Research plan for Danish research centre on

"CLIMAte change effects on biological processes In Terrestrial Ecosystems" CLIMAITE

Participating institutions

Plant Research Department, Risø National Laboratory
Dep. Physiological Ecology, University of Copenhagen
Dep. of Microbiology, University of Copenhagen
Zoological Institute, University of Copenhagen
Dep. Applied Ecology, Royal Veterinary and Agricultural University
Dep. Terrestrial Ecology, National Environmental Research Institute

Research leaders

Claus Beier, RISØ
Sven Jonasson, UC

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Summary

Human activities lead to increased atmospheric CO_2 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 are of central importance for the biological effects because the climatic changes will include simultaneous changes in at least three factors: atmospheric CO_2 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_2, 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.

CLIMAITE 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.

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_2 concentrations, a ~0.6^{o}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_2 concentrations will double during the present century. This will induce an additional 1.4 to 5.8^{o}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_2, 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_2. 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.
Changes in CO_2, temperature and precipitation will interact and 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_2 on plant production were changed to negative effects when combined with changes in temperature and/or precipitation (Shaw et al., 2002). CLIMAITE will therefore consider the effects of simultaneous multi-factor changes and 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. Therefore, CLIMAITE will 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 will employ experimental conditions that mimic the climate 50-70 years from now by combining enhancement of the CO_2 level, a rise in temperature and changes in precipitation patterns and the studies will in particular focus on predicted changes in seasonality of the future climate and extreme weather events.

Aims and outcome

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. By this approach, CLIMAITE will develope a conceptual understanding of how climatic and environmental changes in concert will affect biological processes in the terrestrial ecosystems. The CLIMAITE 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. Through a new multifactor experimental facility and the multidisciplinary research activities, the centre will form a new strong and stimulating Danish scientific environment at

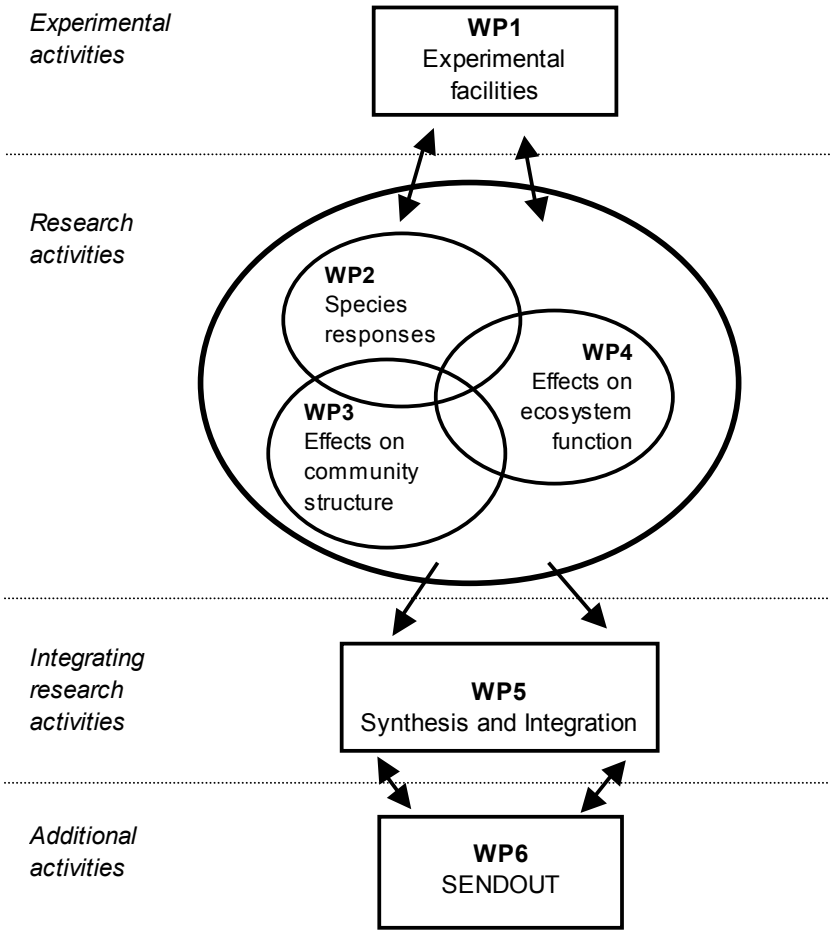
an international level. This will provide a true potential and step forward for the scientific development and education of young scientist within the area. In particular CLIMAITE will:

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.

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_2, 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.



Organisation of the activities within CLIMAITE in 6 work packages

Work package 1 – Experimental facilities

The research will mainly be based on experimental manipulation of climatic factors in the field. WP1 will organise a new Danish field manipulation site in a semi-natural ecosystem. Three factors, atmospheric CO_2 concentration, temperature and precipitation, affecting the terrestrial vegetation significantly will be altered in relation to current climate change prediction models.

Manipulations
The three factors CO_2, temperature and precipitation will be manipulated in the field in a full factorial design. Each study plot will be 4 m^2 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)
- CO_2-enrichment (C)
- Temperature increase (T)
- Precipitation (W)
- CO_2-enrichment and Temperature increase (CT)
- CO_2-enrichment and Precipitation (CW)

- Temperature increase and Precipitation (TW)
- CO_2-enrichment, Temperature increase and Precipitation (CWT)

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 will include 3 main areas of activity:

WP2.1. Plant physiological responses
WP2.2. Physiological responses of the soil fauna
WP2.3. Responses in trophic interactions

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_2-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.

WP3 will include 4 main areas of activity:

WP3.1. Treatment effects on plant community composition and dynamics.

WP3.2. Treatment effects on community structure of the soil fauna.
WP3.3. Population structure of soil bacteria and microbial and fungal biomass.
WP3.4. Effects on plant litter and soil chemistry.

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 will include 6 main areas of activity:
WP4.1. Ecosystem-atmosphere gaseous exchange
WP4.2. Effects on belowground C-transfer.
WP4.3. Internal nutrient transformations in the soil-plant system
WP4.4. Gross rates and potentials of N cycling processes.
WP4.5. Mechanisms and pathways of microbial and plant mediated C and N assimilation.
WP4.6. Leaching losses of N and C from the system.

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. 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. This includes 5 planned PhD projects.

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.
4. **Project workshops**. Internal workshops of 2-3 days duration in late winter will be organised annually to present and discuss sub-projects and work packages, detailed planning of the activities and presentation and discussion of result.
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.
6. **Common publication:** A number of common publications integrating results across the work packages will be produced.
7. **Modelling:** The type of data that will be generated within CLIMAITE will be of general interest to ecosystem modellers. Collaboration between Lund University and CLIMAITE has been decided for a modelling activity.
8. **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.

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

Workpackage 6 – SENDOUT (Steering, Education, Networking, Dissemination and OUTput)

Workpackage 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.
Societal publication and the wider public – 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.

Networking

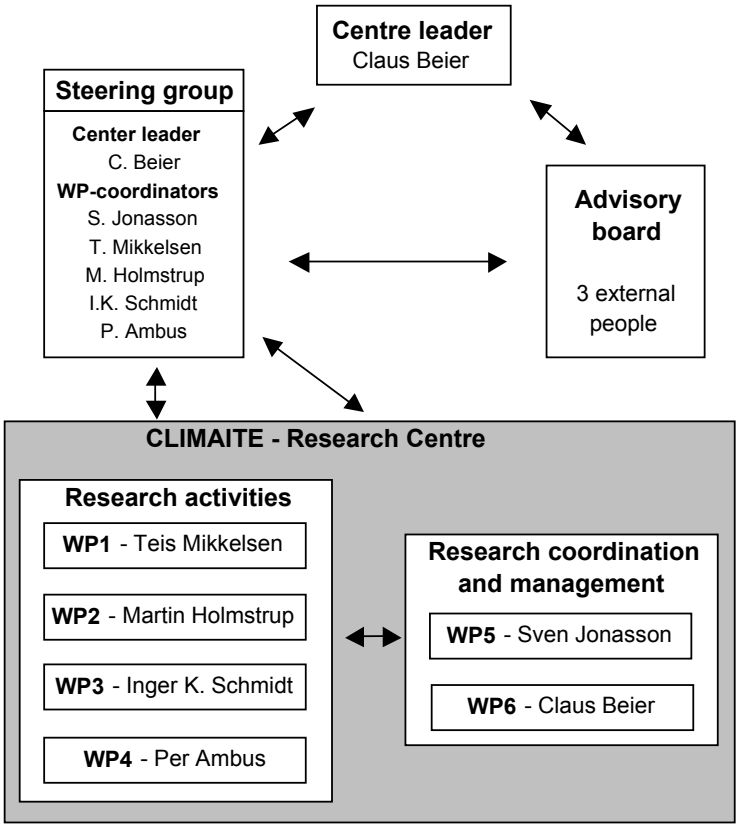
The impact of climate change on biological processes and ecosystems is a complex and clearly global problem. Sharing experiences and results among different research groups at national, regional and global levels therefore provide significant advantages in order to improve our knowledge and reduce loss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

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.

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

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



Management structure of CLIMAITE

Budget and resources

The budget to build the common field site with multifactor manipulations and bringing all the groups together to carry out this strong coordinated research effort during 5 years amounts to 25 mio. DKK.

Total budget	**Donation from VKR**						**Own input**	
	Sci+ PhD	Tech	Salary	Invest	Cons	Sub-Total		
	Mmths		kDKK	kDKK	kDKK	kDKK	mths	kDKK
WP1 – Experimental treatments								
Total	*6*	*30*	*1140*	*1520*	*1880*	***4540***	*6*	*1254*
WP2 – Species responses								
Total	*85*	*36*	*3830*	*490*	*1041*	***5361***	*17*	*2501*
WP3 – Effects on Ecosystem Structure								
Total	*57*	*29*	*2809*	*130*	*989*	***3928***	*29*	*1341*
WP4 – Effects on Ecosystem Function								
Total	*81*	*45*	*3990*	*350*	*882*	***5222***	*24*	*2612*
WP5 – Syntheses								
Total	*52*		*1750*	*0*	*467*	***2217***	*11*	*1432*
WP6 – SENDOUT								
Total	*10*	*10*	*700*	*0*	*3032*	***3732***	*0*	*770*
Total	**291**	**150**	**14219**	**2490**	**8291**	**25000**	**120**	**10660**

Total budget (Mmths (Scientific+PhD and Technician) and kDKK) for CLIMAITE showing budget for the VKR coverage (Salary, investments, consumables) and resources provided from participating institutes and external sources separated into work packages.