

Research plan for Danish research centre on

**"CLIMAtE change effects on biological  
processes In Terrestrial Ecosystems"  
CLIMAITE**

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## Summary

Human activities lead to increased atmospheric CO<sub>2</sub> concentrations that again will affect the global climate causing global warming and changes in precipitation patterns. The “Research Centre on Biological Effects of Climate Change” – CLIMAITE – is a multidisciplinary national Danish research initiative bringing together 6 research groups in order to study the biological effects of such climatic changes in terrestrial ecosystems. The aim of CLIMAITE is to develop a conceptual understanding of how climatic and environmental changes in concert will affect biological processes in terrestrial ecosystems. This will improve our understanding of interactions between external stress factors and biological processes and provide a stronger scientific background for societal and political actions to counteract negative consequences of climatic changes.

CLIMAITE will particularly focus on two issues related to biological processes and climate change, which are believed to play a key role for the biological effects of climate change: multiple environmental changes and temporal variation patterns. Multiple environmental changes are of central importance for the biological effects because the climatic changes will include simultaneous changes in at least three factors: atmospheric CO<sub>2</sub> concentrations, temperature and water availability. Each of these factors directly affect biological processes and there is increasing evidence that the combined effects of these changes will be very complex and include strong interactions between factors, and that the combined effects will be difficult to predict from the effect of the individual factors. Changes in temporal variation patterns including extension of the growing season, increased frequency of freeze/thaw cycles, number of frost free days, frequency of extreme weather events etc. are believed to play significant roles for the biological effects as compared to just average changes in the affecting factors.

The studies will be carried out in a new unique experimental field site in a semi natural terrestrial ecosystem where experimental manipulations with CO<sub>2</sub>, temperature and water will be conducted. The effects of the treatments on individual species, ecosystem structure and ecosystem functioning will be investigated through targeted studies on the soil, plants, meso- and micro fauna and microorganisms. The studies will include changes in carbon and nutrient balances and circulation, stress tolerance and adaptation, species competition and composition and plant tissue chemistry and herbivory. The research will take advantage of novel research tools including field scale ecosystem manipulations, stable isotope techniques, controlled herbivory and DNA techniques. The results from the new experiment will be compared with results from existing relevant field experiments in comparable ecosystems in the Denmark, Greenland and Sweden, which the partners in CLIMAITE are conducting. Such comparisons will be important in order to assess how transient or permanent the results may be and to assess the generality of the results across ecosystems and climatic regions.

The research involves a consortium of 6 research groups from Risø National Laboratory, University of Copenhagen, Royal Veterinary and Agricultural University and the National Environmental Research Institute. The consortium covers the wide range of disciplines needed for the research activities and is highly skilled within their field of expertise. Together, the consortium has strong links to national and international groups and networks of key relevance for the research within CLIMAITE. These contacts and networks will play an important role for the international scientific exchange.

CLIMAITE will provide a strong educational potential, and master and PhD students will be involved in all research activities. The results of the research will be published in high quality scientific journals, through participation in scientific conferences and workshops and through the scientific networks. Furthermore, CLIMAITE will provide general information for the public and policy makers on biological effects of climate change through publication of articles in popular scientific journals and launching of a web page.

## Background and State of the art

There is a growing consensus that 20th century human activities have induced dramatic and unprecedented changes in the global chemical and physical environment, including a ~33% increase in atmospheric CO<sub>2</sub> concentrations, a ~0.6°C increase in mean annual temperature, and changes in timing and magnitude of precipitation (IPCC 2001). Current predictions indicate that, unless greenhouse gas emissions are significantly curtailed, atmospheric CO<sub>2</sub> concentrations will double during the present century. This will induce an additional 1.4 to 5.8°C increase in mean global temperature, alterations in patterns of global air circulation and hydrologic cycling that will affect global and regional precipitation patterns, and increase the frequency and magnitude of severe weather events, including droughts and floods (Easterling et al., 2000; IPCC 2001). Consequently, the climatic and environmental conditions for the terrestrial ecosystems in the future include increased atmospheric CO<sub>2</sub>, increased temperature, changes in precipitation patterns and increased frequencies of extreme climatic events.

Such climatic and environmental changes will alone and in combination have strong effects on the terrestrial ecosystems. The change in atmospheric composition is likely to have direct effects on the earth's ecosystem through e.g. increased carbon (C) sequestration by photosynthesising organisms in an atmosphere richer in CO<sub>2</sub>. This, together with changes in water availability and temperature, which are fundamental drivers of all chemical and biological processes (Whittaker 1975; Jenny 1980), will play central roles in determining the future structure and function of terrestrial ecosystems. Proximate responses to changes in the atmosphere and the climate will translate into interactions among the biotic components of the ecosystem and create a complicated pattern of responses in the ecosystems as a whole. For instance, enhanced productivity due to increased photosynthesis is likely to change competitive interactions and the food-base for herbivores and microorganisms, thereby also changing the rates and means by which the organic matter and nutrients are turned over in the ecosystems. In other words, the predicted changes in atmospheric composition and their secondary effects on the climate are likely to induce a cascade of effects on ecosystem processes and ecosystem functioning that is extremely difficult to foresee.

The man-made perturbations of the atmospheric and climatic systems have not relevance only for ecosystem processes and functioning, but they can also feed back on the atmosphere and the climate and either accelerate or decelerate the changes. There are two main reasons for this. First, the exchange of C between the ecosystems and the atmosphere is controlled largely by biological processes with plant sequestration and decomposer release of C. The turnover time of C between the atmosphere and the earth's ecosystem is only between 3 and 4 years (IPCC, 2001), which illustrates the potential for small changes in the ecosystem C balance to affect the global C cycle and thereby feed back on the climate system. Second, changes in vegetation pattern affect the albedo and, hence, control the amount of radiation intercepted near the earth's surface. In general, increased biomass will increase the interception of radiation and contribute to a warming. This feedback system has received increasing attention, as the effect is likely to approach that of the warming associated with changed atmospheric gas composition (Foley et al., 2003). Hence, in addition to affect the ecosystems, the anticipated changes in the atmosphere and the climate system are, in turn, likely to be modified by feedbacks from the ecosystems themselves.

In order to gain an improved understanding on the environmental controls of biological processes, a large number of experimental manipulation studies have been initiated and conducted in terrestrial ecosystems around the world with measurements of subsequent biological changes. The manipulations include elevated CO<sub>2</sub>, increased temperature or changes in precipitation amounts or patterns (e.g. Kolb et al. 1990; Ellsworth and Reich 1992; Kleiner et al. 1992; Chapin et al. 1995; Lamersdorf et al., 1998; DeLucia et al 1999; Hartley et al 1999; Jonasson et al. 1999; Hanson, 2000; Shaver et al. 2000; Norby et al. 2001; Rustad et al. 2001; Llorens et al., 2003; Beier et al, 2003; Wright , 1998; Bergh and Linder, 1999). These manipulations have, however, not generally combined CO<sub>2</sub> increase with changes in both temperature and precipitation. Instead, they have either concentrated on responses to only one or two factors at a time or to combinations with factors, such as nutrients or light that

are secondary effects as consequences of primary changes in CO<sub>2</sub> and climate. These studies have given most valuable information on various controls of biological processes, but not necessarily of the most immediate responses that can be expected after the predicted changes in the environment.

It is well known that changes in CO<sub>2</sub>, temperature and precipitation will interact. Increases in CO<sub>2</sub> and temperature may for example alter rates of plant transpiration or water use efficiency (Owensby et al., 1999; Shaw et al., 2002), while, conversely, changes in precipitation may alter plant and ecosystem responses to changes in CO<sub>2</sub> and temperature (Smith et al., 2000). However, the effects of multiple climatic and environmental stress factors cannot be predicted or assessed by simply adding up the effects of the individual factors. For instance, a recent field-scale study has shown that stimulating effects of increased CO<sub>2</sub> on plant production were changed to negative effects when combined with changes in temperature and/or precipitation (Shaw et al., 2002). It is important therefore to give increased weight to a research approach that considers the effects of simultaneous multi-factor changes and to direct the research effort to a strong focus on the biological effects of **multiple stress factors**.

Most studies in seasonal environments have focused on growing season responses. However, recent research has shown that the off-season processes (from late autumn to early spring) may be quantitatively much more important than previously thought, and that the influences of off-season biological processes on the ecosystems probably are different from the influences of growing-season processes. This is particularly important if the changes in winter are greater than in summer. For example will increased temperature prolong the growing season and increase the number of frost-free days (Beier et al., 2003) with consequences for the C balance. While plant photosynthesis and C sequestration cease in late summer, decomposition of litter and soil organic matter continues in autumn with associated uni-directional respiratory fluxes out of the ecosystems. The flux rates out of the system continues in winter even at sub-zero temperatures down to soil temperatures of at least -5°C (Clein & Schimel 1995) and reaches a peak again at snow-melt in late spring. When added up to an annual basis, these off-season fluxes may contribute by 10-40% to the annual C budget (Clein & Schimel 1995; Oechel et al. 1997; Larsen et al. 2002). Consequently, these fluxes need to be accounted for in calculation of both climate change effects on ecosystems and the feedback from ecosystems to the atmosphere. On the other hand, increased temperature in the spring will advance the onset of the growing season (Penuelas et al. 2003) which may counteract the increased winter C losses. In addition to changes in temperature, also global and regional precipitation regimes are expected to shift with ramifications for the performance of species (Cohen 1970, Walter 1979, Schwinning and Ehlering, 2001), biomass production (Sala et al., 1998; Knapp and Smith 2001) and the interactions among organisms (Weltzin et al., 2003). Furthermore, as the average climate changes, the likelihood for periods of short-term extreme events, such as periodic drought or flooding or changes in late and early season's periodicity and frequency of freeze-thaw cycles also increases (Houghton et al. 2001). Such extreme events overlaid on the average changes are known to affect organisms and ecosystem strongly (e.g. Larsen et al. 2002), and in some cases cause pronounced step changes in the systems. Therefore, there is a strong need to focus research on biological effects of **seasonal and shorter-term temporal variations** in addition to effects of climate averages (Weltzin et al., 2003).

The research within CLIMAITE is planned to reach the highest international standards, and the experimental design is intended to comply with the most recent model scenarios for atmospheric and climatic changes (IPCC 2001 and local scenarios from Danish Meteorological Institute). To fulfil these criteria, the experimental conditions will mimic the climate 50-70 years from now. We will do this by combining enhancement of the CO<sub>2</sub> level based on known current rise in atmospheric CO<sub>2</sub> with a rise in temperature and changes in precipitation patterns, i.e. of the most likely changes driven by the change in atmospheric gas composition. We have to this added a particular focus on predicted changes in seasonality of the future climate and extreme weather events. These issues are rarely addressed in current ongoing research, although they have attracted increased attention recently.

## Aims, overall hypothesis and outcome

To meet the research needs, CLIMAITE is specifically designed to analyse biological responses to **multiple environmental changes** integrated with a particular focus on effects on **temporal variation patterns**. The emphasis will be on interactions and processes among the main ecosystem components including the primary (plants) and secondary (animals) producers and decomposers (microbes) and their substrates. This holistic approach requires cooperation among a broad array of specialists, at the same time as the research will account for the complexity of the ecosystem processes and reduce the risk for overlooking important interactions (Jonasson et al, revised ms). By this approach, we aim at developing a conceptual understanding of how climatic and environmental changes in concert will affect biological processes in the terrestrial ecosystems as a basis for understanding potential effects of climatic changes and potentially advise actions that will counteract or prevent negative and undesirable effects. In particular CLIMAITE will:

1. Investigate how predicted climatic changes in concert will affect plants (species composition, biomass, primary production, plant leaf chemistry and resource acquisition), soil and microorganisms (decomposition and mineralisation processes, nutrient loss and resource acquisition), above- and belowground fauna (decomposition and herbivory) and their interactions.
2. Study how long term (e.g. length of the growing season) and short-term (e.g. diurnal and seasonal variations) changes will affect processes, structure and dynamic of natural ecosystems.
3. Study to what extent organisms, populations and the ecosystem are able to tolerate, acclimate and recover after extreme climatic events under various stress levels.
4. Create a strong interdisciplinary research environment within biological effects of climate change as a platform for education of young researchers and for international networking.
5. Provide information and knowledge to the public and policymakers on potential climatic impacts on terrestrial ecosystems and the possibilities to counteract negative effects.

## Hypotheses

The work within CLIMAITE will be based on two sets of hypotheses relating to the two overall areas multiple “environmental changes” and “temporal variation patterns”.

1. *The responses of organisms and processes to combinations of environmental changes are generally a result of complex interactions. These interactions are most often not simply additive, but will result in synergistic or antagonistic effects.*
  - a. Individual organisms in the ecosystem will be affected differently by a given stress factor. Multiple stresses by simultaneous changes in temperature, water availability and CO<sub>2</sub> will result in rapid (year(s)) changes in the ecosystem composition, because the rate of physiological response to the changes will differ among organisms and among species.
  - b. Short-term changes in the species composition of the ecosystem in response to multiple stress factors will lead to continuous, long-term adjustments in structure and function of ecosystems.
  - c. Changes in water availability and temperature will affect essential ecosystem processes directly (e.g. carbon accumulation and nutrient cycling), but the response will be modified by simultaneous changes in atmospheric CO<sub>2</sub>-concentrations.
2. *Changes in seasonal climate patterns together with extreme climatic conditions and changes in stochasticity of weather events will contribute strongly to changes in ecosystem structure and function.*
  - a. Changes in the length and timing of the growing season will affect the phenology of organisms and displace the timing and rates of resource use, particularly at the onset and end of the plants' growing season and thereby

contribute strongly to an overall change in community composition and ecosystem functioning.

- b. A higher frequency of extreme climatic events (e.g. drought, freeze/thaw cycles, heavy precipitation) will lead to pulse-changes in populations and species composition with associated rapid changes in rates of biogeochemical matter cycling and exchange of carbon and nutrients with the surroundings.
- c. The ability of organisms and ecosystems to recover after extreme climatic events will depend upon the combinations of stress factors.

### **Outcome**

The summed effects of anticipated atmospheric and climate changes on ecosystem functioning, and thereby also on human welfare is a main issue of global proportions. The research is planned primarily to give a substantial contribution to the scientific understanding of biological responses to these changes. Thereby the research will provide important knowledge and information, which is needed when policy makers and land managers are to decide on potential actions to counteract or combat undesirable or negative effects. At the same time the expected output will contribute to a better understanding of implications of ecosystem responses to the changes for the environment as a whole and, hence, the ramifications to human welfare (IPCC 2001). For instance, it will envisage whether a common national and Western European ecosystem-type is likely to affect the grand-scale carbon balance between the ecosystems and the atmosphere and thereby modify the driving force of atmospheric CO<sub>2</sub> on the climate. Finally, through the new multifactor experimental facility and the multidisciplinary research activities, the centre will form a new strong and stimulating Danish scientific environment at an international level. This will provide a true potential and step forward for the scientific development and education of young scientist within the area.

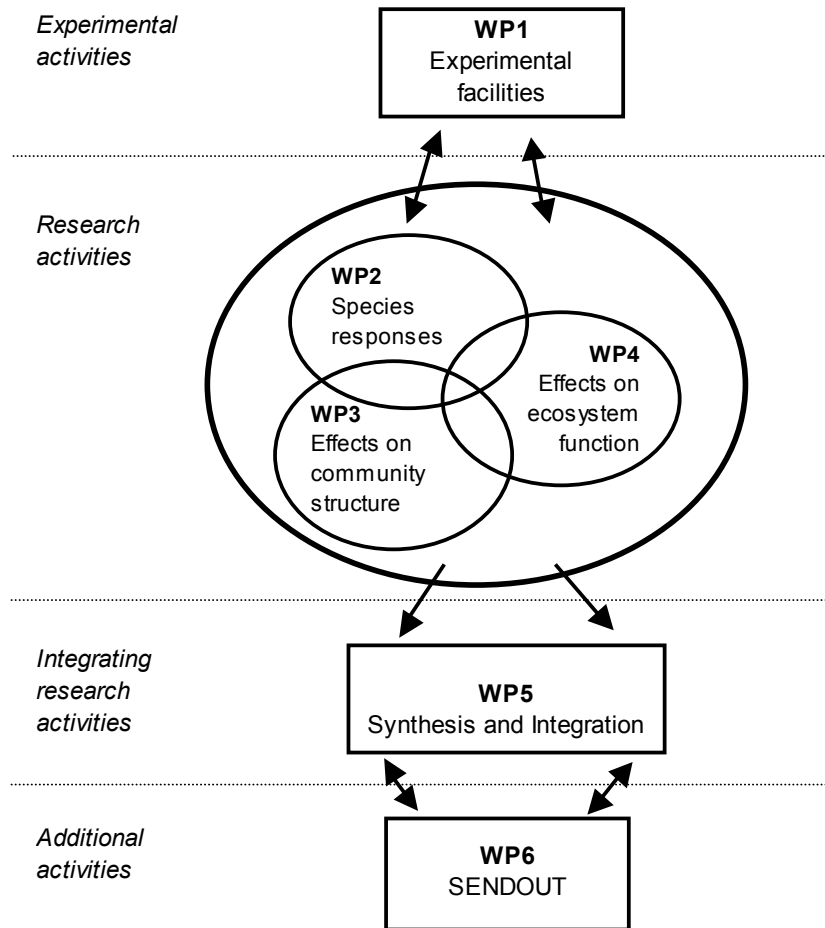
## Method and work plan

The activities within the centre will involve four levels of activities organized in 6 work packages. The four activity levels are: “experimental activities”, “research activities”, “synthesizing research activities” and “additional activities”.

- The “experimental activities” consists of Work package 1 “**Experimental facilities**” which will build up a new experimental field site involving combined field scale manipulations with CO<sub>2</sub>, temperature and changes in precipitation patterns and provide linkages and additional measures at existing field sites and controlled growth chamber environments whenever needed.
- The “research activities” consists of 3 work packages relating to three different scales in the ecosystem. Work package 2, “**Species responses**”, will study the physiological response of individual organisms to climatic stress factors. Work package 3, “**Effects on community structure**” will study the impact of climatic factors on the ecosystem structure. Work package 4, “**Effects on ecosystem function**” will study the impacts of climatic factors on the overall functioning of terrestrial ecosystems.
- The “integrating research activities” consists of Work package 5, “**Synthesis and integration**” which will integrate the specific results from the research activities in WP2-WP4 into a common and conceptual understanding of ecosystem responses to climatic perturbations with particular focus on “multiple stress factors” and “temporal variation patterns”.
- The “additional activities” consists of Work package 6, “**Steering, education, networking, dissemination and output**” – SENDOUT, which will ensure and coordinate activities related to management of the centre, dissemination of research activities and results, linkages and collaboration with other national and international research projects, programs and networks and coordination of the education of master and PhD students with other projects and educational programs.

|                |                                       | WP5 – Synthesis and integration   |  |
|----------------|---------------------------------------|---|--|
|                |                                       | Multiple stress factors   | Temporal variation patterns  |
| Research areas | WP2<br>Species responses              | Plant performance and adaptation<br>Leaf gas exchange<br>Tissue chemistry and herbivory<br>Multiple stress and physiological adaptation<br>Decomposition by fauna | Plant activity<br>Plant stress<br>Fauna response patterns<br>Critical stress levels<br>Plant/herbivory interactions<br>Recovery and adaptability |
|                | WP3<br>Effects on community structure | Plant species composition<br>Soil fauna community structure<br>Decomposition populations – structure, diversity and activity<br>Soil and plant chemistry          | Plant phenology and biomass development<br>Soil fauna community structure<br>Decomposition populations – diversity and activity                  |
|                | WP4<br>Effects on ecosystem function  | Pools, cycling and ecosystem exchange of C & N<br>Root and soil respiration<br>Carbon uptake and allocation<br>Nutrient availability, transformation and loss     | Mineralisation, cycling and ecosystem exchange of C & N<br>Temperature-water-C relationships<br>Nutrient availability, transformation and loss   |

*Research activities and contributions to the integrating syntheses within the two focus areas research themes „multiple stress factors“ and „temporal variation patterns“*



Organisation of the activities within CLIMAITE in 6 work packages

## Work package 1 – Experimental facilities

The research will be based on experimental manipulation of climatic factors in the field or in controlled environments. The experimental tools will be:

- New facility for experimental manipulation at the field scale
- Controlled environments
- Existing field scale facilities

### New facility for experimental manipulation at the field scale

WP1 is organising a new Danish field manipulation site. The manipulation will be conducted in a semi-natural ecosystem with relatively low vegetation. Three factors affecting the terrestrial vegetation significantly will be altered in relation to current climate change prediction models. The factors are atmospheric CO<sub>2</sub> concentration, temperature and precipitation.

#### Climate change scenarios

The atmospheric CO<sub>2</sub> concentration will increase in the future, but the concentrations are tightly related to emission scenarios. The concentration will increase all over the globe and only small regional variations primarily related to seasonality are expected. In 2070 the IPCC models predict concentrations between 380 and 640 ppm. In relation to these predictions the manipulations with elevated CO<sub>2</sub> within CLIMAITE will employ concentrations of CO<sub>2</sub> around 510 ppm. This correspond to an annual increment of 2 ppm, which is a continuation of the

current yearly increase and is within the concentration increment range behind the DMI scenario. Based on the scenarios for greenhouse gas emissions the Danish Meteorological Institute (DMI) has developed a climate change scenario for Denmark for 2070-2100 with respect to air temperature and precipitation based on "business as usual". Predictions are, that the average temperature will increase 2-4 °C and the precipitation pattern will change. The temperature increase will be higher in the spring, summer and autumn compared to the winter and the minimum temperature will increase more than the maximum temperature meaning that the night temperatures will increase more than the daytime temperatures as has already been seen (IPCC 2001). The annual precipitation patterns will change and in particular increase the precipitation by 10-20% during the winter and correspondingly reduce the precipitation during the summer, which is likely to increase the frequency of drought periods (Christensen and Christensen, 2002; J.H. Christensen, personal communication).

#### *Site*

The experimental facility will be established at a suitable semi natural shrubland/grassland ecosystem at Sealand representative for this ecosystem type in Denmark and with a low vegetation of young shrubland vegetation and various grasses, herbs and mosses. The low vegetation is a requirement for the manipulations planned. The ecosystem will be subject to low management activities.

#### *Manipulations*

The three factors CO<sub>2</sub>, temperature and precipitation will be manipulated in the field in a full factorial design. Each study plot will be 4 m<sup>2</sup> and all treatments will be replicated 6 times (48 experimental plots in total) and established randomly at the site. The experimental treatments will be started in year 2 of the project leaving a full growing season for pre-treatment measurements, installation and testing of experimental techniques. The treatments are:

- **Reference (R)** - Untreated reference plots for assessment of treatment effects. The reference plots will be established similar to all treatment plots including "dummies" of heaters, CO<sub>2</sub> dozers etc. in order to make sheltering and shadow effects similar.
- **CO<sub>2</sub>-enrichment (C)** - Free Air CO<sub>2</sub> Enrichment (FACE) experiment. The study plots will be exposed to elevated CO<sub>2</sub> concentrations in the air through fumigation. The target CO<sub>2</sub> concentration will be 510 ppm. The CO<sub>2</sub> will be added to the plots via a mini/mid FACE (Free-Air CO<sub>2</sub> Enrichment) system (e.g. Miglietta 1996 and Miglietta 1997) Concentrated CO<sub>2</sub> will be released from tubes surrounding the plots. The release will be controlled via a data-logger/CO<sub>2</sub> monitor feedback system. The target CO<sub>2</sub> concentration of 510 ppm shall be kept in the centre of the plot. To minimise the CO<sub>2</sub> consumption only tubes situated in the up-wind direction will release CO<sub>2</sub>. Fumigations will only be done during daytime and fumigation will be reduced or interrupted during episodes with high wind speeds.
- **Temperature increase (T)** – The study plots will be heated from above by IR lamps (e.g. Shaw et al. 2002) or a passive night time warming system (IR reflective curtains e.g. Beier et al 2000) to increase the night time temperature in the air and top soil layer by c. 2 °C. The IR lamps or reflective curtains will be chosen as they imply only minimal artefacts on light, water and wind conditions compared to most other systems (e.g. Beier et al., 2000). However, IR lamps may alter the energy balance and accelerate the evapotranspiration. Specific design of the heating system will be tested in the field and assessed in terms of heating efficiency, optimal lamp size and potential artefacts.
- **Precipitation (W)** - Study plots are exposed to changes in precipitation patterns. 10-20% of the precipitation will be removed during the summer (July-September) by automatically/manually operated plastic covers allowing prolonged summer droughts to occur. A similar amount of additional precipitation will be applied manually during the winter in 15 mm rain events (Dec-Feb). Precipitation for reapplication will be collected at the site shortly before application.
- **CO<sub>2</sub>-enrichment and Temperature increase (CT)** – combination of the above C and T treatments
- **CO<sub>2</sub>-enrichment and Precipitation (CW)** – combination of the above C and W treatments

- **Temperature increase and Precipitation (TW)**– combination of the above T and W treatments
- **CO<sub>2</sub>-enrichment, Temperature increase and Precipitation (CWT)**– combination of the above C, T and W treatments.

#### *Study plots*

The full factorial design of 8 treatments and 4-6 replicates means that 32-48 study plots will be established. The study plots will be laid out randomly at the site. The study plots will be sized to match the space requirements for both plant, soil and fauna investigations (c. 4 m<sup>2</sup>). Each plot will be split into areas assigned to specific types of measurements and sampling. In order to minimize shelter and shadow effects a 1-1.5 m high metal pole will be erected outside each plot to carry all technical equipment e.g. IR-lamps or IR reflective curtains, rain exclusion foils, irrigation system. A flexible and easy movable scaffolding/latter system will be developed to ensure secure and easy access to the plots during measurements without disturbing the plots (no trampling) and a fencing system will be developed to protect the plots from trampling and large herbivores. If necessary to prevent migration of meso- and micro-fauna and preventing uptake of nutrients and water from outside the treatment plots by the plant roots the fence will be installed down to 25 cm below ground.

#### *Basic instrumentation and measurements*

A cabin will be installed at the site for protection of measuring equipment. Electricity, a CO<sub>2</sub> supply system for the FACE and a water tank for the irrigation system will be installed. Telephone connections will be installed for surveillance and automatic data transfer. A series of basic measurements will be initiated and used for data evaluation and treatment documentation. All measurements will be stored as average, max. and min. values in dataloggers at appropriate time intervals. Basic instrumentation and measurements include:

- **Meteorological parameters** – A 3m high meteorology mast will be erected at the site and equipped with the following sensors: Air temperature, wind direction, wind speed, relative humidity and PAR. The data will be used simultaneously in the FACE control system, but also stored as 10 min average with maximum and minimum values in a datalogger.
- **Nitrogen deposition** – wet deposition (funnels for precipitation input of NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>) and dry deposition (passive samplers for NO<sub>x</sub> and NH<sub>3</sub>) will be monitored on a monthly or biweekly basis.
- **Air and soil temperature** in treatment plots will be measured continuously. Detailed studies of the temperature distribution patterns will be done.
- **CO<sub>2</sub> concentrations** in treatment plots will be measured continuously to regulate fumigation and to document treatments. Specific studies on CO<sub>2</sub> distribution patterns will be done in campaigns.
- **Soil moisture** in various depths will be measured continuously by TDR to be used for data-evaluation of treatment effects, documentation of treatments and hydrological modelling.
- **Water input to treatment plots** will be sampled in each plot by funnels to control and document treatments
- **Net radiation balance** will be measured in a few selected plots.
- **Surface temperature** will be measured in a few selected plots.

#### **Controlled environments**

Field scale experiments have the advantage of being relatively realistic regarding the ecosystem and the interactions with the treatments. However, natural ecosystems are normally subject to large spatial and temporal variations, which may pose limitations for certain types of studies. Also, testing of interactions with additional impacts may be difficult or practically or economically impossible. In such cases studies will be conducted in the laboratory or in controlled growth chambers. For example meso-ecosystems / monoliths will be transplanted to growth chambers with controlled CO<sub>2</sub> and climate environments to investigate specific mineralisation and immobilisation processes. Furthermore, interactions between climate and other stress factors such as UVB-radiation, ozone or N deposition may be investigated in controlled environments. The participating institutions have excellent growth chamber and laboratory facilities, which will be employed wherever needed.

## Existing field scale experiments

Existing sites with manipulation experiments are available at Mols (DK), Abisko (S) and Zackenberg (Greenland). These sites have involved manipulations with climatic factors alone or in combination with other factors (e.g. nutrient addition) for 8-20 years and are still in operation. None of these sites are in themselves suitable for the manipulations with multiple stress factors planned in this project (logistics, situation, accessibility etc.). However, they provide an excellent opportunity to supplement the studies at the new site for several reasons:

- Long-term studies – Even though the new site will be manipulated for 4 years, which in terms of research projects is relatively long time, this time span will still be relatively short in relation to the time span for ecosystem processes. This inherently causes a problem when using the results to predict future changes. Using the ongoing long-term studies provides an opportunity to assess the long-term sustainability of the observed changes.
- Generality and representation – results obtained at a single site may inherently cause problems when trying to upscale the results to larger areas, as it often remains uncertain to what extent the results represent general trends or are restricted to the site. The ongoing sites provide an opportunity to assess the generality of the results obtained at the new site by comparing results across sites.

## Work package 2 - Species responses

Many of the overall effects of climatic and environmental changes on the ecosystems are consequences of physiological responses at species level. Analyses of physiological effects of the imposed multiple stresses and of changes in seasonality and periodicity of weather events are therefore needed to explain responses in ecosystem structure and function (WP 3 and 4).

The aim of work package 2 is to:

- investigate and understand the immediate physiological responses of plants, herbivores and decomposer organisms to climatic and environmental changes
- to understand how physiological changes in one trophic level will translate into effects in other levels.

The results will serve as a basis for understanding the interactions within and between ecosystem functional groups, how these interactions are influenced by the changes, and which consequences they are likely to have on ecosystem structure and functioning. Consequently, there are strong interactions between this work package and WP3 and WP4, which will be synthesised in WP5.

### WP2.1. Plant physiological responses (*Risø-PRD, UC-PE*)

The applied treatments are likely to affect the physiology of the plants directly inducing short and long-term adjustments of the plants to acclimate to the new conditions through a complex sequence of physiological up- and down-regulation processes. The project will study these short and long-term adjustments for different plant species within all single and combined treatments, and also after short-term exposure to other stress factors. Particular focus will be devoted to seasonal effects and changes in the responses, because the expected changes in the length of the growing season and weather periodicity have the potential to profoundly change the utilisation patterns of energy, water and carbon within the plant species.

The studies will include in situ measurements of the leaf gas exchange (CO<sub>2</sub> and water vapour) with portable gas exchange equipment to quantify changes in net photosynthesis, dark respiration, stomatal conductance, water-use efficiency and nitrogen-use efficiency. In addition some parameters related to light and CO<sub>2</sub> response curves (maximum carboxylation rate of rubisco and maximum electron transport rate) will be investigated. After the

measurements, the leaves will be harvested for analyses of leaf area, mass and N content. The measurements will be done at regular intervals throughout the experiment and include campaigns with shorter frequency during the beginning and the end of the growing seasons and after long period of drought, when we expect the most pronounced treatment effects. Longer-term treatment effects on the leaf chemistry of the harvested leaves will also be included by analyses of primary metabolites and pigments of particular relevance for the photosynthesis and of secondary metabolites with particular relevance for the quality of the food source of herbivores.

Changes in CO<sub>2</sub> and climatic conditions may increase or decrease the susceptibility for other natural and anthropogenic sources of stress (McLaughlin and Percy 1999; Wall 2001). Therefore plant responses to short-term (30-60 min) exposure to single or combined increased ozone and UV-B levels will be investigated in selected treatments in the field. This will be done during a few campaigns in selected years. The responses to these additional combinations of stress factors will be measured as effects on the gas exchange and as chlorophyll fluorescence. We will try to introduce and develop a method for studying the buffer capacity of leaves in relation to stress exposure and climate change.

## **WP2.2. Physiological responses of the soil fauna** (NERI-TE, UC-ZI)

Studies of a few species have shown that the soil fauna is able to tolerate adverse environmental conditions, such as drought and low temperatures by various physiological adaptations, e.g. accumulation of low molecular weight carbohydrates to increase body fluid osmolality (Bayley and Holmstrup 1999; Holmstrup et al. 2002). Despite these adaptations, low water potential in summer and low winter temperatures yet limit the activity of the soil fauna (Rapoport and Tschapek 1967; Holmstrup 2002) and are therefore likely to affect the function of organisms and possibly re-structure community composition. On the other hand, warmer and moister winters are likely to increase faunal decomposing activity and therefore increase the flux rates of C and nutrients from the soil organic matter. Because primary production and the retention of nutrients in plant biomass are limited during winter, the increased activity is likely to increase leaching losses of plant C and nutrients from the ecosystems.

In order to quantify the contribution of soil fauna to decomposition and plant nutrient mobilisations, critical levels of soil moisture and temperature for the activity of selected soil organisms will be identified and the persistency of the effects at the community and population level will be examined. We will focus on responses in protozoans, nematodes, collembolans, mites and enchytraeids that represent various trophic levels and that are likely to play the most significant role for ecosystem functioning. Hence, the chosen combination of species will make it possible to extrapolate responses of key species and functional groups to community responses.

The main work will be related to the field scale treatments, but in order to establish response patterns and functional relationships between the soil fauna and the environmental changes, the field experiments will be combined with laboratory studies under controlled temperature and moisture conditions. These will include analyses of detailed physiological responses to desiccation and temperature extremes including growth rates, reproduction, physiological acclimation processes and costs of acclimation in terms of reproduction and longevity. With these experiments it will be possible to identify critical intensities and duration of drought and temperature extremes of the selected species. The responses will also be measured as effects on the respiratory activity in the laboratory using flow-through respirometry, with particular emphasis on responses at periods of low, but not limiting, winter temperatures. These measurements will give indications also of the litter decomposition and microbial grazing. The results will be extrapolated to field conditions using the monitoring of soil moisture and temperature of the field plots, and the population size data obtained in WP3.

The outcome of the research will be used for generating rules of response patterns for various functional groups of soil fauna subjected to a number of climate change scenarios. This knowledge is to be used in the overall task of predicting ecosystem responses to climate

change (WP5) – especially to the increased length of growing seasons and to predictable changes of within-season fluctuations of weather events.

### **WP2.3. Responses in trophic interactions** (*UC-ZI, NERI-TE*)

Climatic and environmental changes affect plant tissue composition with likely impacts on the performance of insect herbivores (Buck and Callaghan 1999). For instance, elevated CO<sub>2</sub> may change the relative abundance of leaf chewing and leaf sucking insects (Bezemer and Jones 1998). Changes in moisture may stimulate or reduce herbivore activity (Oswald and Brewer 1997), and increased temperature with associated increased nitrogen availability is known to promote attack from herbivores (Coley et al 1985). Because herbivores interact strongly with other consumers of plant carbon above and below ground (Van der Putten et al. 2001) and with the plant itself, the climate change effects on herbivores is likely to translate into effects on the whole community of organisms associated with the plant. One of the most striking effects of insect herbivores on plant performance is their ability to change rates of root exudation of compounds utilised by belowground organisms. The exudation increases in response to attacks of leaf chewers, e.g. beetles, (Wamberg et al. 2003) but is reduced following attack from leaf suckers, e.g. aphids, in the plant growth phase (Vestergård et al. submitted). This effect of herbivores may affect the entire soil fauna and the decomposers with implications for the process rates of the soil organic matter.

Interactions between plants and herbivores in relation to climatic conditions and changes will be studied in an experiment with controlled herbivory in the treated plots. Aphids and leaf beetles will be placed on the plants in clip cages, and the change in abundance will be analysed at intervals. The exact application, including selection of herbivores, will be developed during 2005-2006 and the full-scale experiment will run in 2007 when the accumulated effects of the treatments are expected to be strongest. Two applications will be done with start early in the season when the rise in temperature promotes herbivore activity and in summer when drought-effects are expected to be at a maximum.

The field studies will be combined with mesocosm (monolith) experiments in the laboratory in which the herbivores are subjected to similar treatments as in the field experiment. This will be combined with analysis of belowground respiration and the population growth of protozoa and nematodes, which has proven to correlate positively with carbon exudation from the plant roots (Wamberg et al. 2003). This investigation will also include determination of herbivory-induced changes in microbial diversity (methodology as WP3.3). In the mesocosms we will also measure the transfer of atmospheric C to rhizosphere soil, bulk soil, and soil fauna via the plant roots by following the <sup>13</sup>C signature of these fractions. This will be possible in the elevated CO<sub>2</sub> treatments because of its particular <sup>13</sup>C/<sup>12</sup>C profile. This part of the research is closely linked with WP4.2, and further described there.

For both the field and the laboratory studies, we expect that the results will show how performance of herbivores depends on climate change induced alterations in chemistry of the plants (analysed in WP2.1). We also expect to learn how the likely treatment effects on the leaf herbivores translate into effects in the rhizosphere soil fauna and decomposers through the herbivores' influences on root exudation rates. At elevated CO<sub>2</sub> it is revealed to what extent rhizosphere processes (bacterial channel) interact with decomposition of soil organic matter (fungal channel) as affected by the treatments.

### **Work package 3 – Effects on community structure**

The multiple stress factors and seasonal patterns will affect the physiology of organisms and species in the ecosystem (WP 2). This may translate into changes in ecosystem functions e.g. the ability to compete for resources (WP4). The direct and indirect results of changes in physiological processes may be changes in spatial and temporal distribution of species, timing of phenological events, growth rates and consequently changes in community structure depending on the vulnerability of species.

Hence, work package 3 is expected not only to give result of treatment and temporal effects on the structures per se, but also to form a functional link between the responses of individuals and the ecosystem responses as an aid for the synthesis in work package 5.

The objectives of WP3 are:

- To improve our understanding of how multiple stress factors e.g. warming, CO<sub>2</sub>-enrichment and/or water availability will affect the relative abundance and growth patterns of individuals and the structure of plant, microbial and soil fauna functional groups and whole ecosystem communities.
- Determine the seasonal pattern in nutrient distribution in plant, soil, micro-organisms and soil fauna and how this is affected by multiple stress factors and changes in length of the growing season
- Link changes in plant, microbial, micro- and meso fauna community structure and biomass to climate changes. Link recovery rate of community structure following an extreme weather event to different climatic conditions.
- Determine resource allocation between growth and defence compounds in plants in response to multiple stresses.

Work package 3 consists of two major types of activities:

- 1) analyses of treatment and temporal effects on the relative abundance and growth patterns of individuals, the structure of plant, microbial and soil fauna communities, chemical structure of the ecosystem and on tissue and substrate chemical quality.
- 2) analyses of the “natural” temporal dynamics in the structures across the year and following discrete weather events, and how these characteristics are affected and modified by the changes we impose on the system.

The data of all analyses will be available in a common database so all measurements can be related to primary productivity and plant biomass, nutrient availability, ecosystem C, N and P pools and plant tissue and litter chemistry.

### **WP3.1. Treatment effects on plant community composition and dynamics.** *KVL-AE, UC-PE*

Warming and increased CO<sub>2</sub> may affect shoot growth and meristem activity, increase interspecific competition (Curtis and Wang, 1998) and therefore re-shape plant community composition. Furthermore, predicted changes in growing season length and in shorter-term changes of weather event, as e.g. summer drought, are likely to affect plant growth individualistically among species (Gordon et al. 1999) resulting in changed relative abundance of species and functional groups. We believe that changes in seasonality with earlier onset of the growing season, predicted in the climate scenarios, are particularly important for structuring the plant communities. This is because the different life forms of species are adapted in different ways for starting their early-season activity depending on e.g. differences in leaf traits and physiological triggers of growth. This is likely to affect the relative abundance of plant species with consequences for microbial and animal communities and for ecosystem functions, as e.g. C sequestration.

The composition of the vegetation in the plots will be determined by point frequency analyses, with a method that allows conversion to biomass estimates (Jonasson 1988). This method is commonly employed in similar studies, as it is non-destructive and has proven very sensitive to capture changes in community structure and biomass. The measurement will give an estimate of relative abundance of all species, plant cover and height, dead and live biomass, flowering and frequency of herbivory (by registration of number of leaves with bites).

Seasonal effects of the treatments will be analysed by registration of plant phenology and by reflectance measurements from spring to autumn. The phenological development of individually tagged plants of the most abundant species will be followed by registration of bud burst, shoot elongation and count of active meristems (Schmidt et al., in prep). Changes in overall biomass development will be measured by ground based canopy reflectance in the visible/near-infrared wavelength bands. This method measures the greenness of the

vegetation, which is closely related to biomass and leaf area index (Ruimy and Saugier, 1994).

Pre-treatment conditions and status of the ecosystem, including community composition and nutrient status will be studied in 2004, before the establishment of the treatments. These data will give valuable information on the structure and variability of the site and will help establishing sampling sizes and frequencies of sampling once the experiment is running, and will also be used as a basis for data analyses. Plant species distribution above ground will be documented by vegetation analyses in all plots. However, to minimise the disturbance of the system the pre-treatment year, we will collect destructive samples in six soil profiles dug outside the treated plots in each block, in which also the vertical distribution of roots will be examined. The details of the sample collections and analyses are described below.

The vegetation will be analysed at peak biomass (mid-July) all years, while the analyses of the seasonal dynamics will be done preferentially in the pre-treatment year of 2004 and later in 2005 and 2007, coinciding with the timing of main phenological events and measurements in the other work packages. In 2007 part of the plots will be harvested destructively at the end of the growing season as part of the  $^{15}\text{N}$  labelling experiment in WP4. Aboveground and belowground plant biomass will be separated by species or growth forms (e.g. evergreen shrubs, deciduous shrubs, graminoids, herbs, mosses and lichens) and biomass and nutrient content analysed for each fraction.

### **WP3.2. Treatment effects on community structure of the soil fauna** (*UC-ZI, NERI-TE*).

The community structure of the soil fauna will be analysed in order to detect seasonal and treatment-induced shifts in diversity, relative abundance of species and functional groups. Some faunal groups (primarily protozoans and nematodes) are feeding on roots, root exudates and bacteria and thus closely associated with a rapid turnover of organic C in the rhizosphere. Other functional groups such as collembola and mites are feeding on fungal hyphae and decaying plant material and part of a slow turnover of organic C. It is interesting to see if shifts in the dominance between these functional groups will occur under changing environmental conditions, or whether the soil fauna community is relatively resilient to such changes. These studies will include continuous measurements of various parameters suitable to investigate the effects of extreme events on community structures as well as effects of naturally occurring extreme climate events e.g. cold and heat stress, which may interact with the experimental stresses. For instance, warming may increase the vulnerability of species to frost damage and drought may increase the sensitivity to heat stress. We expect to find a high and different responsiveness to climatic changes among organisms and species and therefore we expect to discern community changes related to the climate manipulations already after three treatment years.

The community structure of the soil fauna will be analysed through extraction of collembola, mites, enchytraeids, nematodes and protozoa from soil cores collected at each plot. The depth of soil cores will be determined on basis of the depth distribution of soil fauna measured in the pre-treatment profiling described above. Collembola and mites will be extracted by a modified MacFadyen dry funnel gradient extraction, enchytraeids by Bermann wet funnel technique and nematodes with a micro-version of the wet funnel technique followed by enumeration in a Doncaster counting dish. Collembola and enchytraeids will be determined to species whereas mites will be determined to higher taxonomic levels. Nematodes will successively be characterised to a sufficient taxonomic level to establish feeding groups (feeding on bacteria, fungi, omnivorous, carnivorous, plant roots). Protozoa will be cultivated in microtiter plates and enumerated with the Most Probable Number technique. This technique also allows us to estimate the dominating forms among the protozoa (flagellates or naked amoebae). Sampling campaigns in the 1st (pre-treatment) and 2nd years will cover the main seasons spring, summer, autumn and winter, while a more frequent sampling throughout the year in the 4th year will be conducted to describe phenology more comprehensively.

The flow of N and C through the plant–microbe–fauna food web will be investigated at specific campaigns by determination of stable isotope profiles ( $^{15}\text{N}$  and  $^{13}\text{C}$ ) of selected species. This activity is co-ordinated with WP4.

### **WP3.3. Population structure of soil bacteria and microbial and fungal biomass.** (UC-MI, UC-PE)

Microbial communities are the major drivers behind many important ecosystem processes. In order to get an in-depth understanding of the impact of the applied treatments on ecosystem functions (WP4) it is essential to link these impacts to concomitant changes in microbial biomass and community structure. Bacteria form complex communities with thousands or tens of thousands of different species in a few grams of soil (Curtis et al. 2002). Individual members of these communities perform essential ecosystem functions like degradation of organic matter and mineralisation of nutrients. Soil warming and elevated carbon dioxide concentrations are known to change the composition of microbial populations in soil (e.g. Montealegre et al. 2000) and extreme weather events can have a profound impact on microbial processes (e.g. Priemé and Christensen 2001). Treatment and temporal effects on the structure, metabolic diversity and activity of the microbial communities will be examined as a background for understanding the changes in ecosystem functions.

Traditional techniques for determination of bacterial community structure have involved cultivation and subsequent plate counts of the colonies. However, the technique is hampered by the fact that in general less than 1% of the soil bacteria can be isolated by the traditional methods (Sørensen et al. 2002). We will use the new molecular technique of terminal restriction fragment length polymorphism (T-RFLP) analysis (Osborn et al. 2000) of 16S RNA and the gene coding for 16S RNA for the analyses, which give a much more representative measure of bacterial diversity. The gene coding for small subunit (16S) ribosomal RNA is universal among prokaryotes and is the best target for an analysis of bacterial community structure (Vandamme et al. 1996). The analysis of 16S RNA will give information on the active fraction of the bacterial community, because the amount of ribosomal RNA in bacterial cells is roughly proportional to metabolic activity (Wagner 1994). The T-RFLP analyses will be compared to a comprehensive clone library containing the most abundant 16S DNA sequences at the onset of the experiment and during the fifth year, and the data will be screened for treatment effects. In addition, we will use T-RFLP analysis of the 18S-to-24S internal transcribed spacer regions (ITS) to also examine the treatment effects on the structure of the fungal communities. Analysis of ITS is chosen here, because it is expected to give a better resolution of the fungal community fingerprinting compared to the more traditional analysis of fungal 18S DNA. In addition, bacterial community structure of denitrifiers and nitrifiers will be characterised if pre-treatment analyses of denitrification and nitrification processes (WP4) indicate that these processes are of significant importance in the soil nitrogen cycling. The treatment effect on the structure of the microbial communities of denitrifiers cannot be studied by 16S RNA, but will instead be done using the functional genes *nirK*, *nirS* and *nosZ*, while the nitrifying communities will be analysed using the *amoA* gene. The analyses of microbial community structure will be done four times in each treatment year.

The treatment effects on prokaryotic metabolic diversity (BIOLOG Ecoplates), fungal metabolic diversity (BIOLOG FF plates), and metabolic activity (Substrate Induced Respiration (SIR) method (Anderson and Domsch 1978)) will be analysed. The metabolic diversity will be tested once in each treatment year by applying suspensions of bacteria extracted from the soil to microtiter plates showing the ability of the bacteria to oxidise the different carbon sources. This technique is most valuable to detect temporal and spatial differences in soil microbial communities and provides a sensitive method to detect treatment effects in the plots. The SIR method gives a rapid measure of the actively respiring biomass and is, hence, a measure that can be used for distinguishing treatment effects on the activity of the fungal and bacterial community. The SIR measurements will be coordinated with the analyses for total microbial C in WP 3.4. Finally, analyses of the ergosterol content will be used to fingerprint for fungal biomass.

### **WP3.4. Effects on plant litter and soil chemistry.** (KVL-AE, UC-PE).

Changes of abundance of species in the communities of organisms are followed by - or are consequences of – changed patterns of nutrient locations within the ecosystems. Changes in species composition generally also are reflected in alterations in tissue chemistry that translates into changes of litter and soil chemistry. In this work package, different ecosystem components (plants, litter, microbes and the bulk soil) are analysed for treatment effects on total content of C, N and P and labile and inorganic fractions of the nutrients.

Plant, litter and soil samples for analyses of the pre-treatment nutrient content will be collected from the vegetation and the soil profiles described above. Subsequent sampling for treatment effects will be co-ordinated with the analyses of organism communities in this work package and with the work on C and nutrient dynamics in work package WP4 on ecosystem function. Furthermore, samples will be collected in winter and in the transition period between winter and spring and summer and autumn, when we expect particularly great changes in pool sizes due to re-distribution of the nutrients between the plant and microbial component of the system.

Plant tissue and litter chemistry will be analysed (total C, N and P content, analyses of structural and non-structural carbohydrates in leaves by chemical fractionation into compounds that are known to affect litter decomposability, including lignin and cellulose). Single species of simple and complex carbohydrates have characteristic NIR reflectance peaks. Thus, we will analyse leaves and litter with NIR-spectrometry and use the chemical analyses to identify the NIR reflectance peaks (Richardson et al. 2004). A successful calibration will enable rough but non-destructively and cheap measurement of leaves and litter quality over time.

Soil chemistry will be measured through extraction and analyses of soils for C,  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , inorganic P, dissolved and total microbial fractions of C and N and microbial P. Soil chemistry measurements will be coordinated with measurements of soil water chemistry and leaching in WP4. The microbial biomass C, N and P will be determined by the chloroform fumigation-extraction method and compared against the results of the determination of the active biomass by SIR, described above.

## **Work package 4 – Effects on ecosystem function**

Ecosystem functioning is a generic term, which can be defined as the interactions between living organisms and the physical environment, such as nutrients, soil development and water budgeting. As such, ecosystem functioning integrates the ecological function of individual species present in the system and will be affected by changes in species response, which is investigated in WP2 as well as by species composition and structure, which is investigated in WP3. In this context, the investigations in WP4 will integrate essentials of WP2 and WP3, and will include components of temporal changes in energy and carbon flow and nutrient cycling processes. Since several components of ecosystem functioning are important links between the system and the surrounding environment, detailed knowledge on the system functioning is therefore a prerequisite to understand and predict how perturbations to the system may affect the surrounding environment.

The overall objective of this work package is to identify effects of climatic perturbations and changes in seasonality and of frequencies of weather events on ecosystem functioning. The focus will be on internal cycling and transformation of the main nutrients and elements C, N and P, and external exchange of these nutrients. The work will include two main types of activities:

- Measurements and analyses of the end results of integrated ecosystem processes in the experimental plots, such as C exchange between the ecosystem and the atmosphere, mobilization and allocation of nutrients to various ecosystem pools and the loss of C and nutrients from the plots.

- Determination of steps and processes controlling the C and nutrient cycles thus being important for the interpretation of the treatment effect, e.g. pathways and rates of internal transfers of C and nutrients within the ecosystem.

#### **WP4.1. Ecosystem-atmosphere gaseous exchange** (*Risø-PRD*)

The C exchanged by fluxes of CO<sub>2</sub> to and from the ecosystems and the atmosphere by biological processes is the quantitatively most important pathway for the C exchange, with well known anticipated consequences for the climate system (IPCC, 2001). Fluxes of CH<sub>4</sub>, and the N-containing gases are quantitatively less important. However, these gases have particular significance for the climate system, as they have several-fold greater forcing effects on the climate than CO<sub>2</sub> and influences atmospheric chemistry, beside the fact that they contributes to the local, ecosystem, C and N balance. Fluxes of these gases are sensitive to climatic and environmental perturbations (Ambus and Robertson, 1999; Hungate et al., 1997).

The exchange of C gases (CO<sub>2</sub> and CH<sub>4</sub>) and N gases (NO and N<sub>2</sub>O) between the ecosystem and the atmosphere will be measured using static flux chambers. In each experimental plot a permanent chamber base of 70 cm × 70 cm will be installed at the start of the project. The bases will be left in the plots throughout the experiment and will be used as chamber bases for all flux measurements. CO<sub>2</sub> fluxes will be measured regularly at two-week intervals and on a diurnal basis in campaigns. The measurements will include net ecosystem CO<sub>2</sub> flux and respiration in transparent and opaque chambers, respectively, placed onto the bases. In the 2<sup>nd</sup> to 4<sup>th</sup> treatment year, measurements will be done with particularly high frequency in order to detect treatment-induced changes in ecosystem C-fluxes and – balances during the three first years of treatments.

Methane, nitric oxide and nitrous oxide fluxes will be monitored on a campaign basis in the 1<sup>st</sup> to 3<sup>rd</sup> treatment years during periods when significant fluxes are expected, e.g. during warm-up of the soil in wet spring, in connection with heavy rainfall events and in autumn after plant senescence. Methane and nitrous oxide will be measured by manual collection of gas samples and subsequent GC analysis, and NO will be measured on-line using a chemiluminescence detector.

#### **WP4.2. Effects on belowground C-transfer** (*Risø, UC-ZI, NERI*).

Treatment effects on the C transformation will be studied in detail by studying the isotopic composition of carbon in CO<sub>2</sub>-enriched plots combined with laboratory based <sup>13</sup>C labelling. In natural soil-plant ecosystems the soil organic matter carbon and plant biomass carbon will have a content of the stable isotope <sup>13</sup>C, which is reflected by the photosynthetic system of the dominant plant species (i.e. approx. –28 ‰ in C<sub>3</sub>-communities). Although isotopic discrimination occurs during cycling processes, leaving behind the heavier <sup>13</sup>C isotope, differences in isotopic signatures between soil carbon and plant carbon is usually inadequate to determine the major carbon cycle processes, However, the “fossil” CO<sub>2</sub> that will be used for the fumigation in the experimental plots receiving increased CO<sub>2</sub> will have a <sup>13</sup>C content significantly depleted compared to atmospheric CO<sub>2</sub>. This <sup>13</sup>C depleted fumigation CO<sub>2</sub> will be used to trace and quantify important processes in the below ground C transfer.

Effects of the warming and precipitation treatments on the belowground C-sequestration and -dynamics will be examined by determination of the isotopic characteristics of the major soil carbon pools and of the evolved CO<sub>2</sub> from the CO<sub>2</sub>-treated plots by isotope ratio mass spectrometry (IRMS). The analyses of isotope composition of the gases will be done regularly on the same samples collected for estimation of the gas fluxes (WP4.1), at the same time as samples of above- and belowground plant material and soil organic matter will be collected for <sup>13</sup>C analysis.

A supplementary growth chamber experiment will be conducted in order to examine effects of elevated CO<sub>2</sub> on the carbon dynamics, in which intact soil-plant samples from ambient vs. elevated CO<sub>2</sub> plots will be pulse-labeled with <sup>13</sup>CO<sub>2</sub>. The pots will be incubated in a small-volume labeling chamber and the signature of evolved CO<sub>2</sub> and soil and plant material will be determined subsequently.

Special attention will be given to trace potential differences in the C sources processed during the growing and non-growing season. This is because earlier studies of winter gas fluxes in other ecosystems have indicated that the substrate decomposed during winter is of more recent origin ("new" C) derived from root exudates and fresh litter compared to C evolved during summer, which has higher contribution of C from the bulk soil ("old" C) (Grogan et al., 2001). This implies that the winter fluxes may not affect the pools of the more resistant, "old" C fractions to the same extent as the summer fluxes.

Differences in isotopic composition will be used to identify C sources used by functional groups of the soil mesofauna over the year to identify their food source and examine whether the treatments affect their processing of the different C fractions in the soil. By comparing <sup>13</sup>C content in functional mesofauna groups, plant litter and soil organic matter, we will be able to identify preferences among the faunal groups for plant, litter or SOM carbon. The analyses will be done on microarthropods (collembolans and mites) and possibly also nematodes if enough biomass is extractable. This experiment links to the belowground respiration and micro fauna growth experiments undertaken in WP2.3 and will be performed with samples from the elevated CO<sub>2</sub> plots. An extension of the experiments can also be done by pulse labeling in the growth chamber.

#### **WP4.3. Internal nutrient transformations in the soil-plant system** (*UC-PE, KVL-AE*)

Treatment and seasonal effects on the transformation of N and P associated with the decomposition of the organic matter will be analyzed. The nutrient transformations (mineralization, release of DOC and DON, microbial N and P uptake and partitioning of released N and P between the soil and microbial pools) will be measured by the buried bag technique (e.g. Eno, 1960). The soil is incubated in a "buried bag" and the nutrient transformation rates are estimated as the pre- and post incubation differences in the various soil nutrient pools. Two sets of samples will be incubated in the spring 2006 (2<sup>nd</sup> treatment year). One set of samples will be retrieved at the end of the growing season for estimates of growing season nutrient mobilization, while the second set will be retrieved in late winter/early spring 2007 to account also for nutrient mobilization during the non-growing season. The results will be linked to the measurements in WP4.5. We will also consider running the traditional method together with a modification of it, by which plants are incubated together with the soil and the plant uptake is measured together with the other soil variables. We have used the method in one accepted publication (Jonasson et al. in press). It seems to give more realistic estimates of the nutrient transformations than the traditional method, because it accounts also for effects on mineralization by root exudation of labile C, possible plant-microbial competition for nutrients and for N plant uptake of dissolved organic N (See WP4.5). Apart from the accepted manuscript, the modified method has also been used in another, submitted, manuscript, and it will also be presented at an international congress for comments in March. If it is favorably received throughout, we will use it in parallel with the traditional method.

Measurements will be carried out to determine treatment effects on P-availability and seasonal pattern in phosphatase activity. In WP3, changes in P availability and plant P pools and concentrations are monitored. If the plants are P limited or become P limited due to the manipulations, increased uptake of P by plants and microbes are likely to occur, which may obscure measurements of soil P availability. As a supplement to these measurements, phosphatase activity will be measured in plant roots and soil in the third treatment year as we expect this to be a more sensitive measurement of plant P limitation.

#### **WP4.4. Gross rates and potentials of N cycling processes** (*Risø-PRD; UC-MI*).

Soil net N mobilization is the net result of rapid microbial gross mineralization and subsequent biological and non-biological N immobilization. Small changes in any of these rates can have pronounced effects on the net nutrient supply to the plant available pool and thereby affect primary productivity as well as rates of N-losses in N-limited systems. It is important therefore

to examine how the treatments change these gross processes in order to understand the ecosystem responses and the longer-term mobilization of N in the system, described in WP4.3.

The turnover of N in the mineralization-immobilization step of the N cycle will be measured by an isotopic pool dilution approach. Replicate sets of soil samples labeled with  $^{15}\text{NH}_4^+$  and  $^{15}\text{NO}_3^-$  will be incubated in the field, and the rates of dilution of the label by  $^{14}\text{NH}_4^+$  and  $^{14}\text{NO}_3^-$  released from the decomposing substrate will be measured over short time intervals in order to determine rates of gross mineralization and gross nitrification, respectively. The immobilization is assessed from the  $^{15}\text{N}$  balance in the incubations after removal of the inorganic N fractions by KCl extractions. The measurements will be done at four events over one year beginning in the spring of the 2<sup>nd</sup> treatment year (2006).

Potential nitrification (oxidation of  $\text{NH}_4^+$  to  $\text{NO}_3^-$ ) and potential denitrification (reduction of  $\text{NO}_3^-$  to  $\text{N}_2\text{O}$  and  $\text{N}_2$ ) will be measured in a laboratory study. The potential nitrification rates will be measured as accumulation of  $\text{NO}_2^-$  and  $\text{NO}_3^-$  during aerobic incubation of ammonium-amended soil samples from the treated plots. The potential denitrification will be estimated by anaerobic incubation of soil samples under near-optimal conditions with added carbon sources and nitrate. Based on these results, we will evaluate if  $\text{N}_2$  fluxes are likely to form a significant part of the ecosystem N-gas loss (see WP4.1).

Based on the vegetation and soil characteristics of the experimental site, we will also consider including measurements on biological  $\text{N}_2$  fixation by the acetylene reduction technique in the laboratory or in the field.

#### **WP4.5. Mechanisms and pathways of microbial and plant mediated C and N assimilation (UC-PE)**

Research during the last decade have shown that plants in various ecosystem types are able to access organic N, which was typically ignored in earlier studies of the N cycle (Lipson and Näsholm, 2001). Consequently, this pathway need to be included in studies of N transformation, and plant uptake of organic N and the short- and long-term partitioning of N between plants and microbes will therefore be quantified. In spring of the 3<sup>rd</sup> year, and prior to soil sampling, we will do an *in situ* labelling of the soil solution by injections with universally  $^{13}\text{C}$ ,  $^{15}\text{N}$ -labeled glycine in three 20\*20 cm subplots per treatment plot. Glycine is an amino acid that can be absorbed either directly by plants or absorbed after microbial mineralization to inorganic N and  $\text{CO}_2$ . This labelling technique allows nitrogen and, in the short term, carbon to be followed through the soil, plant and microbial pools with high resolution and will give complementary information on the timing and pathways of the nutrient mobilizations measured by the modified buried bag technique (WP4.3). We will sample one of the three subplots for isotopic analyses of plant and microbes 6 hours after injection to determine to which extent intact glycine is absorbed. In addition to the measurements of the short-term organic N uptake, we will follow the longer-term, winter and summer, absorption of the added  $^{15}\text{N}$  by plants and microbes. We do this because we expect that the treatments will displace the timing of plant and microbial activity in the system. Thus, sampling of the two remaining subplots will take place after ½ year and after one year, respectively, to determine the longer-term partitioning of the added N in the glycine between ecosystem pools. The combined samplings after ½ year (autumn) and one year (spring) will provide information on the effect of winter processes on nutrient partitioning in the treatments. The analyzed material will include total soil, litter, microbial biomass, plant roots and aboveground biomass of the different plant functional types (graminoids, herbs, deciduous dwarf shrubs, evergreen dwarf shrubs, mosses). These substrates will be analyzed for C and N concentrations and their  $^{13}\text{C}$  and  $^{15}\text{N}$  contents by IRMS. Samplings and analyses will furthermore provide important information on treatment responses in plant and microbial biomass and N pool sizes in the 3<sup>rd</sup> year (spring and autumn) and the 4<sup>th</sup> year (spring). Additionally, the short-term fate of glycine-C will be assessed by inclusion of  $^{13}\text{C}$  analysis of  $\text{CO}_2$  evolved 6 hours, one week and three weeks after labeling.

#### **WP4.6. Leaching losses of N and C from the system (Risø-PRD).**

Changes in mineralization and immobilization processes caused by climatic changes may affect the ecosystem retention of nutrients. Consequently, changes in soil water chemistry may be used as a direct indicator for changes in these processes and soil water chemistry may directly be used to estimate the water-mediated loss of nutrients from the ecosystem. Therefore, treatment effects on leaching losses of C, N and P from the ecosystem will be studied to establish whether the changes in conditions we impose on the system will change the retention of soluble C, N and P compounds.

Leaching of N ( $\text{NO}_3^-$ ,  $\text{NH}_4^+$  and DON), P (inorganic  $\text{PO}_4$ ) and C (DOC) from the humic soil layer and from beneath the rooting zone will be determined from all experimental plots. Humic lysimeters (zero tension plates) will be installed at the depth of the organic layer and PTFE suction cups will be installed below the rooting zone from the start of the project to obtain sampling during the pretreatment year. Soil solution collected from the humic lysimeters and the suction cups will be pooled on a monthly basis and analyzed for inorganic N and P and dissolved organic N and C. More frequent sampling will be done in campaigns to capture changes in seasonality (e.g. spring advancement) or effects of extreme events (e.g. rewetting after drought). Leaching fluxes will be estimated by combining the soil solution concentrations and water fluxes calculated by a hydrological model (e.g. WATBAL). The studies of soil water chemistry will be coordinated with soil chemistry measurements in WP3.

### **Work package 5 – Synthesis and integration**

CLIMAITE will bring together a unique group of expertise from a diversity of national research institutes leading to a synergistic research effort. In comparison to other large-scale projects, e.g. EU projects, the national focus of this project allows us to concentrate on one easy accessible research location, which at the same time facilitates close contact between the involved scientists. On the other hand, the multidisciplinary character of the work necessitates a strong coordination and a constant supervision of the work to keep the direction of the research towards the goals agreed upon. Work package 5 is specifically designed to achieve a strong interaction and synthesis among the work packages and among the researchers and institutions. Thus, the primary goal of WP5 is to promote syntheses within and across the different work packages and ensuring communication of results between the individual scientists.

The main tasks of WP5 will relate to both practical and scientific integration of CLIMAITE. The main **practical tasks** will be to facilitate the accessibility of the results across the sub-projects and work-packages and advice ways for synthesising the results in order to fulfil the overall goals of the CLIMAITE project and to solve practical questions related to the experimental set-up and its optimal use, e.g. timing and coordination of sampling as to inflict minimal damage to the system. The primary **scientific task** will be to make overall syntheses of the results from work packages 2-4 relating to the two common main hypotheses relating to multiple environmental stress and changes in temporal variation patterns. Thus it will be shown to which degree organisms and processes respond to combinations of environmental stresses and whether these effects are simply additive, synergistic or antagonistic. It will also be shown how ecosystem function responds to changes in seasonal climate patterns, extreme climatic conditions and changes in stochasticity of weather events.

#### **Organisation and means of integration**

The work will involve syntheses drawn from the results obtained by different means across the multidisciplinary sub-projects and across the work packages. The activities assume a high degree of cooperation and coordination and will be lead by experienced scientists, but they will also involve post-doctoral researchers and be a component in their research training. To achieve this, we will form a group of coordinators with members from each of the work packages, the post-doc researchers and the coordinator of CLIMAITE.

The multidisciplinary work will typically be concentrated around common, thematically limited problems within work packages 2-4. To this category the PhD projects belong. Although they

typically will be pursued within each of the work packages 2-4, they will draw upon other work packages and be supervised by two senior researchers at different institutes as to guarantee a broad educational basis. A part of the time of the PhD students will be directly allocated to the synthesis activities of WP.5. A list of planned PhD projects is given below.

The various means employed in WP5 to conduct and synthesise the work in CLIMAITE in an integrated and holistic manner include:

1. **Education and mobility.** PhD students and post-doctoral researchers will be actively involved in the research and senior researchers at two or more institutes will supervise all PhD-students.
2. **Work protocol:** During the initial phase of the project a common work protocol will be developed for each work package in order to maximise the integration and coordination of the work across work packages.
3. **Database:** A common database will be created to include all basic data and research data of interest to a wider group of CLIMAITE partners. The database will be accessible for all members of CLIMAITE.
4. **Project workshops.** Internal workshops of 2-3 days duration in late winter will be organised annually. These workshops will be used to:
  - a. Present and discuss sub-projects and work packages
  - b. Detailed planning of the activities the coming year including time-plans for sampling, field campaigns, sharing of samples, publications, changes in plans etc.
  - c. Presentation and discussion of result, sharing of results, syntheses and publications in order to fulfil the goals of the projects.
5. **Open workshops:** 1-2 international workshops will be organised with invitation of a limited number of scientists involved in similar or relevant research projects. Additional researchers outside the project group will be invited, preferably PhD-students and younger post-doctoral scientists. The size of the open workshops will depend on attraction of additional funding.
6. **Common publication:** A number of common publications integrating results across the work packages will be produced. One publication will be aimed at publication in Nature or Science. The PhD students will be involved in these integrated publications.
7. **Modelling:** The type of data that will be generated within CLIMAITE will be of general interest to ecosystem modellers because the project will provide data on how ecosystem processes and ecosystem functioning including soil-plant-fauna interactions will be affected by climatic stressors in combination. This type of data is generally lacking. Presently, there is no single model available directly applicable for the CLIMAITE studies. However, models treating specific processes or part of the system (e.g. models describing decomposition, canopy/stomata exchange, soil N emission) will be employed wherever relevant. Furthermore, the Chemical Engineering group at Lund University, S, has developed a model for forestry, FORCAST, which is linking all the involved relevant processes. Collaboration between the group in Lund and CLIMAITE has been decided involving two potential steps:
  - the initial step within the first year involves identification of model potential, requirements for model development, field measurements and potentially pre-calibration of the model. This step will ensure that the modelling aspect and requirements are brought in from the very start of the project.
  - based on the initial step, funding will be applied for a PhD or Postdoc to apply and test the model by using the experimental results. This will be a collaborative PhD/Postdoc between Lund and CLIMAITE, and the realisation depends on the ability to attract necessary funding.

### PhD projects

CLIMAITE will initiate at least 5 PhD projects linked to the 3 field related work packages WP2-WP4 and the synthesis work package WP5. It is furthermore highly likely that PhD projects funded from other sources will be started in association to the CLIMAITE consortium. All PhD projects will cover at least 2 different WPs and at least 2 involved research groups. Thereby, we intent to enhance the collaboration among WPs and research groups and create a strong

and motivating educational environment for the PhD students. Furthermore, all PhD projects/students will be involved in and contribute to the syntheses work in WP5. The intended PhD projects are:

*PhD in Plant physiology (Year 2-4)* This PhD project will be linked to WP2.1 (stress), WP3.1 and 3.4 (plant phenology and community structure) and WP 4.1 (gaseous exchange). The project will include studies of short term acclimation of leaf physiology (photosynthesis, respiration, stomatal conductance,  $J_{max}$ ,  $V_{cmax}$  etc.) and morphological parameters (specific leaf area (SLA), biomass etc.) to climatic changes, seasonality and leaf stress buffering capacity of different species and changes in stomatal index, transpiration and water-use efficiency. Also, a specific task will be to scale up responses at the leaf level to the canopy and ecosystem level and link alterations in physiological processes to changes in plant species abundance and community structure.

*PhD in soil fauna physiology* – This PhD project will mainly be linked to WP 2.2, but includes elements of work packages 3 and 4 as well. The focus will be on desiccation tolerance in protozoa, nematodes, enchytraeids, Collembola and mites. The studies should elucidate by which mechanisms the selected organisms cope with low soil water potentials, identify critical stress levels and examine life-history traits under sub-optimal soil water potential. Also population recovery times after severe drought will be investigated. These results will be used to explain population dynamics observed in the field experiment (WP3). Respiration and consumption rates will be measured under a range of soil moisture and temperature conditions, to be used for calculation of soil fauna contributions to decomposition, and interactions with microbial organisms. Further the PhD will participate in the  $^{13}C$  flow studies in WP 4.4.

*PhD in plant/fauna interactions (year 2-4)* This PhD. project is rooted in WP2-3 (Trophic interactions above-belowground) with links to WP2-2, WP3-2, WP3-3, and WP4-2. The work centres on the most important foliar herbivores, being leaf chewers and/or leaf suckers and their performance at realistic conditions of climate change and elevated  $CO_2$ . The effects of these insects on carbon transfer belowground, root respiration, rhizosphere bacterial communities, and growth of bacteria-supported micro fauna (protozoa and nematodes) in the rhizosphere is analysed in growth chambers at controlled conditions of climate and  $CO_2$ . Knowledge on microbial communities and biomass, and growth of the microbivorous micro fauna in the field in the various treatments of the experiment is obtained from the work of the technician employed under WP2-3, WP3-2, and WP3-3 and will be available for the PhD. student. By combining field and growth chamber data on foliar herbivores, rhizosphere micro fauna and belowground respiration with knowledge on micro fauna behaviour at extreme climatic events (WP2-2) the PhD student will acquire thorough knowledge on multitrophic interactions above- and belowground as affected by climate change and elevated  $CO_2$ .

*PhD on cycling, uptake and sizes of N pools:* (year 3-5). This PhD project will mainly be linked to WP4 and will focus on the effects of warming, increased  $CO_2$  and precipitation changes on internal nutrient transformations within the ecosystem, on mechanisms and pathways of microbial and plant mediated C and N assimilation, and on nutrient pool sizes within the ecosystem. Methods used will include analysis of nutrient changes by the buried bag method, isotopic labelling and detection of isotopes of N in soil, microbial and plant pools, and determination of changes in N pool sizes of the same pools.

*PhD on carbon cycling (year 2-4)* - This PhD project focuses on carbon cycling in the ecosystem. The project will have its main activity within work package 4, but includes elements of work packages 2 and 3 as well. A main component of the project is the measurement of  $CO_2$  exchange by means of chamber technique at the plot scale and the partitioning of net ecosystem exchange into assimilation and respiration. This will be combined with studies of belowground carbon dynamics and the effects of the treatments by means of the  $^{13}C$  labelling as a result of the  $CO_2$  fumigation of fossil fuel origin. The project will also include measurements of biomass and its C content.

## **Work package 6 – SENDOUT (Steering, Education, Networking, Dissemination and OUTput)**

Work package 6 has the task of conducting all the “additional activities” within CLIMAITE. These are mainly activities related to the management and coordination of the centre activities (described later) and external communication through networking and dissemination of information and results.

### **Publication and dissemination strategy**

The results of the research will be disseminated to various groups of “stakeholders”. The means of dissemination will depend on the group.

**Publication for researchers** – Results will be published in relevant high quality international journals. The publication rate is likely to be relatively low in the first phase of the project during establishment and with an increasing rate as the project progress and the results start to emerge. In order to emphasize the interdisciplinary character of the research and force the collaborative effort researchers will be particularly encouraged to publish joined publications involving at least two different research groups. It will be a specific aim that the two integrating research activity (WP5) will submit a synthesizing publication for Science or Nature. Finally, international research conferences and workshops will be used as important means to distribute results and knowledge and at the same time fertilize collaboration and networking with international research groups.

**Societal publication and the wider public** – The main aim of the research is basic research with limited direct applicability. However, there is a growing interest in the society regarding environmental issues and in particular the potential impact of climate change, and the results obtained will provide a basis for future policy decisions regarding climate change abatement strategies. Consequently, the centre will have a commitment to provide information about the activities and the results to the public and thereby to contribute to the public awareness and understanding of climate change related issues. This will be ensured by publication of a frequently updated web site describing the centre, its activities and the results. Furthermore, the centre will regularly publish articles in national Danish journals for “popular science” (e.g. Naturens Verden, Kaskelot, Illustreret Videnskab), “serious” popular journals (e.g. Samvirke, Ud & Se) and TV science programs such as “Viden om” to describe the project and selected results to a wider audience. Finally, the centre will offer information to the public through the regular press by press releases and contacts to the major Danish newspapers whenever interesting news are available (e.g. at the initiation of the centre and when the field site is fully build). We expect that the experiment is sufficiently novel and spectacular to attract attention from the media. The policy for the contacts to the press will be discussed and decided in agreement with the VKR foundation and will be done in collaboration with the information centre at RISØ.

**Policy makers** – Results generated within the centre may have direct interest for future policies and should therefore be distributed directly to politicians or policy makers either by press releases, press conferences or direct letters. The strategy for this will be decided from case to case in close collaboration with the information centre at RISØ. New knowledge relevant to the IPCC process will be disseminated to the relevant working groups.

| Target group                      | Mean                              | Year 1     | Year 2     | Year 3     | Year 4     | Year 5     |
|-----------------------------------|-----------------------------------|------------|------------|------------|------------|------------|
| Scientists                        | Scientific journals               |            | WP1        | WP2-4      | WP2-4      | WP2-5      |
|                                   | Int. Conferences & workshops      | WP1        | All        | All        | All        | WP1<br>WP5 |
| “Educated layman” & Policy makers | National popular science journals | WP1        | WP2        | WP3        | WP4        | WP5        |
|                                   | Popular “serious” journals        | WP1        | WP2        | WP3        | WP4        | WP5        |
|                                   | Press release                     | WP1        | WP1        | WP5        | WP5        | WP5        |
|                                   | Web page                          | All        | All        | All        | All        | All        |
| Layman                            | Popular “serious” journals        | WP1        | WP2        | WP3        | WP4        | WP5        |
|                                   | Web page                          | All        | All        | All        | All        | All        |
|                                   | Journalist contacts               | WP1<br>WP5 | WP1<br>WP5 | WP1<br>WP5 | WP1<br>WP5 | WP1<br>WP5 |

*Elements in the publication strategy for CLIMAITE. Target groups and means of information during the course of the project.*

### **Coordination of education and training**

Education and training of master and PhD students will be an integrated part of the centre activities. 5 PhD projects have been formulated as a specific part of the centre activities in WP5 to facilitate the synthesis of work across institutions and work packages. The educational and training activities will be coordinated with other similar activities at the institutions and associated networks.

The PhD students will be linked to the national Copenhagen Global Change Initiative (COGCI) and international networks in order to provide a fruitful and motivating research environment. At the Biological Institute at Copenhagen Univ. there are three well-established PhD courses that run regularly and will be the core tutorial activity for the five PhD. students employed in CLIMAITE: The three courses focus on (1) plants (“Methods in Physiological Plant Ecology and Biogeochemistry”, organiser Sven Jonasson, CU), (2) plant-microbe-fauna interactions (“Dynamics of Soil Organic Matter”, organiser Søren Christensen, CU), and (3) global change (“Copenhagen Global Change Initiative, Ecosystem Course”, organiser Sten Struwe, CU). Each course has 10-20 participants from Danish and foreign universities and teachers from all over Europe. The organisers two of which are active members of CLIMAITE, already communicate efficiently to assure that the three courses are complementary and therefore give the students a good insight into current thinking and methodology in the fields of terrestrial ecology and global change.

Master students will be continuously involved through formulation of specific and targeted master projects within the different work packages. These projects will be published at the university courses, at the web and in project catalogues. This type of master projects will be important, not only for the student training, but also as a way to attract potential PhD students to the centre.

### **Networking**

The impact of climate change on biological processes and ecosystems is a complex and clearly global problem. Sharing experiences and results among different research groups at national, regional and global levels therefore provide significant advantages in order to improve our knowledge and reduce loss of resources. The different research groups within the centre are already involved in international collaboration and networks, and these contacts as well as new ones will be strongly supported and developed within the centre.

**National collaboration** - collaboration with the Danish climate change centre for Marine and Freshwater ecosystems, CONWOY will be developed to coordinate activities and eventually take advantage of common ideas (meetings, education etc.). Also, CLIMAITE institutes are involved in the Graduate School for Environmental Stress Studies (GESS) that aims to facilitate and enhance interdisciplinary study of the consequences of natural and anthropogenic stress on ecological systems and their component species. Finally, contacts to other national players in climate change are provided through the forum of "Danmarks Klimacenter" based at DMI that organize workshop across disciplines.

**International collaboration and networks** – the **Nordic countries** have a strong tradition for collaboration and centre partners are already involved in several projects, groups and networks such as Nordic Council of Ministers "Centre of Excellence" and the Council's Arctic Programme (NARP). A close cooperation is since long established with scientists and research groups working at Abisko Scientific Research Station analysing biological responses to environmental manipulations in arctic regions. Contacts are, furthermore, established to the national Norwegian Climate Change project focussing on aspects of C and N cycling relevant to this centre. Furthermore, collaboration with Lund University has been agreed involving development and potentially application of their mathematical model FORCAST. Finally, together the researchers in CLIMAITE have collaboration or contacts to all the leading groups in the Nordic countries.

The partners are involved in several **EU projects and networks** of direct relevance to this centre: VULCAN, EUROCARBOFLUX, GREENGRASS, NOFRETETE, CENTER, AVEC and PRECIP\_CHANGE all deal with climate change and carbon and nitrogen cycling whereas the thematic network CONSIDER and the research training network BIORHIZ have soil organisms and their interaction with plants in focus.

**Outside EU**, the partners have been involved in NSF-supported cross-site evaluations and integrations of biological responses to climate change-related environmental manipulations and through ongoing activities the centre will be involved in the international research networks TERACC (Terrestrial Ecosystem Research and Climate Change), ITEX (International Tundra Experiment) and NEWS (Network of Ecosystem Warming Studies) which will be fruitful for the sharing of ideas and results and COST E21 (Contribution of Forests and Forestry to Mitigate Greenhouse Effects). Finally CLIMAITE will contact GCTE (Global Change and Terrestrial Ecosystems) or the organisation replacing it to form links and share experiences with relevant projects and organisations.

Also, of specific importance to the development of the common field site with **CO<sub>2</sub> fumigation**, the centre has contacts to M.R. Shaw at Stanford University (US), M.Hovenden at Tasmania University and F. Miglietta at University of Tuscany who are skilled in designing and running CO<sub>2</sub> exposure experiments in the field. These contacts will be of great importance in the design and set-up of the experiments.

## Time schedule and milestones

It is important that the research activities have a time frame which relates to the response time of the biological processes. Field scale ecosystem research normally requires a long time horizon (3-10 years) while specific process oriented studies may be shorter (< 1 year). The research within CLIMAITE is planned to run for 5 years. Based on our experience from previous projects at Abisko and Mols we believe 5 years to be sufficient to capture the short, and medium term responses. The true long term responses will undoubtedly require a much longer time frame, but by combining the research results with existing knowledge from the literature and results from the existing long term field scale experiments carried out within the participating institutes we assume that longer term effects to a certain extent can be assessed within a 5 year period. The time schedule for the work plan and the activities within CLIMAITE will fall in three phases:

- 1) Establishment of the centre and the field site and pre-treatment studies (yr1-2)
- 2) Field scale treatments and effect studies including PhD studies (yr2-4)

- 3) Synthesis of the results including completion of involved PhD studies and publication of results (yr 4-5)

A rough time schedule for the first phase with indicated milestones for each work package is shown in the figure and the main types of activities and milestones are further described in more detail.

### **Centre Establishment**

The CLIMAITE centre will be established with the steering group, a board and a secretariat immediately after the start of the project and the centre start will be announced to the public through a press release. The formation of a board and the public announcements through a press release will be discussed and negotiated with the VKR foundation. The establishment of the centre also includes production of information material describing the activities and the aims and launching of a web page. Milestones and time (in brackets) are:

- Formation of steering group (Mmth 1)
- Formation of VKR-CLIMAITE relationship (advisory board) (Mmths 1)
- Dimensioning, initiation and task definition for secretariat (Mmths 2)
- Press release (decision together with VKR) (Mmths 2)
- Development of web-page, logo and information material (Mmths 5)

### **Installation of the field site**

The main research will be conducted at a new field site, which requires basic establishment and instrumentation of the site. The specific establishment of the site and the work planning will be discussed and decided at a kick-off meeting shortly after initiation of the centre in order to get the basic establishment of the site in place within the first few months after initiation.

Milestones and time (in brackets) are:

- Kick off meeting and site planning (Mmths 1)
- Site establishment with basic infrastructure and logistics (Mmths 1-4)
- Basic instrumentation (temp., moisture, climate etc.) (Mmths 2)

### **Pre-treatment measurements**

The first year will be used for pre-treatment measurements of relevant processes and parameters to serve as important baseline information for the field research and as a tool for testing the subsequent treatment effects (e.g. co-variance, random intervention analyses etc.). The pre-treatment measurements will be initiated within the first 2-3 months after initiation of the centre. Based on measurements of climate and soil moisture a hydrological model will be applied for later use in flux estimations. Milestones and time (in brackets) are:

- Initiation of measurements of basic parameters (climate, temperature, moisture, C-exchange and soil respiration, soil water chemistry and fluxes, deposition, *in situ* plant physiology) (Mmths 2-4)
- Ecosystem structure (plant community, vertical distribution of roots, microbial and soil fauna communities, nutrient pools) (Mmths 2-4)
- Measurement campaign (plant species and community parameters) (Mmths 5)
- Hydrological model application (Mmths 15)
- Model conceptual outline and model/measurement interactions (Mnths 3-8)

### **Work protocol, treatment installation and methodological development**

The CO<sub>2</sub>, temperature and water treatments are scheduled to start in year 2 of the project. The potential methodologies for each of the treatments have been decided, but the specific design and control of the treatments will be done during the pre-treatment year. This includes prototype testing of the treatments in the field (e.g. CO<sub>2</sub>-distribution and control, temperature increase and control, temperature increase at plant surfaces in the warming treatment). To ensure maximum coordination of the field activities with respect to in timing, methodology and exploitation of samples and data, a common work protocol will be developed for all activities and each WP. Special notion will be taken to ensure that the different parts of the project are structured in a way suitable for later synthesis including the initial set-up of the database and that the activities allow for advanced multivariate statistics such as MANOVA, principal components and longitudinal data analysis. Methodological development and testing will also be done during the first year (e.g. laboratory testing of soil fauna responses, measurements of

spatial variability to design sampling strategies etc.). Finally, the treatments will be installed at the end of year 1 to be initiated at the start of year 2. Milestones and time (in brackets) are:

- Treatment design and testing (Mmths 3-8)
- Initiation of specific work package studies (Mmths. 3)
- Development and evaluation of detailed work plan and protocol for each WP (Mmths. 5, 12, 21)
- Database decision (mth 6) and database set-up (mth 12)
- Treatment installations (Mmths 10)
- Biomass estimation from point frequency measurements (Mmths 12)
- Evaluation of natural seasonal variability for design of sampling strategy in early spring, late autumn and freeze/thaw cycles (Mmths 15)
- Paper describing the experiment – National (Mmths 10) and international (mth 20)

### **PhD project initiation**

5 PhD projects will be initiated as an integrated part of the research activities. The plans for each of the PhD projects will be discussed and decided during the first year including coordination within CLIMAITE and with the existing PhD-schools. The specific PhD projects will be announced and the PhD students selected to start at the end of year 1 or during year 2. The starting time will be decided individually for each project. Milestones and time (in brackets) are:

- Development of specific PhD plans and application (Mmths 10)
- Selection of students (Mmths 12)
- Start of projects (Mmths 15-24 - see specific PhD plans)

### **Effects studies - measurements**

Generally, all activities related to measurements of treatment effects (WP2-WP4) will be ready to start in the spring of the first treatment year (2005) including measurements started in the pre-treatment year, which will be continued.

- Soil fauna responses to drought - field scale (Mmths 15)
- General relationships between soil water potential and fauna activities – initiation (Mmths 20)
- Herbivory studies in the field (Mmths 14)
- Laboratory monolith study (herbivory-altered C-transfer from plant to rhizosphere fauna,  $^{13}\text{C}$  carbon depletion rate) (Mmths 15)
- Plant structure and community measurements (Mmths 16)
- First year estimate of ecosystem C exchange and N-balance (Mmths 22)
- Evaluation of importance of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emissions and decision about further studies (Mmths 20)

| WP            | Activity                                   | 2004            |   |   |   |   |   |   |    |    |    |    |    | 2005            |    |    |    |    |    |    |    |    |    |  |  |
|---------------|--|-----------------|---|---|---|---|---|---|----|----|----|----|----|-----------------|----|----|----|----|----|----|----|----|----|--|--|
|               |  | Month (in year) |   |   |   |   |   |   |    |    |    |    |    | Month (in year) |    |    |    |    |    |    |    |    |    |  |  |
|               |  | 3               | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1  | 2  | 3               | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |  |  |
| Running month |  | 1               | 2 | 3 | 4 | 5 | 6 | 7 | 8  | 9  | 10 | 11 | 12 | 13              | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |  |  |
| WP1           | Field site                                 | M               |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Pretreatment                               | M               | M | M |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | CO2 treatment                              |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Water/Drought treatment                    |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Warming treatment                          |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Basic instrumentation and measurements     |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Project description & documentation        |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Monolith study in growth chamber           |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
| WP2           | Plant physiology                           |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Stress tolerance of plants                 |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Leaf chemistry                             |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Soil fauna stress physiology studies       |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Fauna respiration studies                  |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Herbivory studies in the field             |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Herbivory monolith experiments C-transfer  |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | PhD projects                               |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
| WP3           | Whole ecosystem C, N & P                   |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Biomass estimation                         |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Community structure - point frequency      |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Phenology (NDVI, LAI, Phenology etc.)      |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Plant tissue quality                       |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Microbial community (DNA, RNA)             |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Fauna community and climate change effects |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | PhD projects                               |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
| WP4           | Atmosphere/biosphere gas exchange          |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Belowground C-transfer                     |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Internal nutrient cycling                  |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Gross N cycling                            |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Hydrological modelling and leaching        |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | PhD projects                               |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
| WP5           | Database                                   |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Internal workshop                          |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Work protocols                             |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
| WP6           | Press release                              |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | WEB site and information                   |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Steering group and advisory board          |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Centre logistics                           |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |
|               | Danish articles                            |                 |   |   |   |   |   |   |    |    |    |    |    |                 |    |    |    |    |    |    |    |    |    |  |  |

Milestone type indication    P Publication    M Method    W Workshop    D Data    C Centre

Rough schedule of activities and milestones for CLIMAITE in phase 1. Indicated types of milestones are: P: Publication; M: Methodology; W: Workshop/Meeting; D: Data and C: Centre development.

## Consortium and organization

The research groups participating in the centre cover the wide range of scientific disciplines including plant, soil, microbiology, fauna and chemistry sciences, which are needed to carry out the interdisciplinary research activities. All groups have been or are presently involved in national or international research projects related to effects of climate change on biological processes and all groups have had previous collaboration with at least one of the other groups. Therefore, the centre forms a strong Danish team with a unique composition and a strong international potential.

## Description of the partners and their roles

### **RISØ National Laboratory, Plant Research Department (Risø-PRD)**

PRD has a strong experience in field scale ecosystem studies including experience in realistic manipulations. The ecosystem research in the department focuses mainly on plant physiological responses to environmental pressures, biogeochemical cycling of carbon, nitrogen and phosphorous in natural and managed ecosystems, atmosphere-biosphere exchange of greenhouse gasses and organic matter mineralisation. The department has strong skills in the use of field scale manipulations, plant growth in controlled environments, gas flux measurements and use of stable isotopes to study plant and ecosystem responses to environmental pressures. The department has participated in numerous national and international research projects and has co-ordinated several EU projects. The research group has a comprehensive network of international research contacts with directly relevance for CLIMAITE.

**Facilities and resources:** PRD has excellent growth chamber facilities including controlled environments with CO<sub>2</sub> control. PRD has a modern chemical and biological laboratory including analytical instruments for stable isotope analyses. PRD is responsible for the Mols bjerge field site with medium term warming and drought experiments, and for a study area at Zackenberg in Greenland for studies of UV-B effects together with UC-PE.

**Researchers:** PRD involve 4 senior researchers in the work with the following roles:

*Claus Beier:* Centre leader, responsible for WP6 \_ SENDOUT, responsible for WP4.6 (water mediated fluxes), central roles in WP1 on the design of the field scale manipulations and WP5 "Synthesis and Integration".

*Teis Mikkelsen:* Responsible for WP1 "Experimental facilities", central roles in plant physiological activities in WP2.

*Per Ambus:* Responsible for work package 4 and studies on carbon allocation, isotopic fractionation of carbon and C and N interactions in WP4.

*Kim Pilegaard:* Responsible for studies of net ecosystem exchange of carbon within WP4. Central role in WP5 "Synthesis and Integration".

### **University of Copenhagen, Physiological Ecology (UC-PE)**

PE has a strong position in field scale ecosystem studies in arctic ecosystems including experience in realistic environmental manipulations. The ecosystem research in the department focuses mainly on biogeochemical cycling of carbon, nitrogen and phosphorous in natural ecosystems, atmosphere-biosphere gas exchange of carbon and nitrogen gasses, mineralisation processes and nutrient mobilisation processes in the soil-microbial-plant interface. The department has strong skills in chemical analyses of soil and biological material, gas flux measurements and use of stable isotopes to study plant and ecosystem responses to environmental changes. The department has participated in numerous national and international research projects and has a large network of international research collaborators and contacts.

**Facilities and resources:** PE has skilled technicians and a well-equipped laboratory for the chemical analyses of soil and biological material, including facilities for analyses of stable isotopes. PE runs long-term ecosystem experiments at Abisko, N. Sweden, with manipulations of temperature, nutrients, light and the soil substrate and, together with Risø-PRD, at Zackenberg in N. E. Greenland with manipulations of UV-B radiation.

**Researchers:** PE will involve 3 professors and senior researchers:

*Sven Jonasson*: Research coordinator, responsible for WP5 “Syntheses and Integration”, central role in WP4 on C and N transformations and WP6 on “SENDOUT”.

*Anders Michelsen*: Responsible for studies on internal nutrient transformations and pathways of microbial and plant mediated C and N assimilation within WP4.

*Helge Ro Poulsen*: Responsible for physiological work on plants within WP2.

### **University of Copenhagen, Department of Microbiology (UC-MI)**

MI has a strong record in studies of microbiological transformations of carbon and nitrogen compounds in soil and in state-of-the-art molecular fingerprinting of microbial communities in soil. The research at the department seeks to link information obtained at different description levels, i.e. from single bacteria to complex bacterial communities. The department participates and has participated in numerous national and international research projects involving microorganisms in soil and has a large international network with collaborators relevant for CLIMAITE.

**Facilities and resources:** MI has in-house access to all equipment needed for DNA- and RNA-based T-RFLP, sequencing, SIR, measurements of key microbial nitrogen transformations, and physiological fingerprinting using BIOLOG Ecoplates.

**Researchers:** MI will involve 1 senior researcher:

*Anders Priemé*. Will be responsible for characterisation and studies of bacterial community structure within WP3 “Ecosystem structure” and partly for studies of microbial N-transformations within WP4 “Ecosystem function”.

### **University of Copenhagen, Zoological Institute (UC-ZI)**

ZI has a strong experience in soil micro fauna (protozoa and nematodes), their trophic activity and interactions between microbivores and microorganisms. These trophic interactions are studied during decomposition of organic debris and in the rhizosphere of plants. Recently we started working on foliar insect herbivory and its interaction with rhizosphere processes such as rhizosphere microbial activity, trophic transfer, and growth of root symbionts. The latter activities form the background for participation in the EU thematic network CONSIDER (Conservation of soil organism diversity under global change) with Søren Christensen as coordinator, and the research training network BIORHIZ (Biotic interactions in the rhizosphere) with start in 2003 and 2004 and duration 4 and 5 years, respectively.

**Facilities and resources:** The institute has a series of different microscopes for inspection and quantification of micro fauna and gas chromatographs for analysis of major components (O<sub>2</sub>, CO<sub>2</sub>, N<sub>2</sub>) and trace components (CH<sub>4</sub>, N<sub>2</sub>O) of the atmosphere are also in stock. High quality growth chamber facilities with a respirometer designed for quantification of rhizosphere respiration during plant growth is also available. Facilities and know-how within related biological disciplines (e.g. population ecology, molecular and cell biology) at neighbouring laboratories at Zoology assures a dynamic and stimulating academic environment.

**Researchers:** ZI will involve 1 senior researcher:

*Søren Christensen*: Responsible for plant-herbivore-rhizosphere interactions (WP2.3) and analysis of microfauna (nematodes, protozoa) (WP3).

### **The Royal Veterinary and Agricultural University, Department for Applied Ecology (KVL-AE)**

AE has a strong experience in large-scale *in-situ* terrestrial ecosystem studies including responses to natural or manipulated stresses by nutrients, climate and water. The main areas of expertise are in whole ecosystem ecology comprising the interactions between vegetation, soil and the environment (e.g. climate, nutrients, precipitation). The research focuses mainly on role of vegetation in ecosystem nutrient cycling, carbon-nitrogen interactions, carbon sequestration, plant succession in natural and managed ecosystems including grass and heath ecosystems, litter quality and decomposition, soil processes and soil water quality. The department has participated in numerous national and international research projects and coordinates presently 4 EU projects. The research group is responsible for the vegetation analyses at the Mols site and has ongoing work using <sup>15</sup>N tracer to model whole ecosystem

nutrient cycling and carbon sequestration. The research group has a comprehensive network of international research contacts with directly relevance for CLIMAITE.

**Facilities and resources:** AE has excellent laboratory facilities including a EU certified chemical laboratory with all equipment needed for the chemical analyses. Further, AE has skilled technicians for field instrumentation, monitoring and experimentation techniques.

**Researchers:** AE involves 2 senior researchers in the work with the following roles:

*Inger Kappel Schmidt:* Will coordinate WP3. Will be responsible for plant community structure, species abundance, plant phenology and plant and litter nutrient and carbon fraction pools within WP3 “Ecosystem structure”.

*Per Gundersen:* Central role in WP5 “Synthesis and Integration” with focus on the effect of nitrogen on carbon storage and the effect of soil carbon on N retention.

| Research group                             | Institution | Senior researchers involved                                 | Disciplines/Roles   |
|--|-------------|---|---|
| Plant Research Department, <i>Risø-PRD</i> | RISØ        | Claus Beier<br>Teis Mikkelsen<br>Per Ambus<br>Kim Pilegaard | Ecosystem manipulation<br>Biogeochemistry<br>Plant physiology<br>Stabile isotopes<br>Element fluxes |
| Physiological Ecology <i>UC-PE</i>         | CU          | Sven Jonasson<br>Anders Michelsen<br>Helge Ro Poulsen       | Plant physiology<br>Biogeochemistry<br>Stabile isotopes<br>Plant/microbe interactions               |
| Dep. of Microbiology <i>UC-MI</i>          | CU          | Anders Priemé   | Microbiology<br>Functional diversity  |
| Zoological Institute <i>UC-ZI</i>          | CU          | Søren Christensen   | Micro-fauna<br>Rhizosphere processes<br>Herbivory   |
| Applied Ecology <i>KVL-AE</i>              | KVL         | Inger Kappel Schmidt<br>Per Gundersen                       | Litter quality<br>Mineralisation<br>Vegetation dynamic  |
| Terrestrial Ecology <i>NERI-TE</i>         | NERI        | Martin Holmstrup<br>Paul H. Krogh                           | Meso- and macro-fauna<br>Soil fauna community structure<br>Ecophysiology of soil fauna              |

*Groups and researchers involved in CLIMAITE indicating their main disciplines and roles*

### **National Environmental Research Institute, Department of Terrestrial Ecology (NERI-TE)**

TE has extensive experience in field and laboratory studies of soil invertebrates. The research of the department focuses mainly on ecotoxicology and functional ecology of soil invertebrates in agricultural and natural soil ecosystems ranging from Mediterranean to arctic regions, and how soil invertebrates interact with plants and microorganisms. Recently the laboratory was certified as having “Good Laboratory Practice” by Danish accreditation authorities concerning these activities. Thus, the department has strong skills in conductance of field studies, laboratory mesocosms, laboratory culturing, and physiological studies of soil invertebrates. The department is currently coordinating 3 EU-projects and has a long experience with management and participation in large research projects. The research group has built up a strong international network of scientists, which will be valuable for the present project.

**Facilities and resources:** TE has excellent laboratory facilities including temperature and light controlled walk-in climate rooms, a greenhouse and programmable freezing and heating cabinets. All necessary equipment for analysis of soil invertebrates is available including

computer-controlled equipment for extraction of soil invertebrates, digital image analysis for counting and growth measurements. Also available are NMR, HPLC and TLC methods for chemical analysis of animal metabolites including free amino acids, and carbohydrates, and equipment for measuring soil water potential in soils.

**Researchers:** TE involves a professor, a senior researcher and 2 technicians highly skilled in soil invertebrate work including taxonomy.

*Martin Holmstrup* will lead WP2 (Species responses and physiology) and responsible for physiological studies of soil animals in this WP. Further he will be responsible for field studies of soil mesofauna, participate in WP4 trophic flow studies of  $^{13}\text{C}$ , and have a central role in WP5 theory building and synthesis.

*Paul Henning Krogh* will take part in WP3 field studies and mesocosm studies.

## Structure, management and internal communication

CLIMAITE will focus strongly on the interdisciplinary and inter institutional character of the research and almost all activities involve at least two groups. Furthermore, activities within the different work packages are of interest or have potential overlaps with other work packages. In order to ensure coordination of the activities and a smooth flow of information and decisions among all groups a coordinator is assigned for each work package and the work package coordinators together form a steering committee.

### Structure

**Centre leader:** The centre leader has the overall responsibility for the centre including ensuring that all activities are conducted according to the plans and to decide about changes in activities and resources.

**Research coordinators:** The research coordinators within the research activities (WP1-WP5) have the responsibility to coordinate the research activities within their work package and among the work packages and to ensure optimal synergy with the other research activities in relation to the integrated research themes. This will be done by development of a work protocol for all activities. The research coordinator for WP5 (Synthesis and integration) has the responsibility to coordinate the integration of the research results into a common framework with particular focus on the overall integrated research themes including publication. The research coordinators cover broadly the scientific areas of the centre as well as the participating institutes.

**Steering group:** The centre leader and the research coordinators form the steering group. They have the responsibility to ensure the scientific and practical coordination and progress of the activities including resource use. The steering group will meet at least 4 times a year to discuss and decide major questions relating to the overall centre activities. The steering group will be involved in the planning of the annual internal workshop.

**Advisory board:** An advisory board of 3 people for the centre will be formed to advise the scientific directions, the management and the communication. The members will be chosen among prominent researchers from the Nordic countries who have worked with relevant issues. The advisory board will meet approximately once a year (more often if needed).

### Management

**Research directions and resources** – Due to the interdisciplinary character of the centre and the many research groups involved a strong planning and coordination of the activities is needed. Therefore, a meeting/workshop will be held each year to present and discuss the plans for the coming year and the results of the work so far. In particular a detailed work protocol will be developed for each work package based on the present research plan. The work protocol will describe the activities, methodology and resources and will be developed through common discussions and decisions among the involved researchers and work package leaders at a "kick off" meeting. The work protocol will be an essential tool to ensure that the activities are coordinated and optimised in terms of resources, timing and use of the samples, and that methodologies are harmonized. The work protocol as well as other

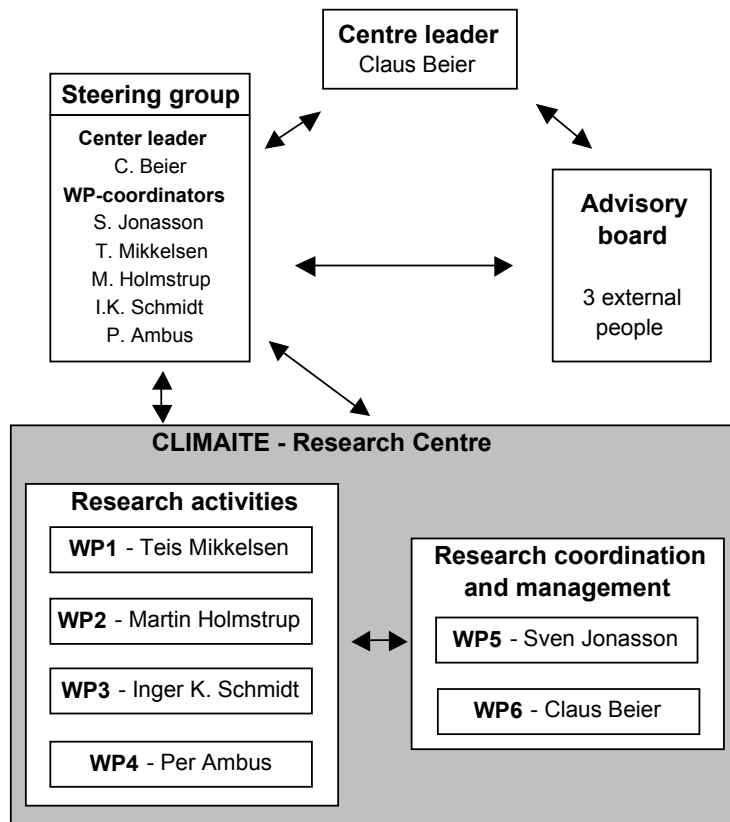
decisions about centre activities will be re-evaluated at the annual meeting. The steering group will make additional decisions.

**Projects/activities** –The individual researchers or research groups will have the task to run the specific activities under the frame of the common decisions.

**Centre management** – Decisions regarding the overall management and activities of the centre will be made by the centre leader in collaboration with the steering committee and if needed with the VKR foundation.

### Internal communication

The internal communication among the scientists and the different research groups will, beyond the obvious, be facilitated through the annual internal workshop (see WP5), where larger organizational, research, economic and planning questions will be discussed and decided and through the opening of the centre web-page (See WP6). The web page will include a “confidential part”, where internal information, documents of common interest, publications still in preparation and a database with common data (e.g. climatic data, treatment documentation etc.) will be available for all centre members.



*Management structure of CLIMAITE*

## CVs for involved Scientists

**Claus Beier**, Plant Research Department, RISOE National Laboratory

Claus Beier (CB) born 1958, holds a degree in chemical engineering (environmental ecology) and a PhD in atmospheric deposition from the Technical University of Denmark. CB has worked intensively with ecosystem manipulation in forested and non-forested ecosystems for more than 15 years focussing on effects of acidification, nitrogen deposition and climate change on ecosystem functioning, in particular the effects on nutrient cycling. CB's main areas of expertise are ecosystem manipulation at the field scale, deposition and nutrient cycling, carbon sequestration in plants and modelling of C and N circulation. CB has participated in 4 EU projects (EXMAN, CLIMEX, CLIMOOR and VULCAN) and is presently co-ordinator of the ongoing EU project VULCAN including 11 European research groups and parallel climate manipulations at 6 European shrubland ecosystems. CB is in the steering committee of the EU funded concerted action AVEC and has formed contacts to many relevant research groups in Europe, US and elsewhere, e.g. CB is involved in the US funded networks TERACC and PRECIPNET. CB has strong experience in managing large multidisciplinary research projects including communication with potential end users and the public through web-communication and popular scientific articles. CB has received in house training in management. CB has published 48 papers in international scientific journals with peer review. Publication list including publications since 1995 is available on [http://iis-03.risoe.dk/netahtml/risoe/publ\\_uk.htm](http://iis-03.risoe.dk/netahtml/risoe/publ_uk.htm) and type: CLBE

### Recent relevant publications

- Van Breemen, N., Jenkins, N., Wright, R.F., Arp, W.J., Beerling, D.J., Berendse, F., Beier, C., Collins, R., van Dam, D., Rasmussen, L., Verburg, P.S.J., and Wills, M.A. (1998) Impacts of elevated carbon dioxide and temperature on a boreal forest ecosystem (CLIMEX project). *Ecosystems*. 1, 345-351.
- Jensen, K.; Beier, C.; Michelsen, A. and Emmett, B.A. (2003) Effects of experimental drought on microbial processes in two temperate heathlands at contrasting water conditions. *Appl. Soil Microbiol.* 24, 165-176.
- Beier, C.; Moldan, F. and Wright, R.F. (2003) Terrestrial ecosystem recovery - Modelling the effects of reduced acidic inputs and increased inputs of sea-salts induced by global change. *AMBIO*, 32, 275-282.
- Beier, C.; Emmett, B.; Gundersen, P.; Tietema, A.; Penuelas, J.; Estiarte, M.; Gordon, C.; Gorissen, A.; Llorens, L.; Roda, F. and Williams, D. (in press) Novel Approaches to Study Climate Change Effects on Terrestrial Ecosystems in the Field - Drought and Passive Night Time Warming. *Ecosystems* (In press)
- Emmett, B.A.; Beier, C., Estiarte, M., Tietema, A., Kristensen, H.L., Williams, D., Peñuelas, J.; Schmidt, I.K. and Sowerby, A. (2003) The response of soil processes to climate change: Results from manipulation studies across an environmental gradient. *Ecosystems* (In Press).

**Sven Evert Jonasson**, Department of Physiological Ecology, Botanical Institute, University of Copenhagen.

Sven Jonasson (SJ) born 1946 with Swedish nationality holds a PhD degree in Botany from University of Göteborg, Sweden. SJ is professor in Plant Ecology, Botanical Institute, University of Copenhagen since 1991 and leader of the Department of Physiological Ecology. He has supervised 10 PhD students (currently 3) and a large number of M.Sc. students.

SJ has more than 30 years' experience of research in terrestrial ecosystems, including plant and animal ecology, physiological ecology, nutrient cycling and turnover of organic matter. The main subject of research during the last 15 years has been on ecosystem functioning and processes in Arctic and sub-arctic ecosystems after manipulations related to global change, particularly with work integrating processes in the soil-microbial-plant interface.

During the last 16 years, SJ has led or coordinated 9 larger research projects. These include "The Arctic Landscape: Interactions and feedbacks among physical geographical and biological processes" under the Danish National Science Research special topic programme for Polar Research and "Multiple environmental changes, effects on arctic organisms and ecosystem processes" under a Nordic Council of Ministers Arctic Programme (NARP). SJ has been member of the steering committee for ARTERI (Arctic-Alpine Terrestrial Research Initiative) a EU concerted action programme with the task to develop scenarios for climate effects in Arctic/Alpine ecosystems and he is currently consulting author to the Arctic Climate Impact Assessment (ACIA).

SJ was Chief Editor for *Ecography* 1993-1995 and is currently member of the Editorial Board of *Oecologia* and Foreign member of The Royal Danish Academy of Sciences and Letters. Other current professional activities and appointments include: Chairmanship of the PhD-school in Botany; Vice-chairmanship of the PhD-board at the Faculty of Science and membership (substitute) of the Board of The Faculty of Science, University of Copenhagen. SJ has published about 80 articles in international, peer-reviewed journals and book chapters. A complete publication list since 1995 is available at <http://www.bot.ku.dk/staff/staff-vip-details.asp?ID=17>

Relevant publications for this project are:

- Jonasson, S., Michelsen, A., and Schmidt, I.K. (1999). Coupling of nutrient cycling and carbon dynamics in the Arctic, integration of soil microbial and plant processes. *Applied Soil Ecology* 11:135-146.
- Jonasson, S., Michelsen, A., Schmidt, I.K. and Nielsen, E.V. (1999). Responses in microbes and plants to changed temperature, nutrient and light regimes in the arctic. *Ecology* 80:1828-1843.
- Jonasson, S., Shaver, G.R. and Chapin, F.S., III. (2001). Biogeochemistry in the Arctic: Patterns, Processes and controls. In: E.-D. Schulze E.D., Harrison, S.P., Heimann, M., Holland, E. A., Lloyd, J. J., Prentice, I. C., Schimel, D. (Eds.) *Global Biogeochemical Cycles in the Climate System*. Academic Press, New York, PP 139-150.
- Larsen, K.S., Jonasson, S. and Michelsen A. (2002). Repeated freeze-thaw cycles and their effects on biological processes in two arctic ecosystem types. *Applied Soil Ecology* 21: 187-195.
- van Wijk, M.T., Clemmensen, K.E., Shaver, G.R., Williams, M., Callaghan, T.V., Chapin, F.S. III, Cornelissen, H., Gough, L., Hobbie, S.E., Jonasson, S., Lee, J.A., Michelsen, A., Press, M.C., Richardson, S.J. and Rueth, H. (In press). Long-term ecosystem level experiments at Toolik Lake, Alaska, and at Abisko, Northern Sweden: generalisations and differences in ecosystem and plant type responses to global change. *Global Change Biology*.

**Teis Nørgaard Mikkelsen**, Plant Research Department, Risoe National Laboratory  
Teis Nørgaard Mikkelsen (TNM) was MSc in 1987 and PhD 1993, University of Copenhagen, Denmark. TNM's main topics are effects of gaseous pollutants (primarily ozone) on crops and trees, effects of acid rain on a coniferous forest ecosystem, effects of UV-B on trees and arctic heath land and ecophysiological studies in mature coniferous and deciduous forests. Gas exchange (CO<sub>2</sub> and H<sub>2</sub>O) between plants and atmosphere and chlorophyll fluorescence have been important tools for detecting effects of anthropogenic-induced stress on plants and for studying natural exchange in the ecosystems. Several cuvette systems have been developed for continuously long-term gas exchange monitoring *in situ* in the top of tree canopies. Also different portable gas exchange systems have been used.

Selected publications:

T.N. Mikkelsen, H. Ro-Poulsen, M.F. Hovmand, N.O. Jensen, K. Pilegaard, A. H. Egeløv.  
Five year measurements of ozone fluxes to a Danish Norway spruce canopy.

Atmospheric Environment *in press*.

Mikkelsen, T.N. Ro-Poulsen H. 2002. *In situ* autumn ozone fumigation of mature Norway spruce – Effects on Net Photosynthesis. *Phyton (Austria)*, 42. 97-104.

Gavito ME, Curtis P, Mikkelsen TN and Jakobsen I. 2001. Interactive effects of soil temperature, atmospheric carbon dioxide and soil N on root development, biomass and nutrient uptake of winter wheat during vegetative growth. *Journal of Experimental Botany*, 52, 1913-1923

Risoe publications since 1995, see: [http://iis-03.risoe.dk/netahtml/risoe/publ\\_uk.htm](http://iis-03.risoe.dk/netahtml/risoe/publ_uk.htm) and type: TEMI

**Per Ambus**, Plant Research Department, Risoe National Laboratory

Per Ambus (PA) born 1959 holds a degree in microbial ecology and a PhD (Cph. Univ., 1992) on N-cycling in riparian wetlands. PA has worked mainly on questions related to soil biogeochemical cycling including organic matter mineralization and trace gas emissions. Has been involved as investigator in three EU-projects (STEP, Nofretete, GreenGrass) and is also responsible for the co-ordination of a national project on green house gas emission from grasslands (DINOG). Experience in supervising at graduate and post-graduate levels. Occupied as senior scientist since 1996 in Plant Research Department at Risø National Laboratory. The past five years PA has been responsible for the isotope-ratio-mass-spectrometry laboratory at Risø acting also as subcontractor to several EU-projects. PA has more than 90 international publications; for a detailed list see [http://iis-03.risoe.dk/netahtml/risoe/publ\\_uk.htm](http://iis-03.risoe.dk/netahtml/risoe/publ_uk.htm).

Selected relevant publications:

Ambus, P., Kure, L.K. and Jensen, E.S. 2002 Gross N transformation after application of household compost or domestic sewage sludge to agricultural soil. *Agronomie*, 22: 723-730.

Ambus, P., Andersen, B.L., Kemner, M., Sørensen, B. and Wille, J. 2002 Natural carbon isotopes used to study methane consumption and production in soil. *Isotopes in Environmental and Health Studies*, 38(3): 149-157.

Ambus, P., J.M. Jensen, A. Priemé, K. Pilegaard and A. Kjøller. 2001. Assessment of CH<sub>4</sub> and N<sub>2</sub>O fluxes in a Danish beech (*Fagus sylvatica*) forest and an adjacent N-fertilised barley (*Hordeum vulgare*) field: effects of sewage sludge amendments. *Nutrient Cycling in Agroecosystems* 60(1/3): 15-21.

**Kim Pilegaard**, Plant Research Department, Risoe National Laboratory

Kim Pilegaard (KP) is PhD in plant ecology. KP is a senior scientist trained in ecology with special emphasis on biosphere-atmosphere exchange of anthropogenic and biogenic compounds. He has worked with micrometeorological measurements of fluxes of carbon dioxide, ozone and nitrogen oxides, and with measurements of fluxes between the atmosphere and soil using chamber systems. Kim Pilegaard has been involved in a number of EC projects (e.g. EUROFLUX and GREENGRASS) and has been project leader of several national projects dealing with exchange of carbon and nitrogen between the atmosphere and terrestrial ecosystems.

Selected publications:

- Hari, P., Raivonen, M., Vesala, T., Munger, J.W., Pilegaard, K. and Kulmala, M. Ultraviolet radiation generates NO<sub>x</sub> emission from Scots pine shoots. *Nature*, **422**, 134, 2003.
- Pilegaard, K., Hummelshøj, P., Jensen, N. O. and Chen, Z. Contrasting the results of the two first seasons of CO<sub>2</sub> eddy-flux measurements over a Danish beech forest. *Agricultural and Forest Meteorology*, **107**, 29-41, 2001.
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**Anders Michelsen**, Department of Physiological Ecology, Botanical Institute, University of Copenhagen

Anders Michelsen (AM) born 1961 holds a master degree in Biology and a PhD in Botany from University of Copenhagen. AM has worked 2 years as post doc at Institute of Terrestrial Ecology, UK and is since 1998 associate professor at the Dept. of Physiological Ecology, Botanical Institute, University of Copenhagen, Denmark. AM is head of the Ecological-Chemical Laboratory at the Institute since 2000, and has served as a member of the board of the institute, and Head of Department. AM has received major grants for advanced equipment and is involved in collaborative research funded by national and international funding agencies. AM has examined 13 MSc students and 6 PhD students, and is currently supervising 5 MSc and 4 PhD students. The focal point of his research is on interactions between plants, microbes and soil. Above- and belowground processes are studied in arctic/alpine, temperate and tropical ecosystems exposed to experimental manipulations. The aim is to reveal the consequences of environmental changes such as global warming or changed land use on soils and on plants and microbes, from organism to ecosystem level. Current activities include experimental studies of the effect of fire in tropical savanna systems, and of the effect of climate change on nutrient and carbon cycling in arctic ecosystems. As responsible for the isotope ratio mass spectrometry, the work is focussed on the use of stable isotopes in ecosystem studies. AM has published 51 papers in international peer-reviewed journals; see <http://www.bot.ku.dk/staff/staff-vip-details.asp?ID=23>

Selected relevant publications:

- Michelsen A., Quarmby C., Sleep D., Jonasson S. (1998). Vascular plant <sup>15</sup>N natural abundance in heath and forest tundra ecosystems is closely correlated with presence and type of mycorrhizal fungi in roots. *Oecologia* 115, 406-418.
- Michelsen A., Graglia E., Schmidt IK, Jonasson S., Quarmby C, Sleep D. (1999). Differential responses of grass and a dwarf shrub to long-term changes in soil microbial biomass C, N and P by factorial NPK fertilizer, fungicide and labile carbon addition to a heath. *New Phytologist* 143, 523-538.
- Illeris L, Michelsen A., Jonasson S. (2003). Soil plus root respiration and microbial biomass following water, nitrogen, and phosphorus application at a high arctic semi desert. *Biogeochemistry* 65, 15-29.

**Helge Ro-Poulsen**, Department of Physiological Ecology, Botanical Institute, University of Copenhagen

Helge Ro-Poulsen (HRP) born 1951, PhD in Plant Ecology at University of Copenhagen 1983, Postdoc-fellowships on open-top chamber experiments 1983-86 (EU grants), Assistant Professor at University of Copenhagen in the field of air pollution effects on plants 1986-90, Associate Professor 1991.

*Main research interests* during the later years have been carbon and water balances of forest ecosystems and tree ecophysiology in relation to air pollution and UV-B, investigated by means of field chambers, cuvette techniques and flux measurements. The framework has mainly been international research programmes (EU, UN/ECE) on air pollution and forest

health, involving comprehensive multidisciplinary collaboration between biologists, foresters, atmospheric chemists, meteorologists and modellers. Recently, involvement in arctic research has taken place. Publication list available at [http://www2.adm.ku.dk/ku/puf\\_www3.forf\\_pub\\_personid?p\\_person\\_id=120113](http://www2.adm.ku.dk/ku/puf_www3.forf_pub_personid?p_person_id=120113)

Selected recent relevant publications:

- Skärby L, Ro-Poulsen H, Wellburn F & Sheppard L, 1998. Impacts of ozone on forests: The European perspective. *New Phytologist* **139**: 109-122
- Mikkelsen TN, Ro-Poulsen H, Pilegaard K, Hovmand MF, Jensen NO, Christensen CS & Hummelshøj P, 2000. Ozone uptake by an evergreen forest canopy - Temporal variation and possible mechanisms. *Environmental Pollution* **109**: 423-429.
- Mikkelsen TN & Ro-Poulsen H., 2002. In situ Autumn Ozone Fumigation of Mature Norway Spruce – Effects on Net Photosynthesis. *Phyton* **42**: 97-104.

**Søren Christensen**, Department of Terrestrial Ecology, Zoological Institute, University of Copenhagen

Søren Christensen (SC) born 1953, D.Sc., full professor in Soil Biology at Copenhagen Univ. SC deals with the dynamics of the decomposition process in soil and interaction of the responsible organisms (bacteria, fungi, protozoa, and nematodes). Main foci are the spatial pattern of organic matter availability and importance of diversity among decomposer organisms for stability of the decomposition towards disturbance. At the population level current work is on resource allocation from plants to above- and belowground organisms. At the system level projects currently deal with increased CO<sub>2</sub> and rhizodeposition, variability of plant residues in organic farming, fire and decomposition in tropical savanna, succession in gap re-colonization in natural forests, and pollutant effects.

Selected recent relevant publications:

- Frederiksen H.B., Ronn R., and Christensen S. (2001) Effect of elevated atmospheric CO<sub>2</sub> and vegetation type on microbiota associated with decomposing straw. *Global Change Biology* **7**, 1-9.
- Wamberg, C., Christensen S., Jakobsen I. (2003) Interaction between foliar-feeding insects, mycorrhizal fungi, and rhizosphere protozoa on pea plants. *Pedobiologia* **47**, 281-287.
- Wamberg, C., Christensen S., Jakobsen I., Müller A.K., Sørensen S.J. (2003) The mycorrhizal fungus (*Glomus intraradices*) affects microbial activity in the rhizosphere of pea plants (*Pisum sativum*) *Soil Biology and Biochemistry* **35**, 1351-1359.

**Anders Priemé**, Department of Microbiology, University of Copenhagen

Anders Priemé (AP) born 1964 holds a PhD degree in soil microbiology. AP has a strong experience in studies of microbial processes in soil and has implemented molecular methods in the study of soil bacterial communities. APs ecosystem research has focused on microbial carbon and nitrogen transformations in soil including atmosphere-biosphere exchanges, and has included studies of the effects of temperature and extreme weather perturbations on these microbial transformations and exchanges. AP has an extended network of research contacts in Europe and North America e.g. as a national delegate of the EU Cost Action on denitrification. Complete publication list since 1995 is available at: [http://mbi-soelv95.molbio.ku.dk/staff/personal-info/Publications/publications\\_aprieme.htm](http://mbi-soelv95.molbio.ku.dk/staff/personal-info/Publications/publications_aprieme.htm)

Selected relevant publications for this project:

- Persson T., Rudebeck A., Jussy J.H., Colin-Belgrand M., Priemé A., Dambrine E, Karlsson P.S. and Sjöberg R.M. (2000) Soil nitrogen turnover - mineralisation, nitrification and denitrification in European forest soils. In: Schulze E.-D. (ed.) *Carbon and Nitrogen Cycling in European Forest Ecosystems*. Ecological Studies 142. Springer Verlag, Berlin, pp. 297-331.
- Priemé A. and Christensen S. (2001) Natural perturbations, drying-wetting and freezing-thawing cycles, and the emission of nitrous oxide, carbon dioxide and methane from farmed organic soils. *Soil Biology and Biochemistry*, **33**, 2083-2091.

Priemé A., Braker G. and Tiedje J.M. (2002) Diversity of nitrite reductase (*nirK* and *nirS*) gene fragments in forested upland and wetland soils. *Applied and Environmental Microbiology* 68, 1893-1900.

**Martin Holmstrup**, NERI, Department of Terrestrial Ecology

Martin Holmstrup (MH) born 1961 is professor in terrestrial ecology and ecophysiology. MH holds a PhD and D.Sc. from University of Aarhus in ecophysiology of terrestrial invertebrates. His research interests include ecophysiology and ecotoxicology of soil invertebrates (primarily earthworms, springtails and enchytraeids), physiological and biochemical adaptations to drought and cold stress, interactions between pollution and climatic stresses. MH has extensive experience with ecophysiological laboratory studies and field studies of soil invertebrates. He has participated in several EU-projects and national centres of excellence and has supervised about 20 Master's and PhD students. MH has published more than 45 scientific papers in international peer reviewed journals (full publication list at [http://www.dmu.dk/1\\_Om\\_DMU/2\\_medarbejdere/cv/liste.asp](http://www.dmu.dk/1_Om_DMU/2_medarbejdere/cv/liste.asp)).

Recent relevant publications

- Bayley, M. and Holmstrup, M. (1999) Water vapor absorption in arthropods by accumulation of myoinositol and glucose. *Science* 285:1909-1911
- Holmstrup M, Sjørnsen H, Ravn H, Bayley M (2001) Dehydration tolerance and water vapour absorption in two species of soil-dwelling Collembola by accumulation of sugars and polyols. *Functional Ecology* 15:647-653
- Højer R, Bayley M, Damgaard CF, Holmstrup M (2001) Stress synergy between drought and a common environmental contaminant: Studies with the collembolan, *Folsomia candida*. *Global Change Biology* 7:484-492
- Pedersen PG, Holmstrup M (2003) Freeze or dehydrate: Only two options for the survival of subzero temperatures in the arctic enchytraeid *Fridericia ratzeli*. *Journal of Comparative Physiology B* 173:601-609

**Inger Kappel Schmidt**, Forest and Landscape, Dept. Applied Ecology, KVL

Inger Kappel Schmidt (IKS) born 1958 holds a degree in soil science and a PhD in experimental arctic plant ecology from University of Copenhagen and a post doc in arctic plants and vegetation ecology at The Ecosystems Center, Massachusetts. IKS has worked on large-scale field experiments in natural and semi-natural ecosystems for 12 years focused on effects of nutritional, climate and precipitation stress on plant-microbe-soil interactions. IKS's main areas of expertise are plant-microbe-soil interactions, C and N interactions, plant nutrient pools and -uptake, litter quality. IKS works presently with plant and vegetation responses to climate change. IKS has participated in 3 EU projects (CENTER, CLIMOOR and VULCAN) and further projects funded by SNF and the American NSF.

Selected recent relevant publications:

- Schmidt IK, Williams D, Tietema A, Gundersen P, Beier C, Emmett BA (in press) Soil solution chemistry and element fluxes in three European heathlands and their responses to warming and drought. *Ecosystems*.
- Schmidt IK, Jonasson S, Shaver GR, Michelsen A, Nordin A (2002) Mineralization and allocation of nutrients by plants and microbes in four tundra ecosystems –responses to warming. *Plant Soil* 242(1), 93-106.
- Schmidt IK, Jonasson S, Michelsen A (1999) Mineralization and microbial immobilization of N and P in arctic soils in relation to season, temperature and nutrient amendment. *Appl Soil Ecol* 11:147-160

**Per Gundersen**, Forest and Landscape, Dept. Applied Ecology, KVL.

Per Gundersen (PG) born 1958 holds a degree in chemical engineering (environmental ecology) and a PhD in nitrogen cycling in forests from the Technical University of Denmark. PG has studied biogeochemical cycling in forests for 20 years by field scale ecosystem manipulation and extensive site comparisons. Recent research also include grass and heath ecosystems. PG's main areas of expertise are nitrogen cycling, soil carbon sequestration,

monitoring and experimentation techniques. PG has participated in numerous EU projects (EXMAN, NITREX, DYNAMO AFFOREST, INCA, Water4all, CLIMOOR and VULCAN) and is presently co-ordinator of CENTER (Carbon – Nitrogen inTERactions in forest ecosystems). PG has co-authored 47 peer review papers and is associate editor of the journal *Biogeochemistry*.

Selected publications

- Gundersen, P. I.K. Schmidt and K. Raulund-Rasmussen (In press) Leaching of nitrogen from temperate forests – effects of air pollution and forest management. In: *Forests and Water* (Eds. R. Vertessy and H. Elsenbeer). IUFRO book, 70 pp.
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- Bergh, J. and Linder, S. (1999) Effects of soil warming during spring on photosynthetic recovery in boreal Norway spruce stands, *Glob.Change Biol.*, 5, 245-253.
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