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European Commission

Terrestrial Ecosystem Research in Europe: successes, challenges and policy

Final conference of the

terrestrial ecosystem research initiative — concerted action

(Terica) Project ENV4 – CT95 – 0051

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A great deal of additional information on the European Union is available on the Internet. It can be accessed through the Europa server (http://europa.eu.int).

The home page of the Terrestrial Ecosystem Research Initiative – Concerted Action (Terica) may be found at http://nbu.ac.uk/terica/.

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Foreword

European ecosystems seem to be under threat from global change. All of our forests, grasslands, shrublands and wetlands exist under pressure from climate change, air pollution and changing land-use. Pressures from climate change include changes in temperature and precipitation regimes, and in a broader sense also sea level rise, ozone depletion and increase of UVB-radiation. Pollution stresses include among others deposition of nitrogen, heavy metals, acidifying compounds and pesticides. Management of the land unavoidably causes pressures if management impacts exceed certain levels. Land-use pressures result from transport, urbanisation, agriculture, industry and tourism. Such changes may apply gradually or through extreme events linked for example to climate, pollution, geological events or pathogens.

At the same time, both natural and managed ecosystems themselves influence global change: natural biogenic emissions affect air quality and climate, the latter through exchange of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Hence ecosystems may be seen as causes of global change as well as being impacted by it.

This two-way interaction has been the focus of the Terrestrial Ecosystem Research Initiative (TERI). Over twenty collaborative projects funded under the EU Environment and Climate Programme (FP4) provide the core activity of TERI, with the TERI Concerted Action (TERICA) put in place to aid the co-ordination of the research projects.

A central theme in the design of TERI was the application of major European transects across climatic, pollution or land use gradients to investigate the interactions of ecosystems with global change. The utilisation of research sites located along such gradients in combination with the exploitation of local variability is allowing data to be obtained and models to be built that cover the wide range of European conditions, while also encouraging integration at a European level.

TERI has largely addressed these issues by providing a fundamental understanding of relevant ecosystem processes. It has established an approach which draws in regional differences across Europe, with the results relevant both for scaling up from local conditions to Europe, and for input to the development of European policies. As the work of TERICA has progressed in parallel with the development of the EU's Fifth Framework Programme, it has increasingly become apparent that there is a need to develop these policy linkages further. While most of the projects are in principle policy relevant, the emerging challenge has been to demonstrate more explicitly the relevance and applicability of the results. The approach of the Final Conference of TERICA reflects this gradual evolution. The results, as summarized in this report, provide an important synthesis of the research achievements and possible contributions to environmental policy, as well as highlight the future challenges.

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1. Introduction

The Terrestrial Ecosystem Research Initiative – Concerted Action (TERICA) was established within the EC 4th Framework Environment and Climate Research Programme to draw together the activities of the various TERI research projects. Key themes of the research have included:

1. Regulation and disturbance of carbon and nitrogen cycles,
2. Emissions and absorption of trace gases, such as CO_2, N_2O, CH_4 and NH_3,
3. The implications of biodiversity for ecosystem functioning,
4. Providing an ecosystem understanding to support the management of particularly sensitive European ecosystems.

In total around 20 TERI projects were supported in two tranches, with projects mostly running from 1996-1999 and 1998-2001. TERICA has involved contributions from all of the projects, including additional contributions from related EC projects beyond TERI.

The activity of TERICA has occurred through a series of workshops, working groups and steering meetings which have brought together co-ordinators and participants of the TERI projects to analyse the issues of common concern. A full log of these meetings may be found on the TERICA home page (http://www.nbu.ac.uk/terica).

The objectives of TERI were established within the context of the 4th Framework Programme and outlined in the TERI Science Plan (Menaut and Struwe 1994). The fundamental principle was to conduct research of the highest quality to provide an understanding of global change interactions with European ecosystems. The aim was to provide largely strategic research to inform European and international global change analysis, essential to underpin future policy developments. In this context, the TERI science plan was developed in parallel with the International Geosphere Biosphere Programme (IGBP) project Global Change and Terrestrial Ecosystems (GCTE). A key common concept was the application of continental scale transects of composite research sites as a means to address the interactions of ecosystem functioning with climate, pollution and land-use change (Koch et al. 1995, Steffen et al. 1999). Over 15 experimental projects established transects in TERI, analyzing a wide range of issues and these have been summarized by Sutton et al. (1999).

TERICA has run from 1996 – 1999 and has therefore developed in parallel with the EU 5th Framework Programme. While at the outset, the concept of TERI was primarily to develop the underpinning science of ecosystems and global change, the focus has evolved increasingly to address environmental policy and sustainable development needs (Catizzone 1999). In May 1998 TERICA met in Toledo, Spain preparing a report on "Ecosystem research and the European Union policy needs" (Lawton et al. 1998). As a result of this meeting, eight cross cutting working groups were established to analyze major policy relevant concerns, with each group providing a written report as input for the TERICA Final Conference. The Working Groups established were:

WG 1. Ecosystem functioning and management under extreme events and multiple stresses.

WG 2. Loss of biodiversity and ecosystem functioning.

WG 3. Alien species and outbreaking species in ecosystems.

WG 4. Restoration and recovery of damaged ecosystems.

WG 5. European carbon budgets / linking C & N cycles.

WG 6. Trace gas fluxes and ecosystem functioning.

WG 7. Ecosystems in the landscape.

WG 8. Policy conflicts: solving one problem creates another.

The mandate of each group was to identify the key scientific achievements of the TERI projects as well as project contributions to support environmental policy and sustainable development. On this basis the working groups were to then highlight future research needs and environmental policy implications. In some cases the Working Groups deliberately reflect newly recognized areas of concern, and here the focus was clearly on the future research challenges.

The development of TERI moved another step forward with the Final Conference of TERICA, which was held at Egmond aan Zee, The Netherlands on 20-23 June 1999. The Final Conference provided the opportunity for Working Groups to feed back their findings to the TERI community, as well as to present the results to invited users of TERI-research representing a broad spectrum of concerns. The involvement of users facilitated the pre-testing of current results and their potential use, as well as helped to better formulate research needs for future European ecosystem research.

This report represents a synthesis of the work under TERI as presented at the TERICA Final Conference. Key scientific findings of the projects are highlighted and placed in the context of European environmental problems and policies. These are presented through the main report, as well as in the Working Group Reports and Extended Abstracts of TERI projects which are included as Annexes. Using this as a basis, the report looks forward both to the new research challenges and the implications for European environmental policy development. Particular attention is given to the research approaches, both to review the transect methodology and to consider new directions for developing integration and scaling up to the European level.

Finally, it should be noted that the activity of TERICA has only been possible through the contribution of many people and a willingness to collaborate between different EU research projects. This has been a new step forward for European terrestrial ecosystem research which should be built upon in future activities. We take this opportunity to thank those convening and contributing to Working Groups, to John Lawton for his lead as chairman during 1998-99, to the Secretariat Gerda Giesen and Ole Lansoe - and to all participants of the Final Conference.

2. Research and Policy Context

TERICA has served as a forum for highlighting research findings and for debate on how the research can contribute to the development of environmental policies. When TERI was established in 1994, the focus was very much on broad global change issues. Linked to the three drivers of global change (climate change, pollution and land-use change), TERI is providing inputs relevant for a range of policy structures, for example:

- UN Framework Convention on Climate Change (FCCC),
- UN-ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP),
- UN Biodiversity Convention (BC),
- EU Nitrates Directive (91/676),
- EU Habitats Directive (92/43) (part of Natura 2000).

Since the start of TERI, further policies have been put into place to which TERI projects are also relevant. These include the:

- FCCC Kyoto Protocol,
- UN-ECE 'Multi-pollutant, multi-effect' Protocol (finalized during 1999),
- EU Acidification Strategy: National Emissions Ceilings Directive (under negotiation during 1999),
- EU Methane Strategy,
- EU Water Framework Directive (under negotiation),
- EU Environmental Impact Assessment Directive,
- CAP reform accompanying measures (including Agri-environment regulation (92/2078) and Afforestation Regulation (92/2080)),
- Agenda 2000: Horizontal regulation (forthcoming; all direct payments to farmers need to conform with environmental obligations).

TERI projects have addressed these issues by developing the fundamental understanding of underlying ecosystem processes using a combination of measurement and modelling approaches. At the simplest level the results are feeding to the policy analysis through national and international global change programmes, such as GCTE. However, given the diversity of projects, outputs are also being provided through a wide range of specific channels. Examples of these include the Intergovernmental Panel on Climate Change (IPCC), the Task Forces and Working Groups of the CLRTAP and through contacts with environment and nature conservation agencies.

3. Experience and achievements from TERI

The achievements of the TERI projects are reviewed in detail in the thematic Working Group reports (Appendix 1). Taking these as a starting point the Final Conference highlighted the main findings considering the key research results and messages for EU policy.

It should be noted that work on second tranche TERI projects only started during 1998, and this includes most of the effort on both trace gases and agro-ecosystems. Initial findings for these areas are reported here, while the main experimental and modelling results will be reported during the lifetime of Framework 5.

3.1. Global change and disturbance of element cycles and trace gas fluxes

TERI has documented and quantified influences of environmental changes on a variety of European ecosystems. Overall, the results of TERI underline that:

- Nitrogen and carbon cycles are tightly coupled, with the consequence that the impact of change in one component cannot be predicted without accounting for change in the other. This interdependence results in spatial patchiness, as well as interactions between fluxes of different pollutants.
- Elevated atmospheric CO_2 input to natural ecosystems does not significantly enhance ecosystem carbon pools, but was found to slightly increase productivity of agro-ecosystems.
- Excess nitrogen produces significant amounts of greenhouse gases and reactive tropospheric pollutants, as well as polluting drinking water sources.
- Enhanced atmospheric carbon and nitrogen input affects both plant and microbe communities. As a result, these atmospheric changes provide significant impacts on ecosystem functioning and biodiversity.

It was particularly striking to see that:

Grasslands

- Semi-natural grasslands show little response to CO_2 increase in terms of carbon storage. However, where loss of biodiversity is incurred, this may impair ecosystem processes, resulting in a reduced ability to store carbon and nutrients.
- Not all functional groups respond similarly to an increase in atmospheric CO_2 concentration. For example, legumes and grasses respond differently to CO_2 increase.
- Grasslands (along with other ecosystems) provide a buffer for atmospheric ammonia levels. As a result, European policies to reduce ammonia deposition may be less effective than expected. Similarly, emission reduction policies need to decrease N inputs in addition to technical measures to be most effective.

Cold wetlands

- Radiatively active trace gas emissions from cold wetlands are controlled by net ecosystem productivity.
- Earlier greenhouse experiments suggested that cold wetlands could be significant sinks for carbon derived from the atmosphere. However, the new field research on cold wetland sites across Europe shows them to be either a source of CO_2 or neutral.
- Enhanced deposition of nitrogen to bog ecosystems leads to an increase in decomposition and therefore reduces carbon sequestration. This may cancel the beneficial role of

European bogs as sinks for carbon under elevated CO_2, and is the opposite to findings for forest ecosystems.

Forests

- C:N ratios in surface soil fractions are a key parameter in regulating the break-out of nitrogen into surface waters of forested catchments. C:N ratios are becoming recognized as an important indicator of ecosystem response to excess nitrogen.
- Climatic factors regulate surface-water quality. In particular, the fluxes of Dissolved Organic Carbon and Nitrogen (DOC, DON) are highly seasonal with a complex and only partly explained relationship to temperature.
- Nitrogen is supplied to trees both through root uptake and foliar uptake of reactive oxidized nitrogen and ammonia from atmospheric deposition. Experiments have shown that the direct uptake of atmospheric N through the leaves can lead to a decoupling of plant N uptake from soil processes. This has important policy consequences for the setting of critical loads and consideration of water quality.

Modelling

- A wide range of time scales is involved in ecosystem C and N fluxes from subannual changes in detrital inputs (related to vegetation physiology and phenology) and N mineralisation rates, to century-scale changes in the slowest carbon pools.
- A modelling framework has been established that deals with the multiple scales and is suitable for assessing European scale global change scenarios on both semi-natural and agro-ecosystems.

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- The work is helping to quantify the potential and controls governing carbon sequestration relevant to the Kyoto Protocol, as well as providing information on unexpected ecosystem responses and feedbacks.
- Mechanistic models of reactive N exchange with ecosystems are being developed. These will feed into the policy analysis under the Convention on Long-Range Transboundary Air Pollution. Already the results are helping to explain the extent to which policy expectations are met for emissions abatement and recovery.
- It is apparent from the TERI research findings that different environmental issues relating to carbon and nitrogen are intimately linked through their biogeochemical cycles e.g. radiatively active fluxes of CH_4, CO_2, N_2O and aerosols, atmospheric deposition of NO_x and NH_3, leaching of NO_3^-. This demonstrates the need to develop integrated and coherent science based European policies which address the interactions.
- The multiple policy linkages have been clearly shown for trace gases and aerosol interactions with ecosystems. The different pollutants can be considered in relation to the source sectors, pollution issues and receptors (Figure 1). Progress is being made with existing international policy frameworks addressing several linkages. However, the separation between these frameworks is expected to lead to sub-optimal control and potential conflicts.

3.2. Managing biodiversity: loss of biodiversity and ecosystem restoration

The interest in research on relations between biodiversity and ecosystem functioning is driven by the conference on biodiversity loss organised in 1992 in Rio de Janeiro. TERI-projects provide a major contribution to the European obligations made at that biodiversity convention. There are three main streams of approach to answer the questions: (1) how may human-induced changes affect biodiversity? (2) What consequences may biodiversity loss have on ecosystem processes, such as productivity, nutrient capture, water storage, preventing the outbreak of aliens, pests and diseases, etc? (3) How may former biodiversity be restored?

Human-induced impacts on biodiversity

- Changing climate, pollution, and land use changes may all change, and often reduce, biodiversity.
- Effects of biodiversity change may appear at different rates in different domains (e.g. aboveground vs. soil).
- Within domains, there is also variation between species in their response to human-induced changes.
- The existence of different vulnerability of species to human-induced changes both within and between domains complicates the predictability of consequences of changes.

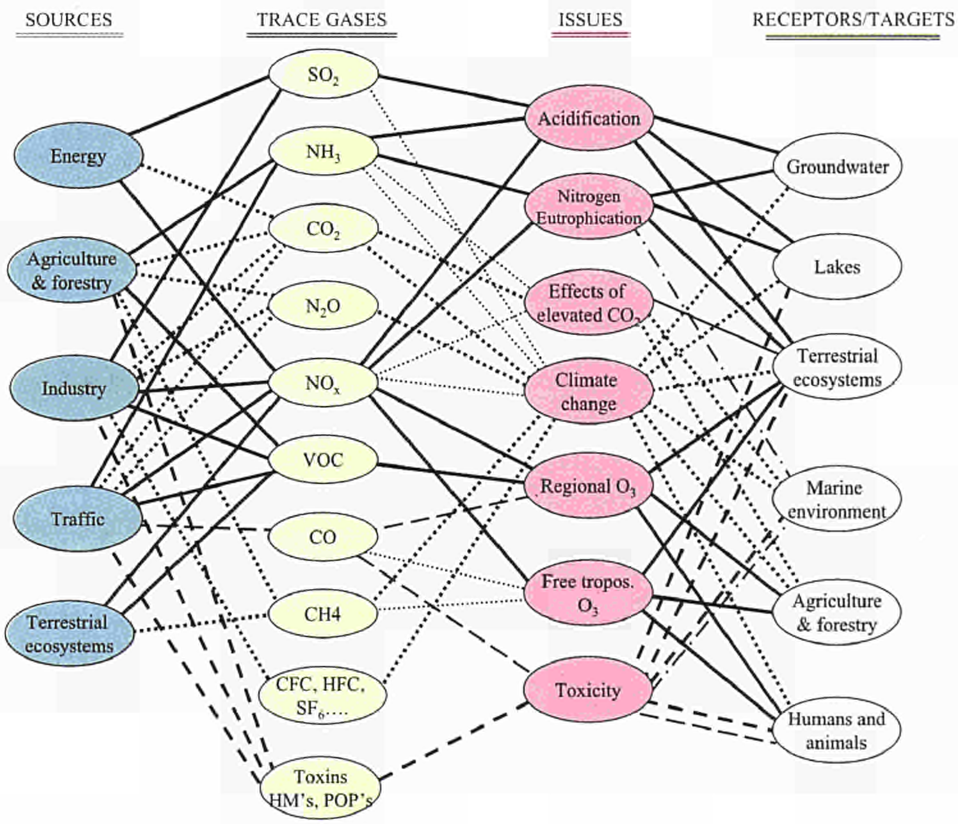

Figure 1: Conceptual linkages between the sources of trace gas emissions, environmental issues and receptors of concern. The multiplicity of linkages demonstrate the complexity of the interactions. (For simplicity, secondary trace gases and aerosols formed by atmospheric reaction are not shown.) The line styles represent the main international policy structure dealing with each link. In many cases policy structures separate linked pollutants and effects, leading to potential conflicts (from TERICA Working Group 6 Report, Appendix 1).

——— UNECE CLRTAP: Multi-pollutant, multi-effect Protocol
········ UN FCCC Kyoto Protocol
– – – UNECE CLRTAP: Heavy Metals and POPs Protocols.
— — — EU Air Quality Directive
—·—· OSPARCOM and HELCOM
.... Policy structures not clear for these linkages

- There is little evidence on effects of loss of diversity in one end of an ecosystem or food chain on biodiversity at the other end. Organisms that drive ecosystem processes (key stone species) are by definition essential for sustainability. There is no consistent information on whether key stone species are more or less prone to human-induced extinction.

Consequences of biodiversity loss on ecosystem processes

To provide rigorous experimental evidence that biodiversity can affect ecosystem functioning has shown to be extremely difficult, because results of diversity experiments are often flawed by the identity of species, especially at low species diversities. TERI-projects have included a new methodology, to be able to separate diversity effects from species effects. The across-site comparison has provided rigorous tools to assess consequences of biodiversity loss. Nevertheless, it should be emphasised that biodiversity conservation is also to provide an of insurance for the future, which does not need experimental testing to stress its relevance. In the ecosystems studied:

- Loss of biodiversity can reduce productivity.
- The composition of the remaining species communities matters for the functions to be performed following species loss.
- Because of effects on productivity, decreased biodiversity can reduce the ability of ecosystems to store carbon, retain nutrients, store or use water efficiently, to protect ground water against leaching nutrients (such as nitrate) and to control erosion.
- Effects of changed diversity of vegetation appears faster in aboveground communities than in soil communities and soil processes, such as decomposition.
- It is critical to get better predictions of delayed responses of soil communities to changes in vegetation.

Restoring former biodiversity

- The regional species pool is crucial for the restoration of former biodiversity. This implies that the landscape configuration should be considered as an important prerequisite for the planning of biodiversity restoration programmes.
- Enhancing initial biodiversity may help to make ecosystem development at restoration sites more predictable and to overcome unwanted phases dominated by weeds.
- For slowly dispersing organisms, such as soil biota, regional species pools may have little value on the short term. Experiments with introducing soil from more natural areas at restoration sites showed considerable effect on vegetation development.

Scope and relevance

The wide range of research conducted by TERI projects has ensured that many aspects of biodiversity have been studied, including: *organisms* (e.g. insects, plants, soil and aquatic organisms); *ecosystems* (e.g. grasslands, forests, wetlands); *methodology* (e.g. manipulation to correlation; field experiments to laboratory studies); *functions* (above-ground and below-ground processes such as photosynthesis and decomposition).

The findings from TERI come from a wide range of European habitats and are therefore relevant to many aspects of EU policy on: C, N and P cycles, sustainability, conservation, pollution and agriculture.

3.3. Dealing with complexity in protecting sensitive areas of Europe

An integrated approach

TERI has developed an integrated approach to ecosystem management at several scales. Geographic integration and regional data acquisition have been achieved through use of large scale transects across the EU linking representative sites in widely dispersed locations with different environmental conditions.

Highlight findings include:

- Landscape level integration has been achieved by GIS based approaches and modelling. Thus, it has been attempted to relate soil animal and vegetation communities to larger scales, such as landscape mosaics, which are usually taken as a starting point for management and policy making. Combined with analysis at the European scale, the work has identified the consequences of the stresses to which ecosystems are subjected, and the ecological implications of changes in land use.
- Observations over time and experimental modification of factors such as CO_2, N, temperature and moisture have demonstrated interactions of these pressures in impacting European ecosystems. The consequences of these complex linkages of different human-induced changes in global atmospheric deposition and temperature must be considered together with the interactions related to changing European ecosystem management practices.
- Predictive spatial models of impacts and recovery, fluxes and processes have been developed and validated at a variety of scales and resolutions, from single leaf to complex landscape levels. These novel approaches require consolidation to deal with the major challenges in addressing the multiple functional linkages.
- A conceptual modelling framework has been developed, which permits linkage of landscape elements with respect to *horizontal* fluxes of soil moisture, migration of species or functional types between landscape elements, and disturbances. The modelling framework permits vegetation dynamics in different landscape elements to be constrained by differences in land-use.

Conflict resolution

The TERI programme has helped identify key indicators of change through a combination of scientific investigations, modelling and consultation with stakeholders. Risk assessment and ecosystem stability has also been the topic of several projects.

- Multiple pressures and conflicts may be present in complex landscapes. Conflict resolution has been approached by consultation with stakeholders in particular for projects dealing with land-use change in European mountain ecosystems and changes to the northern forest-tundra ecotone.
- Scientific investigation of impacts and of means of mitigation have provided useful approaches. While on the one hand intensifying the European land use causes a reduction of biodiversity, enhancement of initial biodiversity at abandoned arable land was shown to be helpful in re-establishing former species-rich meadows. Nevertheless, the soil community responded much slower to specific actions following land abandonment than the plant community, which makes (most frequently used) above-ground indicators poor predictors for below-ground community development at restoration sites.

Applicability: from local communities to the European level

- TERI projects have described key ecological features of complex ecosystems such as wetlands, forests and grasslands, and compared them at representative sites across the EU. There are many common and linking features between sites even when they are geographically widely separated. However, there are also many important regional differences, which implies that too general regulations at the European level may only benefit some regions, while having negative effects in other areas.

BOX 1: Case study threat to a sensitive European ecosystem: Fire in Mediterranean landscapes.

- The landscapes of southern Europe have experienced large changes during the last decades and are still in a very dynamic state due to the interactions between land-use changes and fire. The old pattern characterized by a finer grain controlled by human activities has turned to one with a coarse grain largely controlled by fire.
- Fires do not occur evenly across the landscape, but tend to affect certain areas more frequently. As a result, the impacts on soil and nutrient losses are also concentrated in fire-sensitive places, therefore having the potential to alter whole landscape functioning.
- Fire reduces differences in soil properties of areas differing in land-use and increases soil erodibility. Thus, fire plays a homogenizing role in the landscape making it more prone to soil and nutrient losses.
- Biodiversity values in recently burned areas decrease despite the fact that species richness increases. This is due to increment in frequency of cosmopolitan species at the expense of infrequent species that increase as a result of fire. No evidence has been found for a greater sensitivity or advantage to fire of endemic Mediterranean species.
- Ecosystem models have been developed that are spatially explicit and take into account the main processes of Mediterranean type ecosystems affected by fire, including landscape processes. These models could be applied to management after proper adaptation to particular situations.
- Tools for estimating and upscaling plant diversity in burned areas, from small (1 m) to large scales (thousands of hectares) have been produced, which could be applied to the management of burned areas.

- Projects have identified and are monitoring the pressures on ecosystems, as well as studied how the impacts of these pressures vary across the EU, within localities and over time. This is helping us to conserve and manage complex landscapes and will contribute to formulation and implementation of EU, national and local policies for land use management.

European Environmental Policy

Results from the TERI projects have identified sensitive elements of ecosystems and the spatial distribution of these elements within complex landscapes. This is of direct benefit to the identification and management of Natura 2000 sites, as well as landscape and nature conservation designated areas at local and national levels.

- Examples include the identification of trample sensitivity of plant communities, fire risk of Mediterranean habitats and vulnerability of alpine pastures to snowgliding (See Case Study: Box 1.)
- Information on the ecological implications of land use change is also of great importance in helping to formulate and evaluate the effectiveness of land use support schemes under Objective 1 , 5b other EU schemes, as well as national landscape support schemes partly or fully supported by the EU.
- Information on the functioning and complexity of ecosystems contributes to identification of net C and N sinks and sources so supports EU action post Kyoto.
- Finally, TERI studies can contribute to implementation of EU Environmental Impact Assessment (EIA) regulations by providing information on the ecological implications of change within the ecosystems investigated.

4. The TERI transect approach: strengths and limitations.

Europe is an extremely varied continent in terms of different climates, soils, vegetation, land-uses and environmental pressures. Much of this variation can be characterised by latitudinal and/or longitudinal gradients. Transects from the Mediterranean to Scandinavia, or from the western to eastern Mediterranean demonstrate different vegetation, land-use and management practices, as well as major changes in rainfall and temperature.

Clearly it is essential that European research is integrated into this European-wide picture. The transect approach is a conceptual tool that aims to take account of this variation within Europe that enables conclusions to be made at the European scale. The application of European scale transects in TERI was a novel feature for European ecosystem research, and it is relevant to review the approach.

On the one hand transects may follow geographic space through changing latitude and longitude in order to cover the range of climate, pollution and land-use differences. More precisely, however, the spatial transects across Europe represent transects through 'climate space' or even 'pollution-climate space' (Figure 2). Hence transects do not always translate into simple linear features across Europe (see Transects poster, Appendix 2), while analysis of the results focuses more directly on the site climate, pollution or land-use parameters than on the actual geographic location.

In addition to the benefits for generalization and scaling up, transects may also provide a framework for increasing cohesion in ecological research by encouraging a more integrated analysis at a European level. In this way, the transect concept within TERI was also conceived as a contribution to the global understanding of ecosystem change, for example in collaboration with the IGBP-GCTE network.

Strengths of the transect approach

TERI projects have shown the benefits of the transect approach. As intended, it has provided continental scale reproducibility of results and therefore great scientific power to projects that followed a standardised methodology, enabling between-site comparisons along the transect gradients.

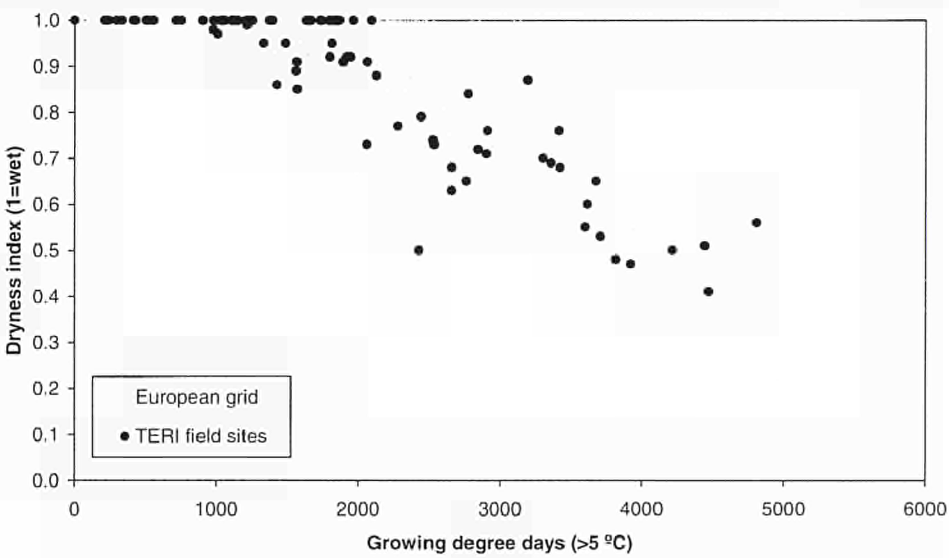

Figure 2: Experimental sites of TERI projects shown in relation to European 'climate space' for two axes of conditions of wetness and growing degree days (from Transects poster, Appendix 2).

By having a series of sites arranged along a transect, it helps researchers to make conclusions about the areas that are located between the study sites in geographic and climate space. A transect approach makes this possible by quantifying the differences in relation to the underlying changes in climate, pollution or land management. When transects approaches are adopted, a clear testable hypothesis needs to be the basis for each project. By contrast a loose regional network of sites can introduce the complexity of too many differences between sites, making a process based interpretation difficult, and actually reducing the applicability of the results.

Major transect themes in TERI

Although TERI projects were established individually following peer review, a number of broadly common transects have been established *post hoc*. These are grouped here in relation to the major ecosystem concerns:

- *Grassland transects:* Transects of temperature (latitude) and continentality (east-west) have been addressed by biodiversity projects (BIODEPTH, CLUE, DEGREE). Projects focusing on carbon and nitrogen dynamics have mostly concentrated on the broad east-west transect of continentality (GRAMINAE, MAGEC, MEGARICH).
- *Forest transects:* The major theme has been to address the effects of temperature through latitude based transects (CANIF, GLOBIS, PROTOS, SUITE). In addition, a transect through varying atmospheric nitrogen deposition was considered (CANIF).
- *Moorland and wetland transects* have necessarily focused on cool, wet parts of Europe, but have addressed a broad range of continentality (BERI, CLIMOOR, CONGAS) as well atmospheric deposition (CLIMOOR).
- *Multi-ecosystem transects* have focused on key sensitive areas of Europe including the effects of temperature and conententality on fire in Mediterranean shrublands (LUCIFER), land use change in mountain areas (ECOMONT) and dynamics of the forest-tundra ecotone (DART).

In total, TERI projects established over 15 transects, and these have been reviewed elsewhere (Sutton et al. 1999). Five examples are given below to demonstrate the approach:

BIODEPTH: Two transects extending from Ireland to Greece and from Sweden to Portugal embrace a wide range of European climates and soil types for European semi-natural grass/herb communities. A multi-site analysis has demonstrated that species richness is an important determinant of harvest yield regardless of geographic location.

CLUE: Along a north-south and east-west double transect five arable sites were abandoned. Above- and below-ground enhancement of species diversity made ecosystem development more predictable at all sites, but the developments in soil lagged behind those aboveground. Results were similar for all geographical locations, while soil type even co-varied with climate.

GLOBIS: A north-south European transect has been used to investigate the effects of climate change on the biodiversity of forest soils and how this affects ecosystem processes. The transect has been used to test the hypotheses that climate change selects for species with less ability to carry out key ecosystem functions and that biodiversity provides apparently 'redundant' species which help maintain ecosystem function in perturbed environments.

DART uses a nested structure with two macro-transects one extending over the latitudinal gradient of the forest-tundra ecotone in northern Scandinavia and the other spanning the longitudinal continentality gradient. Together with local landscape level meso- and micro-transects, these enable DART to explore the interacting effects of seasonality and temperature on the climatic determination of the tree line.

GRAMINAE is using the transect approach to address the effects of climate continentality in relation to biospheric controls on the atmospheric residence time of ammonia. Measurements of ammonia exchange with European grasslands cover a transect from Scotland to Hungary and Greece. The results will be used to calibrate models for use in transboundary air pollution negotiations, with larger scale transport expected in continental climates.

Limitations: not one universal approach

Clearly the transect approach is only applicable to certain questions and problems. There is little point in applying it to studies where a gradient is not integral to the question, for example where work is at the landscape or watershed scale. In these situations a composite site approach is helpful in comparing different ecosystem types and land-use differences. The need for the composite approach in landscape scale studies was also outlined in the original conceptualisation of the transect approach.

Similarly, some ecological questions are too complex for the transect approach. Applying a transect therefore compounds the situation by introducing further complexities. In these cases, a geographical network, instead of a transect of sites might be more appropriate. Nevertheless, care is needed in developing multi-site projects either using transects or loose networks. Even where a transect is used to highlight the gradient under investigation and minimize other differences between sites, it is often difficult make sites entirely comparable. For example, climatic differences are generally reflected in parallel soil and management differences, requiring a careful analysis to select the most appropriate sites. This is often difficult given the need for European research to focus on the most competent groups in different countries, while recognizing the site requirements for particular projects and the resource limitations of working at locations remote from institutes.

Some projects in TERI focused on a small number of sites for detailed studies while covering large geographic distances, for example with 3-4 sites from the Mediterranean to Scandinavia. This design may be the most appropriate strategy, for example if complex integrated analyses are conducted at each site, but a transect interpretation may not be appropriate. In these cases, the development of generalizations at the European level needs to focus on the process understanding of similarities and differences between sites. Thus, the trade-offs between contrasting approaches need to be carefully considered when formulating an approach to solve a particular question or problem.

Recommendations

Where the transect approach is applicable to the question under study, it should be adopted as central to the experiment, and standardised protocols of methodology used at all sites within a project.

Similarly, where a transect approach adds value to the ecological problem under investigation, the clustering process is a good opportunity to align proposed or existing study sites into useful transects. Potentially, there is value in different projects operating at common sites, although it is recognized that logistically this is often difficult to match with different project site requirements. The nature of open competition for projects provides an additional constraint. To address this, efforts should be made to refine experimental designs in relation to linked objectives between projects during the negotiation phase before completing work plans.

The existing data at all TERI sites are a considerable ecological, scientific and European resource. These should be exploited through inter-project comparison and analysis to further elaborate on European-wide applicability of the results.

5. Interactions between TERI and the IGBP project Global Change and Terrestrial Ecosystems (GCTE).

GCTE may be seen as being at the science end of the TERI "end-user" spectrum which ranges from other scientists and the scientific community through the policy-making process to the implementation of policy decisions in land management. GCTE benefits from TERI research findings as contributions to its international programme of synthesis. Similarly, TERI has benefited from linkages to other initiatives through GCTE.

The TERI Science Plan was produced ca. 1993 (Menaut and Struwe 1994) and the GCTE Operational Plan (IGBP Report 21) produced ca. 1991-2. These largely overlap in scope demonstrating the level of agreement on the "big issues" of the time. While TERI established a set of European funded projects, the GCTE Operational Plan was developed to identify keys areas of science that could be integrated and synthesised by networking and co-ordinating ongoing projects. In this way TERI provided a European contribution to GCTE. Key elements of the interaction have included:

- TERI has helped substantially to build-up momentum in European global change science in terrestrial ecosystems, especially promoting interdisciplinarity;
- Many TERI scientists have participated in GCTE conferences and workshops;
- Ongoing TERI projects are increasingly aware of GCTE and vica versa, with a strong foundation for future collaboration;
- The GCTE synthesis process helped develop some TERI 2nd Tranche projects;
- It is realised that TERI research can usefully contribute to both European and international science agendas, thereby enhancing European influence in the international context.

GCTE incorporates a set of international terrestrial transects and recommends the following criteria for which these should be established: i) where the science question <u>needs</u> a gradient in a environmental/socio-economic variable (driver), ii) to understand gradient-driven processes, iii) to identify thresholds along the gradient(s), iv) to promote and facilitate interdisciplinary research, v) to help develop tools for integration and synthesis.

As well as the successes, the interaction has provided lessons in how to improve the interface between European research and global programmes. As there was no formal requirement for TERI projects to register an involvement in GCTE, this has been led by individual involvement. Future European research programmes would benefit by building such connections more comprehensively. This is necessary both regarding progress in the science and in establishing the 'end-user' interface.

6. Looking ahead: the emerging research needs

A significant focus of the conference was devoted to addressing the future challenges, particularly in relation to dealing with key environmental problems relevant to terrestrial ecosystems. Based on the project results and Working Group reports, gaps in both research and current environmental policy were identified.

6.1. Global change and disturbance of element cycles and trace gas fluxes

Implications for policy development

- TERI projects have identified and assessed current issues that underpin the level of integration required to provide best advice for policy formulation associated with C and N cycles and exchange of trace gases.
- A number of Working Groups have identified the need to develop coherency between policies addressing different environmental issues for C and N fluxes. For example, in the short-term, policies are needed to address the link between the different greenhouse gases and different regional atmospheric pollutants. In the longer-term, interactions between both greenhouse gases and regional pollutants and between trace gases and other forms of pollution must be considered.

Research gaps in relation to policy requirements

<u>Major uncertainties in the carbon and nitrogen cycles</u>

- Soil Organic Matter (SOM) pools play a major part in determining the physical properties of soils such as structure and resistance to erosion, and the complexation of contaminants (e.g. heavy metals). In addition, soils provide a major, and poorly quantified, reservoir of biodiversity. This issue is fundamental to our understanding of carbon sequestration and related processes of both the carbon and nitrogen cycles.
- Predicting the longer-term impacts of directional environmental change (e.g. warming, CO_2 increase) on SOM turnover (accumulation, losses and conversion from one pool to another) is currently limited by shortage of quantitative data from longer-term field-based manipulations of semi-natural ecosystems. Data from intensive agricultural soils, and also forest soils are more abundant than for other ecosystems; this imbalance must be redressed.
- Currently there is no *quantitative* understanding regarding nitrogen dynamics (including the very important issue of nitrate leaching) within ecosystems throughout Europe. Provision of such information remains a very high priority in relation to policies on provision of drinking water and eutrophication in aquatic ecosystems.
- Spatial data-sets at appropriate scales of resolution and protocols for their integration are required. Although within the TERI framework a series of spatial data-sets of different scale and resolution has been collected, there remains the requirement for the provision of a range of spatial data-sets relevant to C and N cycles.
- A minimum set of standardized, approved scenarios and baselines are required to improve inter-project integration and inter-model comparison. This is a major challenge requiring collaboration and integration between the TERI research community and other programme areas. The TERI community strongly advocates the development of research priorities that address this issue.

Requirements for trace gas flux estimates to underpin international agreements

- Fate of ammonia: The issue of eutrophication is increasingly recognized as a very high priority in terms of European abatement targets. As controls of SO_2 and NO_x are implemented in UNECE protocols and in the EC National Emissions Ceilings Directive, NH_3 is estimated to be the largest contributor to acidification and eutrophication for the EU-15 by 2010.
- Ozone (O_3) as a trace gas remains an important issue in relation to ecosystem vulnerability that must be addressed in the future. The USA is currently re-emphasising the importance of tropospheric ozone as a key environmental issue.
- N_2O fluxes: Quantification of sources and sinks across major ecosystem types is required, as well as an improved quantification of the partitioning with different nitrogen oxides.
- CH_4 fluxes: An improved understanding of the linkage between plant species composition and fluxes is necessary, as well as of the resilience of the emitting systems.

Needs for other element cycles

- Phosphorus is often a major limiting factor in natural ecosystems. N:P ratios may play an important role in determining ecosystem response to eutrophication.
- Magnesium deficiency may result from high nitrogen inputs to certain natural ecosystems. This remains a key issue in understanding the impacts of eutrophication across a range of European ecosystem types.
- Sulphur remains an important component of atmospheric deposition leading to acidification in certain areas of Europe. Its interaction with other elemental cycles in this context remains an important issue, especially in considering the effectiveness of current abatement of SO_2 emissions.

6.2. Managing biodiversity

We know from the TERI research that biodiversity is important; what we address here are future issues related to managing biodiversity. It is clear that progress within TERI now needs to be extended to larger scales and to interconnected ecosystems in the landscape. Coupling process scales and biodiversity scales with the landscape is required and necessitates a multidisciplinary approach. Interaction between landscape patches (e.g. links between terrestrial and aquatic systems; above and below-ground compartments; spatial location between different ecosystem types) are key to the future management of biodiversity.

Providing management tools

- Biodiversity has been shown to be important but the threshold levels of biodiversity need to be known both when considering impacts on ecosystem functioning and conservation targets.
- Research into the ecological drivers of biodiversity is required. This includes natural internal drivers (i.e. community assemblage), natural external factors (i.e. fire) or anthropogenic factors (climate change, pollution, land use change).
- As a tool for helping management we need functional or morphological means to monitor biodiversity and biodiversity changes practically and simply. The biodiversity of one taxon does not relate to the biodiversity of other taxa, neither does the occurrence of particular species in different ecosystem compartments, so the scientific basis for indicators is weak. This is clearly related to the fact that research must be related to the management and policy objectives (i.e. if the goal is to restore heathlands then specific research on heathlands is required).

- In establishing Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) across Europe under Natura 2000, there is a need to apply an understanding of ecosystem functioning to provide guidance for both site designation and future protection. The responses to pressures need to be understood to develop principles of sustainable SAC/SPA management, both of the sites and in relation to the surrounding landscapes.

Responding to multiple stresses

- Longer term effects need to be considered in addressing the impacts of multiple stresses. Continued monitoring of existing biodiversity plots is essential, together with the use of such plots for multi-stress experiments. All systems experience multiple stresses, therefore this situation is seen as the norm.
- Particular attention is required to address the dynamics and impacts of multiple extreme events. For example, the recent widespread fires in the Mediterranean region were coincidental with a prolonged drought. It is not useful to tease out the individual factors. Rather future work needs to provide a consensus of likely scenarios for research.
- Consideration of multiple events should be a major thrust for future research, and we need new theoretical and experimental systems to accommodate the complexity they involve. The 'insurance' effect of biodiversity needs to be experimentally proven.

Ecosystem recovery and restoration.

Current TERI research on ecosystem restoration is at the plot scale and the gaps in research are therefore directly related to scaling, especially to the landscape level.

- We recognise that not all processes operate at the same scale and time: time lags have been observed between biodiversity development between above- and below-ground systems, and between terrestrial and aquatic systems.
- Generally the medium to long term effects of restoration are not known (>5 years). This requires monitoring, and there is a lack of funding for this essential task. A policy initiative maybe to legislate that monitoring should be prolonged, with attention given to agreement long-term funding, for example has had been established for the European forest health monitoring programme.
- Ecosystem managers need to know how to evaluate the success of restoration activities using sound scientific criteria. This requires an ongoing exchange between the ecosystem scientists and ecosystem managers.

Invasive and outbreak species.

- TERI has addressed whether invasion is more likely in systems which have lost diversity, and shown that it is difficult to predict which species may become invasive. It is necessary to know whether the outbreak of native species is also less likely.
- Would a diverse, non-native system be detrimental in ecological terms? Disturbances are increasingly likely (climate change, pollution and land-use change) so trends in species patterns are expected, and also the increase of cosmopolitan species. TERI has shown that biodiversity is important, but in terms of outbreak/invasion the role of individual species needs to determined.
- The major difference between species outbreaks and other events such as climate change, pollution and land-use change, is that each species outbreak is a unique problem and not predictable because it depends on the identity of the invading species. However, invasion appears to be more likely in disturbed systems and there are also reports on invasion in ecosystems which have lost diversity.

6.3. Dealing with conflicts and interactions

Research approaches are needed to take account of many types of conflicts and interactions between pressures, policies, users and ecological processes: multiple pressure interactions, ecological, social and economic interactions, conflicts between user groups, multiple policy conflicts. A trans-sectoral approach is clearly needed. The central focus will remain ecological, but studies need to be set within the broader context of defined socio-economic and policy scenarios and should take account of possible feedback and interactions between these drivers.

It should be noted that research at the project level may range from being highly focused to highly integrated. In general, a focused approach allows faster progress in a particular area, while increased integration is better suited to questions concerning practical management of ecosystems. The approach taken in any particular instance should depend on the problem to be solved. Highly focused research is frequently necessary to deal with complex problems, but must link within an integrated approach at a wider project-cluster or programme level. While recognizing this, there is still a clear need to develop more integrated problem solving strategies at a project level.

The key elements required to achieve such an integrated approach are:

1. Ongoing ecological process and modelling studies;
2. Input from social and economic sciences to identify important interactions between socio-economic and ecological aspects;
3. Input from stakeholders (concerned individuals groups and organisations) to identify key issues, possible impacts and mitigation and comment on research approaches and results;
4. Within the geographic scale of the investigations (local, regional or EU), it is important to provide adequate identification of the range of social, economic and ecological variation and interactions present.

Specific challenges will be to:

- identify key indicators of change
- create integrated databases to permit dialogue and cross-tabulation between economic, social and ecological disciplines
- develop predictive models of change
- develop decision support systems
- evaluate the implications of existing and alternative policies
- disseminate the results to policy makers, stakeholders and the general public,

Organizing such an integrated approach will require participation of experts from ecological and socio-economic fields in the formulation of the key questions an selection of appropriate methods. On this basis, regular involvement/consultation with stakeholders and other interested parties is required throughout the project. Scale is important when dealing with such interactions and approaches should not just focus at the plot level, but scale up to the landscape, since this represents the level at which management decisions are taken. Finally, it is essential to develop methodologies that permit scaling up in time and space, as well as allow for dialogue with economic and social sciences.

7. Developing the research methodology

7.1. Improving the interface with users of ecosystem research.

Researchers should be policy informed and policy makers should be research informed. However, researchers are less educated and experienced in the processes and the requirements of policy formulation and implementation. There is therefore a need for facilitators and translators to be integrated in planning and conducting research.

Suggestion for a policy and research decision model

We propose that research activities should be seen as an integrated part of a series of actions leading from the formulation of a policy to the development of related applications. User involvement should be intensive at the outset and at the completion phase of this series, as well as appropriate to the topics treated at each stage of the series (Table 1).

Table 1: Examples of user involvement and level of involvement for ecosystem research in relation to different European activities.

Purpose	European Activity	User involvement
Policy formulation	Multi-sectoral Forum	+++
Background information	Integrative Meeting	++
Topical Review	Concerted Action	+
Research	Shared Cost Action	+ to +++
Application Development	Demonstration Project	+++

Types of users to be integrated in research projects

Depending on the type of research conducted and on the type of problem addressed, different user types operating on different geographical scales would be appropriate to participate in a research project (Table 2). The range includes those operating at a local to a global scale and from policy makers to end users. The end-users represent those who have an interest in the research results or related policies and management practices. This group can be very broad ranging from land managers, such as farmers, to members of the public. It is important for projects to target the most appropriate users. However, in general it would be appropriate to link with both users at a European/regional policy level, as well as those with local management concerns.

Table 2: Matrix of possible user involvement in research at different spatial scales for an example project. The 'user profile' would differ between research topics and projects.

	Policy makers	Authorities	Communicators	End users
Local		x	x	x
Regional		x	x	
National	x	x		x
European	x	x		x
Global			x	

Timing of user involvement

User needs, progress of research, and policy formulation do not generally arise synchronously. Therefore, the timing is critical for both user involvement and information sequestration from research projects and programmes. We recommend to:

1. involve potential end users and stake holders from very early stages of project planning,
2. perform regular feedback in order to maintain research activities on their primary target and to adjust to results,
3. devise a communication channel, which is able to respond to requests for information addressed towards the research at any time.

7.2. Servicing known user requirements

Developing the basis for European environmental indicators

The development of usable indicators requires a specific approach, which has not previously been implemented in TERI. Ideally, an indicator to be developed will be accurate, cheap and cost-effective, valid across Europe, applicable for long-term monitoring, and specifically indicating a particular environmental variable. Indicators are required for biodiversity, sustainability, element fluxes and the effectiveness of environmental, agri-environmental and related policies. Monitoring and warning systems need to be developed or adapted from other areas such as meteorology, in order to integrate spatial indicator information and to facilitate its interpretation. Results from indicative monitoring may set new objectives for the formulation of policies. There should also be attention given to evaluate the effectiveness of indicators once developed.

Developing linkages between ecosystem research and monitoring

Ecosystem research can rely on a large amount of previously produced data and knowledge in order to contribute to the development of indicators in the following respects:

- the degree to which ecosystem variables, potentially useful for indication, are ecosystem or region specific.
- the degree to which variables are subject to ecosystem dynamics and loose their indicative value over time.
- issues of sampling statistics and reliability of data.
- issues of required effort, costs and practical feasibility.
- recommendations on the use of multiple parameters or differential parameters as indicators.

7.3. Research approaches: Recommendations

A number of themes may be seen to recur in relation to the approaches to implement the research. It is recommended that future European ecosystem research should include the following key elements:

Measurement and scaling up

- The development functional linkages to *scale up in both space and time*. Particular effort is required to ensure that successful methodologies are shared between projects.
- The development of *common scenarios* between projects, for each of climate, pollution and land-use change. Specific activities need to be put in place to generate major key scenarios for testing by projects.

- The application of the *transect approach* to aid integration of experimental studies analyzing changes over a gradient of conditions at a European level. Interpretation of transect results is less complex than in a network with multiple differences between sites – although it is still difficult distinguish fully the effect of single variables. To implement the transect approach with success requires the implementation of a standard experimental protocol at all sites.
- The application of *structured networks* where the problem to be addressed is less suited to a transect. This may include studies where multiple differences are an integral part of the analysis, or studies analyzing complex interactions where resources need to be focused on a small number of sites. Particular care is needed at the planning stage to ensure that the expected differences between sites of such networks can be interpreted and generalized.
- The development of *process-based models* integrating the functional understanding of ecosystem interactions. These are an important tool to interpret the results of both transect studies and structured networks, and are essential to permit generalization of the results at a European level.

Meeting user needs

- Research addressing both *focused issues and wider integration* of problems. The degree of scope of each project should match the problems being addressed. In some cases it is necessary to take a highly focused approach in order to make progress. Conversely, integration of difference concerns is necessary when dealing with questions of practical ecosystem management. It is essential that focused activities are linked into the integrated picture at a wider programme level.
- Research addressing interactions at a *landscape level*. Landscapes represent the scale at which different ecosystems interact most closely with human pressures. Increasing attention should be given to landscape level processes and interactions. This should be aimed to provide information to support both local ecosystem management decisions and feed into policy development at a wider scale.
- Project investigations should be linked to *users at appropriate scales*. Research activities should be designed and conducted with the involvement of users. User groups are specific to project aims, but should include both regional/European level policy interests and local management concerns as appropriate.
- The development of linkages to *ecosystem monitoring and environmental indicators*. These represent recognized user needs in establishing long-term trends in ecosystem functioning and responses to global change. The research should address these needs and establish the requirements and applicability, as well as thresholds of change.

7.4. Organizing the research: from projects to a programme

European ecosystem research has traditionally been established with research projects acting as the core entity. Organizing a European scale consortium is a major challenge in itself, and can lead to major advances in the area being studied. However, such an exclusive focus at working at the project level has resulted in their often being little interchange between different projects. This is made more apparent by the open competition nature of proposing and selecting research, which leads to a diverse set of projects. Bringing together separate projects into a programme of activity, such as TERI, is recognized as a major challenge which needs to be developed further.

Project clustering

It was agreed that clustering of projects, as increasingly being adopted in Framework 5, is a positive way forward. The projects in TERI represent a wide diversity but have clustered to varying degrees through:

- working on common *ecosystem types* (e.g. clustering of forest or grasslands projects),
- dealing with common *environmental processes* (e.g. trace gas fluxes, biodiversity),
- dealing with common *environmental problems* (e.g. degradation of sensitive landscapes, perturbation of global radiative forcing, transboundary pollution).

The experience of TERICA suggest that clustering in relation to each of these can be helpful. However, a common focus through a common *environmental problem* is the most effective means to maximize the interest of both the research community and users. Clustering on this level also provides significant added value in dealing with the complexities of key threats to European ecosystems.

Organizing clusters

While TERICA has begun to build collaboration between projects, this needs to continue more strongly, building relevant linkages to achieve larger goals than possible at the project level. The experiences of TERICA lead to the following recommendations:

- The cluster problem/theme must be well defined with focused goals being well stated. Projects contributing to a cluster should be ready to revise their work programme during a major negotiation process, with project members to be contractually committed to the cluster objectives. This may require new project participants.
- The cluster may serve as a focus for discussion with users and reporting of key findings. Project users should be involved in the negotiations that lead to revisions to meet cluster objectives. Selected high level users should be involved at the cluster level before the work programme is finalized.
- The cluster should consider experimental protocols, selection of models and agreement on scenarios. Revision of experimental sites is often more difficult, due to the geographic constraints of project partners and site requirements. Nevertheless, the possibilities for establishing common experimental sites should be assessed.
- The cluster should be given an entity and cluster management appropriate authority, e.g. cluster steering committee. Organization may be helped through the activity of a Concerted Action.
- Data management and availability of data need careful attention to ensure appropriate availability for the wider user community.

Links between clusters

Such a cluster would form a major activity drawing together projects and highlighting the results. However, any division of activity will always lead to the existence of important links between different clusters, which also need to be addressed. À wide dissemination of information regarding the clusters and associated projects would be necessary to encourage communication between projects between clusters. In particular, it recommended that related clusters are brought together in major open science meetings with presentation of results. While clusters may be based on problem solving, such open science meetings may be used for scientific interactions of researchers working on similar ecosystems or basic concepts, which would provide advances at a cross-cutting level.

8. Epilogue

The Terrestrial Ecosystem Research Initiative was a major new research approach to organize European ecosystem research for the 4th Framework Programme. A key element was to develop integration to provide a European perspective in global change and terrestrial ecosystems. This included both the use of European scale transects and the development of new modelling tools. Over twenty major collaborative projects were established under TERI, with the research projects linked through the activities of the TERI Concerted Action (TERICA).

TERICA has clearly allowed a major step forward for European terrestrial ecosystem research. For the first time, a framework has been established to bring together the community conducting EU research on ecosystems. The comparison may be made with work in the 3rd Framework Research Programme, where the researchers were highly separated even for work in closely related projects. The forum provided by TERICA has introduced the researchers, building linkages across the European ecosystem research community.

In many ways the task of TERICA has been a major challenge. Taking an ecosystem approach has necessarily implied a broad scope to the work, which has covered major nutrient cycles, trace gas fluxes, biodiversity, and dealing with the problems of sensitive areas of Europe. Of course there are further relevant links to other parts of the EU research programme, but even bringing these issues together has presented a major task for integration. TERICA has worked to synthesize the key findings in these areas. Taking this multi-disciplinary approach it has both highlighted gaps in research, as well as pointed out the needs for new integrated approaches. As with all multi-disciplinary exercises, this task is not rapid and can appear daunting. However, as the bridges are built, the benefits become increasingly obvious. This report demonstrates these achievements.

While TERICA was established under the objectives of the 4th Framework Programme, it has also evolved in relation to the new directions of the 5th Framework. TERICA has provided an important ecosystem perspective to the issues of global change. The next step is to focus the research even more directly to tackle major ecosystem problems, servicing user needs at a range of levels. This introduces further challenges for the research community. However, as TERICA has moved increasingly in these directions, it has provided a firm grounding for European ecosystem researchers to address these needs.

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Appendix 1.
Working Group Reports

TERICA Working Group 1: Ecosystem functioning and management under multiple stresses and extreme events

Giessen, Germany, 4 - 6 February 1999.

Klemens Ekschmitt*, Robert Baxter, Colin D. Campbell, Reinhart Ceulemans, Kurt P. Günther, William O. Heal, Andrew Hector, Frank Henning, Anneliese Kjöller Simone Matouch, Ulf Molau, Péter I. Nagy, Annette Otte, Juli G. Pausas, Anne Pflug, Dagmar Schröter, Gordon Sillence, Nathalie C. Steiner, Sten Struwe, Volkmar Wolters, Phillip A. Wookey.

Represented TERI projects and institutions:

ARTERI, BIODEPTH, CANIF, DART, DEGREE, DYNAMO, GLOBIS, LUCIFER, POPFACE, European Network for Experiences in Sustainable Development, German Aerospace Center, Instituto Portugues de Ecologia, Land Use Conceptions for Peripheral Regions.

1. PRESENTATIONS AND TREATED TOPICS

Presentations

Robert Baxter: Assessing ecosystem state - European uplands in the 21st century.
Colin Campbell: Multiple stresses - interactions between natural and anthropogenic stresses on soil ecosystem processes.
Kurt P. Günther: Environmental parameters derived from satellite data.
William O. Heal: Assessment of response of Europe's cold ecosystems to multiple stress.
Simone Matouch: Sustainable development in Europe and regional demands for ecological research.
Gordon Sillence: Sustainable tourism in the Mediterranean: modelling sustainability.

Topics

The meeting was organised along three working sessions, each with a policy oriented working group, a science oriented working group, and a plenary discussion integrating the two approaches.

Session 1: Political demands for research and envisaged threats of ecosystems
1A) Policy priorities for the management of European terrestrial ecosystems.
1B) Envisaged threats of European terrestrial ecosystems: scenarios, risk assessment.

Session 2: Accessible data and assessment of ecosystem state
2A) The data base for decision making: data sources, data quality, spatial and time scales, costs of data acquisition.
2B) Assessment of ecosystem state: key parameters, multiple values, and uncertainties.

Session 3: Natural dynamics and proactive versus reactive management
3A) Management measures: proactive and responsive ecosystem engineering, costs and benefits of management.
3B) Responses of ecosystems to multiple stresses and extreme events: tolerance limits, time and spatial scales of recovery, and ecosystem change.

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* Working Group 1 Convenor

2. POLICY PRIORITIES AND SCIENTIFIC ISSUES

The maintenance of ecosystem services is clearly a major issue relating to most, if not all EU sectors (fisheries, agriculture, energy, industry, transport, tourism, property, public and communications sectors) and EU Regional Ecosystems (northern, Alpine, Mediterranean, west coast, eastern, industrial, agro-ecosystems, forests grasslands and nature reserves), demanding a holistic approach which can be widely applied. The TERI transect approach provides a possible framework for addressing this issue in relation to the EU Regional Ecosystems.

Arguments for the conservation of biodiversity based on ethical, aesthetic and economic reasons are well established. Research within TERI now suggests that maintenance of ecosystem functioning provides an additional reason for the conservation of biodiversity. In this sense, biodiversity can be incorporated under the wider framework of the provision of ecosystem goods and services to human kind.

The ecosystems of Europe are subject to many pressures from climate, pollution and land-use. Many of these "threats" are an important part of the management of the land. They become a threat or stress when they exceed certain levels or when they are transported to other areas where their effects are uncontrolled. Virtually all European areas and ecosystems are subject to combinations of threats - multiple threats are the norm. Further, many of the individual threats interact and these interactions may be multiplicative, compensatory, or neutral. A distinction should be made between multiple independent threats and sequential consequences. A particular class of multiple threats may come from a change in the frequency or timing of natural events or management measures. Whether such an event is considered to be extreme or moderate is to some degree dependent on the spatio-temporal scale under consideration. However, events with important impacts on ecological functioning are commonly encountered in all ecosystems and on all scales.

Given the societal issue of sustainable maintenance of ecosystem goods and services on a local, regional, national and European scale, and considering the factual subjection of ecosystems to natural and anthropogenic multiple threats and extreme events on all scales, specified demands emerge for scientific products to support the implementation of EU environmental policies:

(a) Monitoring systems and indicators for sustainability and biodiversity,

(b) Prediction systems,

(c) Spatial information systems allowing for dynamic adjustment of scale,

(d) Decision support systems, and

(e) Integrated management systems.

Well established scientific approaches exist to meet these demands:

(a) Monitoring systems are generally addressed in the framework of the Pressure-State-Response model (PSR). Difficulties arise, because important features and indicators of state are ecosystem specific and problem specific, and because the systems are dynamic and therefore the indicators of state are likely to change. Single parameters are unlikely to be of value, multiple parameters are desirable. It is the change in indicator values under particular conditions rather than the absolute level which is important.

(b) Prediction systems are provided by modelling. Here, a major issue for improvement is in the availability and accessibility of the required large amounts of data.

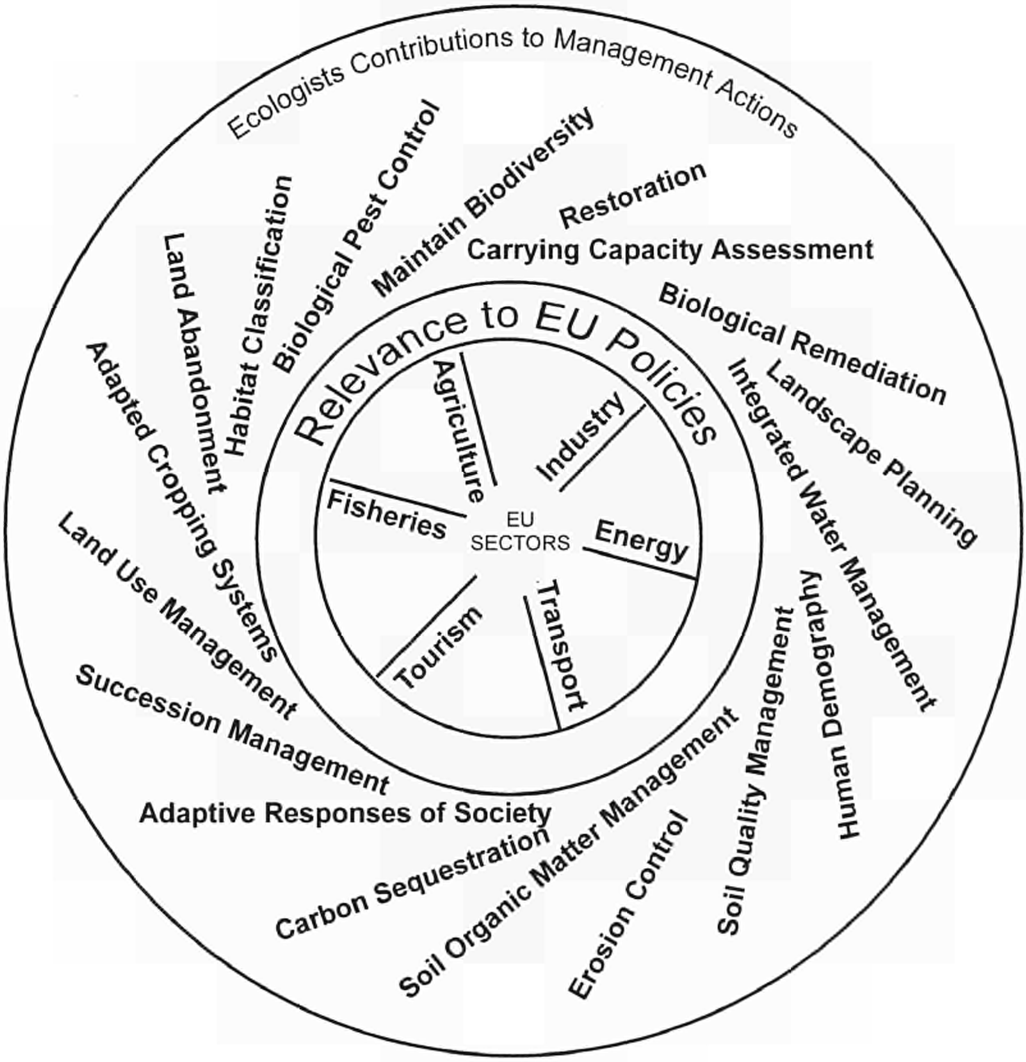
(c) Scalable spatial information can be provided by the "geo-resolution" approach, identifying the relevant scale on a continuum from local to global scale.

(d) The construction of decision support systems can be based on a well established body of mathematical theory.

(e) Integrated management systems can be assembled from a broad palette of traditional, conventional, ecological, and innovative measures.

The following sections provide a compilation of ecologists contributions to EU policies and to environmental management in general, and of the TERI contributions in particular.

3. CONTRIBUTIONS OF ECOLOGISTS TO MANAGEMENT ACTIONS, AS REFERRING TO THE IMPLEMENTATION OF EU POLICIES FOR RELATED EU SECTORS.



4. CONTRIBUTIONS OF ECOLOGISTS TO THE MANAGEMENT OF THE ENVIRONMENT UNDER MULTIPLE STRESSES AND EXTREME EVENTS.

Ecologists contribution to management	Examples of involved TERI projects
Providing basic principles how ecosystems work	All TERI projects
Predictions of the effects of environmental change	TERI
Predictions of the effects of multiple stresses	LUCIFER
Predictions of the effects of extreme events	ARTERI, GLOBIS, LUCIFER
Risk assessment and control of GMO´s	
Risk assessment and control of outbreak species	POPFACE
Demography of the human population	
Adaptive responses of society	
Landscape planning	CLUE, ECOMONT, LUCIFER
Habitat classification	DEGREE
Assessment of carrying capacity	ECOMONT
Assessment and maintenance of biodiversity	BIODEPTH, CLUE
Succession management	CLUE
Water quality assessment	BIODEPTH, DYNAMO
Integrated water management	DYNAMO
Nitrogen management	BERI, CANIF, POPFACE, GRAMINAE
Soil quality management	BIODEPTH
Management of organic matter	BIODEPTH, CANIF
Management of carbon sequestration	CONGAS, DART, POPFACE, CLIMOOR
Erosion control	LUCIFER
Recommendations on sustainable land use	ECOMONT, LUCIFER, DART
Recommendations on the applicability of cropping systems	POPFACE
Recommendations on adapted species	
Recommendations on the timing of fertiliser and/or pesticide application	GRAMINAE
Biological pest control	
Biological remediation	
Restoration	CLUE
Conservation	BIODEPTH, DART, ECOMONT

From this list, a classification of well established versus less developed research areas was derived, and recommendations were specified. These are compiled in the next section.

5. RECOMMENDATIONS AND RESEARCH PRIORITIES

Databases: Presently, there does not exist an approved list of databases potentially useful for modelling, nor a list of existing models and model frameworks. We are aware of the recent efforts of the EC to improve availability of European environmental data through implementation of the European Environmental Reference Centre (E2RC), the European Topic Centre on Catalogue of Data Sources (ETC / CDS) and parts of the work programme in FP5. However, we wish to stress the urgent need of environmental science for access to data and models. Satellite data are currently offered at prices not generally affordable (see

Appendix A5). We recommend that satellite data should be made easily accessible for research. A concerted action in co-operation with data providers should approach this goal.

Multiple stresses: Previous investigations have largely focused on single stresses. The working group was made aware that certain projects within TERI were initially to look at multiple threats to ecosystem functioning, but that funding levels may have prevented this goal from being incorporated in the final work programmes of individual projects. We recommend that future research should focus on multiple threats and their interactions and that appropriate funding should be conceded. A list of stress interactions of prior interest is given in the Appendix (A2).

Extreme and rare events: Extreme events impose severe difficulties to environmental management. We recommend that improved methods should be developed and applied for theoretical and experimental simulation of extreme events and for evaluation of their impacts on the environment. High priority is given to methods that operate on a larger spatial scale (landscape to regional). We also recommend to create a model for application and funding, suited to support *ad hoc* research following important extreme events, such as severe industrial hazards or pest outbreaks.

Long-term investigations: The majority of research projects does not cover a time-scale sufficient to assess long term sustainability. We recommend to implement long-term investigations (monitoring) that meet the time constants of natural ecosystem development and adhere to traditional knowledge on the time-scale of sustainable development (7 generations).

Reference sites: A general experience of the TERI framework programme is that data collection, management and interpretation is much facilitated if it is co-ordinated and focused on particular sites. We recommend to devise a defined set of reference sites across Europe for concerted research on specific topics. Specification and selection of research plots and topics should be conveyed in a concerted action.

Carbon budgets: We recommend to devise regional and European carbon budgets as a pre-condition for the implementation of targeted and efficient management of carbon sequestration.

Spreading of genetically modified organisms: Ecology, as a scientific discipline, is among others specialised on issues of migration and colonisation of organisms. However, ecological expertise in this field has been little transferred into applied genetics. We recommend to conduct experiments and to develop sound models on the spreading of GMO's and their modified genetic compounds.

Integration of Eastern European regions: An obvious challenge for the near future is the integration of Eastern European regions into the implementation of a common European environmental policy. We recommend to systematically involve Eastern European partner groups in future environmental RTD projects. The currently ongoing socio-economic reorganisation of Eastern European countries presents an unrepeatable large scale experiment on the change of environmental use. We recommend to monitor this process as it provides a unique occasion to evaluate the consequences of shifts in environmental policy.

APPENDIX TO WORKING GROUP 1 REPORT

A1 Classification of stresses and extreme events

Stresses

Climate: Temperature, Precipitation, Sea level rise, Carbon dioxide concentration, UVB radiation, Ozone

Land use: Traffic, Urbanisation, Tourism, Agriculture, Forestry

Pollution: Nitrogen (Atmospheric deposition, Fertilizers), Acid deposition, Sewage and waste, VOCs/Oil/Petroleum products, Heavy metals, Pesticides, Radionuclides

Extreme events

Weather events: Wind, Precipitation/Drought, Temperature

Biotic gradations: Epidemics, Pest outbreaks, Outbreaks of invasive species

Industrial hazards: Oil spillage, Emission of toxicants and radionuclides

Geological catastrophies: Earthquakes, Soil displacements, Volcano eruptions

A2 LIST OF INTERACTIVE THREATS TO ECOLOGICAL PROCESSES

Crosses indicate established and assumed second order synergistic effects (i.e. not merely additive effects).

	CLIMATE						POLLUTION								BIOTIC			LAND USE								COMMUNITY	
	Temperature	Precipitation	Extreme events	Carbon dioxide conc.	Sea Level	UVB	Ozone	Nitrogen (atmos. Dep./ferts)	Acid precipitation	Heavy metals	Pesticides	VOCs/oil	Sewage/waste	Radionuclides	Alien species invasions	Genetically Modified Organisms	Pests/Pathogens	Afforestation	Clear felling/harvesting	Urbanization	Tourism	Grazing	Desertification	Soil degradation/loss	Fire management	Fragmentation	Loss of Biodiversity
Temperature																											
Precipitation	X																										
Extreme Events	X	X																									
Carbon dioxide conc.	X	X	X																								
Sea Level	X	X	X	X																							
UVB																											
Ozone	X	X	X	X																							
Nitrogen (atmos. Dep./fertilizers)	X	X	X	X		X	?																				
Acid precipitation	X	X	X	?		X	X	X																			
Heavy metals			X		X			X	X																		
Pesticides	X	X	X	?	X	(X)	(X)		X	X																	
VOCs/oil/petroleum products	X	X	X				(X)	X																			
Sewage/waste	X	X	X																								
Radionuclides			X						X	X																	
Alien species invasions																											
Genetically Modified Organisms																											
Pests/Pathogens																											
Afforestation	X	X	X	X			X	X	X	X																	
Clear felling/harvesting		X	X	(X)				X	(X)	(X)																	
Urbanisation	X	(X)	X		X																						
Tourism	X	X	X		X	X	X											X	X	X							
Grazing	X	X	X	X	X	X		X						X				X		X	X						
Desertification			X	X	?	?						?							X	X	X	X					
Soil degradation/loss																											
Fire management																											
Fragmentation	X	X	X										?														
Loss of Biodiversity	X	X	X	X		X	X	X	X	X			?	X	X			X	X	X		X					

Notes to the table:

1 Some of the effects are fundamental ecological processes e.g. Fragmentation and Loss of Biodiversity
2 Ideally classify as synergistic (+ve) interactions (X). BLANKS have additive effects (either +ve or -ve)
3 Loss of biodiversity caused by any stress factor(s) can potentially make the ecosystem more succeptible to any of the other stresses.
4 Certain factors such as desertification are themselves responses to other factors (e.g. altered precipitation)
5 VOCs = volatile organic compounds
6 ? = Unsure of potential interaction with present knowledge.

At this stage, lack of crosses in boxes does not reflect lack of potential interaction. The membership of the working group had limited expertise in certain areas. Please feel free to amend as you see fit. The point of the exercise is to identify interactions.

NOTE: Two way interactions are of course only one level of interaction. Here we try to explore those, people are aware of and those, people are currently studying.

A3 CHECKLIST FOR USER-INVOLVEMENT

User community / Scale	**Policy makers**	**Authorities**	**Communicators**	**End users**
Local				
Regional				
National				
European				
Global				

A4 INDICATORS OF SOIL HEALTH

From intensive discussions in various fora, four soil variables have been identified as indicators of soil health: (1) Organic matter content, (2) Nutrient availability, (3) Heavy metal content, and (4) pH.

A5 COSTS OF SATELLITE DATA

Prices for Level 2A products (geocoded products)

Typical map scale	Max. image resolution	Sensor	Full scene [km]	Prices for full scene [EURO]
1 : 10.000	2 m	KVR-1000-PAN (1987-1992) KFA-3000-PAN (Priroda)	40 x 40 21 x 21	3860 3630
1 : 25.000	5 m	KFA-1000-PAN (Priroda: 1974-1993)	80 x 80	2735
1 : 25.000	5.8 m	IRS-1C-PAN (level 2A)	70 x 70	2760
1 : 50.000	8 m	MK-4 multispectral (1988-1995)	170 x 170	2735
1 : 50.000	10 m	SPOT-panchromatic (level 2A)	60 x 60	3040
1 : 75.000	20 m	SPOT-multispectral (level 2A) KATE-200 (Priroda: 1974 – 1993)	60 x 60 230 x 230	3040 2200
1 :75.000	23.5 m	IRS-1C-LISS-III	141 x141	3016
1 : 100.000	25 m	ERS-1-SAR	100 x 100	1460
1 : 200.000	30 m	Landsat-TM (level 2A)	170 x 185	4800
1 : 250.000	80 m	Landsat-MSS (1975-1993)	170 x 185	250
1 : 750.000	170 m	RESURS-01	700 x 700	2730
1 : 750.000	188 m	IRS-1C_WiFS	806 x 806	820
1 : 2.000.000	300 m	MERIS (Start: 2000)	1150 x 1150	tbd
1 : 2.500.000	500 m	MODIS (band 3-7 for land; Start: 1999)	2330 x 2330	tbd
1 : 2.500.000	600 m	MOS	200 x 200	Free for research
1 : 3.000.000	1000 m	NOAA-AVHRR	3000 x 3000	127

TERICA Working Group 2:
Changing biodiversity and ecosystem functioning

CABI Bioscience: Environment/NERC Centre for Population Biology, Silwood Park, UK, 26-27 May 1999.

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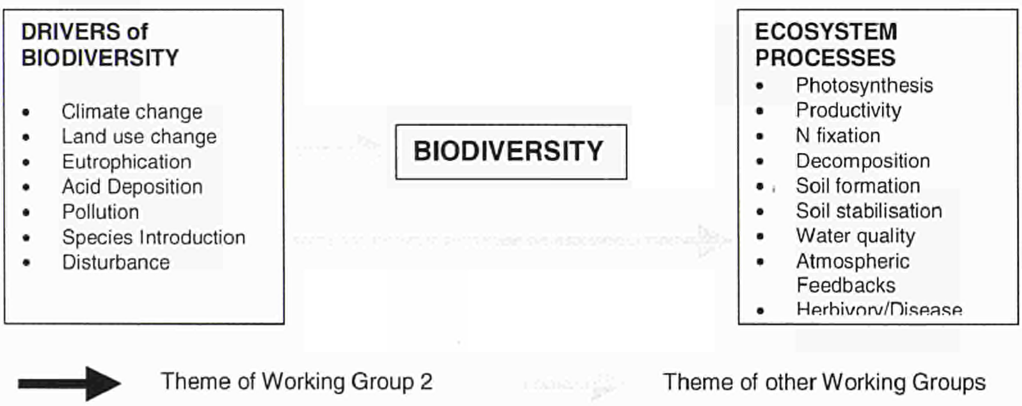
1. INTRODUCTION

This report summarises the contribution of projects funded under the TERI programme to issues concerning the effects of changes in biodiversity on ecosystem functioning. The report highlights the extent of work within TERI on this area, some of the key scientific achievements and their policy relevance, and future research and policy requirements.

Since TERI projects study scenarios of both the degradation of biodiversity and the success of management aimed at enhancing the diversity of degraded sites, the remit of this Working Group was extended. It includes assessment of the impact of changes in biodiversity, rather than limiting itself to the impact of the erosion of biodiversity. TERI research projects address this issue in two main ways. Some assess the impacts of environmental change (climate change, land use change, pollution) on biological diversity and then seek to correlate this information with changes in ecosystem functioning. Others assess the impact of reductions in biodiversity on ecosystem functioning through controlled manipulation of diversity levels.



TERI projects were funded in two tranches (1996-1999 and 1998-2001). Consequently, many of the projects are still in progress. It is therefore important to note that the scientific achievements of TERI outlined here are preliminary and not complete.

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* Working Group 2 Convenor

2. SCIENTIFIC CONTEXT

Recent experimental (Naeem *et al.* 1994, Tilman *et al.* 1997a, Hooper & Vitousek 1997) and theoretical (Tilman *et al.* 1997b, Loreau 1998) research has shown that biomass productivity can be greater in species-rich than species-poor plant communities. Changes in biomass productivity are often accompanied by changes in other ecosystem functions such as nutrient retention. However, the fact that this may not occur in all ecosystems (see Johnson *et al.* 1996 for a review) means that priority in research efforts should now be devoted to understanding the underlying mechanisms, turning the initial question of 'Does diversity beget productivity?' into 'Why and when can diversity beget productivity?' (Grime 1997, Chapin et al. 1998).

Recent work has started to address this question. Two main hypotheses have been proposed. First, the 'sampling hypothesis' (Huston 1997, Aarsen 1997) shows that increasing the number of species also increases the probability of including a highly productive species in a multi-species mixture and hence the overall productivity of that mixture. This effect is also accompanied by a decrease in variance as the number of species increases (Naeem *et al.* 1995, Tilman *et al.* 1997b).

Sampling Hypothesis
Performance of species mixtures of different diversity. Line shows trend of means. Variance in performance decreases with increasing diversity.

The second hypothesis concerns the complementarity in resource use among species. It is assumed that if species differ, however subtly, in the way that they exploit limiting resources, a more complete resource use should be expected with an increase in the number of complementary species. This relates to a mechanism common in the agronomic literature, 'overyielding', which is the phenomenon by which species mixtures to perform above that what is expected from single species' performances in monocultures (de Wit 1960).

Additional mechanisms which have so far received less attention relate to the increase in indirect interactions in species-rich communities, where performance of multiple species mixtures may be enhanced via either positive interactions between plant species or effects on soil food webs that have feedback effects on plant function. The role of the evenness and spatial distribution of species which are also components of biodiversity have been rarely studied. Theoretical work in progress has been addressing these different hypotheses and showing how they can contribute to positive intra-site diversity – productivity relationships (Aarsen 1997, Loreau 1998, Nijs & Roy 1999).

The impact of diversity is also expected to affect the stability of the functioning of ecosystems. Due to the differential sensitivity of species to environmental changes, the probability of maintaining a given function across environmental changes increases with the number of species (McNaughton 1977, 1993). This 'insurance' hypothesis, which can been seen as an extension in time of the complementarity hypothesis above, again may be more or less valid depending on the ecosystem type, the ecosystem function and the environmental changes considered. This hypothesis is potentially the most critical one and needs to be refined and more largely tested.

3. POLICY CONTEXT

The relationship between biodiversity and ecosystem processes has a direct bearing on a number of EU policy areas:

Agriculture and Forestry

Much of Europe's terrestrial biodiversity is associated with systems managed for agriculture or forestry. In many systems, there is a symbiotic link between management and maintenance of biodiversity. However, market failure to take account of the environmental impact of intensive management practices has led to an erosion of the biodiversity of large areas of Europe. Following Regulation 2078/92, agri-environmental programmes have been introduced to address this issue. Currently over 20% of EU farmland is included in such programmes, whereby farmers are paid incentive payments for adopting environmental land management practices. The reform of the Common Agricultural Policy and Agenda 2000 offer further opportunities for encouraging environmentally-sustainable agricultural practices.

Conservation

Loss of biodiversity is associated with a number of causes operating at a European scale, such as climate change, land use change, eutrophication and pollution. These drivers are influenced by the policy framework of different sectors (agriculture, transport, energy, industry etc.). Research aimed at identifying the factors causing loss of biodiversity and understanding the mechanisms promoting biodiversity are essential if the EU's responses to the Convention on Biological Diversity and the European Biodiversity Strategy are to be effective.

Certain threatened habitats have been identified in the Habitats Directive 92/43. A network of protected areas (Special Areas of Conservation) is being established by the EU under the title Natura 2000. Research aimed at investigating the relationship between ecosystem vulnerability and biodiversity in relation to factors operating at a European scale will underpin effective management of these areas and development of the network through restoration schemes.

Carbon Budgets

Much research on the effects of diversity on ecosystem processes concerns elements of the carbon cycle (productivity, decomposition, soil organic matter synthesis etc.). An understanding of the effects of erosion of diversity on the ability of systems to fix and store carbon is essential, if EU policies (in support of the Kyoto agreement) are to have a sound scientific basis.

4. ACHIEVEMENTS OF TERI ON THE EFFECTS OF BIODIVERSITY ON ECOSYSTEM FUNCTION

The interactions between global change factors, biodiversity and ecosystem functioning pervades all TERI projects. Many projects address the impact of various drivers on levels of biodiversity within different functional groups. As these drivers often have a direct effect on ecosystem processes as well as an effect on biodiversity, it is difficult to address questions concerning the fundamental value of biodiversity in maintaining ecosystem functioning. Manipulative experiments, in which levels of biodiversity within a single ecosystem are varied, may be used to examine the effects of the erosion of biodiversity (BIODEPTH) and the recovery of biodiversity as a result of management aimed at the restoration of damaged ecosystems (CLUE). The areas of study of TERI projects addressing the relationship between biodiversity and ecosystem functioning are outlined in Table 1.

Table 1: The contribution of TERI research projects to the working group theme 'Changing Biodiversity and Ecosystem Functioning'.

	Method of studying Biodiversity	Drivers of Biodiversity Studied	Ecosystem Processes Studied	Biome Studied	Scale of Diversity Studied	Questions Addressed
1st Tranche	**Projects**					
BIODEPTH#	Experimental manipulation	General	Productivity Decomposition/SOM Water quality	Grassland	Species Functional group	
CANIF*	Correlational/ observational		Productivity Decomposition Soil quality Water quality	Forest	Species Functional group	
CLUE#	Experimental manipulation	Land use change	Productivity Decomposition/SOM Nitrogen fixation Pests and diseases	Grassland Agricultural	Species Functional group	Successional processes
DYNAMO#	Modelling	Climate change Acid deposition Land use change	Productivity Decomposition/SOM Water quality	Boreal forest Temperate forest		Resilience Recovery
ECOMONT#	Correlation/ observational study, Modelling.	Land use change.	Productivity Nitrogen fixation Soil quality Water quality Atmospheric feedbacks.	Alpine, grassland, agricultural	Species, functional group.	Successional processes
ETEMA#	Modelling	To be decided.				
GLOBIS*		Climate change Air pollution	Decomposition/SOM Atmospheric feedback	Boreal forest Temperate forest	Species, functional group.	Successional processes.
PROTOS#	Correlation/ observational study/ Modelling	Climate change Acid deposition.	Decomposition Soil quality Water quality	Boreal forest Temperate forest Mediterranean forest		
2nd Tranche						
CLIMOOR#	Experimental manipulation of diversity	Climate change Pollution.	Productivity Decomposition Water quality Atmospheric feedbacks	Grassland, Mediterranean	Species, functional group.	Resilience.
CONGAS*	Correlation/ observational study, modelling	Climate change Land use change	Productivity Decomposition Atmospheric feedbacks	Wetlands		
DART#	Correlation/ observational study	Climate change Land use change	Productivity Decomposition Atmospheric feedbacks	Arctic Boreal Forest	Species Functional group	Resistance
GRAMINAE #	Correlation/ observational study, modelling	Pollution Acid deposition Eutrophication	Productivity Atmospheric feedbacks	Grassland.	Species.	Resilience
LUCIFER*		Land use change Fire		Mediterranean	Species	
MEGARICH #	Correlation/ observational study	Climate change	Productivity	Grassland	Species, functional group.	Resistance.
POPFACE*		Climate change Eutrophication	Productivity Pests and diseases Soil organic matter	Agro-forestry	Genetic	
SUITE*		Pollution	Soil quality Water quality		Functional group	

*# Information provided by projects in response to questionnaire from WG2. * Information provided by the Working Group members.*

The investigation of the impact of global change on biodiversity is a major focus of several TERI projects. **GLOBIS** examines the effect of climate change and air pollution on the soil biodiversity, and how changes in diversity affect the quality and quantity of soil organic matter. This project has shown that global change affects different components of the soil biota in different ways. Soil organisms and soil processes may therefore provide useful indicators of ecosystem change. The results emphasise the need for food-web studies to be incorporated into models aimed at predicting the consequences of environmental change and loss of biodiversity.

Several projects address issues affecting specific fragile or vulnerable landscapes. **ECOMONT** has shown how changes in land use patterns in alpine systems affect biodiversity and ecosystem factors, such as productivity, soil stability and water quality. **CLIMOOR** is carrying out a risk assessment of damage to heathland systems as a result of climate change and air pollution, including the consequences for biodiversity. **LUCIFER** examines how changes in land use affect the incidence of fire in Mediterranean systems, and what impact this has on the biodiversity of these ecosystems.

The development of a coupled model framework for identifying the impact of several drivers (climate change, land use change, N deposition) on the biodiversity of natural and semi-natural ecosystems is the subject of **ETEMA**. The model framework will be applicable at a range of scales, from patches to regions.

Table 2: Key achievements of TERI projects with regard to effects of changes in biodiversity within a community on ecosystem processes.

	Key Findings	Policy Relevance
C cycles	Number of species: • Not always higher productivity. • No clear trend for decomposition. Number of functional groups: • Always higher productivity • No clear trend for decomposition. • Increased diversity means increased probability best performers. • No data for soil carbon. • Quality of biomass (*cf* decomposition).	• Carbon storage.
N cycles	• Increased N retention can come from an increase in biomass and/or an increase in microbial immobilisation.	• Air pollution. • Quality of water supply.
Water	• Less NO_3 in percolated water.	• Quality of water supply.
Weeds	• Higher diversity communities are reliably less invasible than lower diversity communities • Low diversity communities vary in their susceptibility to invasion.	• Potential for invasion by exotic species
Pests	• Insect diversity tracks plant diversity (therefore high diversity plant communities brings about high diversity insect communities) but, insect abundance of specific taxa can be higher in low diversity communities. • High diversity plant communities also support high diversity natural enemy communities.	• Potential for pest outbreaks. • Less pesticide use.

Some of the key achievements of TERI projects which have manipulated the diversity of experimental systems and measured the impacts on ecosystem processes are summarised in Table 2. Results from both the **BIODEPTH** and **CLUE** projects suggest that the loss of plant diversity (richness effects), or of particular species and functional groups (identity effects), can decrease plant productivity and therefore potentially reduce the ability of grassland systems to act as a sink for atmospheric C. Both projects also suggest that the loss of plant diversity may reduce N retention in the soil system and increase nitrate leakage, with implications for soil sustainability and water quality respectively. The **BIODEPTH** and **CLUE** projects also provide examples of situations where communities with higher plant diversity were more resistant to invading weeds and less prone to insect outbreaks relative to lower diversity versions of the same community types. In **CLUE,** higher plant diversity promoted insect diversity, and while **BIODEPTH** provides similar cases, the general results were more variable.

One strength of TERI is in placing the results of studies examining potential consequences of the loss of biodiversity into the context of results from projects that look at large scale correlations between diversity and ecosystem functioning at the landscape level, such as **ECOMONT**. Note that small and large scale patterns may sometimes be different, as demonstrated in **ECOMONT** where increased diversity in abandoned fields led to reduced productivity due to the invasion of dwarf shrubs.

The value of biodiversity is an over-riding conclusion of work carried out by TERI projects on the relationship between biodiversity and ecosystem functioning. Diversity, at both the landscape and site levels, leads to predictability of ecosystem function and protection from unusual events (e.g. pest and disease outbreak, invasion by weed species, etc.)

5. EMERGING REQUIREMENTS – SCIENCE

The following gaps in issues addressed were identified:

Biodiversity

- Mechanisms promoting the maintenance and restoration of biodiversity
- Importance of landscape attributes and landscape-scale processes

Carbon

- Non-herbaceous ecosystems (heaths, scrub and forest ecosystems)
- Landscape-scale flow of carbon
- Organic matter dynamics

Nitrogen

- Interaction of biodiversity with N cycle, especially N deposition in non-forest systems
- Critical thresholds for change
- N volatilisation
- Role of organic N

Water

- Water quantity and flow patterns through the landscape

Pests and diseases

- Potential for invasion of different systems by exotics
- Pathogens and diseases in relation to biodiversity

In addition, the following gaps in research methodologies were identified:

- Integration of work on biodiversity as a response to global change and as a driver of ecosystem functioning (drivers may also have a direct impact on ecosystem function not mediated through changes in diversity).
- Complementarity between experimental, observational/correlational and modelling studies.

- The importance of landscape scale processes and landscape diversity.

6. EMERGING REQUIREMENTS – POLICY

The work of TERI projects on biodiversity and ecosystem functioning reinforces understanding of the role of biodiversity in long-term sustainability and protection against environmental problems. A major finding is the need for a better understanding of ecosystem functioning at the landscape level. This includes not only biological processes operating at a landscape scale (such as the dispersal of organisms), but also the impact of the spatial arrangement of ecosystems within landscapes. Landscape diversity is likely to be just as important as site diversity in environmental protection.

The scale of implementation of policy measures is critical in their effectiveness at solving problems associated with the impact of global change on biodiversity. There is already recognition that, for example, agri-environmental policies need to be targeted on specific landscapes and adapted to take account of the local situation. Policy may be best targeted on landscape systems rather than landscape components. Thus, scientific research and policy need to move in opposite trajectories.

The results of the research have clear implications for various sectors:

Agriculture/forestry

- sustainable management practices for agriculture and forestry
- implementation of agri-environment schemes and conservation of diversity
- prevention of pest and disease outbreaks or invasion by exotics

Energy

- production of biomass fuels
- water availability for hydroelectric schemes.

Transport

- fragmentation of habitats through construction schemes
- restoration of diversity following construction of roads or railways

Health

- Drinking water quality, especially NO_3 content
- Use of pesticides and other agro-chemicals

Tourism

- Aesthetic value of biodiversity (both species and landscape)
- Protection of threatened areas

7. PRIORITY FUTURE RESEARCH NEEDS

The following areas were identified as priorities for future research:

Agriculture/Forestry

- Development of sustainable use of soils in respect of soil biodiversity.
- Identification of indicators of sustainability and ecosystem health.

Conservation

- Methods for the protection of fragile ecosystems and restoration of damaged ecosystems.
- Investigation of the impact of landscape attributes/processes on biodiversity.
- Research providing a mechanistic understanding of maintenance and restoration of biodiversity.
- The importance of genetic variation, especially erosion through fragmentation.

Risk management

- Effects of extreme events and slow pervasive changes in diversity on ecosystems.
- Effects of diversity on provision of resistance/resilience.
- Identification of threshold levels of ecosystem vulnerability.
- Effects of diversity on pests and disease outbreaks or invasion by exotics.

Carbon and Nitrogen fluxes

- Changes in diversity both cause and effect of changing carbon fluxes
- Ecosystem modelling incorporating foodwebs (especially soil biota)
- Predicting mass flow of carbon, nitrogen within alndscapes and regions
- N dynamics/processes seem to be especially sensitive and could make indicators

Landscape scale

- Landscape scale processes, including dispersal ability of different organisms
- Understanding effects of spatial arrangement of land use.
- Quantification of landscape diversity and its importance for biodiversity.

Policy conflicts

- Reconciling conservation of biodiversity with economic development, especially agricultural and forestry production.

Research Approaches

- Increased links with end-users in project planning and dissemination of findings.
- Long-term sites with integration of site and landscape components.

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TERICA Working Group 3: Alien Species and Outbreaking Species in Ecosystems

University of Durham, Durham, UK, 17-18 February 1999

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1. INTRODUCTION

The aim of the workgroup was to examine the key policy issues/environmental problems associated with organisms that undergo marked increases in abundance in their native habitat (*Outbreak Species*) or within new habitats where the organisms are not indigenous (*Alien Species*). The distinction is one of species origin rather than the ecological traits or potential impacts on ecosystems. The dynamics of both groups of species are associated with human activities: non-indigenous species are defined as resulting (at least initially) from human introduction and the occurrence of species outbreaks may be related to land-use or anthropogenic climate change. The impact on ecosystems of the resultant changes in species distributions is recognised as a widespread and significant component of human-caused global environmental change (Fig. 1)

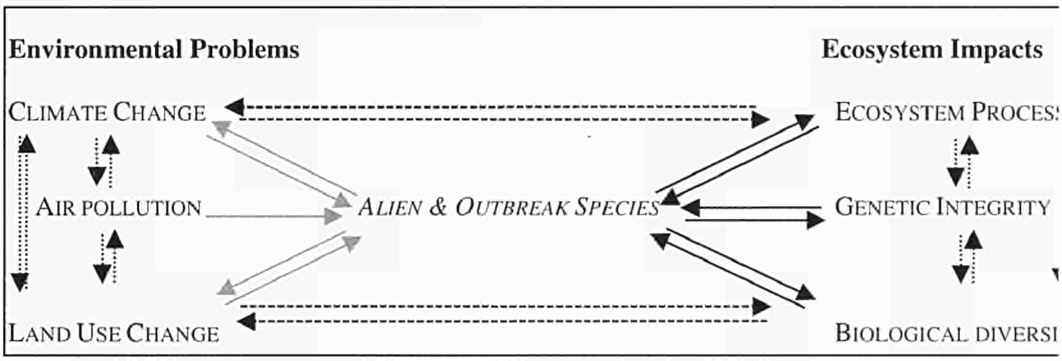

Figure 1: Links between *Alien & Outbreak Species*, their ecosystem impacts and environmental change.

2. KEY ENVIRONMENTAL PROBLEMS AND ALIEN AND OUTBREAK SPECIES

Non-indigenous species comprise a significant component of European flora and fauna. For example, throughout Europe approximately 6% of all vascular plants and 5% of birds are established non-indigenous species. Non-indigenous species may have fundamental impacts on European ecosystems (black arrows in Fig. 1), including the altering of soil C and N fluxes (e.g. low decomposition rates for *Rhododendron ponticum* litter), reducing indigenous biodiversity (e.g. *Hedichium gardnerianum* reducing natural regeneration of laurisilva) and breaching the genetic integrity of species (e.g. *Oxyura jamaicensis* hybridising with *Oxyura*

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[*] Working Group 3 Convenor

leucocephala). Hence, the potential for *Alien and Outbreak Species* to impact ecosystems is considerable. For certain ecosystems, the short and long-term impacts of non-indigenous species may be of similar or greater magnitude than those predicted for other components of human-caused environmental change (e.g. climate, land-use, air pollution etc.). In addition, the dynamics of *Alien and Outbreak Species* will be influenced by these other components of environmental change and may modify their effects on ecosystems (grey arrows in Fig. 1). For example for plants, warmer winter temperatures, increased landscape disturbance and eutrophication of soil/water may all be expected to increase the probability of species outbreaks and to increase the range of non-indigenous species. Furthermore, invasion by *Alien and Outbreak Species* may have important feedbacks on other components of environmental change e.g. altered C sequestration rates of ecosystems, changes in agricultural land-use (grazing land degradation) or increased ecosystem disturbance (fire frequency) etc.. Thus research on *Alien and Outbreak Species* is pivotal to understanding how ecosystems function and their response to environmental change. These studies should be prioritised in future European Ecosystem Initiatives.

3. EUROPEAN POLICY ON ALIEN AND OUTBREAK SPECIES

The European States have a commitment "*to strictly control the introduction of non-indigenous species*" (Bern Convention on the Conservation of European Wildlife and Natural Habitats) and "*eradicate those alien species which threaten ecosystems, habitats or species*" (UN Convention on Biological Diversity). Both the "Habitats" and "Birds" Directives of the European Union also contain provisions to ensure introductions do not prejudice the local flora and fauna. European legislation is restricted to: a) prevention of deliberate rather than accidental introductions; b) exemption of the major sources of accidental introductions e.g. forestry and agriculture species, biocontrol agents, introductions into zoological and botanical gardens; c) no commitment to eradicate or control established non-indigenous species. The European States also have a commitment "*to report the existence, outbreak and spread of plant pests and of controlling those pests*" (UN International Plant Protection Convention). Pests are clearly defined by the convention as "*of potential national economic importance to the country endangered thereby*". The "Plant Pests" Directive of the European Union provides lists of pest species that must be banned from being introduced into particular Member States. The only equivalent directive for animals is the "Aquaculture" Directive that legislates against the introduction of organisms pathogenic to aquaculture animals. European legislature reveals an acute awareness of the economic and environmental costs of non-indigenous and outbreak species. Identification of target species facilitates the control and eradication of agricultural pests, an aspect missing from the environmental legislation. This reflects the absence of a clear European perspective on the ecological impacts of these organisms on natural ecosystems and the difficulty of controlling accidental introductions.

4. EUROPEAN ECONOMIC SECTORS AND ALIEN AND OUTBREAK SPECIES

The major European economic sectors not only exacerbate the problems of *Alien and Outbreak Species*, but are themselves negatively impacted by them (see Table 1 for examples). The majority of economic sectors are important sources of deliberate and accidental introductions of non-indigenous species in Europe, whilst others indirectly aid the dispersal (e.g. freshwater transference between catchments) or establishment (e.g. cooling water discharge) of non-indigenous species. Non-indigenous species may have significant economic and environmental impacts on most sectors and certain sectors introduce species that are problematic within the same sector e.g. *Amaranthus retroflexus* (Agriculture), *Anoplophora glabripennis* (Forestry), *Oxyura jamaicensis* (Tourism). It is likely that few other components of anthropogenic environmental change impact on such a wide range of economic sectors.

Table 1: Examples of situations where the major EU economic sectors act as sources of alien species in Europe and the problems that alien species (from all sources) cause within these particular sectors.

SECTORS	SECTORS AS SOURCES OF ALIENS	ALIENS AS SECTOR PROBLEMS
AGRICULTURE	Feral Crops: *Linum usitatissimum* Contaminated Seed: *Amaranthus retroflexus* Animal Breeding: *Mustela vison*	Alien Weeds: *Amaranthus retroflexus* Alien Pests: *Nyctereutes procyonoides*
FORESTRY	Plantation Exotics: *Eucalyptus* spp. Plantation Pests: *Anoplophora glabripennis*	Alien Weeds: *Prunus serotina* Alien Pests: *Sciurus carolinensis*
ENERGY	Biomass Crops: *Fallopia japonica* Cooling Water Discharge	Hydroelectricity: Waterweeds
HEALTH	Medicinal Herbs: *Tanacetum parthenium*	Hay Fever: *Ambrosia artemisifolia* Toxins: *Heracleum mantegazzianum* Disease: *Anopheles* mosquitoes
INDUSTRY	Imported Raw Materials Pet Industry: *Mustela furo*	
RENEWABLE RESOURCES	Freshwater Transference	
TOURISM	Zoological Gardens: *Muntiacus reevesi* Botanical Gardens: *Galinsoga parviflora* Game Introductions: *Sylvilagus floridensis*	Biodiversity: *Rhododendron ponticum* Hybridisation: *Oxyura jamaicensis*
TRANSPORT	Human Mediated Dispersal Landscaping: *Robinia pseudoacacia*	Air Strikes: *Branta canadensis*

5. THE TERRESTRIAL ECOSYSTEM RESEARCH INITIATIVE (TERICA) AND ALIEN AND OUTBREAK SPECIES

No data are currently available on the economic and conservation costs of *Alien and Outbreak Species* across Europe. However, within the LIFE-2 programme (Environment and Climate) under Framework IV, projects aimed at combating the detrimental effects on biodiversity of non-indigenous species have been funded to the value of over 25 MECU (1997-2001). Ecosystems affected include wetlands, woodlands (alluvial, deciduous and coniferous) and laurisilva, with the principal targets being non-indigenous plant species (e.g. *Nelumbo nucifera*, *Rhododendron ponticum*, *Hedichium gardnerianum*). It is evident that the stakeholders involved (national parks, local governments, wildlife groups) require input from ecosystem scientists as to how best to assess, manage and/or avoid problems caused by non-indigenous species.

To gauge the contribution of TERICA to the study of *Alien and Outbreak Species* in Europe, a questionnaire was sent to all TERICA project coordinators. Although unlikely to encompass entirely the complexity and diversity of the TERICA projects (see differences in two responses from LUCIFER), the responses to the five questions provide a useful insight into TERICA research on *Alien and Outbreak Species* (Table 2). Superscripts relate to project numbers in Table 2.

- Only a minority of TERICA projects examine Outbreak e.g. *Ampelodesmos mauritanica*[15], aphids[20]; or Alien Species e.g. *Larix sibirica*[7], hybrid poplar[19], "weedy" herbaceous plants[2].

Table 2: Results of a questionnaire on alien/outbreak species sent to all TERICA project leaders

KEY TO ANSWERS: X=NO ✓ =YES ?=DON'T KNOW o= POTENTIALLY MODELLED	1. BERI	2. BIODEPTH	3. CANIF	4. CLIMOOR	5. CLUE	6. CONGAS	7. DART	8. DEGREE	9. DYNAMO	10. ECOMONT	11. ETEMA	12. GLOBIS	13. GRAMINAE	14. LAKES	15. LUCIFER (A)	15. LUCIFER (B)	16. MAGEC	17. MEGARICH	18. MICRODIVER	19. POPFACE	20. PROTOS	21. SUITE
Are alien or outbreak species studied?	X	X	X	X	X	X	✓	X	X	X	o	X	X	X	X	✓	X	X	X	✓	✓	X
Is invasion possible in the study ecosystem(s)?	?	✓	X	✓	✓	X	✓	✓	?	✓	o	?	✓	✓	X	✓	✓	✓	X	✓	✓	X
Are impacts on ecological processes expected?	?	✓	?	?	?	✓	✓	X	?	?	o	✓	✓	✓	?	✓	X	?	?	?	?	X
Are the spatial dynamics of species studied?	✓	✓	X	X	✓	✓	✓	X	X	✓	o	✓	X	✓	✓	✓	X	X	X	✓	X	X
Are species interactions examined?	✓	✓	✓	✓	✓	X	✓	X	X	✓	o	✓	X	X	✓	✓	X	✓	X	✓	X	X

- Although a number of respondents were unsure as to the invasibility of their study ecosystem, the working group concluded that the majority of European terrestrial ecosystems examined within TERICA are prone to invasion by non-indigenous species. These range from highly managed e.g. croplands (*Amaranthus retroflexus*) to relatively undisturbed ecosystems e.g. moorland (*Campylopus introflexus*). Invasion of below ground ecosystems is relatively undocumented[8, 18] although the invasion of UK soils by the New Zealand flatworm (*Artioposthia triangulata*) highlights this possibility and its dramatic consequences. Negative responses were received primarily from studies of N & C fluxes through ecosystem components[3, 6, 13].
- More often than not, changes in abundance in either indigenous or non-indigenous species are expected to have an impact on ecosystem processes, although in most ecosystems examined within TERICA the form of this impact is generally not known.

Thus *Alien and Outbreak Species* are issues that impinge on most terrestrial ecosystems but their impact on ecosystem processes is poorly understood. Yet TERICA has only addressed this issue in a minority of projects. Nevertheless, generic approaches (empirical and theoretical) applicable to the study of *Alien and Outbreak Species* have been developed within TERICA:

- Insights into the spatial dynamics of *Alien and Outbreak Species* will stem from TERICA projects examining how species respond strongly to changes in global temperature[7, 11], atmospheric CO_2 concentration[1, 11, 17, 19], eutrophication[1, 10, 17] or changes in land use[5, 10, 11, 14, 15]. Predicting changes in species' distributions will require a knowledge of the underlying dispersal processes[7, 14] and probabilities of colonisation[1, 2, 4, 5, 6, 14].
- Understanding the impact of *Alien and Outbreak Species* on ecosystems will require a knowledge of the relative importance of interspecific competition[1, 2, 3, 4, 11, 15], herbivory/predation[7, 19, 20] and mutualistic interactions[12].

The TERICA projects have provided excellent science and a framework of approaches that can be used to tackle the issue of *Alien and Outbreak Species* in the future, but have not addressed policy issues directly related to the problems of *Alien and Outbreak Species*. These problems are central to future research priorities in European ecosystem research identified by TERICA e.g. loss of biodiversity and ecosystem functioning (WG2); restoration and recovery of damaged ecosystems (WG4) and policy conflicts: solving one problem creates another (WG8).

6. PRIORITY RESEARCH NEEDS IN THE AREA OF *ALIEN AND OUTBREAK SPECIES* IN EUROPE

TERICA projects have focused on 4 major issues of environmental change (dashed arrows in Fig. 1):

- Impacts of climate change on the functioning of European ecosystems.

- Direct impacts of elevated CO_2 on European ecosystems.
- Fluxes and impacts of elevated atmospheric nitrogen in European ecosystems.
- The role of biodiversity in regulating ecosystem functioning.

Alien and Outbreak Species are likely to play a major role in these issues and specific studies on *Alien and Outbreak Species* should be incorporated within the current research framework (grey arrows in Fig. 1). Nevertheless, *Alien and Outbreak Species* are in themselves a major source of environmental change for which there is currently no clear European perspective (black arrows in Fig. 1). Hence future ecosystem research in Europe needs to address a further issue:

- Ecosystem consequences of invasion by Alien and/or Outbreak Species

The research approach should:

a) Identify the relative importance of ecosystem traits e.g. species richness, resource supply, proximity to man etc. that might influence their risk from invasion by alien or outbreak species.

b) Assess the impact of specific *Alien and Outbreak Species* on ecosystem function e.g. biodiversity, N flux, etc. by comparing invaded/non-invaded ecosystems and the response of ecosystems following eradication of non-indigenous species.

c) Integrate the study of ecosystem traits with assessment of impacts in order to elucidate whether feedbacks (positive or negative) occur on ecosystem function e.g. invasion might decrease diversity of species rich habitats but increase diversity of species poor habitats.

d) Examine these species:ecosystem interactions along natural environmental gradients.

e) Develop spatially explicit models, appropriately parameterised, to predict why outbreaks occur and how species spread within ecosystems and across landscapes.

f) Test predictions through studies of ecosystem impacts along a chronsequence reflecting different periods since non-indigenous species were introduced and/or carefully controlled introductions of non-indigenous or outbreak species within experimental mesocosms (where escape into the wider landscape is prevented).

g) Use results to develop management guidelines in association with relevant stakeholders to prevent and/or control invasion where economically or environmentally appropriate.

This approach is consistent with the those currently undertaken by TERICA research projects. However, this research will feedback directly into EU policy on non-indigenous species by identifying vulnerable ecosystems that might require particular protection and notifiable species that are increasing across Europe and have negative impacts on ecosystems. The study of *Alien and Outbreak Species* provide suitable models to assess likely impacts of genetically modified organisms (GMOs) on ecosystems and while GMOs fell outside the direct remit of the workgroup, they represent an issue of considerable policy relevance as well as importance in ecosystem research.

TERICA Working Group 4: Restoration of disturbed and damaged ecosystems

NIOO-CTO, Heteren, NL, 10 June 1999 and additional electronic discussion

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1. INTRODUCTION

Most TERI-projects (1996-1999 and 1998-2001) are focused on impacts of human-induced changes in functioning of terrestrial ecosystems. Why? Possibly because impact studies may support policy and increase socio-economic acceptance of the need to change production and consumption behaviour of humans (Fig. 1). Provided that this works, does reduced exposure of terrestrial ecosystems to carbon dioxide, nitrogen compounds, trace gases, UV-B, or warming of the atmosphere lead to a spontaneous re-establishment of former species-rich communities? Probably not. The solution of a problem, albeit that mechanisms are described, may require a different approach (Fig. 1).

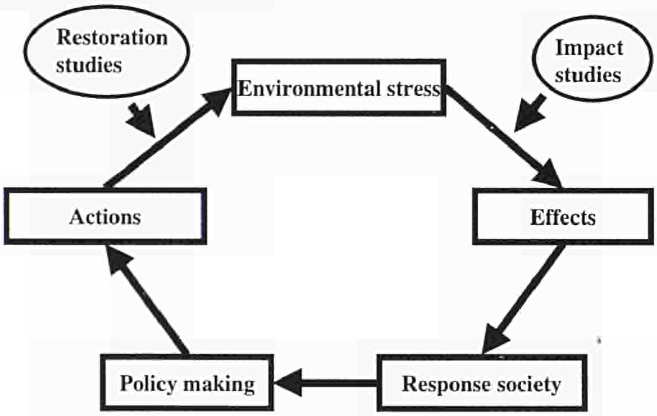

Figure 1: Role of impact and restoration studies in decision chains.

Essentially, restoration should include removal or reduction of the sources that lead to human-induced changes and specific actions to re-establish species or communities that have been lost (Fig. 2). Removal is aimed at the influencing of particular rates, such as of acidification, eutrophication, or combustion of fossil fuels. Specific actions may include measures, such as removal and/or introduction of species or chemical compounds.

A TERI-project directly aiming at restoration is CLUE, which is focused on how to enhance the conversion of arable land into more natural ecosystems. This is current EU-policy to restore **habitats** and conserve **biodiversity**. Consultation of other TERI-projects did not

* Working Group 4 Convenor

reveal restoration-aimed approaches (although possible measures for restoration may be derived from many projects). Because of the few examples in TERI, this report should be regarded as a contribution to research programming and introducing possible policy options, rather than to bringing together a large body of TERI results to synthesize and conclude on policy implications.

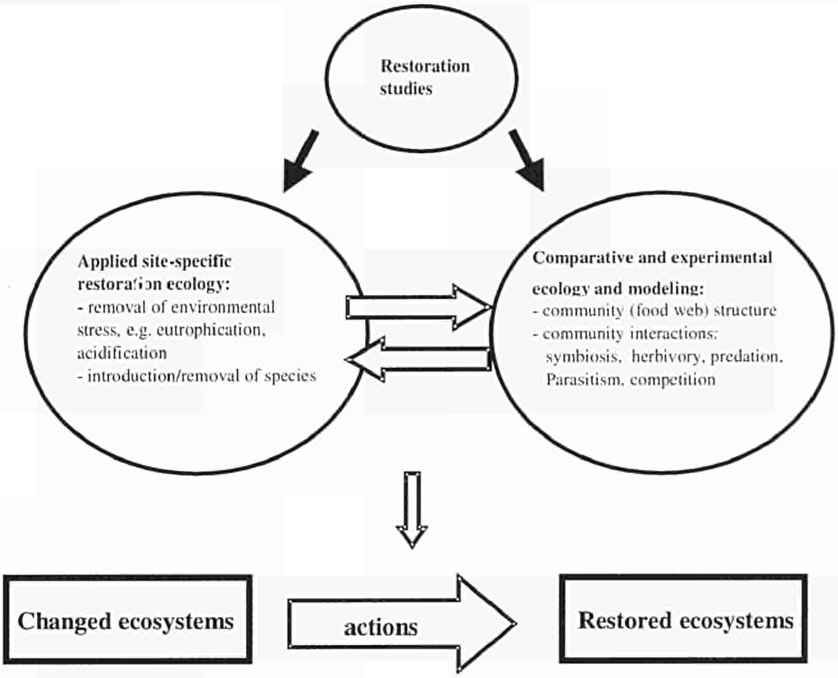

Figure 2: Approach for ecosystem restoration.

2. ECOSYSTEM DISTURBANCE AND DAMAGE, RESTORATION ATTITUDES, INDICATORS AND EUROPEAN DIMENSIONS

Ecosystem disturbance and damage

In the present report, we use disturbance and damage to indicate human-induced changes which drive ecosystem changes either at a faster rate or into a different direction than under natural conditions would have happened. Exposure of ecosystems to environmental influences leading to change is a natural phenomenon. Both cyclic and non-cyclic changes may be the result of natural causes of disturbance. Even the heaviest disturbance, such as by fire, hurricanes or volcano eruptions, may sooner or later lead to restored species composition and richness, as well as tight cycles of nutrients and other resources. These disturbances may act on a long time scale. However, examples of human-induced changes, such as overgrazing in semi-arid areas, cutting of tropical rain forests, airborne nutrient deposition on moors, or intensive agriculture may drive an ecosystem on a short term (within decades) into a state from where the original state may not be easily reached again spontaneously. The loss of diversity may reduce the resistance of communities against environmental (both natural and human-induced) stress. In addition, reduced resilience after the stress factor has been removed may also be related to loss of diversity. Both BIODEPTH and MICRODIVERS have studied the relation between diversity and resistance/resilience.

Ecosystem restoration

Goals of ecosystem restoration may have a wide variety. These may include the conservation or re-establishment of threatened species, habitat restoration, landscape restoration, or restoration of ecosystem functions. Choices are strongly linked to human preference or memory of what was there before changes occurred. Thus, humans define what they would like to restore in order to counteract changes that they have induced themselves, because of a feeling of discomfort with or concern about the present situation.

Measures of restoration of terrestrial ecosystems are less well explored than in aquatic ecosystems, where gradual improvement of environmental quality is combined with shock therapies, such as removal of certain predators from the food web. In terrestrial ecosystems, sowing plants or the release of animals is still topic of dispute and the soil community doesn't get much attention usually. Removal of top soil may be an example of a shock therapy for terrestrial ecosystems, which requires additional circumstances, such as reduction of e.g. airborne nutrient input, restoration of natural hydrology and the availability of propagules to become established.

Evaluation and indicators. Monitoring and action in case of unwanted developments are not the strongest aspects of most restoration projects. Evolutionary and ecological time scales are far beyond those needed to support restoration policy (Fig. 3). Moreover, proper evaluation is time consuming and, therefore, expensive. This may be an explanation why in practice red list plant or animal species are given high indicator value, even though the scientific basis to such indicators is often lacking. Moreover, there is hardly any evidence that these species are indicative of the diversity of other organisms (e.g. the soil community), restored food web complexity or restored ecosystem functioning. It may be necessary to use multiple indicators, include processes in monitoring studies and allow to undertake action if developments do not seem to lead to pre-stated goals.

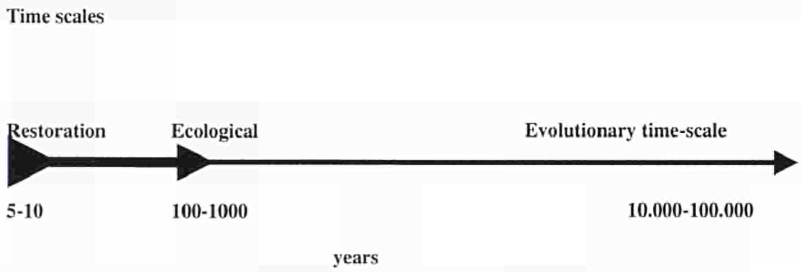

Figure 3: Time scales of restoration, ecological processes and evolutionary processes.

3. ACHIEVEMENTS OF EC RESEARCH LINKED TO TERI

Removal

One of the main prerequisites of recovery after disturbance is that environmental conditions are suitable again for species to get established, grow and reproduce. In case of pollution or eutrophication, emission should be reduced to an acceptable level and the ecosystem may need to be cleaned from accumulated toxic compounds or nutrients. In addition, it should be determined if reduction of one kind of emission may lead to enhanced availability of another toxic compound. One example is the enhanced availability of heavy metals in arable soil after reducing the rate of fertilization. Another example, investigated by BERI, is that the consequence of reducing carbon dioxide without reducing the nitrogen deposition may still lead to the change of bog ecosystems because of enhanced decomposition rates. Therefore, the determining of the environmental conditions to be changed and possible side effects is a major prerequisite for restoration.

Specific action

A second aspect of restoration is the availability of a regional species pool, from which local extinctions may be re-supplied with propagules. In the strongly human-induced changed landscapes with few relicts of former biodiversity, the source-sites for propagules to become re-established at restoration sites may be small in size and often far away. Therefore, the genetic potential of former biodiversity may be limited and propagules may not reach the restoration sites, resulting in less diversity at restoration sites than expected based on reference images. Both BIODEPTH and CLUE have shown that when the plant species pool increases chances are enhanced of including species with specific properties (although specific traits may also occur in small species pools). None of the TERI-projects has addressed consequences of habitat fragmentation for dispersal and re-colonization.

The CLUE project demonstrated that later successional plant species could be established at former arable land, but that the soil community was more difficult to restore by transplantation. Moreover, there seem to be time lags between changes in species diversity and productivity of vegetation on one hand and the response of the soil community on the other. In other words, the soil community seems to have an agenda different from the plant community. This conclusion is supported, especially in the longer running experiments within CLUE and BIODEPTH, by positive relations between the number of plant species or plant functional groups on microbial substrate utilization. However, it may be difficult, if possible at all, to generalize about relations between above and below ground biodiversity. These relations may be different for various species groups. Moreover, spatial scales may vary widely for plants and soil (micro)organisms.

The observed time lags in above- and below- ground coupling are important for the re-assemblage of food chains and food webs, especially when considering specific interactions, such as symbiosis, herbivory and parasitism. Thus, there is a chain of prerequisites for restoration of damaged ecosystems. Limitations at one end may lead to failures of the whole process.

4. SCOPE AND STRENGTHS OF THE TERI APPROACH FOR ECOSYSTEM RESTORATION

The scope and strength of the TERI-approach was in studying similar ecosystem types under different climatic conditions, such as meadows, (ex-)arable land, bogs, moors, forests, mountain areas, Arctic or Mediterranean areas, etc. Such a transect approach is not new in ecology (examples are known from e.g. IGBP), and impact studies on human-induced changes along climate gradients are carried out at other continents already. However, restoration and biodiversity studies along climate transects are scarce.

A major complication of projects such as CLUE and BIODEPTH is that both the local climate and site history co-vary from site to site. The strength of such projects emerges when different sites yield the same results, such as a positive relation between plant species diversity and reliability of suppression of problem weeds, which was achieved at all CLUE sites. For BIODEPTH, there was an over all positive correlation between the number of plant species and biomass production. However, this correlation was not found at all sites when sites were analyzed individually.

A disadvantage of the current transect approach is that funding is not guaranteed for more than three years in a row. Moreover, within climate strata, restoration studies may be performed at a large variety of soil types and results may be obfuscated by differences in history of the sites. When focusing on ecosystem types within Europe, proper statistical analyzes will be crucial e.g. to determine the sample size needed to answer certain questions. Five experimental sites of CLUE were ample to study effects of sowing later successional plant species on the suppression of problem weeds, whereas the effects of interacting below- and aboveground organisms were much more site-specific.

The European-wide approach offers many additional possibilities that are still largely unexplored:

- Studies on whole stream/catchment areas (Rhine, Meuse, Danube) allow to solve problems downstream by taking measures upstream.
- Reference areas (often still occurring in Eastern Europe) are essential to define goals and evaluation criteria for restoration activities and they may serve as source for propagules (provided that they are of suitable genetic constitution; BIODEPTH has addressed this question by Europe-wide transplantation studies).
- Corridors are also essential to enable species to recolonize from still existing hot spots of biodiversity.
- Landscapes may extend across national boundaries and are important to determine the species pool size, which finally determines the availability of propagules at local scales.

5. NEED FOR FUTURE RESEARCH ON ECOSYSTEM RESTORATION AND POLICY IMPLICATIONS

There is a clear need for future research on ecosystem restoration. Policy may benefit from a shift from impact studies to a problem-solving approach when linked to socio-economic analyses. However, it is not only the task of ecologists to involve other disciplines in their studies. A constraint for ecological research is that the time given by planners is often very short. In the case of land abandonment, the policy is already implemented even before ecological studies have been carried out. As ecological research takes time, ecologists should be involved in the process of policy making and planning well ahead to indicate which questions are essential to be solved prior to the implementation phase. Moreover, ecology and policy could mutually benefit from carrying out restoration projects as if they are (well designed!) ecological experiments. This allows action evaluation for policy and enables ecologists to study ecological relationships efficiently at appropriate spatial scales. There are several examples of intensive interactions between policy makers and ecologists at local or national scales already. Part of the budget of restoration projects needs to be labeled for structural accompanying studies which may feed back to management and further policy development.

As goals of restoration are strongly human-determined, perception by the public needs special attention. At a Europe-wide scale, the necessity to restore former ecosystems and consequences for (mostly) rural communities require changes in the attitude, as well as education of people to enhance acceptation. Here, linking ecology and socio-economics may be crucial to find the balance between what may be necessary from an ecological perspective and may be acceptable for the local community. Involvement of end-users in the preparation phase of restoration studies is crucial to define and sharpen the approach of restoration studies, to ensure maximal benefit for society.

Many restoration studies are still anecdotal and for few example situations. Such studies might deliver local solutions and interesting questions. However, they seldom explain the origin of failures. Problem solution with applications at a European level will certainly benefit from a fundamental and interdisciplinary approach, which may allow to relate developments in coupled ecosystem compartments, such as above- and below-ground, or up- and down-stream. However, when encouraging ecologists to think about the 'so what' and other highly relevant aspects of their work, it will be a challenge not to loose the possibility to come up with the unexpected which may seem redundant now, but which is crucial for future breakthroughs.

Acknowledgement. The scope of the working group was defined during the TERICA Toledo meeting (April 1998).

TERICA Working Group 5:
European carbon budgets / Linking carbon & nitrogen cycles.

University of Durham, Durham, UK. 8-9 April 1999.

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PREMISE

1. Application of ecosystem research for policy formulation and implementation requires that fundamental ecosystem processes be characterised and integrated at the appropriate scales of resolution and with a known degree of confidence.
2. This process is essential to the success of any future policy attempting to regulate human interactions with ecosystem dynamics.
3. The broad terms of reference within which WG-5 has operated, common to all working groups within the TERI initiative, are as follows:
   a. To review key research findings of TERI projects in relation to European Carbon Budgets and how C and N cycles can be integrated.
   b. To review key policies, issues and environmental concerns in relation to C and N cycles that current research within the TERI framework is attempting to address.
   c. To identify future priority policy needs for sustainable development in relation to C and N cycles and how ecosystem research can successfully underpin policy requirements.
   d. To identify gaps in current research and prioritise research requirements for future EU programmes.
4. From the outset, WG-5 has recognised there is often a mismatch between the expectations of the policy formulator and the present ability of the research community to fulfil such expectations. Whilst the research community must always be prepared to provide the best advice, based upon current levels of understanding and modelling skills, policy formulators must recognise that the quality of this advice will improve incrementally as the results of further research become available.
5. Policy formulators must also recognise that advancing current understanding on multiple interactions remains a high priority for researchers across Europe. WG-5 recognises that to date it has not been possible to carry out experimentation assessing multiple interactions (*c.f.* TERI working group 1), and how these affect C and N cycling, to a degree which will allow robust advice to be made available for policy formulation.

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[*] Joint Convenor Working Group 5

POLICY CONTEXT

6. WG-5 has identified the essential EU and international policy framework within which the assessment of existing research and prioritisation of future research needs in C and N cycling was carried out.

7. For Carbon

a. The Framework Convention on Climate Change, e.g. Kyoto Protocol on carbon emission control and sequestration.

8. For Nitrogen

a. UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) e.g. multi-pollutant, multi effect "Nitrogen Protocol" (expected to be finalized during 1999).

b. EU Acidification Strategy (Provided the basis for the National Emissions Ceilings Directive, expected to be agreed in 1999).

c. EU Nitrates Directive.

9. Impacts on Biodiversity.

a. Convention on Biological Diversity – BAPS

b. EU Habitats Directive (Natura 2000) and the Ramsar Convention.

KEY ISSUES RELATED TO C AND N CYCLING IN TERRESTRIAL ECOSYSTEMS

10. WG-5 focussed on 3 issues:
    (1) Assessing the sufficiency of existing data of TERI projects to produce C and N budgets for all relevant ecosystems and processes that will support policy requirements.
    (2) Evaluating the capability of ecosystem research of TERI projects to achieve the level of spatial, temporal and process integration required to support policy formulation.
    (3) Prioritising areas for research in support of policy formulation.
11. Issues outlined above were seen by WG-5 as central to an assessment of the role of TERI research initiatives in C and N cycling for current and future research.

Issue (1): Is the current status of knowledge of ecosystem processes arising from TERI activities sufficient to allow construction of C and N budgets for all relevant ecosystems across the EU, which will support policy requirements?

The TERI approach has the potential to allow integration of process research both geographically across Europe and through environmental space. Furthermore, the same approach has allowed research to be undertaken at a range of spatial scales from the whole ecosystem to the individual organism. Existing and emerging datasets can be considered at a number of levels within component parts of the ecosystem; these are considered in a to d, below:

a. Carbon and nitrogen dynamics at the ecosystem level

(1.) In most ecosystems processes and controls of Net Primary Productivity (NPP) are becoming well understood. Quantifying Net Ecosystem Production (NEP), by contrast remains problematic chiefly due to the difficulties associated with determination of ecosystem respiration. NEP tells us directly whether an ecosystem is currently a source or a sink for C: **Priority is therefore high**.

(2.) Decomposition processes are of equal significance to NPP in terrestrial ecosystem functioning: this is not reflected in research effort and current understanding of processes. **Priority is high**.

(3.) Information on the sizes and fluxes of ecosystem carbon and nitrogen pools is patchy and remains inadequate since soil classification and mapping often excludes organic horizons. This is a key issue since global estimates indicate that soil carbon reservoirs are twice those of atmospheric carbon reservoirs. Small adjustments in soil carbon pools may therefore lead to significant alterations in atmospheric carbon dioxide concentration. **Priority is high**.

(4.) There is a need for significantly improved understanding of how the long-term functioning of ecosystems, at all trophic levels, affects trace gas fluxes of C and N. **Priority is high**.

b. Carbon and nitrogen dynamics in the soil

(1.) Predicting the longer-term impacts of directional environmental change (e.g. warming, CO_2 increase) on SOM turnover (accumulation, losses and conversion from one pool to another) is currently limited by shortage of quantitative data from longer-term field-based manipulations of semi-natural ecosystems. Data from agricultural soils are more abundant than for other ecosystems; this imbalance must be redressed. **Priority is high**.

(2.) SOM dynamics are not driven by physico-chemical parameters alone. SOM is also controlled by biological components of the system (organisms and their biodiversity). There is a need to know if biodiversity responds to the physico-chemical environment or if it is the organisms that control the environment. This is essential if future predictions on SOM dynamics are to be made. **Priority is high**.

(3.) Although progress is being made in improving our understanding of the role of saprotroph biodiversity for soil processes, this remains a key issue. A possible link between soil biodiversity and process stability in relation to increased severity and/or frequency of extreme events (e.g. drought, fire, pest/pathogen outbreaks) needs to be assessed. **Priority is high**.

(4.) A clear overarching theory of SOM dynamics, of sufficient detail to enable predictions to be made across terrestrial ecosystems in response to drivers such as acid deposition, elevated atmospheric CO_2 plus disturbances, extreme events and changes in land use and management practice, is still lacking. For example, what happens to C and N reservoirs upon conversion of productive agricultural land to set-aside? **Priority is high**.

(5.) Methodologies for characterising SOM dynamics currently exist (e.g. the Rothamstead and CENTURY model). However, the highly complex and heterogeneous nature of SOM requires further development and refinement of appropriate experimental methodologies. **Priority is high.**

(6.) The responses of dissolved organic C and N compounds to all drivers of environmental change and disturbance (fire, pests etc.) are not sufficiently understood, although TERI projects have begun to address these issues (e.g. illustrating that the magnitude of fluxes is clearly linked to climate variables). DON remains the most important dissolved N compound in many soils (e.g. boreal forests). DON compounds range from very mobile to immobile; this is omportant for N availability (transfer of N from one part of an ecosystem to another). At present little is known about DON characteristics, DON transport and DON decomposability/uptake. **Priority is high**.

Note: WG-5 recognises, and wishes to emphasise, that SOM pools also play a major part in determining the physical properties of soils such as structure and resistance to erosion, and the complexation of contaminants (e.g. heavy metals). In addition, soils and SOM provide a major, and poorly quantified, reservoir of biodiversity, across a broad array of taxa.

c. Carbon and nitrogen dynamics in plants

(1.) Whilst there are initial data (including recent advances made in the CANIF project) to suggest that canopy uptake of nitrogen is a key process under certain circumstances, there is an urgent need to identify the importance and distribution of this pathway for N assimilation. **Priority is high**.

(2.) There is a need to identify root uptake of different nitrogen species; how this changes in response to drivers and how this affects the impact of nitrogen deposition on vegetation and soils. TERI projects have begun to identify a potential north-south gradient in utilisation of different nitrogen species (in relation to N deposition from the atmosphere and major climatic gradients). **Priority is high**.

(3.) There exists a significant body of information on the impacts of key drivers such as climatic change, atmospheric deposition etc. upon assimilation of carbon at the leaf, whole plant, and canopy level, across a range of terrestrial ecosystems, principally at the plot scale. There remain uncertainties in the longer-term impacts of such drivers upon the subsequent partitioning of both carbon and key nutrient species. **Priority is medium**.

d. Storage of C and N in terrestrial ecosystems

(1.) Recent studies have indicated that the potential increase in carbon sequestration in temperate forest ecosystems in response to nitrogen deposition may have been overestimated. Further studies are required in other ecosystems (grassland, boreal forest, heathland, tundra peatlands). For example vegetation extension in the high Arctic and Alpine areas is likely to increase carbon sequestration through increased plant biomass and accumulation of soil organic matter. Increases in grazing pressure will tend to reduce sequestration. In contrast the large stores of carbon in wetlands may change from being carbon sinks to sources through increased decomposition rate. This response could be exacerbated by 'improved' drainage or by forest establishment upon these peat sites. Interactions of carbon and nitrogen at the ecosystem scale remain poorly characterised in many semi-natural ecosystems. **Priority is high**.

(2.) A number of key global and EU policies will have direct and immediate impacts upon C and N fluxes plus storage in managed ecosystems. Land use, climate change & atmospheric deposition will also impact on and interact with C and N storage. The longer-term dynamics of adjustments in C and N fluxes and reservoirs in response to land use change remain poorly defined. Information on site history and system dynamics during the past (across a range of timescales, from decadal to millennial) can provide valuable insight into rates of change and baseline stability of C and N pools. **Priority is high**.

12. *<u>Issue 2</u>. How can ecosystem research achieve the level of spatial, temporal and process integration required to support policy formulation and how is TERI research providing necessary understanding and data?*

By providing relevant data on C and N cycles at the appropriate scales of resolution.

By using empirical data to develop process-based models to upscale in space and time.

By using these models to assess scenarios of rapid environmental change, to assess potential policy scenarios and to assist in the formulation of mitigation strategies.

WG-5 has identified and assessed current issues that underpin the level of integration required to provide best advice for policy formulation associated with C and N cycles.

a. Spatial integration

(1.) Spatial data-sets at appropriate scales of resolution and protocols for their integration. Although within the TERI framework a series of spatial data-sets of different scale and resolution has been collected, there remains the requirement for the provision of a range of spatial data-sets relevant to C and N cycles. **Priority is high**.

(2.) Standardized methodologies for integrating landscape scale issues with regional, national and inter-national policy formulation. This was not planned as a central focus for TERI activities, although some progress has been made towards the provision of relevant methodologies. **Priority is medium**.

b. Temporal integration

(1.) Temporal data sets at appropriate scales of resolution. To date TERI has provided data at sub-annual to triennial timescales; integration with palæo-ecological sequences and other long term monitoring is allowing the analysis of longer time-series. Efforts in this area need to be continued. **Priority is high**.

(2.) Decadal to multi-decadal manipulative experimentation and observation that matches the development rates for C and N processes e.g. SOM turnover. TERI has established manipulative experiments which, if maintained, have the potential for developing decadal to multi-decadal time-series. **Priority is high**.

(3.) Improved understanding of inter-annual and longer-term variability through experimentation, observation and modelling. TERI has only addressed inter-annual and long-term variability where monitoring data-sets have been made available from independent sources. This work needs to be extended. **Priority is high**.

c. Integration of Processes

(1.) Assessing the linkages between processes regulating C and N fluxes in relation to multiple policy issues. The strategic importance of this issue has only recently been recognised. Consequently, no TERI project has directly and systematically undertaken research in this area. **Priority is very high**.

(2.) Investigating the effects of combinations of drivers (climate change, land use change and atmospheric composition change). Although TERI has undertaken research into the combinatory effects of drivers on N and C processes, the complexity of the processes involved and the range of conditions under which interactions can occur is as yet not adequately understood. **Priority is high**.

(3.) Gathering of more information on natural and semi-natural systems to match current levels of understanding for managed systems. This imbalance has long been recognised; TERI research initiatives have been undertaken but fall short of redressing the balance. **Priority is high.**

(4.) Integrating abiotic and biotic C and N processes with foodwebs and foodchains above and below ground in order to achieve a full comprehension of the functionality of relevant ecosystems. TERI has undertaken research in this area, but the complexity of the processes and the range of organisms involved falls well short of this target. An important missing area is an adequate understanding of how the different trophic levels interact in different systems and of how higher trophic levels such as vertebrate herbivores impact of C and N cycling.s e.g. impacts of vertebrate herbivores. **Priority is medium**.

(5.) Integrating biodiversity, including genotypic and phenotypic variability, with C and N dynamics. TERI has addressed this issue to a limited degree for some taxa. **Priority is medium.**

d. Methodological Integration

(1.) Standardized experimental protocols for inter-project integration. TERI has focused principally on intra-project standardisation, with some attempts being made towards inter-project integration. **Priority is very high**.

(2.) A minimum set of standardized, approved scenarios and baselines facilitating inter-project integration and inter-model comparison. This is a major challenge requiring collaboration and integration between the TERI research community and other programme areas. WG-5 strongly advocates the development of research priorities that address this issue. **Priority is very high**

(3.) Experimental networks which are representative of the range of conditions within the EU. TERI has addressed this issue through the transect approach to site selection; further integration is required to assess how representative the selceted sites are of the soils and climates of Europe. **Priority is high**.

(4.) Standardized modelling protocols for inter-model comparison. Although widely recognised as relevant in other programme areas, TERI has not addressed this issue. **Priority is high**.

e. Policy Integration

(1.) Coherency between policies addressing different environmental issues for C and N fluxes. It is apparent from TERI research findings that environmental issues are intimately linked; this requires the development of integrated and coherent policies which address the interactions. **Priority is very high.**

13. <u>Issue 3</u>: How can TERI initiatives be carried forward into Framework 5?

The matrix below details the Key Actions for two of the EU Fifth Framework Work Programmes, and the projects funded under the Framework 4 TERI initiative. The matrix highlights the potential impact that research leading directly from TERI activities can make to Key Actions so far identified in Framework 5:

RTD PRIORITIES:																				
ENERGY, ENVIRONMENT & SUSTAINABLE DEVELOPMENT:	ARTERI	BERI	BIODEPTH	CANIF	CLIMOOR	CLUE	CONGAS	DART	DEGREE	DYNAMO	ECOMONT	ETEMA	GLOBIS	GRAMINAE	LUCIFER	MAGEC	MEGARICH	POPFACE	PROTOS	SUITE
KEY ACTION 1: Sustainable management & quality of water																				
1.2 Ecological quality of freshwater ecosystems and wetlands																				
1.2.1 Ecosystem functioning	X	X					X												X	X
1.2.2 Ecological quality targets	X	X					X												X	X
1.4 Pollution prevention																				
1.4.2 Combatting diffuse pollution	X																		X	X
KEY ACTION 2: Global change, climate and biodiversity																				
2.1 To understand, detect, assess & predict global change processes																				
2.1.1 Atmospheric composition change	X	X					X			X				X		X				
2.1.3 Climate change prediction and scenarios	X											X								
2.2 Foster better understanding of terrestrial (including fresh water)...																				
2.2.1 Ecosystem vulnerability	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.2.2 Interactions between ecosystems and C & N cycles	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
2.2.3 Assessing and conserving biodiversity	X	X	X		X	X		X	X		X	X	X		X		X	X		
2.3 Scenarios and strategies for responding to global issues																				
2.3.1 Mitigation and adaptation to global change	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2.3.2 Reconciling the conservation of biodiversity with economic develp't	X		X		X	X		X	X		X	X	X		X		X	X		
2.3.3. Fighting land degradation and desertification	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
2.4 European component of the global observing systems																				
2.4.1 Better exploitation of existing data and adaptation of existing.........												X				X				
RESEARCH & TECHNOL. DEVP'T ACTIVITIES OF A GENERIC NATURE																				
I1 Natural Hazards																				
I1.4 Forest fires															X					
QUALITY OF LIFE AND MANAGEMENT OF LIVING RESOURCES																				
KEY ACTION 5: Sustainable agriculture, fisheries and forestry																				
& integrated development of rural areas including mountain areas																				
5.1.1. Sustainable agriculture:																				
Sustainable management of resources in agriculture:						X		X			X		X	X	X	X	X	X		X
Sustainable use of soil and water resources				X				X			X		X		X	X	X		X	X
Sustainable land management and conservation of biological diversity			X		X			X	X		X		X	X	X	X	X	X		
5.3. Sustainable and multi-purpose utilisation of forest resources.....																				
5.3.1 Multifunctional management of forests	X			X			X	X			X				X			X		
Improved criteria and indicators in particular at management unit level.....	X			X			X				X				X			X	X	
Understanding the functioning, diversity and stability of different forest	X			X			X	X			X	X			X			X	X	

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A number of TERI projects (BERI; CLUE; MAGEC) were unable to send delegates to the Durham meeting but have contributed by sending written contributions, for which the convenors are most grateful.

ANNEX TO WG5 REPORT:

ACHIEVEMENTS OF THE EC RESEARCH WITHIN, AND LINKED TO, TERI (WITH SPECIAL REFERENCE TO C AND N CYCLING):

The TERICA website (http://www.nbu.ac.uk/terica) and other working group reports have provided detailed information regarding policy relevance and the broader aspects of the achievements and value of the TERI approach. Here we detail the notable achievements of individual projects that have direct relevance to the issue of carbon and nitrogen dynamics within terrestrial ecosystems across Europe. The given aims of each project are those that are directly relevant to Working Group 5 and are, in many cases, only a sub-set of the total.

ARTERI (Arctic and Alpine - EU Concerted Action; completed)

Aim: Provide a forum and focus for information exchange and collaboration. Identify future research priorities via consolidation of existing research. Drivers: climate change, CO_2 and UV-B, land use change in high latitudes, pollution and deposition patterns, impact on ecology, society and policy

Results: Series of international workshops. Future requirements identified as development of issues related in particular to changes in biodiversity, C and N dynamics, acid deposition. Links with human-environment interactions (e.g. Sami people). Support for inter-disciplinary research. Stimulated development of new projects e.g. DART and CONGAS

BERI (completed)

Aim: To study the effects of elevated CO_2 (MiniFACE) and N deposition on the competition between plant species in bogs, and the net exchange of CO_2 and CH_4 between bogs and the atmosphere (see Working Group 6).

Results: After two growing seasons, *Sphagnum* cover increased under elevated CO_2, whilst vascular plant cover decreased. Elevated N deposition showed opposite effects. A shift towards an increased *Sphagnum* biomass will increase carbon sequestration in European bogs, whilst a shift towards vascular plants will cause the opposite effect. CH_4 emissions tend to increase under elevated CO_2 treatments. Elevated anthropogenic N deposition may cancel the beneficial rôle of European bogs as sinks for carbon under elevated CO_2. This is the opposite to findings for forest ecosystems.

BIODEPTH (completed)

Aim: To develop theoretical model linking biodiversity, functional groups, population biology and ecosystem processes. To determine and quantify the effects of reduced biodiversity on key ecosystem processes and structural characteristics. To improve the capacity of ecologists to predict the consequences of loss of biodiversity for ecosystem processes from local to landscape-level scale.

Results: Loss of biological diversity may, in certain instances, impair ecosystem processes such that the ability to store carbon and nutrients is significantly reduced.

CANIF (completed)

Aims: Determination of C and N cycling in forest ecosystems utilising intensive site monitoring,

focussed upon acid soils; atmospheric inputs; biomass production; N and ammonia turnover in soils and fluxes; plants, fungi, microbe, animal flux, modelling.

Results: Effects of N deposition on tree growth; recent data shows only 5-10% of N in organic layer enters the tree. Plant-related and soil-related processes and link to diversity; link to diversity and functional components of certain fluxes. Considerable amounts (range is 15-42 % of requirement per year) of N enter the plant via the stomata, bark, cuticular absorption (foliar uptake) etc. Beech: atmospheric uptake my account for almost all of N found in leaf. Therefore there are differential fertilisation effects during the season e.g. leaf growth from atmosphere in the spring and soil N for stem growth in the summer. Mean residence times for carbon in pools integrated over the whole soil profile to calculate decomposition rates.

Process-model of interactions between N and C and flow between different components in the system and good validation results; future intent to extend modelling programme to larger scales.

Diversity: very complex issue across the spatial scales due to changes in the composition of the soil microbial fauna and this impacts on how plants will adapt to satisfying N requirements; therefore the role of food webs and chain is fundamental across geographical areas in determining how N is taken up.

This in turn may affect species composition, but there is no clear cut understanding of whether structure is a function of diversity or *vice versa*.

CLIMOOR (ongoing)

Aim: To determine the impact of drought and elevated temperature on the functioning of shrub-dominated ecosystems (organic matter turnover, C allocation, species composition, drainage water quality, and gaseous losses)

Results: 1 yr. of experimental data with no manipulation (therefore baseline data).

CLUE (completed)

Aim: To study the effects of community complexity (of both vegetation and soil (micro)organisms) on ecosystem processes and vegetation dynamics on former agricultural, set-aside, land. To examine if the complexity of the community on set-aside agricultural land can be enhanced artificially by increasing plant species diversity. To examine if, and how, a stepping stone approach may be used to enhance the colonization of the soil of set-aside land by soil (micro)organisms of expected/desired successional stages.

Results: Increasing natural biodiversity of plant and soil organisms on set-aside or ex arable land enhances carbon storage and ecosystem development.

CONGAS (ongoing)

Aim: To investigate the biological, physical and chemical controls on CO_2 and CH_4 exchange in northern wetlands (c.f. Working Group 6). Special emphasis is placed upon on the interaction between wetland plant production and CH_4 emission at a variety of scales. A central concept in the study is to work at the interface between different scales of studying trace gas emissions in an attempt to integrate process oriented mechanistic understanding of the controls on trace gas production and consumption with landscape and larger scale modelling of ecosystem/atmosphere exchange of greenhouse gases.

Results: Early stages of field manipulations have been completed. A wet (minerotrophic if possible) and a mesic/dry (ombrotrophic) surface has been selected at each site. The basic experiments are of CO_2 and CH_4 flux and soil water concentration response to reduced availability of light (lowered photosynthesis). The monitored environmental parameters and fluxes/concentrations in the control plots will be subject to a detailed across site analysis of factors controlling the flux rates. These results are a component in attempts to produce a European-wide source-sink budget for carbon.

DART (ongoing)

Aim: To understand how responsive and resilient the birch forest, notably the position of the birch/tundra ecotone, is to environmental change (both climate change and land use pressures), and to determine the relationship of environmental change with some major foodwebs (e.g. ungulates).

Results: Started April 1st 1998 and will run for a period of 4 years. Principal manipulative treatments applied and monitoring facilities installed 1998-9. Baseline data collected.

DEGREE (completed)

Aim: To understand inter-relationship between biotic diversity and functional diversity in response to climate change. To provide parameters for whole ecosystem models (changes in N, soil N and ammonia in soil and relate these to changes in diversity). Impact of climate change on nematode diversity and effect on N balancing.

Results: No correlation between nematode activity, microbial parameters or N pools in organic soils.

Correlation between nematode activity, microbial parameters or N pools in sandy soils.

Microbial activity correlated with size of N pools in soil. Direct effect of nematode activity on soil N balance. Nematofauna affects N balance in sandy grassland soils, both by N extraction and indirectly, via microbial activity. N availability in grasslands reflects the activity of indigenous nematofauna. An indication of changes in nematode taxonomic and genetic diversity across soil types assessed.

DYNAMO (completed)

Aim: To assess the single and interactive effects of three dominant environmental driving variables on biogeochemical cycling in natural terrestrial and aquatic ecosystems, using a modelling approach. The three drivers are: acidic deposition, global change and land use.

Results: Extensive databases are available for the sites/regions selected for DYNAMO which enables the site response to be scaled up to a regional/landscape and river basin level. These data include regional or national surveys of the driving variables (acid deposition, land use change, climatic change) and of response variables (stream and lake chemistry, soil, forest growth and vitality). The driving variables considered in DYNAMO have changed either 'naturally' or by large scale manipulation experiments which include projects in Risdalsheia, southern Norway and Aber, north Wales.

ECOMONT (completed)

Aim: To investigate which changes in the canopy structure occur due to land-use changes in agricultural and forestal Alpine ecosystems along a South/North research-transect across the Eastern Alps and how these changes affect the exchange processes with the atmosphere; to understand the influence of land-use changes on soil organic matter (SOM) status and turnover, on biogeochemical (CO_2, N) and hydrological processes at the ecosystem level, and on the exchange processes between the ecosystems and the lower layers of the atmosphere; to extend this understanding to the landscape level by means of multimedia modelling activities.

Results: Determination of soil physical parameters (pore size distribution, bulk density, contents of clay and organic carbon). These parameters will be used for modelling of the soil water balance. Measurements of SOM status and turnover, and of plant available nutrients in the soil.

ETEMA (completed)

Aim: To develop a comprehensive modular modelling framework for the coupled dynamics of structure and function in natural and semi-natural ecosystems; to develop and test against the best available observational data a range of alternative model formulations for the subsystem modules: ecosystem-PBL interactions; ecosystem CO_2 and H_20 fluxes;

vegetation physiology and phenology; biogeography and vegetation dynamics; detritus and SOM dynamics; human impact and natural disturbance; to test the coupled system dynamics with data from long-term field measurements and experimental programmes (c.f. Working Group 7).

Results (in relation to Working group 5): Detritus and soil organic matter (SOM) dynamics subsystem is being developed. It will deal with the mainly-microbial decomposition and transformation of non-living plant material in various degrees of lignification, resulting from fine root turnover, litterfall and plant mortality. A wide range of time scales is involved, from subannual changes in detrital inputs (related to vegetation physiology and phenology) and N mineralisation rates, to century-scale changes in the slowest carbon pools. ETEMA has established links with the SOMNET project which has carried out comparative tests of SOM models. These tests have established that the well-known CENTURY model structure is still the strongest contender for our needs. However, process studies indicate that a cohort-based approach may be more realistic in the long run.

GLOBIS (completed)

Aim: To understand how decomposer communities will change under future constraints by studying the direct, indirect, cumulative and feedback effect of climate change and the related alteration of organic matter quality on biodiversity in forest soils. To identify and quantify the significance of biological diversity for ecosystem function (decomposition, C and N pools and fluxes) and how this will be altered under global change. To link this knowledge with projects dealing specifically with decomposition processes and ecosystem function (VAMOS, DECO, CORE, NIPHYS, MEDALUS II).

Results: The performance of complex animal and microbial communities under different climatic conditions and moisture stress has been measured (i.e. providing both essential information on environmentally sound management practices and strategies to counteract global change, e.g. by identifying sensitive taxa, processes and regions); An estimation of the role of different groups of organisms in the decomposition of litter in relation to detailed analysis of substrate quality (e.g. lignin and carbohydrate constituents) has been made. GLOBIS provides evidence that strong responses of soil processes and biota to anthropogenic forcing (climate change, air pollution) may significantly alter quantity and quality of soil organic matter. This is important for the long-term sustainability of the soils carbon reserves impacting agri- and silviculture, air and water quality as well as dispersion of toxic substances.

GRAMINAE (ongoing)

Aim: Assessment of ammonia exchange with grassland across Europe.

Comparison between intensively managed grasslands vs. semi-natural grasslands and changes in atmospheric ammonia exchange (emission, deposition etc.).

Results: Project started in October 1998. Increase of continentality expected to result in longer atmospheric residence times of ammonia. Development of inputs to transboundary models underpinning UNECE protocol agreements. Development of SVAT models for ammonia, which provide input into the long-range transboundary models. Scenarios of fluxes of N and C cycling and input into larger scale models. Coupling of models with long range transport models to address policy issues and recommendations (see also report of Working Group 6).

LTEEF-2 (ongoing) (guest project from wider EC programme)

Aim: Assessment of the global carbon cycle in Europe. Is there a net sink in forests? Process models with associated C balance sub-models, are being evaluated at the site level. Regional impact assessments are also being carried out with different climate change scenarios. Determination of effects of forest product removal on C balance.

Results: Variety of upscaling methods are currently being tested. Scenario development in relation to climate change is also being developed. The lack of available data on soil organic layer is being solved by equilibrium runs of process-based models. Nesting of spatial models to develop estimates of Net Primary Productivity (NPP) and of Net Ecosystem Productivity (NEP).

LUCIFER (completed)

Aim: To measure postfire flows of soil, water and nutrients from a burned landscape (watershed) and from the patches of the system, and relate these to the characteristics, and their spatial variability, of factors (soil quality, etc.) potentially affecting such flows.

Results: Increased fire occurrence leads to resource depletion, increases soil and soil nutrient losses and reduces biodiversity. C sequestration is reduced.

MAGEC (ongoing)

Aim: To assess the likely impacts of changes in climate, atmospheric composition, land-use and land-management on agricultural ecosystems at local, national and European scales. To provide modules of the soil / plant system predicting agro-ecosystem CO_2 , water and energy fluxes covering the subsystems: vegetation physiology and phenology, and detritus and SOM dynamics. MAGEC provides a description of processes directly analogous to those provided by ETEMA for natural ecosystems, but MAGEC describes these for agro-ecosystems.

Results: Project has run now for 1 year. Two products are being produced: 1) an agro-ecosystem module (soil, arable crop and grassland) consisting of code for incorporation into the ETEMA framework, and 2) a stand-alone MAGEC agro-ecosystem module that can be coupled to spatially explicit datasets for evaluation and use separately from the ETEMA framework. Information will be provided that will allow assessment of the critical interactions between C and N in scenarios of land-use management and change; critical to this is an understanding of how greenhouse gases are impacted by N management (and deposition).

MEGARICH (ongoing) (guest project from wider EC programme)

Aim: Investigation of interactions between CO_2, rainfall, temperature and management practices (nitrogen application and cutting plus grazing) affect the carbon and nitrogen balance of grassland ecosystems plus the sequestration in soil organic matter.

Results: Key outputs will be assessment of present rates of carbon storage in European grasslands, what happens to rates of C storage under climatic and land use change. Variation in C storage over different grassland types across Europe.

PROTOS (completed)

Aim: Determine the effect of natural climatic variation on concentrations and fluxes of dissolved organic matter (DOM) in forest ecosystems

Results: Production of DOM occurs largely in the surface layers (L and F) of the forest floor. Laboratory studies suggest that decomposition of soil organic matter in boreal forests is rather sensitive to temperature variations. By contrast decomposition processes in temporate and Mediterranean forests seem less temperature sensitive. Concentrations of DOC and DON show a strong seasonality with highest concentrations in autumn and lowest concentrations in spring. At the Spanish Navasfrias site there is no permanent litter layer and much of the litter is decomposed (and DOC is produced) in winter and spring. Adsorption in the mineral soil accounts for a strong reduction of concentrations and fluxes of dissolved organic matter. Concentrations and fluxes of DOC and DON in streamwater are positively correlated with discharge. Temperature explains little of the residual variance of DOC and DON concentrations in runoff. The annual adsorption of DOC in the mineral soil is of minor importance compared with the net C sequestration in the systems investigated. By contrast, dissolved organic nitrogen fluxes are a significant component in the N cycle of N-limited forests. 14-C (bomb carbon) is used as a powerful tracer to follow carbon moving through different pools in the forest ecosystems. In PROTOS we are developing a model to describe transport of DOC and DON in soils as well as the transfer of these compounds to surface water. The model incorporates simplifications of the parameterised equilibrium model WHAM. Currently, the model is parameterised for the investigated sites.

TERICA Working Group 6:
Trace gas fluxes and ecosystem functioning.

Report of the Working Group meeting 13-14 January 1999, ITE Edinburgh, UK.

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1. INTRODUCTION

This report summarizes the scientific achievements under the TERI programme relating to trace gas fluxes and shows how the projects are providing information to underpin current and future European environmental policies. It considers both a) trace gas deposition as a disturbance of terrestrial ecosystem functioning and b) the role of terrestrial ecosystems in controlling trace gas fluxes, relevant for atmospheric budgets. The research approach is reviewed, highlighting the priority concerns that must be addressed to deal with the problems of regional air pollution and climate change. Finally, a new research structure is proposed to further improve the linkages and policy relevance of ongoing and future research.

As the TERI projects were supported in two tranches (1996-1999 and 1998-2001), many of the projects considered here are still ongoing. It is therefore important to note that the second tranch projects here report only initial results. These projects should also provide an important resource for linkages to new work in the 5th Framework Programme.

2. TRACE GAS FLUXES IN RELATION TO KEY ENVIRONMENTAL PROBLEMS.

Trace gas fluxes are linked to many environmental problems. These concerns are being addressed through the development of both national and international policies, which aim to minimize trace gas emissions and their impacts. The key themes are listed below, noting in brackets the relevant agreements, with the instruments of prime importance noted by *:

1. *Climatic change*: a) emissions or sequestration of the greenhouse gases CO_2, N_2O, CH_4, CFC's, HFC's, SF_6, O_3 etc., which cause global warming and b) aerosols (primary emitted and secondary formed), which have a cooling effect (1*, 2*, 3*, 4, 5, 6, 7).
2. *Effects of elevated CO_2:* direct effects of enhanced CO_2 include altered plant productivity (with the effects modified by atmospheric nitrogen deposition) and, potentially, species competition change in semi-natural ecosystems (1*, 2*, 3*, 4, 5, 6, 7).
3. *Acidification:* long-range transport of primary gases SO_2, NO_x, NH_3 and derivatives (aerosols, acid gases) leading to acidification of soils and freshwaters (4, 5, 6, 7, 8*, 9*, 10*, 11*, 12*, 13*).

[*] Working Group 6 Convenor

4. *Eutrophication*: long-range transport of reduced nitrogen (NH_x) and reactive oxidised nitrogen (NO_y) compounds (including NH_3, NH_4^+, NO_x, HNO_3, NO_3^-, HNO_2 etc.), leading to soil and plant community changes particularly in semi-natural ecosystems (5, 6, 7, 8*, 9*, 10*, 11*, 12*, 13*, 14).

5. *Regional ozone* and *particle formation*: through emissions of primary gases (SO_2, NO_x, NH_3, VOC). Peak concentrations of 'episodes' affecting human health, ecosystems, crops and forest trees (5, 7, 9*, 10*, 12*, 13*).

6. *Tropospheric chemistry changes*: through emissions of primary gases (NO_x, VOC, SO_2, NH_3) and formation of O_3, other photochemical products and aerosols, affecting 'background' levels to which the episodes add (5, 7, 9*, 10*, 12*, 13*).

7. *Toxic substances*: including the volatile toxic substances: Persistent Organic Pollutants, (POPs) and Polycyclic Aromatic Hydrocarbons (PAH), plus heavy metals such as Cd, Zn, Hg, Pb, Ni, Cu, which may affect ecosystems (5, 7, 8*, 10*, 13*, 14).

[1] UN Framework Convention on Climate Change - Kyoto Protocol
[2] UN Montreal Protocol
[3] EU Methane Strategy
[4] Helsinki Agreement on Forest Protection
[5] UN Biodiversity Convention
[6] EU Agenda 2000
[7] EU Habitats Directive (Natura 2000).
[8] EU Directive on Integrated Pollution Prevention and Control (IPPC).
[9] EU Acidification Strategy
[10] UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP)
[11] CLRTAP: 2nd Sulphur Protocol.
[12] CLRTAP: multi-pollutant, multi-effect 'Nitrogen Protocol' being developed.
[13] EU Air Quality Directive
[14], Oslo and Paris Commission (OSPARCOM) and Helsinki Commission (HELCOM)

The interactions between the different sources, issues and impact targets (receptors) are given in Figure 1, which is developed from Grennfelt *et al.* (1994). There are strong links between the primary emissions, issues and receptors, apart from the many feedbacks that exist (e.g. ecosystems as sources and receptors). It is important to realise that policies for other receptors/targets might affect ecosystems through these linkages. When focusing on ecosystems the main themes are climatic change, acidification, eutrophication, photochemical oxidants and toxic substances.

3. ACHIEVEMENTS OF THE EC RESEARCH LINKED TO TERI.

The work under TERI has strong thematic links with other EC programmes of the 4th FP, notably the Climate Impacts and Atmospheric Chemistry programmes. To illustrate these links, the following sections consider both TERI projects and example projects from these other programmes. Most of the TERI projects considered in detail here are from the second tranch: CLIMOOR, CONGAS, DART and GRAMINAE, with BERI being a first tranch project. The Climate Impacts programme is represented by LAPP and MEGARICH and the Atmospheric Chemistry programme by FOREXNOX.

Trace gas fluxes are also relevant to the CANIF, DYNAMO, ECOMONT, ETEMA and MAGEC projects of TERI. As projects focusing on developing models of ecosystem functioning and global change, DYNAMO, ETEMA and MAGEC consider a range of trace gas fluxes related to surface energy balance, carbon and nitrogen. CANIF and ECOMONT are experimental projects focusing on European forest and mountain ecosystems, respectively. CANIF has explored the links between forest C/N cycling and fluxes of N_2O, while ECOMONT has considered the response of water vapour, CO_2 and NH_3 fluxes to land use change in mountain areas. ECOMONT has addressed the scaling up from the plant to stand to landscape levels and has applied NH_3 exchange models developed in EXAMINE, a pilot project to GRAMINAE.

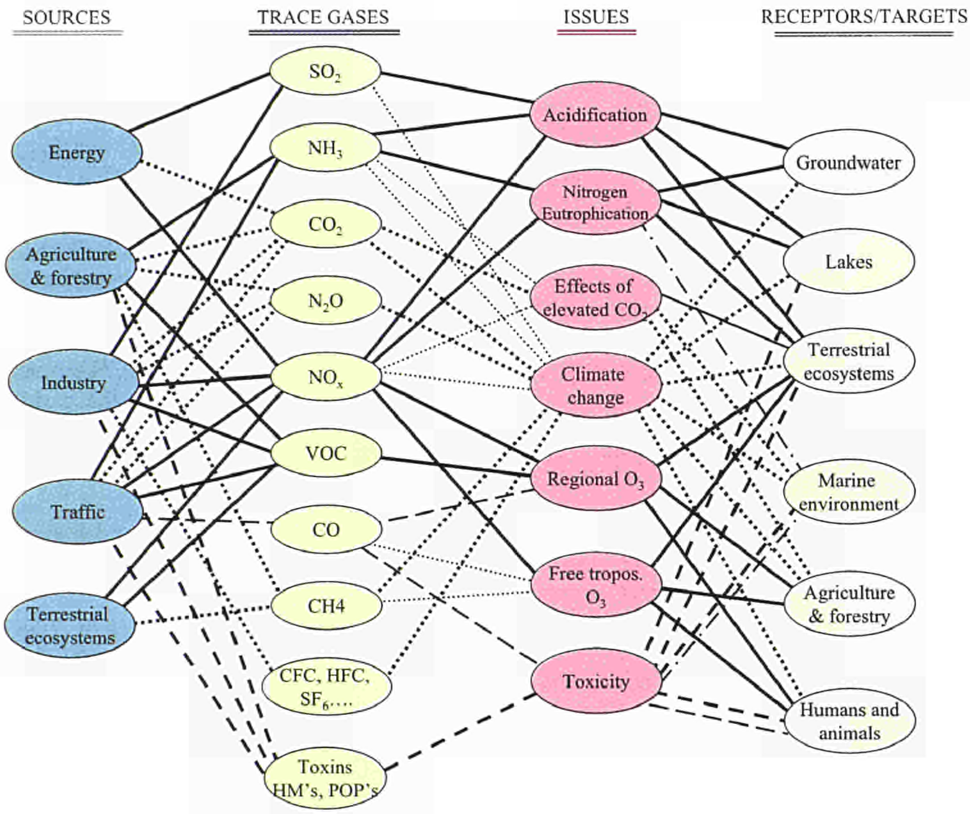

Figure 1: Conceptual linkages between the sources of trace gas (or particle) emissions, the environmental issues and the targets/receptors for which the issues are of concern. For simplicity only primary (emitted) pollutants are shown; a wide range of secondary trace gases and aerosols are formed through subsequent reactions. The different line styles represent the main policy structure dealing with each linkage. Some linkages are not clearly addressed by existing policies. In other cases, policy structures separate linked pollutants and effects, leading to potential conflicts.

——— UNECE CLRTAP: Multi-pollutant, multi-effect Protocol
.... UN FCCC Kyoto Protocol
– – – UNECE CLRTAP: Heavy Metals and POPs Protocols.
— — — EU Air Quality Directive
— · — · OSPARCOM and HELCOM
.... Policy structures not clear for these linkages

3.1. Scientific advances in understanding and quantifying ecosystem-trace gas interactions.

Radiatively active trace gases

BERI The Bog Ecosystem Research Initiative (BERI) studied, at five climatically different sites across Europe, the effects of elevated CO_2 (MiniFACE) and N deposition on: (1) the competition between plant species in bogs, and (2) the net exchange of CO_2 and CH_4 between bogs and the atmosphere. In general, after two growing seasons, *Sphagnum* cover increased under elevated CO_2, while vascular plant cover decreased. Elevated N deposition showed opposite effects, i.e. a decrease of *Sphagnum* cover and an increase of vascular plant cover. Because *Sphagnum* litter and peat are more resistant to decomposition than vascular plant litter and peat, a shift towards increased *Sphagnum* biomass will increase carbon sequestration in European bogs, while a shift towards vascular plants will cause the opposite effect. CH_4 emissions tend to increase under elevated CO_2 treatments.

CLIMOOR will determine changes in CO_2, CH_4 and N_2O fluxes in shrub-dominated ecosystems driven by scenarios of anthropogenic climate change. The project particularly emphasises both the many feedbacks between vegetation and soil and their implications for trace gas emissions, and the differential response across a European pollution and climatic gradient. The experimental approach emphasises realistic scenarios (e.g. winter warming) using a novel design which limits some of the problems often associated with field-based experiments simulating climate change.

CONGAS is in close collaboration with related EU projects (LAPP, BERI, DART, BASIS) operating with novel methods investigating CO_2 fluxes in relation to CH_4 production, transport and net emissions in northern wetlands. CONGAS is contributing to key advances in: a) the use of ^{14}C labelling of peat/live plant monoliths tracing C from the fixation as CO_2, through the plant-root-microbial system to the ultimate formation and release as CH_4, b) the use of comparable experimental techniques in the field (shading) for reducing the carbon flow, c) the application of technically advanced eddy correlation techniques for measurements of greenhouse gas fluxes at the landscape scale, d) integrative modelling of carbon cycling in relation to CH_4 exchange.

DART An objective of DART in relation to trace gas fluxes is to improve the mechanistic understanding of the implications of a shift in ecotone position for landscape and regional-scale CH_4 fluxes, soil processes and C reservoirs. The project will provide improved CH_4 and CO_2 flux estimates for, in particular, sub-arctic/alpine mesic tundra systems and upper mountain birch forest in Fennoscandia. This will be achieved via environmental manipulation experiments (temperature, snow cover and herbivory) along a latitudinal transect and, at individual sites, across an altitudinal gradient. The project will integrate field flux measurements, laboratory microcosm studies, GIS and remote sensing tools to predict how changes in ecotone position will affect source and sink strengths for CH_4 and CO_2 in the region.

LAPP has addressed the net exchange of CO_2, CH_4 and the partitioning of energy fluxes in Arctic wetlands. It has demonstrated from long term flux measurements that the annual net CO_2 exchange was positive (i.e. net emission) over a two year period. The magnitude of the emission flux (0.1 kg m^{-2} yr^{-1}) is of the same order as the net emission of CH_4 when expressed in equivalent units of radiative forcing. The data also quantify the links between the short term net fluxes and key physical variables (surface temperature, water table height).

MEGARICH, in relation to trace gas fluxes, uses Miniface and Solardomes to investigate how the interactions between components of global change (CO_2, temperature and rainfall) and management practices (nitrogen application, cutting and grazing) affect the carbon balance of grassland ecosystems and carbon sequestration in soil organic matter. For a NW-SE transect of representative semi-natural grasslands it will provide information on the feedback effects of climate change and management practices on CO_2 fluxes. Key outputs will include information on (1) present rates of carbon storage in European grasslands (2) what happens to carbon storage under climate change and land use change (3) how carbon storage varies with grassland type and sward composition.

POPFACE. The objective is to determine the functional responses of a cultivated, agro-forestry system, namely a multi-clonal poplar plantation, to actual and future atmospheric CO_2 concentrations and to assess the interactive effects of this anthropogenic perturbation with the other natural environmental constraints on key biological processes and structures. Additionally POPFACE will yield data to help assess the potential for increasing the carbon sequestering capacity within European Union, using such forest tree plantations. The project combines Free-Air CO_2 Enrichment (FACE) technology, with the study of mechanistic and process-based responses of a forest tree plantation. This model ecosystem, included within a FACE facility is being concurrently utilized by several European laboratories and institutions.

Transboundary pollutants

GRAMINAE: Ammonia exchange with vegetation is controlled by both biological and physico-chemical processes. GRAMINAE is integrating physiological and micrometeorological measurements of NH_3 exchange with European grasslands over a NW-SE transect similar to MEGARICH. The primary aim is to develop functional models of the exchange process for scaling up over Europe. A new bioassay is being applied to estimate the 'compensation point' concentration of plant tissues, which is the NH_3 exchange potential of the canopy. As part of integrated measurements, the work is quantifying component fluxes for plant canopies using multi-layer compensation point modelling and a novel inverse Lagrangian source-sink analysis. Measurements show that both cutting and fertilization substantially increase grassland NH_3 emissions. The coupling of fluxes and management practice indicate the need to link physiological ecosystem models to NH_3 exchange processes.

FOREXNOX: Fluxes of NO_2 above forest canopies have often been observed to be both upwards and downwards. FOREXNOX has shown that forests act as sources of NO_2 due to biogenic NO emitted from the forest soil reacting with O_3 mainly in the sub-canopy trunk space. NO emission from forests affected by high atmospheric nitrogen deposition in Europe is much larger than previously reported for temperate forests. FOREXNOX has shown that it is essential to quantify the interaction between atmospheric chemistry exchange processes and biogenic emission.

Both GRAMINAE and FOREXNOX have shown the need for integrated research covering physiological processes, atmospheric chemical reactions, exchange fluxes and modelling.

3.2. Contributions of the research to underpinning EC policies on trace gas fluxes and ecosystem functioning.

Radiatively active trace gases

Carbon cycling studies in TERI are addressing the problem of how anthropogenic climate change might affect European ecosystems and how these in turn might feed back on the radiative forcing of climate through possible altered exchanges of the greenhouse gases CO_2 and CH_4. Wetland ecosystems, for example, store significant amounts of carbon in peat (globally 200-300 Gt) and constitute a substantial natural source of CH_4. According to Article 5 of the Kyoto Protocol, the signatories are obliged to "develop methodologies for estimating sources and removal by sinks of greenhouse gases". TERI trace gas projects are aiming at producing integrated models of the dynamics of CO_2 and CH_4 fluxes in ecosystems validated against field data from a range of scales and sites across Europe and adjacent regions. The outputs will be tools for policymakers to assess the implications of different climate change scenarios regarding future effects on ecosystem radiative forcing and ecosystem functioning.

BERI shows how two major human impacts on European bog ecosystems may have opposite effects. Elevated anthropogenic N deposition may cancel the beneficial role of European bogs as sinks for carbon under elevated CO_2. This is opposite to findings for forest ecosystems. BERI has provided a carbon and nutrients model to a) evaluate and predict the effects of elevated CO_2 and N deposition on bogs along the European transects, and b) translate the findings into policy scenarios.

CLIMOOR will determine the magnitude and the relative effects of climate change scenarios on trace gas fluxes and thus feedbacks contributing to accumulation of greenhouse gases. Data will provide a valuable resource by which to test models developed within other projects such as CONGAS and DART.

CONGAS is showing that northern wetlands have a key role to play in how European ecosystems are contributing to the natural greenhouse effect. CONGAS will provide an integrative modelling tool for policy makers to assess how these ecosystems will respond to, and feed back on, anthropogenic climate warming.

DART addresses several key issues relating to the responsiveness or resilience of the mountain birch-tundra ecotone in Fennoscandia to climatic and land-use drivers. DART complements CONGAS and LAPP as it extends CH_4 and CO_2 flux measurements over a broader hydrological gradient and across a major ecotone in the far north of Europe.

LAPP demonstrates that extensive natural ecosystems in the European Arctic are net contributors to climate radiative forcing. The work has highlighted the existence of major inter-annual variability, although it is not currently known if this reflects natural variation or whether the ecosystems are already responding to anthropogenic climate change.

Transboundary pollutants

GRAMINAE: The detailed process understanding and models models of biosphere-atmosphere NH_3 exchange being formulated under GRAMINAE are providing a basis to develop generalized models for application into atmospheric transport models. Such transport models at a European scale are used in the negotiations of emissions ceilings in the UNECE Convention on Long-Range Transboundary Air Pollution. The current major uncertainties in European NH_x budgets demonstrate the need to parametrize and incorporate the new NH_3 exchange models to establish a reliable basis for protocol agreements.

FOREXNOX: A sophisticated multi-layer model was developed for research purposes, from which a simpler two-layer model was developed for inclusion in transport models. The chemical interactions identified are now being tested in a regional model describing O_3 formation. The finding that NO emissions modify the within canopy O_3 concentrations is also important, since this would have consequences for calculation of O_3 Critical Levels as applied in the UNECE Convention on Long-Range Transboundary Air Pollution.

GRAMINAE and FOREXNOX have demonstrated that detailed models are valuable tools for research purposes, and that these form the basis to develop generalized frameworks for application into policy analysis models.

4. SCOPE AND STRENGTHS OF TERI APPROACH FOR TRACE GAS FLUXES.

TERI has brought together a wide multi-disciplinary community of researchers to address the interactions of trace gases and ecosystem functioning. It has permitted the integration of physiological measurements, plot scale studies, field scale micrometeorological approaches, together with scaling up to landscapes and modelling over longer time spans and regions.

The TERI projects have provided excellent science, representing the leading edge globally in many of the trace gas issues being addressed (Section 3.1). While TERI was established to provide a coherent focus for global research activities (IGBP-GCTE, IGAC), the work on trace gas fluxes has also linked closely to other European research programmes and co-ordination activities. Among these are the EC Atmospheric Chemistry and Climate Impacts programmes (e.g. FOREXNOX, LAPP, MEGARICH, EUROFLUX, SREMP), as well as the EUROTRAC–BIATEX sub-project (BIosphere ATmosphere EXchange of pollutants and trace gases) and the COST 619 (Impacts of elevated CO_2 on grasslands).

TERI has led to the establishment of a series of transects addressing key climatic gradients across Europe relevant to trace gas fluxes. The transect approach has encouraged studies over the full breadth of European ecological and environmental conditions. By contrast, a constraint has been the difficulty to establish the full set of relationships between trace gas exchange and other processes controlling the functioning of European ecosystems. Although this has partly been achieved in some projects, logistic constraints have often limited the possibilities for TERI projects to utilize common measurement sites. Similarly, traditional funding cycles have limited the scope for long term ecological research (>5-10 years) and its linkage to ecological observing systems. Paradoxically, one difficulty in achieving integration in relation to trace gas exchange has been the ambitious approach of TERI to link a wide range of different ecological questions. In contrast, collaboration between TERI and other projects addressing shared *environmental problems* has been much more productive.

As stated in the TERI Science Plan (Menaut and Struwe 1994): "The objective of TERI is to improve the ability to predict the consequences of the interactive effects of changes in landuse, climate and atmospheric composition and physics…for European terrestrial ecosystems." As such the remit of TERI has focused on the link between global change and ecosystem functioning rather than directly developing policy responses. Despite this, many of the TERI projects concerned with trace gas fluxes and ecosystem functioning are providing the understanding necessary to underpin EC policies. Key examples are inputs into assessments and models under the Convention on Long Range Transboundary Air Pollution and the Framework Convention on Climate Change.

5. EMERGING REQUIREMENTS TO MEET THE CHALLENGES FOR SUSTAINABILITY OF EUROPEAN ECOSYSTEMS

5.1. Needs for new policy structures.

Most of the current European environmental policies are directed to one or two issues, as described for trace gases and air pollutants in Section 2. What is currently lacking in the existing agreements is an integration and interaction between different policies, e.g. environmental and agricultural policies. A step towards this in the field of trace gases is the current development of multi-pollutant, multi-effect strategies for controlling regional air pollution in Europe (acidification, eutrophication, photo-chemical oxidant formation) under the replacement for the UNECE 1988 Sofia Protocol for nitrogen oxides and the EU Acidification Strategy. Further integration is nevertheless needed to obtain a general nitrogen strategy in which all the nitrogen effects are addressed (acidification, eutrophication, aerosols and human health, global climate change). Another example is the conflict between the Acidification Strategy decreasing aerosols, which would otherwise have a radiative cooling effect relevant in the Kyoto Protocol. It is clear that future research in ecosystem-trace gas interactions needs not just to respond to the requirements of existing international agreements, but also to provide information for the development of new more integrated agreements that impinge on regional air pollution and climate change.

5.2. Future research approaches for trace gas fluxes and terrestrial ecosystems.

Given the experience of TERI and the need for integrating environmental policies, improvements should be sought in structuring the research programmes and providing better management tools. To maximise the research output and applicability, it is proposed to establish a horizontal structure where projects are grouped from the beginning of proposal development according to the key *environmental issues* (e.g. acidification, eutrophication, carbon sequestration). Within each issue, the following topics should be covered: i) process research, ii) translation into modelling, iii) scenario analysis and iv) monitoring. Integration and interaction across the issues should be ensured by integrating projects (e.g. integrated assessment, effects of land use changes). A preliminary structure for trace gas research is shown in Table 1. Once such a structure is established a pre-screening of project ideas (outline proposals) could provide a way to encourage collaboration and co-ordination at an early stage and make sure that the research needs are covered. Table 1 is completed here showing the activities covered under the existing 4^{th} FP. The many cross linkages between the existing programme areas demonstrate the need for a more problem focused approach with well established integration.

5.3. Priority research issues: Impacts of trace gases and air pollutants on terrestrial ecosystems.

Bearing in mind the need for a more problem focused and integrated research approach the following elements are identified as of priority concern in contributing to the broader picture.

Acidification: While reductions of sulphur emissions have been substantial over the past 20 years, NH_3 and NO_x emissions are anticipated to remain high. Furthermore, non-linearity in the relationship between S emission and deposition means that critical loads will continue to be exceeded for sensitive ecosystems. Long-term impacts in terrestrial ecosystems relate to base cation depletion, nutrient imbalances, alterations in CH_4 source and sink strengths and N_2O emissions. Future research should be focused on: base cation inputs from the atmosphere; influence of ecosystem processes on NH_3 fluxes and their implications for dynamics of S deposition; links between surface properties (e.g. land-use, phenology) and rates of acidifying deposition; the influence of acidification on CO_2, CH_4 and N_2O fluxes; identification of recovery indicators to allow an objective assessment of the success of ecosystem protection policy based upon critical loads.

Table 1: Structure of the EC research programme in relation trace gas interactions with ecosystem functioning. The table shows the research themes (across) intersecting with the environmental issues (vertically) according to the existing 4th FP structures. Notes: +, considered within TERI, - relevant but not considered within the EC programme; AC, considered within the Atmospheric Chemistry programme; CI, considered within the Climate Impacts programme; HD, considered within the Human Dimension of Environmental Change programme; NR, not relevant; QA/QC, Quality Assurance/Quality Control.

Themes:	Land use change	Model development & generalisation	Atmos. chem.-reactions & ecosystem surface exchange processes	Ecosystem impacts of trace gases	Socio-economic aspects	Integrated assessment	QA/ QC	Science / policy exchange
Global issues								
CO_2 balance	+ (CI)	+ (CI)	NR	+ (CI)	-	(HD)	+(CI)	(CI)
CH_4 emission	+	+ (AC)	NR	NR	-	-	+	+
N_2O emission	+ (AC)	(AC)	NR	NR	-	-	(AC)	-
Transboundary issues								
Acidification	+	+	+ (AC)	+	(HD)	(HD)	+	+
Reduced N	+	+	+	+	-	-	+	+
O_3	NR	-	(AC)	-	-	(AC)	-	(AC)
Aerosols	NR	-	+	NR	-	-	-	-
HM's & POP's	-	(AC)	NR	-	-	-	-	-

Ammonia: The current levels of NH_x in the EU are found to play a central role in many environmental problems, such as acidification, eutrophication, human health, radiative forming. European abatement strategies are currently being developed to minimize the acidifying and eutrophying effects. To support the development of these strategies key priorities are to quantify the fate of ammonia and the ecosystem feedbacks relating to fluxes. The fate of ammonia is uncertain both in relation to the consequences for soil acidification and vegetation responses, while the spatial scale of impacts needs to be addressed in relation to European deposition targets. There is an important need to improve the quantification of the functional ecosystem controls on NH_3 fluxes in order to develop links to management practices for semi-natural and agricultural ecosystems.

Ozone and other photochemical oxidants: Exposure of both natural and agricultural vegetation to O_3 in excess of the threshold for damage or yield reduction, represents a major air pollution issue for Europe. Elevated O_3 concentrations also represent a threat to human health over much of the Europe. The priority for research is to quantify the magnitude and spatial variability of the effects on vegetation and human health throughout Europe. To do this an improved understanding of the dose, exposure and surface fluxes of ozone is required.

Direct impacts of elevated CO_2: The impact on vegetation composition and carbon balance is difficult to assess beyond the transition phase with only a few years data. Multi-year long-term studies are needed toegther with full exploitation of existing facilities and development of models to integrate the complex feedbacks. Major (semi-) natural and agricultural ecosystem types should be investigated in a comparable fashion focusing on understanding the processes. This should lead to an integrated knowledge of how the direct impacts of CO_2 would change the carbon balance and stability in soil carbon stores at the landscape scale.

Heavy metals and POPs: The atmospheric deposition of heavy metals and POPs to terrestrial ecosystems is currently not well quantified. Particular attention should be given to establishing concentration fields and quantifying ecosystem dependent fluxes, in particular the contribution of dry deposition of heavy metals from long-range transport and local sources, including resuspension.

Interactions with ecosystem mineral cycling: Interactions with nutrients (especially N) in sustaining increased primary productivity and carbon sequestration at the ecosystem scale are important in interpreting the effects of trace gas fluxes. This exemplifies the need for consideration of impacts in relation to both above and below ground mineral cycling.

5.3. Priority research issues: The role of terrestrial ecosystems in controlling atmospheric budgets of trace gases and air pollutants.

Integration: Emphasis on measurements, and integration at policy relevant modelling scales is required both spatially (landscape & regions) and temporally (e.g. several forest rotations).

CO_2 exchange: Determination of long-term soil carbon turnover rates and an understanding of their climatic controls are needed to underpin quantification of CO_2 fluxes in different major ecosystem types in response to post-Kyoto commitments. Particular emphasis should be placed on the potential for mineral soils to act as a long-term carbon sink (decades to centuries). In addition, studies should address the potential for stored soil carbon to be released as CO_2 either through changes in nutrient cycles (e.g. nitrogen deposition), disturbance (e.g. fire) or land use change (e.g. agriculture to semi-natural systems).

CH_4 exchange: To support the EU methane strategy, quantification of sources and sinks of methane across different major ecosystem types is required together with integrative modelling at landscape to regional scales. Linkage between vegetation composition/ ecosystem functioning on CH_4 formation, transport and oxidation, as well as climatic controls on the long-term on net CH_4 releases will assist in predicting changes in fluxes for the future. Determining the resistance and resilience of key CH_4 producing ecosystems to increased frequency of extreme events particlularly soil water availability will be of particular importance together with the net effects of land-use change effects on CO_2 and CH_4 balances (e.g. bogs to forests).

N_2O fluxes: Quantification of sources and sinks across different major ecosystem types is required, in addition to an understanding of the controls on the relative proportion of N lost as N_2, NO orN_2O. This is necessary if current and future ecosystem feedbacks to nitrous oxide atmospheric budgets are to be calculated. Changes in net fluxes and nitrogen gaseous form in response to ammonia deposition, acidification, land use change and agricultural practices will also be required for future predictions to be possible together with development of process models applicable at the landscape scale.

Ammonia: In order to develop reliable transboundary atmospheric transport models used in the negotiation of emission control strategies (e.g. CLRTAP-EMEP modelling), it is essential to quantify NH_3 fluxes with the major European terrestrial ecosystems, including both semi-natural and agricultural land. Both experimental and modelling work are required to develop and integrate bi-directional flux models into the transboundary transport models. A key policy uncertainty is whether reductions in emissions are matched by equivalent reductions in deposition.

Biogenic emissions interacting with atmospheric chemistry: Research is urgently needed to quantify the conversion of reactive gases emitted from the vegetation or soil, such as NO, NH_3 and VOCs, both within and above vegetation canopies. These reactions may provide a key source for particle formation with implications on radiative forcing and modify surface exchange fluxes and budgets of compounds including NO, NO_2, O_3, NH_3, acidic substances, VOCs and the particulate derivatives.

Aerosols are the main means by which long-range transport occurs and provide the component of air pollution most closely associated with human health effects. Aerosols occupy a key role in radiative forcing of climate, both directly via altering the albedo and indirectly by influencing the optical properties of clouds. The priority research needs include quantifying a) anthropogenic, biogenic and chemical sources; b) the chemical specification and physical properties of atmospheric aerosols; c) the ecosystem specific sink strengths; d) the mechanisms and magnitude of particle production from gases emitted from vegetation; e) the long-range transport of base cations and heavy metals.

Heavy metals and POPs: There is growing evidence that certain heavy metals can be released from ecosystems by processes such as evaporation, resuspension, bacterial transformation and fires. A number of POPs originate mainly from agricultural activities with poorly quantified spatial distribution. Research is required to quantify the effect of ecosystem management (e.g. agricultural practice, biomass burning) on biogenic sources of both heavy metals and POPs.

Changes in land-cover lead to marked changes in the biosphere-atmosphere exchange of trace gases. Examples include the influence of a change from forest to grassland on the net input of reactive nitrogen trace gases (NH_3, HNO_3) and the consequence for other trace gases linked with N supply, or the net exchange of CH_4. Any land-cover change which influences the partitioning of energy or momentum will modify fluxes. The research priorities are to quantify the changes in trace gas fluxes which result from the major changes in land cover.

Models as tools for policy analysis: In order to make the link between research quantifying trace gas exchange and European decision making, it is essential that mechanistic measurements in future projects are directed to developing predictive trace gas models that can be applied for scaling up and use in policy models.

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Annex: Details of projects funded from outside of TERI.

FOREXNOX: European Forests as a source of nitrogen oxides: exchange of oxidants at the forest atmosphere interface (EC Atmospheric Chemistry research programme).

MEGARICH: Managing European Grasslands as a sustainable resource in a changing climate (EC Climate Impacts Research Programme).

LAPP: Land Arctic Physical Processes (EC Climate Impacts Research Programme)

SREMP: Surface resistance emergency measurement programme. (EC Atmospheric Chemistry research programme)

EUROFLUX: Long term carbon dioxide and water vapour fluxes of European forests and interactions with the climate system (EC Climate Impacts Research Programme).

TERICA Working Group 7: Understanding Ecosystems at the Landscape Scale

Potsdam Institut für Klimafolgenforschung, Potsdam, Germany
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1. EXECUTIVE SUMMARY

The landscape scale is the level where "local" interactions between ecosystems play a major role in determining their dynamics and hence their capacity to play the role that is intended for them in current land use policy, be it agricultural or forest production, recreation or the protection of natural resources (wildlife, water, biodiversity). At the landscape scale, ecosystem studies are difficult, since several aspects of complexity need to be studied at the same time. Most landscapes are heterogeneous and they are shaped by the history of land use and/or natural disturbance. Most land use decision making also affects landscape pattern directly. TERI research so far shows that landscape dynamics are not readily assembled by a summation of different landscape elements since, in most cases, interactions between landscape elements affect the overall aggregation. A basic outcome is also that we need to know much more about landscape processes before fundamental policy issues, such as source/sink capacities of ecosystems for carbon or nitrogen, or the protection of biodiversity or other ecosystem services can be managed in a sustainable way.

2. INTRODUCTION

2.1. Background and scope

The term "Landscape" describes a perspective on ecosystems that addresses both the complexity of the living world, and the use of biological resources by people. In the past, most ecosystem research has dealt either with larger areas of homogenous vegetation (planted even-aged forests, agricultural crops), where sufficient material for statistical analysis of plant-environment interactions is available (e.g., yield), or with interactions between organisms and their environment at the local scale of a very few square metres, where measurements and observations are relatively simple and (often) inexpensive. It has long been recognised, however, that, in comparison with the real world, these views of homogenous vegetation indeed represent a special case only. "Real landscapes" are composed of a broad range of ecosystems, they often show a high level of complexity that is created both by the natural environment and by human use, and the interactions between landscape elements are fundamental for their present conditions as well as for their susceptibility to change in the future.

The European environment is currently experiencing significant changes due to changes in socio-economic development, land use-related policy, atmospheric composition (CO_2, but also deposition of pollutants), and possibly rapid anthropogenic climatic change. Many economic sectors such as agriculture and forestry, tourism, water resource management, traffic etc. are directly affected by such changes, and in most cases the change manifests itself at the landscape scale.

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For example, changes in agricultural and forest productivity due to changing water availability do not affect the respective industry equally everywhere. Individual landscape elements (down to a few tens of metres in size) are affected differently due to the differences in their natural environment, as well as the differences in their relationship to surrounding landscape elements (such as the local rainfall pattern or the vicinity to an economic water source for irrigation).

Ecosystem researchers now increasingly recognise that it is both the spatial differentiation within landscapes, and the interactions between different landscape elements that need to be considered if the sensitivity of the ecosystem to (intentional or unintentional) change is the issue. Biodiversity for example, if measured as species richness, is controlled both by the sum of different habitats in a given landscape, but also by the richness of interactions between them, e.g., when small woody patches in an agricultural landscape provide shelter for animals that also use open areas for part of their diurnal cycle. If the sustainability of the European environment, its capacity to produce food and fibre, its diversity, and its intrinsic values for nature conservation, are central goals for future research policy, then landscape-scale processes must play a central role

2.2. Landscapes and landscape elements

As part of an operational definition for landscapes, we define *landscape element* to refer to a contiguous area of the land surface that, for the purposes of a given study and at any given point in time, may be regarded as uniform with respect to all physical, biological and sociological parameters relevant to the study. Parameters envisaged might include, for example, slope, aspect, soil type, vegetation cover and height, presence and density of organisms at various trophic levels, and land use. A *landscape* is then defined as a contiguous area comprising a mosaic of different landscape elements. Landscapes will thus (normally) be heterogeneous with respect to key physical, biological and sociological parameters, and there may be interactions between neighbouring elements and dynamism with respect to their boundaries. This implies that the values and time development of key parameters within any given landscape element will not, in general, be predictable without a consideration of the aggregate behaviour of the entire landscape.

2.3. Landscape processes

The most important processes specific to landscapes consist of interactions between landscape elements with respect to distribution and transfers of materials and energy between them. Such processes are not observable in studies focusing on spatial scales finer than the landscape, and have typically been ignored in studies at coarser scales, such as the region, or globe. Elements within a landscape may affect one another, for example, through transport of water, organic matter, soils or other materials from one element to another; through impacts of topography, vegetation cover and vegetation height on local climate; through dispersal of propagules or individual organisms from one element to another; through impacts on the frequency, intensity or likelihood of disturbances; through effects on soil erosion and other soil processes such as solifluction; and through impacts of different land uses.

Landscape elements may be linked by transport of water between them, as surface runoff, soil drainage, or via water channels (streams and rivers). Meso-scale climate and atmospheric chemistry will be affected by mixing, in the atmospheric boundary layer, of water vapour, CO_2 and other trace gases originating from different elements within the landscape. Other climatic interactions between landscape elements might include shading by mountains of adjacent valleys, topographic rain shadow effects, or wind speed attenuation by tall vegetation. Transfers of water, in particular, but also climatic and other interactions, may influence soil transport and changes in soil structure through erosion and other processes such as frost heave and solifluction.

Transport of plant propagules by wind, water, animal vectors or through vegetative growth facilitates changes in the vegetation composition of different elements within a landscape, or changes in the boundaries between landscape elements differing in vegetation composition. Changes in wild and domestic animal population densities due to migration between landscape elements affect the structure and dynamics of trophic webs, with concomitant changes in ecosystem structure and function.

Disturbances (natural and anthropogenic events causing a significant change in ecosystem structure) include fire, drought, wind-throw, harvesting, landslides, floods and grazing. Differences among landscape elements may influence the frequency and severity of disturbances; for example, clear-felling of a patch of forest may result in increased severity of damage during windstorms in adjacent patches; accumulation of litter or biomass cover in an abandoned agricultural field may increase the risk of fire to not only the field itself but also to surrounding land.

Landscapes are used in various ways, e.g. for agriculture, forestry, nature conservation, urban development and tourism. Socioeconomic and policy considerations, as well as natural values, influence the use to which a particular area of land is put. Land uses within neighbouring landscape units are not necessarily independent; for example, construction of a road (a landscape element) may render agriculture, forestry or urban development in adjacent areas economically viable or socially desirable.

2.4. Scientific relevance of landscape-oriented ecosystem research

In the past, ecosystem research has focused largely on local scales, at which landscape phenomena are not observable and may be regarded as external to the systems investigated. However, the existence of landscape processes (interactions among local ecosystems) implies that an understanding of the structure and dynamics of natural systems at regional, continental and global scales cannot be obtained by studies of local ecosystems alone. In contrast, a landscape approach takes account of the transfers of energy and materials that mediate links among relevant scales, from the individual, species population or biocoenosis, to the region.

2.5. Relevance of landscape-oriented research for sustainable development and decision making in Europe

Recognition of the importance of landscapes for the development of political priorities has led to a growing interest in land-cover and land-use changes. EU policy development emphasises the importance of regional and spatial planning issues (ESDP 1997, AGENDA 2000, UNCED Agenda 21, Natura 2000). Decision making in these areas will apply primarily at the scale of landscapes and regions. Research into the functioning of ecosystems at these scales will lead to improvements in fundamental understanding and will integrate issues and scales relevant to the major European environmental policy sectors of agriculture and forestry, tourism, transport, energy, water and other natural resources, and industry. It will also provide indicators of state and change, scenarios, and scientifically based decision support tools required for regional planning. Knowledge obtained through landscape-scale ecosystem research provides critical input into the planning process leading to sustainable development of European landscapes and regions.

3. METHODS IN LANDSCAPE-ORIENTED ECOSYSTEM RESEARCH

3.1. Observations and monitoring

Measurement records the static and dynamic properties of landscape elements, including: their spatial location and extent; their physical and chemical environment, both above and below ground; the structure and functional characteristics of the ecosystems that they support; the processes occurring within those ecosystems; the fluxes between components of those ecosystems and across their boundaries; and the interactions between landscape elements.

3.1.1. MAPPING AND GIS

The fundamental tool for analysing landscapes is the map, nowadays usually (but not necessarily) in the form of a digital geographic information system (GIS). Maps are defined by their scale which is related to the spatial resolution of mapped elements. The investigation of landscapes may require different scales in different regions, or for different problems – hence a "fundamental scale for landscape analysis" cannot be identified. Maps usually refer to some defined point in time. Trends through time can be conveniently displayed through maps as a time series, sometimes even with an electronic animation.

Maps may be the result of direct observations, from the ground, from aircraft, satellites or other platforms, or they may be the result of the application of some model to observations at a few points (as in most climatic maps) or to area-wide observations of some optical properties which are interpreted in terms of other quantities (such as satellite-derived land cover maps). GIS enables relationships between different aspects or layers within a map to be investigated and spatial models to be formulated.

3.1.2. GAS EXCHANGE

Techniques exist to directly measure the fluxes of gases (e.g. CO_2) between a (small) heterogeneous landscape (a few 100 m across) and the surrounding atmosphere, using towers and eddy correlation devices. Such measurements are important for the overall biogeochemical budget of ecosystems and they are unique since they represent a true aggregation of fluxes from different ecosystem types (Tenhunen & Kabat 1999).

3.1.3. HYDROLOGY

Water is another quantity which is measured as an aggregate across heterogeneous landscapes. The hydrological regime of a landscape is often studied using gauges or other sampling tools to obtain measurements of the flow of water and dissolved substances from entire catchments. Sediments and dissolved organic substances can also be measured and provide important indications of weathering, erosion and the overall nutrient balance. The results of these measurements can then be used to indirectly estimate the remaining parts of some budget (for example, evaporative loss of a catchment can be estimated by subtracting stream discharge from estimated total rainfall, once the different storage terms in the soil and in lakes and snowpack have been accounted for).

Disaggregation of water regimes in different landscape elements can be performed using local measurements of soil water status and fluxes. A chain of connected stream gauges can also be used to follow the movement of water through a larger catchment.

3.1.4. LATERAL FLUXES

Migration of species is a driving force for landscape invasion and post disturbance colonisation and measurements of these fluxes are carried out to understand the potential invasibility of species. Measurements of these parameters are quantified either by seed dispersal curves describing seed density from the seed source to the most far measurable distance, or as the seed rain occurring on a stand. Migration of small animals (insects, small mammals) can be studied by traps as for seeds but migration of larger animals is better studied by the capture-mark-recapture of individual animals as well as various telemetric methods including those using satellite-linked sensors.

3.1.5. REMOTE SENSING

Numerous satellites provide consistent and frequent coverage of the Earth's surface at a range of different scales, but increasingly with high resolution down to a few metres. They can therefore be used to quantify landscape heterogeneity directly (Wessman *et al.* 1999). Data derived from satellite-borne sensors also provide a widely available source of information to quantify spatial and temporal changes in vegetation and land use. Some variables can be directly assessed through remote sensing, such as the height of vegetation or the fraction of light intercepted by leafy canopies. Other variables can only be inferred, such as the seasonal rates of canopy photosynthesis.

Fires are now detected from satellites with increasing precision (e.g., Belward *et al.* 1994; Pereira & Setzer 1996). Analyses of sub-pixel fractional cover (i.e. spectral mixture analysis) provide spatial information on the patterns of tree and grass cover and their potential change over time with management pressures (e.g., Roberts *et al.* 1993; Wessman *et al.* 1997). With the launch of satellites carrying active radar or lidar the potential for obtaining better quantitative estimates of above-ground structure will greatly improve (Lesky *et al.* 1997). Once active sensors are in orbit, quantitative three-dimensional data sets will be available to verify predicted growth, harvest, and conversion rates of major types of vegetation to another life form or land use.

3.2. Historical reconstruction

3.2.1. THE HISTORICAL TIME-SCALE

Land use history is critical for present conditions in many landscapes, particularly in Europe but also elsewhere. Land use history is closely related to the socio-economic events which have occurred in the area. Variations in human population and resource use are important for understanding historical land use changes. However, the spatial distribution of those changes that describe the landscape, can be more difficult to reconstruct, at least for the period before the use of aerial photography. The oldest spatially explicit description of landscapes available nowadays are deduced from accurate reports or maps of natural resources used for the past collection of taxes. Cultivated and urban areas were the main descriptors of these maps, but interesting information on unproductive areas and woody resource are also available. Historical land use maps can be found back to the 17^{th} century.

For the last few decades, land use maps can be made more accurate and more detailed by the use of aerial photography. They can give mainly more information on the natural fraction of the landscape description. A particular interest is to add quantitative information to the previously described qualitative description of landscapes. Dominant species and their relative cover are of major importance for understanding, at the landscape scale, the dynamics of these natural areas, and their future potential behaviour.

The reconstruction of *natural disturbance* is more difficult to establish but is of major importance in understanding natural landscape dynamics. The tools mainly used for this reconstruction are administrative reports such as those from fire fighters, land managers or policemen. These can help to secure the timing of major events, but they often lack information about the extent in different parts of the landscape. The use of aerial photography can partially answer this problem but the frequency of this kind of data (> 10 years) can hide short term dynamics (e.g., in Mediterranean landscapes where the disturbance time return interval can be less than 5 years). Satellite remote sensing, in combination with aerial photography, may eventually provide a better tool for reconstructing disturbance events.

3.2.2. THE PALAEOECOLOGICAL TIME SCALE

The most relevant palaeoecological approach from the perspective of enhancing understanding of ecosystems at the landscape scale is that pioneered by *inter alia* Anderson, Davis (Davis *et al.* 1992; Frelich *et al.* 1993) and Bradshaw (Bradshaw 1988; Bradshaw & Zackrisson 1990; Bradshaw & Hannon 1992; Björkman & Bradshaw 1996). This approach uses sediments sampled from very small basins and mires that typically are < 20 m diameter and that in forest ecosystems lie beneath a continuous canopy. Such sediments record the history of individual landscape elements and can also be used to examine the longevity/stability and origins of present landscape patterns (e.g. Davis' studies of the origins of the present canopy mosaic in the forests of Sylvania). Although these sediments rarely span the entire Holocene, they often provide records extending over several millennia that can be sampled with fine temporal resolution, providing the temporal perspective needed to understand the dynamics of, for example, most forest ecosystems. Such studies are complemented by more conventional palaeoecological studies of the sediments of larger freshwater basins or mires; these provide the basis for integrated reconstructions integrated at landscape to regional scales.

Palaeoecological and palaeoenvironmental data sources include sub-fossil remains of organisms, morphometric data that can be collected from these remains, chemical and physical data that can be collected from these remains and/or the sediments in which they are preserved and other components of the sediments. These data sources can be used as the basis for reconstructions of:

- past environments: e.g., palaeoclimate can be reconstructed from many sources including tree rings, stable isotopes, invertebrate remains and higher plant remains; palaeohydrology can be reconstructed from sources including remains of plants and invertebrates in peats, remains of aquatic organisms in lake muds and minerogenic components of sediments.
- land-use history: e.g., forest clearance, forest management and agricultural practices can be reconstructed from palynological evidence; some forms of industrial activity can be reconstructed from pollutants, both inorganic and organic, preserved in sediments.
- natural disturbance history: e.g., forest defoliation episodes can be reconstructed from the palynological record and from invertebrate remains; epidemic disease/predator outbreaks impacting upon individual tree species can be reconstructed from palynological evidence; fire history can be reconstructed from the record of charcoal in combination with the palaeovegetation record; volcanic eruptions and the deposition of volcanic ash can be reconstructed from tephra grains found in sediments.

To be of greatest value, such reconstructions must be accompanied by geochronological measurements that provide the basis for an independent time scale. A variety of techniques is available, including ^{14}C for the time scale of the entire Holocene (last 10^4 yr), ^{210}Pb for the last *ca.* 200 yr and $^{137}Cs/^{241}Am$ as markers for atmospheric nuclear weapons tests and the Chernobyl nuclear accident, as well as dendrochronology and tephrochronology in appropriate circumstances.

3.3. Experiments

Smaller scale manipulative experiments make an essential contribution to studies of ecosystems at the landscape scale. Such experiments provide two general classes of evidence: firstly, they provide evidence of the response of individual landscape elements to experimentally imposed changes designed to mimic potential environmental changes including land-use changes, climate changes, and changes in atmospheric deposition of nutrients; secondly, they provide evidence of the consequences of these responses in terms of altered fluxes across ecosystem boundaries and hence changes in the interactions between landscape elements.

Some experiments have involved artificial landscapes which have been created from bare soil to mimic landscapes differing by the species diversity, their functional types composition and more recently the spatial pattern of communities. Testing the spread of disturbance in heterogeneous patterns, post disturbance regeneration and colonisation, community invasion and species interactions for resource use, has largely used this kind of manipulation.

Larger landscape scale experiments are difficult and expensive to carry out. A very small number have been attempted, among the most famous is the classical Hubbard Brook forest experiment where different catchments were treated in different ways with regard to logging practices. Such large scale manipulations and monitoring are, however, useful tools in attempts to understand landscape scale processes. A specific type of landscape scale manipulation are experiments such as CLIMEX (Beerling & Woodward 1994) where a small watershed is covered and supplied with different treatments for CO_2. Landscape processes are not, however, the primary goal of this experiment, but rather the response of a naturally heterogeneous patch of vegetation to different treatments.

3.4. Modelling

3.4.1. DOWN- AND UP-SCALING

Landscapes processes occur at different spatial and temporal scales. Methods of up- or down-scaling between these different processes and scales need to be developed if modelling of the landscape as a whole is to be successful. Most monitoring of landscape processes usually takes place at a point or a series of points. The information gathered can then be scaled up to represent a larger area. For example most vegetation models require some form of external driver (climate, soils, CO_2 etc). Data for such drivers are usually gathered at points, e.g. weather stations or field samples of soil moisture. These data are then scaled up or down for use within hourly, daily, monthly or yearly cycles in the model. Weather generators can be used for example to scale monthly data to hourly or daily values for use in modelling.

Information from point sampling can also be disaggregated or down-scaled; for example observations taken of water flow at points in a river can be disaggregated into a measure of runoff in the catchment. The most common methods for scaling are through linear interpolation and/or averaging techniques (e.g., Hutchinson 1995). The success of these methods to represent the process involved clearly influences the successful modelling of any landscape and its internal processes.

3.4.2. SPATIALLY EXPLICIT LANDSCAPE MODELS

Spatially-explicit modelling seeks to represent in a simplified form our understanding of ecosystems at the landscape scale. The modelling approach normally is hierarchical in both the spatial and temporal domains: in the spatial domain it integrates small scale within-element processes, landscape scale between-element processes and larger scale processes that act as drivers when viewed from the landscape scale perspective; in the temporal domain it will integrate responses to environmental drivers varying over time scales from hours and days through months and years to decades and centuries. Model development will utilise data from measurements/monitoring and from manipulations; independent data will also be used for model validation.

The complexity of landscapes is expressed through space and time as well as through the processes that operate within the landscape. Depending on the degree of resolution required it may be possible to capture fully or at least partially some of this complexity through modelling. Such modelling allows testing of hypotheses and the making of predictions of the effects of changes on the landscape and its processes. The choice of scale is influenced by both the questions being addressed and resources available.

Processes within landscapes are many and varied with some form of spatial interaction. Hydrological processes, for example, have both horizontal and vertical structure and operate on both short and long time-scales. Likewise vegetation processes within landscapes operate at different rates and can have both horizontal and/or vertical components. The fastest processes. as in the planetary boundary layer (PBL) interactions, soil moisture and heat fluxes maybe at the rate of minutes to hours. Intermediate processes can be expressed as days to months for example phenology and nutrient cycling. The slowest processes occur over periods greater than a year e.g. slow soil organic matter cycling and vegetation dynamics. Modelling different levels and rates of processes requires that information is passed for example as boundary conditions within the model, from one level up- or down- scale to other processes (Fig.1 illustrates, as a conceptual diagram from the development of the ETEMA model, how temporal and spatial scales may be linked in a landscape scale ecosystem model).

Some processes and drivers operate both within the landscape and between landscapes. Disturbances either natural or man-made are mainly horizontal in extent but do operate at different scales. Fire can for example have a local effect but can rapidly spread within the landscape and beyond. Propagule dispersal can occur both locally and regionally. Spatial modelling needs to take into account these more wide-ranging horizontal processes. The effects of land use can be incorporated into a landscape scale ecosystem model. This occurs conventionally in the form of an additional external driver which has impacts similar to a disturbance module.

3.4.3. REGIONAL APPLICATION OF LANDSCAPE MODELS

Heterogeneity within landscapes can often be great, regionally there may even be more complexity. Modelling different landscapes at the regional scale, e.g. at the European scale, at a sufficiently fine resolution to capture the heterogeneity is not at present feasible for extensive contiguous areas due to limitations in computing technology and limits to available high resolution input data. Instead a of sampling technique needs to be employed to reflect the types of landscapes that exist.

4. INTEGRATED LANDSCAPE RESEARCH

4.1 Levels of integration

Research at the landscape scale demands an integration of three distinct components, each of which also must be integrated at a lower level: the natural sciences; the social sciences; and the stakeholders. Within the natural sciences, ecosystem research at the landscape scale requires the integration of methods from many distinct scientific disciplines. Many influences upon ecosystems at the landscape scale relate to human land-use and other activities, however, demanding the integration of dialogue with the social sciences. Because anthropogenic factors influencing landscapes may be determined not only by landscape-scale considerations but also by regional and even global economic and other factors, the social science approach must encompass many sub-disciplines, ranging from those addressing local socio-economic factors to those addressing psychology and ethnology. The anthropogenic activities that impact upon landscapes occur within all of the principal sectors of activity within the EU (agriculture/forestry; tourism; transport; energy, water and other natural resources; and industry), leading to the need also for a 'transsectoral' integration of social science involvement. Given that a key application of ecosystem research at the landscape scale is to provide assessments of the ecological and environmental sustainability of the activities of these sectors, the involvement of stakeholders is essential. Here again, there is a need to integrate stakeholders both transsectorally and across a range of proximities of involvement with the landscape, from landowners and land managers, through tourists and other visitors, to regional decision makers and ultimately national and EC policy makers.

4.2. Integration within the natural sciences

In order to contribute effectively to improved understanding of ecosystems at the landscape scale, research projects must both be inter-disciplinary and generally will integrate measurements/monitoring, manipulations and modelling activities.

The modelling activity provides a framework for the integration of the scientific methods. The models to be developed should be capable of simulating the integrated response of the landscape as a whole to changes in the external drivers, both those that can be seen as changes in the environment, whether natural or anthropogenic in origin, and those that are changes in human management of the landscape and its components. Such models will provide the basis for integrated assessments of the landscape-scale impacts of scenarios of environmental and land-use changes.

4.3. Dialogue between the natural and social sciences

Amongst the drivers required by landscape-scale ecosystem models are land-use scenarios. The development of such scenarios is a research task for the social sciences. However, to be useful to the ecosystem modelling activity these scenarios must provide drivers in the appropriate form and with the required spatial and temporal precision and resolution.

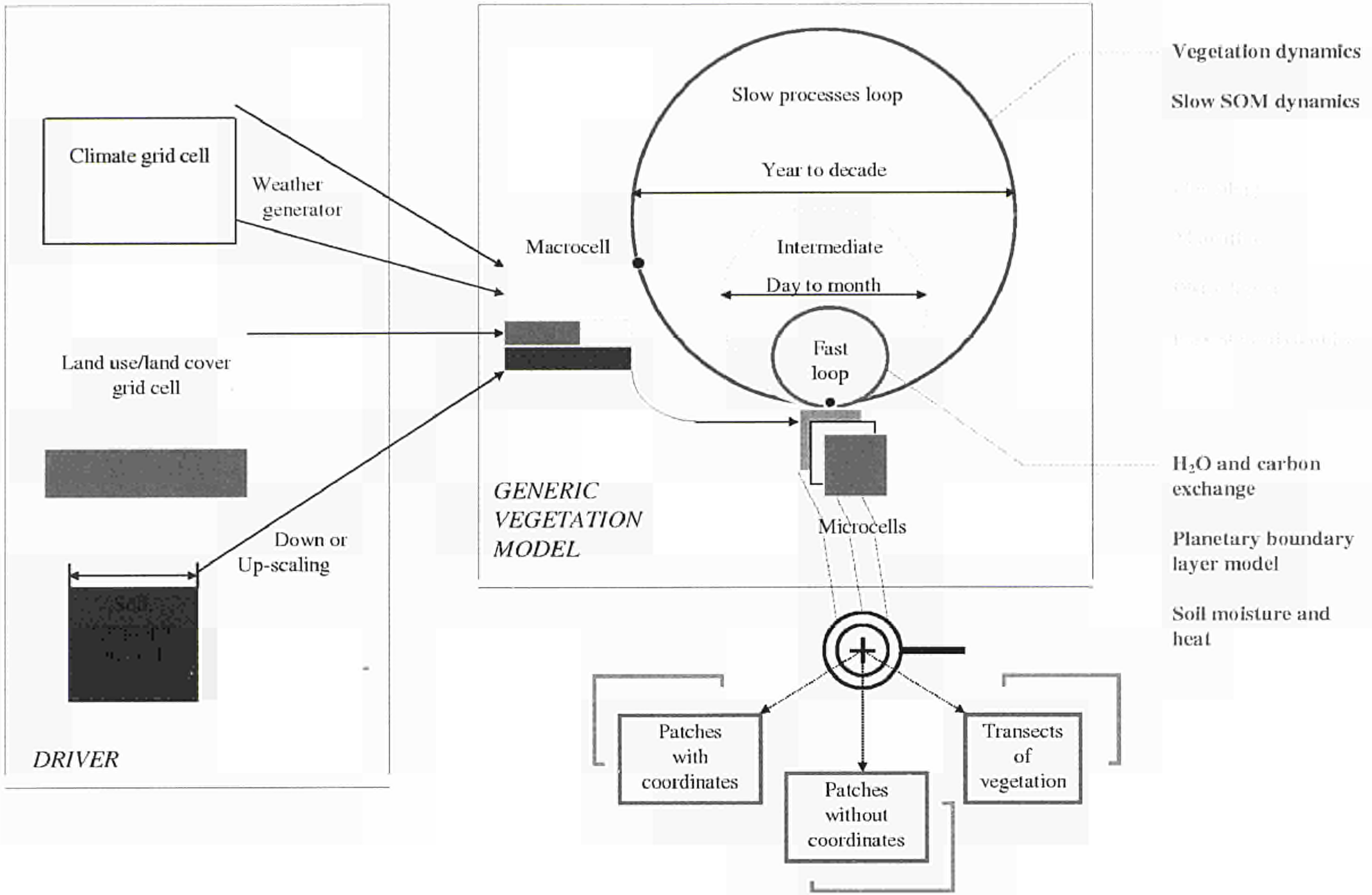

Figure 1: Illustrations of process descriptions at various time scales, and different spatial representations in the ETEMA model.

Thus, for example, it may be insufficient for the natural scientist to know that 25% of the forest in a landscape will be cleared in a given scenario, they may need to know which 25% in terms of its spatial location in the landscape. Ensuring that the appropriate information is provided by the scenario requires a dialogue between natural and social scientists working upon the same landscape.

In a complementary manner, the social scientists, as well as the stakeholders, often will require key indicators as outputs from the ecosystem model. Thus, for example, measures of the impact of a scenario upon biodiversity or the landscape carbon budget may be considered essential by EU policy-makers, whereas a social scientist concerned with local social conditions may be more concerned with impacts upon farm productivity that will require as indicators various measures of the performance of the agriculturally managed landscape elements. Social scientists and decision makers will also be concerned with perceptions of the landscape, for example in the context of tourism, and with non-monetary values placed upon landscape elements that may depend upon aesthetic qualities, for example the diversity of tall forbs with brightly-coloured flowers occurring in a meadow. Once again, a dialogue is essential in order to ensure that the needs of the social scientists and stakeholders in terms of indicators are addressed by the modelling undertaken by the natural scientists.

These dialogues also will serve to identify the extent to which each of the participating groups has unrealistic expectations of the others, as well as contributing to the identification of priorities for further research in the natural and social sciences.

4.4. Integrating stakeholders as participants in the development of research strategies

Whereas stakeholders generally will not directly formulate specific ecosystem research questions, nor design the research strategies needed to address these questions, their interests define the context for the research to be undertaken. Thus, for example, EU policy makers have a stake in biodiversity conservation because the EU is a signatory to the Convention on Biological Diversity; this defines a context in which a series of specific scientific questions can be posed relating to the impacts of various scenarios of environmental and land-use change upon biodiversity. In order that these questions be posed in an appropriate manner, and the results of the research be able to address the needs of the policy makers, a clear definition of those needs is required, along with a clear understanding by policy makers of the 'state of the art' with respect to the ability of the research to address these needs. The most effective approach to this general problem is through the integration of stakeholders as well as researchers into the process of formulation of the research programme. Only through the resulting dialogue between researchers and stakeholders will they understand each others needs and the limitations that they each face. This should result in research strategies that apply available methods to directly address problems identified by stakeholders, as well as in identifying where there are needs for research of a 'capacity building' nature. The latter research will initially be of a more fundamental nature, but will address the need to develop new techniques and approaches where these are necessary in order to undertake the more applied research that will address questions seen as priorities from the perspective of the stakeholders.

5. RESULTS FROM TERI PROJECTS WITH RESPECT TO LANDSCAPES

To investigate landscape-related research in TERI projects, a questionnaire was formulated and mailed to all co-ordinators. The questionnaire contained the following questions:

1. What are the key science findings in relation to "understanding ecosystems at the landscape scale" from your TERI project?
2. What are the key policy implications of your research in relation to "understanding ecosystems at the landscape scale"?

3. What are the priority policy/sustainable development needs that you envisage for the future?
4. What are the gaps in the current research?
5. What do you see as the priority needs for research in Framework 5?

The following table documents the responses made by all project co-ordinators.

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Project	Key science findings in relation to "understanding ecosystems at the landscape scale"	Key policy implications of your research in relation to "understanding ecosystems at the landscape scale"	Priority policy/sustainable development needs that you envisage for the future	Gaps in the current research	Priority needs for research in Framework 5
PROTOS	PROTOS addresses hydrochemical processes in different soil – vegetation types in watersheds with a focus on dissolved organic matter. There is a major emphasis on hydrochemical interactions between the terrestrial and the aquatic environment. The main is to quantify the effect of natural climatic variation on production and transport of dissolved organic matter in the terrestrial and aquatic environment of small forested watersheds. A key result is a hydrological sub-model for watersheds, including by-pass flow that was developed in another project is further refined. PROTOS contributes to a better understanding of water chemistry, in particular with respect to natural dissolved organic matter, at the watershed level. Processes at the level of soil – vegetation type will be integrated.	<u>Agriculture / forestry</u>: The role of forests in long-term carbon sequestration in soil humus <u>Energy, water and other natural resources</u>: Projections of concentrations and fluxes of natural dissolved organic matter in surface water in relation to climate change scenarios. Increased concentrations of dissolved organic matter represents a hygienic problem for drinking water production from surface water.	-	-	-
DYNAMO	DYNAMO aims to extrapolate understanding of ecosystem biogeochemistry at the site/stand level to the more complex landscape scale of the catchment. For example, there is strong European evidence to suggest that there is a potential breakthrough of N under forests in response to N enrichment, and this is controlled by the C:N ratio of the surface soil horizons. At a catchment scale where there is a mosaic of moorland and forest, do the same controlling mechanism operate, or is the spatial arrangement of landscape elements critical in defining the observed response in lakes and streams? Similarly what are the key ecosystem characteristics controlling responses and can these be extrapolated to other regions where data is poor, or where "surrogate" information may be available? DYNAMO has focussed on defining the required balance between model complexity and data availability, in order to resolve the desire for assessment at the regional and EU scale, whilst maintaining the most rigorous representation of ecosystem processes. DYNAMO has identified the impact of changing land use (forestation) on the "catchment "scale response to the impact of atmospheric deposition, through the signals contained in lake and stream waters. It has attempted to define the requirement for the spatial "splitting" or "lumping" of ecosystem responses.	<u>Agriculture / forestry</u>: Forestry may exacerbate the impact of atmospheric deposition. <u>Transport</u>: Enhanced production of NOx, will increase the potential for N enrichment of natural and managed ecosystems, leading to altered biogeochemistry. <u>Energy, water and other natural resources</u>: Climate change phenomena caused by enhanced CO_2 and Temperature will alter biogeochemical cycles in ecosystems. This in turn may lead to eutrophication responses, as the hydrochemistry of aquatic systems is changed. <u>Industry</u>: As fo Energy sector.	Emissions control legislation is extremely costly, and there is a requirement to identify appropriate levels, which allow for continued socio-economic development without compromising environmental and resource protection.	• Determine the interaction of global change and enhanced N on biogeochemistry of natural and managed ecosystems. • Determine the importance of spatial arrangement of landscape elements within catchment systems to assess the impact on aquatic resources.	

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ETEMA	ETEMA has produced simulation results which provide new insights as to the relevance of landscape scale processes to patterns at various scales, as well as solutions to the problems of incorporating landscape scale structure in regional-scale models. Results of simulations performed with a PBL flux model confirm the hypothesis that structural heterogeneity among vegetation patches within a landscape influences the horizontal distribution of atmospheric moisture and CO_2 concentrations. This demonstrates the importance of including horizontal structure, and a PBL formulation driven by such structure, in predictive models of ecosystem processes at the regional scale. A conceptual modelling framework has been developed, which permits linkage of landscape elements with respect to horizontal fluxes of soil moisture, migration of species or functional types between landscape elements, and disturbances. The modelling framework permits vegetation dynamics in different landscape elements to be constrained by differences in land-use.	European landscapes are highly heterogeneous with respect to land-use and vegetation structure. This is a result of a long history of human activity, locally variable topography and the existence at small spatial scales of mosaics of land uses (e.g. forests and crops) differing widely in structure, gas exchange and hydrology. High-quality predictions of vegetation structure and ecosystem fluxes are needed to provide guidance to policy makers and land users under global and European environmental change. There is a need for regional scale models incorporating landscape scale heterogeneity and land-use as boundary conditions to provide such guidance.	We envisage a demand for (1) models that can provide predictions of carbon sequestration, fresh water supply and biodiversity given different climate and land-use scenarios as boundary conditions; (2) interfaces between models of natural systems and predictive/ decision support tools for land utilisation.	• PBL model development. • Methodologies for scaling up and down from the landscape scale. • Models and observations of landscape-scale disturbance. • Flux observations at the landscape scale are required for model calibration and testing. • Long time series in vegetation structure development. • Predictive models and/or decision support tools for land utilisation, and techniques for linking such tools to models of natural systems.	See previous question.

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ECOMONT	Quantitative methods are developed to describe exchange processes and coupling between vegetation and the atmosphere as influenced within complex land use mosaics of selected landscape sections. Pools and fluxes for carbon, water, nitrogen, and other trace gases are defined at ground level in ecological surveys and with flux stations, with a landscape model, and as an integrated measure via aircraft measurements. The systematic studies along the vertical gradient led to recognition of new intermediate level advection phenomena influencing landscape level fluxes at the Monte Bondone test site. It was found that the spatial patterns determined for fluxes, for soils development, and vegetation exchange characteristics are much more dependent on land use history than on site climate factors. Transport modelling demonstrated that the effects of land use change on the Monte Bondone plateau are experienced 40 km distant at valley sites near Trento. Both increasing intensity of management as well as abandonment lead to decreases in biodiversity, while restoration of a species rich landscape is only possible with high labour input. Abandonment also leads to increase in potential risks of catastrophic events such as avalanches and erosion.	The studies demonstrate that traditional land use methods are important for the maintenance of the biodiversity, water balance, and stability of alpine grassland ecosystems. The studies have supported development of computer-based tools that can be used to generate land use change scenarios by utilising correlations describing the effects of stake-holder decision making processes in terms of landscape structuring, and subsequently landscape function. The implementation of these methods could be tested in the context of an Environmental Information-Decision System designed for the Cairngorms site in the Scottish Highlands. In this application, links between monitoring of ecosystem characteristics, evaluation of suites of ecosystem level indicators, and management decision making were established. Furthermore, results from the Kaserstattalm are being applied in the EU INTERREG II project to identify possible effects of land use change on potential risks due to torrents and avalanches in the valley of the Bachergraben. The city of Trento is interested in utilising tools produced in ECOMONT in order to assure a sustainable development of the recreation area at Monte Bondone. The EU research project SUSTALP is using the scientific results from ECOMONT in order to evaluate the effects of EU agricultural subsidies on the ecological functioning of mountain areas in Europe.	Policy needs to take into account the importance of high quality resources abundant in mountain areas (especially water).	It is necessary to focus effort on quantifying with measurements and as components of the models the effects of heterogeneity at the level of ecosystems and landscapes, especially the heterogeneity of soils. Both measurements and models must be conducted to determine fluxes for trace gases on inclined slopes. Light interception by vegetation established in such situations has seldom been considered in energy exchange and hydrological models. Methods for up-scaling from spatially distributed ground test sites to larger areas require a further investment of effort to 1) achieve better understanding of the topographic influences on advection phenomena identified at the Monte Bondone test site, 2) to achieve better recognition of landscape elements via remote sensing, and 3) to include biological acclimation phenomena that occur along the strong elevational and temperature gradients on mountain slopes.	Future research on land use changes in mountain areas should: • be trans-disciplinary and trans-sectoral and thus initiate a dialogue between scientists from the fields of human and natural sciences and decision-makers, practitioners and farmers in the conception, implementation and monitoring of research • consider implications of small-scale processes on larger scales by means of up-scaling • relate effects of changes in mountain areas to valleys • promote the definition and development of indicators of change and of sustainability suitable for application to monitoring • include the importance of the historical development of land use • consider effects of the heterogeneity typical for mountain areas on biodiversity and its effects on ecosystem processes • be directed to provide a sound basis for developing management plans which contribute to a sustainable development in the ecologically sensitive mountain areas

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LUCIFER	LUCIFER addresses aspects of landscape structure and spatial processes which may have driven changes in Mediterranean area. The main focus are the historical changes which have occurred in land use and consequently the landscape pattern. To understand the driving forces of theses changes, the reconstruction of the disturbance regime is of major importance. A particular effort has been made in the historical reconstruction at the landscape scale of this parameter. Field measurements for vegetation dynamics and lateral fluxes (water, seed dispersal, fire spread) were performed. A modelling approach was developed to synthesise and simulate these dynamics at the landscape scale. Particular efforts were made for remotely sensed identifications of fire shapes and vegetation maps. The modelling approach takes into account the particular case of resprouting species and the specific fire response of Mediterranean communities. It was built by using the disturbance response efficiency of vital attributes models and the biomass dynamics of functional models. Diversity was simplified by the use of functional grouping and individuals were aggregated into cohorts to permit large scale simulations	The main results illustrate the strong influence of land use history on the present pattern. Forested areas have expanded. Land abandonment has favoured the establishment of more flammable and water stressed species. This post abandonment invasion has created large homogeneous patches of fuel biomass. Coupled with old fire practices for land management, this has induced the occurrence of large fires on the areas. A vicious circle has been created on the shrubland community. This community promotes the spread of fire and conversely, successive fires maintain this community.	<u>Agriculture/forestry:</u> Land use changes in Mediterranean areas have considerably influenced the disturbance regime. It appears now that restoring landscape heterogeneity is of major importance for long term management of these areas. Fire suppression will not be a sufficient policy without landscape scale management. <u>Tourism:</u> No direct studies are concerned with tourism, but if we assume that tourism is can be related to landscape beauty, homogenisation of landscape in low maquis shrubland and burnt areas is not a gain of wealth in this context. <u>Energy, water, and other natural resources</u>: The reconstruction of fire history coupled with climate database can be largely related to flooding events at the watershed scale. Simulations of water processes at this watershed scale represents a practical tool for understanding this kind of events. Finding a compromise between the need of pasture areas and the spread of forests constitutes a major question which can be answered by a reasonable land use management.	• Long term information from birth to death of individuals on carbon and water budgets to understand the functional processes which drive population dynamics. • Finding a compromise in the modelling approach between vegetation/process complexity and realism to allow large scale simulation • Understanding fire intensity pattern and its influence on vegetation regeneration	Building a realistic landscape model will be useful to propose management scenarios, and show to local populations the wealth or the risk of these management proposals.
GLOBIS	none	-	This is a question for a 3 days workshop.	• How does landscape heterogeneity affect processes in individual elements? • Does management at the landscape level allow for a higher degree of sustainability?	-

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DART	DART investigates the dynamics of the forest–tundra ecotone in Fennoscandia. In particular, the project will result in insight into the likely extent of the spatial response of the tree line to climatic warming, the modulating effect of grazing upon this potential response, and the consequences of both climatic warming and the vegetation responses for soil organic matter mineralisation rates, soil trace gas fluxes (CO_2, CH_4) and hydrology. Our understanding of the ecosystem dynamics will be expressed in terms of an integrated landscape-scale model of ecosystem processes and hydrology. This model will enable alternative scenarios of climate and land-use (reindeer grazing) to be explored in terms of their consequences for the ecosystems, for biodiversity, for water resources and for fluxes of radiatively-active trace gases.	The policy implications of our research findings will relate to the EU commitments both to the Framework Convention on Climate Change (fluxes of radiatively-active trace-gases) and to the Convention on Biological Diversity (biodiversity impacts of ecosystem responses including potential tree-line advance into tundra areas). In addition, our results will have relevance to EU policies in relation to the indigenous Sámi people and their traditional way of life that is centred around the herding of semi-domesticated reindeer.	The key priority will be for more comprehensive integrated landscape models able to be used in a 'decision support' role by policy-makers and other stakeholders. These models will need to integrate modules that address biodiversity, trace-gas fluxes, soil processes and hydrology for landscapes comprised of elements that include natural, semi-natural and managed ecosystems. Drivers for these models will include scenarios of environmental change (climate, N deposition, etc.) and of land-use change, the latter derived from socio-economic models taking account of the demography of the human population, economic factors and policy issues.	Integrated landscape scale modelling is at an early stage of development. Key issues in relation to up- and down-scaling need to be addressed, as a do approaches to simulate landscape-scale processes. Such models are often constrained by the lack of spatial data sets of appropriate resolution, extent and consistency of recording. In addition, most present models address only the vegetation component. There is a need to develop the interface between natural science research, aimed at developing integrated landscape-scale 'ecosystem' models, and social science research, aimed at developing scenarios of land-use change and evaluating the policy implications of output from the 'ecosystem' models.	Research projects that combine measuring/monitoring of the present state of the environment and the ecosystems therein, at landscape scales, with experimental manipulations and the development of integrated models of those systems. Research projects that adopt a multi-trophic approach with respect to ecosystems. Research projects that address vulnerable landscapes, such as those in which key ecotones between structurally distinct ecosystems (e.g. the Arctic tree line!) are found, those subject to increased frequency of disturbance as a consequence of environmental or land-use changes, and those in which (semi-)natural landscape elements are fragmented.
MAGEC	MAGEC is intended to be applied to landscapes. Through the soil and land-use / land-management data the project indirectly addresses landscape structure. Other elements of the landscape, however, are not addressed, for example lateral water flows and surface hydrology. We are applying novel statistical methodologies which will allow us to define the appropriate level of model parsimony / complexity for a given process description at the landscape scale. New results: a) Landscape-scale projections of C and N dynamics in agro-ecosystems. b) impacts of land-use & management change at a landscape-scale.	Mainly agriculture / forestry implications but some bio-energy crops could be considered which would then impact upon the energy sector.	Accurate answers to the questions (see to the right) would allow policy makers to define the confidence associated with which model projections. The level of confidence or uncertainty associated with model projections is rarely quantified but is essential when formulating policy options and making policy decisions.	• How does model non-linearity affect model application at the landscape scale? • How are error propagated through the system when applying models developed for use at the small scale at larger spatial scales? • How complex do models need to be to successfully simulate ecosystem processes at the landscape scale?	

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GRAMINAE	The primary landscape interest of GRAMINAE is the interaction between landscape elements via atmospheric transport. We are addressing fluxes of ammonia with contrasting grasslands across an E-W European transect of continentality. The major comparison is between intensive grasslands and semi-natural grasslands. Ammonia impacts occur in many cases at the landscape scale, and GRAMINAE is therefore also addressing the sideways (advective) fluxes between sources and sinks. GRAMINAE shows the importance of atmospheric transport of ammonia between sources and sinks at the landscape scale. While atmospheric transport of pollutants is generally addressed with continental scale models, the work is quantifying how a substantial fraction of the transport occurs in at the sub-grid scale (<5 km to <150 km) of these models. The results also show how the spatial distribution of different landscape elements affects the extent of local recapture. This will have consequences on both local impacts and on scaling up to the regional level.	Currently, much of the European policy to reduce ammonia emissions and their impacts on sensitive ecosystems is based on modelling at a very large scale. While the work of GRAMINAE is feeding into the policy models used in the European negotiations, it is equally apparent that the variability at a landscape level provides important constraints on the likely success of the developed strategies. A key element is the spatial variability of emission and deposition at a landscape scale: the negotiations are based on targets to reduce the exceedance of critical loads thresholds at a 50 km resolution. The landscape variability implies that much more stringent reductions would be necessary to protect sensitive ecosystems in the agricultural landscape. The work suggests that current abatement policies for agriculture which focus solely on national targets are likely to be sub-optimal. In contrast, the landscape perspective also needs to be considered, particularly in managing the spatial relationships between source and sink areas. This indicates a need to integrate the issue of ammonia abatement in to agro-environment schemes.	To meet the nitrogen deposition targets, landscape interactions need to be increasingly fed into the modelling used in policy negotiations. For example, the local re-deposition of ammonia back to farmland may reduce impacts further afield, while there is a need to integrate better agricultural and environmental policies. • Using the landscape scale modelling would allow to consider different policy issues in a framework which integrates the different impacts of sector activities, e.g. effects of agriculture on: ammonia emissions and impacts, biodiversity change, greenhouse gas fluxes, etc. • In most cases there is too much separation between policies. On the other hand, integration is both complex and expensive. Quantifying the extent of the functional links at the landscape level will help to quantify the optimum level of policy integration. • Developing linkages between the different available models, would provide an important tool for policy evaluation in managing the environmental impacts of different sectors.	The consequences of different spatial interactions on net fluxes of a range of different trace gases, such as ammonia, nitrogen dioxide, carbon dioxide need to be addressed. In some cases, this may have a considerable effect on the net exchange budget. • How can the landscape focus be used to integrate issues of ecosystem functioning in relation to land management practices and their impacts? • What is the balance between integration of many issues and specific focus that is needed in future landscape modelling and analysis? Focus allows more depth, but misses the links between issues; Integration links different themes, but can lose the depth. • Can we integrate the different available modelling frameworks applied at a landscape level to consider the link between sector based activities, multiple component fluxes and the different environmental issues linked to these fluxes? • How can we use the existing landscape scale models to provide corrections to the simpler models that are used on regional, continental and global scales?	See previous question. Also: landscapes are critical level of integration of ecosystem functioning, since land management practices are implemented at a landscape level. There is a need across FP5 to provide a much clearer focus to integrate the different factors affecting ecosystems at a landscape scale. The modelling at this level would provide a connecting theme between many issues, such as trace gas fluxes, changes in nutrient storage, biodiversity and hydrology changes.

TERICA Working Group 8: Policy conflicts: solving one problem creates another – ecosystem and multi-sectorial perspectives

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1. BACKGROUND

Following the TERICA Working group in Toledo, Spain in April-May 1998 a document was produced, "Ecosystems Research and the European Union Environment Policy Needs" (Lawton et al., 1998), summarising among other things, future research needs. Under the heading of "The Complexity of Understanding and Managing Ecosystems in the Real World", three research priorities were identified, a) to understand ecosystems in the landscape, b) policy conflicts: solving one problem creates another, and c) developing scenarios to integrate diverse policy options. It is the latter two areas that were addressed in this working group.

A number of EU policy documents exist which are relevant to these issues. The EU document "Towards Sustainability" (also known as The Fifth EC Environmental Action Programme; European Commission, 1998a) outlines an EU environmental strategy and list a number of target sectors, themes, areas and policy instruments relevant to the integration of environmental policy into other policy areas. Another document "Partnership for Integration – A Strategy for Integrating Environment into European Union Policies" (European Commission, 1998b) expands upon "Towards Sustainability" by presenting guidelines for policy integration with particular reference to Agenda 2000 and the Kyoto Protocol. Most recently, a review of policy and action in relation to "Towards Sustainability" was published in October 1998 in the Official Journal of the European Communities (L 275/1-13; European Commission, 1998c).

From these documents it is clear that the EU have already taken many steps towards the integration of environmental policy into other policy sectors. The primary aim of Working Group 8 was to assess the contribution towards this integration made by TERI, and to examine how future research programmes / projects might better address policy conflicts within the environment sector and between sectors.

2. AIMS OF THE WORKING GROUP

Policy conflicts arise at many different levels. Ecosystems are subject to multiple stresses but policies in the past have often been developed in isolation for individual factors and for individual land uses. At the ecosystem level, there may be policies to promote ecosystem management that are beneficial from one perspective (e.g. carbon sequestration) but damaging from another (e.g. trace gas fluxes). Similarly, at the multi-sectorial level, there may be policies that are beneficial to Europe from one perspective (e.g. development of transport infrastructure), but damaging from another (e.g. loss of fragile ecosystems).

[*] Working Group 8 Convenor

Specifically the aims of the Working Group were:

a) to summarise the achievements of TERI in identifying, and suggesting ways in which to resolve, policy conflicts

b) to identify current and potential policy conflicts (with examples from TERI)

c) to identify other potential policy conflicts at the multi-sectorial level

d) to suggest a research framework within which possible policy conflicts can be identified and resolved

e) to suggest a framework within which agreed policy-driven scenarios could be formulated to allow optimal policy solutions based on research findings

3. BRIEF DEFINITIONS

In this report we concentrate on within sector and cross- or multi-sector policy conflicts. *Within sector conflicts* occur when a policy solution within a sector leads to conflicts with other policies within the same sector. *Cross- and multi-sectorial conflicts* occur when a policy solution within one sector leads to conflicts with policies in a different sector. The sectors considered are those target sectors listed in "Towards Sustainability" into which environmental policy is to be integrated, i.e. industry, energy, transport, agriculture and tourism.

4. ACHIEVEMENTS OF TERI IN IDENTIFYING, AND SUGGESTING WAYS IN WHICH TO RESOLVE, POLICY CONFLICTS

Working Group 8 is unique among working groups in that it focuses upon an area that TERI was never intended to address. This Working Group, therefore, focuses less upon TERI research and the new research priorities that have arisen from it, but focuses more on how future research programmes / projects might better address policy conflicts within the environment sector and between sectors.

Because TERI was not explicitly intended to address policy conflicts only a few TERI projects have identified potential policy conflicts, and none have (yet) attempted directly to solve these (Table 1). Most of those that were identified were within-sector policy conflicts, i.e. where one environmental policy was in conflict with another, although some can be regarded as bi-sectorial (agriculture and environment). One project (DART, last row of Table 1) has identified a number of multi-sectorial policy conflicts.

5. POTENTIAL MULTI-SECTORIAL POLICY CONFLICTS

It would be possible make a matrix that includes the impact of each policy sector on every other but this Working Group was concerned only with the interactions of environmental policy with each sector and not with other sectorial interactions (e.g. transport with agriculture, energy with tourism etc.). By way of identifying potential multi-sectorial policy conflicts, in Tables 2 and 3 we list some examples of potential impacts of sectorial policy on the environment (Table 2) and the impact of environmental policy on other sectors.

Table 1: Examples of policy conflicts identified by TERI projects

Project	Policy conflict
PROTOS	It is clear that changes in land-use policy have important implications for surface water quantity and quality. PROTOS has focused on the dynamics of dissolved organic matter in forested watersheds. In terms of the role of forests as a carbon sink the contribution of dissolved organic matter (DOM) runoff in the carbon balance should be considered. Afforestation, as one of the policy options to reduce the increase in global CO_2, may cause an increase in the concentrations of DOM in surface water. Increased DOM poses a hygienic problem for waterworks when producing drinking water. This causes a policy conflict between reducing greenhouse gas emissions and maintaining drinking water quality.
BERI	BERI shows how two major human impacts on European bog ecosystems may have opposite effects. Elevated anthropogenic N deposition may cancel the beneficial role of European bogs as sinks for carbon under elevated CO_2. This is opposite to findings for forest ecosystems. This is a policy conflict not only within the same sector (environment) but also within the same policy commitment (to reduce greenhouse gas emissions).
GRAMINAE	One way to reduce ammonia emissions when applying manure to agro-ecosystems is to inject the manure into the soil. However, this can lead to increased N_2O and NO emissions and to increased nitrate leaching. This causes a conflict between acidification policies and policies for reducing greenhouse gas emissions.
MAGEC	Under Article 3.4 of the Kyoto Protocol, agricultural soils may be used to sequester carbon to offset carbon emissions. A number of management options have been suggested to sequester more carbon in agro-ecosystems. Some, such as adding organic amendments to soils (e.g. sewage sludge, manure, cereal straw) will increase carbon sequestration but may increase nitrate leaching or the flux of other trace gases. Within forestry, a similar conflict may arise concerning N fertilisation of forests. This causes within-sector (environment) policy conflicts between (and within) policies to reduce greenhouse gas emissions and policies to maintain drinking water quality.
DART	The potential policy conflicts in the forest-tundra ecotone relate principally to the various land-use pressures. Forestry, hydro power, exploitative industries and (eco-)tourism tend to conflict with the traditional patterns of land-use by the native Sámi people of northern Fennoscandia. At the same time, subsidy on reindeer meat etc. leads to over-stocking with damaging consequences for the natural environment, something that is then intensified by the artificial boundaries imposed upon both Sámi and their reindeer in the far north today. All of these policies have ecosystem implications.

Table 2: Potential policy conflicts – Potential impacts of policy in other sectors on the environment

Policy	(Potential) Impact on the environment
Transport	Air pollution, climate change, infrastructure on habitat loss, noise (wildlife), light pollution, toxic (e.g. heavy metal) pollution
Energy	Air pollution, climate change, noise (wildlife), light pollution, different energy sources have different environmental impacts (e.g. wave power could cause loss of wetland habitats etc.)
Industry	Air pollution, climate change, infrastructure on habitat loss, soil and water quality
Agriculture	Air pollution, climate change, land use and management on habitat, soil and water quality, biodiversity, erosion, toxic effects of POPs (pesticides)
Tourism	Habitat loss (directly and via infrastructure), local cultural loss (human ecology)

Table 3: Potential policy conflicts – Potential impacts of environmental policy on other sectors

Policy	**Impact of environmental policy on other sector**
Transport	Cancellation of transport infrastructure developments, impact on the dynamics of roads (e.g. bypass vs. urban traffic), dynamics of different forms of transport (e.g. road vs. rail), dynamics of public transport infrastructure
Energy	Dynamics of different forms of energy production, constraints on polluting energy sources, constraints on alternative energy sources, nuclear vs. fossil fuel vs. alternative sources – different policies impact all
Industry	Cost associated with clean-up (e.g. polluter pays) and clean technologies, constraints regarding development of infrastructure
Agriculture	Increased regulation vs. agricultural competitiveness (e.g. nitrate directive), constraints vs. potential benefits of GMOs, impacts of extensification schemes (e.g. set-aside and others)
Tourism	Restrictions on assess, restrictions on the development of infrastructure, dynamics of tourism

The above tables provide a few examples how policy conflicts may arise at the multi-sectorial level. Tables 2 and 3 can be regarded as "two sides of the same coin" in that other sectors may directly impact the environment leading to the development of policies to protect the environment, but environmental policy then often places restrictions on the other sectors.

6. AN EXAMPLE OF HOW CROSS-SECTORIAL POLICY CONFLICTS ARISE AND HOW THESE LEAD TO QUESTIONS REQUIRING RESEARCH

Having provided examples of how policy conflicts may arise at within-sector and multi-sector levels, the Working Group went on to develop strategies to address these potential policy conflicts in future research. The first step was to take an example of EU policy and examine its consequences to define where research would be needed to solve policy conflicts.

The review of policy and action in relation to "Towards Sustainability" published in October 1998 in the Official Journal of the European Communities (L 275/1-13; European Commission, 1998c) outlines a number of areas in which environment policy will be integrated, including integration into the agricultural sector. We took the example of increased extensification of agriculture (Section 1, Article 2, 1c, L275/4) and examined potential policy conflicts. The environmental benefits of extensification are clear; we examined the potential environmental risks and the possible consequences for agriculture. These are summarised in Table 4.

Similar analyses can be performed for any other environmental policy, within any other sector. Some policy conflicts can be resolved without new research; instead existing knowledge needs to be implemented (see section 8 below). However, this example demonstrates that when multi-sectorial policy conflicts require research, multidisciplinary teams are needed to provide policy options that minimise potential conflicts.

Table 4: Potential policy conflicts posed by example agricultural extensification practices

Extensification practice	**Possible environmental risks**	**Possible consequences in agriculture**	**Possible research requirements**
Reduced N inputs	Decreased carbon sequestration?	Reduction in yield Reduced profitability?	Balancing environmental benefits of reduced N fertilisation with impact on yield (agriculture), profitability (economics), and decreased storage of carbon (environment)
Organic farming	Increased nitrate leaching and other N losses?	Reduction in yield Reduced profitability?	Balancing environmental benefits of organic farming with impact on yield (agriculture), profitability (economics), and increased losses of N (environment)
Afforestation	Acidification of water? Increase in emission of some greenhouse gases?	Less land available Pest reservoir? Reduced profitability? Change in public amenity value?	Balancing environmental benefits of afforestation with impact on land available for production (agriculture), dynamics of pest species (agriculture, environment) profitability (economics), change in public amenity value (tourism, economics) the increased emission of greenhouse gases (environment) and acidification of water sources (environment)

7. DEVELOPING A RESEARCH STRATEGY TO ADDRESS POLICY CONFLICTS

Figure 1 is a schematic representation of how research project areas fit in a sectorial, cross-sectorial and multi-sectorial framework. Each project area is represented by a circle. Those actively investigated in a project are shaded. At the lowest level, projects carry out research in one sector. Most TERI projects fit in this category. At the cross-sectorial level, more than one sector is involved; a few TERI projects (especially the agri-environment projects) fit in this category. At the highest level, all sectors are considered. Potential policy conflicts are shown as lines between circles whilst information flow is shown by arrows.

Future research may still need to focus on the detailed science that is carried out at the single-sector level but more integration is required from other projects which have a wider, cross- and multi-sectorial remit. Research driven by policy conflicts can only be successful at the upper two levels of research or at the third level where within-sector conflicts are addressed. Even where within-sector conflicts occur, these are often mediated through other sectors (Table 3). Hence projects at each level are required.

A similar scheme could be used for dividing sectorial policy conflicts into subsectorial policy conflicts. In this respect, the scheme is non-dimensional / applicable at any scale. A scheme for harmonising policy conflicts arising from research projects represented in Figure 1 is presented in section 8.

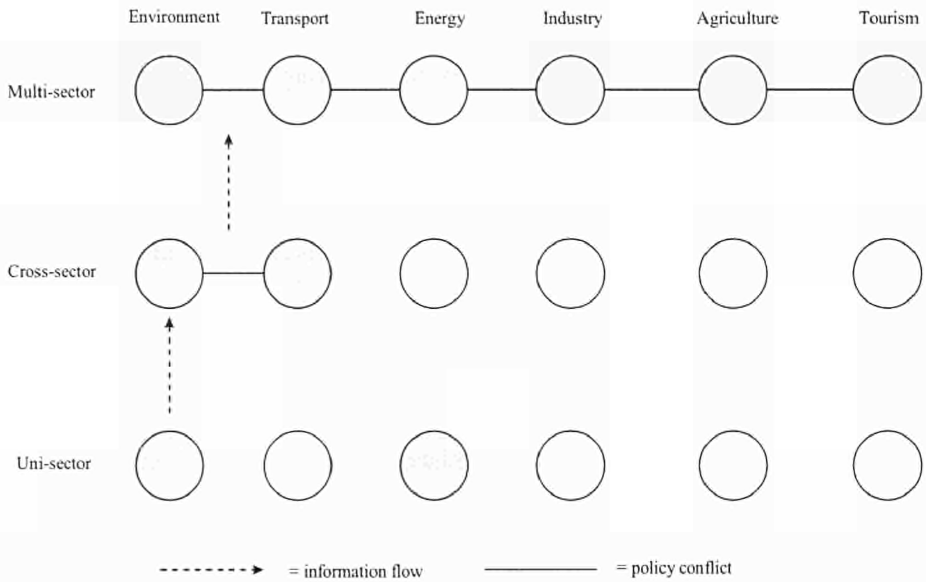

Figure 1: Schematic representation of how research project areas fit in a sectorial, cross-sectorial and multi-sectorial framework

8. SCHEME FOR ITERATIVE HARMONISATION OF POLICIES WHERE CONFLICTS OCCUR AND THE DEVELOPMENT OF AGREED SCENARIOS

The following scheme (Box 1) can be applied at many levels from the policy making level, through the science management level to the level of individual projects. It can be applied between two sectors or between many sectors. It is intended to include stake-holders from each sector in the decision making process.

***Box 1:* Scheme for iterative harmonisation of policies where conflicts occur and the development of agreed scenarios**

Step 1 - Each sector develops a scenario or set of objectives that would most benefit that sector without the reference to constraints from other sectors. It maps its implementation.

Step 2 - Sector 1 reviews the scenario or set of objectives of sector 2. Sector 2 reviews the scenario or set of objectives of sector 1. A set of policy conflicts is determined.

Step 3 - The policy conflicts are then analysed by both sectors. Some policy conflicts will be solved simply by implementation whilst others will require research input. The science gaps are defined.

Step 4 - An environmental science agenda (at the policy, research programme or project level) is developed to address the gaps.

Step 5 - The environmental consequences of the conflict resolution are quantified

Step 6 - Sectors modify scenarios or sets of objectives and return to step 2 (to repeat until policy conflicts are resolved)

If the science and implementation have been successful, only one iteration of the above scheme will be necessary.

9. DISCUSSION AT TERICA FINAL MEETING

At the final TERICA meeting (21-23 June 1999) the following points were made in the discussion:

1. Projects operating at different scales will identify different policy conflicts. Systems that address policy conflicts must take account of the different scales at which projects operate.
2. Science has been useful in the past in solving policy conflicts as well as identifying them. Science has an important role in this area in the future.
3. It is important only to answer questions in projects that can be answered with confidence; all possible environmental problems cannot be solved in a single project. It is, however, important to work with other disciplines where necessary / desirable.
4. The meeting welcomed the suggestion that a named contact (EC Officer) in the relevant DG for each sector covered by a proposal should be provided (see 10. 5. below).

10. RECOMMENDATIONS FROM WORKING GROUP 8

On the basis of discussions during TERI-Workgroup 8 and the TERICA final meeting, we make the following recommendations:

1. Policy conflicts can act as the driver for research. Research frameworks to address policy conflicts need a multi-sectorial approach at each level of the science commissioning process.
2. When dealing with research driven by policy conflicts, research priorities, science management organs and cross –sectorial projects should all be integrated across sectors.
3. Ensuring a multi-sectorial perspective might involve end-users/stake-holders at the project/programme evaluation stage as well as during the lifetime of the project.
4. Research budgets tend to be allocated to address specific single-issue problems. To address this, part of the research budget might be reserved for cross- or multi-sectorial projects. This requires that communication channels be built between currently separate research programmes.
5. For projects dealing with cross-sectorial problems, it would be useful to have, as well as a named EC project officer in DG XII, a named contact in the relevant DG for each sector covered by a proposal. Results from multi-sectorial research could then be fed back into the policy negotiation / decision level via these named EC officers. These officers would complement other national and international project users. This would help to ensure that other DG's were informed of relevant research developments, as well as encourage the DGs to have direct input to the projects.

ACKNOWLEDGEMENTS

The Working Group is grateful for additional written contributions from Jan Mulder (Norway, PROTOS), Bill Heal (UK, ARTERI), Marcel Hoosbeek (Netherlands, BERI) and Brian Huntley (DART).

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Appendix 2.

Extended abstracts of TERI projects and additional posters.

Extended abstracts of TERI projects and additional posters.

The following projects were presented as posters during the Final Conference. These are ordered here according to the major ecosystem types considered. Projects are distinguished between the first tranche 1996-1999 (FT) and the second tranche 1998-2001 (ST) of TERI.

The Functioning of European Grassland Ecosystems: Conclusions of the BIODEPTH project

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The BIODEPTH project:

- Investigates the impact of the loss of plant diversity for the functioning of grassland ecosystems
    - ◊ Across a pan-European network of manipulative field experiments
    - ◊ With relevance to the development of EU policy on conservation and sustainability

Methods

- Five hundred model plant communities with different diversities were established from seed and maintained by periodic weeding for three years
- Plant diversity and a suite of ecosystem functions and ecological processes were regularly monitored

Results

- An analysis including all eight sites revealed a general effect of reducing plant diversity: there was a linear decrease in productivity with the simulated loss of plant diversity (Figure 1).
- Altered diversity also affected many other ecosystem functions and ecological processes (Table 1).

Scientific conclusions

- The loss of plant diversity can have a negative impact on productivity and related ecosystem processes in grasslands
- Other ecosystem processes show a more complex relationship with diversity or appear unresponsive in the short term
- Further research should explore responses in the longer-term and under environmental fluctuation

Policy relevance

Biodiversity is a prerequisite for the maintenance of ecosystem services, with application for:

- management of grassland ecosystems (productivity, forage quality, resistance to weed invasions & pest outbreaks)
- preservation of ground water quality (nitrate retention and leaching)
- conservation of biodiversity (the preservation and restoration of grasslands)

Results: plant diversity and productivity in European grasslands

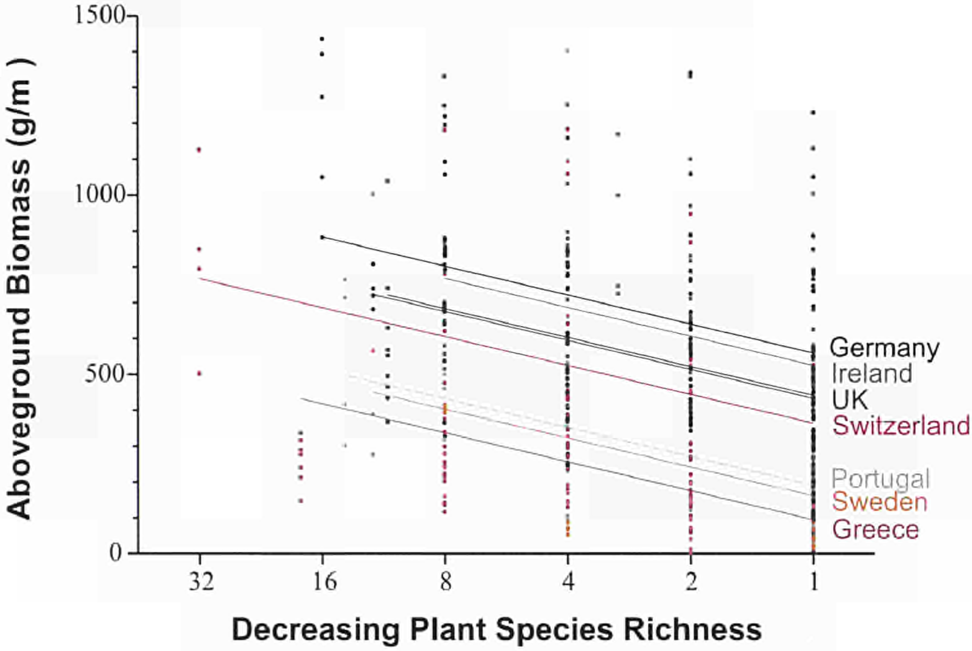

Figure 1: Productivity declined linearly with the simulated loss of plant diversity (on a log scale). On untransformed axes the loss of productivity would be initially weak but accelerating with the progressive loss of plant species.

BIODEPTH publications

Hector, A. & the BIODEPTH consortium. *Science.* (In review).

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Hector, A. (1998) *Oikos,* **82,** 597-599.

Loreau, M. (1998) *Oikos,* **82,** 600-602.

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Results: summary of the effects of declining plant diversity on ecosystem processes

Table 1: Effects of declining plant biodiversity

Ecosystem function monitored	Response to declining biodiversity
Plant productivity	
Above-ground biomass production	**Decrease**
Plant canopy architecture	**Decrease**
Below-ground root production	**Decrease**
Nutrient dynamics	
Nitrogen retention in plant biomass	**Decrease**
Soil nutrients	**Decrease**
Soil nitrate leaching	**Increase**
Soil moisture	**Increase / Decrease**
Decomposition processes	
Birch stick method	None
Plant litter, cellulose, cotton methods	None / **Decrease**
Plant community dynamics	
Community invasibility by weeds	**Increase**
Plant parasites and fungal pathogens	**Increase**
Soil microbial dynamics	
Soil respiration	**Decrease**
Soil microbial biomass	**Decrease**
Bacterial functional diversity/activity	**Decrease**
Mycorrhizas (root fungi)	**Decrease**
Invertebrate communities	
Above-ground invertebrate diversity	None
Above-ground invertebrate abundance	Increase / **Decrease**
Above-ground herbivore damage	Increase / **Decrease**
Above-ground invertebrate predators	None
Below-ground invertebrate diversity	None
Below-ground invertebrate abundance	None / **Decrease**
Other notable patterns	
Invertebrate herbivores	**Changes**
Plant development, competitive behaviour	**Changes**
Community assembly, spatial patterns	**Changes**
Genetic variation in plant races: performance of non-local seeds	**Decreases**
Variation in processes and susceptibility to disturbance	**Increases**: stability declines
Disturbance/trampling	**Increases**

BIODEPTH

Changing Land Usage: Enhancement of biodiversity and ecosystem development (CLUE)*

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INTRODUCTION

Due to the intensification of agricultural practices and developments in the world market, the European Union has introduced set-aside and abandonment measures for agricultural land. When agricultural land is set-aside permanently, restoration of natural ecosystems may be achieved in which the ecosystem has maximum carrying capacity in terms of biodiversity, biomass and nutrient cycling.

As a result of set-aside policies, former agricultural land will be changed from a high input/output (HIO) ecosystem into a low input/output (LIO) ecosystem. Although management schemes have been developed to obtain maximum species richness during this secondary succession with regard to the initially high soil fertility, little attention has been paid to the development of the soil community upon fallow and its interactions with the developing plant community and biogeochemical cycles. Especially in the first years after setting-aside, the spontaneous development of vegetation and soil community, both by reorganization of existing communities and seedbanks, as well as by colonization from nearby refugia, will be highly dynamic and unpredictable. This early stage of ecosystem development is critical because of the loss of basic resources from the ecosystem and because the ecosystem may become dominated by undesired species, thereby preventing intended ecosystem development.

The first plants to become established, after setting-aside agricultural land, are weedy species. These are opportunists, and during the initial phases after setting-aside they will be highly competitive, as resource availability is initially high. Experiences in e.g. the Czech Republic and the Netherlands, the UK, and Sweden show, that, after land abandonment initial dominance by some strong competing grasses may prevent further vegetation development for many years. Similar bulkheads in the soil ecosystem development are to be expected, however, integrated information on this is virtually non existent.

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* Contract No. ENV4-CT95-0002. (1 February 1996 - 31 January 1999) http://www.nioo.knaw.nl/cto/clue/clue.htm

The **main objective** for the study, to enhance biodiversity and ecosystem development on former agricultural land, required knowledge on how to best direct ecosystem development to maximum carrying capacity for biodiversity, biomass, and nutrient cycling, while reducing risks of nutrient losses during the initial stages of community rearrangement.

The **main hypothesis** is that the enhancement of biodiversity and ecosystem development may be achieved through stimulating the development of the soil community and biogeochemical processes to aid the colonization of plants and soil organisms from later successional stages by increasing the initial plant species diversity, in combination with the application of a 'stepping stone' approach.

BRIEF DESCRIPTION OF METHODOLOGY

The principle: In the Netherlands, Sweden, UK, Spain and the Czech Republic, two field experiments, equally designed at all sites, have been installed. Basic measurements have been performed by every participant, whereas more specialised measurements will be covered by single participants. The French participant has, in addition to processing samples from the other fields, carried out a large greenhouse study to experimentally examine the effect of different degrees of biodiversity on ecosystem processes in a Mediterranean old field succession. This experimental approach enabled additional, and more detailed, measurements than in the field.

The multidisciplinary approach: Each participant contributed a specialised expertise (the project team included the expertises of vegetation science, plant ecology, plant ecophysiology, soil zoology, entomology, nematology, soil phytopathology, soil microbiology, and soil science). In addition, each participant carried out basic measurements at the local field site in combination with specialised measurements at other sites, or at (soil) samples collected from the other sites.

The transect approach: Both field experiments carried out at all five sites were according to a the same experimental design. In practice, most other variables between sites were different (soil texture, site history, plant species to be used). A baseline for data collection at all field sites was formulated and these data were shared to prepare manuscripts. In total, multi-authored seven manuscripts have been prepared on the baseline data. In addition, each participating group will release a number of more specialist manuscripts.

SUMMARY OF RESULTS, CONCLUSIONS AND POLICY IMPLICATIONS (DETAILS IN TABLE 1)

1. Sowing high diversity mixtures of plant species at abandoned arable land enhanced the chance of success to obtain a high biomass production, provided effective suppression of emerging weeds, counteracted the development of a weed seed bank, and enhanced ecosystem processes (photosynthesis, productivity). The average high diversity mixture performed better than the average low diversity mixture. However, the best low diversity mixture was as effective as the best high diversity mixture. The performance of plant species in the high diversity mixture is a good predictor for the success of the species in a given low diversity mixture. Thus, the identity of plant species was more important than diversity as such.

2. The stepping stone treatment (i.e. soil inoculation combined with soil core transplantation) works for enhancing colonisation by later succession plants, but the site of origin has to be chosen carefully (e.g. by analysing the soil seed bank). The conditions of the recipient plot are essential (e.g. plant establishment was better when stepping stone plots were not combined with sowing plants). For the soil organisms, however, stepping stone treatments were not very effective at a three year time scale.

3. In the first three years, the main changes in the soil community were due to the abandoning of the land (i.e. stopping soil tillage, fertilisation and the use of pesticide). The

development of the soil community at abandoned arable land lagged behind the (artificially accelerated) vegetation development. The stepping stone experiment has shown that this is not only due to dispersal limitation. The origin and consequences of the observed time lag need further study.

4. Aboveground, the sowing treatments at abandoned arable land invoked change in the associated community of (herbivorous) insects.

5. CLUE showed that the development of the soil community in abandoned arable land clearly has a different trajectory than the visible (aboveground) community. Moreover, the soil community is less well to be manipulated than the plant or above-ground (insect) community. Hence, evaluations of policy implications of ecosystem restoration and biodiversity conservation should not be exclusively based on above-ground biota (red list plant species, etc.), as these may be poor predictors of the status of the below-ground community.

6. The transect approach showed consistent trends across Europe. However, there were site-specific idiosyncratic responses. Satellite experiments (replications at different sites within the same climate region) may be helpful to determine if these idiosyncratic responses are site or climate related.

7. Pilot results at 1-2 sites that need further testing are: (i) leaching of nitrogen after land abandonment may be less of concern than often is suggested, (ii) high diversity sowing treatments may be negative for *in situ* mycorrhizal infection potential, (iii) microbial biomass does not necessarily have to respond to short-term enhanced plant productivity, (iv) abandoned land has different phosphorous dynamics (with other microbial processes active) than more undisturbed ecosystems, (v) the vegetation in transplanted soil cores is limited to expand into the surrounding soil, and (vi) the soil of arable land has biotic constraints for growth of later succession plant species as compared to later succession soil.

8. Further studies are needed to determine if and how aboveground biodiversity may be linked to below-ground biodiversity at abandoned arable land, and in natural ecosystems in general.

Table 1. Effects of management options of short-term land abandonment on ecosystem processes and biodiversity development in vegetation and in soil. * are pilot studies at one - two study sites.

Variables	**Management options land abandonment**			
	Stop agricultural practice; no further actions	Introduce later succession plants (low diversity)	Enhance plant diversity (high diversity)	Introduce soil + soil blocks later succession stage
Vegetation development	Weeds dominate	Some combinations suppress weeds	Weed suppression more predictable	Plant propagules in soil become established
Predictability initial vegetation development	Unpredictable; depends on last crop, weed community, etc.	More predictable but depends on species identity	more predictable than in low diversity	Effects expressed most without sowing later successionals
Plant species diversity	Relatively diverse (10-20 sp. m-2)	Diversity depends on No. of sown species	Diversity depends on No. of sown species	Some enhanced plant diversity. NC $\geq$ HD
Plant species characteristics	Early successional	Early → early & later successional	Early → later successional	Some extra later successionals
Structure plant community	Open	Dense, little structure	Dense, more structure	If extra structure then in natural colonisation
Biomass above ground	Relatively low	Higher; depends on species mix	High; relatively little variation	If extra effect then in natural colonisation
Photosynthesis	Relatively low	Higher	Highest	Not determined

Root biomass	Relatively low	Higher; depends on species mix	High; relatively little variation; depends on country	If extra effect then in natural colonisation
Root length	Not compared with continued crop rotation	Effects depend on country: from no to positive	No effect of high diversity	Not determined
Carbon storage (based on productivity)	Enhanced	Further enhanced	More than average low diversity	Depends on sowing of later succession plants
Seed bank	Highest increase (mainly weeds)	Smaller; effect increases in time	Smaller; effect increases in time	?
Herbivorous insects	Enhanced abundance	Slight further enhancement; not always significant and species-specific	No further effect	No further effect
Earth worm abundance and biomass	No effect; in one country numbers, mass enhanced	No further effect	No further effect	No effect (not to be expected)
Collembola numbers	Numbers have increased	No further effect	No further effect	No further effect
Mites numbers and community diversity	Numbers have increased; spec. compos. differed	No further effect	No further effect	No further effect
Nematode numbers and community diversity	Total numbers not different; somewhat less plant parasites; shift of bacterial to fungal feeders	Plant parasites remain dominant; shift of bacterial feeders to fungal feeders	Plant parasites remain dominant; shift of bacterial feeders to fungal feeders	Depends on sowing of later succession plants
Fungal diversity (Oomycetes)	Not determined	No effect as compared to NC*	No effect of plant species diversity	Not determined
Endomycorrhizal fungi	Still inoculum potential present	No effect in biotest (reduction *in situ**)	No effect in biotest (reduction *in situ**)	Slight trend?
Symbiotic N2 fixing bacteria	Still inoculum potential present	If legume species then selective (?) enhancement	If more legume species then more enhancement	?
Free-living N2-fixing bacteria	Results depend on country	No extra effect	No extra effect	No consistent trends
Microbial activity	Probably reduced by stopped fertilisation	No further effect	No further effect	Usually no, but incidentally positive effect
Microbial biomass	Results variable from no-positive	Results variable from no-positive	Results variable from no-positive	Results variable from no-positive
Biocide application (to determine effects of excluding soil organisms)	Biocide effect at half of all sites; most pronounced for legumes and grasses	In one case, the biocide effect interacted with sowing (esp. for legumes)	No further	Biocide treatment not applied in combination with this treatment
Nitrate production *	Probably little nitrate to leach	No further effect, but greenhouse experiment: less leaching	No further effect, but greenhouse experiment: less leaching	No further effect
Ammonium oxidising bacteria *	Less than in continued crop rotation	Not further effect	No further effect	No further effect
Litter decomposition *	Not compared to continued crop rotation	Slightly reduced (trend only)	Slightly reduced (trend only)	Not determined
Ectomycorrhizal fungi *	Positive effect	Similar as or less than in not sown	Negative effect *in situ*	No effect
Microbial community composition*	Slight shift bacterial to fungal-dominated microbial community	Results differ: no effect to stimulation bacteria-domination	Results differ: no effect to stimulation bacteria-domination	Results depend on plant treatment (see left)

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DEGREE - Functional role of soil nematode communities in European grassland ecosystems under climatic change.*

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1. INTRODUCTION

DEGREE (Diversity Effects in Grassland Ecosystems of Europe) has investigated modifications in the diversity of soil biota in typical European grassland ecosystems under climatic change, and the functional impact of these modifications on plant nutrient availability. DEGREE focused on a particular subsystem of the soil ecosystem, which consisted of three major compartments: (1) free living soil nematodes (grazers of the microflora), (2) microflora (re-mineralisation, immobilisation of C and N), and (3) N availability for plants (target parameter). This subsystem is particularly qualified as a model system for investigating diversity-function relationships by its high functional and taxonomic diversity within the compartments, and by close links between the compartments.

The investigated research sites represented six major European grassland ecosystem types: Northern tundra (Abisko, Sweden), Atlantic heath (Otterburn, United Kingdom), wet grassland (Wageningen, The Netherlands), semi-natural temperate grassland (Linden, Germany), East European steppe (Pusztaszer, Hungary), and Mediterranean garigue (Mount Vermion, Greece). The locations of the sites covered a climatic cross-transect (oceanic-continental, boreal-Mediterranean).

Here, we report on three major activities performed within the project: (1) laboratory experiments on nematode-microflora interactions, (2) the concerted field experiment on the functional role of nematode communities under varying climatic conditions, and (3) analysis of the functional importance of nematode diversity.

2. LABORATORY EXPERIMENTS

Several series of laboratory and microcosm experiments were conducted in order to analyse nematode-microflora interactions. The experiment reported here investigated the spreading of micro-organisms by nematodes. Nematodes previously fed on selected micro-organisms were transferred to sterile agar plates, left to walk for 12 hours, and then removed. Agar plates were incubated and micro-organism colonies arising in the trails of nematodes were classified and counted. In total 175 plates and 12 397 colonies were evaluated.The following organisms were used in all suitable combinations of nematode feeding type and microorganism prey: Bacterivorous: *Panagrolaimus spec.*, Fungivorous: *Aphelenchus spec.*, Omnivorous: *Rhabditis spec.* Bacteria: *Escherichia coli XL1*, Fungi: *Penicillium glaucum*, Yeast: *Saccharomyces spec.*

Results from this agar-plate experiment demonstrate that various feeding groups of nematodes, although they feed on several types of micro-organisms, almost exclusively

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spread bacteria (ANOVA, $p < 0.001$). Results from microcosm experiments suggest that nematodes frequently reduce, or do not measurably affect fungal biomass and fungal activity, and that they typically increase bacterial activity and sometimes also bacterial biomass. Results also demonstrate that nematode effects depend on nematode activity, which in turn varies with soil structure, temperature and moisture. We conclude that soil nematode populations have the potential to measurably modify soil microbial activities, and can shift the bacteria/fungi ratio towards higher metabolic activity of the bacterial compartment.

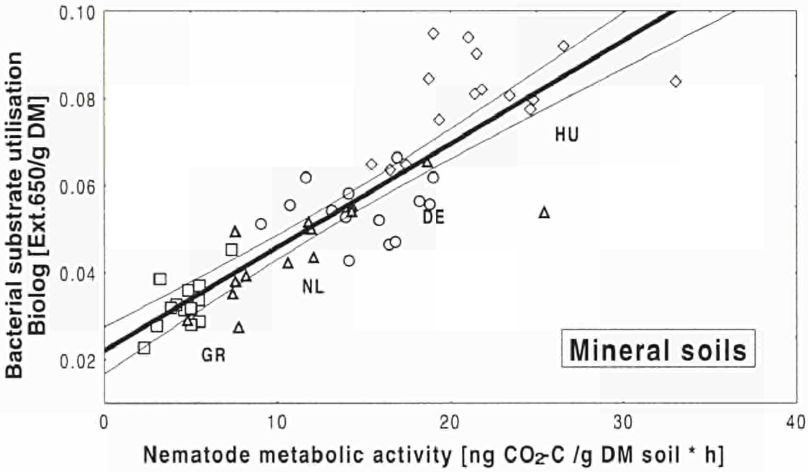

Figure 1: Bacterial substrate utilisation correlates with nematode metabolic activity.

3. THE CONCERTED FIELD EXPERIMENT

Soil microclimate was manipulated in the field in order to extend the range of temperature and humidity conditions naturally experienced during the investigation period. For this purpose, combinations of light reflection, shading, wind shelter, rain protection, and irrigation were used. On each research site 14 plots were established, representing a D-optimised incomplete cross table with 6 levels of temperature and 6 levels of water supply. Samples were taken at 6 occasions during 1996. Measurements included soil microclimate (water content, temperature), soil nitrogen pools (NH_4^+, NO_3^-, $N_{organic}$, N_{total}), microbial biomass (fumigation-incubation, ergosterol), microbial activity (CO_2, BIOLOG), nematofauna (Cobb), as well as nematode metabolic activity and excretion (metabolic model developed in the project).

The investigated soils fall into two groups: mineral soils that are precipitation fed (garigue, wet grassland, semi-natural grassland, steppe), and wet organic soils that are groundwater fed (heath, tundra). In the mineral soils, correlations among nematode activity and bacterial activity were significantly positive (Fig. 1). Microbial parameters, in turn, were significantly correlated with soil nitrogen pools. Average monthly nematode excretion contributed up to 25% of soluble soil nitrogen, depending on site and microclimate. No correlations among nematodes and microbial parameters, or nitrogen pools, were found in the wet organic soils. We conclude that nematodes affect nitrogen balance in mineral grassland soils both directly by excretion of N, and indirectly by regulating microbial activity.

4. ANALYSIS OF DIVERSITY EFFECTS

Results from the field experiment were analysed for functional effects of nematode diversity. Correlations between nematode taxonomic richness and target parameters were tested by means of multivariate regressions. Models included nematode abundance and microclimate as independent variables in order to separate mass effects from diversity effects. Tested target parameters were: average intensity, spatio-temporal variability, and microclimatic niche width of nematode metabolic activity and bacterial substrate utilisation. Relative importance of richness effects was assessed from differences in explained variance (R^2) between models including and excluding nematode richness as independent variable. Potential cross-correlations (hidden treatments sensu Huston 1997) were analysed by comparison of R^2 from models where nematode richness was replaced by functionally important traits of nematodes, such as body mass.

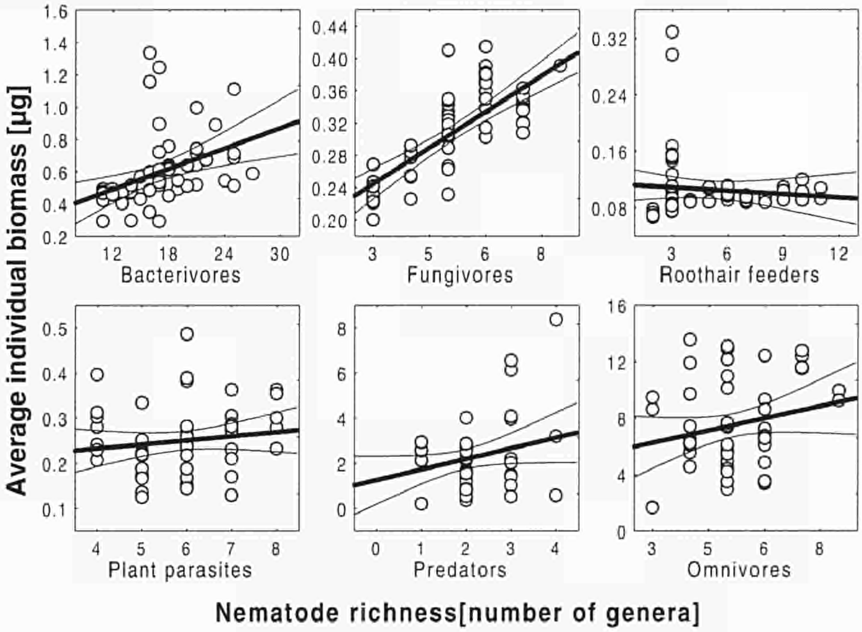

Figure 2: Changes in nematode diversity are associated with changes in body size. These correlations differ among feeding types.

Nematode taxonomic richness was positively correlated with nematode metabolic activity and with bacterial substrate utilisation (Multivariate regression, $p<0.05$). However, with few exceptions, richness as such explained only marginal proportions of variance (ca. 2%). Higher proportions were explained by individual nematode body mass and by c-p class (longevity), which were cross-correlated with richness (Fig. 2). Correlations differed considerably among nematode feeding types.

We conclude that nematode richness is not generally a functionally operative factor. However, high nematode richness is on average a good indicator of an active nematofauna and microflora. Changes in nematode richness are associated with measurable changes in the functioning of the nematode and microbial communities within the soil ecosystem.

Effect of environmental change on the biodiversity and function of below-ground microbial communities (MICRODIVERS)*

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There have been relatively few experimental demonstrations of the relationships between diversity and function for soil microbial communities. This has largely been due to the complexity of the soil system at a range of levels, the heterogeneous nature of the soil environment, the complexity of the soil food web, the very high absolute diversity of organisms present, methodological problems of measuring biodiversity in microbial communities, and technical difficulties in manipulating biodiversity in soil. We report on the use of progressive fumigation to reduce soil microbial biodiversity, and its effect on the stability of key soil ecosystem processes.

The diversity of cultivable bacteria (from isolated colonies), total bacteria (from directly extracted soil DNA), protozoa and nematodes was determined in soil fumigated with chloroform. Soil was fumigated for up to 24h and then incubated for 5 months to allow growth and recolonisation by surviving organisms. There was a clear trend that increasing fumigation progressively decreased biodiversity. The number of trophic groups, the number of phyla within trophic groups, and the number of taxa within phyla, all decreased as fumigation increased. Total microbial biomass was similar within soils fumigated for different periods of time, although this was lower than for the unfumigated soil. There was, however, no direct relationship between biodiversity and function. Some general parameters increased as biodiversity decreased, such as thymidine and leucine incorporation, growth on added carbon and nitrogen under both aerobic and anaerobic conditions, and the short-term decomposition rate of grass, barley and maize residues. Other, more specific, parameters decreased as biodiversity decreased, such as nitrification, potential denitrification and methane oxidation. The implication from this is that specific functional parameters are a more sensitive indicator of environmental change that more general parameters.

Although progressive fumigation reduced soil microbial biodiversity, there was evidence to suggest that it was not a random reduction but selected for organisms with particular physiological characteristics. Thus, we cannot rule out a 'hidden-treatment effect' (Huston 1997), and the consequences of this for interpreting biodiversity – function relationships from the results are discussed.

The stability of the resulting communities to perturbation was examined by subjecting the soil to a transient (brief heating to 40°C) or a persistent (addition of $CuSO_4$) stress. Decomposition of isotopically labelled grass residues by the soils was determined on three occasions after the perturbation. This allowed for a measure of resistance and resilience (sensu McNaughton

* Contract number: ERB ENV4-CT 950017

1994) by soils differing in biodiversity to different classes of environmental stress. The soils clearly demonstrated resilience to the transient stress, decomposition rates were initially depressed by the stress and recovered over time. Resilience was reduced for the soils with decreasing biodiversity. Soils were not resilient to the persistent stress, there was no recovery in decomposition rate over time, but the soils with the highest biodiversity were more resistant to the stress than soils with impaired biodiversity. These results show that the study of functional stability under applied perturbation is a more powerful means of examining the effects of biodiversity, than simple biodiversity – function relationships.

GRAMINAE: Quantifying biosphere-atmosphere interactions of ammonia with European grasslands.

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1. INTRODUCTION

The issue

Ammonia (NH_3) occurs naturally in the atmosphere, but most of the European emission (>90%) is of anthropogenic origin. The largest source is volatilization from livestock wastes with a significant fraction from fertilized agricultural land. NH_3 is important since:

- with emissions of SO_2 and NO_x, it contributes to long-range pollutant transport and acidic deposition - "acid rain",
- with emissions of NO_x, it causes eutrophication of sensitive N-poor ecosystems - changing species composition of threatened habitats.
- atmospheric reaction of NH_3 produces ammonium aerosol (NH_4^+), which contributes to a negative global warming potential.

While NH_4^+ may be transported for >1000 km, deposition of NH_3 is largest in source areas. Hence relict natural habitats in intensive agricultural landscapes are particularly at risk.

Policy context

The 1979 Geneva Convention on Long-Range Transboundary Air Pollution (CLRTAP) was established under the auspices of the UNECE to tackle European air pollution as an international problem. In 1984 the first Sulphur Protocol ("30% club") was signed, and this was followed in 1991 by the NO_x Protocol, and in 1994 with the Second Sulphur (Oslo) Protocol. The agreements have now shifted from simple % cuts, to an effects- based approach minimizing the European exceedance of deposition over ecosystem sensitivity thresholds ('critical loads').

Since 1994, the Convention has been negotiating revision of the NO_x protocol and to deal with the linked issues is taking a multi-pollutant, multi-effect approach, including effects of NO_x, NH_3, SO_2 and VOCs. Hence, international abatement of NH_3 is being negotiated for the first time. The new UNECE Göteborg Protocol has now been signed (late 1999), while in parallel, the EC has developed its Acidification Strategy, which will lead to the National Emissions Ceilings (NEC) Directive, again including SO_2, NO_x, NH_3 and VOCs.

2. OBJECTIVES

GRAMINAE is a 2nd tranche TERI project running between 1998 and 2001 that has been designed to address these issues. It is widely recognized that there are major uncertainties in the quantification of the atmospheric NH_3 cycle. A key element is the biosphere-atmosphere exchange process. Data on this aspect are essential to parametrize the European transboundary models used in both the UNECE and EC negotiations. With this in mind, GRAMINAE has the following objectives:

- to quantify emissions from different sources (including land area sources such as intensive agricultural land)
- to quantify the rates of NH_3 deposition to receiving ecosystems
- to understand & quantify the biospheric controls on these processes
- to understand the controls on NH_3-NH_4^+ dynamics
- to develop models both to explain the processes and for incorporation in the European policy models used in the negotiations.

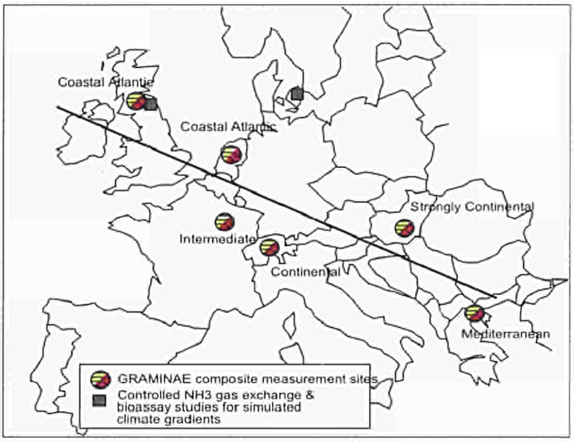

Figure 1: GRAMINAE experimental transect across Europe to address the effect of increasing continentality. It is hypothesized that biospheric controls result in longer atmospheric residence times of NH_3 in continental than in oceanic climates. This has implications for modelling the transboundary transport of NH_3 for example in estimating polluter-receptor 'blame matrices' for different European countries.

2. APPROACHES

The objectives of GRAMINAE are being achieved through:

1. Applying state-of-the-art technology to measure NH_3 fluxes with European grasslands using micro-meteorological methods.

2. Exploiting the TERI transect approach to quantify interactions with climate, particularly continentality (Figure 1).

3. Considering both I) intensive grasslands as these impact on the atmosphere (through emissions), II) semi-natural grasslands as these are impacted by the atmosphere (deposition).

4. Making complementary laboratory & interpretative measurements to understand the exchange processes.

5. Developing quantitative process based models of both I) biosphere-atmosphere exchange and II) grassland ecosystem functioning.

6. Providing the models to European policy modellers to underpin the negotations for revision of the UNECE N Protocol, and EC NEC.

7. Engaging in the UNECE and EC negotiations on the potential for and difficulties in NH_3 abatement across Europe.

Novel scientific elements in the project include: Europe-wide analysis of NH_3 exchange with grasslands; linking of micromet approach with laboratory cuvette analysis and plant bioassays; new flux sampling methods (Relaxed Eddy Accumulation, REA) for NH_3; Assessment of gas-aerosol flux interactions; Assessment of biospheric controls on atmospheric NH_3 concentrations; Development of dynamic ecosystem-NH_3flux models able to consider management practice.

3. MODELLING AMMONIA FLUXES

Ammonia exchanges in relation to a compensation point (χ_s) which is the concentration at equilibrium with [H^+] & [NH_4^+] in the apoplastic solution. Models being developed under GRAMINAE, describe the different component fluxes in relation to Ohm's Law: '*Voltage = Current x Resistance*' transposes to '$(\chi_1-\chi_2)$ = *Flux x Resistance*' (Figure 3).

The resistances are: R_a, R_b, atmospheric transfer; R_w, uptake to leaf cuticles; R_s, stomatal transfer; R_{ac}, R_{bl}, in-canopy transfer (for the 3-layer model), while the subscripts p and f denote upper and lower canopy parts. χ is air concentration, with χ_l and χ_c the litter and canopy compensation point, respectively.

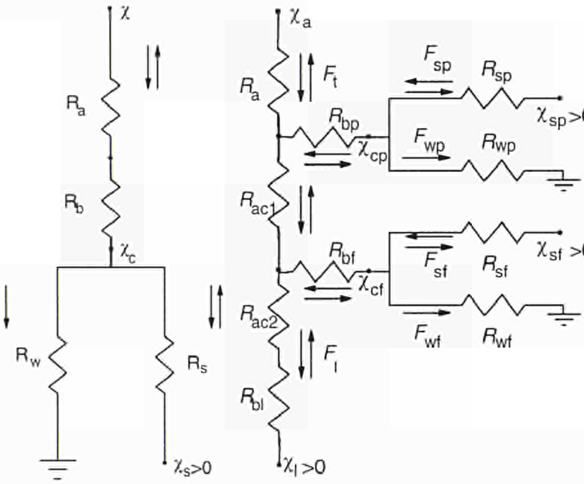

Figure 2: Example NH_3 models under development in GRAMINAE showing a 1-layer and 3-layer model. See text for explanation of concentration (χ), flux (F) and resistance (R) subscripts.

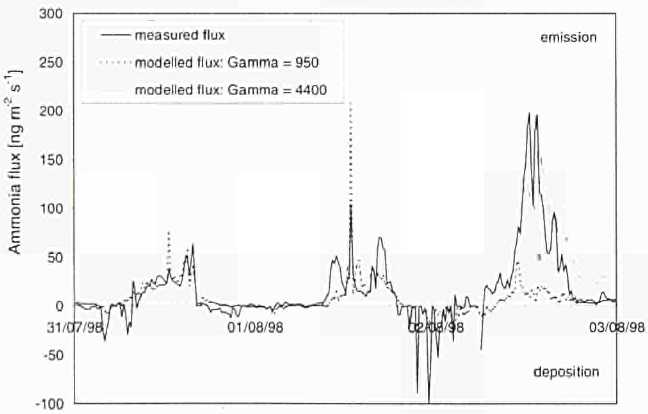

Figure 3: Example NH_3 models under development in GRAMINAE showing a 1-layer and 3-layer model. The one layer model is applied to grassland in the right hand graph.

The measurements shown in Figure 3 are for the Scottish GRAMINAE site. The period is after the second cut of the field, but before fertilization, with the grass being lifted on 2 August. The model (see Figure 2 – one layer model) is parametrized with $R_w = 30\ \exp^{[100-\%RH]/7}$ (s m^{-1}) with the ratio of apoplastic [NH_4^+]/[H^+] = Γ = 950. The emissions following lifting of the grass would be consistent with $\Gamma > 4000$.

These results demonstrate both the close coupling of NH_3 fluxes to N turnover in the grassland, and the performance of the 1-layer model in rapidly changing conditions. A key challenge is to generalize these results for scaling up in time and for different European grasslands. In this respect GRAMINAE are coupling the NH_3 resistance modelling approaches with dynamic grassland ecosystem models in order to develop a functional prediction of NH_3 fluxes in relation to C and N cycling.

4. CURRENT POLICY DEBATE - THE 'AMMONIA GAP'.

As Europe moves towards NH_3 emissions abatement for the first time, it is important to ensure that the investment will result in environmental benefits. To do this, it is necessary to show the link between changing emissions and monitored deposition of NH_3 and NH_4^+.

Over the last century the link is clear, with deposition estimates more than doubling at remote locations (e.g. ice cores, long-term precipitation chemistry).

However, NH_3 emissions should already have been reduced in two cases:

- *Eastern Europe* (e.g. Hungary), due to the collapse of the agricultural sector (reduced animal numbers and fertilizer consumption).
- *The Netherlands*, due to the implementation of an NH_3 abatement policy.

In both cases, analyses by GRAMINAE partners in the Netherlands, Hungary & UK have shown that the expected reductions are difficult to observe.

This has important implications for the policy negotiations, as it indicates uncertainty in our understanding of the controls on NH_3 levels. In recent discussions for the UNECE Protocol (5/1999) it was agreed that countries should proceed with caution using a selection of well established abatement techniques, but that further measurements are essential to investigate these issues.

One of the messages of GRAMINAE, is that a feedback exists (via the NH_3 'compensation point') where ecosystems can control NH_3 concentrations as well as being impacted by NH_3 deposition. In a further linkage it needs to be recognized that NH_3 abatement will be much less effective if N inputs to the system are also not reduced. Together with interactions with SO_2 chemistry, inter-annual variation and possible reduced efficiency of some abatement measures, this may go some way to explaining the ammonia gap.

ACKNOWLEDGEMENTS

The authors are grateful for funding of GRAMINAE through the EC TERI programme under contract ENV4-CT98-0722, for the UK, NL, DK and FR, under the EC International Co-operation Programme for HU (INCO-IN2O-CT98-00118), and the Swiss National Research Foundation (SNRF) for CH. National funding is provided by Ministries of Environment and Research in the UK, NL and FR. M. Riedo is supported under a two-year TMR Fellowship (1999-2000) from the SNRF. The authors gratefully acknowledge the contribution of Kim Pilegaard as an independent observer to the project.

Managing European Grasslands as a Sustainable Resource in a Changing Climate (MEGARICH)*

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INTRODUCTION

MEGARICH is a European collaborative programme of experiments and modelling activities. It is comprised of six partners (Figure 1) and three sub-contractors. MEGARICH is a 2nd tranche project of the Environment Climate Programme

The aim of MEGARICH is to investigate the long-term responses of a representative selection of European semi-natural grassland communities to climate change (elevated CO_2 and temperature) and interactions with management regimes (nitrogen fertiliser, cutting frequency and grazing). The following hypotheses will be tested:

- That global climate change affects the structure and botanical composition of grassland ecosystems.
- That interactions between the components of global climate change (CO_2, temperature, drought) and management practices (nitrogen, cutting frequency and grazing) affect the growth, development and productivity of grassland ecosystems and carbon sequestration in the soil organic matter.
- That global climate change affects tissue quality which impacts on the activity of grass herbivores and decomposers.
- That models can be used to simulate and predict responses to global climate change, and they can be used on a European scale to develop sustainable grassland management systems in a changing climate.
- That management and environmental policy can be directed towards land-use practices that mitigate the effects of global climate change.

- **Ireland:** MB Jones, Trinity College Dublin (TCD).
- **UK:** TW Ashenden, Institute Terrestrial Ecology, Bangor (ITE-Bangor).
- **Italy:** A Raschi, CeSIA-Accademia Dei Georgofili, Firenze (CeSIA).
- **Hungary:** Z Tuba, Agricultural University of Godollo (AUG).
- **France:** JF Soussana, INRA, Centre de Clermont-Ferrand (INRA-CF).
- **Germany:** HD Payer, GSF, Neuherberg (GSF).

Figure 1: The MEGARICH partners.

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* . Contract No: EV5V-CT-93-5213 (January 1998-December 2000).

METHODS

Each partner has established a replicated (x3) randomised block experiment involving two treatments (CO_2 and one other). The other treatments are different levels of applied nitrogen ambient (355 ppm) and elevated (ambient + 250 ppm) CO_2.

Table 1: MEGARICH grassland communities.

Partner	Classification	Characteristic species	Representative of:	Distribution
Ireland	*Centaureo-Cynosuretum.* Wel-drained 'neutral' grassland.	*Holcus lanatus* *Festuca rubra* *Trifolium repens.*	Temperate-oceanic community of North-Western Europe.	Widespread but localised.
UK	*Lolio-Cynosuretum.* Wel-drained 'neutral' grassland.	*Lolium perenne* *Trifolium repens.*	Temperate-oceanic community of North-Western Europe.	Ubiquitous.
Italy	*Brometalia erecti.* Dry 'calcareous' grassland.	*Bromus erectus* *Ononis spinosa.*	Submediteranean community.	Localised.
Hungary	*Festuca-Brometea.* Dry 'calcareous' grassland.	*Dactylis glomerata* *Festuca rupicola.*	Temperate-continental community of central Europe.	To be defined.
France	*Lolion.* Well-drained 'acid-neutral' grassland.	*Lolium perenne* *Trifolium repens.*	Continental community of Western and Central Europe.	Ubiquitous.
Germany	Mesobrometum alluviale. Dry 'calcareous' grassland.	*Bromus erectus* *Medicago lupulina.*	Temperate-continental community found throughout Europe.	Widespread but localised.

* Grasslands of Nature Conservation importance.

Five partners have established a miniFACE exposure system comprising of 12 'rings'. Rings measure 1.2m - 1.5m in diameter (varying with country). The solardome CO_2 exposure system is operating in the UK (http://www.nmw.ac.uk/ite/bang/solar.html).

At each experimental site a full climate record is maintained and a range of measurements are being made including, species presence and absence, sward composition, single leaf and canopy gas exchange, below ground respiration, total plant and species biomass, total leaf area, N yield, C:N ratio, digestibility, leaf carbohydrate content, root mass and root turnover, plant root and soil organic matter and a full carbon balance of monolith cores.

RESULTS

Ireland: Preliminary results five weeks after the start of CO_2 fumigation in 1999, indicate differences in plant community structure between treatments and controls for 3 grassland types of contrasting fertility (Figure 2). There was a stronger positive response by *Holcus lanatus* to N than to CO_2. *Festuca rubra* showed a negative response to N and a positive response to CO_2. *Trifolium repens* responded positively to CO_2 and, as expected, negatively to N. The effect of both treatments on *Anthoxanthum odoratum* and *Plantago lanceolata* was mainly to reduce cover relative to the controls.

Hungary: Preliminary results indicate that increased N has a stronger effect than elevated CO_2. There appears to be a trend of smaller leaf area indices in the high CO_2 plots than in the ambient CO_2 with or without added N (Figure 3).

France: First results (Table 2) show a negative trend for the CO_2 effect on light interception. In ambient CO_2 light interception was also on average higher in the low cutting frequency treatment. Soil moisture content was higher in the high cutting frequency communities indicating that these communities dehydrate the soil at a slower rate than those from low cutting frequency treatments. Throughout July 1998 dry matter yield of the swards was higher under ambient CO_2 concentration than elevated CO_2.

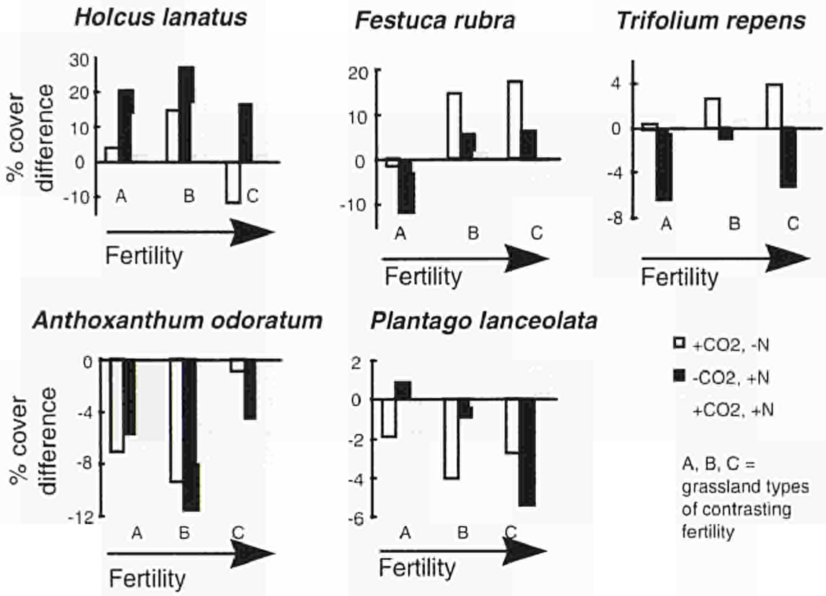

Figure 2: Differences in cover of grassland species in response to elevated CO_2 and Nitrogen.

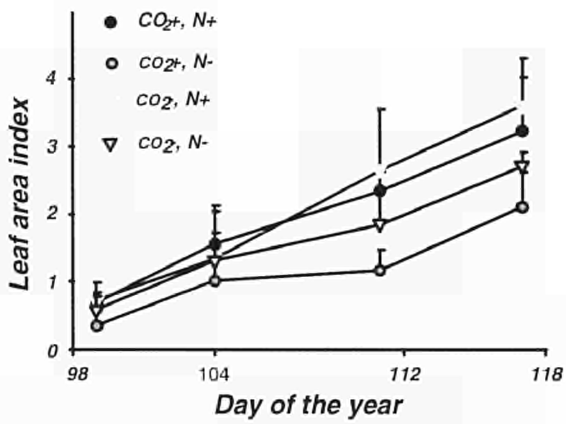

Figure 3: Preliminary trends of leaf area index in the four Hungarian treatments.

Table 2: Mean values (±SEM) of light interception, soil moisture content and dry matter measured in the period from August to October 1998.

CO_2	350		600	
Cuts per year	3	7	3	7
Light interception	0.72 (0.09)	0.60 (0.07)	0.56 (0.02)	0.55 (0.13)
Soil moisture content (%)	14 (2)	19 (1)	16 (2)	18 (1)
Dry matter (g m^{-2})				
July	317 (35)	306 (43)	206 (33)	257 (27)
August		70 (7)		54 (11)
September	217 (21)	157 (19)	124 (18)	65 (11)
October		70 (7)		68 (10)

MODELLING ACTIVITIES

Within the MEGARICH framework, the LINGRA model has been further developed to accommodate CO_2 responses. The previous version simulated key processes such as light utilisation, leaf formation, leaf elongation, tillering and carbon partitioning (storage, shoot, root). Source-and sink-limited growth were simulated independently. In the present study the new version of LINGRA i.e. LINGRA_CC was developed and tested by comparison with the experimental results from the "Wageningen Rhizolab".

The model was then used to study the effects of different combinations of cutting intervals and cutting heights on biomass production, at ambient and double CO_2 conditions. Under both ambient and doubled CO_2, maximum biomass was produced and cuttings up to a LAI of 1, and at cutting intervals of 20 and 17 days for ambient and increased CO_2 environments, respectively. Under high CO_2 conditions the cutting interval for maximum yield was 15% shorter than at ambient CO_2. The Hurley Pasture Plant-Ecosystem model will be applied at the patch scale. A co-ordination model (Canopt), will be extended to binary mixtures and more complex vegetation.

The CANIF - Carbon and Nitrogen cycling in European Forests – project

E.-D. Schulze, P. Högberg, G. Scarascia-Mugnozza, E. George, F. Martin, D. Read, T. Persson, S. Struwe, V. Wolters, A.F. Harrison, B.R. Andersen, F. Berendse and T. Paces

INTRODUCTION

The European research project CANIF studies the biogeochemical cycling of carbon and nitrogen, and the significance of biodiversity for these processes. The experimental investigations are performed in forest ecosystems along a latitudinal and deposition transect through Europe. The sites (see Figure 1) selected represent the major forest species of Europe,

Figure 1. The forest sites of the CANIF project along a latitudinal transect in Europe. Nitrogen deposition is highest at the mid European sites.

Sweden:	Åheden - Ahe (Picea, Pinus, Betula)
	Skogaby - Sko (Picea)
Denmark:	Gribskov - Gri (Fagus)
Germany:	Waldstein - Wal (Picea)
	Schacht - Sch (Fagus)
Czech Republic:	Nacetín - Nac (*Picea*)
	Jezerí - Jez (*Fagus*)
France:	Aubure - AuP (*Picea*)
	Aubure - AuF (*Fagus*)
Italy:	Monte di Mezzo - MdM (*Picea*)
	Collelongo - Col (*Fagus*)

Picea abies and *Fagus sylvatica*, with inclusion of *Pinus sylvestris* and *Betula pubescens* in the boreal region.

AIM

The objectives of the CANIF are:

- to better understand mechanisms driving pools and fluxes of carbon, nitrogen and water and other nutrients in forest ecosystems
- to identify ways in which biological diversity regulates ecosystem function, structure and dynamics

- to extrapolate this understanding to scenario's of land-use and climate change

APPROACH

Key ecosystem processes were studied along the transect by specialized researchers. Data per site were collected in a databank. The modeling subproject integrated the knowledge gathered within the other subprojects at the level of the whole ecosystem.

MAIN EXPERIMENTAL RESULTS

- ^{15}N labeling indicates that in *Picea* stands a major sink for nitrogen is the humus layer (90%) and the trees take only a minor part (10%), whereas in broadleaved *Fagus* stands, 70% of the label is found in the trees and only 30% in the humus layer.
- ^{14}C-bomb measurements and laboratory incubations indicate that there are increases in mean residence time of organic carbon leading to carbon accumulation in soil at sites with high N deposition
- At these sites with high N deposition, laboratory incubations indicate a high N turnover
- Denitrification activity is low. N_2O emission was generally less than 1 kg ha^{-1} yr^{-1}
- Trees and mycorrhizae are able to utilize a broad spectrum of N sources such as amino acids, ammonium and nitrate, but the conditions vary along the transect. While mineralization is low in the North and nitrifiers are missing, the trees utilize organic nitrogen via mycorrhizal activity as main N source. In Central Europe, mineralization on acid soils under *Picea* is high and ammonium is the main N source, while under *Fagus* as well as on calcareous soils in Italy where nitrifiers do occur, nitrate is the main N source for trees. *Pinus* mycorrhizae do not function well under high N supply whereas *Fagus* mycorrhizae can cope with eutrophication.
- Biodiversity appears to follow but to thrive the N cycle according the soil chemical conditions. In the North, mycorrhizae are found that only use organic N, these are replaced by species that use ammonium in Central Europe, or nitrate in the South. Whether trees can persist without mycorrhizae under eutrophic conditions is not clear yet.

MAIN MODEL RESULTS

- Climatic factors determine to a large extent the characteristics of each site
- No clear differences between *Picea* and *Fagus* forests emerged although differences in humus form and soil dynamics are known to be different for the two vegetation types
- N availability is a strong controlling factor for net primary production and net ecosystem productivity (Figure 2)
- C mineralization (heterotrophic respiration) is co-determined by temperature, soil organic matter pools (Figure 3) and site-specific decomposition rates (that are lower in high N deposition areas)
- The controlling factor for N mineralization, C mineralization and NPP and NEP is the total amount of above-ground litterfall and below-ground root decay. C:N ratios affect N mineralization but to a lesser extent than amounts of litter
- Net ecosystem productivity, defined as net primary production minus heterotrofic respiration, is thus dependent on N availability, temperature, soil organic C pools and site-specific decomposition rates
- Site-specific conditions of growth limiting factors determine the response to climatic change. Higher temperatures can increase NEP at sites with an ample water supply but

decrease NEP at sites with drought stress. Higher temperatures can increase N availability, and NPP and NEP, but only at sites where growth is N-limited whereas sites with high N availability may depict higher N leaf concentrations, higher N leaching and smaller NEP

CONCLUSIONS

- The study of isotopes and mass balances together with the study of biodiversity gave insight into the mechanisms of N and C turnover as well as of C/N interactions. This becomes especially obvious in the tracer studies of ^{15}N, and the quantification of turnover rates of C and N by ^{14}C.
- At this point we can describe the interaction between ecosystem fluxes and biodiversity and we can conclude that species are important to explain certain ecosystem functions. However, we are not able to say if biodiversity follows certain physico-chemical ecosystem parameters, or if diversity determines this environment. Most likely, both components are important, but the interactive nature remains unclear.
- It becomes apparent that some of the relations that were established along the CANIF transect need to be confirmed for a broader range of habitats.

GLOBIS - Global change and biodiversity in soils

Wolters V*, Anderson J, Bengtsson J, Gourbiere F, Kallimanis A, Lindberg N, Persson T, Pflug A, Schroeter D, Sgardelis S, Stamou G, Taylor AR, Tsiafouli M, Van Maanen A, Wilkinson A

GLOBIS (**GLO**bal change and **B**iodiversity **I**n **S**oils) is an investigation of present and foreseen effects of global climatic change on the biodiversity in forest soils and its impact on ecosystem processes. Species diversity, functional diversity and trophic connectivity of the animal and microbial communities are considered. The project utilises the natural environmental variation by carrying out studies along a European transect (e.g. Figure 1). This strategy is combined with both field experiments, where relevant environmental conditions are controlled, and manipulation experiments in the laboratory to evaluate the importance of different factors.

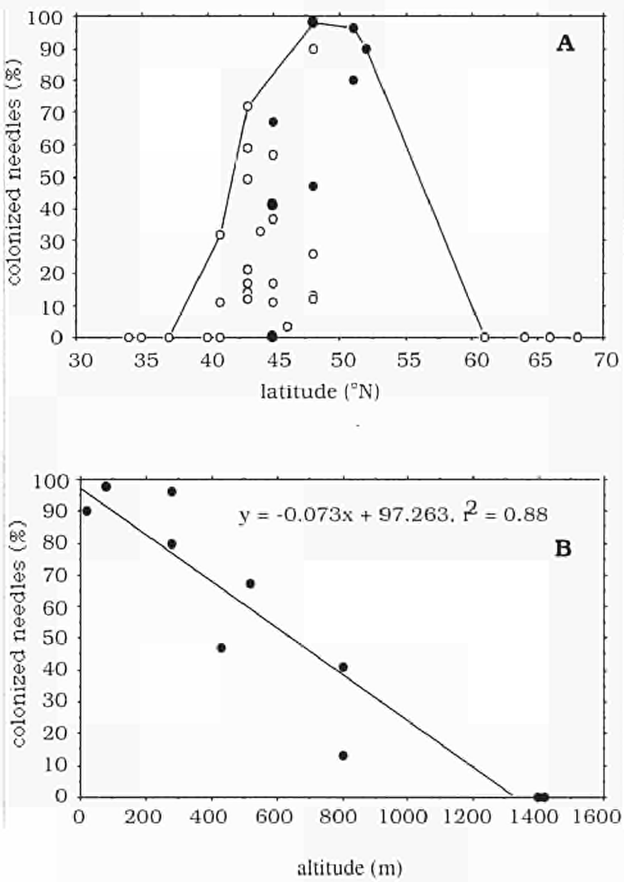

Figure 1: Geographical distribution of *Verticicladium trifidum*. (A) Latitudinal distribution on *Pinus* and *Cedrus* litter in western Europe. The line connects maximal values for each latitudinal group of values (open circles). (B) Altitudinal distribution on *Pinus sylvestris* between 40° and 55° N (solid circles in A).

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APPROACH

All partners focus on the litter layer and SOM of deciduous and coniferous forests (sites in Sweden, Germany and Greece). Two additional transects are investigated by the French partner (focusing on fungi colonising *Pinus* litter): (i) latitudinal transect (Finland to Greece, and within Sweden; Figure 1A), (ii) altitudinal transect in France (Figure 1B). Transect studies are complemented by field and laboratory experiments (irrigation, drought, N fertilisation, litter quality, keystone taxa). The following pools and fluxes are measured: (i) C and N mineralization in litterbags, (ii) mineralization rates from microcosms, (iii) methane and gaseous N release from microcosms, and (IV) Phenylpropanoids and Carbohydrates. Available data on diversity are: (i) indices of soil animal diversity, functional groups and food web structure; (ii) indices of bacterial diversity and fungal : bacterial ratios using PFLA profiles; (iii) diversity of main fungal decomposers colonising coniferous litter; (iv) presence/absence of species and presence/absence of functional groups in microcosm studies.

RESULTS

Fungi colonising **Pinus** *litter*

Some results of the investigations on fungi colonising *Pinus* litter are summarised in Figure 1A and B. The data indicate that changes of climatic conditions along latitudinal and altitudinal transects lead to modifications among fungal communities (see Van Maanen and F. Gourbière, 1997).

Joined litterbag experiment in the field

Traditional investigations on the composition of the decomposer biota were complemented by analysis of PLFA and litter quality characterisation. This novel and integrative approach demonstrates the sensitivity of soil community structure to environmental change. However, links to processes are tenuous for many groups (e.g. bacterial diversity in tree litters). The main conclusions are:

- microclimate significantly affects the structural and functional diversity of the soil organisms;
- site-specific differences in the response of the biota reflect different patterns of adaptation to ambient climate.

In particular, changes in substrate humidity seem to be of overwhelming importance. At the Greek site, for example, a fine-grained mosaic of soil biota activities triggered by substrate humidity seems to be essential for the community to overcome disturbances of the habitat. Another important result is that alterations in one component of the decomposer food web (e.g. mesofauna) may drastically affect other components (e.g. microfauna). Certain animal groups may thus gain functional importance through their effect on other animals.

Complementing field experiments

a. Long-term investigations: effects of soil moisture and nutrient level treatments.

Oribatid and collembolan abundance increased in irrigated plots and decreased in drought plots. In addition, species composition of these two groups was significantly affected (e.g. Fig. 2). Drought plots had very low densities of enchytraeids. Additional manipulations indicate a total recovery of *Cognettia sphagnetorum* (living in the forest floor), while the *Achaeta* species (living below the humus layer) did not increase during the first year. Samples from nutrient addition plots revealed changes in faunal composition. The total abundance of Oribatida and Collembola was affected in different ways. A few species among the oribatid mites and the collembolans showed higher numbers in the nutrient addition plots, while root-sucking aphids decreased in abundance.

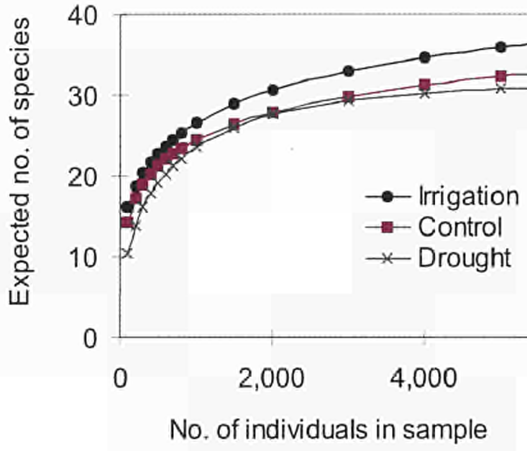

Figure 2: Impact of irrigation and drought on oribatids (Oribatida) species richness at Skogarby.

b. Litterbag experiment in Greece

The experiment focused on the impact of microclimatic differences between shrub covered and adjacent uncovered areas on litter decomposition rates at a Mediterranean site. There were 3 major phases of the decomposition process:

- initial phase of high mass loss rates,
- period of stability (no further weight loss), and
- second period of high mass loss rate.

Significant effects of mesh size were observed. Microbial biomass as well as microarthropod abundance and species richness had maximum values during the initial decomposition phase and subsequently reduced towards summer.

Accompanying experiments showed that decomposition was significantly affected by the biomass of lichens (Figure 3).

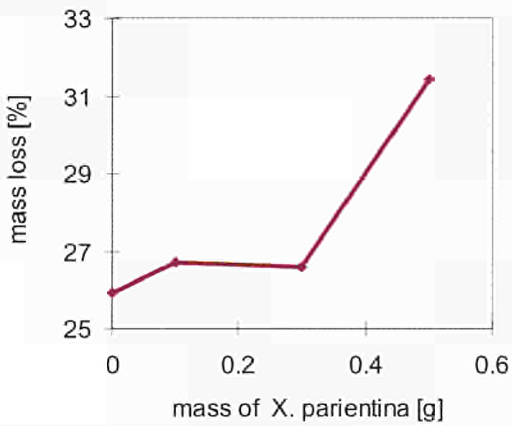

Figure 3: The effect of lichen biomass on litter decomposition.

c. Litterbag experiment: impact of litter quality on the colonisation by soil biota.

Six litter types were exposed in each of the two study sites (beech and spruce forest): freshly fallen and aged beech litter; freshly fallen and aged spruce litter; freshly fallen ash litter, cotton wool. Nematodes were significantly affected by litter quality. This effect was different between the 2 sites. The effect of litter age was related to the type of litter. Only for the beech litter differences in colonisation according to litter age were demonstrated. The results suggest that under the conditions of the experiment the abundance of the fauna groups was mainly influenced by litter quality.

Microcosms

A microcosm experiment was installed by the German group to quantify the impact of changes in microarthropod density on the soil community and on functional parameters. The results proof that microarthropods significantly affect other components of the decomposer food web (bacteria, nematodes, enchytraeids; Figure 4). This may have considerable back-loop effects on ecosystem functions. The hypothesis gained from the first joint litterbag experiment is thus confirmed.

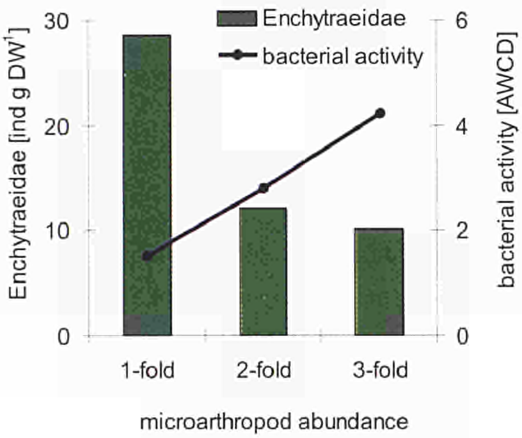

Figure 4: Influence of microarthropod abundance on enchytraeid density and bacterial activity.

GENERAL CONCLUSIONS

GLOBIS shows that strong responses of soil biodiversity and soil processes to climate and atmospheric input significantly impact the quantity and quality of soil organic matter. Anthropogenic forcing (climate change, air pollution) will probably have a similar effect. This is important for the long-term sustainability of the carbon reservoirs of soils, with consequences for agriculture, air and water quality, dispersion of toxins and biodiversity (Huber-Sannwal and Wolters 1998, Wolters 1997).

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PROTOS: Effects of climate on the dynamics of dissolved organic carbon (DOC) in European forest ecosystems

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BACKGROUND

A quantitatively important fraction of the total store of organic carbon (C) in forest ecosystems is in the soil. A considerable proportion of this has accumulated due to sorption of dissolved organic carbon (DOC), produced from fresh and partly decomposed tree litter. Current interest in the potential of forests to store organic C requires detailed understanding of the dominant processes of C transfer. These processes include production, transport, sorption and decomposition of DOC in soils. Apart from its relevance for the C budget, DOC in runoff water also represents a major hygienic problem where surface water is used as a source for drinking water. DOC in soils and surface water is also important with respect to its ability to bind and transport heavy metals and radio-nuclides in soils.

Both DOC and CO_2 result from the decomposition of organic matter. Decomposition of organic matter is a biological process and sensitive to climatic conditions. So far, little is known about the relative rates of production of CO_2 and DOC from organic matter in forest soils. Even less information exists on how the rates of production of CO_2 and DOC change with an increase in temperature. Transport and sorption of DOC depend on water transport rates. Few field studies exist where fluxes and concentrations of DOC are estimated in different parts of the forest ecosystem and where the potential effects of a change in climate on short-term and long-term dynamics of DOC and soil organic C stores are evaluated.

PROTOS OBJECTIVES

- Measure DOC concentration & flux and $DO^{14}C$ signals in different parts forest ecosystem
- Quantify various pools of organic C; determine ^{14}C signals
- Quantify effects climatic variations on DOC concentrations and fluxes in soils and runoff
- Identify parameters that control DOC fluxes
- Determine key parameter values in lab experiments
- Model organic C turnover & DOC transport

PROTOS RESEARCH SET-UP

- Field data all sites (DOC fluxes, ^{14}C, C pools, climatic variables)
- Lab studies production, decomposition, adsorption DOC
- Modelling DOC transport

PROTOS FIELD SITES

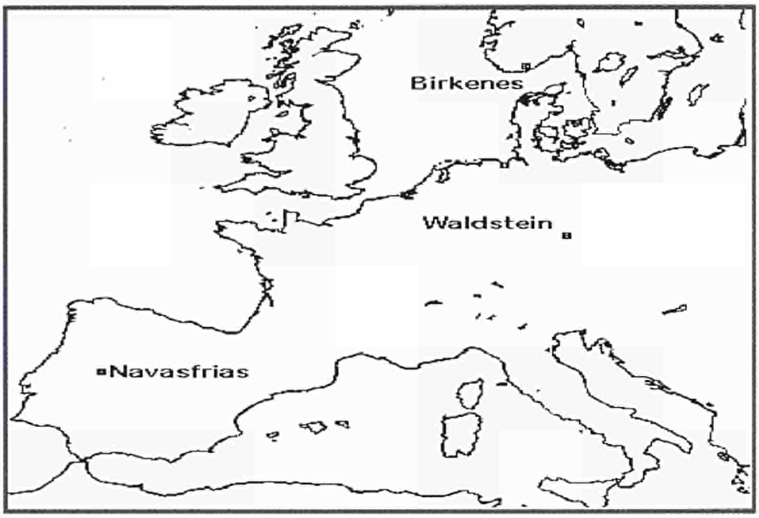

Figure 1. PROTOS field sites are at Birkenes (Picea abies), Waldstein (Picea abies) and Navasfrias (Quercus pyrenaica)

PROTOS MAIN FINDINGS

1. Fluxes of Dissolved organic carbon (DOC)

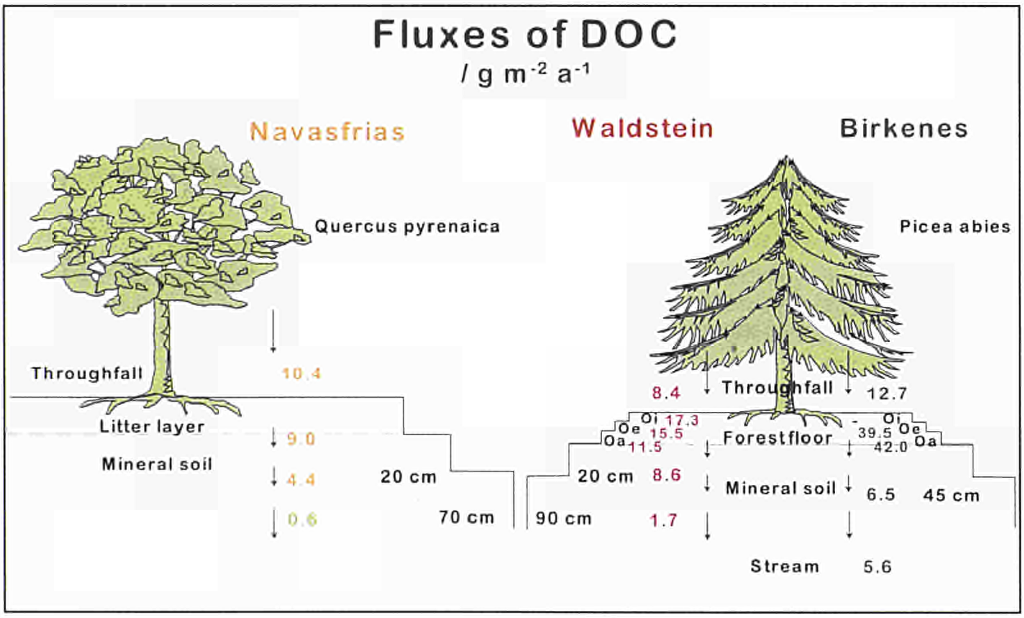

Figure 2. Fluxes of DOC at the three sites. Annual fluxes of DOC from the forest floor increase in the order Navasfrias < Waldstein < Birkenes. Particularly at the boreal Birkenes site the DOC fluxes are quantitatively important in the C budget (compare to litterfall of about 140 g m^{-2} a^{-1} organic C). Most of the DOC leached from the forest floor adsorbs in the mineral soil.

2. Effects of climate on short-term DOC dynamics in soils and streams

	DOC conc. soil	DOC flux soil	DOCconc, stream	DOC flux stream
Water transport rate	-	++	++[§]	++

Table 1. The flux of DOC in soil- and runoff water is largely determined by water transport rates. The decrease in DOC concentration in soil water at elevated water transport rates is due to dilution. At high runoff rates DOC concentrations in stream water increase considerably due to inputs of DOC-rich O horizon water. Particularly in the boreal forest at Birkenes an increase in temperature is associated with an increase in DOC concentration in soil water. Short-term effects (months) of temperature on DOC fluxes in soil water and on concentrations and fluxes of DOC in stream water are only marginal.

[§]At runoff rates approaching zero the concentration of DOC increases rapidly probably due to in-stream or near-stream processes associated with a decrease of the water table (see also Fig. 3).

3. Prolonged dry periods result in marked peaks in DOC concentration in runoff

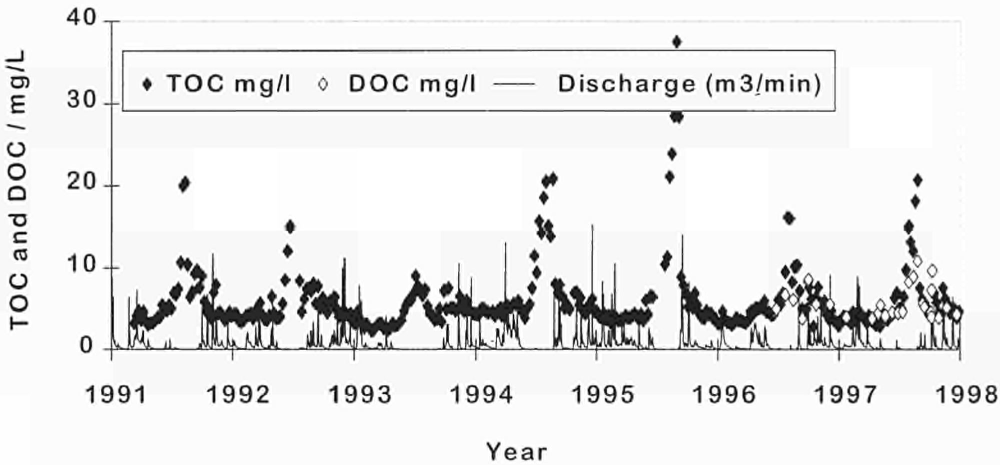

Figure 3. Concentrations of TOC and DOC in stream water at Birkenes range from 2 mg/L at base flow to about 12 mg/L at peak flow. Only at discharge rates close to zero DOC concentrations increase to values between 15 and 40 mg/L. These concentrations represent a major hygienic problem for drinking water companies utilising surface water.

4. Dynamic modelling of DOC transport

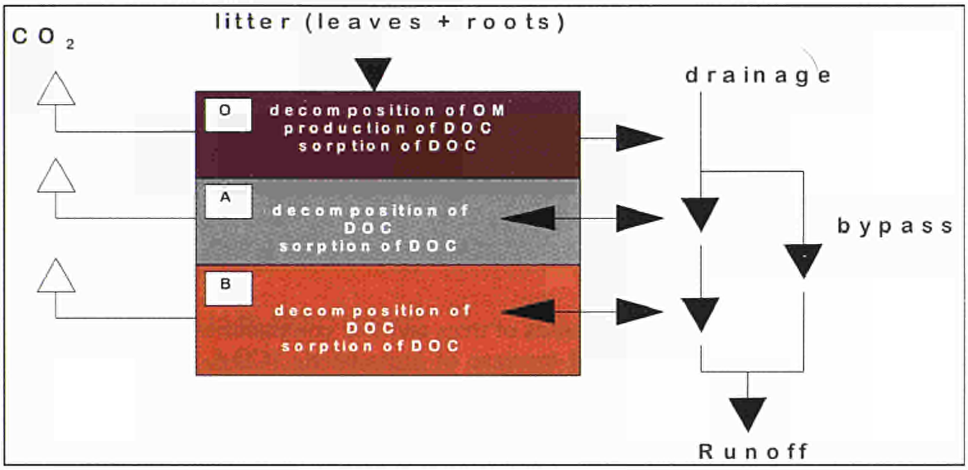

Figure 4. The model DyDOC is a self-consistent framework for observations and concepts of PROTOS relating DOC fluxes to other fluxes of C. C^{14} signals in DOC and in soil organic C pools are of major importance for model parameterisation. DyDOC simulates short-term and long-term dynamics of DOC and will be used to predict effects of climate change.

POLICY IMPLICATIONS

- Predicting long-term changes in the pool of organic C in mineral forest soils as induced by changing climatic conditions requires understanding of the long-term dynamics of DOC.
- Proper management of surface water resources for drinking water requires understanding of the dynamics of DOC in catchments in response to climate change.
- Short-term changes in DOC concentrations and fluxes in soil- and stream water reflect variations in climatic conditions.

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A FACE experiment on short rotation, intensive poplar plantation: objective and experimental set up of POPFACE.

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INTRODUCTION

The mechanistic and process-based responses of trees and tree communities to global change, particularly in response to the predicted increase of atmospheric [CO_2], will be crucial in determining the ability of woody plantations and natural forests to sequester carbon at the global scale (Jarvis 1998). This in turn will have feedback effects where tree stands may influence climate at a regional and global scale and therefore influence the process of environmental change at these different scales (IGBP 1998). Despite the key role played by trees and forests within the terrestrial biosphere, we still have very limited information on the total responses of agro-forestry and forest systems to enhanced CO_2 because of the complex web of possible interactions (Saxe et al. 1998; Catizzone 1999). The few studies conducted at the whole-tree and community scale indicate that there will be a marked increase of primary production, but this increment will be mainly allocated into below-ground biomass. However, the proportionality of this response may well depend on nutrients and water availability in the soil and, also, on genotypic characteristics.

Another critical point to be clarified concerns the implications of below-ground carbon allocation for long-term carbon storage. The enhanced carbon transfer to the root system may be used mainly to increase root respiration or, otherwise, to permanently augment the amount of root dry matter and the mycorrhizal activity. The water balance of agro-forestry systems is a key process to understand the coupling of the biosphere and atmosphere responses to CO_2. The possible effects of changes of stomatal activity and leaf area production on whole-stand transpiration need to be precisely assessed and quantified. The responses of trees and forests to enhanced CO_2 will ultimately depend on the interactions connecting the different organisms that compose the complex trophic webs of such systems.

A fundamental issue of the research on global change effects on terrestrial biosphere is the need to appropriately design the experiments to be conducted at the community and ecosystem level (DeLucia et al. 1999). The FACE technology has the great merit of not altering the general microclimate of the test area and allows to conduct the research on impacts of global change truly at the ecosystem level (Hendrey et al. 1993); however, FACE facilities should be combined with adequate forest tree systems in order to avoid such drawbacks as lack of replication, large genetic variability and delayed response of already adult trees.

This research is unique because it combines a fast growing, agro-forestry ecosystem, capable of elevated biomass production, with a large-scale FACE system, the only one available in the European Union on a forest tree stand. The FACE facility is located close to a natural CO_2 source and is drawing scientists from several European countries to co-operate closely and combine their scientific efforts on the same experimental system.

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* With contributions from N. Anselmi (Univ. Tuscia, I), S.P. Long (Univ Essex, UK), D. Godbold (Univ. Wales at Bangor, UK), N. Van Breemen (Wageningen Agricultural Univ., NL), G. Taylor (Univ Southampton, UK) and A. Polle (Univ. Gottingen, D).

OBJECTIVES

The main objective of this experiment is to determine the functional responses of a cultivated, agro-forestry system, namely a multi-clonal poplar plantation, to actual and future atmospheric CO_2 concentrations, and to assess the interactive effects of this anthropogenic perturbation with the other natural environmental constraints on key biological processes and structures. Additionally, this project will yield data relevant to assess the potential for increasing the carbon sequestering capacity within European Union, using such forest tree plantations. This project, therefore, combines the FACE technology with the study of mechanistic and process-based responses of a forest tree plantation, used as a model. Tree plantations represent a particular type of intensively managed ecosystem where the emphasis is placed on maximising biomass production over a relatively short time-scale (Stettler et al. 1988).

Specific questions to be addressed are:

- Is above-ground biomass production stimulated during a long-term exposure of a fast-growing tree stand to elevated [CO_2] and will C-allocation patterns change in relation to N-treatment and genotypic differences?
- Does the exposure to elevated [CO_2] affect both leaf cell production and expansion?
- Will elevated [CO_2] increase leaf area duration and LAI of poplar stands because of a better adaptation of foliage to shade?
- Does elevated [CO_2] decrease leaf stomatal conductance but not canopy transpiration?
- Will fine roots production and turnover increase in response to [CO_2] enrichment, specifically in the low N-treatment?
- Will elevated [CO_2] exposure increase carbon accumulation into the soil and nitrogen utilization efficiency?
- Will insects performance decline under elevated [CO_2] and will pathogens virulence be differently affected in biotrophic vs. weakness fungi?

The same model ecosystem, included within a FACE facility, will be concurrently utilized by eight scientific laboratories and institutions from five European countries. The co-ordinated research effort will utilize complementary skills from the various groups to ensure an integrated project where the following tasks will form the core activities throughout the three-year study:

- Task 1: Implementation and management of the FACE facility
- Task 2: Carbon metabolism at leaf and stand scale
- Task 3: Water balance and transpiration
- Task 4: Canopy structure and light utilisation
- Task 5: Soil processes and nutrient interactions
- Task 6: Roots processes and mycorrhizal functioning
- Task 7: Host-parasite interactions

EXPERIMENTAL SET-UP

The POPFACE experimental site has been established near the city of Tuscania (VT, Italy), on an agricultural field, 9 ha wide. GPS-co-ordinates of the experimental field site are: 42°37'04" N and 11°80'87" E; the elevation is 150 m. The facility consists of six circular experimental plots, each 314 m^2 wide. Three of these plots are treated at 550 ppm of CO_2

concentration, the forecasted concentration for the middle of the next century, whereas the remaining plots are at ambient CO_2 concentration. The plantation was realized in spring 1999 utilising 30-cm long hardwood cuttings of three different poplar species, *Populus alba*, *P. nigra* and *P. x euramericana*; plant spacing is 1 x 1 m^2 within the plots and 2 x 1 m^2 in the remaining plantation, according to the principles of a high density, short rotation culture. The entire area and all plants will be irrigated by drip irrigation throughout the project. There will be two fertilization treatments, i.e. low nitrogen (N) and high nitrogen (HN), starting from the second year onwards. The planting design within the rings will be a radial, sectorial design. The nitrogen fertilization treatments will be rotated with regard to the E-W direction. Each ring (314 m^2) has 6 sectors (three clones, two N-treatments) yielding 52 plants per sector. 24 assessment plants per sector and per clone. Within each clonal sector a permanent growth plot made of 6 trees will be selected to closely monitor, by means of non-destructive measures, the growth and the crown development of the trees in the plantation.

Plate 1: The CO_2 supply system of POPFACE.

The site is equipped with a 25 ton container for liquid CO_2 and with 3 vaporizers; CO_2 will be supplied every 3 to 4 days with a truck, from a natural source located 40 km away. Electrical power was brought to the site with a connecting line 1 km long. Irrigation is assured by a series of dripping tubing, 50 km long in total

The design of the FACE system was optimized by the use of a gas dispersion model based on the principles of Computational Fluid-Dynamics (CFD). The model that was specifically developed for POPFACE showed, in fact, that a significant improvement of a "pure CO_2" FACE system is achievable by enhancing the velocity of the CO_2 gas released from a number of thin nozzles located upwind of the fumigated area. In fact, when the gas is released at a velocity that approaches sonic speed, the turbulent mixing between air and CO_2 is greatly enhanced, and such improved mixing was demonstrated both by the model results and by a series of direct measurements made in the laboratory and in the field. The POPFACE-CFD model, which is now fully implemented, permits calculation of the exact amount of gas which is released by each venting hole and its speed; it can calculate the forced air-CO_2 mixing and can compute gas dispersion downwind of the releasing pipes. The effect of different weather conditions, of canopy height and distribution of the CO_2 releasing point on the gas dispersion is also simulated. Based on detailed information on canopy height and leaf area density (LAD), the model determines in fact the vertical wind profiles within and above the canopy, it calculates turbulent kinetic energy created by the vegetation and turbulence dissipation (K-epsilon model), and compute gas dispersion from any given CO_2 mass source. The model may also be used in a "predictive" mode to investigate the effect of changes in the weather conditions turbulence and canopy structure on gas dispersion; Accordingly it may be used to optimise the spatial arrangement of the releasing points as well as the amount of CO_2 that has to be injected to reach target concentrations. The model may be finally used to calculate the total amount of CO_2 required for the fumigation as a function of canopy development and height and the prevailing weather conditions at the site.

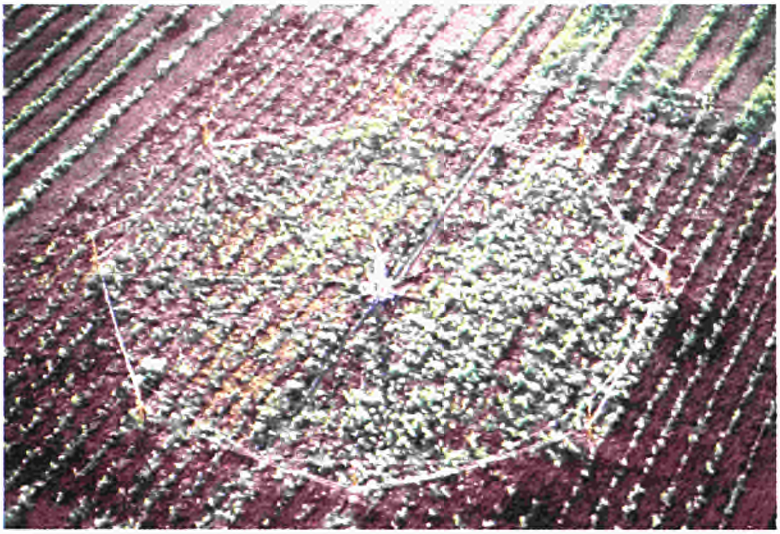

Plate 2: Aerial view of one of the FACE rings.

The FACE rings, surrounding the three, $[CO_2]$-enriched experimental plots, have an octagonal shape enclosing a circular area of 22 m of diameter. Each ring consists of eight vertical telescopic masts that can be pneumatically erected up to 12 m above ground, of 16 horizontal polyethilene pipes (25 mm diameter) bearing a variable number of small holes (33 to 43 holes per meter). Each hole has a diameter of 0.3 mm. 16 on/off solenoid valves which are located at the centre of the rings actuate the directional control of the releasing pipes. The amount of CO_2 that is eventually vented out by the horizontal pipes is modulated by means of an automated pressure regulator with an operational range from 0 to 10 bars. The POPFACE computer that is located in the centre of each FACE ring controls both the on/off valves and the pressure regulator. Each ring is equipped with an independent computer that can store the data in an internal 512K memory or send them to a remote system through an optically isolated RS422 serial connection. The transmitted data are stored in the HDD of a desktop computer located in the "service area" of the installation. Two IRGA's, an anemometer and a wind vane per ring are the monitoring devices which are used to control the whole FACE system via a PID (Proportional Integral Differential) algorithm corrected for wind speed.

PRELIMINARY RESULTS

A total of 900 cuttings per each of the three experimental clones of *Populus nigra*, *P. alba* and *P. x euramericana* were planted in all the 6 experimental plots. In the rest of the plantation about 40,000 cuttings of *P. x euramericana* were utilized. Rooting of the cuttings has been successful (99% for the black and hybrid poplars, something less, about 90%, for the white poplar); failures have been immediately replanted.

The performance of the FACE fumigation system is sufficiently satisfying although it needs some further tuning; more than 80% of the data points of [CO_2], measured at the centre of each ring, fall within +/- 10% of the set value of 550 ppm and more than 90% of the points fall within +/- 20% of the same set value.

The field campaigns of integrated data collection involving the different research groups have already started in summer 1999 and will continue at least until the third growing season of the short rotation-forest stand, when the poplar trees will come close to their harvesting time.

ACKNOWLEDGMENTS

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Sulfonates in European soils: the SUITE program

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INTRODUCTION

Aromatic sulfonates are interesting compounds from several points of view that are of relevance for development of sustainable environment policy in Europe. These compounds are common synthetic chemicals that are released into the environment in large quantities as e.g. surfactants, dyestuffs or cement additives (Cook *et al.*, 1998), and an understanding of their biodegradation in the environment is therefore of critical importance. Whereas the toxicity of these compounds is relatively low, some are persistent and appear in bank filtrates, therefore representing a potential problem in maintaining drinking water quality. In contrast to this role as xenobiotics, sulfonates also constitute a major component of the sulfur content of natural soils, making up more than half of the total sulfur in agricultural or forest soils (Autry & Fitzgerald, 1990). The sulfonate constituents of soils have not yet been characterized at a molecular or structural level, and they may arise in part from plant sulfolipid in litter, and in part via reactions of sulfide and polysulfide with lignin-derived polymers as part of early diagenesis. These sulfonates play a considerable part in the soil sulfur cycle, and the organically bound sulfur they contain has been shown to be slowly released into the sulfate pool with time.

OBJECTIVES

The objectives of the SUITE program are to investigate the capacity of European soils, and the bacterial populations they contain, to metabolize both natural and xenobiotic sulfonates as part of the sulfur cycle. The soils to be studied will include soils representative of different climatic zones of Europe, and carrying different vegetative cover. The program has the following main objectives, which are being worked on by a consortium of microbiologists, biochemists, soil scientists and analytical chemists:

- Identification of the genes responsible for sulfonate transformation as part of the sulfur cycle in aerobic and anaerobic bacteria,
- evaluation of the expression of these sulfonatase genes in pristine and contaminated soils from across Europe,
- correlation of sulfonate metabolism in the studied soils with the sulfur status of the soils and with soil sulfur cycling,
- development of new analytical methods for analysis and structural characterization of natural soil sulfonates,
- evaluation of the capacity for degradation of xenobiotic sulfonates in pristine and contaminated soils.

RESULTS

The SUITE program commenced in May, 1998, and the results presented here therefore represent the first year of the program. Much of this first year has involved methods development. The main outputs from the program with relevance for policy development are not expected until the methodological results of the different work packages can be combined, in order to ask important interdisciplinary experimental questions.

Some important results obtained are:

- The rate of organosulfur turnover differs dramatically in soils from different climatic zones in Northern and Southern Europe. Soil arylsulfatase levels were used as a marker of soil sulfur cycling, and found to be much higher in a pristine Italian beech forest soil than in an equivalent soil from Denmark. Temperature dependence of sulfur turnover (measured as S^o-oxidation) was determined in Danish soils, and will be extended to other European soils.
- The genes involved in sulfonate metabolism in a typical aerobic soil bacterial species (*Pseudomonas putida*) have been identified and characterized (Vermeij *et al.*, 1999). These encode a novel type of desulfonative oxygenase, and closely related genes have been found in a number of related strains isolated from contaminated and uncontaminated field sites.
- Anaerobic bacterial species including a *Clostridium beijerinckii* strain have been identified that can grow with sulfonates as sulfur source (Denger & Cook, 1999). This species responds to growth with toluenesulfonate by synthesizing a set of additional, sulfate starvation-induced proteins. Cloning of the genes encoding these proteins is under way.
- Methods have been optimized for isolation of RNA from soils in a form that is useful for gene expression measurements using reverse transcriptase-PCR (RT-PCR). Characterization of the expression levels of the *Pseudomonas* desulfonative oxygenase genes mentioned above has begun, using standardised soil samples.
- Analytical methods have been developed for the extraction and analysis of sulfonates and their desulfonation products from soil samples. These include methods for cleanup (solid phase extraction) using graphitized black and styrene-divinylbenzene co-polymers, derivatization methods (addition of a fluorescent chromophore to the extracted sample) and optimized ion-pair reversed-phase HPLC (IP-RP-HPLC) separation using tetra-*t*-butylammonium bromide as ion pair reagent.

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Preliminary results of the BERI project: Effects of elevated CO_2 and N deposition on plant dynamics and CH_4 emissions of five European bogs

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OBJECTIVES

The Bog Ecosystem Research Initiative (BERI) project studied, at five climatically different sites across Europe, the effects of elevated CO_2 and N deposition on plant dynamics and CH_4 emissions.

METHODS

At each experimental site (1 through 5 on the map, Figure 1) the following four treatments were replicated five times:

- Elevated CO_2 (560 ppm) in Mini-FACE rings;
- Mini-FACE rings venting ambient air;
- Plots receiving extra N (NH_4NO_3, 3 g N m^{-2} yr^{-1});
- Control N-plots.

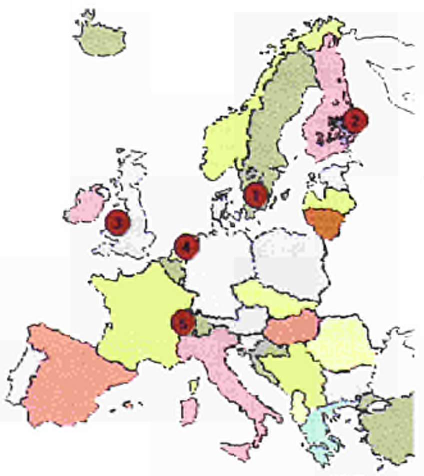

Figure 1. BERI experimental sites in bog ecosystems.

RESULTS

Plant dynamics

Preliminary analyses showed no significant elevated CO_2 treatment effect on the growth of *Sphagnum*, except for the Dutch site where *Sphagnum* length growth increased. No significant treatment effects on the above ground biomass of vascular plants were found. All data will be analyzed in more detail with the use of co-variables like water level and species composition.

There are indications of interactions between peat mosses and vascular plants as a result of elevated CO_2 and N treatments at the NL site. *Sphagnum* length growth was 33% higher under elevated CO_2. Elevated CO_2 also stimulated growth of most vascular plant species, but not the growth of the species *Vaccinium oxycoccus* and *Drosera rotundifolia* which are growing close to the moss surface. *Drosera* almost disappeared from the elevated CO_2 plots, as a consequence of the high *Sphagnum* length growth.

Above ground vascular plant biomass at final harvest was 53% higher under elevated N at the Dutch site. During the third growing season *Sphagnum* length growth was significantly reduced under elevated N due to increased shading by vascular plants (Figure 2).

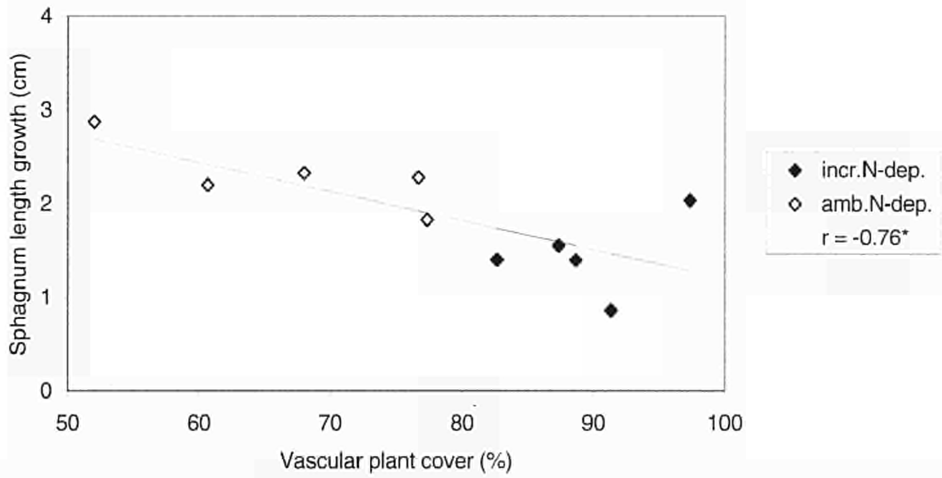

Figure 2. Relation between *Sphagnum* length growth and vascular plant cover at the Dutch site (p = 0.011).

Methane emission

During the summers of 1997 and 1998, CH_4 emissions increased under elevated CO_2 treatment with 4, 15, 20 and 33 % in the Swedish, Finnish, Swiss and Dutch sites, respectively (Figure 3).

The Finnish and Swedish sites showed higher CH_4 emissions under elevated N, while at others sites lower emissions were observed. Further analyses will include environmental factors like water table and temperature.

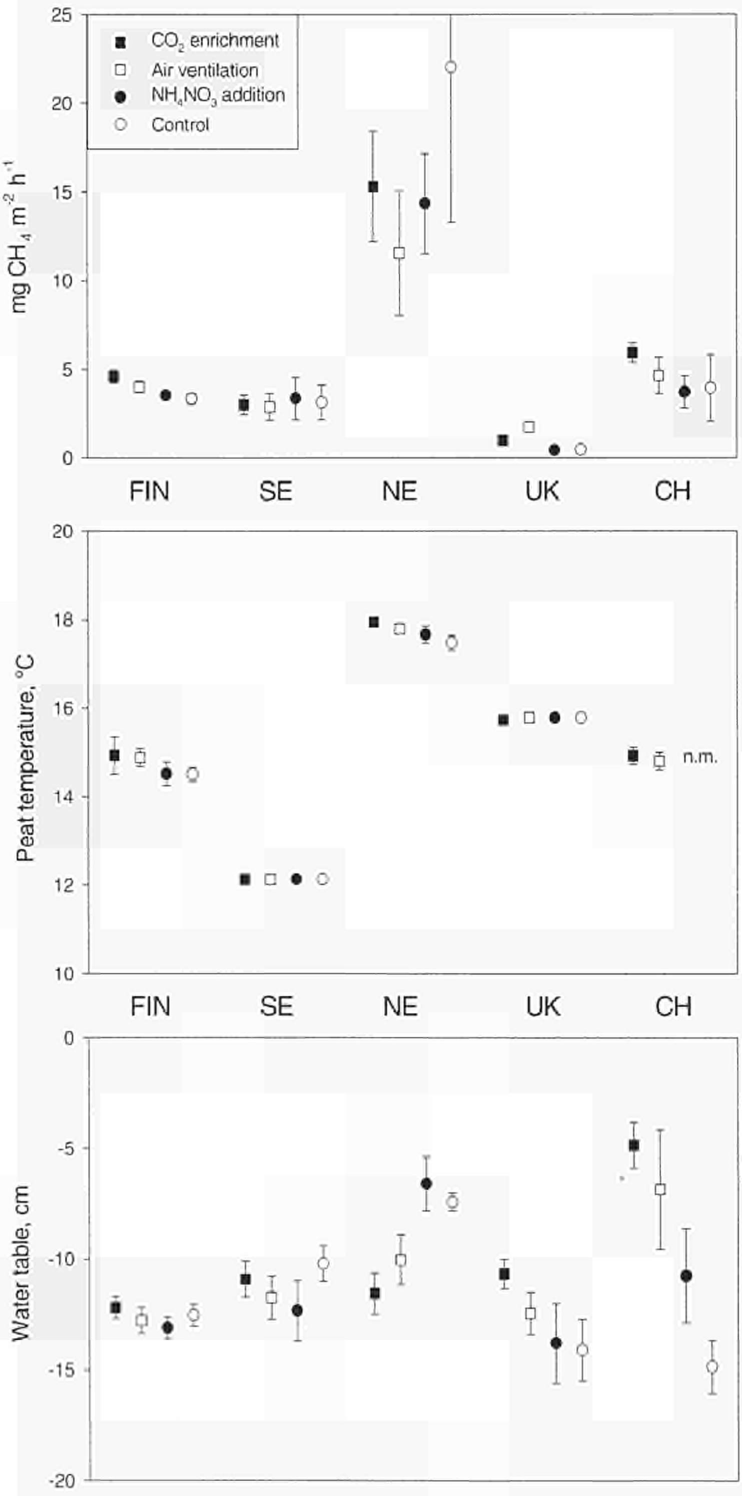

Figure 3. Effects of elevated CO_2 and N treatments, as well as effects of peat temperature and water table, on CH_4 fluxes during the periods 15/6 - 15/8 of 1997 and 1998.

CLIMOOR* - Climate driven changes in the functioning of heath and moorland ecosystems

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Field scale experimental warming and drought in heath- and moorland ecosystems in Denmark, Wales, the Netherlands and Spain play the key role in the project. Manipulations are conducted by flexible and removable curtains and the effects of the treatments on plants, soils, water quality and trace gas exchange are investigated.

BACKGROUND

Anthropogenic emissions of CO_2 and other green-house gases are predicted to lead to increased temperature and other global changes. Historical records show the co-occurrence of elevated atmospheric CO_2 and warmer global temperature (Watson et al. 1991; Luxmoore et al. 1993). Model predictions have further projected an increase in global mean surface temperature of 1-3.5 ^{o}C based on scenarios of increases in concentrations of CO_2 and other green-house gases (IPCC, 1995). Along with these changes a more vigorous hydrological cycle is expected leading to more severe droughts and floods (IPCC, 1995). CO_2 enrichment and warming in combination with the predicted changes in rainfall pattern will have a large influence on the functioning of natural and semi-natural environments both directly and through interactions with land management and pollutant loading (IPCC, 1990).

Temperature and water are main drivers for many biological and chemical processes and thereby for ecosystem functioning. Recent studies in terrestrial ecosystems have shown that elevated temperatures affect the overall C storage in the ecosystems (Cao and Woodward, 1998; Lindroth et al., 1998) and have potential to change the ecosystems from being sinks to being sources for carbon and nitrogen (e.g. Wright et al., 1998). Increased frequency of summer droughts may have profound effects on soils and water quality through the effects of soil organic matter turnover (Freeman et al., 1993). and the resistance and resilience to drought stress may be affected by plant species richness (Tilman and Downing 1994) which may decline because of warming (Farnsworth et al., 1995; Chapin et al., 1996) and elevated atmospheric nitrogen loading (Bobbink et al. 1993). However, the effects of global change on ecosystem functioning and storage and fluxes of C are still uncertain. Consequently, CLIMOOR is designed to investigate the effects of warming and drought on ecosystem functioning of heath and moorland ecosystems.

The objectives of CLIMOOR are:

- To identify the effects of temperature and reduced summer rainfall on the functioning of non-forested semi-natural ecosystems, in particular the effects on:
  - organic matter production and turnover
  - carbon allocation
  - drainage water quality
  - gaseous losses of C and N
  - plant growth and biodiversity
- To relate results across the sites to climate and nitrogen and sulfur deposition

* CLIMOOR was initiated may 1st 1998 in the 2nd tranch of projects funded under EU's 4th framework programme Contract number ENV4-CT97-0694

- To carry out a qualitative assessment of the risk of changes in functioning in low vegetation ecosystem to predicted climatic change

SITES AND MANIPULATIONS

The manipulations are carried out at 4 sites heath and moorland sites in Mols, DK; Oldebroek, NL; Clocaenog, UK and Garraf, ES. Heath and moorland ecosystems have been chosen because they represent an important nature resource which will be very sensitive to the changes in climate and pollutant loading observed and predicted for the future. The heath- and moorland ecosystem may further serve as a good "model-ecosystem" for climate driven changes in natural and semi-natural terrestrial ecosystems.

The sites span a gradient in the loading of the most important impact factors to be studied, temperature, precipitation and N-deposition (Table 1). In this way the sites represent the span in the main impact factors given by European conditions and the combination of gradients and experimental manipulation of the temperature and water will allow the evaluation of the interaction of effects of temperature, precipitation and N-deposition.

Sitename Country	Mols DK	Clocaenog UK	Oldebroek NL	Garraf ES
Temperature (^oC)	6-8	5-7	7-9	15
Prec. (mm)	500-600	1500-2000	700	500-600
Soil	Sandy podzol	Peaty podzol	Sandy podzol	Calcareous
Vegetation	Calluna Vulgaris Desch. Flexuosa	Calluna Vulgaris Desch. Flexuosa Vacc. Myrtillus Empetrum nigrum	Calluna Vulgaris Desch. Flexuosa Mollinia caerulea	Erica multiflora Globularia alypu
N-input (kgN ha^{-1})	18-22	20-25	30-40	5-7

Table 1. Main site characteristica for CLIMOOR sites

The combination of geographical transects and experimental experiments is essential because understanding and predicting the impact of future global change on ecosystems requires whole-ecosystem experiments (Mooney et al 1991) whereas longer term responses in vegetation patterns have shown closer correspondence to distributions along environmental gradients (Chapin et al., 1995).

The manipulations

Global warming is basically caused by a reduced loss of long wave IR-radiation from the earth back into the atmosphere because of the green house gas accumulation in the atmosphere. Therefore warming will mainly occur at night as supported by recent analysis of global temperature records showing that the global temperature increase of 0.3 to 0.6 ^oC observed up till today has been due to larger increases during night compared to increases during the day (IPCC, 1995). At the same time changes in the input of water are predicted leading to prolonged and more sever drought periods during the summer and eventually more water inputs during the winter (IPCC, 1995). Therefore CLIMOOR focuses on studying the effects of night-time warming on the ecosystem by reducing the IR radiation from the vegetation (3 plots per site) and reduced water input due to prolonged summer drought situations (3 plots per site).

Warming treatment

Ecosystem manipulation with warming has been carried out in a large number of projects during the last decade by various methods many of which have restricted applicability due to artefacts (Schulze et al., 1999) or ecosystem specific design like the small OTC's used in the arctics (Marion et al., 1997). Consequently many existing methods are unrealistic as tools to study whole ecosystem responses, especially in ecosystems with larger plants. Alternatively, CLIMOOR employs warming by radiative coverage of the vegetation at night anticipated to closely mimic global change (Luxmoore, 1994) with very little disturbance. It has been applied recently with an effect of warming the soil and plants in the order of 2°C (Rich Alward, pers. communication) and is used at all CLIMOOR sites. The warming plots are 20 m^2 covered by a light scaffolding carrying the reflective aluminum curtain. The curtain is coiled on a beam and connected to a motor. The motor is activated automatically according to the following preset climatic conditions:

- Light intensity – a light sensor registers the light intensity. When the sun sets the curtain i drawn over the vegetation to reduce the IR reflection. This is the basic heating principle.
- Rain – in order not to disturb the hydrology in the plots a rain sensor will activate the removal of the curtain in case of rain during the night. When the rain stops the curtain will automatically be drawn over the vegetation again.
- Wind –to avoid damage to the curtain and the whole set-up, a wind sensor will activate the removal of the curtain in case of high winds (>10 m/s) during the night. When the wind calms the curtain will automatically be drawn over the vegetation again.

Results from a test roof established in Denmark and the first results from the installed roofs show two important results:

- the heating effect varies substantially dependent on the weather conditions, but in general a temperature increase of 2°C is obtained (Fig. 1).
- the edge effect is very small meaning that the roofs seem to warm the vegetation and the upper soil effectively to the border of the roof.

Drought treatment

The drought treatment is carried out for a 6-10 week period in the spring or summer. The drought plots are constructed similar to the warming treatments except that the curtain material is a transparent plastic and that the moving of the curtains are governed by the rain and wind only. During the drought period the rain sensors will activate the curtain to cover the plots whenever it rains and remove the curtains when the rain stops. Also here the curtains will be removed automatically if the wind speed exceeds 10 m/s. For the part of the year without drought treament the drought plots are run parallel to the control plots.

Control

Parallel to the treatment plots 3 untreated control plots are put up for comparison.

EFFECT STUDIES

The focus of CLIMOOR is on changes in dynamics of soil organic matter and the consequences for the pools and fluxes of carbon and major nutrients. Soil organic matter is a major store of carbon and nutrients in the soil and has importance for soil physical properties. Changes in soil organic matter dynamics may have many consequences and thus should be considered within the context of over-all ecosystem functioning. Furthermore species composition is an important issue, since global warming and altered hydrology will lead to changes in competitiveness of many plants, especially in vulnerable ecosystems and plants and ecosystems existing at the edge of their ecological niche (IPCC, 1995). The effects of the manipulations on the ecosystem functioning are investigated. the work includes:

Plant response

Yearly monitoring of plant responses to climate-manipulation treatments in terms of: plant cover (point quadrat), growth, phenology, leaf properties, light interception, canopy reflectance, leaf gas exchange, plant chemistry, litterfall, and litter quality.

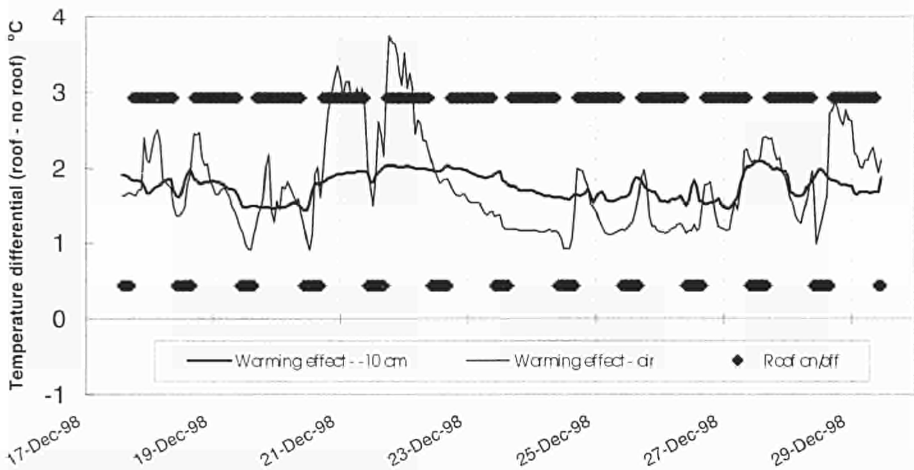

Figure 1. Temperature differential in the air and the soil (-10 cm) between CLIMOOR roof covered heating plot and control plot during 12 days in December 1998.

Soil Response

Decomposition processes are hypothesised to be the main processes affected by the heat and the drought. Litter decomposition of the main plant species is studied by the litterbag method. Soil N mineralisation is studied by the soil buried bag technique or by resin bag technique.

Trace gas emission

Effects of warming and drought on trace gas emissions are studied campaign wise. Exchange of CH_4 and N_2O between the ecosystem and the atmosphere is studied by static chamber measurements. Ecosystem exchange of CO_2 is studied by static chambers including the dominant plant species and soil respiration is measured by small chambers on bare soil.

Water chemistry

Changes in the soil water chemistry, especially increased leaching of nitrogen, are anticipated to be sensitive indicators for changes in the decomposition processes. Water chemistry is measured monthly by precipitation collectors, soil water samplers collecting soil water from the humic layer and soil water below the root zone and measurements of soil water content.

Carbon allocation

Possible changes in the allocation of carbon within the dominant plant species are studied by an on-site ^{14}C pulse labelling experiment. Plants are transferred to PVC-columns and labelled by ^{14}C and ^{15}N. Subsequently total carbon and ^{14}C content in shoots, roots, and soil are determined after wet digestion. A carbon budget is calculated including total net ^{14}C-uptake and distribution of ^{14}C among shoots, roots, soil and root/soil-respiration.

Risk assessment

Based on the results from the field experiments a qualitative risk assessment will be conducted to assess the potential effect of global change on the carbon storage and biodiversity of European heath and moorlands

CLIMOOR – SOCIO-ECONOMIC BENEFITS

It is the intention that the results from CLIMOOR can play a valuable role in formulating policy to:

- optimise land use and landscape planning, balancing nature conservation, agriculture, tourism and recreation in an environmentally sustainable way
- limit the environmental impacts from transport, energy production and other industrial sectors
- limit the environmental impacts of water use and abstraction within the context of changing global climate.

In order to guide the project and to obtain the optimal benefit of the effort an advisory board has been formed consisting of 2 researchers with links to the global change area and 1 person from the industry sector.

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Information

Information about activities, methods and progress of the project are provided on the CLIMOOR homepage: WWW.RISOE.DK/CLIMOOR

CONGAS: Biogenic controls on trace gas fluxes in northern wetlands†

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OBJECTIVES

The main objective of the present project is to study the biological, physical and chemical controls on methane emissions in northern wetlands from the process level to landscape and larger scales.

The objectives of the individual Work Packages are:

1. To quantify biological, physical and chemical controls on the C-budget of the plant-soil-microbe system and in particular biological (including physiological) controls of C-fluxes leading to CH_4 and CO_2 emission under different environmental conditions (temperature, moisture and mineral nutrient contents of soil, radiation balance). A small scale mechanistic model will be calibrated and tested in a hierarchy of laboratory experiments on (i) substrate-amended soil samples, ii) individual/separate plants and iii) plant-soil microcosms maintained under pulse or/and continuous input of $^{14}CO_2$ and fully controlled environmental conditions simulating those *in situ*.
2. To quantify the biological, physical and chemical controls on the dynamics of CH_4 and CO_2 exchange rates *in situ* through comparable measurements of seasonal variations, and responses to environmental manipulation (shading), at a number of sites with different vegetation, soil chemistry and climatic conditions. The sites will be along a transect from NE Greenland over Iceland, N Sweden, N Finland to West Siberia. Further to simulate the observed field dynamics using the mechanistic model developed under WP 1.
3. To validate the linkage between process studies and larger scales through micrometeorological (and chamber-) flux measurements of H_2O, CO_2 and CH_4 in combination with measurements of hydrological and plant-related subsurface parameters at an intensive study site (W Siberia). Modelling the subsurface physical and biological processes (in linkage with objectives mentioned above) is of pivotal importance here and the aim is to cover a long enough period to evaluate seasonal dynamics and contributions to annual flux budgets. Further to develop landscape models of CO_2 and CH_4 exchange with input parameters as prioritised in the field and laboratory work described above. These models should be validated against comparative data on seasonal dynamics as obtained with chamber (WP 2) and micrometeorological techniques at the field sites.
4. To develop large scale models based on the dynamic landscape model developed under WP 3 for coupling of methane/plant production dynamics with large scale vegetation/NPP

† European Union contracts ENV4-CT97-0583 (partners 1-7) and IC20-CT98-0107 (partner 8).

models. The aim is to further develop an established model and improve the geographical data-sets used for large scale extrapolations. Hence, the improvement of large scale models under WP 4 are ultimately based on the sensitivity studies at the earlier stages (WP 1 - 3).

Specific objectives for CONGAS 1998-1999

1. To initiate laboratory incubations of peat monoliths and detailed analyses of subsurface concentrations of gases, organic compounds and processes including methanogenic and methanotrophic potentials (WP1).
2. To initiate the evaluation of existing small scale models for the integrated modelling use in CONGAS (WP1).
3. To establish experimental plots and manipulations at five different northern wetland sites and carry out routine measurements of gas fluxes and a number of environmental parameters (WP2).
4. To establish a weather station and carry out an initial survey at the intensive study site in Siberia.
5. To prepare for initiation of the work on integrated modelling.

Specific objectives for CONGAS 1999-2000

1. To conduct ^{14}C labelling experiments on peat+live plant monoliths under controlled conditions with the objective of following the carbon flow from fixation as CO_2 through the plant-root-microbial system through to the ultimate release as respired CO_2 and CH_4. (WP1)
2. To continue the shading experiments at all sites during the full 1999 growing season.
3. To conduct three major intensive campaigns at the Plotinikovo site in West Siberia measuring energy, CO_2 and CH_4 fluxes simultanouosly.
4. To intiatite the work on integrating models at a the different scales of study.

MAIN ACTIVITIES UNDERTAKEN

Laboratory experiments (WP1)

Peat monoliths have been brought in from a boreal peatland in southern Sweden and intensive work has been carried out in Lund on preliminary shading experiments and preparatory system tests for the ^{14}C labelling experiments.

An initial set of monoliths were brought to the lab in the autum of 1997 and used for an experiment testing the effects of shading on the photosynthesis, net ecosystem carbon exchange and CH_4 emissions. Subsurface concentrations of organic acids were also analysed. The results from this preliminary experiment has been reported in Joabsson et al. (in press).

A second set of 12 peat monoliths (25x25x40 cm) were brought in from the Kopparås mire in October 1998. Six were taken through an artificial winter (freezing) and six were kept in a greenhouse at ambient temperatures. Three of each of the ”winter” and ”no-winter” monoliths were clipped (vascular plants only). The purpose of these treatments were to test which monoliths would have the most vigorous growth after a limited number of weeks and those would then be used in the ^{14}C labelling experiments. It turned out that the clipped cores at ambient temperatures were most healthy and they are currently being set up for use in the ^{14}C labelling experiments.

One of the frozen monoliths was used for a thaw experiment also testing the closed continouos flow system which was developed during the autumn of 1998 in preparation for the ^{14}C labelling experiments. The main conclusion from this pilot experiment is that it is possible to monitor continuously for several weeks CO_2, CH_4 and N_2O exchange in a completely closed chamber system using an INOVA 1312 photoacoustic multigas analyser (aquired on separate grant from Swedish Natural Sciences Research Council). The actual thaw experiment data are too new to elaborate on the interpretation of but they will be discussed in next years report.

The analytical setup between Lund and Linköping universities is now organised so we are able to measure surface fluxes and subsurface concentrations of CO_2, CH_4, N_2O and H_2O as well as a large number of organic acids and other intermediary compounds. These analytical facilities are currently utilised in the monolith experiments that started during the spring of 1999.

In addition to the monolith experiments in Lund preliminary experiments measuring subsurface concentrations of dissolved gases CH_4, CO_2 and O_2 using a quadrupole mass spectrometer has been conducted in Cardiff. This technique will be applied on further peat monolith experiments in connection with integrated experiments in Lund during 1999. Also the Moscow team has developed techniques for measuring methanogenic and methanotrophic activity in monoliths and *in situ*.

Field manipulations (WP2)

At the February 1998 CONGAS meeting it was decided to operate with a minimum of two typical vegetation types at each site. A wet (minerotrophic if possible) and a mesic/dry (ombrotrophic) surface. The basic experiments is of CO_2 and CH_4 flux and soil water concentration response to reduced availability of light (lowered photosynthesis). The monitored environmental parameters and fluxes/concentrations in the control plots will be subject to a detailed across site analyses of factors controlling the flux rates. The methodologies for the varies measurements are described in the CONGAS field manipulation and monitoring protocol. A quantitative cross site comparison will not be carried out before the 1999 field season data are available.

Landscape flux studies (WP3)

The landscape scale studies are currently having their major campaigns (summer 1999) and most of the WP3 work in the past year has been of preparatory nature. A huge effort has gone into sorting out the logistics and customs formalities for the major shipping of equipment during the spring of 1999.

During a site visit to Siberia in August 1998 different possibilities for scientific and technical collaboration with local Tomsk-based insitutions were investigated. As a result of this an agreement has been made with Institute of Atmospheric Optics (Russian Academy of Sciences) in Tomsk on different practical and scientific collaboration during the ongoing 1999 field season.

Integrated modelling (WP4 + all others)

The integrated modelling activities are not scheduled in the work programme to begin before the third quarter of 1999. However, preparatory work on identifying the road ahead for this part of the project has been developed. Central to the plans for integration is a number of existing modelling components:

- MOSES (the Met. Office Land Surface Scheme)
- A series of small scale models of CH_4 related microbial kinetics (Panikov, 1995)
- BIOME 2+ (the respiration/CH_4 routine reported in Christensen et al., 1996)

- The Hadley Centre CH_4 model (Christensen and Cox, 1995)

The modelling plan for 1999 is to integrate MOSES with the three different CH_4 routines and run the MOSES+CH_4 routines model for the five CONGAS sites and evaluate the outputs in relation to our data gathering efforts (NPP and CH_4 fluxes). A modeller, Michael Mastepanov, has been appointed to perform this task which will be carried out as a collaborative effort between the CONGAS partners and the Hadley Centre at the British Meteorological Office (Dr. Peter Cox).

PUBLICATIONS

As this is the first year of the project few published peer reviewed scientific publications can be attributed entirely to the CONGAS project as yet. However, the papers by Joabsson et al. are a result of the WP1 and WP2 experiments.

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ECOMONT: Ecological effects of land-use changes on European terrestrial mountain ecosystems‡

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ECOMONT aimed at investigating ecological effects of land-use changes in European terrestrial mountain ecosystems. Co-ordinated by Prof. A. Cernusca, University of Innsbruck, ECOMONT was carried out by nine European partner teams in six composite landscapes in the Eastern Alps, the Swiss Alps, the Spanish Pyrenees and the Scottish Highlands. ECOMONT focused on an analysis of structures and processes in the context of land-use changes, scaling from the leaf to the landscape level.

The following research topics were investigated:

- spatial distribution of vegetation and soil in the composite experimental sites;
- physical and chemical soil properties, SOM status and turnover;
- canopy structure;
- water relations of ecosystems and hydrology of catchment areas;
- microclimate and energy budget of ecosystems;
- gas exchange and nutrient relations of single plants, ecosystems and gas exchange between the composite experimental sites and the atmosphere;
- plant-animal interactions;
- potential risks through land-use changes.

In order to link biodiversity with ecosystem functioning and to ensure a profound analysis of the ecosystemic processes at the level of composite landscapes a specific up-scaling approach was applied in ECOMONT combining empirical field studies and mathematical modelling. At each level of integration the results of the modelling approach were validated by direct field measurements. Both the up-scaling approach and GIS-based analyses of spatial and temporal pattern were shown to have great potential of integrating processes in complex mountain terrain and developing scenarios as a baseline for concepts of sustainable development.

ECOMONT has shown that land-use changes have strong impacts on vegetation composition, structure and processes, on soil physics and chemistry, and therefore strongly affect exchange processes with the atmosphere and biogeochemical cycles. In spite of common principles of changes of vegetation, soils and related processes with altered land-use geology, climate, exposition, slope inclination and land-use history may play an important role in determining species composition and specific patterns and processes on a community, ecosystem and landscape level in different European mountain ecosystems. Abandonment of traditional agricultural practices (grazing, mowing) causes in most cases a successional reversion to the vegetation growing naturally at the sites. Land-use induced changes in the uppermost layer of the soil profiles may occur within decades, whereas changes in deeper soil layers may take thousands of years. Abandonment of meadows and pastures leads to a reduction of carbon and nutrient fluxes and thus to a slowing down of biogeochemical processes.

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In comparison to managed mountain meadows and pastures abandoned grassland was characterised by a decrease in litter quality and decomposition, which favours the accumulation of organic matter at the soil surface, thus affecting canopy microclimate and water relations, as well as soil chemistry and physics (Fig. 1). In the A horizon humus content as well as C/N ratio increase whereas pH and cation exchange capacity decrease from intensively managed hay meadows to abandoned areas. Soil physical parameters like particle size distribution are less influenced by land-use changes. Soil aggregate stability in the A horizon, which affects water storage capacity and potential infiltration, decreases from the intensively to lightly managed hay meadows but increases again to abandoned areas and coniferous forests. Abandonment leads to a decrease in soil respiration, litter decomposition, net nitrogen mineralisation, the latter being related to changes in microbial biomass and community structure.

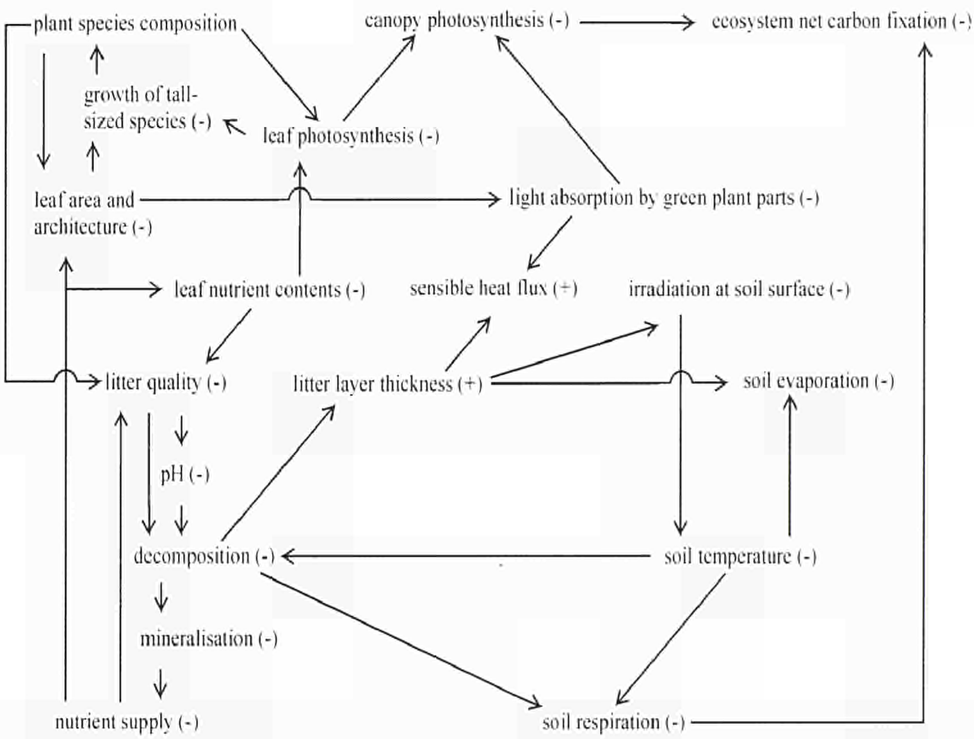

Figure 1: Effects of abandonment of mountain meadows and pastures on some major ecosystem process components investigated by ECOMONT. Arrows indicate relationships between the parameters. (+) and (-) indicate positive and negative effects of abandonment, as compared to meadows and pastures.

Photosynthesis of grassland canopies decreases with abandonment (Fig. 2), which is the effect of a decreased nutrient availability on photosynthesis, changes in photosynthetic capacity and nitrogen use efficiency due to altered species composition, and the effect of an increasing proportion of photosynthetically inactive components of the phytomass (attached dead plant material). At the levels of plant and of canopy, variation in leaf area and its vertical distribution play a more pronounced role in response of carbon uptake to land-use change than does physiology.

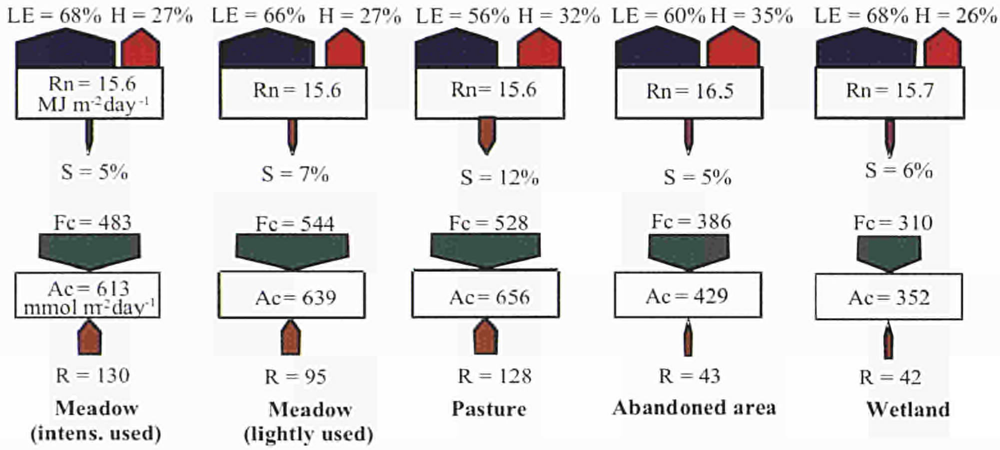

Figure 2: Energy budget and daily total CO_2 fluxes in differently managed and abandoned grassland ecosystems (LE ... evapotranspiration, H ... heat convection, Rn ... net radiation, S ... soil heat flux, Fc ... CO_2 flux from the atmosphere, Ac ... canopy photosynthesis, R ... soil respiration)

Evapotranspiration tends to be higher on intensively managed meadows as compared to abandoned areas (Fig. 2), where soil evaporation is distinctly reduced. Run off is higher on pastures than on meadows and shows an increase on abandoned areas. The structure of consumer assemblages reflects the different land-uses, although the response to changes is also site- and taxon-specific. The results underscore the importance of differences in the canopy structure due to land-use in determining the habitat selection by consumer species. Abandonment may lead to an increase of potential risks. For example, on abandoned areas snow gliding increases, which may enhance erosive processes (Fig.3).

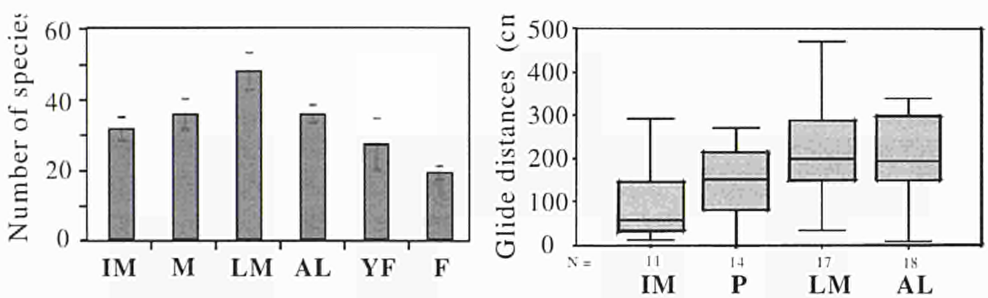

Figure 3: Species numbers, snow glide distances, and soil loss on differently managed and abandoned ecosystems, as indicators of land-use effects on diversity and stability of mountain ecosystems (IM ... intensively used hay meadow; M ... less intensively used hay meadow LM ... lightly used hay meadow; P ... pasture; IP ... intensively used pasture; LP ... lightly used pasture; AL = abandoned land; YF ... young forest; F ... mature forest).

Land-use has a decisive influence on diversity and ecological complexity at all levels and scales (species, ecosystems, landscapes) (Fig. 3). Traditional land use in mountain areas favours a high number of plant species, which declines with abandonment but also with intensification (high fertilisation). The restoration of species-rich mountain meadows and pastures from abandoned ones is only possible with a strong input of human resources.

ECOMONT has developed a number of activities concerning the application and dissemination of its scientific results. ECOMONT has opened the possibilities of application of trans-sectoral research results in three major European policy sectors relevant for mountain areas: agriculture, tourism and transport. Secondly, results of ECOMONT are now being extended within of the applied interregional programme INTERREG-II. In this context the ECOMONT research area in the Stubai Valley has been enlarged to include a dangerous avalanche and torrent tunnel with the aim to predict effects of land-use changes and of an reforestation project on the catchment behaviour and its influence on potential risks down to the valley bottom. At the research site at Passeier Valley similar questions are being addressed, and are in particular related to driving forces of land-use changes, such as the accessibility of farms and meadows on mountain slopes, and alternative forms of income to farmers. Thus, regional socio-economic conditions of management can be immediately related to ecological effects of land-use changes in mountain areas. Thirdly, the EU-Transfer- and Mobility-programmes have been applied to establish a transfer-network on the sustainable development in the ecologically sensitive mountain areas of Europe. The LEONARDO-programme allowed to disseminate newly developed methodologies as well as results of ECOMONT between universities and a number of non-university institutions and companies across Europe. Three SOCRATES-intensive courses were launched to disseminate methodologies and results of ECOMONT, their topics being "Training on Sustainable Development in Mountain Areas of Europe" (held in Austria, Italy and Spain in May and June 1998), "Training on integrated ecosystem and landscape ecology in alpine areas of Europe" (held in Austria in May and June 1999), and "Decision-making modelling in European mountain areas" (held in Scotland, Austria and Italy in August and October 1999). Furthermore, results of ECOMONT were presented both to the scientific community (in a number of scientific papers and at international conferences), and to decision-makers and stake-holders in the regions hosting the different project areas. By founding a forum of ecologists, socio-economists and decision-makers transdisciplinary collaborations have been started to ensure both the application of results and the development of follow-up projects in Framework 5.

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LUCIFER: Land use change interactions with fire in Mediterranean landscapes

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INTRODUCTION

The Mediterranean landscapes have been considered a model of fine-grain, most diverse, natural and cultural landscapes caused by the ancestral human use of the land. However, in the last decades, improved socioeconomic conditions in EU-countries have altered the use of the land, eventually resulting in a change of landscape features. Parallel to this, fire occurrence has increased manifold. Fires dominate now in many areas in an unprecedented way, and may be altering the ecosystems in unknown ways. How the changes in the landscape have affected fire occurrence is little known. Similarly, little is also known about the impacts on key ecosystem structure and processes produced by the changes in the landscape caused by fire. Understanding these interactions is needed to properly manage these areas. This knowledge could also serve as a model to anticipate the impacts of land-use change in other fire-prone areas of the world.

In LUCIFER we attempt to:

a. Determine how the structure of the landscape has changed in the last 2-4 decades in fire-prone areas of all the Mediterranean countries of the EU, how fires themselves have contributed to such change, and what role have landscape changes played in promoting fire.

b. Asses whether fires induce a further homogenization of the burned area, hence increasing fire hazard.

c. Evaluate the relationship between land-use and patch heterogeneity and the post-fire flows of soil, water and nutrients from the burned area.

d. Establish the role of burned area on the post-fire species dynamics, asses the basis for species change between burns, in particular for rare/endemic species, as well as the potential colonization of burned areas by new species.

Models have been, and are being, developed that could serve to evaluate fire hazard and other threats to the ecosystem in fire-prone areas resulting from landscape changes.

ACTIVITIES AND EARLY RESULTS

1. Landscape changes and fire

Land-use/land-cover changes during the last 3-4 decades are being determined by means of aerial photography and remote sensing in all Mediterranean-type countries of the EU. First conclusions from three of the sites analyzed (Gredos, Cuenca and Alicante sites) indicate that the rate of change of the areas studied has been rather large (over 50% of the territory changed in the land-cover it sustained during the past 3-4 decades). In general, there has been a tendency for a reduction in cultivated areas and an increase in pine-woodlands. Two different tendencies have been observed: at the sites were fires started to become frequent in the early

1970's (Gredos, Alicante) there was an initial tendency towards landscapes becoming more homogeneous but this tendency was stopped with the onset of fires. At sites like Cuenca, the landscape became first more heterogeneous, as a likely result of sustained management, and later it turned more homogeneously. In 1994 this place sustained one of the very large fires in record in Spain. Fires are also being mapped in each of the landscapes studied. The analysis of the relationship between fire occurrence and features of the landscape is still preliminary but it appears that fires are very clumpy, do not occur evenly across a given area, tending to occur at preferred locations and topographies. Based on the analysis of two of the sites (Spain, Portugal), it appears that once-burned areas tended to sustain additional fires more frequently than expected, hence apparently conducing to an acceleration of the fire cycle. Analysis in all the areas being studied will confirm whether this is a general tendency of Mediterranean landscapes. The sensibility to fire of the various landscapes under study is being evaluated by analyzing the relationship between the structure of burned surfaces and fire conditions. Additionally, fractal analysis of burned area and number of fires is being conducted at all sites. Results from one of the Italian sites indicate that this approach could give indications of the limits of a given landscape to sustain certain types of fires.

2. Role of fire on altering landscapes

The role of fire in altering landscape structure is being established by detecting changes in the landscape after fire in relation to pre-fire land-use history or variations in fire-severity by combining remote sensing and field work, in this case focussing on plants and animals. After fire, landscapes are very dynamic and no clear relationship with the pre-fire structure has been found. Changes in land-uses through abandonment in one of the PT sties determined changes in vegetation composition and structure, which played a strong influence on the composition of animal (birds) species. The dynamics in relation to fire do not revert to those of previous land-uses. As for plants, based on one of the sites (E) persistence of a given land-use affected plant species richness after fire differently, depending on the substrate: greater permanence in land-use produced greater richness in basic substrates but lower richness in acidic substrates.

3. Soil, water and nutrient flows and fire interactions with the landscape

Sediments accumulated at erosion-dams in 12 catchments have been collected and are being analyzed to determine erosion losses through time in relation to fire and to land-use/land cover. Catchment post-fire sediment yield (0.13-10 Mg ha^{-1} yr^{-1}) was significantly higher than the pre-fire one (0.33-1.76 Mg ha^{-1} yr^{-1}). Sediment yield was positively correlated with the amount of area with steep slopes, fragile substrata and abandoned crop terraces. Soil erodibility decreases with increased plant cover following abandonment of cultivation. Fire, however, tends to homogenize all areas by increasing erodibility irrespective of their land-use type. Preliminary analysis of the spatial variability of soil properties within a given land-use type indicates that there exists a greater homogeneity of organic matter, organic carbon, and total nitrogen content in burned than in unburned soils, irrespective of land-use type. These results seem to confirm the hypothesis that the passage of the fire is able to homogenize some soil differences determined by initially different land uses.

4. Landscape, fire and species dynamics

The evaluation of how the size of burned areas (or patches within burned areas) affect species (plant and some animal groups) maintenance in the system, with particular attention to rare and endemic species or to species with an invading potential, is being investigated at sites of the East and West Mediterranean. The basic approach consists in selecting a large fire, whose land-use/land-cover history has been reconstructed, and sample selected plant and animal in relation to the edge of the burn. Particular attention is being devoted to rare/endemic species. Early results from one the large fires studied indicates that most plant species are rare, either in the burn or unburned area (less than 10% of the species are present in more than 50% of the sampled plots). Plant species richness increases in the burned area (157 vs. 233 and 195 vs.

264 for acidic and basic substrates, respectively). This increment is due mainly to cosmopolitan species and rarity increases for those species present in the unburned area. Although clearly distinct patterns of species richness were observed in the landscape, this were related to substrate. No clear fire-size effect was observed, as total species richness did not vary with the distance to the edge of the fire. Further fieldwork is still in progress, in particular to elucidate the causes (dispersal, herbivory) of the patterns being observed. Particular attention is being devoted to rare or endemic plant species. Lists of endemics of fire prone areas have been produced for the Eastern (HE) and western (E) Mediterranean. Hemicryptophytes and chaemophytes dominate the spectrum of life forms of endemics. The hypothesis that Mediterranean-endemic species would be more affected by fire than cosmopolitan ones has so far not been confirmed: the number of plants of different distributional range (cosmopolitan, endemics of restricted distribution) whose frequency changed as a result of fire was not different. Ecophysiological studies of the germination of 22 taxa of the genus *Centarea*, varying from broadly cosmopolitan to endemic did not find any relationship whatsoever to fire-related cues. Further work is in progress with additional groups of species from the East and West Mediterranean being investigated.

5. Modelling

Completed modelling efforts within LUCIFER comprise the development of a spatially explicit, generic vegetation model, which combines a dynamical simulator for each landscape unit, with a map that describes the spatial distribution of landscape features. A vertical representation of the vegetation structure (herbaceous, shrubby and tree components) and a weekly water budget of three soil layers are also simulated. The model takes into account the particular case of Mediterranean vegetation, with multiple species, and varied regeneration abilities after fire. The model takes a functional approach towards carbon and water to drive growth, competition and to simulate plant water status from which fire danger can be inferred. Spatial processes for water and seed dispersal are simulated and it can be easily linkable to fire ignition and fire spread routines. Initial results indicate that this a good tool to evaluate the change of fire hazard in the landscape through time and the interaction with additional fire as it may affect vegetation composition and structure. Changes in fire regime can also easily produce an evaluation of its likely impacts on the landscape. Additional modeling efforts within the project comprise cellular-automata approaches for the spreading of disturbances taking into account spatial interactions. Validation efforts are now underway to the various sites whose landscapes and fire incidence has been evaluated.

DART: Dynamic response of the forest–tundra ecotone to environmental change*

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OBJECTIVES

The overall objective of DART is to increase understanding of ecosystem dynamics at the forest–tundra ecotone in northern Europe and, in particular, to quantify the dynamics of the response of this ecotone to climate and land-use changes . In order to achieve this overall objective we are testing the following hypotheses:

1. That the Arctic tree line is subject to strong stabilising feedback controls, especially relating to annual duration of snow cover, that render it insensitive to climate changes of the magnitude forecast for the next century.
2. That despite observations of outlying individual suppressed/krummholz trees, probably established during unusually favourable seasons, the ecotone was stable throughout the last millennium of substantial natural climatic variations.
3. That the mean, over at least a decade, annual thermal sum above 0°C is the principal climatic determinant of the position of this ecotone both at broad geographical and at landscape scales. At both scales, however, although the effect is more immediately apparent at the landscape scale, this interacts with duration of the snow-free period.
4. That at broad geographical scales interaction between climate and the 'light climate' will limit latitudinal displacement of this ecotone.
5. That anthropogenically-enhanced herbivore pressure enhances ecotone stability in the face of climatic warming by limiting establishment opportunities for seedlings of woody species in adjacent tundra areas, thus increasing resilience of the tundra to tree invasion.
6. That, even when elicited by a sufficiently large environmental change, dynamic response of this ecotone also may be limited by propagule dispersal and seedling establishment, including any associated disturbance requirements.
7. That, in areas of tundra colonised by trees, carbon sequestration will increase, the methanogenesis:methanotrophy balance in soils will be altered, potentially leading to methane flux changes, run-off will decrease and soil organic matter mineralisation rates will increase. In addition, that the relative importance of these various effects will differ between areas of dry, mesic and wet tundra.

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* Contract number: ENV4–CT97–0586. DART commenced on 1 April 1998 and will run to 31 March 2002. In addition to the nine contracted partners, the consortium has established a collaboration with CIRC (Abisko and Kiruna) and has a sub-contract from PIK to the Forestry Commission Research Agency (Alice Holt).

APPROACH

The project is employing a combination of observation and monitoring of the tree-line ecotone in Fennoscandia, manipulative experiments at a series of sites (Fig. 1), each of which spans an instance of the tree-line ecotone, and development of a landscape-scale model of ecosystem dynamics able to simulate the response of the tree-line to environmental and land use changes. The primary and secondary study sites have been selected so that they lie along two 'macro-transects' spanning two principal environmental gradients. The first transect extends from lower to higher latitude, whereas the second extends from oceanic to continental climate regimes and intersects the first at high latitude. At each study site a 'meso-transect' then spans the forest–tundra ecotone, extending from continuous forest to continuous tundra *via* the intermediate zone where forest and tundra stands occur in a mosaic. Some observations and experiments then use 'micro-transects' that span individual instances of the transition from a patch of forest to an adjacent patch of tundra.

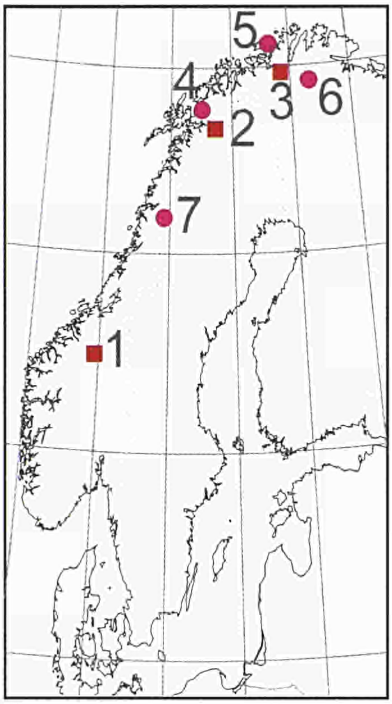

Figure 1: Location of study sites

Primary sites (squares):
1. Dovre, 2. Abisko, 3. Joatka.
Secondary sites (circles)
4. Vassijaure, 5. Seiland, 6. Kevo, 7. Tjärna-fjället

The project comprises 16 Work Packages, as follows:

1. Obtain contemporary climate data.
2. Obtain time-series of snow-cover data.
3. Analyse the interaction between climate, snow-cover and latitude as determinants of tree-line position.
4. Obtain palaeoclimate records.
5. Obtain high-resolution palaeovegetation records.
6. Monitor propagule flow and evaluate the extent to which it is limiting.
7. Investigate the role and establishment of outlying individual trees.
8. Assess the sensitivity of tree seedling establishment and growth to elevated temperature.
9. Assess the sensitivity of tree seedling establishment and growth to duration of snow-lie.
10. Assess the sensitivity of tree seedling establishment and growth to presence of a tree canopy.
11. Assess the sensitivity of tree seedling establishment and growth to herbivory.
12. Assess the sensitivity of tree seedling establishment and growth to disturbance.
13. Assess the impact of environmental change and of the response of the tree line upon trace-gas fluxes and soil organic matter mineralisation rates.
14. Assess the interaction between the forest–tundra ecotone and landscape-scale hydrology.
15. Model ecosystem dynamics at the forest–tundra ecotone.
16. Evaluate the impacts upon the forest–tundra ecotone of alternative scenarios of environmental change and landscape management.

ACHIEVEMENTS

Field work commenced in the early summer of 1998 and most of the targets set for the first season were achieved, despite a later than planned start date. The work achieved to date includes the following:

- basic climate stations were installed along the 'meso-transects' at each of the three primary study sites;
- an extensive campaign of field work has been undertaken at two of the primary sites to ground-truth synthetic aperture radar (SAR) remote-sensed images that will be used to develop spatio-temporal snow-cover data;
- series of SAR images have been ordered and obtained for the two primary sites;
- sediment cores have been collected from a series of small lakes at the Joatka study site and preliminary pollen and plant macrofossil analyses commenced;
- a seed-trapping array has been established at the Abisko study site so as to monotir propagule flow;
- outlying individuals of *Betula pubescens* ssp. *tortuosa* have been located and initial recording undertaken at the Dovre and Abisko study sites;
- a sample of outlying individuals has been selected for experimentation at Dovre and Abisko, and half of them has been enclosed in ITEX OTCs to impose a warming treatment;
- ITEX OTCs have been installed at four locations along the meso-transects at each of the three primary study sites and small saplings of *B. pubescens* ssp. *tortuosa* planted into the OTCs;
- preliminary experiments have been performed to determine the most effective treatments to use for passive manipulations of the duration of snow-lie;
- a 'fake forest' canopy of felled birch trees has been erected above the present tree line at the Abisko study site to examine its impact upon the duration of snow lie and upon the performance of birch saplings that will be planted during 1999;
- three sets of exclosures, each comprising a reindeer exclosure, a microtine exclosure and an unenclosed control plot, have been installed along the meso-transects at the Abisko and Joatka primary study sites and at the oceanic secondary sites of Vassijaure and Seiland;
- disturbance regimes have been imposed upon randomised plots within the exclosures and control plots and seeds of four tree species are currently being sown into disturbed and undisturbed plots;
- preliminary measurements of tree performance in the four sites with exclosures have been made, along with surveys to establish the intensity of reindeer browsing and the densities of microtines;
- soil organic matter mineralisation rate studies have been initiated at all three primary sites with litter bags placed both within OTCs and in the control plots for the warming experiments;
- initial methane flux measurements have been made at the Abisko site, contrasting the rates in the control and OTC sites shortly after the installation of the OTCs;
- work has commenced on the modelling of landscape-scale hydrology; and
- preliminary work has begun on development of the landscape ecosystem dynamics model.

The 1999 field work season is now fully underway and by the end of this season the project will have begun to generate results from several of the experiments established in 1998 and will also have the first results from the remote sensing of snow cover. Two project workshops were held in 1998 in order, firstly, to undertake detailed planning of the field work to be undertaken (Klinta, May 1998) and, secondly, to review the progress during the season and the priority targets for the winter months and the early season field work in 1999 (Abisko, October 1998). The third project workshop will take place in September 1999 at the Dovre study site.

FURTHER INFORMATION

More details of the project, including further information about the design of our experiments and the field sites, can be found on our web site at http://www.dur.ac.uk/DART. There you will also find the full text of our First Annual Report to the European Commission in .pdf format. This may be downloaded and read, but **may not** be cited, nor its content used in any way, without the expressed permission of the authors; such permission must be sought in the first instance from the project co-ordinator by e-mailing Brian.Huntley@Durham.ac.uk.

Community complexity and decomposition process in aquatic systems: an ecosystem approach to manage biodiversity - CoDePASs

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INTRODUCTION

The project addresses the integration of process-oriented and population-community approaches to asses the role of biodiversity on detritus processing. The main purpose is to establish a scientifically based procedure for biodiversity and habitat management in inland aquatic ecosystems. The project results from the integration of correlative field researches, carried out at large and small spatial scales, in rivers, lakes and lagoons in five significant areas of Western Europe, together with experimental laboratory research.

The project addresses some basic ecological questions and will supply deliverables to the end-users relevant for management and conservation policy.

<u>Basic ecological questions:</u> (1) how is biodiversity related to detritus processing in aquatic systems with different typologies? (2) Are decay rates of plant detritus related to community complexity and stability, as measured by food web patterns? (3) How does disturbance affect biodiversity and decomposition processes? Does the effect scale with disturbance strength? (4)Does the fractal dimension (Perimeter/Area) affect spatio-temporal variations of detritus decay rates of the habitat and can it be used as measure of habitat vulnerability?

<u>Deliverables:</u> (1) a data-base of detritus processing rates and decomposer biodiversity at a regional and European scale, that for the Mediterranean region is not yet available and underestimated in EU-NATURA 2000. (2) geocoded maps of the intra-habitat variation of biodiversity and decomposition rates in the studied ecosystems and mapping methodology applicable to other aquatic ecosystems.

Experiments both in the field and in the laboratory were designed also in order to test explicitly the role of some principal ecological drivers of biodiversity (i.e. the energy availability, the food web constrains, the community assembly rule, the niche constraints).

APPROACHES

First year results of CoDePASs programme are summarized below. Decomposition patterns and rates have been determined in 140 sample sites throughout Europe. Up to 30 sites per habitat have been sampled at some selected habitats to address the study of the intra-habitat variation of both ecosystem process and decomposer community structure. The leaf pack technique was used to study decomposition processes. *Phragmites australis* was used as a common plant substrate for comparative purposes. Different plant species (*Alnus glutinosa Chara hispida, Potamogeton pectinatus, Populus spp.*) were also utilized at specific study sites according to their relevance on the natural detritus deposits on bottom sediments. Laboratory studies on the role of species diversity and of stress (as diversity driver) have also been carried out. Common laboratory work included also analysis of nutrient contents in the water and sediment of all the European sites. Based on these analysis a hierarchy of trophic conditions can be established: Eutrophic sites are in Holland shallow lakes, Tirso Sedilo in

Italy and Ebro River in Spain, mesotrophic sites are in Tancada coastal lagoon in Spain and Rome, the sites in Portugal, and the coastal pond and stream in Spain are oligotrophic.

RESULTS

Field correlative experiments

The results show significant differences of the rate of decomposition (estimated as mass loss) both within and among habitats. The vulnerability to species invasion, the salinity and the detritus potential input were the major basic constraints affecting the observed variability: decomposition rate increases with decreasing vulnerability, with decreasing salinity and with intermediate detritus input. At one site (Vico Lake) spatial dependency of decomposition rate has been reported by geostatistical mapping. This method of representation will be then extended to all the study sites. An example is given in Fig 1.

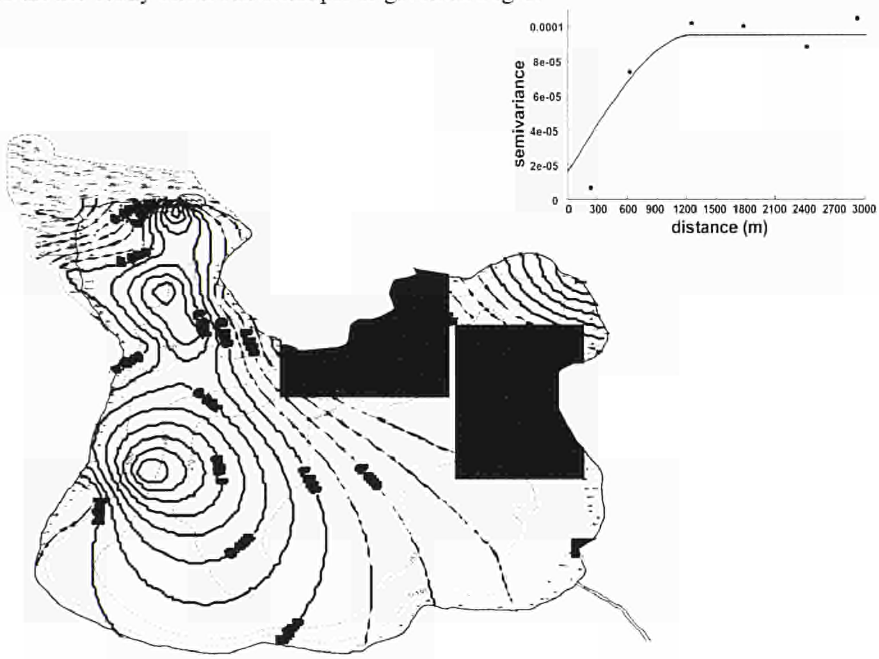

Figure 1. Semivariogram and geostatistical map of decomposition rate in lake Vico (Central Italy).

An increasing number of macroinvertebrates colonizing the litter bags is observed during the decomposition process, with huge numbers of *Gammarus* and other crustaceans compared to the relatively low number of other detritivorous species.

Detritivores biodiversity (Hs) is demonstrated to be positively related with detritus decomposition rates, thus suggesting in the investigated ecosystem an underlying link between functional attributes of the detritus compartment and structure of the detritivores community.

The isolation of microfungal strains from particulate detritus evidenced a conspicuous number of species, thus testifying a high diversity of the microfungal community also at the low temperature conditions characterizing the environment in the winter season. A lower fungal diversity (and colony density) was detected on leaf detritus protected from macrofauna in comparison to unprotected conditions.

Laboratory-mesocosms experiments

1. Species richness of two different trophic levels (detritus-colonising fungi and invertebrate detritivores) and its effect on the vegetal decomposition efficiency have been considered. Two experimental trials have been performed to assess the influence of detritivores and microfungi multispecies coexistence on decomposition rate. Leaf mass loss and ergosterol mass on the leaf disks was measured. Results showed that the effects of fungal richness on decomposition depend on the substrate type. In fact, the decomposition rate of the fastest decomposition substrate (A.*glutinosa*) increased with the number of fungi, while it was the fastest at intermediate fungal richness in the other substrates. After 30-days incubation, ergosterol concentration of alder leaf disks was higher than, in order, reed and oak disks, approximating concentrations in pure fungal mycelium. An increasing trend was observed with the number of fungi on alder. Leaf mass loss is directly related to ergosterol concentrations. Animal's activity both reduces the ergosterol concentration and increases the leaf mass loss producing inverse relationships between the two measures. As detritivores influence the leaf mass loss by interfering with fungal activity as well as by feeding on the leaves, animal species richness determines two effects. On one hand, the number of leaf disks completely consumed increases with the species number, while on the other, the leaf degradation is the greatest with intermediate number of detritivore species.

2. In order to study the effects of agricultural pesticides on the decomposition process, an experiment was performed in outdoor mesocosm. After a one-month circulation period, pesticides were added to the systems and the decomposition process was monitored for a period of 98 days. The fungicide carbendazim (a carbamate pesticide) was tested at 50 µg/L (realistic worst case field concentration), 8000 µg/L (maximum solubility) and 623 µg/L (intermediate concentration). Similarly, the organophosphorus insecticide dimethoate was tested at 5 µg/L, 100 µg/L and 2000 µg/L, the latter concentration being equal to the geomean LC_{50}. Three mesocosms were treated with a combination of carbendazim and dimethoate, in the indicated low, medium and high concentrations. Triplicate blancs complete the total number of 12 mesocosms. Dimethoate had a slight, temporary effect on the macroinvertebrates colonising the packs, at the lowest concentration. The middle concentration affected especially *Gammarus sp.*, and at the highest concentration hardly any invertebrates were found in the packs. The litter-bag weight loss was significantly lower at the middle and high concentration, compared to the blanc (with a k of 0.0028 d^{-1}). Carbendazim substantially reduced the number of invertebrates at the lowest concentration. Gammarus was found inactive at day three, and was not found again after that. Similar results were found at the middle concentration; at the high concentration the number decreases to 0 at day 100. At all three concentrations, the weight loss is significantly lower than in the blanc mesocosms. In the combination (dimethoate + carbendazim), the effects of carbendazim dominate the impact on the invertebrate community. Weight loss is significantly lower at the middle and high concentration. The conclusion is that pesticides can affect the decomposition process. Carbendazim shows significant effects at a realistic worst-case field concentration, and a reduced decomposition rate in the field situation can therefore not be ruled. The Dutch environmental quality standard is 0.05 mg/L. Dimethoate affects the decomposition process significantly at a concentration of one twenties of the LC_{50}, thus proving the decomposition rate to be a very sensitive and ecologically relevant effect parameter.

CoDePASs PUBLICATIONS

Alberto Basset, Luca Tafuri & Piervincenzo Pintozzi. 1999 - Fine scale analysis of leaf pack colonization in a salt marsh Mediterranean lagoon: lake Alimini Grande (Otranto, LE, Italy). *First International Conference on Biodiversity and Renewable Natural Resource Preservation*. Ifrane 13-15 May 1999.

Alberto Basset, Maurizio Pinna & Alessio Fonnesu. 1999 - Heterogeneity of body size structure of detritus based guilds in the river Tirso basin (Sardinia, Italy). *First International Conference on Biodiversity and Renewable Natural Resource Preservation*. Ifrane 13-15 May 1999.

Rossi L., Costantini M. L. & Marchetti S. 1999 - Laboratory experimental tests of the relationships between decomposers biodiversity and decomposition process in a detritus-based three-trophic foodweb. *First International Conference on Biodiversity and Renewable Natural Resource Preservation*. Ifrane 13-15 May 1999.

Rossi L., Sabetta L. and Costantini M. L. 1999 - Intra-habitat variation of ecosystem structure and function: a study in a volcanic lake ecosystem. *First International Conference on Biodiversity and Renewable Natural Resources Preservation* Ifrane 13-15 May 1999.

LAKES: Long distance dispersal of aquatic key species

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SUMMARY

The main objective of the LAKES project is to determine the relationship between waterfowl migration and wetland diversity in aquatic plants and zooplankton. Integrated modelling systems will be developed to predict the consequences for wetland biodiversity of changes in waterfowl migration arising from, climate change, hunting and wetland management practices. The results will be of importance to researchers involved in modelling the biotic consequences of global climate change. They will also be of benefit to a user community of plant and bird conservationists, as well as those involved in wildfowl management at both local and international scales.

GENERAL OBJECTIVES

1. To investigate bird-mediated propagule dispersal and gene flow between different catchments of zooplankton and aquatic plants.
2. To develop process-based, spatially explicit models to simulate the impact of potential changes in waterfowl migration in Europe on the genetic and interspecific diversity of aquatic ecosystems.

APPROACH

The different members of the LAKES consortium are assembling the first coherent assessment of interspecific diversity of pondweed and cladoceran communities across Europe.

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[*] Alphabetical order; co-ordinator: S. P. Rushton.

For this, field data are collected in a number of selected catchments from a wide geographical and climatic range (North Russia to South Spain; 30 randomly-chosen lakes per catchment). Genetic markers (allozyme electrophoresis and DNA markers) are being used to differentiate between taxonomically problematic species.

The two key species, the pondweed *Potamogeton pectinatus* and the cladoceran *Daphnia galeata*, are studied in the same set of selected catchments. We use highly polymorphic genetic markers (e.g. RAPD anchored microsatellites, cytoplasmic DNA markers) to estimate within-catchment intraspecific diversity and gene flow between populations in different catchments. Within-species phylogeographic relationships will be quantified to obtain an independent measurement of gene flow and to separate historical and ecological factors from long distance dispersal.

We are also carrying out experiments with captive birds, to measure the retention time and survival of the propagules (seeds and resting eggs) in the gastrointestinal tract of the different waterfowl species. The ability of the propagules from each catchment to germinate/hatch and establish in other catchments will be tested by means of laboratory and field-based reciprocal transplant experiments. Additional field work focus on obtaining catchment-specific data on the ingestion and survival rates of pondweed seeds and cladoceran ephippia ingested by wild waterfowl.

As an integrative tool, we are developing spatially-explicit population models (SEPM) to simulate the propagule dispersal and gene flow between different catchments, for each of the two model species *D. galeata* and *P. pectinatus*. Both the SEPMs and stochastic bird migration models will be integrated within a Geographic Information System (GIS). Remote-sensed (satellite) data held in the GIS will be used to map the wetland habitats in Europe and to provide inputs to the models. Where possible, the population processes of dispersal, colonisation, reproduction, and mortality are explicitly modelled for each individual or population in the landscape. Model parameters are being derived from data on intraspecific variability and gene flow, and field and laboratory data on the carrier ability of the different waterfowl species as well as the colonisation capacity of the different populations of pondweeds and cladocerans.

We are also developing a generalised model in order to investigate the effects of bird migration on the composition of cladoceran and pondweed communities. This model utilises the data on source composition of each catchment, the carrier abilities of waterfowl and stochastic bird migration models to predict the composition of the colonising flora and fauna. A rule-based approach is used to predict the likelihood of colonisation by individual species within each community. The key species will be used as markers to test the validity of this generalised model using outputs from the SEPMs.

PRELIMINARY RESULTS

- Nuclear and mitochondrial markers were developed for a number of *Daphnia* species. An initial analysis of *D. galeata* across Europe using pairwise comparisons of individuals revealed no significant correlation between geographic and genetic distances. These results ruled out the existence of isolation by distance, for the European populations of *D. galeata*.
- For *P. pectinatus* anchored microsatelites were developed as molecular markers. Such primers are used to screen the entire genome. An initial set of 33 different primers were screened and four have been selected for the population surveys. The anchored microsatelite primers can distinguish between the closely related species of *P. pectinatus*, *P. filiformis* and their hybrid *P. x suecicus*. An initial analysis of *P. pectinatus* samples revealed that Scottish, Dutch and English populations are closely related to each other but significantly different from the Spanish and Russian populations.

- We assessed the abundance of intact seeds and their germinability and viability, in the feaces of 10 different duck species collected in the field (Guadalquivir marshes, SW Spain). *Rupia maritima* and *Arthrocnemum* sp. seeds were the most frequent and abundant. The different species of duck clearly differed with regard to the amount of seeds and seed viability within their faeces. The pattern of variation across waterfowl species was consistent for *R. maritima* and *Arthrocnemum* sp. Though seed-eating waterfowl probably ingest more seeds, animal-feeders such as the shoveler (*Anas clypeata*) showed higher proportions on intact seeds in their faeces – and the highest germination rates. This indicates that seed-eating waterfowl do not necessarily have the highest impact on seed dispersal.
- A modelling framework for duck migration incorporating species-specific bioenergetic modules was developed (Fig. 1). The migration model is linked to a genetic model simulating gene flow between different catchments arising from passive transport through waterfowl movements.

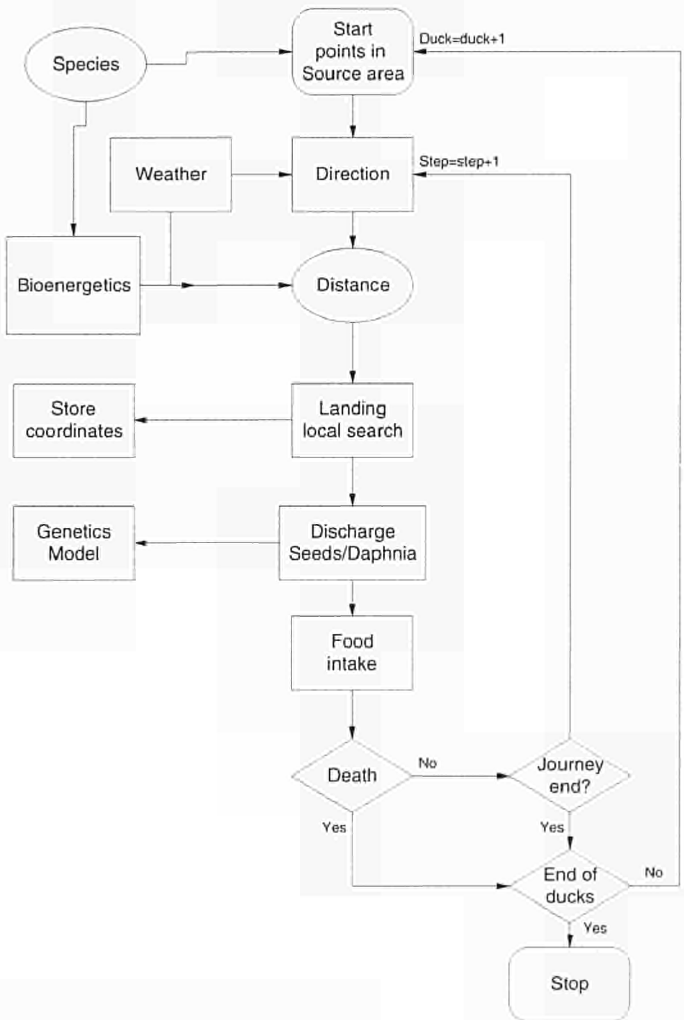

Figure 1. Outline of the modelling framework in LAKES

DYNAMO: Dynamic models to predict and scale up the impact of environmental change on biogeochemical cycling.

R.C Ferrier and R.C. Helliwell,

Macaulay Land Use Research Institute (MLURI), Scotland, UK.

The focus of the DYNAMO programme of research is on biogeochemical cycling in terrestrial ecosystems, and the effects on soil, surface and ground water quality in catchments. Integrated European process based research programmes, have created substantial databases and the utilisation of such data in modelling studies maximises the potential value of this research. DYNAMO aims to integrate this data with dynamic models within a spatial framework, extrapolating our understanding of systems at the individual stand and site level to the larger units of ecotype, landscape, region and continent.

OBJECTIVES OF DYNAMO:

- Enhance the current model structures to evaluate the synergistic effects of global environmental change, and develop appropriate modelling approaches for regionalisation;
- Apply and evaluate these dynamic biogeochemical models at intensively-studied (and manipulated) catchments/large forest stands;
- Use these models to scale up in space from the catchment/stand to the regional and continental scale;
- Use these models to scale up in time from observations over several years to predict future impacts over decades under scenarios of global change, acid deposition and land-use.

APPROACHES

Regionalisation techniques are necessary in order to provide meaningful information for evaluating environmental consequences of alternative control strategies of emissions of acidifying air pollutants and greenhouse gases. These methods are based on new kinds of mathematical constructs that are no longer calibrated just for individual sites, field plots, stands or catchments, but can make use of spatial information.

For calibration and enhancement of models at different scales, sites with the best, most extensive European data on effects at the stand/catchment level, and at which environmental-driving factors (acid deposition, global change, land-use) have changed either "naturally" or by large-scale manipulation experiment, and at which the ecosystem response has been measured as the change has occurred have been selected. Furthermore, these sites are located in areas for which there are extensive regional data such that the site response can be scaled up to the regional/ landscape/ National level. These data include regional or national surveys of driving variables (Evans *et al.,* 1998) and of response variables e.g. stream and lake chemistry (Skjelkvale, 1998) and soils (Helliwell *et al.*, 1998b).

Research networks of large-scale manipulation experiments were initiated in the 1980's under the auspices of the Commission of European Communities. Such manipulation experiments provide an ideal opportunity for evaluating model formulation and performance in response to enhanced atmospheric deposition of nitrogen (Wright *et al.*, 1998a b). Similarly, the CLIMEX project (Climate Change Experiment), provides a unique data set to evaluate the interactive effects of enhanced CO_2 and temperature (Wright *et al.*, 1998b). There are also other National networks targeted towards specific goals (Helliwell *et al.,* 1998a), or the impact of forest management practices on soil and water quality (Kamari *et al.*, 1998).

There have been two major approaches adopted in regional modelling studies, namely; Monte-Carlo analysis and multiple site application. The former approach involves the stochastic modelling of observed distributions of measurements, whilst the later involves the modelling of numerous soil or catchment systems as individual entities. Monte-Carlo analysis is able to simulate the response of systems over time, however it cannot distribute any predicted changes in space.

A Monte-Carlo simulation technique enables the incorporation of variability into the model to account for the inherent regional heterogeneity and uncertainty in the measurement of parameters. This provides an excellent assessment tool in situations where regional data availability or quality are lacking, but where mapped characteristics of, for example, soils data exist. An alternative approach is to under take a multiple site calibration incorporating known land use histories for each of the study catchments. This latter approach has been undertaken by Collins and Jenkins (1998), using regional data. This technique makes use of the best available information for the chemical and physical characteristics of soil and water at many sites, and has the benefit of being able to predict in both time and space. The ability to examine geographical patterns of response is becoming increasingly important in regional assessments, both as an analysis and as a policy tool, and examples of predictive output at a range of spatial scales is highlighted in Figure 1.

The DYNAMO project homepage is located at: www.mluri.sari.ac.uk/~rh0804/dynamo.htm

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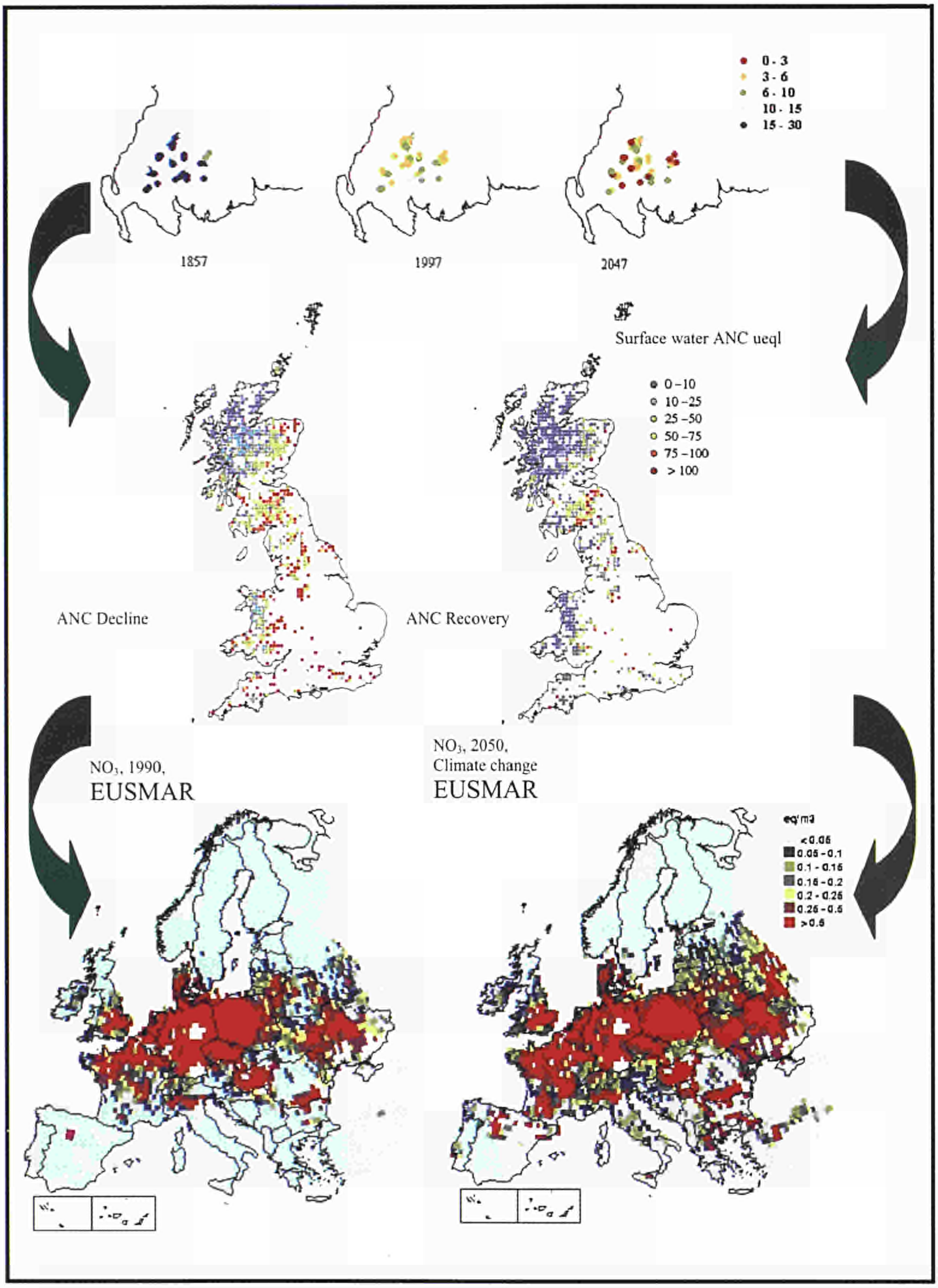

Figure 1: Examples of regional model applications in DYNAMO a) historical reconstruction, observed present day, and predicted future base saturation in the Galloway Region, SW Scotland: b) UK wide application of the MAGIC model highlighting ANC decline from pre acidification condition to present day, and predicted recovery in response to the Second Sulphur Protocol: c) Predicted soil water NO_3 concentrations in the year 2050 as predicted by EUSMART when considering both changes in atmospheric deposition and climate change.

ETEMA: European Terrestrial Ecosystem Modelling Activity*

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ETEMA focuses on:

- Comparative analysis of state-of-the-art modelling approaches within the subsystems:
  - Ecosystem-Planetary boundary layer interactions
  - Vegetation canopy-atmosphere CO_2 and H_2O fluxes
  - Vegetation physiology and phenology
  - Soil organic matter dynamics
  - Biogeography and vegetation dynamics
- Development of a coupled modular framework and computer code for modelling of natural and semi-natural European ecosystems at the landscape to regional scale.

Ecosystem-PBL interactions

A new surface-layer model developed by the Sheffield group predicts changes in fluxes from vegetation into the planetary boundary layer (PBL), and at the transition from one type of vegetation to another.

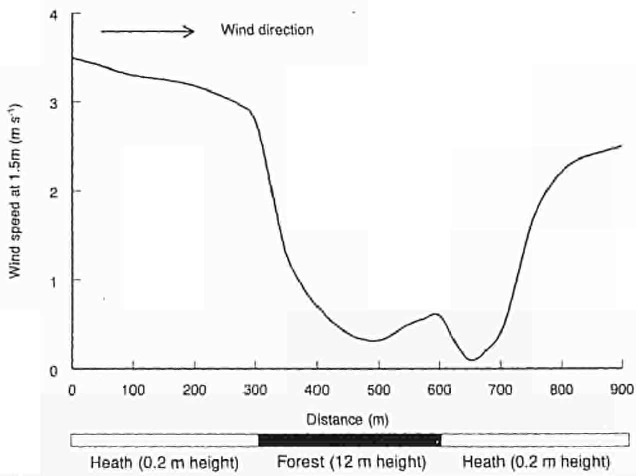


Figure 1. Variation in wind speed at a height of 1.5 m across a transition from a dwarf heath to a forest patch and back to a heath, as predicted by the PBL model.

* Contact: Dr Ben Smith, Climate Impacts Group, Department of Ecology, Ecology Building, Sölvegatan 37, S-22362, Lund, Sweden. # project co-ordinator.

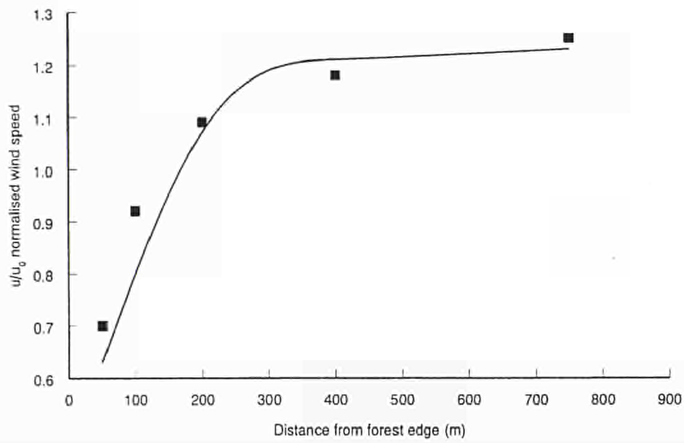


Figure 2. A comparison of PBL model predictions of wind speed across a transition from a forest to a heathland, compared with observations by Gash (1986, Boundary Layer Meteorology 36: 227-237).

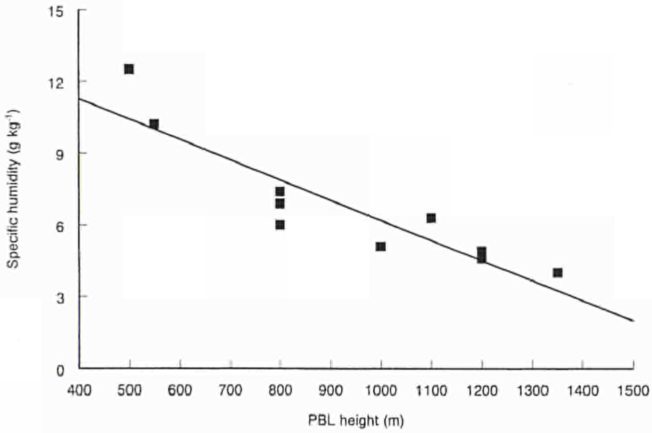


Figure 3. Relation between PBL height and mean specific humidity as predicted by the model and according to measurements reported by Dunmead et al. (1996, Global Change Biology 2: 255-264).

Vegetation canopy-atmosphere CO_2 and H_2O fluxes

The model ESCAPES (Exchanges between Structured Canopies and their Physical Environments), developed at Ispra, provides an analytical solution for the exchange of physical or chemical quantities – including carbon dioxide and water vapour – between a vegetation canopy and the atmosphere above it.

Vegetation physiology and phenology

We have developed a complete, internally-consistent, scheme for modelling "intermediate time-scale" processes determining allocation of carbon and nitrogen to different tissues and functions within a plant functional type (PFT). Comparisons of alternative approaches to modelling key processes have shown, for example, that correct simulation of leaf area index (LAI) in forests requires a less-steep vertical profile of leaf nitrogen than would be predicted by optimising with respect to the "Beer's law" relationship currently assumed by many models. This has led to inclusion of an alternative semi-empirical parameterisation of leaf nitrogen in the coupled model.

SOM dynamics

Paris group has developed a cohort-oriented model of soil organic matter (SOM) decomposition specially designed for use in modelling of transient systems under climate- or land-use change, at spatial scales from single plants to the landscape level. In the model, decomposition is driven by microbial physiology and demography, carbon quality of the substrate (litter or older SOM) and secondarily by C:N ratio. Outputs of the model include soil carbon storage, microbial respiration and production of mineral nitrogen.

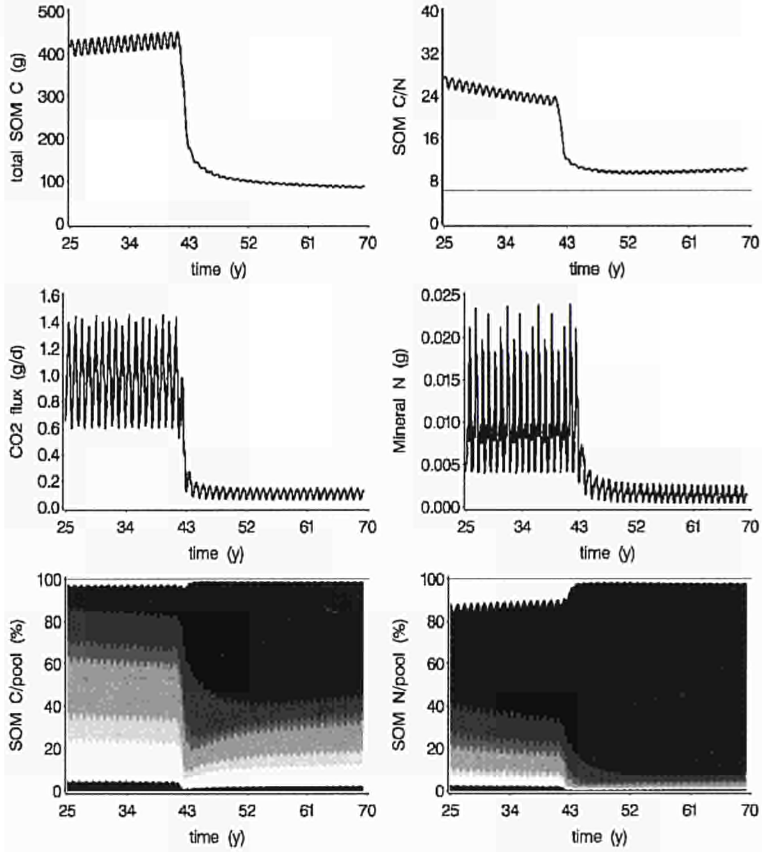


Figure 4. Simulation of the effects of a land-use change scenario on soil organic matter using the SOM model. Reduction of annual litter inputs to 10% through a land-use change at year 40 produces marked reductions in total SOM, C:N ratio, soil CO_2 fluxes and mineral nitrogen stock, while organic nitrogen becomes concentrated in the poorest chemical quality pools (decreasing quality represented by darker shades of grey). The scenario provides an acceptable match to observed effects of vegetation clearing on soil properties.

Biogeography and vegetation dynamics

Lund group have developed modelling tools which, for the first time, achieve precise comparability between (a) a non-spatially explicit patch model of vegetation dynamics based on individuals and their competition for resources, and (b) a generalised regional-scale model of the "DGVM" type, that markedly simulates individual-level processes. Parallel testing of both models across the range of climates found in Europe has highlighted the advantages and weaknesses of each approach (see Figure 6).

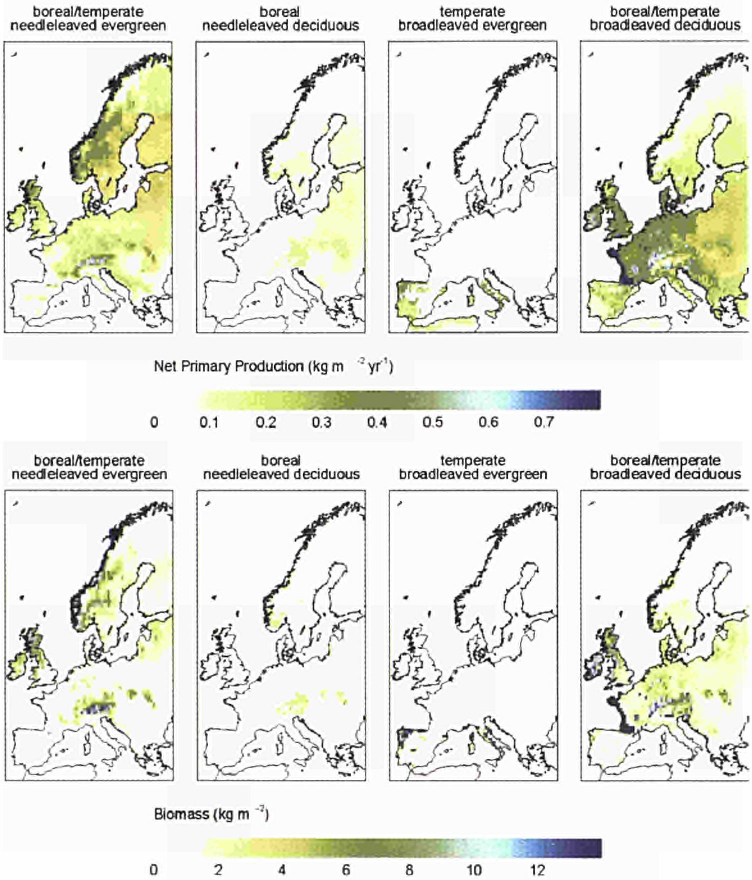


Figure 5. Predictions of (a) net primary production and (b) biomass of woody plant functional types for potential natural vegetation in Europe, according to the regional-scale model.

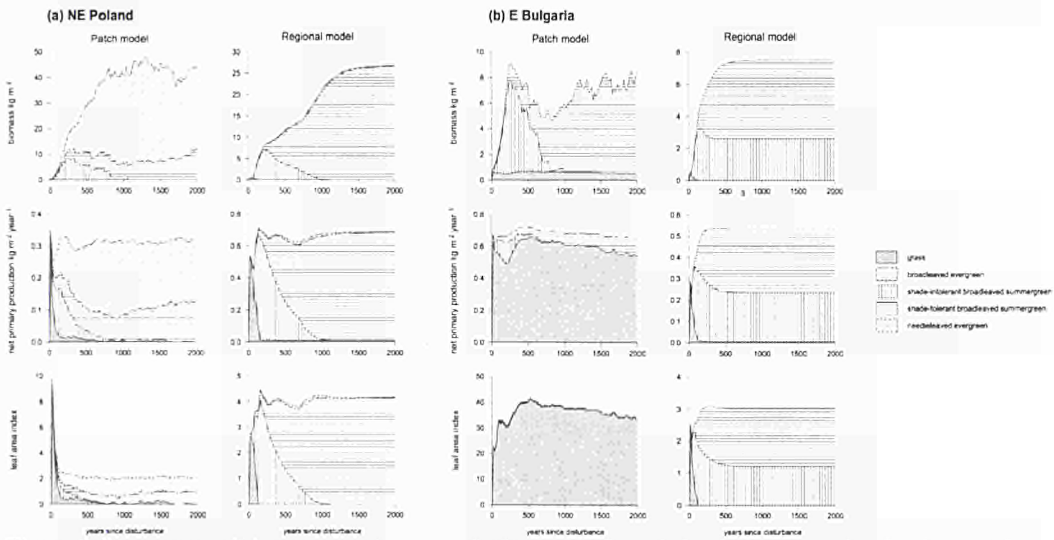


Figure 6. Time course of biomass, net primary production and leaf area index during vegetation development for (a) Bialowieza Forest, NE Poland and (b) forest-steppe vegetation in E Bulgaria, as predicted by the patch and regional models.

Both the models of Figure 6 reproduce the observed potential vegetation succession with acceptable precision. However, the regional model overestimates the deciduous woody components at these and other locations with mixed woody vegetation and/or seasonal water deficits, a result of its simplified parameterisation of processes governing vegetation dynamics.

Coupled model development and testing

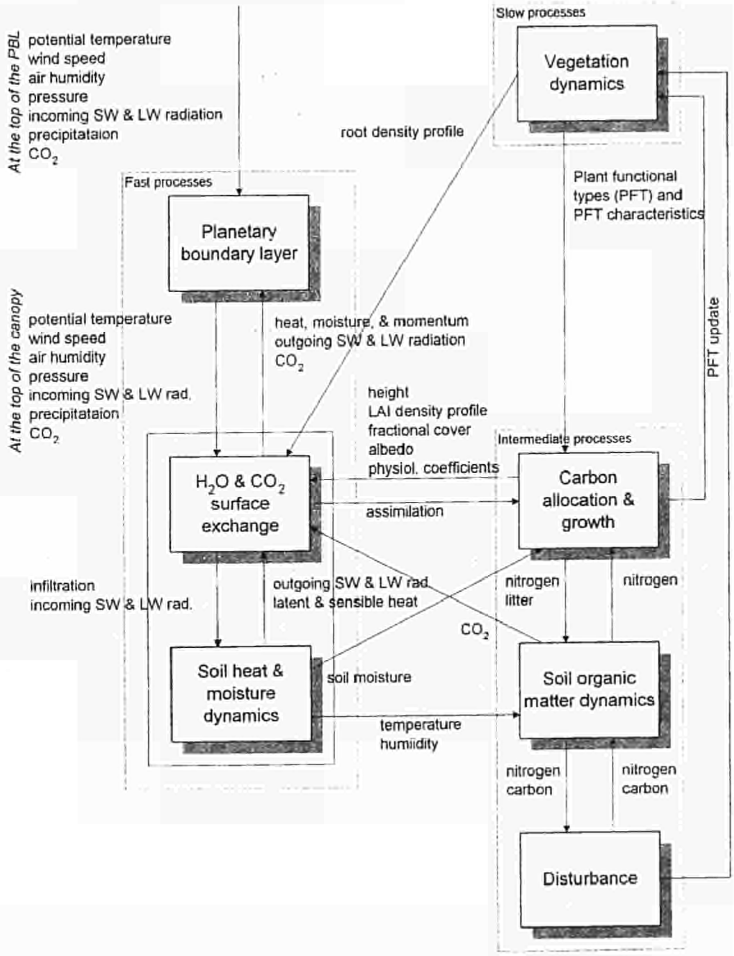
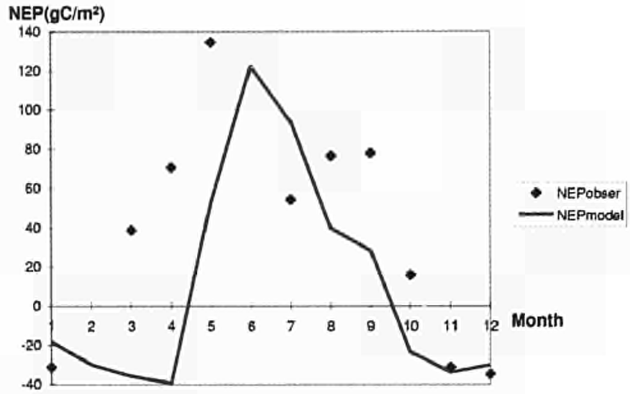


Figure 7. The generalised structure of the coupled modelling framework.



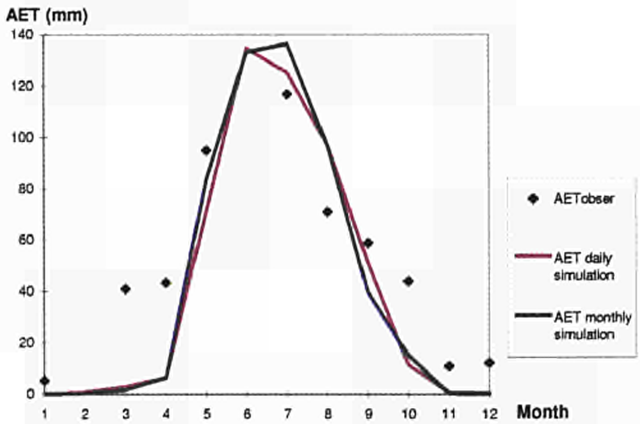


Figure 8. Testing of a preliminary version of the coupled model by comparison with CO_2 and H_2O ecosystem-atmosphere flux data from the EUROFLUX project: (a) seasonal cycle of of net ecosystem production (NEP, gC m^{-2}) for the EUROFLUX site at Tharandt, Germany in 1997; (b) seasonal cycle of actual evapotranspiration (AET, mm H_2O) for the same site and year, using daily and monthly average climate drivers.

The MAGEC project: A regional-scale tool for examining the effects of global change on agro-ecosystems.

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Agro-ecosystems cover over 51% of the land area of the European Union and so form a vital component of any future prediction of global change impact at the European level. The MAGEC project (Modelling Agroecosystems under Global Environmental Change) will provide modules of soil / plant interactions in agro-ecosystems to contribute to patch (<0.1 km) and regional scale (10-100 km) modelling frameworks already under development within the EU-TERI programme. The agroecosystem processes addressed by MAGEC are depicted in Figure 1 below.

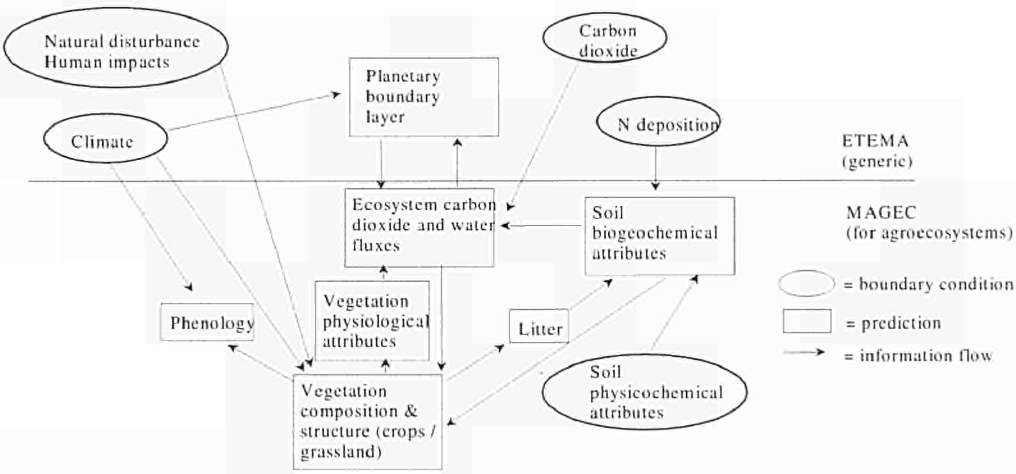

Figure 1. Agroecosystem processes addressed by MAGEC and those addressed by the European Terrestrial Ecosystem Modelling Activity (ETEMA)

During the course of the MAGEC project, we will a) evaluate to process descriptions used by leading agro-ecosystem soil models (e.g. Bradbury et al., 1993; Smith et al., 1996a) and plant models (e.g. Donatelli et al., 1997) using available data (e.g. Smith et al., 1996b), b) use the best process descriptions to formulate new agro-ecosystem modules for use in patch and regional scale modelling frameworks, c) test the accuracy and precision of the new modules (e.g. Smith et al., 1996c & 1997a; Booltink et al., 1996), d) incorporate the agro-ecosystem modules into existing patch / regional scale modelling frameworks as well as develop stand-alone versions for use elsewhere, e) test the performance of the coupled soil / plant agro-ecosystem modules in patch / regional scale modelling frameworks, f) contribute an agro-ecosystem module to a modelling tool under development elsewhere.

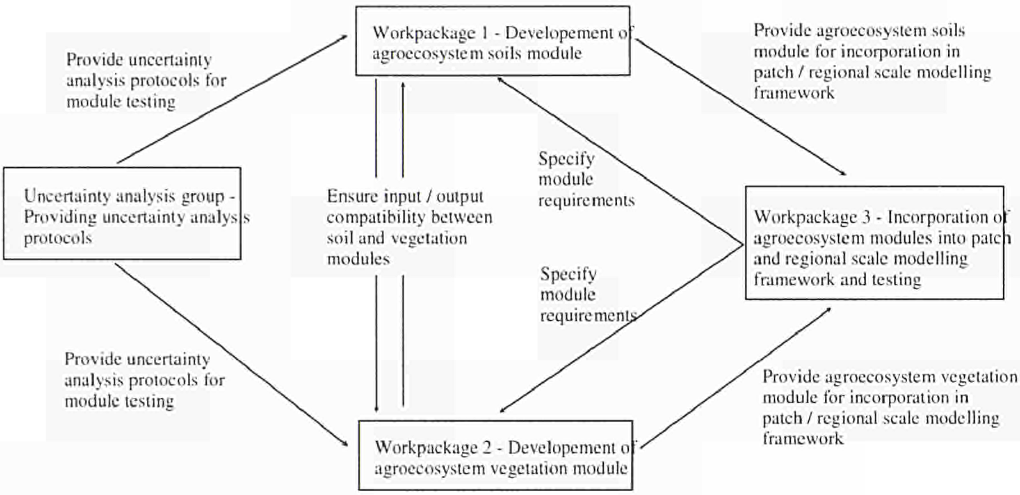

Figure 2. Interactions between MAGEC Work-packages

The work undertaken is divided into three main Workpackages as shown in Figure 2 above. The resulting regional-scale tool will allow policy makers in the EU and individual governments to study the environmental impacts of land-use and climate change and examine scenarios for mitigation (e.g. Smith et al, 1997b,c, 1998). More information on MAGEC can be found at the MAGEC web site at URL: http://www.res.bbsrc.ac.uk/soils/magec.

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Pan-European programme for the intensive monitoring of forest ecosystems

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The Pan-European Intensive Monitoring of Forest Ecosystems started in 1994. It covers 31 countries in Europe and consists of approximately 860 intensive monitoring plots. In expert meetings harmonized methods for the assessment have been agreed. The data are collected by National institutes and submitted to a European data centre for validation and further evaluation (FIMCI). External institutions are invited to use these data for additional evaluations within the scope of the Programme.

BACKGROUND OF THE INTENSIVE MONITORING PROGRAMME

The original major aim of the Intensive Monitoring Programme is to contribute to a better understanding of the impact of air pollution and other factors which may influence forest ecosystems.

The Intensive Monitoring Programme is part of the European Scheme on the Protection of Forests against Atmospheric Pollution. At the same time it is also part of the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the convention of the Long-Range Transboundary Air Pollution (CLRTAP). The establishment of the programme was furthermore supported by Resolution No. 1 of the First Ministerial Conference on the Protection of Forests in Europe (Strasbourg, 1990) and Resolution No. 1, 2 and 4 of the Second Ministerial Conference on the Protection of Forests in Europe (Helsinki, 1993). The latter three resolutions refer to sustainable forest management, conservation of biological diversity and adaptation to climate change. Widening the scope of the Programme in relation to these topics thus seems relevant, also considering the assessments made already within the Programme. At the moment 31 countries participate in the Pan-European Intensive Monitoring Programme.

SET-UP OF THE MONITORING PROGRAMME

The intensive monitoring plots have been selected to represent the most important national or regional forest ecosystems. As the plots are not selected according to a statistical randomised sample, the data are not representative for the forest in Europe in a statistical sense. On these intensive monitoring plots the following aspects of the forest ecosystem are assessed: crown condition, forest growth (increment) and the chemical composition of foliage and soil. Additional measurements on part of the plots include the species diversity of ground vegetation, atmospheric deposition, meteorological parameters and soil solution chemistry. Within each of these surveys, a number of mandatory and optional parameters have been defined. In expert meetings the methods for sampling and analysis of these parameters are discussed and agreements on harmonized methods are reached. The minimum temporal resolution of the surveys is scheduled as follows:

The location of the intensive monitoring plots and the assessments (foreseen to be) carried out. The "core" surveys consist of the annual crown condition, the soil, the foliar and the measurements for forest growth

- Core surveys (crown & soil & foliage & forest growth)
- Core & deposition
- Core & deposition & soil solution
- Core & deposition & meteorology
- Core & deposition & soil solution & meteorology
- Other combinations

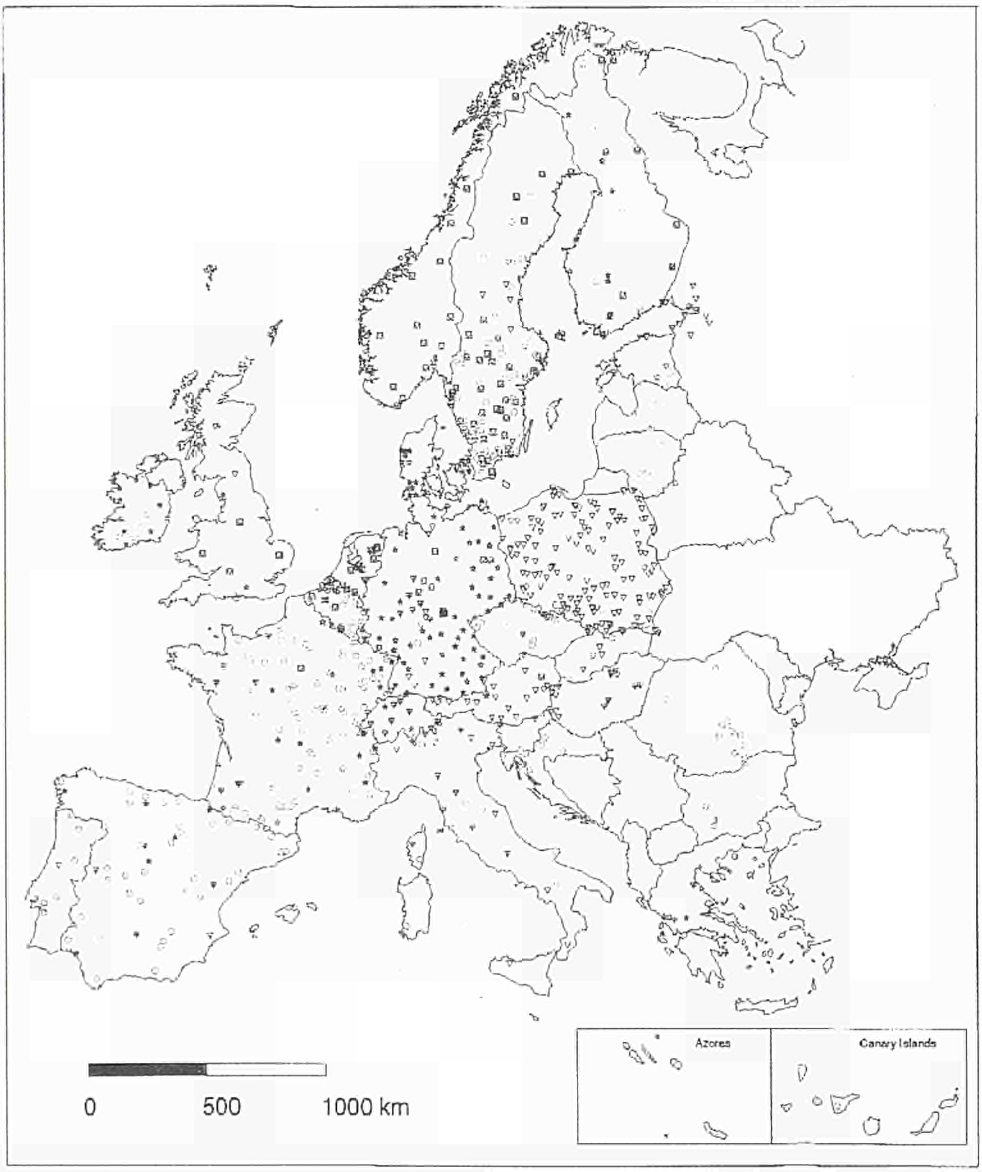

Figure 1. Geographical distribution and surveys carried out at the plots of the Pan European Intensive Monitoring Programme (based on information received until April 1999).

- Crown condition (at least once a year, on all plots on all trees in (sub-)plot)
- Chemical composition of the contents of needles and leaves (at least every 2 years, on all plots on 5 trees)
- Soil chemistry (every 10 years, on all plots)
- Increment / forest growth (every 5 years, on all plots, on all trees in (sub-)plot)
- Atmospheric deposition (continuous, on a selection of the plots, in- and outside the plot)
- Soil solution chemistry (continuous, on a selection of the plots)
- Meteorology (continuous, on a selection of the plots)
- Ground vegetation (every 5 years, on a selection of the plots)
- Remote sensing / aerial photography

At present, the Programme covers 862 selected plots in 31 participating countries (512 plots in the EU and 350 plots in non-EU countries) (Figure 1). Although the Intensive Monitoring Programme started in 1994 and most first assessments were made in 1995, sometimes existing plots were also used, which lead to longer time series. Whenever possible these older data sets were converted in the correct format and included in the databanks. As several countries only started later and some new plots are still added the quantity will grow in the coming years. The validation of the 1997 data is in process.

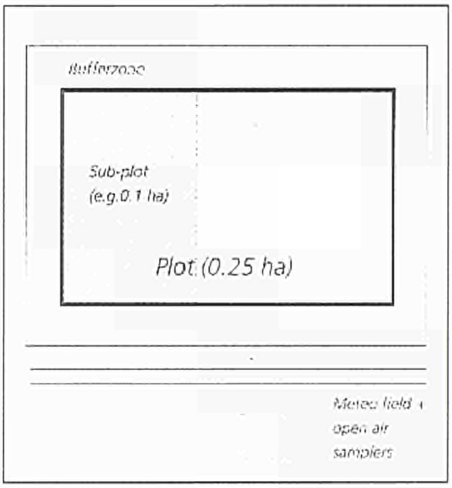

Figure 2. Field set up at the intensive monitoring sites.

OBJECTIVES

Objectives of the Intensive Monitoring Programme are presently focussed on possible adverse impacts of air pollution on forest ecosystems. It includes the assessment of the various aspects of the forest ecosystem and the integrated evaluation of these different aspects to derive:

- Responses of forest ecosystems to changes in air pollution by trends in stress factors and ecosystem condition.
- Critical loads of atmospheric deposition, in relation to present loads by evaluating the fate of atmospheric pollutants in the ecosystem.
- Impacts of future scenarios of atmospheric deposition on the ecosystem condition.
- Relevance of the results on a European scale, to contribute to a European wide overview of impacts of air pollution and its control strategies.

The Intensive Monitoring Programme is considered of importance in the evaluation and further development of air pollution protocols by giving insight in the effects of present emission control measures. Apart from the air pollution, the Programme may contribute to a number of actual issues. Examples are the criteria related to the sustainability of forests as a carbon sink to reduce the build up of atmospheric greenhouse gases, forest ecosystem health and vitality, forest production, species diversity of the ground vegetation and protective functions of soil and water resources.

POTENTIALLY AVAILABLE DATA

Although the majority of the plots have been installed by now, still some (parts of the) plots are incomplete or in test phase. A summary of the available data of the various surveys over the years is given below (see Table 1). The data from 1997 are now (Spring 1999) being validated by the FIMCI data centre. After the completion of the network a large number of data on the intensive monitoring plots in Europe will be available (see the last column of Table 1). The Intensive Monitoring database will ultimately contain data on the following assessments in between 180 and approx. 860 plots on:

- Site factors: stand and site characteristics, stand history / management.
- Stress factors: meteorological data and air pollution / atmospheric deposition data, pests and diseases.
- 'Biological' ecosystem condition: crown condition, forest growth, species diversity of the ground vegetation.
- 'Chemical' ecosystem condition: foliar chemistry, soil chemistry, soil solution chemistry, while aerial photographs will be available for around 150 plots.

In the last column the main parameters are stated. For a full review of all mandatory and optional parameters reference is made to the Manual of ICP Forest, the relevant Regulation of the European Commission and the 'Basic document for the implementation of the Intensive Monitoring Programme of forest ecosystems in Europe'.

Table 1. Summary of data availability[1] (in terms of where data have been assessed)

	1990	1991	1992	1993	1994	1995	1996	1997	Ultimately available	Main parameters
General plot information									862	Coordinates, altitude, soiltype, species, age, etc.
Crown (annual)	18	35	23	25	303	430	697	715	859	Defoliation, Discolouration
Soil (once per 10 Years)	11	22	22	63	62	345	87	15	847	C, N, pH, BS and other major elements
Foliar (every 2nd year)	12	4	24	117	145	425	283	565	847	N, S and other major elements
Forest Growth (every 5 years)	0	71	80	113	187	266*	266	138	852	DBH, height stem density
Deposition (cont.)	0	4	4	4	9	35	100	137	505	Throughfall, bulk, N, S and other major elements
Soil solution (cont.)	12	4	15	29	29	32	167	137	238	P, Ca, Mg and other elements
Meteorology (cont.)		4	4	4	9	35	100	137	180	Precipitation, wind, temperature, etc.
Ground vegetation (5 years)						3	35	...	596	Species
Aerial Photography (once)					46				150	

* year that principal assessment should have taken place; [1] situation in spring 1999

STUDIES TO REACH THE PROGRAMME'S OBJECTIVES

In terms of data availability, the ultimate level II database allows us to reach most of the objectives of the Intensive Monitoring Programme, such as to derive at critical loads and relationships between (trends in) stress (site and stress factors) and (trends in) effects (chemical and ecological ecosystem condition). Relevant studies that are needed to reach the various objectives of the Programme include: statistically-based correlative studies, relating site and stress factors to the forest ecosystem condition, trend studies, providing insight in statistically significant trends in stress factors and/or ecosystem conditions and input-output studies, describing the fate of atmospheric pollutants. Furthermore, the use of modelling in the assessment of critical loads, predicting future impacts and up-scaling results on a larger scale by combining data from the Intensive Monitoring Programme with other databases (e.g. level 1 sites and EMEP data) is strongly advocated. Active participation of external institutes is needed to carry out the proposed activities in the near future.

DATA ACCESS AND RULES FOR DATA AVAILABILITY

The data remain the property of the participating countries. The data are kept and managed in a central place at the FIMCI databank. Use of the data for additional evaluations is encouraged, but the assurance of scientific accurate work has to be provided before data are released. To enable an optimal use of the efforts by internal and external institutions a brief description of intended evaluations has to be presented. Complete details on the rules for data access are included in the Annex 1 to the 'Basic document for the implementation of the Intensive Monitoring Programme of forest ecosystems in Europe'.

Further information:

For more information please contact the European Commission DG Agri, ICP Forest or the FIMCI Secretariat. The technical report for 1999 can be downloaded from: http://europa.eu.int/comm/dg06/fore/index_en.htm.

FIMCI

Application of European scale transects in the Terrestrial Ecosystem Research Initiative

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b, Potsdam Institut für Klimafolgenforschung (PIK), Germany (ETEMA).

INTRODUCTION

To quantify the responses of European terrestrial ecosystems to global change, it is essential to recognise the substantial variability in climate, land-use and pollution. A fundamental principle in the design of the Terrestrial Ecosystem Research Initiative (TERI) was to provide integration across these differences by the application of European scale transects (Menaut and Struwe 1994). By focusing studies on specific ecosystems along such transects it is possible to:

- assess the effects of altered climate on ecosystem functioning
- examine the interactions with variations in atmospheric pollution
- integrate the above effects with regional changes in land-use across Europe.

Additionally, transects provide a means to increase cohesion in the research addressing these issues at a European scale and in the context of global international programmes (Koch et al. 1995; Steffen et al. 1999).

In the first instance, the TERI transects may be viewed as crossing Europe in a geographic sense. Strictly, however, the geographic differences only provide a means to compare the climate, pollution and land-use differences. This short contribution summarizes geographic maps of the TERI transects, and then compares these with transects in "climate space" considering the range of conditions of the different sites.

TRANSECTS AND CLIMATE SPACE

The network of TERI sites as collated by Sutton et al. (1999) is shown in Figure 1. Geographically, the TERI sites cover the full range of Europe including measurements in eastern Europe and the European Arctic. The TERI transects have largely been established at a project level. Key transects themes have addressed:

- the effect of latitude (temperature) (N-S)
- the effect of continentality and wetness (W-E)

These are shown in geographic space on the European maps that follow. Taking latitude, longitude and altitude as inputs, these sites may be also be mapped in European climate space. Possible axes could include:

- mean annual temperature or seasonal temperature ranges
- precipitation and wetness
- air pollution climate e.g. acidifying S & N inputs

In the present analysis, plant growing degree days are plotted against a dryness index, with these values being taken from a European climate model (unpublished database, W. Cramer). This provides a general description of the range of climatic conditions. In addition, an example is provided where projects address climate continentality, with mean temperature plotted against mean monthly temperature range. In each case the distribution of climate is shown from the conditions at 0.5 ° spaced points over Europe. Onto this base distribution, field sites are shown, given their location and altitude.

For comparison against the European map (Figure 1), all the TERI sites are plotted with these climate space axes in Figure 2. This shows that again most of the European climate is represented. However, it is notable with these axes that much of Europe is classified as rather wet (dryness index >0.9), so that these points are not well distinguished on Figure 2. Much of the variation in conditions occurs in dryer and warmer parts of Europe. The figure shows the driest parts of Europe are the least well represented.

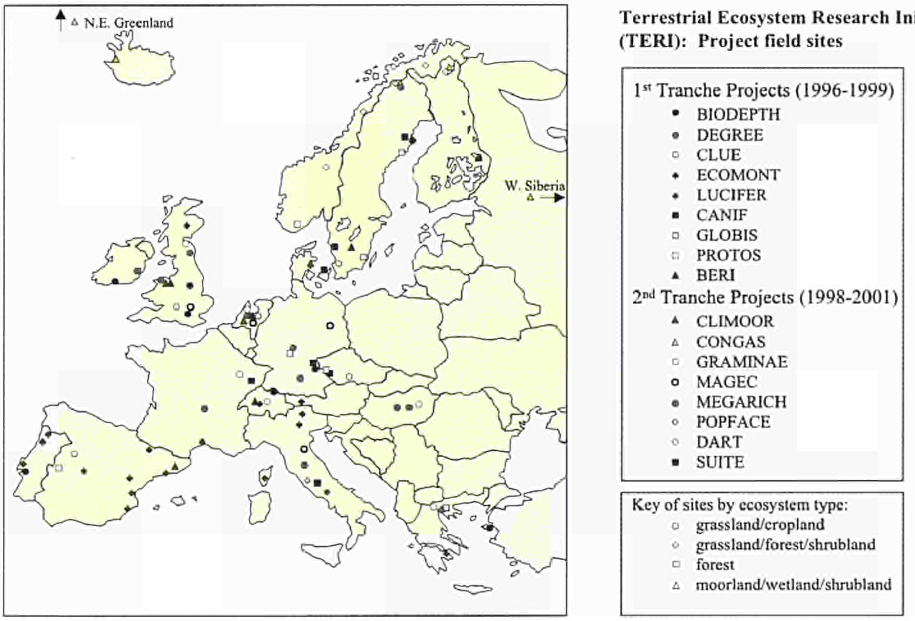

Figure 1. Map of TERI project field sites

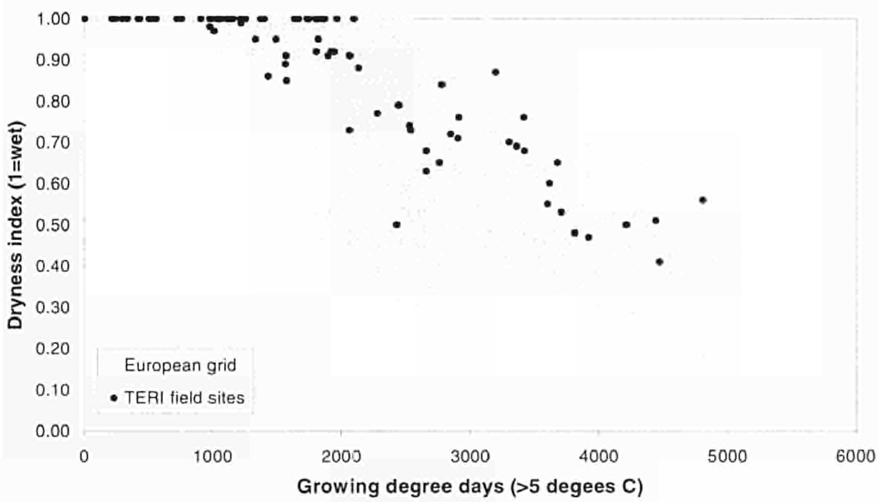

Figure 2. TERI project research sites in European climate space.

TERI PROJECT TRANSECTS ACCORDING TO ECOSYSTEM TYPE

Grasslands

A large number of projects in TERI have addressed the interactions of global change with grassland ecosystems, including arable and former arable land.

Much of European climate space is covered, but it is notable that with these climate axes, SW-NE transects are actually very similar to NW-SE transects (e.g. DEGREE, BIODEPTH).

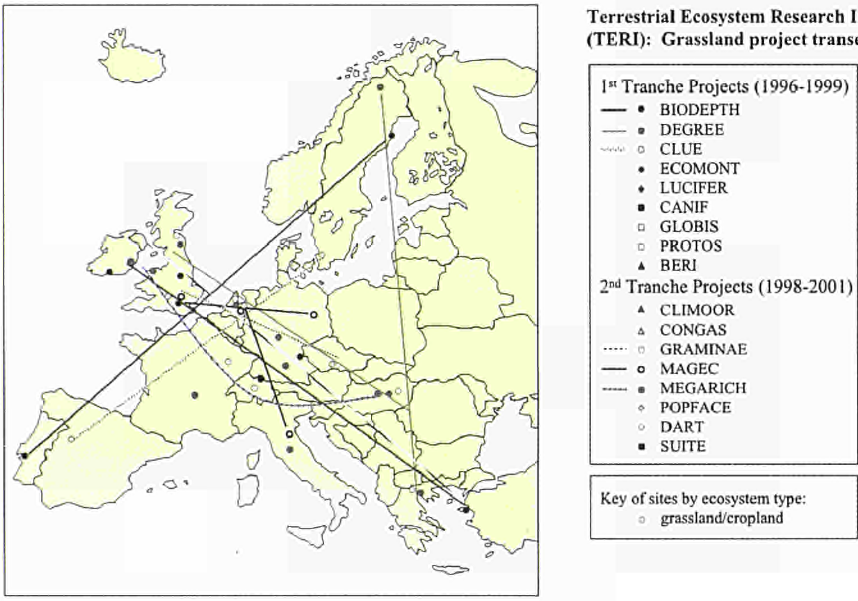

Figure 3. TERI project transects addressing grasslands and croplands.

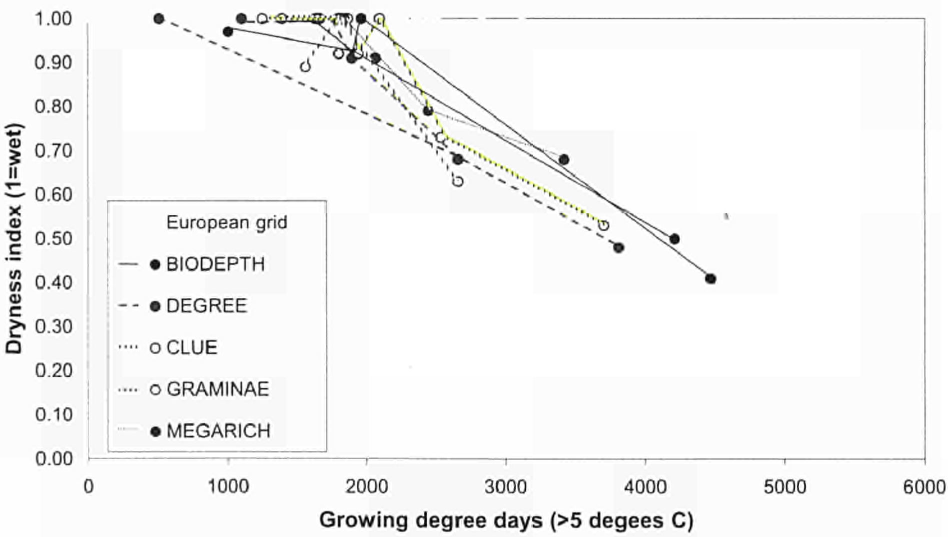

Figure 4. TERI grassland sites in European climate space.

Forests

TERI forest ecosystem projects have mostly addressed the effect of latitude, with N-S transects. CANIF also considered a transect of 'air pollution climate'. Altitude is a key factor: in relation to the climate space criteria used here, varying site altitudes (e.g. in CANIF) result in some of the S. European sites having a cooler, wetter climate than N. European sites.

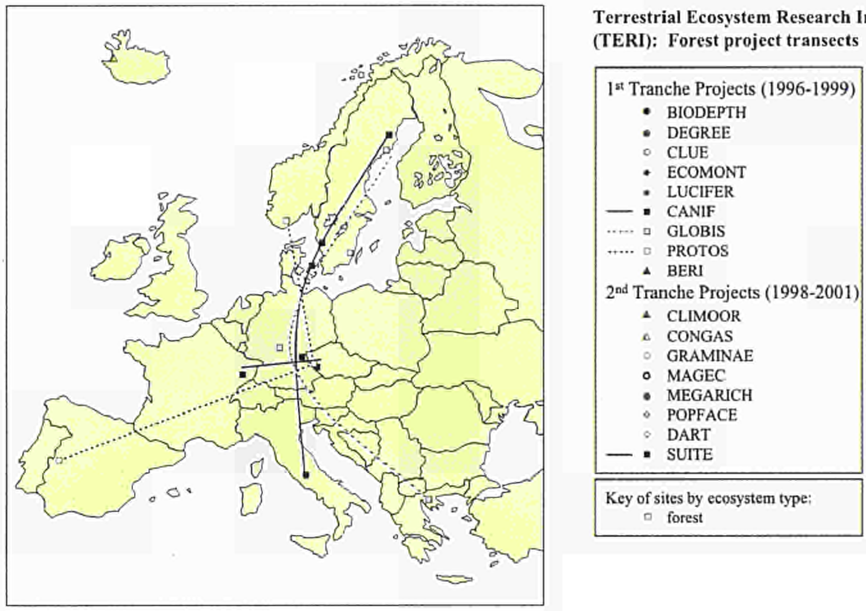

Figure 5. TERI project transects addressing forests.

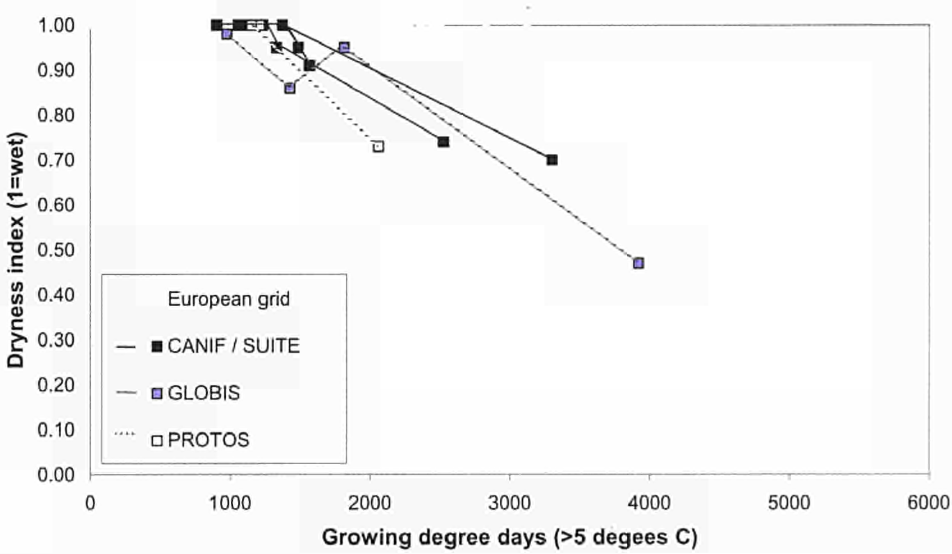

Figure 6. TERI forest sites in European climate space.

Moorland and wetlands

For the wetland ecosystem projects BERI and CONGAS, the geographic space may be very wide. This is especially so for CONGAS which includes sites from Greenland to Siberia. However, with the general climate space criteria used here, the range of conditions is very narrow. This clearly reflects the climate requirements for wetlands.

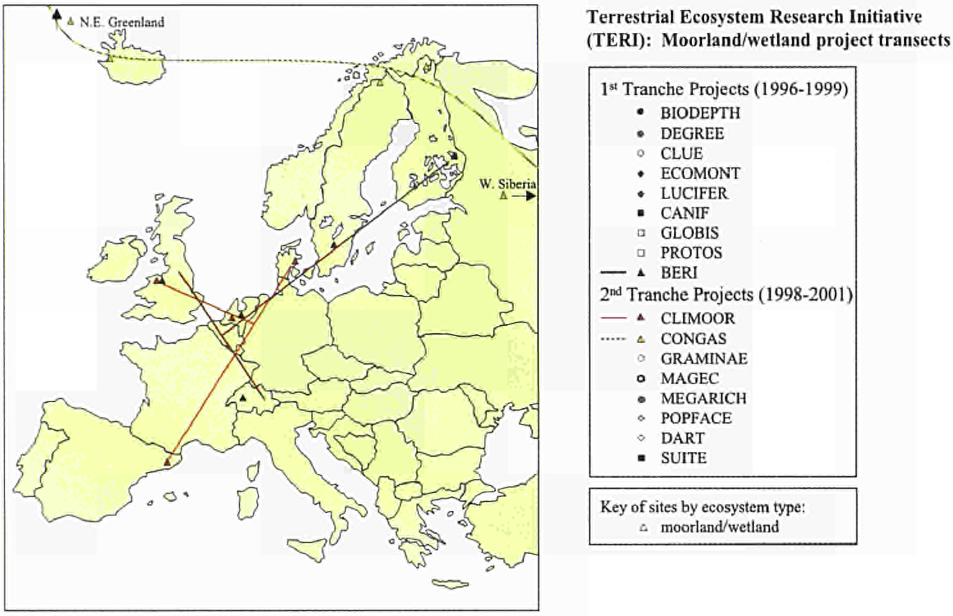

Figure 7. TERI project transects addressing moorlands and wetlands.

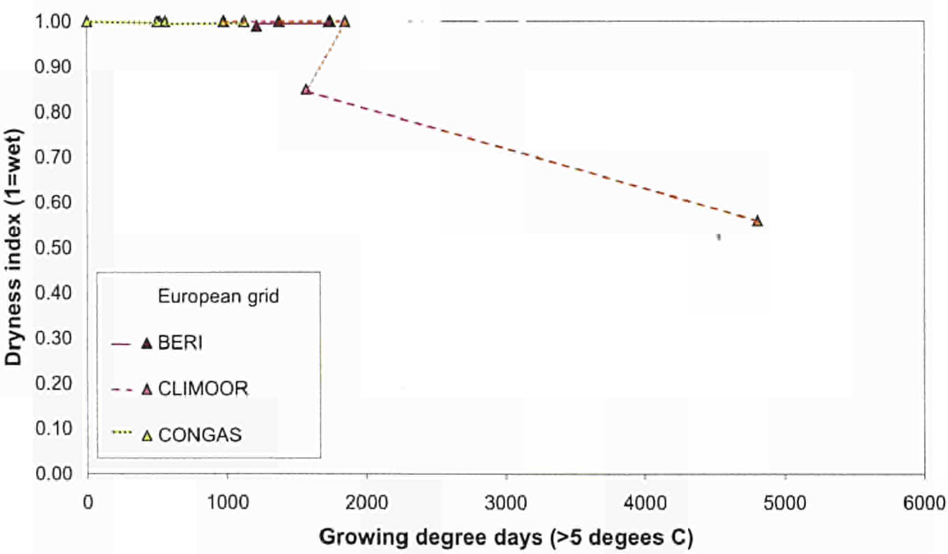

Figure 8. TERI moorland and wetland sites in European climate space.

Multi ecosystem studies

Three projects in TERI address multi-ecosystem interactions considering: the impact of fire on Mediterranean shrublands (LUCIFER), effects of land-use change on mountain ecosystems (ECOMONT) and effects of climate and land-use change on the northern tree line (DART). In the case of DART, a main transect of latitude is supported by meso- and micro-transects at a local level, although, by definition, the subsidiary transects of DART refer to only a very small part of European climate space.

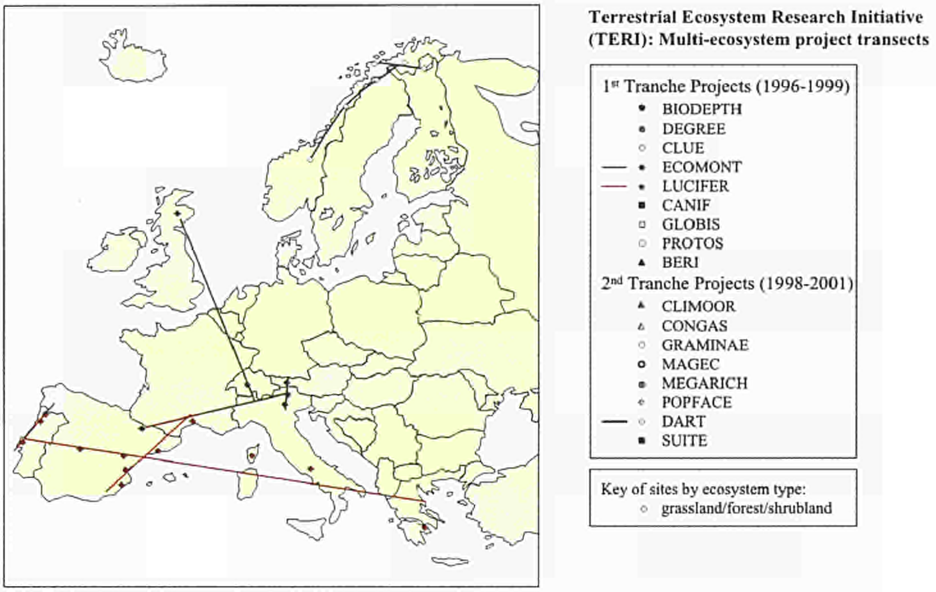

Figure 9. TERI project transects addressing interactions between grasslands, forests & shrublands.

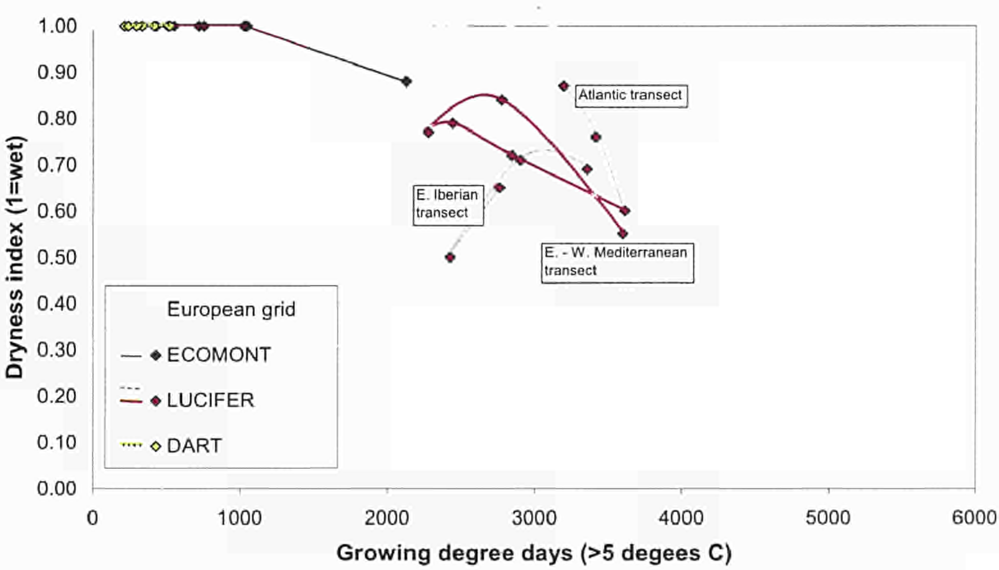

Figure 10. TERI project sites addressing interactions between different ecosystem types in climate space.

CHOICE OF CLIMATE PARAMETERS

LUCIFER includes a network of 3 transects and these illustrate the complexity of differences that may occur in climate space. The Atlantic (Portuguese) transect clearly shows the effect of wetness increasing south to north (Figure 10). By contrast, the main W-E transect 'loops' in climate space from the Portuguese sites, through France and Italy to Greece. Hence, what may appear as a simple linear transect in geographical space must be carefully interpreted in relation to climate space.

As an example of a different climate space comparison, Figure 11 shows the LUCIFER, GRAMINAE and MEGARICH transects in relation to mean annual temperature and climate continentality (as indicated by the mean temperature difference between the warmest and coldest month). With these axes it is clear how the LUCIFER sites cover a range of continentality. In the case of GRAMINAE, the effect of continentality is part of the hypothesis under investigation by the project. Comparison of Figure 11 with Figure 3 shows that to maintain a similar mean average temperature, the transects of GRAMINAE and MEGARICH are actually oriented NW-SE.

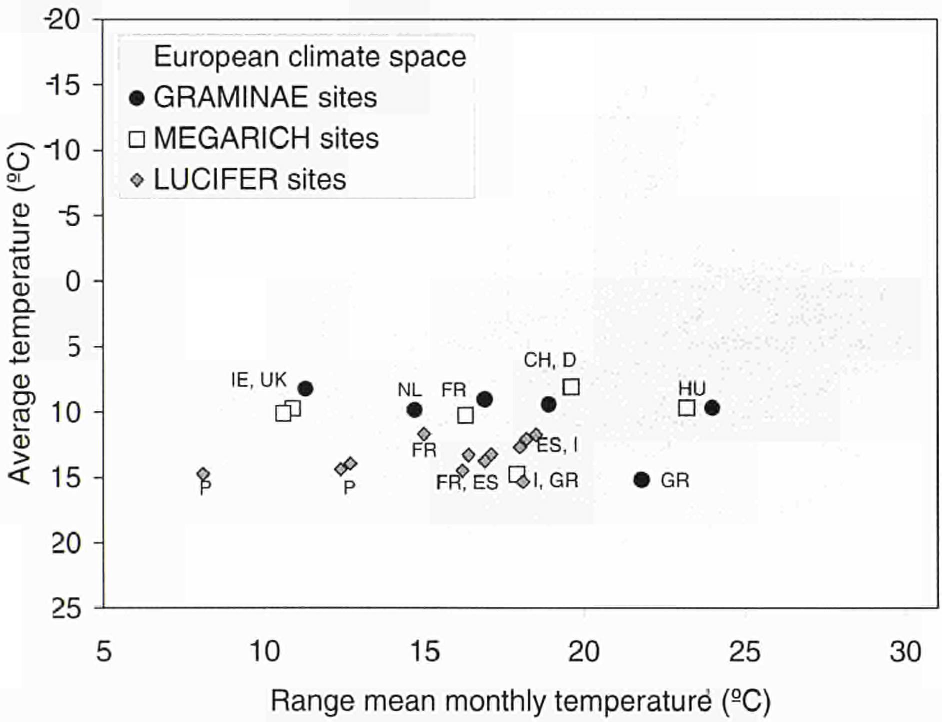

Figure 11. Examples of TERI projects in climate space showing alternative climate axes: The GRAMINAE, MEGARICH and LUCIFER projects cover a wide range of climate continentality, while maintaining a similar mean annual temperature. Letters indicate nationality of sites.

CONCLUSIONS

At a minimum level, transects provide a means to integrate researchers and provide a European perspective. In this sense, they are simply 'networks', representing a range of conditions. However, transects provide the facility to take this network approach a step further and represent a useful tool to examine the interactions of climate, pollution and land-use with ecosystem functioning. By selecting a major transect through specified changing conditions, the aim of the approach is to simplify analysis. In contrast, the multiple differences experienced in loose geographic networks can easily become too complex to analyze.

It is, nevertheless, important to bear in mind that geographical transects do not always translate into the most obvious transects through climate space. This may arise both through the highly structured climate of Europe, as well as the effects of altitude. Care is therefore needed in designing such transects in relation to climate, pollution and land use differences, rather than as simple geographic lines.

To ensure that a transect provides more than a simple network, requires that the transect addresses a specific hypothesis related to the gradient being covered, and then implements a standard protocol at the different sites. Clearly this poses major challenges for the researchers to develop scientific contacts in the exact climate space area required, rather than just working at the locations of established collaborators.

Finally, it is essential that the transect observations are compared with predictions. Hence, there needs to be a close coupling between model development and the transect results. By providing data for different climate regimes, results from such continental scale transects can help ensure a wide applicability of the model outputs.

ACKNOWLEDGEMENTS

Thanks to the following for supplying data: M. Bahn, C. Beier, C. Byrne, T.R. Christensen, K. Ekschmitt, B. Emmett, J.W. Erisman, A. Hector, M. Hoosbeek, L. Horvath, B. Huntley, B. Loubet, C. Milford, G.S.Mugnozza, J. Mulder, A. Neftel, F. Roda, L. Rossi, L. Sable, E.-D. Schulze, A. Tietema, W. van der Putten. This report provides a contribution to TERICA (ENV4-CT95-0051) from GRAMINAE (ENV4-CT98-0722) and ETEMA (ENV4-CT95-0052).

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Appendix 3.
Conference plan and presentations

20 June 1999

José Moreno	Chairman's welcome: Overview of TERICA and aims of the Final Conference.
Mark Sutton	Conference approach: working groups and the user interface.
Wim van der Putten	Host's welcome: The conference setting and local information.
Denis Peter	Perspective from DGXII on ecosystem research in the context of EU policies.

21 June 1999

Presentations from Working Groups

Klemens Ekschmitt	WG 1. Ecosystem functioning and management under extreme events and multiple stresses.
Val Brown	WG 2. Loss of biodiversity and ecosystem functioning.
Phil Hulme	WG 3. Alien species and outbreaking species in ecosystems.
Wim van der Putten	WG 4. Restoration and recovery of damaged ecosystems.
Bob Baxter	WG 5. European carbon budgets / linking C & N cycles.
Mark Sutton	WG 6. Trace gas fluxes and ecosystem functioning.
Wolfgang Cramer	WG 7. Ecosystems in the landscape.
John Ingram	WG 8. Policy conflicts: solving one problem creates another.

Presentations from research users

John Ingram (United Kingdom).
The Terrestrial Ecosystem Research Initiative and the International Geosphere Biosphere Programme (IGBP): Global Change and Terrestrial Ecosystems (GCTE).

Tor-Bjorn Larsson (Sweden).
Needs for biodiversity research – experience of the European Working Group for Research in Biodiversity (EWGRB).

Marja Veino (Finland).
Providing a link between biodiversity research and multiple users: co-ordination of the Finnish Biodiversity Research programme (FIBRE).

Michele Shortanner (France).
Research requirements to help the designation and management of Special Areas of Conservation under Natura 2000.

Leonidas Louloudis (Greece).
The interface between environmental research and reform of the Common Agricultural Policy.

Till Spranger (Germany).
Research needs to support European policy on transboundary air pollution.

22 June 1999

Presentations of TERI research projects

The TERI projects were presented during a special poster session (see Appendix 2).

Projects linked mainly to grassland ecosystems:

BIODEPTH, CLUE, DEGREE, MICRODRIVERS, (MEGARICH)*, GRAMINAE

Projects linked mainly to forest ecosystems:

CANIF, GLOBIS, PROTOS, POPFACE, SUITE

Projects linked mainly to moorland and wetland ecosystems:

BERI, CLIMOOR, CONGAS

Projects addressing links between different ecosystem types:

ECOMONT, LUCIFER, DART, (MODMED)*

Projects focusing on aquatic systems:

CODEPASS, LAKES

Projects focused entirely on modelling and scaling up.

ETEMA, DYNAMO, MAGEC.

* Indicates guest contribution to TERI from a related EC research programme.

Presentations and responses to TERI from research users

Evert Vel (for DGVI ICP-Forests/The Netherlands).
Improving the linkage between ecosystem research and monitoring: European forest ecosystem monitoring as a case study.

Diana Wilkins (United Kingdom).
TERI in relation to the research requirements of the UK Ministry of Agriculture Fisheries and Food (MAFF).

Bente Herstad (Norway)
Response to TERI in relation to the needs of multiple user groups.

Text drafting groups and discussion

1. Experience and achievements of TERI (Appendix 4).

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Text drafting groups and discussion

2. Looking ahead – emerging research and policy needs (Appendix 4).

Final discussion and close of conference.

Appendix 4.
Contributors to Drafting Groups

The main conference report is largely the product of the edited texts from Drafting Groups convened during the Conference. The following groups were established, with the reports modified following debate in plenary.

Tuesday 22 June: Experience and Achievements of TERI

Key issues included: highlighting scientific achievements of TERI, explaining the results in terms understandable to non scientists, indicating how work under TERI is supporting EU environmental policy.

Group 1. Threats on European ecosystems

Klemens Ekschmitt, Leonidas Louloudis, Till Spranger, Mark Sutton, Hans van Veen

Introduction to the range of problem issues and the major policy frameworks tackling these problems. The approach taken by TERI to address these issues.

Group 2. Global change and disturbance of element cycles

Bob Baxter, Claus Beier, Reinhart Ceulemans, Torben Christensen, Jan Willem Erisman, Rachel Helliwell, Marcel R. Hoosbeek, Mike Jones, Christian Körner, Marie Mattsson, Jan Mulder, Hlynur Oskarsson, Jean-Francois Soussana, Sten Struwe, Diana Wilkins

Including: A) C, N and other element cycles, B) trace gas fluxes.

Group 3. Managing biodiversity

Alberto Basset, Bryan Griffiths, Andy Hector, Bente Herstad, Karl Ritz, Loreto Rossi, Peter de Ruiter, Andreas Troumbis, Evert Vel, Wim van der Putten, Volkmar Wolters

Including: issues regarding the loss of biodiversity and restoration of damaged ecosystems.

Group 4. Dealing with complexity in protecting sensitive habitats

Brian Huntley, Neil Bayfield, Margarita Arianoutsou, Alexander Cernusca, Phil Hulme, Denis Peter, Luis Santamaria, Michelle Shortanner, Martin Sykes, Ramon Vallejo

Including: developing an integrated approach to ecosystem management, dealing with conflicts in the landscape.

Group 5. Strengths and limitations of the TERI transect and composite site approach.

Asher Minns, Alexander Cernusca, Wolfgang Cramer, Juan F. Gallardo, José Moreno, Mark Sutton, Martin Sykes

Including: the comparison between transects, networks or other approaches, the benefits of the transect approach, what it can and cannot provide. Advantages and limitations in use of composite sites.

Group 6. Interactions between TERI and IGBP-GCTE

John Ingram (GCTE Focus 3 Officer), Wolfgang Cramer (Focus 2 Leader), Volkmar Wolters (Activity 4.3 & Task 3.3.3 (co-)Leader), Valerie Brown (Task 4.3.2 Leader) & Sten Struwe (Task 3.3.3 Co-Leader); with written input from Pep Canadell (GCTE Executive Officer).

History of TERI and GCTE development, joint core projects, extent of linkages, successes and limitations, future directions.

Wednesday 23 June: Looking Ahead

Key questions included: what are the gaps in the research in relation to emerging policy needs? Has TERI research identified the need for *new* environmental policies? What new approaches have been identified to improve the organization and applicability of the research effort? Assessment in relation to new elements and gaps in the Fifth Framework Programme.

Group 1. Global change and disturbance of element cycles

Bob Baxter, Reinhart Ceulemans, Kevin Coleman, Wolfgang Cramer, Juan F. Gallardo, Rachel Helliwell, Marcel R. Hoosbeek, Brian Huntley, Mike Jones, Marie Mattsson, Jan Mulder, Hlynur Oskarsson, Peter de Ruiter, Sten Struwe, Martin Sykes, Xinyou Yin

Including: Major uncertainties in the carbon and nitrogen cycles. Requirements for trace gas flux estimates to underpin international agreements. Needs for other element cycles.

Group 2. Managing biodiversity

Alberto Basset, Soren Christensen, Andy Hector, Bryan Griffiths, Phil Hulme, Karl Ritz, Claudino Rodriquez-Barrueco, Loreto Rossi, Peter de Ruiter, Ramon Vallejo, Andreas Troumbis, Wim van der Putten, Volkmar Wolters

Including: Providing tools for protecting special areas of conservation. Responding to multiple stresses and extreme events. Guidelines for ecosystem recovery and restoration. Dealing with invasive and outbreak species.

Group 3. Dealing with policy conflicts/interactions and research approaches

Margarita Arianoutsou, Neil Bayfield, Alexander Cernusca, Luis Santamaria, Michelle Shortanner, Mark Sutton

Including: Research requirements to deal with conflicts (making new connections where needed). Requirements for *new* policy linkages. What is the balance between focus (fast progress, little attention to interactions) and integration (interactions considered, but progress harder)? The need for common scenarios, methodologies for scaling up and the role of analyses at the landscape level.

Group 4. Improving the interface with users of ecosystem research

Klemens Ekschmitt, Bente Herstad, Leonidas Louloudis, Asher Minns, Claudino Rodriquez-Barrueco, Evert Vel, Marja Vieno.

Including: Establishing the users and the user needs. How users should be involved in the research projects. Developing the basis for environmental indicators. Developing linkages between ecosystem research and monitoring.

Group 5. Organizing the research

José Moreno, Sten Struwe, Mark Sutton, Andreas Troumbis, Wim van der Putten

Including: Approaches for clustering European research on ecosystems e.g. Problem basis, ecosystem basis, identification of the primary linkages. Identifying the balance between focus versus integration. Possible models to manage clusters.

Appendix 5.

Project acronyms and web sites

Project	Home page address	Notes
TERI	http://europa.eu.int/comm/dg12/teri/point3.html	Describes TERI transect approach.
TERICA	http://www.nbu.ac.uk/terica	TERI Concerted Action
ARTERI	http://www.dpc.dk/ARTERI.html	Arctic Concerted Action
First Tranche		
ETEMA	http://www.planteco.lu.se/global/etema/etema.html	Modelling project. Transects potentially useful for data-model comparisons
BIODEPTH	http://forest.bio.ic.ac.uk/cpb/cpb/biodepth/contents.html	
DEGREE	http://www.uni-giessen.de/~gf1019/degree.htm	
	http://www.uni-giessen.de/~gf1019/degree/deg-site.htm	
CLUE	http://www.nioo.knaw.nl/cto/clue/clue.htm	
ECOMONT	http://info.uibk.ac.at/ecomont	
LUCIFER	http://www.uclm.es/PROYECTOS/LUCIFER/	
CANIF	http://www.uni-bayreuth.de/departments/planta/research/research.htm	A new site being set up at: www.bgc-jena-mpg.de
	http://www.bgc-jena.mpg.de/english1.html	
GLOBIS	http://www.uni-giessen.de/~gf1019/globis.htm	
	http://europa.eu.int/comm/dg12/teri/globis.html	
DYNAMO	http://www.mluri.sari.ac.uk/dynamo.htm	Modelling project (sites from other networks)
PROTOS	http://www.nisk.no/prosjekter/protos/default.htm	
BERI	http://www.joensuu.fi/mekri/beri/abstract.htm http://joynws1.joensuu.fi:80/mekri/beri/index.html	
Second Tranche		
CLIMOOR	http://www.risoe.dk/climoor/	
GRAMINAE	http://www.nmw.ac.uk/ite/edin/graminae.html	
	http://www.nbu.ac.uk/cara/graminae/graminae.html	
MAGEC	http://www.res.bbsrc.ac.uk/soils/magec/	Modelling project (sites from other networks)
MEGARICH	http://www.tcd.ie/botany/megarich/	
POPFACE	Under development	
DART	http://www.dur.ac.uk/DART/	
CONGAS	http://planteco.lu.se/cig/iascgcte/congas.html	
SUITE	http://profile.biologie.uni-konstanz.de/cook/suite/	

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This report represents a synthesis of the work under TERI as presented at theTerica final conference. Key scientific findings of the projects are highlighted and placed in the context of European environmental problems and policies. These are presented through the main report, as well as in the working group reports and extended abstracts of TERI projects which are included as annexes. Using this as a basis, the report looks forward both to the new research challenges and the needs for European environmental policy development. Particular attention is given to the research approaches, both to review the transect methodology and to consider new directions for developing integration and scaling up to the European level.

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