_3^-$-content, moisture tension, the presence of plant residues) and their interaction on the denitrifying activity and on the ratio $N_2O/N_2O+N_2$ under laboratory conditions.
- The determination of the denitrifying activity under field conditions to estimate the total $N_2O$ and $N_2$ production (special attention is paid to farming systems including large amounts of animal wastes).
- A validation and improvement of available simulation models developed in our research group focusing on quantification of soil aggregate distribution and its impact on denitrification.

### 3.1.9 Wetlands and waterbirds: Effects of global change

Many species of waterbirds, especially geese, swans, ducks and waders, breed in the Arctic and subarctic and winter in temperate or tropical wetlands. As these birds use a great variety of habitats and migrate over long distances they are ideal indicators of global change, especially since their main habitats, wetlands, are very sensitive to changes. Data from the breeding areas are sparse, although this is recently changing. In contrast the knowledge of population sizes and winter distribution is rather good. This results from an international cooperation, of many ornithologists all over the world (through the International Waterfowl and Wetland Research Bureau (IWRB). Since 1967 yearly counts (in January) from most of the wetlands of the Western Palearctic are available. At the Institute of Nature Conservation several research projects collect data on waterbirds and their habitats and on the processes influencing the distribution and populations of some species. Those projects relevant to the Global Change Program (GCTE) are summarized.

One of the research topics is the study of numbers, distribution and habitat use of waders and waterfowl in Flanders within the framework of the international counts organised by the IWRB. A database with counts since 1967 is available and by now monthly counts between October and March are organised and coordinated by the Institute. Annual reports with population estimates and distribution maps are published. Also the habitat use of the different species is studied. These parameters are greatly influenced by weather conditions, especially by cold spells. As long time series are available, any changes could be detected and interpreted in a national and international context.

In Flanders some important wintering haunts of wild geese occur. These have been studied in detail since 1959, resulting in 1) a mathematical population model which can be used to predict population size, and 2) a conceptual model of habitat distribution. Any change in key population parameters as reproduction or mortality could be detected. The models can also be used to forecast the effects of different scenarios of climatic change on the populations. The third project relevant to this topic is the study of factors influencing numbers and distribution of waders in the estuary of the Schelde. First of all, the estuarine ecosystems, notably the intertidal habitats, are studied and monitored, so any effects of sea level rise can be detected. Secondly the regulation of bird numbers is studied, especially the aspects of food resources (carrying capacity).

### 3.1.10 Human impact on biodiversity: Systematics, ecology and zoogeography of African freshwater fishes

There are two large projects: the first deals with coastal basins in the so-called Lower Guinea area (Cameroun-Gabon-Congo-Brazzaville), the second deals with the lakes in Rwanda and Burundi. Faunal lists are being established on the basis of actual revisions using both classical (biometry, osteology) and more recent techniques (karyology; enzymatic variation). Fieldwork in the areas enables a study of the physico-chemistry of the different biotopes and to establish habitat preferences for the different species. Comparison between species composition in different areas (forest-savannah) is made, and changes in biodiversity due to human activities (oil exploitation; introduction of exogene species; dam constructions; etc.) are studied.

### 3.1.11 Euthrophication and toxical algal blooms in surface waters

The increasing enrichment of water with nutrients (eutrophication) is responsible for more and more blooming of algae in surface waters. Several blooming alga produce toxins of which some can be deadly for man and animals. The structure, working mechanisms, chemical detection methods of toxins and the ecological conditions for toxin production are insufficiently known. Since in Flanders toxic blooms of microalgae regularly appear during summer (e.g. the bluegreen algae *Microcystis aeruginosa*), in 1989 a project was started in collaboration with the Study Center for Water, and the Antwerp Water Works and the Laboratory for Biological Research in Aquatic Pollution in Gent, to study the relations between toxin production and different ecological variables. The toxicity seems to be influenced by several variables such as nutrient composition, pH, light, temperature and culture age. The endotoxin production also varies according to the season, the site and the strain of concerned algal species (e.g. *Microcystis*).

To unravel these mechanisms batch and chemostat culture experiments with *Microcystis aeruginosa* are being made. The possible formation of toxins in *Microcystis*, cultured under different circumstances, is assessed by means of acute toxicity tests with mammals. Research is also focusing on predictive assessment of the eutrophication potential by means of algal growth stimulation tests.

### 3.1.12 Effects of changing environmental conditions on energy metabolism in aquatic organisms

*Aims*: To evaluate the use of integrating biochemical and physiological responses as clinical measures for the energy status of aquatic organisms. The final objective is to find direct quantitative relations between short term physiological responses of an organism and its long term performance (survival, growth, reproduction).

Tasks:

1) Development and adaptation of the analytical methodology necessary for the analysis of the key clinical indicators (i.e. (UV/VIS; HPLC; NMR techniques)
   - Use of energy reservoirs (proteins, lipids and carbohydrates)
   - Protein synthesis (DNA and RNA)
   - Aerobe and anaerobe respiration (oxygen consumption and production of organic acids and ammonia)
   - Energy conversion (ATP, ADP, AMP)
2) Maintenance of animal cultures of water flea and fish
3) Biochemical and physiological effects of short term (hours, days, weeks), exposure to combinations of temperature, hardness and acidity. For an organism with a short term generation time like the water flea a four week experiment means 3 to 5 generations.
4) Instrumental analysis of the above mentioned clinical indicators
5) Evaluation of the results and reevaluation of clinical indicators and experimental design
6) Biochemical and physiological effects of short term (hours, days, weeks), exposure to combinations of temperature, hardness and acidity. These experiments include regular (days) evaluations of scope for growth and reproduction rate.
7) Integration of short- and long-term evaluations into a strategy for the assessment of environmental stress.

### 3.1.13 Climatic change and freshwater ecosystems

Area I

An evaluation of physico-chemical and biotic disturbances in sensitive boglake ecosystems due to climatic change. Several thousands of originally oligotrophic moorland pools are found in non- or poor-calcareous, sandy areas in Belgium, the Netherlands, Germany, U.K. and Poland. Most of these isolated boglakes are exclusively fed by precipitation. The increase of greenhouse gases in the atmosphere are expected to cause important changes in air temperature, precipitation and evapotranspiration. It appeared from former long-term survey studies (since 1975) on Campine boglake ecosystems that such climatic changes cause hydrological and physico-chemical disturbances with profound effects on the original fauna and vegetation.

Tasks: The long-term evaluation of boglake ecosystems will be continued with respect to global change effects (hydrological data and physico-chemical data). Boglakes will be sampled frequently and data will be stored in the database "BIOVEN" (since 1975). Comparison with climatological data (K.M.I.) will reveal information on the susceptibility of the boglake ecosystems to climatic change. A number of these boglake ecosystems show extremely low pH levels and increased concentrations of toxic metals (e.g. Al and Mn) as a consequence of anthropogenic acidification. Few organisms which survive at such extreme conditions are at the limits of physiological tolerance. An evaluation of species distribution will be made since it is expected that selection for tolerance to environmental stresses, such as a small climatic shift with consequent physico-chemical and hydrological changes (temperature, pH, metal-concentrations, drought) will be most intense at the margins of tolerance.

Area II
Ecophysiology of the biological adaptations of freshwater organisms to multiple environmental stresses. Basic physiology of organisms will become rapidly restrictive as tolerance limits are increased. Currently, adaptation of freshwater fishes to environmental stress as low pH and increased levels of metals (Al, Mn) is studied in our laboratories. Physiological and biochemical parameters (osmotic balance, gas exchange and their hormonal control) are evaluated in tolerant and non-tolerant organisms. Substantial changes in acidified freshwater ecosystems, such as e.g. increased temperature and decreased oxygen supply can have cumulative stress effects.

Tasks: Evaluation of multiple environmental stresses, such as low pH, metals, temperature, availability of oxygen on basic physiology of some freshwater fish species. Data from laboratory studies will be related to field conditions (area I) in order to interpret changed distribution of organisms or species extinction due to global change.

## 3.2 Canada

The Canadian Global Change Program (CGCP) of the Royal Society of Canada is an umbrella organization for Canadian contributions to the WCRP, the IGBP and the HDGCP (Human Dimensions of Global Change Program). The overall goal of the CGCP is to ensure that Canada's approach to global change research is cohesive, comprehensive and responsive to national needs and international initiatives. The overall direction of the CGCP is set by a Board of Directors. Research Plans and assessments are developed through a Research Committee which reports to the Board of Directors. Areas of attention include:

- The Arctic
- Critical Zones
- Climate, oceans and hydrology
- Culture and values
- Data and information systems
- Energy
- Human health
- Ecosystem research and monitoring
- Past environment
- Renewable resources
- Security

The majority of research in Canada is, however, still being undertaken by individuals using a variety of funding sources, which makes it difficult to make an inventory. Information Specialist Dave Henderson has kindly assisted with choosing the relevant activities in Canada to be presented here, as well as provided a considerable part of the information. With the exception of BIOMTEL, all of the programs are related to the CGCP.

### 3.2.1 Boreal Ecosystems Atmospheric Study (BOREAS)

Boreal areas represent one of the largest biomes on the planet and a major storehouse of organic carbon, yet many questions remain concerning their sensivity to climate change and the possible consequences of ecological perturbation in these areas. BOREAS is being developed in conjunction with NASA to broaden our knowledge of boreal carbon dynamics through satellite technologies and surface validation efforts. The experiments will be an international collaborative effort, involving scientists from the U.S.A., Canada and other countries and will consist of contributions from the fields of land surface climatology, terrestrial ecology, tropospheric chemistry and remote sensing. Two sites in Canada will be equipped in 1991-1992 and a "dry run" will occur during 1993. The main equipment year will be in 1994, with subsequent data reduction and analysis continuing through 1997. The following gives a summarized description taken from the BOREAS Science Plan:

The goal of BOREAS is to improve our understanding of the interactions between the boreal forest biome and the atmosphere in order to clarify their role in global change.

The study will be centered on two 20∗20 km sites within the boreal forest region of Canada located near the northern and southern limits of the biome. Studies based at these sites will be used to explore the role of various environmental factors (temperature, soil moisture, etc.) in controlling the extent, character and functioning of the biome. The sites will be subject of surface, airborne and satellite based observations which aim to:

i) Improve our understanding of the biological and physical processes and states which govern the exchange of energy, water, heat, carbon and trace gases between boreal forest ecosystems and the atmosphere with particular reference to those processes and states that may be sensitive to global change. The initial focus will be on the study of the relatively short time-scale processes (seconds to seasons) which are amenable to measurement within a one to two year field program.

ii) Develop the use of remote sensing techniques to transfer our understanding of the above processes from local scales to regional scales. It is anticipated that the models and algorithms developed and tested at the scale of the intensive measurement sites (meters to a few kilometers) will be used to calculate regional and ultimately global-scale fields of energy, water, carbon and trace gas exchange.

### 3.2.2 Northern Biosphere Observation and Modeling Experiment (NBIOME)

The potential for significant climate changes in northern latitudes over the next century poses numerous challenges for Canadian resource managers, researchers and citizens. Prognostic capability to guide the formulation of appropriate resource management policies requires improvement in contemporary understanding of 1) the likely response of northern terrestrial ecosystems to a rapidly changing climate and 2) the dynamic role of these systems in modifying climate systems (feedbacks). This understanding must be developed over a demanding range of spatial and temporal scales. Process observations and detailed ecophysiological theories at the level of individual ecosystems may be used to delineate the critical process controls on system response at these scales, but to meet the prognostic needs of policy makers and resource managers this detailed understanding must be scaled up to the biome and global level. This biome-level formulation must permit examination of both short-term (decades) and medium-term (ca. 100 years) implications of alternative climate change and resource management scenarios.

The Northern Biosphere Observation and Modeleing Experiment (NBIOME) is a collaborative, truly interdisciplinary project developed for Canada's forests, wetlands and agro-ecosystems by university and government agency scientists from across the country. Combining observations over a wide range of scales with integrating models of ecosystem structure, function and response, NBIOME will focus on the likely effects of global environmental changes on three interacting aspects of these terrestrial ecosystems: 1) the role of disturbance regimes in shaping spatial and temporal patterns of structure and function, 2) the changes in vegetation and distribution dynamics, and 3) the size of changes of terrestrial carbon pools and the net exchanges of important greenhouse gases with the atmosphere.

There is a close connection between the NBIOME and the BOREAS programmes. BOREAS focuses on the ecosystem dynamics and interactions with the physical climate system during a single growing season, and may thus be regarded as a first step within NBIOME - in the sense that many of the techniques (experimental and theoretical) developed within BOREAS will be of direct relevance to NBIOME. Indeed many if the Canadian scientists involved in BOREAS are also involved in NBIOME.

The planned NBIOME programme period is 10 years (1992-2002). It has been accepted into the NASA Earth Observing System (EOS) programme, which will provide access by the research teams to important and leading-edge satellite remote-sensing data.

### 3.2.3 Paleoecological Analysis of the Treeline (PACT)

The goal of PACT is to obtain detailed records of the impact of postglacial climate on terrestrial peatlands and aquatic ecosystems along the circumpolar treeline zone. Data will be collected from lake cores and peat sections taken from Northern Canada and the Russian Federation. PACT, a joint Canada-CIS experiment, is scheduled to be a five year undertaking, starting the summer of 1992.

### 3.2.4 Integration of Remote Sensing Data in a Geographic for Impact Modeling of Long-term Climate Change in Québec's Boreal Forests (BIOMTEL)

In addition to being a major biome in a global connection, boreal forests are of large economic importance to Québec and similar northern regions were it serves as the resource base of major industries. The object of the research project is to study the global transformations of the global boreal forest ecosystems with regard to climate changes and to investigate synoptic remote sensing as a tool for quantifying biogeophysical characteristics of the boreal forest biome.

### 3.2.5 Mackenzie Basin Impact Study (MBIS)

The purpose of the study is to describe the impacts of several scenarios of global warming on the region bounded by the Mackenzie Basin watershed, including parts of British Columbia, the prairie provinces and the Yukon and Northwest Territories. It is intended to be a broad, integrated, multi-disciplinary, interagency study of all regional issues that may be climate-sensitive, such as terrestrial ecosystems, fresh water resources, resource extraction and local/regional economies.

The project, which is now in its second year, is providing full or partial support for a number of projects, all of which will be active in FY 1992/93:

- Forest-wetland response (U. Alberta)
- Regional accounting framework (U. Victoria)
- Permafrost in the Mackenzie Valley and Beaufort Sea region (Terrain Science Division, Geological Survey Canada)
- Freshwater fisheries (U. Manitoba and Freshwater Institute)
- Pease River ice (Alberta Research Council)
- Basin runoff (U. Waterloo)
- Wildlife response to fire (GNWT Renewable Resources)
- Agriculture impacts and opportunities (U. Waterloo)
- Tourism inpacts and opportunities
- Vegetation response to fire at treeline (U. Alberta)
- Land cover data from remote sensing (U. Calgary)
- Remote community´s adjustment to floods (U. Toronto)
- Dene traditional knowledge on climatic variability (proposal only: Dene Cultural Institute, Arctic Institute of North America.
- Fish habitat and yield in large lakes (Saskatchewan research Council)
- Forest sector impacts (Pacific Forestry Centre, British Colombia Ministry of Forests, U. British Colombia, U. Victoria)

## 3.3 China

This subsection was kindly authored by Prof. Fu Congbin.

China has established a core project of global change studies on national level, i.e. *Research Project on Future Trends of Changing Eco-environment in China* *the Next 20-50 Years*. It is funded by the State Commission of Science and Technology for the period of 1991-1995 with the possibility of renweal for another five years. There are also several associated projects within the IGBP-framework which are supported by the China Natural Science Foundation and Chinese Academy of Sciences, respectively.

In these projects, the climate-ecosystem interaction is a major component of research which includes field experiments, numerical modelling, as well as theoretical studies on different scales.

On global, continental and regional scales, the major research activities may be summarized within the following categories.

### 3.3.1 The development of remote sensing technique in monitoring and studying vegetation dynamics on continental scale

The NOAA AVHRR (National Ocean and Atmospheric Administration, Advanced Very High Resolution Radiometer) data are now receiving in three stations in China (Beijing, Wulumuqi and Guangzhou) and have been archieving since October 1988. These data have been used to retrieve the Normalized Difference Vegetation Index (NDVI) for the Chinese continent and its surrounding regions, and to study the vegetation dynamics and its relationship with climate.

A preliminary analysis of the weekly NDVI for the period of October 31, 1988 to October 29, 1989 shows a significant seasonal variation of vegetation cover in association with the monsoon activities. There seems to be an abrupt change in the vegetation cover following the onset of the summer monsoon. The study of the interannual variation of vegetation cover and their relation-ships with climate are now being undertaken.

However, the existing AVHRR HRPT (Advanced Very High Resolution Radiometer, High Resolution Picture Transmission) data in China should go through the preprocessing procedures, such as radiometric calibration, atmospheric correction, geometric correction and soil background correction and so on, to ensure the data quality.

Since a high resolution of land cover data sets is strongly required in many core projects of IGBP and WCRP, a global 1 km AVHRR data set is being developed by the joint effort of many countries under DIS (Data and Information System)/IGBP. China has established a research group to the Chinese data as part of the international project. From this data set, some biological parameters such as the NDVI, biomass, vegetation type and leaf index, etc. will be retrieved in order to study the climate-vegetation interaction.

### 3.3.2 The development of a regional climate model for the study of climate impacts on ecosystems

The increasing demand by the scientific community, policy makers and the public for realistic projections of possible regional impacts of future climate changes, has rendered the issue of regional climate simulation critically important.

In the study of biological effects of climate change, the simulation of regional climate and climate change is also crucial. Although the global atmospheric circulation models (GCMs) simulate the main characteristics of the global climate reasonably well, their performance in producing regional climate in detail is rather poor. The lack of details in the scenarios seriously hampers the analysis of impacts on ecosystems on regional scale. However, a sufficiently fine GCM resolution may not be computationally feasible for another 5-10 years. Thereafter, a nested GCM meso-scale model methodology for regional climate simulation has been developed.

a) To develop a climate version of meso-scale models

The present version of meso-scale models are used mostly for short-term weather forecast and for strong convection and so on. The meso-scale model used for climate studies must be reformed in their physical process description, especially the radiation processes in which the effects of major trace gases such as $CO_2$ , $CH_4$, and $O_3$ must be taken into account, and the surface boundary layer structure in which the atmosphere-vegetation-soil interaction must be presented more realistic.

In order to take account of the effects of land surface characteristics of China, the land use patterns in East China are classified into 10 categories: 4 in natural vegetation cover, i.e. broad leaf forest, deciduous forest, deciduous-coniferous mixed forest and coniferous forest, and 5 in agro-ecosystems, i.e. rice paddy, rice-wheat rotation crop system, wheat-bean rotation crop system, the Northeast agricultural system and the agriculture-forest mixed system, and the interior drainages.

b) GCM-RCM nesting technique

To assure the stability of long-term integration of regional climate models and the consideration of boundary effects coming from the background fields, the one way nesting techniques are being developed to drive the mesoscale model by the interpolated GCM output as the initial condition and the changing lateral boundary condition as the function of time for the climate version of the meso-scale model.

In replace of the GCM output, the observed global meteorological fields are used to drive the meso-scale model to simulate the regional climate too.

Of course, the two way nesting technique would allow better representation of the effects of regional processes on large scale circulations. At present it seems too difficult to develop such a technique, because of the difference in resolution between driving GCMs and the nested meso-scale models and the computational capability.

c) Three major simulations of the nested model

Validation of the model against present-day climate by comparing with the observed data as well as with the GCM simulated present regional climate.

Evaluation of the model's ability to reproduce the past climate change over the region by a comparison with the reconstructed regional climate from available data.

Simulation of regional climate changes under hypothesized change in the climate forcing, such as change of $CO_2$ concentration in the atmosphere, changes of large scale biological characteristics (e.g. vegetation index, vegetation types, etc.) and surface physical properties (e.g. albedo, soil, moisture) and so on.

### 3.3.3 Model simulation on the effects of regional climate changes on ecosystems

The results from the nested GCM-mesoscale model, either the climatology or the climate change under $2{*}CO_2$ would be used as the input for either static vegetation model or the dynamic vegetation model in the study on biological effects of climate change.

### 3.3.4 Development of patch scale atmosphere-vegetation model

This model will be in a scale of 10-100 km with a resolution of about 100 m. In this atmospheric boundary layer- vegetation- soil coupled system, the role of vegetation not only in the energy and water transfer, but also in carbon exchange have been taken into account. The effects of environmental conditions on the vegetation physiology are also included. The results of this study will furnish the development of the regional climate model which needs better description of the atmosphere-vegetation-soil system.

## 3.4 Denmark

Denmark does not coordinate their global change research through one central programme. There are, however, a number of running projects within the field. Danish projects relevant for the IGBP have recently been identified through a questionnaire distributed by the Danish IGBP-committee. From the resulting report, six projects were considered relevant for the present purpose. Project leaders were requested for short descriptions in English which are presented below.

### 3.4.1 ZERO - Zackenberg Ecological Research Operations. Global change studies in an high Arctic ecosystem

As part of the program of ZERO a digital database will be established in 1992 as a basis for global change studies in an high Arctic ecosystem in the Greenland National Park. A digital topographical and geomorphological mapping will be conducted by means of aerial photographs, and the regional and seasonal variations of climate parameters will be registered in detail by means of computer models, digital terrain and satellite data, and field research. Regional and seasonal variations in the distribution of selected plant societies and biomass production will be recorded by means of detailed spectro-radiometer measurements in the field, as well as digital terrain and satellite data. Through intensive field tests, attempts will be made to register short-term variation in the different parameters in relation to radiation, energy, and water balance, and their influence respectively on flora and fauna in selected test areas.

The test area is nominated as biosphere reserve in accordance with Unesco´s international scientific programme of MAB (Man and the Biosphere), and the scientific results will be included in the ITEX programme (sec. 2.5.1). The ZERO programme also forms an integral part of the international scientific programme of ISLSCP (International Satellite Land Surface Climatology Project) and the EC programme EPOCH (European Programme on Climate and Natural Hazards.

### 3.4.2 The Physiology of "Red" Norway Spruce, and the selection of healthy provenances

*Background:* Norway spruce grown in Denmark have had severe "health" problems in recent years, problems that are thought partly to be caused by air pollution in combination with increased winter temperatures. Norway spruce examples a continental species at the edge of its natural geographic distribution, and as such may function as an "early warning" of increasing winter temperatures due to the predicted increase of the greenhouse effect. Further, the project is related to the on-going planting of forests in Denmark (a planned doubling of the national forest area), and whether Norway spruce is the best choice for future forests in Denmark.

*Aim:* The aim of the present project is to study the impact of our present air pollution ($O_3$, $NO_X$, $CO_2$, VOC, etc.) on the health of different provenances of Norway spruce in interplay with environmental parameters: temperature, radiation, precipitation, nutrients).

*Method:* To identify the individual effects of possible stress parameters, the dose-response effect on photosynthesis, respiration and transpiration by each parameter is analyzed with offspring of healthy and unhealthy Norway spruce. The measurements are carried out in a pollution gas exposed mini-cuvette system in climate chambers. Presently, 112 families of Norway spruce are being cultivated, while chemical analysis are carried out on branches and needles of the parents of 62 families. The same plant material will be used in two types of stress-physiological tests (photosynthesis and transpiration response to acute levels of $SO_2$ and $O_3$ as a refinement of a previously developed early warning test for healthy/unhealthy offspring of Norway spruce.

*Preliminary results:* The exposure direction from which the analyzed branches and needles were cut, did not affect the needle mineral contents. This may be taken as an indication that an air pollutant was not involved: The needle age affected mineral contents. This is in accordance with the visual injuries (worst in 1989). There was a significant positive correlation (Spearman Rank) between a decrease in health and the needle contents of certain minerals (measured for needles over all exposure directions and ages). When comparing health class 2 (the least healthy in our study) with class 9 (the most healthy), we found a 39% significant increase in K, 71% in Ca, 60% in Mg, 24% B and a 28% significant increase in ash in the injured trees. There were no significant effects on seed weight or germination.

### 3.4.3. Biological monitoring of climatic changes by plant population dynamics - an ITEX experiment

This project is a Danish contribution to ITEX - the International Tundra Experiment (2.5.1). It is designed to anticipate the reaction of Arctic plants to an eventual global climatic change. From simulation models it is deduced that arctic terrestrial ecosystems may be most severely influenced by changes in climatic conditions.

During the last four years we have followed the populations of *Papaver radicatum* on Disko. We have observations of natural fluctuations in growth and flowering, seed production and germination due to the annual change in weather conditions. These results represent a zero-situation which is important as base for manipulation with climatic parameters, i.e. temperatures around the plants. In accordance with the ITEX initiative translucent, angular screens have been placed around plants in an otherwise undisturbed natural environment, and the scope of this project is to follow the reaction of the manipulated plants. We intend to follow the plants by regular observation of: total biomass, flower production, seed set, germination, survival of seedlings, general phenology and incorporation of secondary plant compounds, the latter especially in relation to survival after herbivore attack to plants. All observations will be related to similar observations of undisturbed plants.

### 3.4.4 Sensitivity of Arctic terrestrial ecosystems towards global climate change, in particular with respect to UV-B radiation and temperature variation

High Arctic Greenland (Qaanaaq) heathland (dominant: *Cassiope tetragona*) with a substantial content of epigeic lichens such as *Cladonia*-species are being investigated in the field and in the laboratory. The purpose is to disclose eventual early signs of adverse effects of global change to ecosystems believed to be particularly sensitive to e.g. UV-B radiation and $CO_2$ increase as well as altered precipitation and temperature conditions. In the high arctic and Antarctic particularly severe changes in radiation and temperature regimes are expected in the course of few decades as a consequence of anthropogenic changes of atmospheric chemical equilibria.

### 3.4.5 Exchange of ammonia and other trace gases between plants and the atmosphere

The project focusses on the exchange of nitrogen gases, particularly ammonia, between plants and the atmosphere. The work includes growth chamber studies of $NH_3$ compensation points and interrelationships between ammonia exchange and basic physiological and biochemical processes involved in nitrogen transport and nitrogen metabolism in plants (root-shoot transport of low-molecular nitrogen compounds, pH and $NH_4^+$ concentration in leaf apoplast, activity and localization of key enzymes in nitrogen metabolism, nitrogen source-sink relationships during scenescence, photorespiration and photosynthesis). In addition, flux measurements of ammonia above arable land are made using the micrometeorological gradient technique.

### 3.4.6 Denitrification in European forests. Biogenic $N_2O$ emissions

It is the aim to quantify denitrification and $N_2O$ emissions from widely distributed forest Ecosystems in Europe. The project is organized as part of the

EC's environment research programme in the CORE and NIPHYS programmes.

Spruce forests under different climatic and pollution conditions - from Ireland to central Germany- have been examined for $N_2O$ emission using a simple enclosure system inserted in the soil on location. Influence of factors as temperature, water content, pH and substrates for the denitrifying bacteria are being studied. The perspective for the project is a survey of denitrifying activity in different forest soils under varying environmental conditions. Wet stands of alder and ash show higher activity than drier and more acidic beech and spruce forests. Temperature experiments have shown increasing denitrifying activity in soils at higher temperatures provided that substrates and water not become limiting. The end product of denitrification is nitrogen but at low pH and under substrate rich conditions $N_2O$ becomes the dominant product.

Most natural ecosystems show low denitrifying activity with a $N_2$ or $N_2O$ emission near 1 kg per hectare per year. So far it is not known whether the $N_2O$ escapes to the atmosphere or is trapped in the forest canopy. It is envisaged that management practices like liming or addition of tillage may be introduced to minimize $N_2O$ emissions.

## 3.5 Finland

The research on biological effects of climate changes in Finland is incorporated in the Finnish Research Programme on Global Change (SILMU). The programme goals are:

- Increase our knowledge on climate change, its causes, mechanisms and consequences,
- Strengthen the research on climate change in Finland,
- Increase the participation of Finnish researchers in international research programmes,
- Prepare and disseminate information for policy makers for adaptation and mitigation.

The key areas where research is to be directed are:

- Quantification of the greenhouse effects and magnitude of anticipated climatic changes,
- Assessment of the changing climate on ecosystems,
- Development of mitigation and adaptation strategies.

SILMU consists of four sub-programmes:

**Atmosphere**

The central aim is to quantify the magnitude of past and anticipated changes in the climate, especially in Northern Europe. In addition, research is carried out to understand the causal mechanisms of these changes. Studies on air chemistry and pollutants also form a part of this subprogramme.

## Waters

The waters subprogramme aims at analyzing the effects of global climate change on the hydrology and ecology of Finnish lake and sea ecosystems, including interactions between the atmosphere, hydrosphere and biosphere. Various studies in the Baltic Sea are part of this subprogramme.

## Terrestrial ecosystems

The aim is to study the effects of changing climate on the functioning of terrestrial ecosystems. Studies on the effect of climate change on agriculture and forestry are included in this subprogramme, as well as studies on peatlands and their role in the dynamics of biogeochemical cycling of carbon.

## Human interactions

The human interactions subprogramme aims at studying the human aspects related to global climatic change, including health, social and economic factors, energy and industry. Studies on the assessment of control strategies and economic impacts of greenhouse gas emission are included in this subprogramme.

Almost two hundred researchers have been involved in the subprogrammes.

In March 1992, the Academy of Finland published a Progress Report for SILMU. Future progress in SILMU will be reported periodically, with a final volume when the programme ends. The 1992 volume included reports of the research projects, of which those relevant for the present survey were selected. One researcher for each of the relevant works was requested to provide a short description of the project. Of 11 requests, 9 project descriptions were provided and they are presented in the following:

### 3.5.1 Response of the boreal forest ecosystem to changing climate and its sivicultural implications

The aims of the study are to investigate the ecological and sivicultural implications of a changing climate, i.e. (i) how the expected climatic change will modify the functioning and structure of the boreal forest ecosystem, and (ii) how sivicultural management of the forest ecosystem will be modified in order to maintain a sustainable forest yield in changing conditions.

The study deals with the Scandinavian conditions, particularly Finland, where Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and a few deciduous species (e.g. *Betula pendula* and *Betula pubescens*) are the main species of commercial value.

The study problem is approached on the basis of model computations incorporating climatic (temperature, precipitation, radiation, air humidity, wind, atmospheric carbon) and edaphic (temperature, water, nutrients) factors and sivicultural practices (e.g. regeneration, thinning) into the model as factors controlling birth, growth and death of trees and dynamics of matter and nutrients in forest ecosystems.

The results of the model computations are validated against the experimental findings to be obtained from the field experiment, where natural Scots pines of about 20 years old (2-3 m tall) are grown in field conditions in chambers of 2.5∗2.5∗3.5 m in size. The chambers represent the current and future climatic conditions, i.e. (i) no elevation in temperature or atmospheric carbon, (ii) elevated temperature alone, (iii) elevated atmospheric carbon alone, and (iv) elevated temperature and atmospheric carbon. Furthermore, similar trees outside the chambers are included in the experiment. The factorial design with four replicates of each treatment is applied.

### 3.5.2 The effect of climate on the phenology of perennial plant species

This study was initiated to investigate the relation of climate and the phenology of wild, perennial plants. The specific goals of the project are: (1) to study the long term variability and spatial geographical patterns of the observed first occurrence of leaf and flower bud emergence in several indigenous plant species in Finland; (2) to test models that simulate the dependence of plant phenology on climate with a specific interest in predicting the large scale spatial patterns of phenology under present and future climate; (3) to participate in the organization of a new phenological observation network, by co-ordinating routine observation activities and by studying the field observation methods.

Published phenological records from Finland range back to the early part of the 19th century. A major part of these data, namely the periods 1896-1902, 1918-1955 and 1960-1965 have recently been entered into a form of a relational data base. The data contain observations of altogether 46 plant taxa of which the onset of flowering was observed on 44, onset of leafing on 6, onset of fruit ripening on 10 and onset of leaf colouring in autumn on 6 species. The total number of observations in the data base is currently about 80 000 of which 50 000 are dates of the onset of flowering. The total number of sites that reported at least once during the periods was 395. Of these only 32 sites had nearly continuous records for more than 20 years during the period from 1918 to 1955. The long term field observation routine was carried out by volunteer observers according to pre-written instructions.

Statistics on phenology, reported in Heikinheimo and Lappalainen (1992), for the period from 1918 to 1955 include the first, mean and last dates of occurrence of each phenological phase and the corresponding standard deviation at sites which had operated continuously for more than ten years.

The phenological records are being analysed in relation to observed climate. The most important environmental factors assumed to affect plant phenology during spring are air temperature and photoperiod (day length). Due to the mismatch of the climatological and phenological observation networks, optimal interpolation methods have been applied to obtain estimates of daily mean temperature representative of the phenological observation sites.

### 3.5.3 Physiological and genetical adaptation of forest trees to climate changes

In old provenance experiments trees have been grown for several decades under climatic conditions different from those to which they are adapted to. Because of this, such experiments could give useful information on the adaptation of forest trees to climatic changes, specifically on long term effects.

In Finland a series of provenance experiments for both Scots pine and Norway spruce was established during the early 1930´s. For pine there are three experiments in southern Finland, for spruce seven experiments all over the country. They include origins from all over Finland and its nearby areas, whereas the spruce series also include origins from central Europe. These experiments are used now for more or less intensive studies on survival, growth, phenology, frost hardiness and chemical stress indicators in order to obtain quantitative information on the climatic effects.

The results on production in spruce show that there is an increase in growth when northern origins are moved southward. This increase is largest when comparing growth in northern Finland with central and southern Finland. In the northernmost areas the climate is the major limiting factor of tree growth, whereas more southward other factors become limiting. Another important result is that the northern origins do not produce as well as the local southern origins.

Two years of phenological observations have shown that bud burst occurs in the northern origins at a lower heatsum than in the southern ones. It is, however, doubtful if this results in higher risks for frost damage, because freezing tests showed a possible rehardening after a mild period during winter.

### 3.5.4 Anthropogenic environmental changes and the risk of forest insect outbreaks

The predicted climatic changes present a great challenge to forest entomologists. The processes affecting insect population densities work in so large spatial scales that it is generally not feasible to do experiments in that scale. The aim of this project is to test the effects of anthropogenic environmental changes on the basic processes important for density changes of forest insects in boreal and subarctic areas, and to use that information in simulation models predicting the possible changes in the frequency, intensity or duration of outbreaks.

Herbivorous insects have an unfavorable trophic position between plants with variable and often suboptimal foliage quality and various kinds of natural enemies. The relative importance of climatic factors, host quality and natural enemies varies among different herbivore species, and that is why studying several species with different life histories is necessary. Our study objects are both pine and birch feeding aphids, the European pine sawfly (*Neodiprion sertifer*), the autumnal moth (*Epirrita autumnata*) and a chrysomelid beetle (*Phratora polaris*) feeding on mountain birch. So far the work has concentrated on the effects of pollutants (mainly simulated acid rain) on the performance of insect herbivores. Furthermore, we study the effects of pollutants on the efficacy of natural enemies of *N. sertifer* (on pine) and *P. polaris* (on birch).

In the future we will concentrate on experiments dealing with interactions among environmental changes (emphasis on climatic change), foliage quality, and natural enemies. The experimental results will be incorporated to GIS-based models for simulation.

### 3.5.5 The development of a soil/plant/atmosphere model

An interface model which simulates the thermal and hydraulic exchanges between the soil, the vegetation and the atmosphere and estimates the energy fluxes at the surfaces was used over different canopies during the growing season in southern Finland. The verification of the model in the microscale was done against the ground truth data measured with Campbell's Bowen ratio system.

Remotely sensed land use, which has been classified from Landsat TM images was used to calculate the land use distribution in river basins and also for finding homogeneous areas in NOAA AVHRR scale. NDVI and the surface temperature, interpreted from AVHRR images, were used as input data to calibrate some vegetation and soil parameters in a one dimensional soil/plant/atmosphere model.

The objective of this study is to develop the model for Finnish conditions, so that it can be used for modelling large scale surface fluxes and soil moisture for different time scales (day, week, month) and to use the validated model to estimate the climate change on these variables.

### 3.5.6 Carbon balance of peatlands and climatic change

The project, which is part of the Finnish Programme on Climatic Change (SILMU) is coordinated in the Dept. of Forest Ecology, Univ. of Helsinki and contains ten subprojects, which are carried out at the Finnish Forest Research Institute, Univ. of Joensuu, the National Public health Institute and the National Board of Waters and the Environment.

The aims of the project are (1) to study the role of peatlands in the balances of $CO_2$, $CH_4$ and $N_2O$ and (2) to determine how the predicted changes in the atmosphere and climate will affect the functioning of peatlands, both virgin and those under land-use.

The project started in the summer of 1990 and has so far concentrated on the measurement of carbon input and accumulation, and emission of greenhouse gases from virgin and managed peatlands. The effect of drainage for forestry has been of special importance since 5.3 mill. hectares (of the total 10 mill. ha) are managed in Finland

The project is planned to continue till the end of 1995 and will concentrate on studying the processes involved in the cycling of carbon between the atmosphere and the mire ecosystems. The responses of these processes of temperature and hydrological conditions will be used in predicting the effects of climatic change. GIS-applications and available data bases will be used to compute the greenhouse gas balance for the whole century.

### 3.5.7 Impact of climate change on carbon cycle in freshwater ecosystems

The aim of this project is to produce a carbon cycle model which could be used for predicting the impact of climate change on structure and functioning of food webs in lake ecosystems. The emphasis is mainly directed to changes in the pelagic system in conditions where, due to changes in the drainage area, discharge and leaching of nutrients and organic matter will increase, and the ice-free period will last for 9-12 months compared to the present length of 7 months. In 1991 three sets of factorial experiments in four limnocorals (diameter 1.9 m, volume 8.5 $m^3$) were carried out in Lake Pääjärvi, in Southern Finland. Physical and chemical changes as well as metabolic activity (respiration, primary production, bacterial production) and changes in the community structure (bacteria, phyto- and zooplankton) were studied every third day for 16-17 days of each experiment. In winter 1991-1992 the growth of phytoplankton and bacteria were measured in low temperatures and poor light conditions prevailing in the lake. The response of winter communities to increasing loads of nutrients and organic matter were also studied in the lake as well as in the laboratory. In summer and autumn allochthonus organic matter input increased bacterial production (34-72% compared to control), whereas in spring no increase was found. In primary production no change was found due to the addition of organic matter, but phosphate addition increased primary production (17-60%). The increased bacterial and primary production gave rise also to the production of zooplankton in those limnocorals into which phosphorus and/or humic matter was added. Both the summer as well as the winter experiments showed that the bacteria were heavily controlled by the heterotrophic flagellates and ciliates, and that the carbon bound by bacteria was efficiently transferred further in the food chain. The results support the hypothesis that increased nutrient and humic matter loadings from the catchment will accelerate the metabolic processes (primary production and mineralization) which may cause essential changes in the structure and functioning of freshwater ecosystems.

### 3.5.8 Effects of climate change, air pollutants and land use on lake ecosystems

The aim of the study is to quantitatively assess the possible climate change effects on hydrological, chemical and biological properties of lakes affected by different kinds of human activities, such as agriculture, forestry, and acid deposition. Mathematical models are applied and developed. The hydro-dynamical model applied so far is the PROBE-model. Recently a simple water quality model has been incorporated into it in Finland. But the description of nitrogen dynamics still has to be included and the modeling of phytoplankton growth must be improved. Special emphasis will be given to the modeling of the growth of harmful blue-green algae in lakes affected by agriculture.

The estimation of material fluxes will be done in co-operation with the catchment projects of SILMU. In lakes affected by agriculture the changes in runoff and nutrient inputs will be estimated with the HBV-model supplemented by a description of water quality. For predicting soil and water acidification, models like SMART can be used as a starting point. It needs to be complemented by a description of nitrogen dynamics. Two study areas are mainly affected by agriculture, two have a forested basin.

### 3.5.9 Effects of climate change on fishes, fish stocks, fisheries and aquaculture

The aim of the project is to produce knowledge about the possible effects of climate change on fishes, natural fish populations and ecosystems, and the prerequisites for aquaculture. The background hypothesis is that temperature will increase and the open water season will lengthen. In addition we expect that the thermal summer stratification will sharpen resulting in e.g. changed oxygen conditions in many lakes. Due to increasing winter precipitation the leaching will increase affecting water quality. Study area consists of about 25 water areas in Finland, both inland and coastal waters and some inland waters in Estonia and Lithuania and coastal waters in Sweden. The fish species selected for the study include: *Coregonus lavaretus, Salvelinus alpinus, Perca fluviatilis, Stizostedion lucioperca, Rutilus rutilus, Salmo salar* and *Salmo trutta*.

In its present state the study is divided into three subprojects: 1) The dependence of year-class strength and fish production on climatic factors 2) The effects of climate change on the reproduction of cultured fishes and 3) The effects of climate change on the possibilities to breed some salmonid fish species.

## 3.6 France

The French global change research is grouped into the French IGBP programme which encompasses the national participation of both IGBP and WCRP. It is coordinated by the Ministry of Research and Technology (MRT). The MRT has prepared an excellent overview of the French research within "Evolution of the climate and the global environment" from which the present information was drawn.

Six national scientific programmes currently cover essential fields of study: atmosphere, ocean and biomass. The insertion of this national effort into international programmes is ensured by the participation of French scientists in the international IGBP and WCRP committees. Each of the national programmes has its own scientific committee and inter-organization committee, or an ad-hoc committee that provides the liaison with the French IGBP executive committee and the French scientific committee.

The following (3.6.1.-3.6.6.) introduces the six national research programmes, with emphasis on research on biological effects of climate changes.

### 3.6.1 Le Programme National d'Etude de la Dynamique du Climat (PNEDC)

This programme was established in 1980, with the objective to improve the understanding of the mechanisms that define climate and control its fluctuations and, on a more long-term basis, to forecast future changes. It is focused on five themes:

1: Paleoclimatology

2: The carbon cycle.

The research is based upon several themes of which three are relevant for this Report:

• Assessment of $CO_2$ exchange between the atmosphere and the ocean. The objective of the field programmes is to measure the spatial and temporal variability of $CO_2$ exchanges and to identify the physical and biological processes which can explain the observed variability. The Indian and Austral oceans between 35°S and 45°S are a net sink of $CO_2$. As far as the instrumental domain is concerned, the development of an in-situ sensor for the continuous measurement of dissolved $CO_2$ is presently under way. Such sensors will be deployed on autonomous drifting buoys and the data will be collected through the Argos system.

• Continental biosphere-$CO_2$ interactions: development of methods allowing the spatial integration of the productivity of the terrestrial biosphere; extension of the studies of the effect of doubling the atmosphere´s $CO_2$ content on the productivity of forest ecosystems.

• Climatic impact of an increase in atmospheric $CO_2$: sensitivity experiments have been conducted with the general circulation model of the Laboratoire de Météorologie Dynamique coupled with a single oceanic boundary layer.

3: Participation in TOGA - Tropical Ocean Global Atmosphere Project/WCRP

4: Participation in WOCE, World Ocean Circulation Experiment/WCRP

5: Atmosphere This component concentrates the efforts on the first objective of the WCRP, i.e. in the description and simulation of the variability of the climate on monthly and seasonal time scales, and on the GEWEX (Global Energy and Water Cycle/WCRP).

### 3.6.2 Le Programme Atmosphère Météorologique et Océan Superficiel (PAMOS)

The main objective of this programme is to understand and define parameters for the energy transfer and transformation processes that determine, on small and medium scales, the variation of the atmosphere and the oceans, interacting on a larger scale with the meteorological and climatic changes.

### 3.6.3 Le Programme Flux Océaniques (France - JGOFS)

The prime objective of this multidisciplinary programme, which is a contribution to the international Joint Global Flux Study (JGOFS/IGBP) programme, is to understand the factors that govern the carbon cycle and that of the main chemical elements which interact with the living marine environment. Emphasis is on the role of the "biological pump" with respect to air-sea exchange of $CO_2$ and the transfer of particulate and dissolved organic carbon from oceanic mixed layer to deep waters and ultimately to the sediments where a small but unknown fraction of carbon is buried over geological time scale. France JGOFS is focused primarily on open ocean regions, whereas the coastal zone will be studied in the context of the new Programme National d'Oceanographie Côtière.

Three types of activities are currently in progress:

1. **Process studies** at the scale of ocean basins, which are integrated into the international JGOFS programme. These activities are based on oceanographic cruises, the use of remote sensing information and the development of models which take into account both physical and biological processes.

ANTARES(1992-1995), which is the French part of the international JGOFS-Austral programme, will operate as follows:

- in 1992, participation in campaigns on board foreign research vessels aimed to the understanding of the silica cycle and the determination of the factors that control the size structure of the pelagic ecosystem. These campaigns will allow the study of marine systems covered by ice pack which are not accessible to French ships.
- beginning in 1993, campaigns of the Marion Dufresne in the Southern Indian Ocean to study the open ocean and the Polar Front. Collaboration with Japan and Australia will allow the investigation of key temporal patterns, such as during late winter and early spring, which are poorly documented.

• long-term deployment (one-year) of multi-instrumented lines (particle interceptor traps, currentmeters, etc.) in each of the sub-systems of the Austral Ocean.

EUMELI (1989-1992) is presently studying the processes that govern the primary production of the North Tropical Atlantic for three zones covering a range of photo-synthetic activity which is representative of the World´s oceans. This programme involves five campaigns over three years. The long-term deployment of particle interceptor traps has already shown higher than expected temporal variability at the oligotrophic site (range 1-10). Biogenic particulate fluxes are on the average 5 times higher at the mesotrophic site, although at that site primary production is only twice that measured at the oligotrophic site. This confirms that the oligotrophic regime is dominated by intense regeneration processes controlled by microbial food webs.

2. **Flux studies** in areas characterized by strong physical and biological gradients such as continental fronts and margins. This implies 3-D mesoscale experimental and modelling approaches.

ECOMARGE is concerned with the flux of energy and matter in continental margins, which can act as a source and sink of material with respect to the deep ocean. FRONTAL aims to determine the role of oceanic fronts in the enhancement of biological production and export fluxes of organic material.

3. **Long-term marine environment monitoring** programmes at permanent stations. This approach has become an important activity in France-JGOFS. The implementation of such programmes will however require substantial effort in terms of human resources and field support.

ANTARFIX, to the South West of Kerguelen, in the Indian sector of the Austral Ocean, will be implemented in 1992. This station is part of the JGOFS time-series stations, and seasonal changes in carbon and silicia fluxes are being studied. DYFAMED, which began in 1986 in the Ligurian Sea aims at understanding the interactions between the biological cycle and air-sea transfer of materials.

A prospectus of this programme has been issued (in both French and English) by the Institut National des Sciences de l'Univers.

### 3.6.4 Le Programme Atmosphére Moyenne (PAMOY)

The change in the ozone layer, and its impact on climate and the environment are primary scientific issues approached by the PAMOY.

### 3.6.5 Le Programme Phase Atmosphérique des Cycles Biogéochimiques

The primary objective of this programme is to describe and quantify all of the production processes (primarily biogenic emissions) for chemically active substances in the atmosphere, and the transport and chemical reaction mechanisms in the troposphere. The main substances concerned are ozone, carbon compounds (methane and other hydrocarbons, soot carbon etc.) nitrogen compounds (nitrogen oxides, ammonia) and sulphur compounds (sulphur dioxide, dimethyl sulphide, sulphates, etc.) whose cycles are disturbed to varying extents by human industrial and agricultural activities. These changes can influence the radiation budget, and affect the oxidising capability of the atmosphere, and the supply of nutrient elements to terrestrial and aquatic ecosystems.

This programme is the French contribution to IGBP's International Atmospheric Chemistry (IGAC) programme.

### 3.6.6 Le Programme Ecosystèmes

The goal of this programme is to study the effect of increasing $CO_2$ and global warming on some major natural ecosystems (savannas and tropical forests, temperate grasslands and forests), in collaboration with the EFFET project at INRA (Institut National de la Recherche Agronomique), which is more focused on soils and cultivated areas. This project is the French contribution to the IGBP core project GCTE, and, in part, to BAHC (Biospheric Aspects of the Hydrological Cycle). It aims to establish simple models of the continental biosphere which can be used at the global scale, in relation with research undertaken within the PNEDC - programme. The three foci are:

1. Experimental studies of processes affected by global changes: photo-synthesis, respiration, evapo-transpiration, mineral nutrition, decomposition of organic matter.
2. Quantitative measurements within natural ecosystems: $CO_2$ and hydric exchanges, budget of carbon, water and nutrient elements.
3. Spatial extension of these measurements to the regional scale by using satellite data, land-surface maps and ecosystem models.

Five projects have been undertaken:

The "SALT "(Savannas A Long Term) project studies the response of the savannas to to disturbances of natural and anthropogenic origin (fires, land clearing, traditional cultivation, fallows, over-pasturing), their role in the hydric and gaseous ($CO_2$) exchanges with the atmosphere, and the effects of these changes on regional climate. This Franco-African project is carried out at several sites in the Sahelian region, along a transect of increasing aridity from the Ivory coast to Niger. It also involves the use of satellite data (vegetation index, surface temperature). This project will also be part of the HAPEX-SAHEL experiment which will investigate water vapour fluxes, in a 100 $*$100 km area in Niger, for different vegetation coverages.

The "Processus et formations herbacées" project studies the functional responses of several gramineous and leguminous species to enrichments in $CO_2$ with or without changes in temperature or water availability. It is based on experiments using thermostated chambers and the modelling of the observed responses, and on field measurements in natural grassland ecosystems.

The "Ecosystèmes forestiers tempérés" project consists of the three foci described above: process studies, experimental studies and modelling of temperate forest ecosystems and spatial integrations. Interesting results have been obtained with respect to several processes: strong interaction between nitrogen cycling and $CO_2$ enrichment, decrease of respiration when air is enriched in $CO_2$, effect of the faunas in soil on the decomposition rate of dead leaves which grew in air enriched in $CO_2$. In the Landes region (Southwestern France), water vapour flux measurements above the forest canopy have been complemented by $CO_2$ flux measurements which are most useful for testing models of the carbon budget. The first attempts of spatial extension of data have been performed with reflectance measurements in the middle infra-red, on board aircraft. These measurements are used to estimate the nitrogen and lignin contents of leaves which control the decomposition rate and the cycling of nitrogen.

The objective of "ECOFIT" (ECOsystèmes et paléoécosystèmes des Forêts InterTropicales) is to study the variations in the spatial extension of intertropical forests since the last glaciation. The hypothesis is that the changes in precipitation patterns and temperature (2-3°C) over the last 10.000 years have caused declines and extensions in forests which can be evidenced by several tracers in soil and lacustrine sediments. This project will evaluate these tracers at several sites in order to provide a scheme of the evolution of the vegetation in a given region. Such a scheme will be more presicely defined from studies of the relationships between climate and ecosystems for the present times. The project started in 1991 and includes about ten French laboratories: Institut Francais de Recherche Scientifique pour le dévloppement en Coopération (ORSTORM); Centre National de la Recherche Scientifique

(CNRS), Muséum d'Histoire Naturelle, and about ten French research teams which offer technical support to numerous foreign teams (mainly in Brazil, Cameroon, Congo and Gabon).

The "Paléocarbone Continental" project started in 1991 and aims at the reconstruction of vegetation maps since 18.000 years BP over Eurasia and Tropical Africa. The data being used are pollen records (most of them already exist) archived in a central databank in Marseille. These maps will be used to calculate carbon storage in plants, and, if possible in soils.

## 3.7 Germany

In Germany, the global change research is not coordinated through a central programme, yet there is a substantial amount of activities on the field coordinated by the national IGBP council and sub-committees. An inventory of projects relating to the GCTE on national level is underway, but not yet finished. The major biological research relating to climate change is within TERN (the Terrestrial Ecosystem Network of Germany)[2]. TERN is a network of five ecosystem research centres , which was founded and are supported by the German Federal Minister of Research and Technology. The five research centres are:

- Bayreuth Institute für Terrestrische Ökosystemforschung (BITÖK)
- Forschungszentrum Waldökosysteme (FZW)
- Projectzentrum Ökosystemforschung
- Forschungsverbund Agrarökosysteme München (FAM)
- Verbundprojekt Agrarökosysteme Halle (VAH)

TERN submitted in November 1991 an application for a multidisciplinary project to be accepted as GCTE National and Core Research Project. The proposal was approved by the GCTE Scientific Steering Committee shortly after. The coming information was drawn from this application.

The following three research projects relates to GCTE, with main emphasis of GCTE focus 1 (sec 2.1.1).

### 3.7.1 Effects of increasing $CO_2$ concentrations on plants and terrestrial ecosystems

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[2]Attempts to compile information on German marine climate research was unsuccessful. This does not mean that such projects are non-existent.

The reason for emphasizing experiments on the effects of $CO_2$ is based on the fact that $CO_2$ concentrations are expected to double within the next 50 years, which is half of the lifespan of a tree in cultivated forests of Europe. Despite of this short-term perspective of change, it is quite unclear what effects this will have on growth of plants and on carbon and nutrient cycles in ecosystems. Speculations range from higher productivity and improved water use efficiency, to changes in herbivory, plant defense and decomposistion as a result of changed C/N ratios. It is expected that rising $CO_2$ levels will have profound influences on ecosystem structure as a result of changing plant competition, but we really cannot predict what direction these changes will take. It is intended in this project to carry out experiments using an integrated system of open top chambers and FACE technology. This will be in Munich in a crop rotation using corn, wheat and potato.

It is quite clear that changes in $CO_2$ will affect the water relations and the biogeochemical cycles. It may also affect agricultural land use. On a global scale the important question remains unanswered, if temperate managed forests act as carbon sink and if agricultural productivity will increase with rising $CO_2$.

**Objectives:**

- to determine and to predict the effect of elevated $CO_2$ on temperate forest ecosystems
- to determine and to predict the effect of elevated $CO_2$ on agricultural ecosystems and crop rotations.

**Research tasks:**

**Task 1**: Responses of single plants or leaves
- Gas exchange of plant in $CO_2$ enriched environments and in the presence of other gases like $O_3$, $SO_2$ or $NO_x$ (GSF exposition chambers and cuvettes).
- Growth of different plants and genotypes under conditions of $CO_2$ enrichment (GSF exposition chambers) and at different locations.
- A separate project has been submitted to the German Science Foundation in which the physiology and biochemistry of elevated $CO_2$ will be studied in a network of research laboratories throughout Germany.

**Task 2**: Gas exchange of presently existing vegetation
- $CO_2$ exchange of ecosystems at present $CO_2$ levels in relation to soil conditions and along climate gradients in Germany.
- Development of ecosystem carbon models

**Task 3**: Responses of terrestrial ecosystems to elevated $CO_2$

- Field studies under $CO_2$ enriched atmosphere (FACE experiments). This experiment shall be carried out at two sites:

a) Enrichment in a forest ecosystem: This experiment will be carried out in NE Bavaria which has a very continental climate and contains ecosystems which are similar in their vegetation to boreal forests as well as forests typical of the temperate zone. There are two options for the experimental site: 1) a mixed *Fagus/Picea* natural regrowth (25 years old, 10 m high) or 2) a boreal type Pine forest (10 years old, 8 m high). At this stage of technology we like to avoid very old and very young stands because of technical difficulties in sampling and in maintaining elevated $CO_2$ in old stands, and because of heterogeneity in very young stands. Therefore, the study will be performed in a young even-aged managed forest with closed canopy, and processes might be different in very old or very young forest stands. The broad leaf-conifer comparison would allow predictions on competitive interactions of these important tree structures.

b) Experiments in an agricultural crop rotation, including wheat, corn and potato: The experiment will be carried out close to Munich, which is similar in climate to the forest experiment. This experiment is planned within the framework of a large-scale investigation on the nutrient cycling in agricultural crops under different intensities of agricultural management.

The experiment is embedded in an international experiment of the EEC, namely the CLIMEX (see 2.7.1). The greenhouses used in that experiment will be used for studies on elevated $CO_2$ in a watershed including labelling with $^{15}N$.

The German FACE experiment should act as an initiative at the EEC to start additional research on carbon input-output budgets in terrestrial ecosystems in the framework of Concerted Actions (COST, see 2.8). In this framework it will be possible to make the connection to open top chamber work. In order to make the FACE experiment truly international, BITÔK will provide support for international guest scientists.

A cooperation with the Stanford Jaspers Ridge Project is intended and help will be needed with respect to remote sensing techniques for biomass.

### 3.7.2 Regulation of the energy- and water-exchange of vegetation surfaces

**Objectives:**

- Determine maximum canopy conductances for different plant communities
- Investigate the regulation of canopy conductance by climate, soils and soil condition
- Account for patchiness
- Develop canopy conductance an SVAT models based on plant physiology, climate and soils
- Validate SVAT models using long-term observation plots of agricultural and forest ecosystems.

**Research tasks:**

**Task 1**: Measurements of canopy transpiration by xylem flow and eddy correlation.

- Seasonal xylem flow measurements of coniferous and deciduous canopies
- Comparison of xylem flow with eddy correlation techniques and soil water models
- Investigation of the effect of patchiness (forest edge effect)

**Task 2**: Determination of canopy transpiration of agricultural crops using soil water budgets, isotope and micrometeorological methods.

- Daily and seasonal water flux measurements of crops in rotation agriculture
- Comparisons of different methods, including spectral vegetation indices and remote sensing
- Effects of slope aspect, inclination and advective energy inputs

**Task 3**: Development of SVAT models as a joint project with BAHC

- Development of SVAT models on different scales
- Development of regional SVAT models controlled by remote sensing data
- Validation of SVAT models using long-term observation plots

The research on canopy conductance and SVAT will have the following design:

- Bayreuth will measure xylem flow of various forest species and growing conditions
- Göttingen will compare xylem flow and eddy correlation measurements in differently managed forests (fertilized, thinning)
- Kiel will integrate canopy transpiration to the landscape level (part of BAHC)

- Munich and Halle will measure water use of agricultural crops in relation to management using a spectrum of methods
- International cooperation already exists with New Zealand and with the USSR. It is planned to carry out measurements on canopy conductance in the Siberian tundra together with the NZ and the USSR groups.

### 3.7.3 Regulation of the biogeochemical cycles of C, N, S and P by global change

Existing activities:

• Input/output studies of biogeochemical cycles have a long history in Germany. One of the first nutrient budgets worldwide started in 1966 in the framework of IBP in the Solling area. The same forest stand has been observed since then and has supplied important information about soil acidification processes in Germany as a result from acid depositions.
• The Göttingen Ecosystem Centre maintains several forest sites for inpu/output studies in North Germany. These cover the full range of forest types and soil conditions. The studies range from plot to water shed scale. In addition to these input/output studies, more detailed research on nitrogen transformations in soils is being carried out at Bayreuth. The integration to landscape levels, including interactions of terrestrial ecosystems with surface waters is already performed at Kiel in North Germany.
• The research in activity 3 is closely linked to existing EEC projects, in which soil columns are exchanged and exposed to different climates (CORE project, participant Munich) or standard plant material is exposed for decomposition (DECO project, Göttingen and Munich). In addition, the EXMAN participation of Göttingen attempts to manipulate nutrient cycles by exchanging acid rain with clean rain and by imposing drought (roof study), while the NITREX manipulated forest ecosystems at Göttingen become nitrogen saturated. The Göttingen Ecosystem Centre also manages the data bank of the European network of watershed studies (ENCORE). Bayreuth coordinates the Nitrogen Physiology (NiPhys) Project, a study of nitrogen transformation.

**Objectives**:

• Measure and model C, N, S, P and cation cycles in coniferous and deciduous forest ecosystems as well as in agricultural systems on different soil types (continuation of long-term budgets which range back to 1966) and different climatic conditions.
• Investigate the transformation of nitrogen ($NH_4$, $NO_3$, $N_2O$, $N_2$) in forest trees and soils along an environmental gradient from North Sweden (Umeå) to Southern France (Montpellier).
• Study the rate and form of decomposition of soil organic matter and plant residues.
• Investigate the C, N and S transformations using stable isotopes in different soil under different management conditions.
• Model of C, N and S turnover with modified SVAT models.

**Research tasks:**

**Task 1:** Input/output budgets of forest and agricultural ecosystems

- Measurements of nutrient budgets in water sheds
- Measurement of deciduous and coniferous forest nitrogen budgets
- Measurements of nutrient budgets of agricultural systems and watersheds under conditions of crop rotations

**Task 2**: Transformation of nitrogen in forest trees and soils

This task will investigate the fate of ammonium and nitrate and the associated nitrification and denitrification processes in forest soils because they have primary importance for all other nutrient fluxes. This task is part of the NiPhys project which is coordinated by the Bayreuth in the framework of EEC research. Research sites range from North Sweden to Southern France. Only the Bayreuth contributions to NiPhys are listed

- Investigation of Nitrate reductase activity
- Measurement of $^{15}N$-values along a gradient of pollution
- Denitrification in relation to climate and soil conditions

Absorption and immobilization of deposited nitrogen

**Task 3:** Changes in C, N, S and turnover in transplanted cores of agricultural soils of different origin along a climatic transect through Europe

- Decomposition pattern of soil organic matter
- Decomposition of $^{13}C$, $^{15}N$ and $^{34}S$ labelled plant residues
- Changes in microbial and faunal activities
- Gaseous and leaching losses of C, N and S compounds.

**Task 4**: Management effects on C, N and S turnover in agricultural soils (tracer studies)

- Effects of reducing tilling on C, N and S dynamics in soils
- Organic and inorganic fertilizer effects on C, N and S dynamics
- Management effects on gaseous losses and leaching
- Effects of rotation and intercropping on C; N and S turnover

**Task 5**: Modelling

- Develop models of nutrient cycling which include canopy processes of water and energy exchange
- Regional models of landscape evapotranspiration

## 3.8 The Netherlands

The Netherlands has two programmes relevant for climate change: 1) The Global Change Research Programme (VVA) governed by the Netherlands Organisation for Scientific Research (NWO) and 2) the National Research Programme on Global Air Pollution and Climate Change (NOP) which is a government programme funding research projects within both governmental and non-governmental institutions.

Most of the relevant projects are part of one of these two programmes, and an overview of such projects including titles and contactpersons was kindly provided by Hans de Boois, secretary for both global change programmes. Individual scientists within nine projects were requested for short descriptions, of which 8 were provided and these are presented below.

### 3.8.1 An investigation on the physiological response of plants to elevated $CO_2$ in the atmosphere, with emphasis on root physiology

In this project the effects of elevated levels of atmospheric $CO_2$ on the physiology of species from natural vegetations are studied. Effects on root functioning and below-ground processes are emphasized. The central issue is whether roots contribute to the response of whole plants to an increased $CO_2$ concentration. Growth and allocation of dry matter to the roots are studied under carefully controlled growth conditions. As the uptake of water and nutrients are important root functions, the $CO_2$ effect on their acquisition by the roots is investigated. In order to provide a basis for extrapolation to possible effects in natural ecosystems, interactive effects of increased atmospheric $CO_2$ with other environmental factors have to be taken into account. Therefore, the interaction of $CO_2$ and nitrogen or water stress are included in the present project. So far two species, *Plantago major* and *Urtica dioica*, have been used in the experiment. In future experiments, other more slowly growing species will also be included.

The project is a Ph. D. project and part of the NWO Global Change Programme.

### 3.8.2 The seasonal cycle of the $CO_2$ exchange between atmosphere and vegetated surfaces

The existing carbon cycle model WCCM2 operates with annual time steps, and does not consider the precise seasonal and diurnal pattern of $CO_2$ exchange. This study will emphasize these cycles while retaining the final result of the net annual exchange rate. To this end an existing simulation model for crop growth (SUCROS) will be utilized as a basis, in combination with other models for carbon dynamics in the soil (CENTURY). The model will first generate the diurnal cycle to obtain the net daily assimilation rate, and daily soil respiration. These daily rates follow a seasonal cycle, and will generate a net annual uptake. The net annual uptake of the above ground vegetation is called the Net Primary Productivity.

Factors such as green soil cover, progress in the growing season on the basis of accumulated temperature, soil wetness, partitioning of assimilates between plant organs and root dynamics will be considered. Respiration rate of plant and soil will be modelled on the basis of temperature, biomass and growth rate.

The model has the potential to drive a 3-D model for atmospheric $CO_2$ content, first to generate a diurnal cycle in the vertical profile, second to obtain net $CO_2$ exchange rates of a region on a seasonal basis. However, for this purpose anthropogenic sources must almost certainly be taken into account. If possible, the dynamics of carbon isotopes will be included.

### 3.8.3 Distribution of carbon over plant and soil compartments during the growth of perennial plants at elevated atmospheric $CO_2$ concentrations

The terrestrial ecosystem plays a major role in the global carbon cycle. It acts both as a source and a sink of carbon. Carbon is fixed photosynthetically in plant biomass and is subsequently transported to soil through litter fall and root turnover and is released to the atmosphere through plant and soil respiration. Since carbon stored in soil has much longer resident-times than carbon in the above-ground biomass, the translocation of carbon to the soil and the turnover of soil organic matter are of prime importance of the fate of carbon in terrestrial ecosystems. The aim of the project is to get a better understanding of the translocation of carbon via roots of perennial plants (i.e. coniferous trees and grasses) to the soil, and the dynamics of this and native soil organic carbon under conditions of elevated $CO_2$ concentrations in the atmosphere and increased temperatures. Carbon transport in a plant/soil system will be studied with different soils, soil nutrient status and different temperatures in growth chambers using $^{14}CO_2$. Also the decomposition of plant material grown under 350 and 700 ppm $CO_2$ will be followed in time. This information is needed to predict the future role of terrestrial ecosystems with regard to the global carbon cycle.

The project is part of the Dutch National Research Programme on Global Air Pollution and Climate Change (NOP).

### 3.8.4 Quantification of carbon fluxes in grasslands

The terrestrial ecosystem is an important component of the global carbon cycle. The reservoir in vegetation and soils is estimated to be approximately 2000 Pg C and the current annual exchange between the atmosphere and the terrestrial ecosystems to be roughly 100 Pg C. Photoassimilated C is distributed over all plant parts including roots. Via translocation and root turnover (including exudation) and litter fall, organic C enters the soil where it is transformed by soil biota into a wide variaty of compounds or returned to the atmosphere as $CO_2$. Decomposition of (soil) organic matter and respiration of the vegetation are the major contributing processes of $CO_2$ output from terrestrial ecosystems to the atmosphere. Elevation of the $CO_2$ content of the atmosphere is expected to increase primary production. This may change the rate of subsequent processes in soil, such as mineralization of nitrogen as well. Information of the C dynamics in (semi-) natural ecosystems is scarce. Since grasslands are one of the most productive and important vegetation types in terms of C-fluxes, the main objective of this project is to quantify the C-fluxes in (perennial) grasslands under field conditions with the $^{14}C$ pulse-labelling technique. The information will be used for the development and testing of simulation models on C-dynamics. These models will on a regional scale link detailed data on basic processes and mechanisms with global circulation type studies.

The research is part of the Dutch National Research Programme on Global Air Pollution and Climate Change (NOP) and includes scientists from three Dutch Institutes (the Institute of Soil Fertility Research, Agricultural University, and Energy Centre Netherlands) as well as the University of Alaska.

### 3.8.5 Effects of increased $CO_2$ levels and temperature on plant production and plant biomass turnover

This project is part of the CLIMEX programme (see section 2.7.1). In two of the three headwater cathment enclosures, both $CO_2$ and temperatures will be raised. The programme will contain studies on $CO_2$ utilization by plants, plant nutrient status, plant productivity and biomass turnover, soil/soil solution chemistry, soil organic matter dynamics, soil fauna, stream water chemistry and hydrological processes. The present project on plant productivity and biomass turnover will study the effects of elevated $CO_2$ and temperature on the growth of *Calluna vulgaris* and *Vaccinium myrtillus* and of the lifespan of leaves and roots of these species. Special attention will be paid to the effects of the different treatments on the chemical composition (e.g. lignin, cellulose and starch concentrations) in plant tissues and their consequences for litter decomposition and grazing by phytophagous insects.

### 3.8.6 Effect of doubling atmospheric $CO_2$ on the water balance of forested land surface

The project aims to evaluate the impacts of climatic change and the change in $CO_2$ on the water consumption of forests. Hydrological changes, such as an increase in droughts or flooding will be caused by changes in temperature, precipitation pattern and also by the changes in water use of the vegetation. Not only the effects of change in climate, but also changes in plant physiology are to be taken into account. Forest is selected as ecosystem for detailed study as it uses a lot of water, relative to agricultural vegetation. A physically based, time dependent, one-dimensional model is used to investigate the possible changes. The influence of the different parameter in the system will be analysed, but also climate scenarios are used to analyse the possible impacts. The model will be calibrated on different forests. Data are available of 3 coniferous, 1 deciduous and 1 mixed forest-site in Europe.

The research is part of the Dutch National Research Program on Global Air Pollution and Climate Change, which is sponsored by the Ministry of Housing, Physical Planning and Environment and organized by the National Institute of Public Health and Environmental Protection (RIVM).

### 3.8.7. Phenological reactions of the main Dutch tree species to climate change described by a simulation of the annual cycle.

Climatic change and air pollution are changing site conditions for growth of trees and forests. The reaction of tree development to these changes may consist of changes in growth, and changes in phenology and the annual cycle of growth and development. Susceptibility to this differs between species, and depends on possibilities for adaptation. The project aims at understanding and modelling tree phenology and primary production for the main tree species in Netherlands, under various scenarios for climate change. The range of species studied includes Scots pine, Douglas fir, Norway spruce, Japanese larch, pedunculate oak, red oak, beech, and birch. Primary production models, based on carbon balance for the whole forest stand, are available to analyse the effect of climate change on growth; these models are combined with elementary models describing phenological development in relation to environmental factors. The combined model is used to quantify effects of changed site factors, both separate and in combination, on growth and development of individual tree species as a first approximation of forest ecosystem response to climate change. The advantage of using dynamic simulation models to study such interactions, lies in the opportunity to quantify individual component processes and to integrate them within an ecosystem context. Thus, the models can be used to scale up from the level of the individual physiological process, through individual plant response, to ecosystem phenomena over time-scales beyond the scope of experiments.

This project is part of the NOP. Five scientists within tree institutes are involved in the project (Inst. for Forestry and Nature Research, NL; Wageningen Agric. Univ, NL; Univ of Uppsala, Sweden), and it is planned to last for 4 1/2 years (1990-1994).

### 3.8.8 Regional climate change and its effect on forest productivity

This is a joint project between IIASA (International Institute for Applied System Analysis), RIVM (National Institute of Public Health and Environmental Protection) and the Swedish University of Agricultural Sciences. It is budgeted for 1993, but depending on the results generated, it may be extended.

The objective of the study is to generate a first assessment of the effects of climate change on European forest resources.

The focal points of research are as follows:

• Modification of the Integrated Model to Assess the Greenhouse Effect (IMAGE) to produce regional scenarios of temperature and precipitation. This will be done by incorporating into the system a Two-Dimensional Energy Balance Model.

• Modification of the Forest Assessment Model (FAM) to consider the effects of climate changes.

• In order to do this the effect of eco-physiological parameters will be estimated. This is carried out as a specific sub-task.

• Analysis of the long-term consequences for European forests in a set of different greenhouse gas emission-scenarios.

• Formulation of policy recommendations, based on the results presented above.

## 3.9 Norway

In Norway the majority of climate related research is financed through the "Climate and Ozone Research Programme" administered by the National research council for science and humanities (NAVF). However, studies on biological effects of climate changes have been given low priority in the programme. In spite of this, there are several relevant projects currently running. In order to initiate GCTE research and to get an overview of GCTE-related activities in Norway, the Norwegian IGBP Committee invited scientists from the universities and research institutions to a symposium in Oppdal, in March 1992. All of the participating scientists were subsequently contacted in order to collect information for this survey. Several scientists within relevant institutions were contacted in addition to those attending the "Oppdal-meeting", in order to provide a broad coverage of the relevant activities, including marine research. An overview of the relevant projects are given in the following:

### 3.9.1 Effects of high $CO_2$ concentrations on different horticultural and agricultural crops at various soil and climate conditions

Project period: Medio 92 - Ultimo 95.

The objectives of the project are to study the effect of increased $CO_2$ concentrations on:
- the growth, yield and quality of some important grasses and cereals.
- the growth, yield and quality of some important horticultural crops
- the growth at different soil types, and at different water and nutrient supplies
- the water consumption of plants
- the growth at different temperature regimes.

In 1992 an experiment with carrot, Chinese cabbage, onion, leek, parsley, celery, timothy grass, rye-grass, oat and barley has been carried out in 12 open-top chambers in the field. Each chamber had a ground area of 6-8 $m^2$ and was surrounded by 1.8 m high walls made of plastic foil. $CO_2$ was supplied through perforated tubes at the bottom of six of the chambers and a level of about 600 µmol mol $^{-1}$ was maintained. The $CO_2$ concentration, $O_3$ concentration, global radiation, precipitation, air and soil temperature, and air humidity were recorded continuously during the growth season.

### 3.9.2 STEP (Scandinavian Terrestrial Ecosystem Profile) - an all-Scandinavian terrestrial climate change research programme

Project period: 1993-1998 (?)

The primary aim of the study is to connect contributions from various observational, experimental and modelling activities (performed by independent groups) into a unified, spatially explicit information system for the prediction of terrestrial ecosystem change forced by climate change. Providing a conceptual core for a series of specialized subprojects, STEP will provide starting point, data exchange facility and synthesis tool for several independent activities, including aspects of both ecology, climatology and soil science.

STEP should operate at four different spatial scale levels; patch, landscape, transcontinental transect, and Northern European grid. Intensively studied research sites would involve studies of plant distribution limits and experimental impact studies at a "patch" level and detailed stand ecosystem modelling at a "lanscape" level. These sites could include sites previously studied or monitored, and they would allow individual, local ongoing projects to be connected to the overall STEP initiative. Two major transects, from the High Arctic (Svalbard) to the Nemoral Zone (Skåne), and from the hyperoceanic (Møre) to the continental Boreal Zone (Karelia), would connect the intensive sites to a geographical network following the two dominating macroclimatic gradients.

Along the transect, model predictions about climatic limits for species and ecosystems will be checked and calibrated. Full spatial coverage of model predictions would be achieved using GIS technology, involving high resolution (1∗1 km) databases on abiotic ecosystem components, such as present-day climate, soils and topography, and on human land use systems. Maps and quantitative databases will be constructed for predictions based on climate change scenarios and scenarios for key ecosystem processes.

### 3.9.3 Bioclimatic limits for plant functional types in Europe

Project period: 1992-1994.

In this project we propose to further develop and use bioclimatic models, implemented in a GIS structure, to analyze and predict equilibrium distributions of plant species and plant functional types. Although this must largely be based on "correlative" methods, special attention will be paid to the development and testing of mechanistic hypotheses about plant/bioclimatic relationships. We will study ecosystem implications of global climatic change in two spatial frameworks; i) for Europe, based on approx. 50∗50 km grid, and ii) for Norway, based on a finer grid. On both levels, good biological and climate databases are available, and the proposed studies will provide the necessary complement to both global and more local studies. Distributions of plant species of functional types will be correlated with bioclimatic variables to achieve physiology-based predictive models which can be used for predictive scenarios.

As a second step we propose the development of the essential structural elements for a dynamic ecosystem simulator. Important processes to be covered by this are competitive between-species relationships, disturbance regimes and successional trends. Within an international research network several conceptual developments now emerge which we will pursue and integrate into the framework developed from earlier correlative model.

### 3.9.4 Effects of rapid climatic change on plant diversity in boreal and montane ecosystems

Project period: 1992-1995.

Biodiversity, defined as the number of species present in a landscape, can be diminished by rapid climatic change if species either do not have a sufficient area of potentially suitable new habitat to which to retreat, or if poor dispersal prevents them from reaching their new habitat in time. Enhanced greenhouse warming will, in the next century, diminish the extent of boreo-alpine habitat. A similar reduction occurred under the Holocene thermal maximum. This project will determine the extent of these readjustments in four 20-km mountain squares, situated in Norway, Scotland, western Alps and Appenino Abbruzese, and will assess their consequences for local biodiversity. The vegetation of each square will be mapped from multidate satellite images. Methods developed for global biome modelling will be applied to the study sites; the link between continent-wide bioclimatic drivers and local climatology will be strengthened. Flora and vegetation will be interpreted in terms of a typology of plant functional types developed for global studies. Biodiversity will be related to species abundance curves within plant functional types for broadly defined biotopes, coupled to an estimate of the abundance of biotopes. Altitudinal limits of species in the mountains will be related to their geographic limits at the continental scale. Predictions of biodiversity based on reconstructions of past climate at the continental scale will be verified by macrofossil analysis of sedimental cores. In particular, we shall seek to quantify the magnitude of the bottleneck at the thermal maximum. Predictions for the future will be based on GCM scenarios of climate change coupled to spatially explicit models of the 20-km study squares using a combined GIS-modelling approach.

The project includes participants from Norway, France and the U.K.

### 3.9.5 Production of greenhouse gases from biological processes in soil

Project period: 1992-1996

The goals of the project are to quantify emissions of the greenhouse gases $CO_2$, $CH_4$, and $N_2O$ from the terrestrial compartment and to determine mechanisms and factors influencing the gas emissions.

Biological processes are among the most important sources of greenhouse gases, in particular the gases methane and dinitrogenoxide. The gases are normal metabolites ($N_2O$) or end products ($CO_2$ and $CH_4$) in microbial conversion of mineral and organic nutrients. Different physio-chemical characteristics determine the gas release, i.e. water and oxygen, availability of microbial nutrients as ammonia/nitrate, and available organic carbon. These factors are influenced by human agriculture and forestry, where soils are treated with fertilizer, irrigation and tillage. Pollutants that affect normal microbial activity and possibly gas production are also studied.

Thus, background gas emission levels and emissions after different treatment are monitored from undisturbed soil columns (Ø50∗12 cm) taken from different soils (silt, clay and organic agricultural soils and acid forest podzol). Soil columns are placed in chambers at different temperatures and exposed to different treatment: irrigation, pollutants, commercial and manure fertilizer. Gas samples are collected with a static chamber technique and analysed on a gas chromatograph.

Increased soil temperature caused by enhanced greenhouse effect might increase microbial production of greenhouse gases. Together with a more frequent summer rain, which also probably enhances gas production, this is an important feedback mechanism that has to be taken into consideration.

### 3.9.6 Effects of climate change on growth and development on northern landscape plants

The great variation in climatic conditions in Norway and the fact that many plant species have their northernmost distribution in this part of the world, create the ideal background for studying the effect of global warming on natural and planted vegetation in arctic and northern temperate regions. The growing season ranges from less than two months in the north with continuous and an average temperature of 10-12° C, to more than 7 months in the south with daylengths varying from 12 to 18 hours and with an average temperature of 15-17° C. In addition, the maritime climate in the west and the continental climate in the northeastern mountainous parts exhibit great differences in temperature.

During the last 15 years experiments have been carried out under controlled climatic conditions in a phytotron and in regional field stations at 5-8 different locations in Norway to study the responses of maritime, continental, temperate and arctic ecotypes to climatic and edaphic factors. So far, adaptations to the following environmental factors have been found:

1. Climatic factors: light intensity, light quality, photoperiod, temperature, chilling requirement, air pollution
2. Edaphic factors: soil pollution, nutritional status, heavy metal tolerance.

### 3.9.7 Winter dormancy and climate change relations in boreal forest trees

Project period: 1989-1995.

The aim of the project is to provide an increased physiological understanding of temperature and daylength regulations of bud dormancy release and regrowth in boreal forest trees for the prediction of their vulnerability to winter damages following climatic warming.

The problem is approached by the combination of studies in natural and controlled (phytotron) environments. Both detached twigs (cuttings) and intact small trees are being used. Studied species are: *Betula pendula, B. pubescens, Alnus incana, A. glutinosa, Fagus sylvatica, Populus tremula, Prunus padus* and *Picea abies.*

Particularly, the course of the dormant state in nature has been studied to determine the actual time of dormancy release and the heat sum (thermal time) requirements for bud burst at various times throughout the winter season. Also, the efficiency of various low temperatures, and the temperature limits for dormancy release is being determined. The interaction with daylength (which, of course, will not change with global warming) in these processes is highlighted. The variation among geographical (latitudinal and altitudinal) ecotypes will be the subject of further studies.

The results underline the quantitative nature of bud dormancy; it is a physiological state that is gradually acquired and released. Accordingly, the heat sum requirements for bud burst change systematically during the winter. The modifying effect of daylength varies drastically among the studied species. Due to this fact and to considerable differences in low temperature requirements for dormancy release, the species exhibit considerable variation in winter stability and, accordingly, in their vulnerability to late frost in a mild and unstable winter climate. Some, like the *Alnus* species, and to some extent the birches and Norway spruce would seem rather vulnerable to an increase in winter temperature of the order predicted by the IPCC and others.

### 3.9.8 Genetic stability studies in order to evaluate the greenhouse effect upon evolution and tree breeding

Project period: 1991-1993.

This project is a joint effort of scientists from Finland, Sweden and Norway. Norway spruce *(Picea abies)* is object for the studies. Following is a summary of the Norwegian results:

The project deals with the ability of trees to stand warm winter weather without being damaged. Genetic components in such a study are provenances, variation between stands within provenances, progenies from different trees as well as controlled crosses within and between different populations. Components to explain why winter damage occurs or is avoided could be knowledge to winter photosynthesis by different temperatures and light conditions, respiration, transpiration, and loss of hardiness (dormancy). The mentioned components are expected to be more or less correlated. The study has accordingly concentrated upon measurements of different genetic materials and their loss of hardiness related to periods of warm winter weather under normal light conditions.

A total of 50 controlled crosses, including ten parent trees of eastern European origin and ten trees of southern Norwegian origin, have been subject for the study. Cuttings from eight trees within each of the 50 crosses have been taken regularly through the winters and put into growth chambers at different temperatures varying from + 9°C to +15°C. After periods varying from 16 to 7 days, the material has been subjected to freezing tests at temperatures from - 13°C to - 25°C.

The statistical analyses show distinct genetic differences between crosses to stand warm winters followed by cold March or April weather. The heritability is mainly additive and covary with the ability of the particular cross to maintain dormancy in spite of warm winters. Eastern continental materials, earlier selected for high winter hardiness and ability to respond slowly upon warm spring weather, have shown the best results. Spring flushing data can be used to predict winterstability in warm winters if the deepness of winterdormancy induced in autumn is not widely different. Through more than 30 years, forest geneticists in several countries have accumulated knowledge about genetic variation in spring flushing, late frost hardiness, growth cessation, early frost as well as winterfrost resistance under different environmental conditions. This knowledge is valuable to explain what would be the possible effects of a climatic change leading to warmer winters for Norway spruce.

### 3.9.9 Possible effects of climatic changes on the ecology of Norwegian Atlantic salmon (*Salmo salar* M.)

Project period: 1991-1992.

Increases in the greenhouse gases corresponding to a doubling of the $CO_2$ content of the atmosphere is expected to occur around 2030. The most likely scenario indicates a temperature increase of 1.5 to 3.5° C in Norway, mainly due to changes in winter temperature and particularly in inland areas. The precipitation is expected to increase by 7 to 8 per cent. The winter runoff will increase manifold, while the summer runoff will decrease. The spring flood will be considerably reduced in rives in western and central Norway. Water temperature will increase, except in winter in rivers which will continue to have an ice cover.

Possible effects of the climatic changes on the ecology of Norwegian Atlantic salmon are predicted, the salmon population in two Norwegian rivers are used as case studies. Hatching of eggs will be accelerated, and the initial feeding time for alevins will occur earlier in spring. Due to changes in water temperature and water flow regimes, the initial feeding time may be a critical period in many salmon rivers.

Growth and survival of presmolts are expected to increase, and smolt age will decrease. Hence, smolt production will probably increase considerably.

Altered temperature and flow regimes in rivers may change the timing of smolt runs. The smolt run may be less concentrated in time, schools will be of smaller size, and predation from marine fish species will probably increase. Hence, survival from smolt to adult is expected to be lower than today.

In the ocean the change in climate may affect distribution, total salmon production, as well as sea age at maturity of the salmon.

The upward migration of adult salmon is expected to be easier in early summer, while in late summer droughts may more frequently prevent salmon ascent. Reduced spring peak flow may probably select for a smaller salmon size in Norwegian rivers than today.

### 3.9.10 Effects of climatic changes on the biomass yield of the Barents Sea, Norwegian Sea and West Greenland Sea

Project period: 1991-1994

Biological effects associated with a particular climatic event, the large temperature/salinity anomaly in the North Atlantic are considered. The climatic anomaly is briefly described, from its initiation in the East-Greenland area during the 1960s to its appearance in the Barents Sea around 1980. Large scale biological effects were first observed in the stock of Norwegian spring spawning herring which changed its migration pattern in the Norwegian Sea and showed reduced reproduction. In West Greenland waters a drastic reduction in the cod stock occurred simultaneously with a temperature decrease. In the Barents Sea, perturbations were recorded on several levels of the food chain, and the stocks of capelin, herring, cod and harp seals were strongly affected. A similar ecological event, under similar climatic conditions, occurred in the Barents Sea just after the turn of the century.

### 3.9.11 Influence of climate variations on fish stocks in the North Sea

Project period: 1990-1992

The objective is to study the influence of heat flux and volume flux variations into the North Sea on the fish stocks in the region. The study includes both the influence on adult stages and early stages. Climate influences the production in fish stocks both directly and through phytoplankton and zooplankton production. A numerical model describing larval drift has been developed.

### 3.9.12 Climate variations of the Barents Sea and the effects on juvenile growth

Project period: 1990-1993

There is a strong relation between growth of fish stocks in the Barents Sea and the general temperature conditions in the region. In this project the relation between juvenile growth and temperature during early summer is analysed.

### 3.9.13 Influence of turbulence on recruitment

Project period: 1990-1993

The objective of the project is to investigate the influence of small scale turbulence on the contact rate between fish larvae and their prey. Fish larvae and their prey are confined to the wind mixed layer of the ocean, where the wind energy is the main source for production of turbulent energy. Consequently, interannual variations of the wind climate will influence the feeding conditions of the larval stages and the recruitment to fish stocks.

### 3.9.14 Comparative studies on growth and survival of larval and juvenile cod from Atlantic stocks

Project period: 1992-1995

Growth and survival of larvae and juveniles from different cod stocks in the North Atlantic show large variations. In this project growth and survival are studied under equal environmental conditions in a mesocosm basin in Austevoll Aquaculture Station. The objective is to investigate the relative influence of genotypic and phenotypic condtions, i.e. the environmental conditions in the different habitats and the influence of the gene material of the various stocks.

## 3.10 South Africa

The national IGBP programme in South Africa, i.e. the South African Global Change Programme, attempts to coordinate all the global change research efforts.

As stated in a pamphlet on the goals and objectives of the Programme,  Africa´s natural environment is characterized by scarce water resources and great variability in its climate, soils and vegetation. It is a high-risk environment. Superimposed on this variability is global climate change.

The strategic goal of the programme is: Understanding global environmental change in order to devise effective strategies for preventing and lessening its impact on the natural resources of southern Africa, its people and their welfare.

The following strategic priorities have been identified:

1 to monitor long term environmental change in southern Africa,
2 to increase knowledge of the causes, mechanisms and consequences of global environmental change,
3 to maximize the flow of relevant information,
4 to train scientists who can address global change issues,
5 to develop centres of expertise in southern Africa,

6 to coordinate financial support.

The broad fields of scientific endeavour underpinning the international programme have been identified. In South African Global Change programme the following are of high priority:

Atmosphere and climate systems
Hydrological systems
Marine systems
Earth system history
Terrestrial systems
Agricultural and forestry systems
Human response systems

Each of these key fields will form a sub-programme of the South African Global Change Programme. The following gives a brief introduction to the two key fields relevant to this Report, followed by a summary of current projects within these fields.

**Terrestrial systems**

The objective is to predict the response of ecosystems, and the plants and animals they contain, to changes in greenhouse gases, regional climates, and increased ultraviolet radiation. Of particular concern will be:

- How terrestrial ecosystems contribute to, or absorb greenhouse gases,
- what useful predictions can be made for land managers on the basis of global trends
- adaptation or migration of organisms, implications for conserving southern Africa's biological diversity,
- climate change, disturbance and ecological responses (fire, grazing and invasive plants.)

Current projects relevant for biological effects of climate changes:

| | Project title | Description |
|---|---|---|
| 3.10.1 | The effects of elevated atmosphere $CO_2$ on plant carbon allocation in resource-poor environments | Aims to determine how elevated $CO_2$ levels will interact with water and nutrient stress to alter photosynthetic performance and plant growth in two resource-limited environments, the succulent Karoo and Fynbos biomes |

| | | |
|---|---|---|
| 3.10.2 | Paleoclimate and evolution | An analysis of the role of climate in the mechanisms of evolutionary change with special reference to human origins |
| 3.10.3 | Sustainable utilization of plant resources in natural systems: effects of selective cropping on patterns of carbon assimilation under changing environmental conditions | As title |
| 3.10.4 | Photographic and historical evidence of vegetation change in semi-arid Karoo, South Africa | As title |
| 3.10.5 | Distribution ecology of Acacia species along environmental gradients | Deterministic models of environmental requirements of acacias and dynamics under global warming scenarios |
| 3.10.6 | Vegetation monitoring in Lowveld and arid Lowveld of Natal | Monitor changes in plant species composition which can be related to global warming |
| 3.10.7 | Southern African fire atmosphere research initiative | Assess the contribution of savanna fires in southern Africa to global carbon/ozone balance |
| 3.10.8 | Study of the chemical and physical processes underpinning the Okavango ecosystem | The project examines the relationships between hydrology, sedimentology and vegetation in the Okavango |
| 3.10.9 | Responses of savannas to stress and disturbance | Predictive capacity for savanna structure and productivity under various climate soil and management conditions |
| 3.10.10 | Impact of climate change on seed germination ecology of selected arid Fynbos species | The germinability of seed under different temperature and moisture regimes will be investigated in order to understand the impact of climate change on their natural distribution |
| 3.10.11 | The development of a log-linear model for Nama-karoo vegetation and its application to monitoring Karoo | Development of a log-linear model using altitude, median annual rainfall and geology |

| | | |
|---|---|---|
| 3.10.12 | Patterns and dynamics of soil erosion and vegetation in Succulent Karoo rangeland | As title |
| 3.10.13 | Modelling the impacts of climatic and land-use change: Spatial and compositional shifts of plant populations and communities | As title |
| 3.10.14 | Ecological implications of a changing climate at a Sub-Antarctic island | Currently occurring climate change in the Sub-Antarctic is having a marked effect on ecosystem structure and function on Marion Island |
| 3.10.15 | Tropical soil biology and fertility programme | Examining controls, rate and pool sizes of C, N and S cycling in terrestrial ecosystems, including agro-ecosystems |
| 3.10.16 | Vegetation monitoring by means of NOAA AVHRR data | Monitoring changes in vegetation over entire sub-continent of Africa using standardised calibrated AVHRR data. |
| 3.10.17 | Southern Africa bird atlas project | Build a database on distribution and seasonality of all bird species in Southern Africa; publish atlas |
| 3.10.18 | South Africa bird ringing unit | Coordinates bird ringing activities in Southern Africa, and has extensive base of ring recoveries |
| 3.10.19 | Ecological aerial surveys in the Kruger National Park | Monitoring of large herbivore population |
| 3.10.20 | A study of desertification processes in the Karoo biome with special reference to soil and plants | Changes in soil properties and plant communities due to desertification |

## Marine systems

It will be neccessary to study ocean processes which influence climate and which could modify climate change, and to assess impacts of such change and variability on the oceanic and coastal environment. Of particular concern will be:

1 ocean circulation around Southern Africa,
2 monitoring Southern Ocean front south of Africa

3 heat exchange between Indian and Atlantic Oceans and its influence on southern African climate
4 variability of key interactions between ocean and atmosphere (heat, wind, moisture),
5 flows of carbon and nitrogen related to the global $CO_2$ budget,
6 the effect of global change on the abundance and availability of marine resources such as fish stocks
7 monitoring sea level rise and assessing its implications for Southern Africa.

The following projects relevant for biological effects of climate changes are currently running:

| | Project title | Description |
|---|---|---|
| 3.10.21 | Sea level rise: impacts and adaptive responses | Aim: to establish a sound scientific basis for decisions on sea level rise, its impact on South African coastal environment, and adaptive responses |
| 3.10.22 | Demography, climate change and life-history styles of surface nesting seabirds at Marion island | As title |
| 3.10.23 | Climate change and South Africa's living marine resources | Aims to investigate possible impact of climate change on certain of South Africa's abundant marine resources |
| 3.10.24 | Coastal silt loading and its effects on intertidal filterfeeders | Concentrating initially on bivalves, the project seeks to elucidate the effects of increased silt loads resulting from erosion due to increases in sea level |
| 3.10.25 | South African turtle monitoring project | Conservation and monitoring of two species of sea turtles nesting on Zululand Coast |
| 3.10.26 | Plankton biomass and production in relation to hydrography and pelagic fish distribution | Each recruitment survey (May, West Coast) and spawner survey (November, Algulhas Bank) biomass and production of plankton are measured on the Continental Shelf. |
| 3.10.27 | The Antarctic marine ecosystem and global climate change | A programme that addresses the problem of the capacity of the Southern Ocean to respond to and modify global climate change; providing scientific information to SCAR and other related climate change programmes such as WOCE and JGOFS |
| 3.10.28 | Sandy Coasts | Ecology and dynamics of beach and dune coast in Southern Africa |

| | | |
|---|---|---|
| 3.10.29 | Marine Eutrophication Project | Variability, long-term effects and mechanisms of land based eutrophication of coastal embayments in Southern Africa |
| 3.10.30 | Atmospheric $CO_2$ regulation by diatom production and shelf carbon deposition | Investigating the role of nutrient fluctuations in driving diatom production and organic carbon sequestration in sediments off the Central Benguela |
| 3.10.31 | Western Cape Wader Study Group | The group does bi-annual surveys of birds at Langebaan Lagoon and other wetlands, and conducts an extensive bird ringing programme |

## 3.11 Sweden

Sweden does not coordinate the country´s climate change efforts through a central programme. A Nordic inventory of research projects within the areas global climate change and ozone depletion has just been published (Nordic Council of Ministries, 1992). This work was carried out in Sweden (by Zetterberg and Klemedtsson) and gives an excellent overview of current research within several sub areas relevant for climate changes, and appears to cover Sweden particularly well. Three of the nine sub areas covered in that report were examined for relevant projects for the present survey (3b: Terrestrial Systems: Effects of Climate Change, 4: Marine Systems and, 5: Arctic Systems), yet it turned out that only area 3b included relevant activities. These are presented in the following. Projects that are not yet started, i.e. proposed projects, are not included.

### 3.11.1 Models of biosphere reactions to increased carbon dioxide in the atmosphere

*Description*: The predicted future increase of atmospheric carbon dioxide is expected to affect terrestrial ecosystems in at least three ways; i) the rate of photosynthesis increases; ii) changes in temperature and precipitation affects the production rate of vegetation both directly and indirectly through species replacement; iii) a higher temperature increases the mineralization of carbon and mineral nutrients in the soil. We intend to develop models to follow the changes in carbon stores in the biosphere as a consequence of the above mentioned effects. We have previously formulated a theory for terrestrial ecosystems, where these are viewed as coupled systems of a vegetation and a soil system. The production rate is controlled by the nitrogen productivity, which in this context needs to be generalized to take into account effects of temperature and carbon dioxide. The models will be used both under assumptions of constant species composition and to predict consequences of larger shifts in species composition.

### 3.11.2 Simulation modelling of global vegetation change

*Description*: Development of a globally applicable generic model for vegetation dynamics and transient responses to climate change.
*Methodology*: Modelling
*Associated projects*: Cooperation in a consortium including scientists from: Trondheim University, Uppsala University, University of Virginia, Michigan Technical University, US Forest Service, Netherlands Government (RIVM), IIASA.

### 3.11.3 Regulatory mechanisms in woody vegetation in arid savanna

*Description*: The project works/will work along a rainfall gradient in arid savanna, Botswana. Vegetation dynamics (cover, leaf area etc. by species) is followed over time and related to rainfall pattern, temperature and interactions with fires and large herbivores. Special emphasis is put on natural regulation of the woody component and the relations between the woody and the herbaceous vegetation.
*Methodology*: Field observations and field experiments.

### 3.11.4 Sensitivity of natural forests to climate change

*Description*: Use of a landscape-scale forest dynamics model to simulate present forest composition and structure in old growth forest in different climatic zones. Sensitivity experiments under a range of climate change scenarios.

*Methodology*: Modelling and sensitivity analysis. Testing with field data. Impact analysis.

*Associated projects*: Parallel to SJFR-funded research at SLU on climate change effects of Swedish forestry. Direct cooperation with the Swedish (SNV) environmental monitoring programme (PMK).

### 3.11.5 Plant physiology and environmental changes

*Description*: This research programme includes several specific research projects, which will mainly study physiological-biochemical mechanisms of plants and their response and adaptation to environmental stress. The programme is a continuation of an earlier SJFR financed programme 'Air Pollution and Plant Physiology'. As a continuation of the programme, research concerning the 'greenhouse effect' will be intensified.

### 3.11.6 Organic matter turnover in a Western European climate transect in coniferous forests

*Description*: Measurements of litter and humus decomposition rates are to be related to estimated (modelled) soil climate as well as to the chemical composition of litter, humus.
*Associated projects* : This project is part of a Europe-based project.

### 3.11.7 Effects of climate change on vegetation in subalpine environment - indications and mechanisms

*Description* : The aim is to develop models for climatic regulation of distribution of plants and vegetation. The study system is the altitudinal tree-limit in the southern Swedish Scandes. An old network of sites and permanent plots is analysed.

*Methodology*: Field work, analysis of permanent plots.

### 3.11.8 The Autumnal Moth, the Winter Moth and the Mountain Birch forest in a warmer climate

*Description*: It is hypothesized that the defoliating outbreaks of the Winter Moth (*Operophtera* spp.) in a "greenhouse" world will spread eastward from Norway and overtake the outbreak area of the Autumnal Moth (*Epirrita autumnata*) in the Scandinavian mountain chain. The project elucidates the biological prerequisites for such a change and monitors the insect/bird system over time.
*Methodology*: Field work: Larval census along west-east profiles. Lab. work: Experiments and biochemical analysis
*Associated projects*: Parallel projects: 1) The role of *Epirrita autumnata* outbreaks in the dynamics of the mountain birch forest (O. Tenow & H. Bylund, NFR project), 2) The mountain birch forest, the autumnal moth and the parasitoids of the moth - an unstable system (O. Tenow, H. Bylund & O.R. Strong, NFR project)

## 3.12 United Kingdom.

### TIGER-Terrestrial Initiative in Global Environmental Research

The majority of terrestrial climate impact research in the U.K. will be coordinated through the Terrestrial Initiative in Global Environmental Research (TIGER), funded by the Natural Environment Research Council. The mission of the TIGER programme is to create a better understanding of the processes in the biosphere so that causes and consequences of climate changes can be foreseen and forestalled. Its scientific aims concern terrestrial processes which drive the climate through exchanges of carbon, trace greenhouse gases, water and energy between the biosphere and the atmosphere. TIGER is focusing on the causes and consequences of climate change at sites in Britain and in selected tropical biomes and is organised within four main components:

I. The carbon cycle on land.
II. The generation of trace greenhouse gases
III. The influence of the water and energy budgets.
IV. The effect on ecosystems.

TIGER encompasses the objectives of a number of IGBP core projects; BAHC, IGAC, and GCTE and represents part of the U.K. contribution to the Global Weather Experiment within the WCRP. While TIGER I-III is already started, TIGER IV, which is the most relevant for this report, is underway.

## GERD-Global Environmental Research Database

The U.K. Global Environmental Research (GER) Office has produced and is continually updating a national database on projects relating to global change (including marine research). The database is distributed on a floppy disk, free of charge (se app. B). Four different classification codes are used in the database; Geographical focus, Relevance to international GER science programmes; Type of research; Subject classification. One of the subjects within the latter classification code is "climate change". All of these were examined, and projects relating to both *impact studies* and *biology* were chosen for presentation. The following lists the projects considered relevant for this purpose as selected from the GERD. For clarity, the projects are grouped into terrestrial (3.12.1 - 3.12.36), freshwater (3.12.37 - 3.12.40) and marine (3.12.41 - 3.12.44) research.

### 3.12.1 The likely impact of elevated $CO_2$ and temperature on European forests

To assess the likely impact of elevated atmospheric $CO_2$ concentrations upon processes that determine growth, water-use-efficiency and the capability of forests to act as a net sink for $CO_2$. To provide knowledge of the canopy process that determine the role and extent of the ability of European forests to act as a sink for atmospheric $CO_2$, and to provide model parameters to allow the prediction of regional scale forest responses to elevated $CO_2$.

### 3.12.2 Sensitivity of heat and water vapour fluxes of vegetation to changes in canopy phenology, physiology and structure resulting from $CO_2$ fertilisation

Estimation of the effects of global $CO_2$ increase on the exchanges of heat and water vapour by vegetation mosaics over periods of days and years using an existing SVAT model (MAESTRO). MAESTRO will be used to simulate the radiation balance, water use and heat flux by vegetation of contrasting types (heathland, woodland, crops). Parameterisation will be with physiological, phenological and structural canopy data obtained from ongoing $CO_2$ fertilisation projects and from remotely sensed data.

### 3.12.3 The $CO_2$ exchanges of Sahelian vegetation in HAPEX-II-SAHEL

The measurement and modelling of $CO_2$ and water vapour fluxes from Sahelian vegetation with ground-based instrumentation to determine current performance at two spatial scales, to test scaling up procedures, to relate to remotely sensed data and to predict responses to climatic change. The approach is to measure at one scale, parameterise a model to predict at a larger scale and to test predictions by measurements at the larger scale. There will be measurements at the 'leaf scale' of leaf, stem and soil radiative and gas exchange properties and at the 'stand scale' of canopy structure and $CO_2$ and water fluxes by eddy covariance. Models will be tested for scaling up from leaf to stand to regional scales and used for prediction.

### 3.12.4 Net carbon dioxide uptake of Scottish forests

The specific aims of the project are three-fold. (a) Evaluate the carbon balance of a selected range of stand types, by making use of existing scientific knowledge in a current model - MAESTRO - that has been developed for this purpose. (b) Test the model used in arriving at stand carbon balances by making measurements of net carbon dioxide fluxes to selected forest stands. (c) Make predictions of the likely rate of $CO_2$ sequestration by stands in different climate change scenarios.

### 3.12.5 The $CO_2$ exchanges of boreal forest in BOREAS

To measure and model the net $CO_2$ exchanges of boreal forest to determine whether the soils and vegetation are significant global sinks for anthropogenic, atmospheric $CO_2$. Measurements will be made of $CO_2$ influx and efflux using eddy covariance methods within the framework of the international IGBP/WCRP Land Surface Experiment in Canadian boreal forests. The measurements will be used to construct carbon budgets and to test models that will be used to scale up the carbon budgets in space and time.

### 3.12.6 Effects of CO2 enrichment of the atmosphere on water use by trees and herbaceous plants.

The rate of evapotranspiration is partly governed by stomatal conductance. It is known from laboratory studies that increases in atmospheric $CO_2$ concentration can substantially reduce stomatal conductance. A major aim of this project is to discover whether stomatal conductance continues to be depressed when plants are exposed to a $CO_2$-enriched atmosphere for all or a major part of their lifetime. The long-term experiments are being conducted in daylit hemispherical chambers ("Solardomes") with $CO_2$ concentrations of circa. 350 and 600 ppm. Plants being studied include Sitka spruce, ash, sycamore and herbaceous species from upland communities in the Pennines.

### 3.12.7 Arctic ecosystems and environmental change

1. To contrast the response in structure and function of high Arctic (polar semi-desert) and sub-Arctic (dwarf shrub heath) communities to environmental perturbation. 2. To predict the resilience of Arctic ecosystems to likely global change. Environmental manipulations will perturb temperature and the supply of water and nutrients at both sides, and $CO_2$ and UV-B in the sub-Arctic heath. The response of soil processes and plant species and communities to the perturbations will be assessed from studies of soil biogeochemistry, plant growth and population dynamics, and plant ecophysiology.

### 3.12.8 Interactions between $CO_2$, $O_3$ and soil moisture deficit

There is little doubt that the combustion of carbon-based fossil fuels will continue to elevate the $CO_2$ concentration of the atmosphere and increase photochemical oxidant pollution. It is predicted that these changes will have profound implications for plant growth and water use. However, the actual impact of these changes will depend upon plant species, longevity, and important interactions between $CO_2$, $O_3$ and other environmental factors (water stress, nutrient deficiency, other air pollutants and temperature). Despite repeated research recommendations, the vast majority of studies on the response of plants to elevated $CO_2$ have been carried out under favourable growth conditions, with little regard paid to air quality. Consequently, there is actually very little information on which to base predictions of how plants will respond in the field. The aim of this research programme is to investigate the hypothesis that increasing levels of $O_3$, a highly phytotoxic air pollutant, will modify the response of plants to elevated $CO_2$ and soil moisture deficit and vice versa. Spring wheat (*Triticum aestivum* L) and certain native British species will be used as models to test this hypothesis. Particular attention will be paid to elucidating physiological and biochemical mechanisms that underlie any interactions.

### 3.12.9 The effects on anthropogenic perturbations in the atmospheric composition ($0_3$, $SO_2$, $NO_x$, $CO_2$) on plant and soil systems.

The objectives are to get a better understanding of the dynamics of woodland and forest ecosystems and their biogeochemical systems in relation to known and predicted changes in both atmospheric composition and climate. This will enable major negative and positive feedback loops to be identified between the plants, soil fertility and water relations. In this way conceptual frameworks can be derived to provide systems of sustained management of the ecosystems in a changed world.

### 3.12.10 Effect of climate change on tree root growth, carbon flows and nutrient cycling

The soil reservoir of carbon is a major component of the global carbon budget and as such could potentially have a significant effect upon atmospheric levels of $CO_2$. The soil carbon pool also influences the storage of other elements, principally nitrogen in the soil. At the field scale the input of carbon into the soil by plant root growth is poorly understood and only crudely quantified. This derives mainly from a lack of adequate methodology. Studies here are developing the mini-rhizotron technique as a means of quantifying the amount of carbon moved into the root system and some associated rhizosphere organisms, eg. VA mycorrhizas. This is being done partly by improving the mini-rhizotron method and partly by understanding the relationship to other methods which are able to quantify spatial aspects of root production; the mini-rhizotron method is weakest in this aspect. Methodological development is crucial to obtaining data to fit to models of effects of temperature on carbon flow into soil. In addition to using a series of sites in Europe, effect of temperature on the fate of nitrogen and the importance of different soil and climatic factors influencing nitrogen transformation are being assessed for a series of common species and treatments.

### 3.12.11 Effects of $CO_2$ and ozone on downland vegetation and possibly Beech

Aim: To determine the impact of environmental stress on key physiological processes in plants, particularly trees and downland vegetation. Current interest is focussed on predicted changes in moisture supply, temperature and $CO_2$. This includes studying the (i) Biophysics of leaf cell expansion, water relations and leaf area development, (ii) patterns of root development, root function and water uptake in downland vegetation following exposure to elevated $CO_2$ and epizodes of ozone; (iii) leaf growth physiology and stomatal characteristics of Beech and downland vegetation.

### 3.12.12 Elevated Atmospheric $CO_2$ and Temperature: Effects on Growth, Physiology and Biochemistry of Plants

Plants (trees, grasses) are exposed to ambient or twice-ambient $CO_2$ and/or to ambient and ambient +2-4 degrees C temperatures in either controlled environments or chambers situated outside. Their growth and physiology is then monitored. Particularly, we measure: growth rate, photosynthesis, respiration and carbon partitioning. The aim is to understand the mechanisms by which climate change will modify plant growth.

### 3.12.13 Below ground carbon allocation in relation to atmospheric $CO_2$ enrichment and temperature

Below-ground processes are of major importance in the carbon cycle and yet little is known of the rates of carbon flow through root systems. In particular, root turnover and metabolism will change as temperature and atmospheric $CO_2$ concentrations rise. We aim to characterise the effect of enriched atmospheric $CO_2$ and temperature on root growth turnover and metabolism of root carbon in four important species in the Moor House ecosystem, by direct observation of the seasonal pattern of root growth and turnover using fibre optics and destructive harvests. In addition we shall perform studies on root metabolism and growth in the field and under controlled enriched $CO_2$ conditions.

### 3.12.14 Forestry and environmental change effects of air pollution on trees

1. Interactions in the effect of $CO_2$ and other site/environmental factors on UK forestry tree species. Experimental work currently focuses on *Picea sitchensis* water availability, nutritional status and $CO_2$ concentrations. 2. Effects of air pollutants on trees in naval areas. There are three sites of 16 open-top chambers. In each site, *Fagus sylvatica* (Beech), *P. Sitchensis, P.abies,* (Spruce) and *Pinus sylvestris* (Scotspine) are grown in filtered and in unfiltered polluted air. The experiment will run for 6 years in total.

### 3.12.15 Process-based modelling of grasslands and forests: $CO_2$-fertilization and climate effects on carbon storage

Specific objectives: The general objective is to develop and utilize the Hurley Pasture model and the Edinburgh Forest model to quantify the effect of increasing $CO_2$ levels (N inputs and climate change) on the net flux of carbon between vegetation/soil systems and the atmosphere. In order to achieve this general objective, several specific long-term objectives are envisaged: i) Development of the models to represent more fully the fluxes of N, P and water, as well as carbon, at the stand level; ii) Development of a process-based individual tree growth model, incorporating development of a process-based height and diameter, crown shape and within-crown foliar distribution, and branch and root morphology; iii) Development of the carbon flux processes (photosynthesis, partitioning, plant respiration, soil respiration) to represent better the ideas and information coming from experimental studies on the effects of elevated $CO_2$ on plant physiology. Particular attention will be given to the partial processes of photosynthesis, to soil organic matter breakdown, partitioning and the composition (C/N ratio) of litter material; iv) Scaling up of the tree model to the stand level, incorporating competition for light and nutrients, and comparison with the stand-averaged forest model in order to determine which aspects of the physiology at the tree level are essential to the prediction of responses to elevated $CO_2$ at the stand level; v) Validation of the models by comparing model output with data from $CO_2$ - enhancement experiments, hypothesis generation, and exploration of the impacts of elevated CO2 levels and climate change on carbon storage in grassland/moorland and forest vegetation. Part of NERC TIGER Programme

**3.12.16 Effects of elevated nitrogen availability on the growth and mycorrhizal infection of Arctic dwarf shrubs**

Arctic vegetation is strongly nutrient limited, with nitrogen (N) generally being the most limiting element, and tundra plant communities are thus potentially sensitive to increases in N availability. Such increases are already occurring due to acidic deposition and, more locally, due to increased soil mineralisation resulting from activities such as vehicle use. Increased temperatures and depth of thaw caused by the global rise in carbon dioxide concentration are also predicted to increase N availability in Arctic soil. The aims of the project are: (i) to investigate how increased availability of N (& P) affects whole-plant productivity and resource partitioning in two ectomycorrhizal dwarf shrubs of contrasting growth form and one shrub and ericoid mycorrhizas; (ii) to investigate the effects of elevated N (& P) supply on the degree of mycorrhizal infection of Arctic dwarf shrubs and on the species composition of the ectomycorrhizal community, and to relate any changes to (i) above; (iii) by use of the information collected for (i) and (ii) above, to facilitate prediction of the significance of possible anthropogenic changes in N supply to mycorrhizal dwarf shrub species, and to interpret the mechanisms of plant responses to such changes.

**3.12.17 Air pollution, climate change and the ecology of snowbed vegetation**

There is increasing international concern about pollution in mountain environments. Snowbed plant communities owe their existence to prolonged snowlie, which favours chinophilous and competition-sensitive bryophytes, and so would be threatened by reduced snowlie due to climatic change. Snowflakes are very efficient scavengers of atmospheric pollutants, deposition of which is greatest at high altitude. Pollutants are released in very high concentrations in the initial stages of snowmelt, exposing snowbed species to high pulses of acidity and inorganic nitrogen. This project investigates relationships between snowlie and pollutant release from snow, and the growth and physiology of snowbed bryophytes.

### 3.12.18 Dendrochronological study of storm-felled trees from Royal Botanic Gardens, Kew, Surrey, U.K.

This project aims to extract information from the growth rings of trees felled as a result of storms at Kew. The sampling covers many genera whose rings have not been previously investigated dendrochronologically. Long meteorological records exist for Kew. Relationships between growth and climate are being studied. The affects are being investigated. Comparisons with growth at the RBG Wakehurst Place, Sussex are being made.

### 3.12.19 Global biodiversity monitoring. Climate effects on Ecosystems

Aims: The development of a constructive theory of Large Ecosystems. The quantification of Ecosystem Objects not woolly ecosystem concepts. Objectives: Monitoring and Modelling predator distributions as a component of Global Bio Diversity. Theory of Biodiversity Measurement. Relevance to GER: identifies how and what measurements to make to characterise and monitor global ecological status.

### 3.12.20 EEC MEDALUS Programme (Mediterranean Desertification & Land Use)

Current research is focussed on the evolutionary dynamics of complex systems as defined by human environmental interaction and their socio-economic consequences. This work involves the construction of dynamic spatial models which explore climate/plant/soil interactions and their hierarchical linkages. Two broad orientations are defined as a) the study of temporal and spatially extended natural ecosystem processes and b) the role of disturbance agents (climatological and anthropogenic) in structuring ecosystems. This research contributes to a broad spectrum of environmental issues such as land degradation and desertification processes and their socio-economic implications.

### 3.12.21 DoE Core Model Project

Develop methods for capture of European distribution maps of higher plants. Develop climate response surfaces for selected species. Demonstrate how the latter can be used to simulate the impact of given climate-change scenarios upon the potential range of species.

### 3.12.22 Vegetation change from global warming in Korea

The researchers have recently completed a new analytic biogeographic survey of Korea. This will be extended by research on three mountain masses to investigate the potential effects of climatic warming in E. Asia on these biogeographic units. The mountain masses are Sorak-san, Chir-san and Halla-san.

### 3.12.23 Modelling the effects of climate change on aphids and their natural enemies

To determine the effects of a range of increases in temperature on the interaction between aphids and their natural enemies and determine the consequences on the frequency of aphid outbreaks. (i) quantify the effects of increases of temperature on aphid bionomics; (ii) estimate the increase in the number of generations per year as a consequence of temperature increases; (iii) quantify the effects of temperature increases on the bionomics of natural enemies; (iv) develop simulation models to integrate knowledge on the bionomics of aphids and their natural enemies in order to quantify the interaction between them.

### 3.12.24 Ecosystem and community development

The aim of the project is to develop models of Antarctic terrestrial and freshwater ecosystems to facilitate predictions of the results of climate change and active environmental management/conservation based on an holistic understanding of these simple systems.

### 3.12.25 Colonisation of terrestrial environments

The aims of the project are to describe and quantify the processes of primary colonisation for several groups of organisms. Of particular interest is the characterisation of propagule types, assessment of viability and dispersal potential, and description of acceptable niche types. The long-term study of protozoan and microbial colonisation of sites under cloches simulating the effects of global warming will continue at Signy Island. Year-round monitoring is carried out by BAS contract biological assistants.

### 3.12.26 Effects of climate change and management on the growth of trees in Britain

This project aims to determine the past growth of trees under specified management regimes, to separate the effects of management and climate on growth and to use these responses to predict future growth of trees under specific management conditions in a changing climate.

### 3.12.27 Implications of climate change for plant disease occurrence

A study to determine how climate variation affects the annual severity of cereal leaf and ear diseases is utilizing disease and meteorological data collected from locations in the US and UK, over 10-20 years. The work currently focusses in *Septoria tritici* leaf blotch for wheat. It is facilitated by the iterative computer program WINDOW which was developed at the National Centre for Atmospheric Research, Boulder, Colorado to analyse daily meteorological data by averaging or summing data in sequestrial time periods. The main objective of the work is to develop a general methodology aimed at making it possible to rapidly quantify the expected effects of climate change in specific plant pathogen populations.

### 3.12.28 Ecology and evolution of tick-borne orbiviruses

Impact of climate change on the distribution and prevalence of seabird ticks. Consequences for the distribution and prevalence of tick-borne seabird orbiviruses in terms of genetic interactions between sympatric viruses and the evolution of new viruses (Virus Gene reassortment) and increased disease potential.

### 3.12.29 Landscape dynamics and climate change at national and regional scales

1.Review of the current status in modelling landscape dynamics in response to climate change and ecological impact of change within landscapes. 2. To assess the availability of data needed to support such modelling activities nationally or in Europe. 3. To negotiate access to strategically important datasets.

### 3.12.30 Modelling climate change impacts on biochemical and ecological systems: core model project

The aim of the project is to provide core models for predicting impacts of climate change on biogeochemical and ecological systems. The models will run for both equilibrium and transitional climates and will be coupled with a geographical information system (GIS) to examine impacts spatially across the UK.

### 3.12.31 Understanding of SVATS for global modelling using mesoscale and hydrological models

The overall aim of the project is the understanding of soil/vegetation/ atmosphere transfers leading to the improvement of schemes in GCMs and macrohydrological models. Particular attention will be paid to the representation of processes which are sub-grid scale for climate models. Sub-grid variability will be investigated using a hydrological model (TOPMODEL) and a mesoscale meteorological model. A framework for the calibration and verification of SVAT models will be set up. Sensitivities and appropriateness of new schemes will be investigated using a 1-D version of a GCM.

### 3.12.32 Vertebrate population and tropical ecology (amphibians and reptiles)

To investigate and determine the long term trends in population fluctuations of amphibians and to relate these to changes in climatic variables over time. Particular emphasis being put on breeding success, egg production, juvenile and adult growth and juvenile and adult mortality. ASIA (Royal Geographical Society/Universty Brunei Darussalam Tropical Rainforest Project 1991). As part of the above expedition, to determine the amphibious species diversity of the Batu Apoi Forest Reserve in Brunei, Borneo. To also investigate the niche utilisation by amphibians in the tropical lowland dipterocarp rainforests of Brunei -including time, space and resource partitioning.

### 3.12.33 Preliminary study of indicator plants and plant communi-ties

1. To identify suitable plant species and communities as indicators for biological responses to changing climate. 2. To identify autecological parameters affecting plant responses to climate factors. 3. Identify factors controlling the rate of climate change. 4. Define useful datasets for the above. 5. Develop theoretical underpinning and appropriate methodologies for predicting effect of climate change on these indicator species.

### 3.12.34 Effects of climate change in insect populations

Analysis of the long term database of the Rothamsted Insect Survey to determine the potential of the network to monitor the effects of a changing climate and to quantify the impacts on agriculture.

### 3.12.35 Effects of environmental change on the growth of trees in southern Chile

Cores are being collected from a variety of tree species in southern Chile. Trees are growing in stressed sites (dry in the north, cold in the south), with a view to developing climatic reconstructions in an area where climatic change is poorly understood. The data will provide information on two key themes: the effects of Antarctic ozone depletion on the growth of trees and variations in climate associated with the Southern Oscillation over the last 500 years.

### 3.12.36 National Waterfowl Counts/Special Surveys

This programme monitors waterfowl populations throughout the UK. This serves to provide criteria for assessing the importance of individual wetland sites, and also provides information on trends in numbers of individual species. The data are required to fulfill U.K. responsibilities under the Ramsar and Bonn Conventions, the EC Directive on the Conservation of Wild Birds and the Wildlife and Countryside Act. Some 2000 wetlands are visited by more than 1500 volunteer observers in each month between September and March. Data are held on 6000 wetlands throughout the UK. Special surveys are carried out of individual species sites or groups of sites to cover areas which are not included in the regular surveys. This monitoring scheme provides data relevant to climate change, where bird numbers may provide a relatively easily measured biological indicator.

### 3.12.37 a) Effects of climate change on Ghanaian terrestrial & freshwater ecosystems. b) ODA Climate Change Country Study Ghana.

The overall objective is to draw attention to possible impacts of climate change in Ghana so that policy makers will be more aware and better informed regarding actions that might be necessary in the future. This part of the study concentrated on the terrestrial and freshwater environment and the impact of changes in land use over the past 30 years are reviewed. Three climate scenarios for the period 1990-2030 are considered involving a 2 degree C increase in mean temperature, a 10% increase in evaporation and a 12% increase in precipitation. Environmental sensitivities to climate change are discussed and some impacts are predicted for the Forest Zone, Savanna Zone, Freshwater Ecosystems and the incidence of Insect-borne diseases. Implications for future policy for the Ghana Government are made with recommendations for inter-departmental co-ordination, collaboration and long-term monitoring.

### 3.12.38 Global warming and surface water acidification: their role in structuring amphibian assemblages

(1) To determine how temperature and pH may interact to affect amphibian growth and development, (2) to determine how temperature and pH may regulate interspecific interactions (i.e. competition and predation), (3) to make predictions concerning the long-term effects of global warming and acidification on amphibian assemblages.

### 3.12.39 Impact of climate change on freshwater ecosystems airborne and satellite remote sensing of freshwater lakes.

To explore the fundamental links between climate, lake chemistry and plankton growth and develop predictive models of climate-induced change. Particular attention will be paid to the influence of extreme events eg strong winds. To assess the viability of using airborne and satellite remote sensing techniques to study the physical, chemical and biological characteristics of lakes. Particular attention will be paid to those techniques that can be used to study water quality and fisheries problems in the water industry.

### 3.12.40 Long-term assessment of physical and biological components in waters of the Windermere catchment

Weekly or bi-weekly (winter months) sampling of Blelham Tarn, Esthwaite Water, Grasmere, North and South basins of Windermere. A recent introduction to the programme has been the bi-weekly sampling of Bassenthwaite Lake and Derwentwater, which are outside the Windermere Catchment. Programme includes vertical profiles for temperature and dissolved $0_2$; secchi disc extinction depth for light; algal counts and chlorophyll a determination; nutrient analysis for $NO_3N$, $NH_4N$, $SIO_2$, $PO_4P$ and total P. The aim of the project is to assess changes in water quality from long-term data records. Changes in the freshwater environment can be identified and related to activities such as nutrient enrichment and possible climatic change.

### 3.12.41 Biogeochemical ocean flux study (component on particle production and fate). (Further projects in planning stage). Part of Joint Global Ocean Flux Study

We aim to improve understanding of the role of microzooplankton in the carbon cycling of the upper mixed layer of the ocean. Carbon dioxide from the atmosphere is fixed in photosynthesis by microscopic marine algae. These are grazed by microzooplankton at rates and by routes that affect the rates of primary production and influence whether the fate of fixed carbon is to return combined carbon to $CO_2$ or to sediment it at the sea floor. Our measurements in the North Atlantic will be integrated with those of others in models describing the oceanic carbon cycle and indicating what roles the oceanic plankton play in regulating atmospheric $CO_2$ levels.

### 3.12.42 Temperature change and marine organisms (part-investigator in inter-institute study programme)

The project aims to examine the effects of temperature change on the physiology of marine fish and invertebrates; in particular growth, metabolism, reproduction, osmotic regulation and immunity. My component is to examine effect of temperature change on immune capability and disease resistance in marine invertebrates. Mainly high latitude marine environment.

### 3.12.43 Predictive Modelling of Backbarrier Salt Marsh Response to accelerated sea-level rise, Norfolk, U.K.

This project, funded under the UNESCO Man and the Biosphere Programme (see 2.5), aims to investigate the likely response of contrasting backbarrier environments of the North Norfolk Biosphere Reserve under the full range of sea-level rise scenarios prepared under the IPCC scientific assessments. Use will be made of the large existing database of geomorphological and ecological information available for this site, with additional data on marsh elevational statistics and barrier overwash processes being collected over a field measurement programme (initially 3 years in duration). Sites include Blakeney Point, Wareham, Scolt Head Island and Brancaster. Data will be used in conjunction with numerical mass balance models designed to simulate marsh sedimentary and ecological status under given sea-level and sediment supply scenarios. The ultimate objectives are twofold. Firstly, an improved scientific input to future management strategies implemented at this site. Secondly, formulation of an improved methodology for field data acquisition and environmental simulation that will be capable of application elsewhere, including open-coast salt marsh sites.

### 3.12.44 Climate Change Sea Level Rise and the English Coast

1. To study and predict the effects of sea level rise on coastal habitats of England and Wales. 2. To study the effects of changing environmental factors on the dynamics of salt marshes, sand dunes and shingle banks. 3. To study key processes in the physical and biological environment of coastal habitats. 4. To

review and predict the effects of sea levels rise and climate change on the conservation and management of wildlife in the coastal zone.

## 3.13 United States of America

The United States Global Change Program (USGCRP) is coordinated across several Federal agencies by the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering and Technology. It is an integrated research effort with the goal of establishing the scientific basis for national and international policy making related to natural and human-induced changes in the global earth system.

CEES science funding agencies (Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, Smithsonian Institution, and the Departments of Agriculture, Commerce [NOAA], Defense, Energy and Interior), each with a defined agency role, work together to develop programmatic activities that respond to one or more of the following objectives:

- To establish an integrated, comprehensive long-term program of documenting the Earth system on a global scale.
- To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales.
- To develop integrated conceptual and predictive Earth system models.

The seven interdisciplinary science priorities established for the USGCRP, representing interconnected parts of the total Earth system, are listed below. The items higher on the list currently receive greater priority for funding growth than those lower on the list (per FY 1991-1992):

- Climate and Hydrological Systems
- Biogeochemical Dynamics
- Ecological Systems and Dynamics
- Earth System History
- Human Interactions
- Solid Earth Processes
- Solar Influences

Selected activities relevant for biological effects of climate changes are presented below. It should be noted that this section by no means covers the majority of the U.S. research relating to biological effects of climate changes. Naturally, it was not possible to obtain information on project-level in the same manner as for some of the smaller countries. Neither was I able to locate any database like the one in the U.K. Initially I requested most of the CEES funding agencies (all but the DoC and the DoI) for information on current research, yet ultimately only DoE, DoA, EPA and NASA provided the needed data. However, these institutions represent very important units within the American science community. Thus, although this section is incomplete, I still consider the information given here highly valuable to the reader.

### 3.13.1 Department of Energy: Carbon Dioxide Research Program

The Environmental Sciences Division of the Office of Health and Environmental Research of the U.S. Department of Energy (DoE) supports a **Carbon Dioxide Research Program** to determine the scientific linkage between the rise of greenhouse gases in the atmosphere, especially carbon dioxide, and climate and vegetation change. One facet is the **Core $CO_2$ Program** (Table 3.13.1), which the DoE established more than ten years ago to understand and predict the ways that fossil-fuel burning could affect atmospheric $CO_2$ concentration, global climate and the Earth's biosphere. The $CO_2$ core program has five components: Global Carbon Cycle; Climate Detection and Models of Climate Change; Vegetation Research; Resource Analysis; and Information and Integration. A second facet of the program is the **Expanded Program** within which several initiatives have been launched: Quantitative links; Atmospheric Radiation Measurement (ARM) Program; Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) Program; Ocean Research Initiative; Global Change Education Initiative; and the National Institute for Global Environmental Change (NIGEC).

Table 3.13.1. Breakdown of the Carbon Dioxide Research Program showing the Core Program and the newer Expanded Program components. Those marked with an asterisk (*) are described in more detail below.

| **Core Program** | **Expanded Program** |
|---|---|
| Carbon Cycle | Oceans |
| Climate Diagnostics | CHAMMP |
| Vegetation Research* | Quantitative Links/ARM |
| Resource Analysis | Education |
| Information and Integration | NIGEC* |

Following is a more detailed presentation of the components relevant for this report (Vegetation Research and NIGEC - Oceans are excluded due to a general lack of biological research within this program-component), including a list of current projects (from DoE/ER 1991).

### 3.13.1.1 Vegetation Research

A summary of this component was kindly provided by Program Manager Roger Dahlman.

*Description:* This program provides information about (i) the effects of CO2 and climate on plants and the vegetative component of ecosystems, and (ii) plant physiological controls that affect exchange of $CO_2$ between the atmosphere and terrestrial biota. The research strategy is to determine the effects of increasing $CO_2$ and temperature/moisture stress for representative plants, and to develop modeling approaches for extrapolating basic information on processes and controls to other plants and ecological systems. A key facet of the research is to acquire new experimental data, and to develop and validate models for understanding effects of altered $CO_2$ and climate conditions on plants and ecosystems. Once developed and tested, the models would be applied to different types of vegetation (e.g. forests and rangelands) and at larger geographical scales.

Studies of plants involve physiology, biochemistry and whole-plant responses with emphasis on fundamental mechanisms, and, at the larger scale, the research focuses on productivity and structural/functional properties of ecosystems, and on plant-animal-microbial relationships. Fundamental plant processes, (e.g. carbon metabolism, water balance) and ecosystem processes (e.g. productivity, nutrient turnover) are examined as they might be affected directly by $CO_2$, and indirectly by changing climate conditions.

*Research Objectives* are to (1) understand plant physiological mechanisms that control $CO_2$ fixation, and the net $CO_2$ uptake by plants of terrestrial ecosystems; this involves experiments to determine the role of plants and terrestrial ecosystems as sinks in the global carbon balance; (2) experimentally determine relative effects of increased $CO_2$ and altered climate conditions on representative plants and ecosystems; (3) develop models for predicting effects of changing $CO_2$ and climate on vegetation.

*Research questions*: Examples of questions to be addressed are:

• How much does plant growth, productivity and carbon content change in relation to increasing atmospheric $CO_2$, and associated climate changes? Fundamentally, what are the interactive effects of simultaneous changes of these and other variables on photosynthesis and transpiration?

• How will functional and structural properties of plants and ecosystems change with different $CO_2$ and climate regimes?

• What data and models are required to estimate plant responses to $CO_2$ and other influences, and to translate information on biological/ecological processes into estimates of larger-scale responses to global change?

• What are the general mechanisms controlling CO2 fixation of terrestrial biota, and how do the controls operate to sequester carbon of major vegetation types?

• How can plant carbon sequestration be best modeled to determine the role of terrestrial vegetation in balancing the global carbon budget?

Relevant research projects include[3]:

• Integration of experimental and modeling approaches to study competitive interactions among plants under elevated $CO_2$ (F.A. Bazzaz, Harvard University)
• Photosynthetic acclimation to elevated $CO_2$: Basis for variability among plants (Jennifer D. Cure, Duke University)
• A field study of the effects of elevated ambient $CO_2$ on ecosystem processes in Chesapeake Bay Wetlands (Bert G. Drake, Smithsonian Institution)
• Elevated $CO_2$: Modeling cotton response interactions with temperature on photosynthesis, insect population dynamics and temperature interactions, and long-term effects on trees (B. Kimball, Water Conservation laboratory *and* Western Cotton Research Laboratory)
• Experimental studies of ecosystem responses for elevated $CO_2$: Interactions with nitrogen, water, and species characteristics (Harold A. Mooney, Stanford University)
• $CO_2$ exchange, environmental productivity indices, and productivity of agave and cacti under current and elevated atmospheric $CO_2$ concentrations (Park S. Nobel, University of California at Los Angeles)
• Elevated $CO_2$ effects on woody plant soil systems (R.J. Norby; R.J. Luxmoore; and E.G. O´Neill, Oak Ridge National Laboratory)
• Response of tundra ecosystems to elevated atmospheric $CO_2$ (Walter C. Oechel, San Diego State University)

[3] As complete addresses has not been obtained, the name and institution of project leaders are given consecutively (in parenthesis) throughout section 3.13.1, instead of  in appendix B.

• Rangeland-plant response to elevated $CO_2$ (Clenton E. Owensby, Kansas State University)
• Development of a generic ecosystem model for assessing the effects of elevated $CO_2$ on ecosystems (J. Reynolds, San Diego State University)
• Integration of experimental and modeling approaches in the unmanaged-ecosystem research plan (Boyd R. Strain, Duke University)

### 3.13.1.2 National Institute for Global Change (NIGEC)

The House Appropriations Subcommittee on Energy and Water established and provided the resources for the National Institute for Global Environmental Change (NIGEC) in September, 1989. The purpose was to contribute to the knowledge base of global climatic change, the reduction of key scientific uncertainties inherent in the projections of future climate states and perturbations attributed to man's activities, and to the development of policy options applicable for plausible climate change. NIGEC´s mission is to support the sponsoring agency, DoE, in its challenging tasks within the federal Global Change Research Program and at the same time, giving significant emphasis to educational needs by nurturing young scientists specially trained for global environmental change research.

During its first months of existence, one of the main activities of the NIGEC was the creation of the four regional centers and their directorships at Harvard, Indiana University, Tulane, and the University of California, and the development and review of the proposed research for the first years funding (FY 1990). Each regional center has adopted research thrusts to promote synergism between related projects, to focus on significant global-change features of their geographical region, and to provide integration and applicability of the information obtained. The research thrusts of each of the regional centers, as well as lists of current projects, are given below:

Northeastern Regional Center

- Temperate forests, their role in the global carbon cycle, decomposition processes, and their energy balance.
- Studies of the past climate and the development of techniques using $C_4$ plants (e.g. corn and maize) for estimating past climate states over continents.
- Development of a framework for risk assessment of global climate change.

Relevant projects:

- $CO_2$ rise, nutrient dynamics, and litter decomposition in a deciduous forest ecosystem: Relationship between $CO_2$ levels, tissue chemistry, and litter decomposition (F.A. Bazzaz, Harvard University)
- Decomposition rates and nutrient dynamics in a temperate forest: Effects of $CO_2$ and nitrogen enrichment (J. M. Melillo; K. Nadehofer; and P. Steudler, Yale University).

Midwestern Regional Center

- Atmospheric trace gases, their trends and spatial variability.
- Water resources, biological productivity, and their relationships to climate (with a regional focus on midwestern wetlands).
- Policy issues related to energy use.

Relevant projects:

• Effects of environmental factors on phytoplankton emissions of dimethyl sulfide: Implications for climate change (J.W. Birks, University of Colorado)
• A field study of methane and carbon dioxide fluxes in a boreal wetland system: Measurement and analysis (S. B. Verma and F.G. Ullman, University of Nebraska)
• Temporal and spatial variability of methane cycling in wetland ecosystems of the northern temperate zone (J. R. White and K. H. Nealson, Indiana University and University of Wisconsin)
• Simulation experiments of inertia in forest response to climatic warming (M. P. Armstrong and G.P. Malanson, Center for Global and Regional Environmental research, University of Iowa)
• Genetic basis for variation in freshwater phytoplankton productivity related to water temperature (K. D. Hoagland; S.G. Ernst; and D.M. Denicola, University of Nebraska at Lincoln)
• Climate and North American plant formations: Associations between the water balance and satellite-derived vegetation patterns (D. E. Jelinski and A.M. Carleton)
• Potential effects of global climate change on midwestern lakes: Physics, fishes and plankton (J.J. Magnuson, Center for Limnology, University of Wisconsin)
• Adaptation, migration or extinction? A study of the influence of climate change on the biodiversity and biotic productivity of selected biomes of North America (J.C. Randolph, Indiana University)
• Biological hysteresis in climate change models for the Great Plains: Implications for productivity and hydrologic cycles (T.R. Seastedt and D.S. Ojima)

Southern Regional Center

- Modeling of recent past global climate changes
- Atmospheric chemistry of greenhouse gases with focus on methane emissions from rice fields and ocean-bed methane hydrates
- Ocen biochemistry

Relevant projects:

• Impact of global environmental change on biodiversity of mammals in the South-Central United States (G.N. Cameron, University of Houston)

• Methan emissions from natural wetlands (R. A. Burke jr. and D.L. Wilkinson, Texas A&M University)

• Modeling patterns of $CO_2$ flux from forest ecosystems: Implications of climate change (T.M. Smith; H.H. Shugart; and G.B. Bonan, University of Virginia)

Western Regional Center

- Atmospheric and oceanographic modeling of global climate change
- Variation in concentrations of radiatively and chemically important trace (greenhouse) gases in the atmosphere
- Ecological consequences of global warming for both managed and natural ecosystems
- Policy related research and education

Relevant projects:

• Interactive vegetation for climate models over the seasonal cycle (R.E. Dickinson and L. J. Graumlich, University of Arizona)

• Effects of global climate and atmospheric change on the structure and function of Mediterranean shrub ecosystems and associated forest ecotones in California (W.C. Oechel, San Diego State University)

• Modeling analyses of methane emissions from ruminants (R.L. Baldwin, University of California at Davis)

• Interactive effects of heat stress and elevated carbon dioxide concentration on plant reproduction (A. E. Hall, University of California at Riverside)

• Plant and ecosystem respiration in a changing climate: Modeling and empirical studies (H. A. Mooney and P. M. Vitousek, Stanford University)

### 3.13.2 Department of Agriculture

An excellent survey of the most relevant programs has kindly been provided for the present purpose by Carol E. Withman, at the Office of the Assistant Secretary for Science and Education. The following programs are administered by the USDA's Cooperative State Research Service (CSRS) and the Forest Service (FS):

#### 3.13.2.1 Improved Response Models

*Objectives*: To address physiological and ecological responses of plants and animals to global change, including climate, atmosphere gas concentrations, and increased UV-B radiation levels in order to provide knowledge necessary for understanding how basic life processes may be affected by environmental changes.

*Description*: Individual scientists initiated studies and multidisciplinary investigations will be funded under USDA's competitive grants program. research will focus on improved understanding of: 1) responses to relevant environmental parameters; 2) identification of mechanisms which either permit adaptation or take advantage of possible adverse conditions; 3) the role of plants and animals in the short carbon cycle; and 4) the impact of environmental responses on interactions of organisms.

### 3.13.2.2 Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX)

*Objectives*: To develop comprehensive models capable of addressing both the response of forests and related ecosystems to global change induced stress and their associated feedbacks to the climate system.

*Description*: Process research on the impacts of weather/global change on forest and range system will focus on two areas: 1) determining responses of forests and range systems and ecosystems to changes in concentrations of greenhouse gases, as well as direct and indirect effects such as UV-B levels, terrestrial ozone, and acidic deposition; and 2) determining emissions from forest and range systems into the atmosphere. Research on trace gas enrichment will assist in resolving uncertainties in the global carbon balance and quantifying the magnitude of plant response.

### 3.13.2.3 Ecological Systems Dynamics (ECODYN)

*Objectives*: To understand and predict the changes that will result from environmental change, and to understand the sensitivity of ecosystem processes and components to environmental gradients.

*Description*: The responses of terrestrial (forest, range, wildland) and aquatic ecosystems (wetlands, lakes, rivers) and resources as a result of global change is the focus of a FS research program. Species migrations and ecosystem composition changes over time will be predicted based on rate-of-change scenarios from GCMs and other sources. Causes and effect relationships will be developed. Threshold limits of ecosystem stability and diversity will be determined. Life histories, population dynamics, competitive interactions, and community dynamics of plants and animals under altered environments will be addressed. Attention will be given to threatened, endangered, and sensitive species.

### 3.13.3 U.S. Environmental Protection Agency (EPA)
Office of Research and Development

This section was kindly authored by Technical Director Dr. Peter A. Beedlow at the U.S. Environmental Protection Agency.

The ecological uncertainties concerning global change are substantial, but the potential risks are most serious. A balanced policy demands that research be carried out now to: 1) reduce or resolve the significant scientific uncertainties regarding the effects of global climate change on natural and managed ecosystems, and 2) to develop the predictive capability of producing the scientific basis for cost-effective mitigation and adaptation options. The U.S. Environmental Protection report has identified global change as one of its highest research priorities over the next few decades. The EPA Global Change Research Program (GCRP) is managed from the Office of Research and Development (ORD), and is implemented through eight EPA research laboratories.

*Priority Scientific Questions Addressed by the EPA's Ecological Research Program*

A. How much will the response of the terrestrial and near coastal biosphere amplify or dampen global climate change associated with greenhouse gases?

Currently, it is estimated that on average about 50 percent of the carbon emissions to the atmosphere is removed by sinks. For many years it was assumed that the ocean was the major sink and that the annual flux of carbon in the terrestrial biosphere was in equilibrium with the atmosphere if tropical deforestation was not considered. Today we know that global forest systems capture over 110 Gt. C annually, with decomposition and respiration contributing approximately 100 Gt. of $CO_2$: to the atmosphere. Net emissions from tropical deforestation and burning has been estimated to range between 1 and 2 Gt. of carbon per year.

However, uncertainties regarding the size of carbon pools and flux exist. Evidence suggests that this sink could increase or decrease in effectiveness and importance under a changing climate. A major objective of the EPA research is to provide the scientific basis for closing the carbon budget with respect to carbon flux to and from the terrestrial biosphere. Early results of the program will provide better estimates of current fluxes. Future results will allow us to account for terrestrial biofeedback in predictions of global climate change.

B. How will Climate Change Effect Important Terrestrial Ecosystems?

The rate and magnitude of change could exceed the capacity of natural systems to adapt without dramatic disruptions, and tax our ability to manage agriculture and forest systems. At the present time, our ability to predict the effects of climate change on natural ecosystems is limited in two ways. First, current climate models do not provide credible estimates of change at the regional scales necessary to link change to ecological effects. Second, we are limited in our ability to estimate ecological effects at regional and continental scales.

The EPA effects program has been designed to improve our ability to provide policy-makers with information about potential effects of climate change on the natural environment and major agricultural systems. The approach is to develop process-based models that can predict steady-state shifts in regional scale vegetation owing to climate change. Later the program will expand to address transient response of vegetation and associated ecological resources. Of particular concern are systems that have been judged as vulnerable to climate change. This research will provide the scientific basis to estimate potential effects of global climate change on terrestrial ecosystems.

C What is the net rate of deforestation and biomass burning?

A major gap in our ability to balance the carbon budget is a lack of accurate estimates for the rates of deforestation, afforestation and biomass burning worldwide. Working with NASA and the United States Geological Survey, the EPA is conducting research to develop a satellite-based program which will allow operational monitoring of biomass burning and forest land cover changes. Data from the NOAA AVHRR sensor is being used to develop a monitoring system for biomass burning in tropical, sub-tropical, and boreal regions. Landsat data is being used to derive the record of land cover change in North America and the Tropics every 5 years. This research will improve our understanding of the carbon cycle, and provide the basis for international policy discussions on global climate change and degradation of global forests.

*Research and Project Areas.*

The USGCRP has organized its program into four research areas: (1) observing systems and data management; (2) process studies; (3) modeling; and (4) assessments. We have conformed to this organization.

### 3.13.3.1 Observations and Data Management

Three ecological project areas have been established: (1) observing and characterizing the historical changes in landscapes within the North America ; (2) establishing and implementing an observation system for the extent of biomass burning and associated land use changes within the tropics; and (3) observing and characterizing the atmospheric content and relative abundance of radiatively important trace gases, particularly $CO_2$, $NO_x$, $O_3$, OH, $CH_4$, and CO.

#### a. North American Landscape Characterization

In collaboration with the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), this project will derive a record of land cover change in key areas of North America using Landsat data from the 1970's, 1980's and 1990's. The project area covers the U.S.A., Mexico, Central America and the Caribbean.

#### b. Monitoring Tropical Deforestation/Biomass Burning

This project is developing the methodology to monitor forest conversion in several key regions of the world using repeat coverages of satellite imagery to detect burns and land use changes. Emphases will be on providing georeferenced digital files depicting the spatial and temporal occurrences of fires and land use conversions on a per country basis.

#### c. Atmospheric Chemistry Measurements

The relative importance of fossil fuels and the natural environment as sources of atmospheric $CO_2$ is being determined. Research will provide regional and global scale validation of estimates for the role of natural sources and sinks. The $O_2$ concentration in the atmosphere will be measured and will be used in conjunction with $CO_2$ data to quantify better the interaction of the biosphere and the climate system.

### 3.13.3.2 Process Studies

This research area comprises research activities to improve our knowledge of how the terrestrial biosphere influences the global climate. Ecological research is supported in two areas: 1) biogeochemical cycling and carbon cycle dynamics, and 2) effects of climate change on ecosystems.

a. Biogeochemical Cycling

The research on biogeochemical cycling is attempting to quantify current fluxes of carbon from the terrestrial biosphere (at regional and national scales), improve the accuracy of estimates of net global biospheric carbon storage, and to determine the relationship between climate change and alterations in carbon flux from terrestrial ecosystems. The approach is to develop a predictive understanding of carbon flux as a function of climate (especially precipitation), vegetative cover, and catastrophic events (massive diebacks, fires, rapid changes in biome type, etc.).

b. Effects on Ecosystems

Terrestrial ecosystem effects research is evaluating ecosystem response to climate change for potentially vulnerable systems. The climate response of ecosystems with respect to carbon cycling, species composition, and succession is being investigated.

3.13.3.3 Modeling

The modeling area includes four project areas:

a. Terrestrial systems response, vegetation redistribution, and the related water balance

The primary goal is development of process-based models to predict global vegetation redistribution under a changing climate. Key research issues include: processes controlling the movement of nutrients and water within ecosystems; how these processes change over time; the probable magnitudes, rates and variations of human-induced change in ecosystems, and how changes can be distinguished from natural fluctuations; the ecosystems and sensitive species where significant change is most likely to occur, and the attributes most important to humans that are at risk.

b. Biogeochemical cycling

Research addresses the cycling of carbon and nitrogen in the terrestrial biosphere with respect to climate change. The role of chemically active gases derived from the biosphere in affecting atmospheric concentrations of greenhouse gases is being studied. Of importance are biospheric feedbacks related to changes in climate and land use.

c. Earth Systems Modeling

This research is developing terrestrial biosphere components for fully coupled, three-dimensional models of the earth system. The focus will be on interfacing terrestrial biospheric models and data sets with other components of the earth system.

d. Terrestrial Systems Model Evaluation

The interaction of terrestrial systems with land use changes and the changing climate system is the central theme of both terrestrial response modeling and earth systems modeling. The goal of this research is to develop data sets for model validation. The approach will use field studies and experimentation to develop model testing procedures and produce estimates of uncertainty.

3.13.3.4 Ecological Assessment

To support policy development, a series of phased assessments has been planned to summarize the state of scientific knowledge.

a. Carbon pools and fluxes for managed ecosystems including forests and agricultural systems

The objective is to evaluate the current and future status of forest carbon pools and flux in forest and agricultural systems, and to determine if forest and agricultural systems can be managed to conserve and enhance carbon sinks .

b. Effects on sensitive habitats and ecosystems

A series of assessments will be conducted to: evaluate the species, habitats, and ecosystems at risk from future climate change; determine possible management strategies to adapt and/or anticipate change to retain ecological structure and function.

c. Enhancement of terrestrial sinks for $CO_2$ in vegetation and soils

The purpose of this project area is to identify, design, implement, and demonstrate the intensive management forest and agricultural systems to sequester carbon, enhance wildlife habitat, and adapt to residual climate changes.

d. International Assessments

The goal of this task is to foster international exchange of research findings via IPCC and IGBP, and to participate in timely international assessments as appropriate. International assessments on selected topics will include: carbon cycle dynamics; ecological effects; and carbon management in terrestrial ecosystems.

### 3.13.4 NASA - National Aeronautics and Space Administration

Earth Science and Application Division (ESAD)

Within ESAD there are two Program Offices which conduct research. One of them, The Process Studies Program Office includes the Ecosystem Dynamics and Biogeochemical Cycles Branch. One program within this branch is the Terrestrial Ecology Program. Its major goal is to achieve an improved understanding of the role of the terrestrial biosphere in processes of global significance. Specific objectives include improving the understanding of:

3.13.4.1 Trace gas fluxes and carbon/nitrogen pools in the biosphere

Priority is given to projects which:
a) Investigate through manipulative experiments the ecological processes controlling fluxes of $CO_2$, $CH_4$, $N_2O$, $NO_x$, NMHC's between terrestrial ecosystems and the atmosphere;
b) Measure or calculate the size/dynamics of the major carbon and nitrogen pools in the biosphere (terrestrial and near coastal marine);
c) Provide independent estimates of rates of ecological processes, such as those derived from stable isotopes; and
d) Test quantitative predictions from existing ecological and biogeochemical models.

3.13.4.2 Ecosystem function on landscape and regional scales

Priority is given to projects which:
a) Integrate biogeochemical and energy/water-related processes into landscape and regional scale models, particularly those that use remote sensing data as inputs or as validation:
b) Concentrate on processes of importance to ecosystems' response to global change and to regulation of biogeochemical/energy-water feedbacks to the climate system.

### 3.13.4.3 Links between ecosystem structural properties and function

Priority is given to projects which:
a) Investigate the interplay between ecosystems' structural characteristics, including physiognomy, species relative abundances, etc. and their functional aspects; and
b) examine the effects of habitat fragmentation on landscape functional properties and species numbers and relative abundances.

## APPENDICES

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**Rubenstein, D.I.** 1992. The greenhouse effect and changes in animal behavior: Effects on social structure and life-history strategies. In: Peters, R.L. and Lovejoy, T.E. (eds) - Global warming and biological diversity. Yale University Press, New Haven & London. Pp. 180-192.

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**Woodward, F.I., Thompson, G.B.** and **McKee, I.F.** 1991. - The effect of elevated concentrations of carbon dioxide on individual plants, populations, communities and ecosystems. Ann. Bot. 67 (Suppl. 1). Pp. 23-38.

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**B. List of contact points**

## International programs (chapter 2)

### 2.1 The IGBP - International Geosphere Biosphere Programme

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### 2.1.2 Other IGBP Core Projects

**JGOFS** (Joint Global Ocean Flux Studies). *Executive Scientist*: Dr. Geoffrey Evans, JGOFS Core Project Office. Institut für Meereskunde, Universität Kiel, Düsternbrooker Weg 20, Kiel, Germany. Tel: +49 431 597 4019; Fax: +49-431 565 876: E-mail: JGOFS.Kiel (Omnet)

**BAHC** (Biospheric Aspects of the Hydrological Cycle).*Chair:* Dr Hans-Jürgen Bolle. *Officer*: Dr. Alfred Becker, BAHC Core Project Office. Institut für Meteorlogie, Freie Universität Berlin, Dietrich-Schäfer-Weg 6-10, D-1000 Berlin 41, Germany. Tel: +49-31 838 711 84; Fax: +49-30 838 711 60

**IGAC** (International Global Atmospheric Chemistry project) *Chair:* R.G. Prinn. Department of Earth, Atmospheric and Planetary Sciences, M.I.T., 54-1824, Cambridge, MA 02139, USA.

**GOEZS** (Global Ocean Euphotic Study). *Chair*: Dr. Ken L. Denman. SVOR/IGBP Working Group, Institute of Ocean Sciences, P.O.Box 6000, Sidney, BC V8L 4BZ, Canada. Tel: +1-604 363 6346; Fax: +1-604 363 6746; E-mail: K.Denman (Omnet)

**LOICZ** (Land-Ocean Interactions in the Coastal Zone). *Chair*: Dr. Patrick Holligan LOICZ Core Project Planning Committee. Natural Environmental Research Council, Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK. Tel: +44-752 22 27 72; Fax: +44-752 67 06 37; E-mail: P.Holligan (Omnet)

**GAIM** (Global Analysis, Interpretation and Modelling). *Chair*: Dr. Berrien Moore, Task Force for Global Analysis, Interpretation and Modelling, University of New Hampshire, Complex System Research Center, O'Kane House, Durham, NH 03824, USA. Tel: +1-603 862 1792/826 1763; Fax: +1-603 862 1915; E-mail: B.Moore.UNH (Omnet)

### 2.2 SCOPE Scientific Programme

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#### 2.2.1 ISBI - International Sustainable Biosphere Initiative

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#### 2.2.2 IUBS - SCOPE - Unesco Programme on Ecosystem Function of Biodiversity - Diversitas.

IUBS *Executive Director*: Talal Younes. International Union of Biological Sciences. 51 bld de Montmorency, 75016 Paris, France. Tel: +33-1 4525 0009, Fax: +33-1- 4525 2029.

### 2.3 The Role of Antarctica in Global Change (SCAR)

SCAR *Executive Secretary*: P.D. Clarkson. Scott Polar Research Institute, Lensfield Rd., Cambridge CB2 1ER, U.K. Tel: +44-223 62 061; Fax: +44-223 336549

### 2.4 GLOBEC-Global Ocean Ecosystem Dynamics (SCOR/IOC/ICES)

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## 2.5 MAB - Man and the Biosphere (Unesco)

MAB Secretariat/Unesco, Division of Ecological Sciences, 7, Place de Fontenoy, 75700 Paris, France. Tel: 33-1 45681000; Fax: 33-1- 40659897

### 2.5.1 ITEX - International Tundra Experiment

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*Co-Chair*: Dr. Marilyn Walker, Institute of Arctic & Alpine Research, University of Colerado, Boulder, CO 80309-0450, USA.
*For more information*: Dr. Per Mølgard, Danish Polar Center, Hausergade 3, DK-1112, Copenhagen K, Denmark.

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## 2.6 IPCC -Intergovernmental Panel on Climate Changes

The three volumes of the First IPCC Assessment Reports may be ordered at the following addresses:

*Working Group I*: "Climate Change - The IPCC Scientific Assessment". Publishing Division, Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 2RU, England. Tel: +44-223 312393; Fax: +44-223 315052

*Working Group II*: "Climate Change - The IPCC Impact Assessment". International Specialized Book Service, 5602 Northeast Hassalo Street, Portland, Oregon 97213, U.S.A. Tel: +1-503 2873093; Fax: +1-503 2848859

*Working Group III*: "Climate Change - The IPCC Response Strategies", Island Press, P.O.Box 7, Covelo, CA 95428, U.S.A. Tel: +1-202 2327933

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SDME 3/59

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<u>Climatology and Natural Hazards</u>
*Head of Unit*: Roberto Fantechi Tel: 32-2-2355735 - Fax: 32-2-2363024
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**2.8 ICAT -Impacts of Elevated $CO_2$ Levels, Climate Change and Air Pollutants on Tree Physiology (COST)**

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### 2.9 Science of Global Environmental Change (NATO)

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## National research (chapter 3)

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| Prof. Dr. I. Impens, University of Antwerpen, U.I.A., Biology Dept., B-2610 Wilrijk. Tel: +32-3 8202254; Fax: +32-3-8202271. | An investigation into the impact of elevated $CO_2$ upon the response of European forests |
| Prof. Dr. I. Impens, University of Antwerpen, U.I.A., Biology Dept., B-2610 Wilrijk. Tel: +32-3 8202254; Fax: +32-3-8202271. | Global change effects of elevated atmospheric $CO_2$ levels and increased air temperature on grassland ecosystems |
| Prof. Dr. R.A. Impens. Faculty of Agricultural Sciences, Dept. of Biology and Plant Protection, B-5030 Gembloux. Tel: +32-81 622464; Fax: +32-81 614544. E-mail: EARN: ““LOOSVELD@BGXFSA51”” | Ecophysiological study of the effects of high atmospheric $CO_2$ concentration on a forest ecosystem in open top chambers |
| Prof. Dr. R. Lemeur, Ir. A. Clarysse, Universiteit Gent, Faculteit Landbouwwetenschappen, Laboratorium voor Plant ecologie, Coupure links 653, B-9000 Gent. Tel +091-646112 | Effects of increased atmospheric $CO_2$ content on primary productivity and carbon allocation in typical Belgian forest ecosystems |

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|---|---|
| Prof. Dr. ir. N. Lust, Laboratory of Forestry, Gerraardsbergse steenweg 267, B-9090 Gontrode | Changes in the biogeochemistry of carbon in terrestrial ecosystems |
| Dr. Dirk Bauwens, Institute of Nature Conservation, B-3500 Hasselt. | Thermal biology of European reptiles: Toward a prediction of climate change effects. |
| Ph. Trefois, Musée Royal de l´Afrique centrale (MRAC-KMMA), Département de Géologie et de Minéralogie, Laboratoire de Télédétection aérospatiale, Stw op Leuven, 13, B-3080 Tervuren | Detectability of land systems by classification of Landsat Thematic Mapper data, Virunga National Park, Zaïre |
| Prof. K. Vlassak, K.U. Leuven, Faculty of Agricultural Sciences, Laboratory of Soil Fertility and Soil Biology, Kardinaal Mercierlaan 92, B-3001 Leuven (Heverlee). Tel: +32.16.220931; Fax:+32.16.205032 | $N_2O$ production through biological denitrification in soils |
| Lic. P. Meire and Dr. E. Kuijken, Institute of Nature conservation, Kiewitdreef 3, B-3500 Hasselt, Fax: +32.11.242262 | Wetlands and waterbirds: Effects of global change |
| D. Thys van den Audenaerde, MRAC, Laboratoire d´Ichtyologie, B-3080 Tervuren. | Human impact on biodiversity: Systematics, ecology and zoogeography of African freshwater fishes. |
| Prof. dr. N. De Pauw. Laboratory for Biological research in aquatic pollution, University of Gent, J. Plateaustraat 22, B-9000 Gent. | Euthrophication and toxical algal blooms in surface waters |
| R. Blust & W. Decleir. Biochemistry and Zoology laboratory, University of Antwerp, R. U. C. A., Groenenborgerlaan 171, B-2020 Antwerpen. Tel: +32-3 2180211; Fax: +32.3.2180217; E-mail BANRUC 01@GDECO1, network EUARN. | Effects of changing environmental conditions on energy metabolism in aquatic organisms |
| Dr. H.E. Witters, S.C.K.-V.I.T.O., Boeretang 200, B-2400 Mol. Tel +32.14.333111; Fax:+32.14.320372 | Climatic change and freshwater ecosystems. |

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| Henrik Saxe, Ministry of Environment, Natural Environmental Research Institute, Vejlsøvej 25, P.O. Box 314, DK-8600 Silkeborg. Tel +45-89 20 14 00; Fax: +45-89 20 14 14 | The Physiology of "Red" Norway Spruce, and the selection of healthy provences |
| Per Mølgaard, Royal Danish School of Pharmacy, Universitetsparken 2, DK 2100 Copenhagen. Tel: +45-3537 0850/335. Fax: +45-3537 5744 | Biological monitoring of climatic changes by plant population dynamics - an ITEX experiment |
| Ib Johnsen, Institut for økologisk botanik, Københavns Universitet, Øster Farimagsgade 2D, 1353 Copenhagen K. Tel: +45-33 12 65 06, Fax: +45-33-14 57 19 | Sensitivity of arctic terrestrial ecosystems towards global climate change, in particular with respect to UV-B radiation and temperature variation |

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| Jan K. Schjoerring, Plant Nutrition Lab., Royal Vet & Agric. Univ., Thorvaldsensvej 40, DK-1871 Fredriksberg C, Copenhagen. Tel: +45-35 28 34 95; Fax + 45-35 283460 | Exchange of ammonia and other trace gases between plants and the atmosphere |
| Annelise Kjøller/Sten Struwe, Sølvgade 83 H, 1307 Copenhagen K. Tel: +45 33 123485; Fax: +45 33 145058 | Denitrification in European forests. Biogenic $N_2O$ emissions |

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| Dr. Martti Heikinheimo, Finnish Meteorological Institute, Climatology Division, Siltasaarenkatu 12 A, PL 503, 00101 Helsinki | The effect of climate on the phenology of perennial plant species |
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| Dr. Seppo Neuvonen; University of Turku, Department of Biology and Kevo Subarctic Research Institute, SF-20500 Turku.<br>E-mail: SEPNE@sara.cc.utu.fi | Anthropogenic environmental changes and the risk of forest insect outbreaks |
| Yrjö Sucksdorff, National Board of Waters and the Environment, Environment Data Centre, PB 250, 00101 Helsinki. Tel: +358-0 7314 4213. Fax:+358-0 7314 4280 | The development of a soil/plant/ atmosphere model |

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| Jukka Laine, Dept. of Forest Ecology, Univ. of Helsinki. Unioninkatu 40 B, SF-00170 Helsinki, Finland. Tel: +358-0 1911; Fax: +358-0 191 7605 | Carbon balance of peatlands and climatic change |
| Lauri Arvola/Paula Kankaala. Lammi Biological Station, University of Helsinki, SF-16900 Lammi | Impacts of climate change on carbon cycle in freshwater ecosystems |
| Lea Kauppi/Martin Forsius, National Board of Waters and Environment, Water and Environment Research Institute, P.O.Box 250, SF-00101 Helsinki | Effects of climate change, air pollutants and land use on lake ecosystems |
| Hannu Lehtonen, Finnish Game and Fisheries Research Institute, P.O.Box 202, 0051 Helsinki. Tel:+358-0 624 211; Fax: +358-0 631 513 | Effects of climate change on fishes, fish stocks, fisheries and aquaculture |

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- Forschungsverbund Agrarökosysteme München (FAM)
  GSF-Forschungszentrum für Umwelt und Gesundheit GmbH und TU-München-Weihenstephan Ingolstädter Landstr. 1, 8042 Neuherberg.
- Verbundprojekt Agrarökosysteme Halle (VAH)
  Universität Halle, Neuwerk 21, 0-4020 Halle

## 3.8 The Netherlands

*Chairman of the national IGBP Committee*: Prof. Henrik Postma, Koninklijke Nederlandse Akademie van Wetenschappen, Postbus 19121, Nl-1000 GC Amsterdam. Tel:+31-20 622 29 02; Fax: +31-20 620 49 41; E-mail: n102.texel

*Secretary NWO/NOP Global Change Programme V.V.A.*: Hans de Boois, Nederlandse organisatie voor wetenschappelijk onderzoek (NWO), Postbus 93138 2509 AC-Den Haag. Tel: +31 70 3440 640; Fax: +31-70 3850 971

Contact persons for specific projects:

| Name, address | Project title |
|---|---|
| Prof. dr.ir. P.J.C. Kuiper, University of Gronongen, Dept. of Plant Biology, P.O.Box 14, 9750 AA Haren. Tel: + 31-50 63 22 81; Fax: +31-50 63 22 73. | An investigation on the physiological response of plants to elevated $CO_2$ in the atmosphere, with emphasis on root physiology. |
| Dr. J. Goudriaan. Dept. of Theoretical Production Ecology. Wageningen Agricultural University. Bornsteeg 65, 6708 PD Wageningen, P.O.Box 430, 6700 AK Wageningen Tel: +31-8370 82141; Fax: +31-8370 84892 | The seasonal cycle of the $CO_2$ exchange between atmosphere and vegetated surfaces |
| Dr. ir. A. Gorissen, Institute of Soil Fertility Research (IB-DLO) Keijenbergweg 6, P.O.Box 48, NL 6700 AA Wageningen Tel: +31-8370 91227; Fax: +31-8370 14435 | Distribution of carbon over plant and soil compartments during the growth of perennial plants at elevated atmospheric $CO_2$ concentrations. |

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|---|---|
| Dr. Peter Kuikman, Institute of Soil Fertility Research (IB-DLO) Keijenbergweg 6, P.O.Box 48, NL 6700 AA Wageningen Tel: +31-8370 91254: Fax: +31-8370 14435 | Quantification of carbon fluxes in grasslands |
| Dr. Siebe C. van de Geijn, Agricultural Research dep., Centre for Agrobiological Research. Bornsesteeg 65, P.O.Box 14, NL-6700 AA Wageningen. Tel: +31-8370 75700; Fax: +31-8370 23110 | Effects of increased CO2 levels and temperature on plant production and plant biomass turnover. |
| Harry Lankreijer. Dep. of Physical Geography and Soil Science, University of Groningen, Kerklaan 30 9751 NN Haren Gn. Tel:+31-50 63 61 33; Fax: +31-50 63 52 05 | Effect of doubling atmospheric $CO_2$ on the water balance of forested land surface |
| Dr.ir. G.M.J. Mohren. Agric. Research Dep., Inst. for Forestry and Nature Research (IBN-DLO) Bosrandweg 20, P.O.Box 23, NL-6700 AA Wageningen. Tel: +31-83 7095 111; Fax: +31-83 7024 988 | Phenological reactions of the main Dutch tree species to climate change described by a simulation model of the annual cycle |
| Prof. Sten Nilson and Dr. Matthias Jonas International Institute for Applied System Analysis, IIASA, A-2361 Laxenburg. Tel: +43-2236 715210; Fax: +43-2236 71313 | Regional climate change and its effect on forest productivity |

## 3.9 Norway

*Chairman of the national IGBP Committee*: Ivar S. A Isaksen, Institute of Geophysics, University of Oslo, P.O. Box 1022 Blindern, N-0315 Oslo.

Contact persons for specific projects:

| Name(s), address | Project title |
|---|---|
| Dr. agric. Leiv M. Mortensen, Særheim Research Station, N-4062 Klepp st. Tel: +47-4 425544; Fax: +47-4 425696 | Effects of high $CO_2$ concentrations on different horticultural and agricultural crops at various soil and climate conditions |

| | |
|---|---|
| Dr. Jarle I. Holten, Norwegian Institute for Nature Research, Tungesletta 2, N-7005 TRondheim. Tel: +47-7 580500; Fax: +47-7 915433 | STEP (Scandinavian Terresrtial Ecosystem profile) - an all-Scandinavian terrestrial climate change research programme. |
| Dr. Wolfgang Cramer, Department of Geography, University of Trondheim, N-7055 Dragvoll. Tel: +47-7 591919; Fax: +47-7 591878. | Bioclimatic limits for plant functional types in Europe. |
| Dr. Jarle I. Holten, see above. | Effects of rapid climatic change on plant diversity in boreal and montane ecosystem |
| Dr. Freddy Engelstad, Centre for Soil and Environmental Reserach, JORDFORSK, N-1432 Ås. Tel: +47-9 948163; Fax: +47-9 948110. | Production of greenhouse gases from biological processes in soil |
| Prof. A. Håbjørg, Dep. of Horticulture, Agricultural University of Norway, P.O.Box 22, 1432 Ås. Tel: +47-9 947800; Fax: +47-9 947802. | Effects of climate change on growth and development on northern landscape plants |
| Prof. Ola M. Heide, Dept. of Biology and Nature Consevation, Agricultural University of Norway, P.O. Box 5014, N-1432 Ås. Tel: +47-9 948486; Fax: +47-9-948502 | Winter dormancy and climate change relations in boreal forest trees |
| Prof. Dr. Agric. Jon Dietrichson, Dept. of Forestry, Agricultural University of Norway, P.O.Box 44, N-1432 Ås. Tel: +47-9- 948896; Fax: +47-9 948890 | Genetic stability studies in order to evaluate the greenhouse effect upon evolution and tree breeding |
| Dr. Arne Jensen, Norwegian Institute for Nature Research, Tungesletta 2, N-7004 Trondheim. Tel: +47-7 580625; Fax: +47-7 915433 | Possible effects of climatic changes on the ecology of Norwegian Atlantic salmon (*Salmo salar* M.) |
| Johan Blindheim, Institute of Marine Research, Box 1870, Nordnes, 5024 Bergen. Tel: +47-5 238500, Fax: +47-5 238584 | Effects of climatic changes on the biomass yield of the Barents Sea, Norwegian Sea and West Greenland waters |
| Einar Svendsen, Institute of Marine Research, Box 1870, Nordnes, 5024 Bergen. Tel: +47-5 238500; Fax: +47-5 238584 | Influence of climate variations on fish stocks in the North Sea. |
| Harald Loeng, Institute of Marine Research, Box 1870, Nordnes, 5024 Bergen. Tel: +47-5 238500; Fax: +47-5 238584 | Climate variations of the Barents Sea and the effects on juvenile growth |

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|---|---|
| Svein Sundby, Institute of Marine Research, Box 1870, Nordnes, 5024 Bergen. Tel: +47-5 238500; Fax: +47-5 238584 | Influence of turbulence on recruitment. |
| Kjell Naas, Institute of Marine Reserach, Austevoll Aquaculture Station, 5392 Storebø. Tel: +47-5 380342; Fax: +47-5 380398 | Comparative studies on growth and survival of larval and juvenile cod from Atlantic stocks. |

## 3.10 South Africa

*Chairman of the Programme Committee and the national IGBP Committee*: Prof. Peter Tyson, University of Witwatersrand, 1 Jan Smuts Ave., Johannesburg 2001, Wits 2050. Tel: +27-21 716 34 00; Fax:+27-11-339 82 15; Telex: 4-50937 vcwits

*Programme coordinator*: Lesley Shackleton, P O Box 24022 Claremont 7735. Tel. and fax: +27-21-683 5785

Contact persons for specific projects: (Complete addresses were not obtained, by they will probably be provided by the programme coordinator).

<u>Terrestrial systems:</u>

| Project leader(s) and research institution(s) | Project title |
|---|---|
| Mr G.F. Midgley, G.A. Pickett, Dr. C.F. Musil, National Botanical Institute | The effects of elevated atmosphere $CO_2$ on plant carbon allocation in resource-poor environments |
| Dr. L.H. Burckle, Prof. G.H. Denton, Prof. T.C. Partridge, Prof. E.S. Verba. Lamont-Doherty Geological Observatory/ University Of Maine, Transvaal Museum, Yale University | Paleoclimate and evolution |
| Dr. G.W. Dawis, S. Wand, National Botanical Institute | Sustainable utilization of plant resources in natural systems: effects of selective cropping on patterns of carbon assimilation under changing environmental conditions |
| Dr. M.T. Hoffman, National Botanical Institute | Photographic and historical evidence of vegetation change in semi-arid Karoo, South Africa |

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|---|---|
| C.R. Hurt, R.I. Yeaton, Dep. of Agriculture, Botany, Univ. of Natal | Distribution ecology of Acacia species along environmental gradients |
| C.R. Hurt, Dep. of Agriculture | Vegetation monitoring in Lowveld and arid Lowveld of Natal |
| Dr. J. Lindesay, Dr. H. Annagam, Dr. B.W. van Wilgen, Mr. G. Tosen, Dr. R. Scholes. CSIR, ESKOM, University of Witwatersrand | Southern African fire atmosphere research initiative |
| Prof. T.S. McCarthy. University of Witwatersrand | Study of the chemical and physical processes underpinning the Okavango ecosystem |
| Prof. J.C. Menart (International collaborators) Dr. R.J. Scholes (South African team). Botany Department, University of Witwatersrand | Responses of savannas to stress and disturbance |
| P.J. Mustart, R.M. Cowling, Botany Dep. Univ. of Cape Town | Impact of climate change on seed germination ecology of selected arid fynbos species |
| A.R. Palmer. Grassland Research Centre | The development of a log-linear model for Nama-karoo vegetation and its application to monitoring Karoo |
| G.A. Pickett, Dr. M.T. Hoffman, L.W. Powrie, Dr. M.C. Rutherford. National Botanical Institute | Patterns and dynamics of soil erosion and vegetation in Succulent Karoo rangeland |
| Dr. M.C. Rutherford, M.O´Callaghan, L.W. Powrie. National Botanical Institute | Modelling the impacts of climatic and land-use change: Spatial and compositional shifts of plant populations and communities |
| V.R. Smith, R Van Aarde, J. Skinner.Botany Dep. Univ. of the OFS, Mammal Research Institute, Univ. of Pretoria | Ecological implications of a changing climate at a Sub-Antarctic island |
| Prof. M. Swift, Prof. P.A. Sanchez (International collaborators), Dr. R.J. Scholes, Dr. M.C. Scholes (South African team). Botany Department, University of Witwatersrand | Tropical soil biology and fertility programme |
| B. Turner. EMATEK, CSIR | Vegetation monitoring by means of NOAA AVHRR data |

| | |
|---|---|
| Prof. L.G. Underhill, J.A. Harrison.Dep. of Mathematical Statistics, Univ. of Cape Town | Southern Africa bird atlas project |
| Prof. L.G. Underhill, T.B. Oatley. Dep. of Staistical Sciences, Univ. of Cape Town | South Africa bird ringing unit |
| P.C. Viljoen, National Parks Board | Ecological aerial surveys in the Kruger National Park |
| C.N. Webber, T.H. Van Rooyen, E Verster. University of South Africa | A study of desertification processes in the Karoo biome with special reference to soil and plants |

## Marine systems:

| Project leader(s), research institution(s) | Project title |
|---|---|
| Prof. G.B. Brundrit, Dr. F.A. Shillington. University of Cape Town | Sea level rise: impacts and adaptive responses |
| J. Cooper, Percy Fitzpatrick Institute of African Otnithology, Univ. of Cape Town | Demography, climate change and life-history styles of surface nesting seabirds at Marion island |
| R. Crawford, P. Brown, C Raubenheimer. Sea Fisheries Research Institue | Climate change and South Africa's living marine resources |
| A.H. Dye. University of the Transkei | Coastal silt loading and its effects on intertidal filterfeeders |
| Dr. G.R. Hughes. National Parks Board | South African turtle monitoring project |
| Dr. L. Hutchings. Sea Fisheries Research Institute | Plankton biomass and production in relation to hydrography and pelagic fish distribution |
| M.I. Lucas, J.R.E. Lutjeharms, J.G. Field, C. McQuiad. Univ. of Cape Town Zoology and Oceanography Dep. Rhodes Univ. Zoology Dep. | The Antarctic marine ecosystem and global climate change |
| A. McLachlan. University of Port Elizabeth | Sandy Coast |
| Mr. P.M.S. Monteiro, Dr. L.F. Jackson. Sea Fisheries Research Institute | Marine Eutrophication Project |

| | |
|---|---|
| Dr. D.E. Pollock et al. Sea Fisheries Research Institute | Atmospheric $CO_2$ regulation by diatom production and shelf carbon deposition |
| M. Waltner, Prof. L.G. Underhill. Dep. of Statistical Studies, Univ. of Cape Town | Western Cape Wader Study Group |

## Sweden

*Chairman of the national IGBP Committee*: Nils Malmer, University Lund, Dept. of Plant Ecology, Östra Vallgatan 14, 223 61 Lund.

Contact persons for specific projects.

| Name(s), address | Project title |
|---|---|
| Göran Ågren, Swedish University of Agricultural Sciences, Dept. of Ecology and Env. Research, P.O.Box 7072, S-750 07 Uppsala. Tel: +46-18 67 24 49. Fax: +46-18 30 28 76 | Models of biosphere reactions to increased carbon dioxide in the atmosphere |
| Colin Prentice, Swedish University of Agricultural Sciences, Dept. of Ecological Botany, Box 559, , S-751 22 Uppsala. Tel: +46-18 18 28 50. Fax: +46-18 55 34 19 | Simulation modelling of global vegetation change |
| Christina Skarpe, Swedish University of Agricultural Sciences, Dept. of Eclogical Botany, P.O. Box 559, S-751 22 Uppsala. Tel: +46-18 18 28 65. Fax: +46-18 55 34 19 | Regulatory mechanisms in woody vegetation in arid savanna |
| Martin Sykes, Swedish University of Agricultural Sciences, Dept. of Ecological Botany, Box 559, S-751 22 Uppsala. Tel: +46-18 18 28 50. Fax: +46-18 55 34 19. | Sensitivity of natural forsts to climate change |
| Sune Linder, Swedish University of Agricultural Sciences, Dept. of Ecology and Env. Research, Box 7025, S-750 07 Uppsala. Tel: +46-18 67 24 40. Fax: +46-18 30 28 76 | Plant physiology and environmental changes |
| Björn Berg, Swedish University of Agricultural Sciences, Dept. of Forest soils, P.O.Box 7001, S-750 07 Uppsala. Tel: +46-18 67 24 39. Fax: +46-18 30 08 31 | Organic matter turnover in a Western European climate transect in coniferous forests |
| Leif Kullman, University of Umeå, Dept. of Physical Geography, S-901 87 Umeå. Tel: +46-90 16 68 93. Fax +46-90 16 63 59 | Effects of climate change on vegetation in subalpine environment - indications and mechanisms |

Olle Tenow, Swedish University of Agriculatural Sciences, Division of Forest Entomology, Dept. of Plant Forest Protection. P.O. Box 7044, S-750 07 Uppsala. Tel: +46-18 67 23 36. Fax: +46-18 30 17 26

The Autumnal Moth, the Winter Moth and the Mountain Birch forest in a warmer climate

## 3.12 United Kingdom

*Chairman of the national IGBP-Committe:* Prof. Peter Liss, School of Environ. Sci., University of East Anglia, Norwich NR4 7TJ. Tel: +44-603 592 563´; Fax: +44-603 507 719

*TIGER IV coordinator*: C.P. Cummings, Institute of Terrestrial Ecology, Monks Wood Experimental Station, Abbots Ripton, Huntingdon PE17 2LS. Tel: +44 4873 381; Fax: +44 4873 467

Requests for the U.K. GERD: Steve Morgan, UK GER Office, Polaris House, North Star Avenue, Swindon SN2 1EU

| Name(s), address | Project title |
|---|---|
| Professor Paul Gordon Jarvis, University of Edinburgh, The Institute of Ecology and Resource Management, Darwin Building, King's Buildings, Mayfield Road, Edinburgh, EH9 3JU. Tel: +44-31-650-5426; Fax: +44-31-662-0478; E-Mail: EBF554@ED.AC.UK | The likely impact of elevated $CO_2$ and temperature on European forests |
| Professor Paul Gordon Jarvis, University of Edinburgh, The Institute of Ecology and Resource Management Darwin Building, King's Buildings, Mayfield Road, Edinburgh EH9 3JU. Tel: +44-31-650-5426; Fax: +44-31-662-0478; E-Mail: EBF554@ED.AC.UK | Sensitivity of heat and water vapour fluxes of vegetation to changes in canopy phenology, physiology and structure resulting from $CO_2$ fertilisation |
| Professor Paul Gordon Jarvis, see above | The $CO_2$ exchanges of Sahelian vegetation in HAPEX-II-SAHEL |
| Professor Paul Gordon Jarvis, see above | Net carbon dioxide uptake of Scottish forests |
| Professor Paul Gordon Jarvis, see above | The $CO_2$ exchanges of boreal forest in BOREAS |
| Professor Terry A Mansfield, Lancaster University, The Institute of Environmental and Biological Sciences,Lancaster LA1 4YQ. Tel: +44-524-65201; Fax: +44-524-843854 | Effects of $CO_2$ enrichment of the atmosphere on water use by trees and herbaceous plants. |

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|---|---|
| Dr. Malcolm C. Press, University of Manchester, Department of Environmental Biology, Manchester M13 9PL. Tel: +44-61-275-3849; Fax: +44-61-275-3938 | Arctic ecosystems and environmental change |
| Dr. Jeremy David Barnes, University of Newcastle, Dept of Agriculture and Environmental Science, The Ridley Building, Newcastle upon Tyne NE1 7RU. Tel: +44-91 2227899; Fax: +44-91 2611182 | Interactions between $CO_2$, $O_3$ and soil moisture deficit |
| Mr Frank Bristo Thompson, University of Oxford, Oxford Forestry Institute, Department of Plant Sciences, South Parks Road, Oxford OX1 3RB. Tel: +44-865-275000; Fax: +44-865-275074 | The effects on anthrogenic perturbations in the atmospheric composition ($0_3$, $SO_2$, $NO_x$, $CO_2$) on plant and soil systems. |
| Professor David Atkinson, Scottish Agricultural College, Dept of Land Resources, 581 King Street, Aberdeen AB9 1UD. Tel: +44-224-480291; Fax: +44-224-276962 | Effect of climate change on tree root growth, carbon flows and nutrient cycling |
| Miss Rachel Ferris, University of Sussex, Department of Population & Plant Biology, Biological Sciences, Falmer, Brighton BN1 9OG. Tel: +44-273 606755; Fax: +44-273 678433 | Effects of $CO_2$ and ozone on downland vegetation and possibly beech |
| Dr. John Farrar, University College of North Wales, School of Biological Sciences, Bangor, Gwynedd LL57 2UW. Tel: +44-248-351151; Fax: +44-248-370731 | Elevated Atmospheric $CO_2$ and Temperature: Effects on Growth, Physiology and Biochemistry of Plants |
| Dr. Alastair Fitter, University of York, Dept of Biology, York YO1 5DD. Tel: +44-904 432814; Fax: +44-904 432860; E-Mail: AHF1@UK.AC.YORK,VAXA | Below ground carbon allocation in relation to atmospheric $CO_2$ enrichment and temperature |
| Dr. Peter Freer-Smith, Forestry Commission, Research Division, Site Studies (South), Alice Holt Lodge, Farnham, Surrey GU10 4LH. Tel: +44-420 22255; Fax: +44-420 23653 | Forestry and Environmental Change Effects of Air Pollution on Trees |
| Dr. Melvin G. R. Cannell, NERC Institute of Terrestrial Ecology (North), Edinburgh Research Station, Bush Estate, Penicuik, Midlothian, Scotland EH26 0QB. Tel: +44-31-4454343; Fax: +44-31-4453943 | Process-based modelling of grasslands and forests: $CO_2$-fertilization and climate effects on carbon storage. |

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|---|---|
| Dr. Sarah Woodin, University of Aberdeen, Department of Plant and Soil Science, St Machar Drive, Aberdeen, AB9 2UD. Tel: +44-224 272688, Fax: +44-224 272268. | Effects of elevated nitrogen availability on the growth and mycorrhizal infection of Arctic dwarf shrubs |
| Dr. Sarah Woodin, see above. | Air pollution, climate change and the ecology of snowbed vegetation |
| Dr. Martin C Bridge, City of London Polytechnic, Geography Dept., Old Castle Street, London. Tel: +44-71 320 1029; Fax: +44-71 320 1117; E-Mail: M.BRIDGE@UK.AC.CLP.TUAX | Dendrochronological study of storm-felled trees from Royal Botanic Gardens, Kew, Surrey, UK |
| Associate Professor Steven Cousins, Cranfield Institute of Technology, International Ecotechnology Research Centre, Cranfield, Bedford, MK43 OAL. Tel: +44-234 752797; Fax: 0234 750163. | Global biodiversity monitoring. Climate effects on Ecosystems |
| Dr. Francisco Perez-Trejo, Cranfield Institute of Technology, International Ecotechnology Research Centre, Cranfield, Bedford, MK43 OAL. Tel: +44-234 752797; Fax: +44-234 750163 | EEC MEDALUS Programme (Mediterranean Desertification & Land Use) |
| Dr. Brian Huntley, University of Durham, Environmental Research Centre, Dept of Biological Sciences, South Road, Durham DH1 3LE. Tel: +44-91 374 2432; Fax: +44-91 374 2432, E-Mail: Brian Huntley @UK.AC Durham | DoE Core Model Project |
| Dr. David Watts, University of Hull, School of Geography, Hull HU6 7RX. Tel: +44-482-465421; Fax: +44-482-466340 | Vegetation change from global warming in Korea |
| Dr. Nick Carter, AFRC Institute of Arable Crops Research, Farmland Ecology Group, Dept of Entomology and Nematology, Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ. Tel: 0582 763133, Fax: 0582 760981 | Modelling the effects of climate change on aphids and their natural enemies |
| Dr. Ronald I Lewis Smith, British Antarctic Survey, Terrestrial and Freshwater Life Sciences Division, High Cross, Madingley Road, Cambridge, CB3 0ET. Tel: +44-223-61188; Fax: +44-223-62616; E-Mail: CBS%UK.AC.NBS.VC::U-RILS | Ecosystem and community development |

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|---|---|
| Dr. David D Wyn-Williams, British Antarctic Survey, Terrestrial and Freshwater Life Sciences Division, High Cross, Madingley Road, Cambridge CB3 0ET. Tel: +44-223-61188; Fax: +44-223-62616; E-Mail: CBS%UK.AC.NBS.VC::U-DDWW | Colonisation of terrestrial environments |
| Dr. John Innes, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH. Tel: +44-420 22255; Fax: +44-420 23653 | Effects of climate change and management on the growth of trees in Britain |
| Dr. David J Royle, The Institute of Arable Crops Research , University of Bristol, Dept of Agricultural Sciences, Long Ashton Research Station, Long Ashton, Bristol BS18 9AF. Tel: +44-275 392181; Fax: +44-275 394007 | Implications of Climate change for Plant Disease Occurrence |
| Dr. Patricia Anne Nuttall. NERC, Institute of Virology & Environmental Microbiology, Mansfield Road, Oxford OX1 3SR. Tel: +44-865-512361; Fax: +44-865-59962 | Ecology and Evolution of Tick-Borne Orbiviruses |
| Dr. B K Wyatt, NERC Environmental Information Centre, ITE Monks Wood, Abbots Ripton, Huntingdon CambsPE17 2LS. Tel: +44-4873-381; Fax: +44-4873-467 | Landscape Dynamics and Climate Change at National and Regional Scales |
| Andrew Eatherall, NERC Institute of Hydrology, Wallingford, Oxon OX10 8BB. Tel: 0491 38800; E-Mail: AEA@NWL.UA | Modelling climate change impacts on biochemical and ecological systems: core model project |
| Dr. Richard Harding, NERC Institute of Hydrology, Wallingford, Oxon, OX10 8BB. Tel: +44-491 38800; Fax: +44-491 32256 | Understanding of SVATS for Global Modelling Using Mesoscale and Hydrological Models |
| Dr. Christopher James Reading, NERC Institute of Terrestrial Ecology, Furzebrook Research Station, Wareham Dorset BH20 5AS. Tel: +44-929 551518; Fax: +44-929 551087 | Vertebrate Population and Tropical Ecology (Amphibians and Reptiles) |
| Dr. Nigel Webb, NERC Institute of Terrestrial Ecology Furzebrook Research Station, Wareham, Dorset BH20 5AS. Tel: +44-929-551518; Fax: +44-929-551087 | Preliminary Study of Indicator Plants and Plant Communities |
| Dr. Mark Tatchell, Rothamstead Experimental Station, Harpenden, Herts AL5 2JQ. Tel: +44-582 763133; Fax: +44-582 760981 | Effects of climate change in insect populations |

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|---|---|
| Dr. John Innes, Seale Cottage, Gracious Street, Selborne Alton, Hampshire GU34 3JE. Tel: +44-42 050 396 | Effects of environmental change on the growth of trees in southern Chile |
| Mr Jeff Kirby, The Wildfowl and Wetlands Trust, Slimbridge, Glos GL2 7BT. Tel: +44-453 890333; Fax: +44-453 890827; E-mail: SL_JSK@UK.AC.WSL.VA | National Waterfowl Counts/Special Surveys |
| Dr. Robert Colin Welch, NERC Institute of Terrestrial Ecology (South) Monks Wood Experimental Station, Abbots Ripton, Huntingdon, Cambs PE17 2LS. Tel: +44-4873 381; Fax:+44-4873 467 | a) Effects of climate change on Ghanaian Terrestrial & Freshwater Ecosystems. b) ODA Climate Change Country Study Ghana. |
| Dr. Richard Alun Griffiths, University of Kent, The Durrell Institute of Conservation and Ecology. Canterbury, Kent, CT2 7NX. Tel: 0227-764000, Fax: 0227-475481 | Global warming and surface water acidification: their role in structuring amphibian assemblages |
| Dr. David Glen George, NERC Institute of Freshwater Ecology, Windermere Laboratory Far Sawrey, Ambleside, Cumbria LA22 OLP. Tel: +44-5394 42468; Fax: +44-5394 46914; E-Mail: UK.AC.NWI.VA(WI-DGG) | Impact of climate change on freshwater ecosystems airborne and satellite remote sensing of freshwater lakes. |
| Mr George Hugh Mieczystaw Jaworski, NERC Institute of Freshwater Ecology Windermere Laboratory, Far Sawrey, Ambleside, Cumbria LA22 OLP. Tel: +44-5394 42468; Fax: +44-96 62 6914; E-Mail: W1 GHJ @ NW1.VA | Long-term assessment of physical and biological components in waters of the Windermere catchment |
| Professor Michael A Sleigh, University of Southampton, Department of Biology, Biomedical Sciences Building, Bassett Crescent East, Southampton Hants SO9 3TU. Tel: +44-703-594397; Fax: +44-703-594269 | Biogeochemical ocean flux study (component on particle production and fate). (Further projects in planning stage). Part of Joint Global Ocean Flux Study |
| Dr. Valerie J Smith, University of St Andrews, Gatty Marine Laboratory, Fife, Scotland FY16 8LB. Tel: +44-334-76161; Fax: +44-334-78922 | Temperature change and marine organisms (part-investigator in inter-institute study programme) |

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|---|---|
| Dr. Jonathan R French,University College London, Department of Geography, 26 Bedford Way, London WC1H 0AP. Tel: +44-71 387 7050; Fax: +44-71 380 7565, E-mail: JRF3@UK.AC.CAM.PHX | Predictive Modelling of Backbarrier Salt Marsh Response to accelerated sea-level rise, Norfolk, UK. |
| Dr. L A Boorman, NERC Institute of Terrestrial Ecology (South), Monks Wood Experimental Station, Abbots Ripton, Huntingdon, Cambridgeshire PE17 2LS. Tel: +44-4873 381; Fax: +44-4873 467 | Climate Change Sea Level Rise and the English Coast |

## 3.13 United States of America

*Chairman of the national IGBP Committe:* Ralph J. Cicerone. Geosciences Dep., 220 Physical Sciences Building, Univ. of California, Irvine Tel 095 1 714 725 2157. E-mail: R. Cicerone (Omnet)

### 3.13.1 Department of Energy:

3.13.1.1 Vegetation Research :
*Program Manager*: Roger C. Dahlman, Environmental Sciences division, ER-74, Office of Helath and Environmental Research, Office of Energy Research, Department of Energy, Washington, DC 20585. Tel: +1-301 903-4951; Fax: +1-301 903 5051

3.13.1.2. National Institute for Global Environmental Change (NIGEC):
*Program manager*: Jerry W. Elwood, Environmental Sciences Division, Department of Energy, ER-74, Washington, DC 20585. Tel: +1-301 903 3281

### 3.13.2 Department of Agriculture

3.13.2.1 Improved Response Models

Dr. Boyd Post, USDA/CSRS, Rm 329L, AEROSPACE, Washington, DC 20250. Tel: +1-202-401 5016; Fax: +1-202-401 1706

3.13.2.2 Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX)

Dr. Elvia Niebla, USDA/FS/FASR, AUDUTORS BLDG, Washington, DC 20250. Tel: +1-202-205 1561; Fax: +1-202 205 2497

3.13.3.3 Ecological Systems Dynamics (ECODYN)

Dr. Elvia Niebla
see above.

**3.13.3 U.S. Environmental Protection Agency (EPA)** Office of Research and Development

*Subsection author*: Dr. Peter A. Beedlow, Technical Director, U.S. Environmental Protection Agency, Environmental Research Laboratory, 200 SW 35th Street, Corvallis, Oregon 97333

Contact persons for the EPA research and project areas:

3.13.3.1. Observations and Data Management
a. North American Landscape Characterization.
*Contact*: Ross Lunneta, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, NV 89193; Tel: (702) 798-2175; Fax: (702) 798-2692.

b. Monitoring Tropical Deforestation/Biomass Burning.
*Contact*: Ross Lunneta, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, NV 89193; Tel: (702) 798-2175; Fax: (702) 798-2692.

c. Atmospheric Chemistry Measurements.
*Contact*: Joseph E. Sickles II, U.S. Environmental Protection Agency, Atmospheric Research and Exposure Laboratory, RTP, NC; Tel: (919) 541-2446; Fax: (919) 541-1379.

3.13.3.2. Process Studies
a. Biogeochemical Cycling
*Contact*: Lee Mulkey, U.S.. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA 30613; Tel: (706) 546-3129; Fax: (706) 546-2018.
b. Effects on Ecosystems.
*Contact*: David Tingey, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4621; Fax: (503) 754-4799.

3.13.3.3. Modeling
a. Terrestrial systems response, vegetation redistribution, and the related water balance
*Contact*: Allen Solomon, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4772; Fax: (503) 754-4799.
b. Biogeochemical cycling
*Contact*: Lee Mulkey, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA 30613; Tel: (706) 546-3129; Fax: (706) 546-2018.
c. Earth Systems Modeling
*Contact*: Lee Mulkey, see above.

d. Terrestrial Systems Model Evaluation
Contact: Allen Solomon, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4772; Fax: (503) 754-4799.

3.13.3.4. Ecological Assessment
a. Carbon pools and fluxes for managed ecosystems including forests and agricultural systems
*Contact*: Jeff Lee, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4578; Fax: (503) 754-4799.
b. Effects on sensitive habitats and ecosystems
*Contact*: Don Phillips, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4485; Fax: (503) 754-4799.
c. Enhancement of terrestrial sinks for $CO_2$ in vegetation and soils

*Contact*: Tom Barnwell , U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA 30613; Tel: (706) 546-3180; Fax: (706) 546-3340.

d. International Assessments
*Contact*: Robert Dixon, U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR 97333; Tel: (503) 754-4578; Fax: (503) 754-4799.

### 3.13.4 NASA - National Aeronautics and Space Administration
Earth Science and Application Division (ESAD)

Terrestrial Ecology Program:

Manager: Anthony C. Janetos. NASA HQ, Code SEP03, NASA, Washington, DC 20546. Tel: +1-202 358 0272; Fax: +1-202 358 3098.

## C. List of project titles

This appendix provides a list of the titles of all projects (and, in some instances, programs or research areas) described in *Chapter 3*. It is divided into terrestrial, freshwater, and, marine ecosystems. The titles are given in the order in which they appear in Chapter 3, i.e. sorted by country.

### Terrestrial ecosystems

3.1.1 An investigation into the impact of elevated $CO_2$ upon the response of European forests
3.1.2 Global change effects of elevated atmospheric $CO_2$ levels and increased air temperature on grassland ecosystems
3.1.3 Ecophysiological study of the effects of high atmospheric $CO_2$ concentration on a forest ecosystem in open top chambers
3.1.4 Effects of increased atmospheric $CO_2$ content on primary productivity and carbon allocation in typical Belgian forest ecosystems
3.1.5 Changes in the biogeochemistry of carbon in terrestrial ecosystems
3.1.6 Thermal biology of European reptiles: Toward a prediction of climate change effects
3.1.7 Detectability of land systems by classification of Landsat Thematic Mapper data, Virunga National Park, Zaïre
3.1.8 $N_2O$ production through biological denitrification in soils
3.1.9 Wetlands and waterbirds: Effects of global change
3.2.1 Boreal Ecosystems Atmospheric Study (BOREAS)
3.2.2 Northern Biosphere Observation and Modeling Experiment (NBIOME)
3.2.3 Paleoecological Analysis of the Treeline (PACT)
3.2.4 Integration of Remote Sensing Data in a Geographic for Impact Modeling of Long-term Climate Change in Québec's Boreal Forests (BIOMTEL)
3.2.5 Mackenzie Basin Impact Study (MBIS)
3.3.1 The development of remote sensing technique in monitoring and studying vegetation dynamics on continental scale
3.3.2 The development of a regional climate model for the study of climate impacts on ecosystems
3.3.3 Model simulation on the effects of regional climate changes on ecosystems
3.3.4 Development of patch scale atmosphere-vegetation model
3.4.1 ZERO - Zackenberg Ecological Research Operations. Global change studies in an high Arctic ecosystem

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|---|---|
| 3.4.2 | The Physiology of "Red" Norway Spruce, and the selection of healthy provenances |
| 3.4.3. | Biological monitoring of climatic changes by plant population dynamics - an ITEX experiment |
| 3.4.4 | Sensitivity of Arctic terrestrial ecosystems towards global climate change, in particular with respect to UV-B radiation and temperature variation |
| 3.4.5 | Exchange of ammonia and other trace gases between plants and the atmosphere |
| 3.4.6 | Denitrification in European forests. Biogenic $N_2O$ emissions |
| 3.5.1 | Response of the boreal forest ecosystem to changing climate and its sivicultural implications |
| 3.5.2 | The effect of climate on the phenology of perennial plant species |
| 3.5.3 | Physiological and genetical adaptation of forest trees to climate changes |
| 3.5.4 | Anthropogenic environmental changes and the risk of forest insect outbreaks |
| 3.5.5 | The development of a soil/plant/atmosphere model |
| 3.5.6 | Carbon balance of peatlands and climatic change |
| 3.6.1 | Le Programme National d'Etude de la Dynamique du Climat (PNEDC) |
| 3.6.2 | Le Programme Atmosphère Météorologique et Océan Superficiel (PAMOS) |
| 3.6.5 | Le Programme Phase Atmosphérique des Cycles Biogéochimiques |
| 3.6.6 | Le Programme Ecosystèmes |
| 3.7.1 | Effects of increasing $CO_2$ concentrations on plants and terrestrial ecosystems |
| 3.7.2 | Regulation of the energy- and water-exchange of vegetation surfaces |
| 3.7.3 | Regulation of the biogeochemical cycles of C, N, S and P by global change |
| 3.8.1 | An investigation on the physiological response of plants to elevated $CO_2$ in the atmosphere, with emphasis on root physiology |
| 3.8.2 | The seasonal cycle of the $CO_2$ exchange between atmosphere and vegetated surfaces |
| 3.8.3 | Distribution of carbon over plant and soil compartments during the growth of perennial plants at elevated atmospheric $CO_2$ concentrations |
| 3.8.4 | Quantification of carbon fluxes in grasslands |
| 3.8.5 | Effects of increased $CO_2$ levels and temperature on plant production and plant biomass turnover |
| 3.8.6 | Effect of doubling atmospheric $CO_2$ on the water balance of forested land surface |

3.8.7. Phenological reactions of the main Dutch tree species to climate change described by a simulation of the annual cycle.
3.8.8 Regional climate change and its effect on forest productivity
3.9.1 Effects of high $CO_2$ concentrations on different horticultural and agricultural crops at various soil and climate conditions
3.9.2 STEP (Scandinavian Terrestrial Ecosystem Profile) - an all-Scandinavian terrestrial climate change research programme
3.9.3 Bioclimatic limits for plant functional types in Europe
3.9.4 Effects of rapid climatic change on plant diversity in boreal and montane ecosystems
3.9.5 Production of greenhouse gases from biological processes in soil
3.9.6 Effects of climate change on growth and development on northern landscape plants
3.9.7 Winter dormancy and climate change relations in boreal forest trees
3.9.8 Genetic stability studies in order to evaluate the greenhouse effect upon evolution and tree breeding
3.10.1 The effects of elevated atmosphere $CO_2$ on plant carbon allocation in resource-poor environments
3.10.2 Paleoclimate and evolution
3.10.3 Sustainable utilization of plant resources in natural systems: effects of selective cropping on patterns of carbon assimilation under changing environmental conditions
3.10.4 Photographic and historical evidence of vegetation change in semi-arid Karoo, South Africa
3.10.5 Distribution ecology of Acacia species along environmental gradients
3.10.6 Vegetation monitoring in Lowveld and arid Lowveld of Natal
3.10.7 Southern African fire atmosphere research initiative
3.10.8 Study of the chemical and physical processes underpinning the Okavango ecosystem
3.10.9 Responses of savannas to stress and disturbance
3.10.10 Impact of climate change on seed germination ecology of selected arid Fynbos species
3.10.11 The development of a log-linear model for Nama-karoo vegetation and its application to monitoring Karoo
3.10.12 Patterns and dynamics of soil erosion and vegetation in Succulent Karoo rangeland
3.10.13 Modelling the impacts of climatic and land-use change: Spatial and compositional shifts of plant populations and communities
3.10.14 Ecological implications of a changing climate at a Sub-Antarctic island
3.10.15 Tropical soil biology and fertility programme
3.10.16 Vegetation monitoring by means of NOAA AVHRR data

3.10.17 Southern Africa bird atlas project
3.10.18 South Africa bird ringing unit
3.10.19 Ecological aerial surveys in the Kruger National Park
3.10.20 A study of desertification processes in the Karoo biome with special reference to soil and plants
3.11.1 Models of biosphere reactions to increased carbon dioxide in the atmosphere
3.11.2 Simulation modelling of global vegetation change
3.11.3 Regulatory mechanisms in woody vegetation in arid savanna
3.11.4 Sensitivity of natural forests to climate change
3.11.5 Plant physiology and environmental changes
3.11.6 Organic matter turnover in a Western European climate transect in coniferous forests
3.11.7 Effects of climate change on vegetation in subalpine environment - indications and mechanisms
3.11.8 The Autumnal Moth, the Winter Moth and the Mountain Birch forest in a warmer climate
3.12.1 The likely impact of elevated $CO_2$ and temperature on European forests
3.12.2 Sensitivity of heat and water vapour fluxes of vegetation to changes in canopy phenology, physiology and structure resulting from $CO_2$ fertilisation
3.12.3 The $CO_2$ exchanges of Sahelian vegetation in HAPEX-II-SAHEL
3.12.4 Net carbon dioxide uptake of Scottish forests
3.12.5 The $CO_2$ exchanges of boreal forest in BOREAS
3.12.6 Effects of CO2 enrichment of the atmosphere on water use by trees and herbaceous plants.
3.12.7 Arctic ecosystems and environmental change
3.12.8 Interactions between $CO_2$, $O_3$ and soil moisture deficit
3.12.9 The effects on anthropogenic perturbations in the atmospheric composition ($0_3$, $SO_2$, $NO_x$, $CO_2$) on plant and soil systems.
3.12.10 Effect of climate change on tree root growth, carbon flows and nutrient cycling
3.12.11 Effects of $CO_2$ and ozone on downland vegetation and possibly Beech
3.12.12 Elevated Atmospheric CO2 and Temperature: Effects on Growth, Physiology and Biochemistry of Plants
3.12.13 Below ground carbon allocation in relation to atmospheric $CO_2$ enrichment and temperature
3.12.14 Forestry and environmental change effects of air pollution on trees

3.12.15 Process-based modelling of grasslands and forests: $CO_2$-fertilization and climate effects on carbon storage
3.12.16 Effects of elevated nitrogen availability on the growth and mycorrhizal infection of Arctic dwarf shrubs
3.12.17 Air pollution, climate change and the ecology of snowbed vegetation
3.12.18 Dendrochronological study of storm-felled trees from Royal Botanic Gardens, Kew, Surrey, U.K.
3.12.19 Global biodiversity monitoring. Climate effects on Ecosystems
3.12.20 EEC MEDALUS Programme (Mediterranean Desertification & Land Use)
3.12.21 DoE Core Model Project
3.12.22 Vegetation change from global warming in Korea
3.12.23 Modelling the effects of climate change on aphids and their natural enemies
3.12.24 Ecosystem and community development
3.12.25 Colonisation of terrestrial environments
3.12.26 Effects of climate change and management on the growth of trees in Britain
3.12.27 Implications of climate change for plant disease occurrence
3.12.28 Ecology and evolution of tick-borne orbiviruses
3.12.29 Landscape dynamics and climate change at national and regional scales
3.12.30 Modelling climate change impacts on biochemical and ecological systems: core model project
3.12.31 Understanding of SVATS for global modelling using mesoscale and hydrological models
3.12.32 Vertebrate population and tropical ecology (amphibians and reptiles)
3.12.33 Preliminary study of indicator plants and plant communi-ties
3.12.34 Effects of climate change in insect populations
3.12.35 Effects of environmental change on the growth of trees in southern Chile
3.12.36 National Waterfowl Counts/Special Surveys
3.12.37 a) Effects of climate change on Ghanaian terrestrial & freshwater ecosystems. b) ODA Climate Change Country Study Ghana.
3.13.1.1 Integration of experimental and modeling approaches to study competitive interactions among plants under elevated $CO_2$
3.13.1.1 Photosynthetic acclimation to elevated $CO_2$: Basis for variability among plants
3.13.1.1 A field study of the effects of elevated ambient $CO_2$ on ecosystem processes in Chesapeake Bay Wetlands

3.13.1.1 Elevated $CO_2$: Modeling cotton response interactions with temperature on photosynthesis, insect population dynamics and temperature interactions, and long-term effects on trees

3.13.1.1 Experimental studies of ecosystem responses for elevated $CO_2$: Interactions with nitrogen, water, and species characteristics

3.13.1.1 $CO_2$ exchange, environmental productivity indices, and productivity of agave and cacti under current and elevated atmospheric $CO_2$ concentrations

3.13.1.1 Elevated $CO_2$ effects on woody plant soil systems

3.13.1.1 Response of tundra ecosystems to elevated atmospheric $CO_2$

3.13.1.1 Rangeland-plant response to elevated $CO_2$

3.13.1.1 Development of a generic ecosystem model for assessing the effects of elevated $CO_2$ on ecosystems

3.13.1.1 Integration of experimental and modeling approaches in the unmanaged-ecosystem research plan

3.13.1.2 $CO_2$ rise, nutrient dynamics, and litter decomposition in a deciduous forest ecosystem: Relationship between $CO_2$ levels, tissue chemistry, and litter decomposition

3.13.1.2 Decomposition rates and nutrient dynamics in a temperate forest: Effects of $CO_2$ and nitrogen enrichment

3.13.1.2 A field study of methane and carbon dioxide fluxes in a boreal wetland system: Measurement and analysis

3.13.1.2 Temporal and spatial variability of methane cycling in wetland ecosystems of the northern temperate zone

3.13.1.2 Simulation experiments of inertia in forest response to climatic warming

3.13.1.2 Climate and North American plant formations: Associations between the water balance and satellite-derived vegetation patterns

3.13.1.2 Adaptation, migration or extinction? A study of the influence of climate change on the biodiversity and biotic productivity of selected biomes of North America

3.13.1.2 Biological hysteresis in climate change models for the Great Plains: Implications for productivity and hydrologic cycles

3.13.1.2 Impact of global environmental change on biodiversity of mammals in the South-Central United States

3.13.1.2 Methan emissions from natural wetlands

3.13.1.2 Modeling patterns of $CO_2$ flux from forest ecosystems: Implications of climate change

3.13.1.2 Interactive vegetation for climate models over the seasonal cycle

3.13.1.2 Effects of global climate and atmospheric change on the structure and function of Mediterranean shrub ecosystems and associated forest ecotones in California
3.13.1.2 Modeling analyses of methane emissions from ruminants
3.13.1.2 Interactive effects of heat stress and elevated carbon dioxide concentration on plant reproduction
3.13.1.2 Plant and ecosystem respiration in a changing climate: Modeling and empirical studies
3.13.2.1 Improved Response Models
3.13.2.2 Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX)
3.13.2.3 Ecological Systems Dynamics (ECODYN)
3.13.3.1 North American Landscape Characterization
3.13.3.1 Monitoring Tropical Deforestation/Biomass Burning
3.13.3.1 Atmospheric Chemistry Measurements
3.13.3.2 Biogeochemical Cycling (process studies)
3.13.3.2 Effects on Ecosystems (process studies)
3.13.3.3 Terrestrial systems response, vegetation redistribution, and the related water balance (modeling)
3.13.3.3 Biogeochemical cycling (modeling)
3.13.3.3 Earth systems modeling
3.13.3.3 Terrestrial systems model evaluation
3.13.3.4 Carbon pools and fluxes for managed ecosystems including forests and agricultural systems (ecological assessment)
3.13.3.4 Effects on sensitive habitats and ecosystems (ecological assessment)
3.13.3.4 Enhancement of terrestrial sinks for $CO_2$ in vegetation and soils (ecological assessment)
3.13.3.4 International Assessments
3.13.4.1 Trace gas fluxes and carbon/nitrogen pools in the biosphere
3.13.4.2 Ecosystem function on landscape and regional scales
3.13.4.3 Links between ecosystem structural properties and function

**Freshwater ecosystems**

3.1.9 Wetlands and waterbirds: Effects of global change
3.1.10 Human impact on biodiversity: Systematics, ecology and zoogeography of African freshwater fishes
3.1.11 Euthrophication and toxical algal blooms in surface waters
3.1.12 Effects of changing environmental conditions on energy metabolism in aquatic organisms
3.1.13 Climatic change and freshwater ecosystems
3.2.3 Paleoecological Analysis of the Treeline (PACT)
3.2.5 Mackenzie Basin Impact Study (MBIS)

3.5.7 Impact of climate change on carbon cycle in freshwater ecosystems
3.5.8 Effects of climate change, air pollutants and land use on lake ecosystems
3.5.9 Effects of climate change on fishes, fish stocks, fisheries and aquaculture
3.6.1 Le Programme National d'Etude de la Dynamique du Climat (PNEDC)
3.9.9 Possible effects of climatic changes on the ecology of Norwegian Atlantic salmon (*Salmo salar* M.)
3.12.36 National Waterfowl Counts/Special Surveys
3.12.37 a) Effects of climate change on Ghanaian terrestrial & freshwater ecosystems. b) ODA Climate Change Country Study Ghana.
3.12.38 Global warming and surface water acidification: their role in structuring amphibian assemblages
3.12.39 Impact of climate change on freshwater ecosystems airborne and satellite remote sensing of freshwater lakes.
3.12.40 Long-term assessment of physical and biological components in waters of the Windermere catchment
3.13.1.2 Genetic basis for variation in freshwater phytoplankton productivity related to water temperature
3.13.1.2 Potential effects of global climate change on midwestern lakes: Physics, fishes and plankton
3.13.1.2 Methan emissions from natural wetlands
3.13.1.2 A field study of methane and carbon dioxide fluxes in a boreal wetland system: Measurement and analysis
3.13.1.2 Temporal and spatial variability of methane cycling in wetland ecosystems of the northern temperate zone

**Marine ecosystems**

3.1.9 Wetlands and waterbirds: Effects of global change
3.6.1 Le Programme National d'Etude de la Dynamique du Climat (PNEDC)
3.6.2 Le Programme Atmosphère Météorologique et Océan Superficiel (PAMOS)
3.6.3 Le Programme Flux Océaniques (France - JGOFS)
3.9.9 Possible effects of climatic changes on the ecology of Norwegian Atlantic salmon (*Salmo salar* M.)
3.9.10 Effects of climatic changes on the biomass yield of the Barents Sea, Norwegian Sea and West Greenland Sea
3.9.11 Influence of climate variations on fish stocks in the North Sea
3.9.12 Climate variations of the Barents Sea and the effects on juvenile growth
3.9.13 Influence of turbulence on recruitment

3.9.14 Comparative studies on growth and survival of larval and juvenile cod from Atlantic stocks
3.10.21 Sea level rise: impacts and adaptive responses
3.10.22 Demography, climate change and life-history styles of surface nesting seabirds at Marion island
3.10.23 Climate change and South Africa's living marine resources
3.10.24 Coastal silt loading and its effects on intertidal filterfeeders
3.10.25 South African turtle monitoring project
3.10.26 Plankton biomass and production in relation to hydrography and pelagic fish distribution
3.10.27 The Antarctic marine ecosystem and global climate change
3.10.28 Sandy Coasts
3.10.29 Marine Eutrophication Project
3.10.30 Atmospheric $CO_2$ regulation by diatom production and shelf carbon deposition
3.10.31 Western Cape Wader Study Group
3.12.41 Biogeochemical ocean flux study (component on particle production and fate). Part of Joint Global Ocean Flux Study
3.12.42 Temperature change and marine organisms (part-investigator in inter-institute study programme)
3.12.43 Predictive Modelling of Backbarrier Salt Marsh Response to accelerated sea-level rise, Norfolk, U.K.
3.12.44 Climate Change Sea Level Rise and the English Coast
3.13.1.2 Effects of environmental factors on phytoplankton emissions of dimethyl sulfide: Implications for climate change

**D. Acronyms**

| | |
|---|---|
| AGCM | Atmospheric General Circulation Model |
| ARM | Atmospheric Ratioation Measurement Program (DOE/USA) |
| ATBIOX | Atmosphere/Biosphere Gas and Energy Exchange (DOA/USA) |
| AVHRR | Advanced Very High Resolution Radiometer |
| BAHC | Biospheric Aspects of the Hydrological Cycle |
| BITÖK | Bayreuth Institute für Terrestrische Ökosystemforschung (D) |
| BOREAS | Boreal Ecosystems Atmospheric Study (Ca &NASA) |
| CACGP | Commision on Atmospheric Chemistry and Global Pollution (IAMAP) |
| CEES | Committee on Earth and Environmental Sciences (USA) |
| CGCP | The Canadian Global Change Program |
| CHAMMP | Computer Hardware, Advanced Mathematics and Model Physics Program (DOE/USA) |
| CICERO | Centre for International Climate and Energy Research in Oslo |
| CLIMEX | Climate Change Experiment |
| CNRS | Centre National de la Recherche Scientifique (Fr) |
| CORE | Mechanisms of nutrient turnover in the soil compartment of forests |
| COST | European Cooperation in the Field of Scientific and Technical Research |
| CSRS | Cooperative State Research Service (DOA/USA) |
| DECO | Forest organic matter turnover in a European transect (ESF) |
| DGVM | Dynamic Global Vegetation Model |
| DIS | Data and Information System |
| DOA | Department of Agriculture (USA) |
| DOC | Department of Commerce (USA) |
| DOE | Department of Energy (USA) |
| DOI | Department of Interior (USA) |
| ECODYN | Ecological Systems Dynamics (DOA/USA) |
| ECOFIT | ECOsystèmes et paléoécosystèmes des Forêts Inter Tropicales (Fr) |
| EFTA | European Free Trade Association |
| EOS | Earth Observing System (NASA) |
| EPA | Environmental Protection Agency (USA) |
| EPOCH | European Programme on Climatology and Natural Hazards |
| ESAD | Earth Science and Application Division (NASA) |
| ESF | European Science Foundation |
| EXMAN | Experimental Manipulation of forest ecosystems in Europe (CEC) |
| FAM | Forschungsverbund Agrarökosysteme München (D) |
| FAM | Forest Assessment Model |

| | |
|---|---|
| FS | Forest Service (DOA/USA) |
| FT | Functional Type |
| FZW | Forschungszentrum Waldökosysteme (D) |
| GAIM | Global Analysis, Interpretation and Modelling (IGBP) |
| GCM | General Circulation Model |
| GCTE | Global Change and Terrestrial Ecosystems (IGBP) |
| GER | Global Environmental Research |
| GERD | Global Environmental Research Database |
| GEWEX | Global Energy and Water Cycle (WCRP) |
| GIS | Geographic Information System |
| GLOBEC | Global Ocean Ecosystem Dynamics |
| GOEZS | Global Ocean Euphotic Study (IGBP) |
| HDP | Human Dimensions of Global Change Program |
| HDGEC | Human Dimensions of Global Environmental Change |
| HRPT | High Resolution Picture Transmission |
| IAMAP | International Association of Meteorology and Atmospheric Physics |
| IASC | International Arctic Science Committe |
| IBP | International Biological Programme |
| ICAT | Impacts of Elevated CO2 Levels, Climate Change and Air Pollutants on Tree Physiology |
| ICES | International Council for the Exploration of the Sea. |
| ICSU | International Council of Scientific Unions |
| IGAC | International Gloobal Atmospheric Chemistry (IGBP) |
| IGBP | International Geosphere-Biosphere Programme |
| IIASA | International Institute for Applied System Analysis |
| IMAGE | Integrated Model to Assess the Greenhouse Effect |
| INRA | Institut National de la Recherche Agronomique (Fr) |
| IOC | Intergovernmental Oceanographic Commission |
| IPCC | Intergovernmental Panel on Climate Change |
| ISBI | International Sustainable Biosphere Initiative |
| ISLSCP | International Satellite Land Surface Climatology Project |
| ITEX | International Tundra Experiment |
| IUBS | International Union of Biological Sciences |
| IUCN | International Union for the Conservation of Nature and Natural Reseources |
| IWRB | International Waterfowl and Wetland Research Bureau |
| JGOFS | Joint Global Ocean Flux Study (IGBP) |
| LEMA | Long-term Ecosystem Modelling Activity |
| LOICZ | Land Ocean Interactions in the Coastal Zone (IGBP) |
| MAB | Man and the Biosphere |
| MBIS | Mackenzie Basin Impact Study (Ca) |
| NASA | National Aeronautics and Space Administration |

| | |
|---|---|
| NATO | North Atlantic Treaty Organization |
| NAVF | National Research Council for Science and Humanities (No) |
| NDVI | Normalized Difference Vegetation Index |
| NERC | Natural Environment Research Council (U.K.) |
| NBIOME | Northern Biosphere Observation and Modelling Experiment (Ca) |
| NIGEC | National Institute for Global Environmental Change (DoE/USA) |
| NMHC | Non methane hydrocarbons |
| NOAA | National Ocean and Atmospheric Administration (USA) |
| NSN | Northern Sciences Network (MAB) |
| PACT | Paleoecological Analysis of the Treeline (Ca) |
| PAMOS | Le Programme Atmosphère Météologique et Océan Superficiel (Fr) |
| PAMOY | Le Programme Atmosphére Moyenne (Fr) |
| PNEDC | Le Programme National d'Etude de la Dynamique du Climat (Fr) |
| RAIN | Reversing Acidification In Norway |
| RIVM | National Institute of Public Health and Environmental Protection (Ne) |
| SALT | Savannas A Long Term project (Fr) |
| SCAR | Scientific Committee on Antarctic Research |
| SCOPE | Scientific Committee on Problems of the Environment |
| SCOR | Scientific Committee on Oceanic Research |
| SILMU | The Finnish Research Programme on Climate Change |
| STEP | Science and Technology for Environmental Protection |
| SVAT | Soil-Vegetation Atmosphere Transfer |
| TERN | The Terrestrial Ecosystem Network of Germany |
| TIGER | Terrestrial Initiative in Global Environmental Research (U.K.) |
| TOGA | Tropical Ocean and Global Atmosphere Project (WCRP) |
| TSBF | Tropical Soil Biology and Fertility Programme (IUBS) |
| UNEP | United Nations Environment Programme |
| UNESCO | The United Nations Educational, Scientific, and Cultural Organization |
| USGCRP | The United States Global Change Research Program |
| USGS | United States Geological Survey |
| VAH | Verbundprojekt Agrarökosysteme Halle (D) |
| VOC | Volatile Organic Compounds |
| WCRP | World Climate Research Programme |
| WOCE | World Ocean Circulation Experiment (WCRP) |
| WMO | World Meteorological Organization |
| ZERO | Zackenberg Ecological Research Operations |