conference

Global Change and Arctic Terrestrial Ecosystems: an International Conference
21 - 26 August 1993
Oppdal, Norway

Recommendations

ARCTIC GLOBAL CHANGE CONFERENCE
Oppdal, Norway 21 - 26 August 1993

NINA

hosted by the
NORWEGIAN INSTITUTE FOR NATURE RESEARCH

Global Change and Arctic Terrestrial Ecosystems: an International Conference 21 - 26 August 1993 Oppdal, Norway

Recommendations

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PREFACE

Arctic terrestrial ecosystems constitute a significant part of the world's land surface area and of the biosphere's organic matter pool. These ecosystems are often exposed to human activities such as resource exploitation, and are slow to recover from disturbances. In addition, they are increasingly threatened by anthropogenic effects collectively known as global change. Principal among these is the threat of climate warming caused by increased greenhouse gas emissions. Global warming is predicted to be high in high northern latitudes. This, in concert with arctic ecosystems and the importance of permafrost to system functions, means that arctic areas will be greatly impacted.

Regularly scheduled international meetings have not been held for ecologists working in the Arctic since the termination of the International Biological Programme in the early seventies. The accelerating rate of impact and the improved opportunities for circumpolar meetings and exchange of scientists provide us with an ideal opportunity for such an international symposium these days.

The Oppdal conference is arranged in order to increase our understanding of arctic systems, to allow better predictions of rates and directions of change, and to provide policy makers with up-to-date information. The principal immediate benefit, though, is to stimulate international scientific communication and cooperation.

The main objectives of the conference are to:

- Increase international cooperation, collaboration, and exchange of ideas among researchers interested in arctic ecosystems;
- Assess our current knowledge and ability to predict the likely effects of anticipated global change on the structure and function of arctic ecosystems;
- Assess the likely positive and negative feedbacks of arctic ecosystems on the global atmosphere and climate; and
- Identify high priority areas of future research and the appropriate approaches for accomplishing that research.

Karl Baadsvik
Director (NINA)

EXECUTIVE SUMMARY

This was the first international conference on arctic terrestrial ecosystem ecology since 1974, and the first in history with free and open participation by Russian arctic ecologists. There were approximately 140 participants from 17 countries. Approximately 20 of the participants were from Russia.To help achieve these objectives, there were invited lectures, contributed oral and poster presentations, and a panel discussion. The major topics addressed in the conference through invited oral presentations and contributed oral and poster presentations are listed below.

After presentation of most invited lectures and contributed oral and poster presentations, the workshops met to discuss the following topics and to recommend highest priority research areas and organizational changes. The charges to the working groups were to:

- Evaluate past conference recommendations (i.e. progress towards responding to questions raised, indicate what information gaps still remain).
- Consider the need for addressing additional research topics.
- Suggest approaches and techniques appropriate for dealing with problems requiring additional attention.
- Identify where proposed research would contribute to the GCTE Operational Plan (IGBP Report No. 21) and if priority research areas cannot be accommodated in the current GCTE Operational Plan, indicate how this plan should be modified.
- Determine needs for international cooperation and linkages to other research groups.

Following discussion with conference participants, the priority working group topics below were identified:

1) Carbon stocks, fluxes, and feedbacks
2) Nutrient cycling and decomposition
3) Sensitive and at risk ecosystems prone to climate change
4) Species level effects on, and affects of, global change
5) Phenology, development, reproduction, and plant establishment under global change
6) Arctic biodiverstiy of species, populations and communities versus global change
7) Plant-herbivore interactions and global change
8) Needs for experimental manipulation: CO_2, nutrients, temperature, U.V., and water.
9) Temperature and humidity manipulations
10) Modelling, GIS, and remote sensing
11) Integrating efforts of arctic organizations and programmes

The reports available to the working groups for review are listed in the appendix and included the IGBP/GCTE Operational Plan (IGBP Report No. 21), the 1990 Trondheim recommendations entitled: "Impact of Climate Change on Natural Ecosystems, with Emphasis on Boreal and Arctic/alpine Areas ", the 1992 Pushino Recommendations and Resolutions entitled "Trace Gas Flux and Carbon Balance in Arctic Ecosystems", the NSF Arctic System Science, Land/Air/Ice Interactions Research Implementation Plan (ARCUS, 1991), and the Draft Arctic ecology and ecosystem section of the IASC document entitled "Scientific Plan for a Regional Research Program in the Arctic on Global Change."

Individual workshop recommendations were presented to the conference plenary for questions, discussion, and ratification. Representatives of the working groups then met together with the conference organizing committee to discuss organization of the recommendations included here. The workshop reports and recommendations were then circulated to all participants for comment before publication.

There were certain recommendations which were made by many or all of the working groups. These are listed in this summary.

Current state of knowledge

The arctic has obvious significance to the functioning of earth systems including atmospheric chemistry, regional weather patterns, and global atmospheric circulation patterns. The role of the arctic in future atmospheric and climate change is of great societal importance. The arctic is not only extremely sensitive to regional climate change, but also is in an area expected to experience especially large and early climate changes. The arctic has the capacity for long-term carbon storage (negative feedback) of carbon in peat layers and permafrost, and significant loss of carbon gases to the atmosphere (positive feedback). The arctic also impacts global circulation patterns by the strong seasonal variation in albedo. Changes in vegetation can have major impacts on albedo and surface water flux.

Broad coverage of the current state of the knowledge on the interaction of global change with arctic ecosystems will be summarized in two volumes. One, edited by Callaghan et al., will present the results of contributed papers and posters. The other, edited by Oechel et al. will present the invited and plenary talks. These papers cover a wide variety of topics and set the stage for the research recommendations covered here.

Gaps in current research and major research needs

Specific working group recommendations are found in the individual workshop reports. General conference and workshop recommendations for additional research are as follows.

1 Patterns of, and controls on, carbon, water, and energy flux in the arctic including:

- Direct effects of elevated CO_2 and changing temperature, moisture, and U.V.-B and their interactive effects on terrestrial ecosystems.
- Sources and sinks of trace greenhouse gases (e.g., CO_2, CH_4, N_2O)
- Importance of losses of organic matter and nutrients to aquatic and marine habitats

2 Patterns, causes, and consequences of the loss of species and biological diversity

- Sub specific to landscape diversity
- Relationships between trophic levels

3 The consequences of changes in biodiversity including the distribution of ecotypes, species, communities, and landscapes including:

- Predicting, identifying and monitoring changes
- Evaluating the biotic controls of regional trace gas, carbon, water, and energy balance
- Evaluating the impact of changes on human life support and conservation

The arctic community has a depth of expertise and understanding of regional processes and phenomena which range in importance from regional human welfare, climate, and biological conservation to globally important atmospheric chemistry (including important trace greenhouse gases), cloudiness, and global weather patterns. The arctic community recognizes that for long term predictions of important changes in the structure and function of arctic ecosystems, it is necessary to understand the underlying states and processes.

These states and processes include patterns and controls on the distribution and composition of communities, the performance and distribution of species, the flux and storage of carbon, nutrient cycling and water and energy balance. New approaches in measurement and experimentation open exciting possibilities for future research, including the possibility of coordinated research campaigns. The idea of intensive multidisciplinary research campaigns was enthusiastically endorsed as a way to rapidly address the very important questions facing the arctic with respect to global change including the importance of global change on arctic ecosystems and the feedbacks of arctic terrestrial ecosystems on the atmosphere energy balance and other regional and global processes.

Because of the depth of understanding of underlying processes from evolution to ecosystem dynamics, it was also acknowledged that the arctic terrestrial ecology community, building on traditional areas of research and borrowing approaches and techniques from the geosciences, is uniquely suited to address a range of questions of human and global significance. It was therefore agreed that the terrestrial arctic research community should seek to undertake an international research programme under the auspices of GCTE. This programme would be directed to identifying the patterns and controls on carbon gas, water, and energy flux in the arctic and in predicting future fluxes. The arctic community should undertake this programme because of its depth of understanding on the patterns and controls on the functioning of arctic ecosystems. It is suggested that a major new initiative under GCTE be initiated. This initiative could be implemented by the GCTE arctic research programmes.

Organization, communication, and implementation of arctic biological science

Several main themes ran throughout the conference. These included the need for improved and more frequent communication and the need for better organization within the arctic research community. A regular conference meeting schedule was proposed. Upon further discussion, it appeared that conferences should be scheduled to occur about every three years. Ideally the time and location of the following conference would be passed as a resolution at the previous conference. It was further suggested that consideration be given to costs to and support of young investigators as well as continuing support for Russian scientists as needed. Several arctic organizations exist and appear willing to assist in advertising and promoting periodic meetings including the MAB Northern Sciences Network.The major observations and recommendations regarding organization, communication, and implementation of arctic biological science were:

1 Improved communication is required within the arctic research community. Specific recommendations included:

  - More frequent conferences and workshops
  - Better availability of electronic mail, especially within Russia

2 Improved organization within the arctic research community and the organizations and agencies which support arctic research

3 Establishment of an arctic GCTE working group which would:

  - Be nominated by the national IGBP (or GCTE where it exists) committees
  - Develop an international arctic GCTE implementation plan based on the recommendations contained in this report and the IASC International Science Plan
  - Identify national and international sources of funding and support to help ensure the long-term success of the GCTE arctic research programme

- Establish linkages and communication between the GCTE arctic research programme and other national and international science programmes

- Form a small task force to revise the arctic ecology and ecosystems section of the IASC document entitled "Scientific Plan for a Regional Research Programme in the Arctic on Global Change".

Group 1:
CARBON STOCKS, FLUXES AND FEEDBACKS

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Participants (alphabetically)

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The group identified objectives in two distinct areas of activity:

1. coordination and administrative needs, and

2. scientific goals and current limitations.

Coordination and administrative needs

A genuine need exists for improved communications between scientists researching issues of global change in the Arctic. In particular the difficulty of east-west communication and of communication between scientific disciplines is limiting to progress in this field. Considerable efforts are being made to collect information pertinent to the evaluation of carbon stocks and fluxes, but the community of scientists responsible for these efforts remain largely isolated due to barriers of distance, culture, and academic tradition. There is a consensus of opinion among the group that this meeting was very valuable for scientific exchange. International meetings of the arctic research community should be held on a regular basis.

The group recommends either establishing a new newsletter or identifying an existing newsletter to communicate information relating to the coordination of research efforts, publication of information of common interest to researchers, and coordination of joint research and research campaigns.

The possibilities of further enhancing communications and scientific coordination through the establishment of electronic bulletin boards, and the coordination and publication of circumpolar data bases in CD format are perceived as longer term goal for this community of researchers.

Scientific goals and current limitations

The principle limitation to the study of carbon pools, fluxes and feedbacks is that of inadequate spatial and temporal scales of measurement necessitated by limited research resources. The equipment and time required for the measurement of carbon fluxes greatly limits the number and duration of such efforts due to limitation of research resources. Coordination and integration is essential to reliable estimates of carbon stocks and fluxes. A large scale integrated international effort is necessary to effectively measure the carbon stocks and fluxes in northern boreal forest and arctic and alpine ecosystems. This will require significantly more money than currently exists for this kind of research. The overwhelming evidence of the importance of arctic and boreal systems to global carbon cycling and the likely susceptibility of their large soil carbon stocks to greenhouse-induced temperature change suggests that the highest priority should be placed upon a large international coordinated scientific campaign in this region.

Current carbon stocks in arctic and boreal ecosystems are poorly known, and estimates generally do not have a high degree of resolution of categories. Most uncertainty exists in the extent of soil carbon stocks, and the amount of carbon in permafrost that is potentially subject to climate-induced thaw is unknown. Information is needed on many fractions of soil carbon including dissolved organic matter and the fraction highly resistant to decomposition. In general a need exists for more categorization of carbon pools.

Additional monitoring of atmospheric carbon is needed in high latitude sites. Both long term monitoring from fixed sites such as mountain tops and other sites characteristic of regional effects and from aircraft are desireable. It is important that atmospheric monitoring strategies incorporate ecological as well as atmospheric objectives in the location of long term monitoring sites. The methodology for interpreting local ecological effects in atmospheric monitoring networks needs to be developed, but represents a potentially effective tool in the suite of methods available to ecosystem flux prediction.

There is a need in the arctic science community for inexpensive access to polar data sets including a polar projection of AVHRR, NDVI or equivalent data. Current and future mapping efforts including landscape, ecoregion, permafrost, soils and vegetation need to be made available in digital form in a common polar projection format to the arctic science community.

Carbon fluxes between all carbon pools should be measured, but at present the fluxes between the soil and the atmosphere and between the atmosphere and vegetation are considered the highest priority for extensive measurement. In addition to CO_2 and CH_4, which are likely to contribute most to carbon budget determination, it is important to measure CO, N_2O, and other gas fluxes due to their potential importance to atmospheric chemistry or as indicators of key ecosystem processes.

Research on the dynamic response of carbon stocks and fluxes is likely to be dominated by feedbacks at a variety of spatial and temporal scales. Additional research at all levels including physiological processes, patch, and ecosystem scales must be initiated to provide mechanistic understanding of processes constraining the future fluxes and carbon stocks in arctic and boreal regions.

Group 2:
NUTRIENT CYCLING AND DECOMPOSITION

Chair: Knute Nadelhoffer, USA
Co-chair: Sven Jonasson, Sweden
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Critical research questions

We identified five major questions that need to be pursued in relation to climate change in the Arctic. These questions, and related sub-questions, are listed below.

1 What controls C and nutrient partitioning among non-living organic matter, microbes and plant roots in arctic ecosystems?

1.1 What are the relative importances of different soil organic matter pools (e.g., recent litter, microbial biomass, humus) for supplying nutrients to plants? What controls the turnover times of these different soil organic matter pools?

1.2 How do moisture, temperature and litter quality interact to control carbon and nutrient dynamics in decomposing materials?

1.3 What determines the primary form(s) of N (ammonium, nitrate, organic N) available to plants?

1.4 What role do mycorrhizae play in nutrient cycling?

1.5 How do freeze-thaw and wetting-drying cycles influence decomposition and nutrient dynamics in litter and soil organic matter?

1.6 What importance does biological N-fixation play in tundra ecosystems?

2 What are the direct effects of increasing atmospheric CO_2 on decomposition and nutrient cycling?

2.1 How is litter quality (e.g., lignin content, N concentration, soluble carbohydrates) influenced by CO_2 concentration?

2.2 Does CO_2 concentration influence the relative proportions of litter inputs to soils originating from roots and aboveground tissues?

2.3 How will elevated CO_2 concentrations influence plant-microbe interactions in the rhizosphere?

3 How do animals influence decomposition and nutrient cycles?

3.1 How do herbivores influence litter chemistry, decomposition and nutrient cycles?

3.2 How will the role of herbivores be affected by climate change?

3.3 How do soil fauna (e.g., invertebrates, detritivores) influence decomposition and nutrient cycling?

4 What are patterns of N deposition and outputs of C and nutrients at watershed and regional scales?

5 How are transports of nutrients and organic matter between ecosystem types and across arctic landscapes regulated?

Evaluation of past conference recommendations:

A number of recent conferences and documents have placed high priority on the need for integrated research on nutrient cycling and decomposition in the Arctic. Better understanding of controls on plant litter and soil organic matter decomposition and on the mineralization and immobilization of nutrients is required in order to predict responses of arctic plant communities and ecosystems to changes in climate. Most recommendations, however, are general in nature. An exception is the GCTE Operational Plan (IGBP Report No. 21). The GCTE Operational Plan lists the boreal forest/tundra as one of four biomes that should receive high priority for research support.

Specific GCTE recommendations for the Arctic include the establishment of three research transects, one each in Fennoscandia-Europe, Alaska and Russia, with at least five experimental sites established along each transect. Recommended activities at these sites include field experiments examining the effects of temperature, moisture and nutrient availability on decomposition, nutrient cycling, plant tissue quality and trace gas dynamics. Levels of research on decomposition and nutrient cycling vary among the regions in which these transects are located. The northern European region has a history of research on decomposition and nutrient cycling dating back to IBP studies that continues through the present at sites in Finland, Sweden, Norway and Iceland. As a result, the Fennoscandian-European transect is multidimensional with north-south, east-west, climatic and geological gradients. There is also a history of biogeochemical research in Alaska at Barrow, Toolik Lake and in central Alaska (Fairbanks and Eagle Creek) that provides a basis for advancing our understanding of decomposition and nutrient cycling. The current north-south transect, however, should be expanded to include an east-west component. For example, research activities in northwest Alaska, the Northwest Territories, the eastern Canadian arctic region and western Greenland should be developed and linked to form a North American transect or network. There appears to be a rich climate/soil/vegetation data base for the Russian arctic region. We recommend that a network of research sites with strong nutrient cycling and decomposition components be established and supported.

Recommended research approaches and techniques

We identified several new approaches to nutrient cycling and decomposition studies in the Arctic. These approaches have been used successfully in lower latitudes but, as yet, have not been fully integrated into climate change research in the Arctic. They are:

Catchment studies

Catchments (watersheds) are composites of ecosystem types and can be viewed as fundamental landscape units. Catchment drainage water chemistry can provide integrated information on nutrient cycling in defined areas. Long-term monitoring of streamflow and dissolved carbon and nutrients in representative streams and rivers should be a priority in arctic global change research. Catchment manipulations should also be initiated if our understanding of ecosystem responses to perturbations is to be scaled up from the plot-level to landscapes and regions. Responses of catchments to manipulations will provide critical validation data for biogeochemical models.

Ecosystem manipulations

Previous and current experimental manipulations are often conducted on small plots with relatively strong treatments. New approaches to manipulations should consider larger experimental units, longer time scales and experimental treatments that more closely simulate predicted climates.

Isotope surveys

Information on natural abundances of stable and radioactive isotopes (e.g., ^{15}N, ^{13}C, ^{18}O, ^{14}C, ^{210}Pb) has the potential to provide information on patterns of nutrient cycling, moisture regimes and soil carbon dynamics at large scales. Research that incorporates the use of naturally occurring isotopes in the Arctic should be supported.

Remote sensing of canopy chemistry

The use of remote sensing to characterize canopy and litter characteristics over large areas should be further developed in the Arctic. The inaccessibility of large areas of the Arctic to researchers requires the development of techniques that will allow for characterizing plant canopy chemistry. If ground-based research on the relationship between canopy chemistry and nutrient cycling characteristics yields predictive relationships, then remotely sensed information on canopy chemistry can be used in models to simulate patterns of nutrient cycling over large regions in the Arctic.

Species or species combinations as indicators

Arctic research should explore the potentials of key plant species or species assemblages as indicators of rates and patterns of nutrient cycling. For example, plant species with characteristic nutrient-use requirements could possibly be used to identify areas where critical biogeochemical processes (e.g., nitrification, N fixation, denitrification) are occurring.

Relationship of recommendations to the IGBP/GCTE Operational Plan

Our group's recommendations are consistent with and compliment the GCTE Operational Plan (IGBP Global Change Report No. 21: Global Change and Terrestrial Ecosystems). They support the long-term objective "to determine the interactive effects of land use, altered atmospheric composition, and climate change on the biogeochemical cycles of carbon, nitrogen and other elements" (GCTE Activity 1.2) as related to possible changes of biogeochemical cycles at global scales. Moreover, implementation of our recommendations will allow the international arctic research community to better..." determine the interactive effects of increased temperature and changes in nutrient availability on carbon and nutrient pools ..." (Short-term objective of GCTE Operational Plan Task 1.2.2.)

International collaboration and linkages

Research on nutrient cycling and decomposition in the Arctic will require joint projects that involve investigators from all arctic nations. Without such international collaborations accounting for variability in predictive models simulating responses of the entire arctic region to climate change will be impossible.

Group 3:
SENSITIVE AND RISK ECOSYSTEMS PRONE TO CLIMATE CHANGE

Chair: W. D. Billings, USA
Co-chair: Nadya Matveyeva, Russia
Rapporteur: W.D. Billings, USA

Participants (alphabetically)

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Catherine Mourdant, UK

This working group discussed the possible effects of climatic change on those arctic ecosystems seemingly most prone to such disturbance within the next decades or centuries. Some of these ecosystems are regional or local; some are pan-Arctic. These ecosystemic problems are listed here, but not in any order of priority. All, however, are urgently in need of research.

Given the uncertainties in the state of our knowledge, there is a likelihood that rising carbon dioxide and other greenhouse gases will trigger a variety of secondary changes in the physical and chemical environments of the biosphere. We emphasize that all ecosystems are potentially at risk from climatic change. Our focus on those ecosystems that may be particularly sensitive in no way implies insensitivity of ecosystems not addressed here.

1 The preservation of permafrost in tundra ecosystems by the maintenance or restoration of vegetational cover and its litter layer stands very high on our list of urgent ecosystemic problems. It is the vegetational cover that prevents thermokarst erosion by its insulating properties. Conversely, permafrost is the glue that holds tundra ecosystems together, particularly those on wet, sedimentary substrates.

2 The thermokarst process itself concerns the breakdown of and thawing of the frozen peaty substratum of the tundra soil. This releases carbon dioxide and methane to the atmosphere both in tundra and taiga, a positive feedback to the atmosphere that results in a loss of ecosystemic stability. (Billings and Peterson 1992; Billings 1994). In this process, nutrients are also released that may aid in ecosystem restoration, particularly in taiga bogs (Luken, J.O., and Billings, W.D.1983.)

3 In wet tundras, the thaw-lake cycle needs much more research particularly in regard to nutrient cycling and permafrost status during the cycle. Soil nutrients, including nitrogen and phosphorus, are limiting factors in most arctic ecosystems (Shaver, et al. 1992).

4 Unstable and windblown sandy soils and their biota and permafrost relationships are unique ecosystems needing study from a practical standpoint as well as from that of purely scientific one. Pingos are also in this category (Walker, Marilyn D. 1990). Both dunes and pingos, with deep active layers, are prime ground-squirrel habitats on the tundras of the North Slope of Alaska. These small mammals are important food sources for terrestrial carnivores.

5 Bog and other wetland ecosystems of the tundra. Will they dry up and disappear in a warmer climate - or will they be enhanced?

6 What will happen to the "tundra oases" (sensu Svoboda and his students) such as Truelove Lowland on Devon Island and Alexandra Fiord on Ellesmere, and similar ecosystems on other arctic islands? These particular problems are in the High Arctic where they may be (and probably are) less resilient to climatic change. Also, the sea-ice may disappear for long periods and thus impede migrations of terrestrial mammals.

7 Other sensitive ecosystems such as *Cladonia* ridges and plateaus grazed by caribou and reindeer are easily damaged by changes in animal populations and migrations. Also, wet *Sphagnum* communities are not really as well-known in the Arctic as they are in the boreal forest, particularly in regard to what will happen if warmer soils release nutrients that may inhibit growth of these peat moss vegetations.

8 There is a strong possibility of the breakdown of stratospheric ozone over parts of the Arctic. Arctic plants and their ecotypes are more sensitive than their alpine counterparts of the middle latitudes to the impacts of Ultraviolet-B irradiation (Caldwell, Robberecht, and Billings. 1980; Robberecht, Caldwell, and Billings, 1980; Caldwell, Robberecht, Nowak, and Billings, 1982; Billings, 1984). This problem should not be ignored,(Billings, 1994).

9 More research is needed on the sensitivities and cycles of herbivore-vegetation relationships: lemmings, caribou, reindeer, moose, etc.

10 We consider monitoring of LTERs as baselines of very high priority and urgency.

11 The highly productive coastal saltmarshes of the Arctic and Subarctic need more study because of their fragility and nutrient cycling (see, goose population studies of Bob Jeffries in the Hudson's Bay Region).

12 The open seas, once the ice is gone, may be subject to oil spills and their pollution.

13 We must not forget that research is needed on the matrix ecosystems as well as the unique ones.

14 Fast climate change may result in migrations that are slower and cannot keep up because of "resistances". This could lead to biotically poor "new" ecosystems prone to invasion and takeover by "weedy" plants and animals. Ecosystems do not migrate, species and populations do.

15 Regulations and laws may be needed to keep the global greenhouse gases (emissions, etc.) below certain limits. Is this possible?

16 Research results and recommendations should be translatable by policy makers and administrators into operational management decisions.

17 Accelerate research on direct effects of CO_2 increase on arctic ecosystems -- not just the green plants themselves.

18 Problem-oriented research is needed now as industry (and agriculture?) expand and develop in the Arctic.

19 How will certain native peoples be affected by climate change? Involve them in the research.

20 How will decisions, actions, and changes outside the Arctic affect arctic ecosystems, as, for example, migratory birds?

21 How will arctic species of plants adapt to changing climates *in situ*? Ecotypic evolution? Acclimation of phenotypes or ecotypes?

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Group 4:

SPECIES LEVEL EFFECTS ON, AND AFFECTS OF, GLOBAL CHANGE

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Previous recommendations

Several previous workshops and groups have noted the importance of understanding the responses and effects of arctic species on ecosystem processes. In general, this report supports previous recommendations and provides a more explicit structure for considering species effects.

The Arctic Research Conference in Leningrad in 1988 recommended studies on adaptations of organisms, biological diversity, population dynamics, including migration. Similarly, the NINA/DN conference on climate change in Trondheim in 1990 recommended long-term studies of animals and plant species and communities, particularly how plants adjust to environmental change. The IASC workshop in Reykjavik in 1992 recommends manipulation experiments with key species, studies on within-species diversity, and studies of the effects of climate on reproductive success. The ITEX manual produced in 1993 suggests specific details on how to study species responses to environment. We incorporate these recommendations in our report and provide a framework for a more general consideration of species effects.

Our recommendations fulfill for the Arctic the objectives set forth in the GCTE Operational Plan (IGBP Report No. 21) for monitoring global change in terrestrial ecosystems and for studying the consequences of ecological complexity for ecosystem function.

Questions addressed

This report addresses three major questions in which species effects are critical to understanding the role of the Arctic in the Earth System.

1 Is global change occurring? By monitoring the growth and distribution of sensitive species, studies of individual species can provide convincing evidence that global changes in climate and land use are affecting terrestrial ecosystems.

2 What processes control biome shifts? Changes in treeline and other community boundaries can have large effects on regional and global energy balance and can feed back to global warming in major ways.

3 Under what circumstances do species or functional groups differ strongly in their effects on

3.1 biogeochemistry and trace gas flux (with feedbacks to atmospheric chemistry and global warming),

3.2 disturbance regimes and biome shifts (and therefore regional/global energy balance), and

3.3 species interactions (including human land use).

Approaches and techniques

In this report we suggest three major approaches to the study of species responses to environment and species effects on ecosystem processes.

1 Monitoring of indicator species. In order to determine whether global change is occurring, we recommend several programmes in monitoring. First, we suggest monitoring of species that are sensitive to changes in climate and land use. This approach has been initiated for plant studies by ITEX and could be extended to other groups of organisms. In particular, top predators and diseases may be sensitive indicators of important changes in ecosystem health. Past records of ecosystem change through examination of the paleorecord or long-term data sets can show which environmental factors most strongly affect particular species and can therefore guide design of experiments and provide background to detect changes in species growth or abundance. Finally, satellite monitoring of dominant functional groups can provide an inexpensive method of monitoring the distribution of dominant functional groups as critical boundaries such as treeline.

2 Experiments. Experiments are the most direct way to determine the sensitivity of species and functional groups to global changes in climate and land use (through changes in growth/biomass or changes in demographic and fitness parameters). Any large-scale ecosystem experiments should incorporate these species-level measurements on key species. Experiments also serve to tease out the effects of individual species or functional groups on ecosystem processes. These experimental studies should initially emphasise functional groups. However, selected studies should also be done to study the effects of species within functional groups and the role of genetic variability within species on ecosystem processes. These latter studies should be selective but are critical to determine the role of species and genetic diversity on ecosystem processes. Four types of experiments are likely to prove most useful:

2.1 species addition/removal experiments conducted under field conditions. These should be complemented under some circumstances by controlled environment studies to determine the effect of particular environmental conditions on species interaction.

2.2 colonization experiments in which seed rain and seedling establishment is studied standardized disturbances and in closed vegetation.

2.3 transplant experiments involving transplants of propagules, individuals, and communities. Transplants into different climates and vegetation types will demonstrate the circumstances controlling invasion and growth, and the likely response of existing communities to changes in climate and vegetation.

2.4 Finally, we recommend study of "natural experiments" such as reindeer introductions to islands. These uncontrolled, long-term experiments often provide data and insights which are impractical to obtain on short-term controlled experiments.

3 Modelling. Modelling plays a critical role for understanding the causes and consequences of changes in species composition because it allows extrapolation to large spatial scales and long time scales that are impractical in experimental

manipulations. Modelling also allows efficient tests of hypotheses about how species and species interaction affect ecosystem processes. Studies of species effects on soils and of the demographic processes leading to species changes are particularly appropriate to modelling exercises.

4 Patterns of distribution. Studies of patterns of species distribution with respect to environmental parameters that are expected to change with global change (e.g., temperature, moisture, soil organic content) provide a basis for hypotheses about factors controlling species distributions and provide a basis for designing experiments and monitoring project.

International cooperation

International cooperation is essential to coordination in design and methodology of experiments. In particular, we strongly recommend exchange of students and other investigators among experimental sites as an efficient way to stimulate exchange of ideas. In particular, it may be more efficient and interesting with investigators having particular skills to travel and make measurements in many experimental sites, rather than for each site to attempt to duplicate all the measurements made in other sites.

Group 5:

PHENOLOGY, DEVELOPMENT, REPRODUCTION, AND PLANT ESTABLISHMENT UNDER GLOBAL CHANGE

Chairman: Terry V. Callaghan, UK
Rapporteur: Esther Lévesque, Canada
Inga Svala Jonsdottir, Sweden

Participants (alphabetically)

Bruce C. Forbes, USA
Ivar Myklebust, Norway
Urban Nordenhäll, Sweden
Mikael Ohlson, Sweden

Evaluation of past conferences

Several past conferences have made recommendations on important research objectives within the global change complex:

- Evaluate impact of climate change on the distribution and composition of natural ecosystems.
- Study soil-vegetation and soil-atmosphere interactions.
- Monitor long term responses of species.
- Monitor and model effects of elevated CO_2, enhanced UV-B, changed climate, and altered nutrient availability.
- Study effects on pools and fluxes of carbon and other elements.
- Estimate impact on diversity, and its relationship to ecosystem function, genetic variability and related issues.

In the context of this present workshop we recognize the following three major aspects which need to be addressed with regards to Global Change:

I. Impact
II. Biodiversity
III. Feedback processes

General objectives and research needs

I. Impact

To determine the impact of climate change variables on phenology, reproduction, dispersal, establishment and survival of genotypes and species leading to changes in community and patch dynamics at all levels of vascular and non-vascular taxonomic organization.

Both direct and indirect biotically mediated impacts should be targeted. We know least about the indirect impacts. Overlooking these impacts in the initial stages of modelling may lead us to predict incorrect scenarios.

Adequate predictions will depend on the success with which we can integrate these aspects as well as interactions between and within trophic levels.

II. Biodiversity

To determine the causes and consequences of changes in biodiversity by understanding demographic processes and species movement.

III. Feedback processes

A better understanding of carbon fluxes from and to the atmosphere, throughout the arctic, are critical to estimate future degrees of global change. We also need to understand the relationship between albedo and the variation in seasonal development and in extent of canopies.

Objectives within the specific areas of demography and phenology

We need to:

- Identify the most sensitive stages in the life cycle of target species, such as establishment.
- Establish the balance between vegetative and sexual reproduction and how this balance is affected by environmental change.
- Study the interactions within and among trophic levels (such as competition and herbivory) as they affect and are affected by demographic processes.
- Study the contribution of demographic processes to diversity and dispersal.
- Establish the variation in phenology and in leaf area index (LAI) as it can be used to calculate feedbacks relevant to GCMs.
- Continue existing and expand standardized monitoring of phenology and reproductive effort (such as ITEX).
- Study of critical rates of changes such as to allow the development of management tools.

Suggested approaches and techniques

Impact

- At the genotypic and species level, keystone species should be targeted (using species lists tested by ITEX and CAFF).
- At the community level, extensive and "at risk" communities should be targeted.
- Impact on genotypes should focus on disturbed areas or contrasting sites, where steep environmental gradients exist. Current techniques are available and include: DNA analysis, electrophoresis, reciprocal transplants, common garden and greenhouse experiments.
- Impact on species should focus on comparison between distribution limits and core distribution, using the techniques listed above.
- Impact on communities should focus on distributional limits by long term monitoring and mapping.

Biodiversity

- At the genotypic level, keystone species should be targeted to understand their variation while "at risk" species are more critical at the species level.
- At the community level, refer to Impact.
- Reproductive biology, demographic processes and dispersal are the preferred approaches for the genotypic and species levels. Current techniques are inadequate to address genotype and species dispersal and migration. Pollination, gene flow and reproductive strategies could be addressed with the presently known techniques.
- Floristics should be analyzed for the community level.

Feedback

- Dominant species in each functional group should be targeted at all levels.
- Phenology and allocation of biomass are important biotic determinants of feedback (such as albedo).Techniques similar to the ones used in ITEX should be used for monitoring at the genotypic and species level. GIS and remote sensing could be used to integrate the changes observed at the community level into landscape and regional synthesis.

Relationship with the GCTE

- Phenology, reproduction and establishment are key components of patch dynamics. Focus 2 of GCTE is Ecosystem Structure; it emphasizes a patch dynamics perspective.
- The approach, as suggested here, will better allow us to understand the processes influencing changes in structure and composition of communities. This is a central tenet of the mechanistically-based predictive model being requested by GCTE.
- Since it will not be feasible to develop models for every arctic ecosystem, nor represent every species within those ecosystems, GCTE suggests the use of functional types. However, we stress that different resolutions are required in addressing specific questions (e.g. individual genotypes are critical for determining phenological responses).

Group 6:

ARCTIC BIODIVERSITY OF SPECIES, POPULATIONS, AND COMMUNITIES, VERSUS GLOBAL CHANGE

Chair: David F. Murray, USA

Participants (alphabetically)

Sven Bråkenhielm, Sweden
Galina A. Evdokimova, Russia
Jarle I. Holten, Norway
Richard Luxmoore, UK
Vladimir Raszhivin, Russia
Leonid R. Serebryanny, Russia
Anna-Liisa Sippola, Finland
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Boris A. Yurtsev, Russia

Evaluation of past conference recommendations

What follows below derives in part from and enlarges upon recommendations and resolutions from several international conferences and workshops, which several of the participants named above played key roles.

Research questions

How can the international community of scientists accomplish an inventory of arctic biodiversity and provide the basis to monitor and ultimately to predict changes in biodiversity?

Recommendations

1 Accomplish an initial documentation of arctic biodiversity through surveys and inventories of libraries and museum collections for what is already known. These surveys would be conducted in a computer environment (example - Panarctic Biota Project, Flora North America, Flora Nordica).

1.1 During the initial stage of inventory we expect to determine:

1.1.1 Rare species.

1.1.2 Species sensitive to climatic and anthropogenic changes (indicator species).

1.1.3 Species key (dominant in frequency or cover) to ecosystem structure.

1.1.4 Species key (critical in relation to maintenance of other species) to ecosystem function (see working group reports 8 & 9 in this volume).

1.2 Gaps in information, both geographic and taxonomic, will become immediately apparent, and these gaps will become the priorities for new surveys of biota, Unified approaches should be adopted for sampling and recording data and for providing permanent physical documentation (with voucher specimens) of biodiversity.

2 Establish a network and/or transects of sites (Biosphere Reserves, ITEX sites) for monitoring. Site selection would be based on several criteria, such as:

2.1 Protected areas.

2.2 Logistic infrastructure, i.e. field stations, transportation, communications.

2.3 History of prior work and biotic and abiotic datasets.

2.4 Increase the likelihood of filling gaps in our sampling of biogeographic areas.

3 Surveys and inventories would then determine the biodiversity baseline for:

3.1 Protected areas.

3.2 Representative biogeographic areas (zones and sectors).

3.3 Unique and rare habitats.

3.4 Biodiversity "hot spots", that is, small areas with this species richness.

3.5 Ecotones of various scales, such as between biogeographic regions, eco-systems, landscapes, and communities.

Recommended approaches and techniques

1 Work at taxonomic and geographic levels, using and improving upon a network of well-studied sites throughout the Arctic, ones representative of zonal and sectoral diversity, which can be re-inventoried at various time intervals.

1.1 Qualitative local flora/fauna approach with quantitative assessments and mapping.

1.2 Community approach.

1.2.1 For plants to include a classification of vegetation units and mapping (example - Circumpolar Arctic Tundra Mapping Project), and

1.2.2 For animals a classification of habitats.

2 Use sampling design suitable for GIS and amenable to statistical tests; perhaps employing a series of nested areas based physically on the smallest sampling unit, the permanent plot.

3 Ground survey of plant and animal species and communities at large map-scales with accounts of species for:

3.1 Microscale topographic gradient and ecotones.

3.2 Mesoscale topographic gradient and ecotones.

4 Remotes sensing survey for macroscale features with attention to:

4.1 Rare species/habitats.

4.2 Unexplored areas.

5 Monitoring

5.1 Record change of diversity, in terms of both species abundance and species richness, in both protected and unprotected areas.

5.2 Distinguish effects of climatic change on biodiversity from other anthropogenic factors.

5.3 Determine species sensitive to climate change that can be useful as indicator species.

6 Management

6.1 *In situ* protection of rare species and habitats (Conservation of Arctic Flora and Fauna)

6.2 Mitigation of losses through restoration.

6.3 *Ex situ* preservation of taxa in botanical gardens and zoological parks.

6.4 Political and social action. We must not underestimate what we as a community can accomplish. Speaking with a single voice with the strength of conclusions based on our scientific studies, we are in an excellent position to persuade authorities of the need for legislative change in hopes of reducing rates of anthropogenic change and consequent losses of biodiversity (see working group report 11 in this volume).

7 Actions in progress.

7.1 Inventory of arctic biota (Panarctic Biota Project).

7.2 Inventory of rare biota (Conservation of Arctic Flora and Fauna).

7.3 Prodromus of arctic vegetation syntaxa and map (Circumpolar Arctic Tundra Vegetation Mapping Project).

8 Actions Proposed.

8.1 Inventory logistic resources in support of surveys and inventories and monitoring:

8.1.1 Field stations.

8.1.2 Technical equipment on-site.

8.1.3 Communications links.

8.2 Review status of biotic inventories for protected areas.

8.3 Review status of protected areas for comprehensive coverage of ecosystems.

8.4 Prepare draft recommendation of intensive sites.

Relationship to IGBP's GCTE Operational Plan

GCTE (Global Change and Terrestrial Ecosystems) is a separate core project within IGBP (The International Geosphere-Biosphere Programme). Global Change and

Ecological Complexity is incorporated into GCTE as a Focus 4 for future research. The Operational Plan (IGBP Report 21: 72-75) gives four major activities, which are relevant to biodiversity studies in the Arctic:

Activity 4.1: Effects of biodiversity and ecological complexity on ecosystem function.

Activity 4.2: Interactive effects of global change on biodiversity and ecological complexity.

Activity 4.3: Consequences of global change for the viability of isolated populations.

Need for international cooperation and linkages

- Compile directory of specialists, institutions, projects.
- Coordinate research, especially field activities through electronic bulletin board.
- Exchange of data between projects in hard copy and electronic formats.
- We have found the following governmental and non-governmental organizations relevant to the study and monitoring of biodiversity in the Arctic. Our objectives and recommendations overlap to some extent with these other efforts for which cooperation and coordination is very desirable:

CAFF - Conservation of Arctic Flora and Fauna of the Arctic Environmental Protection Strategy,

ICSU - International Committee of Scientific Unions.

FAO - United Nations Food and Agricultural Organization.

ITEX (MAB) - International Tundra Experiment (Man and the Biosphere).

PAB - Panarctic Biota Project (consisting of Panarctic Flora and Panarctic Fauna projects), which at present is managed by a joint committee of U.S. and Russian scientists.

UNEP - United Nations' Environmental Programme.

UNESCO - United Nations Educational, Scientific, and Cultural Organization.

WMO - World Meteorological Organization.

Group 7:

PLANT - HERBIVORE INTERACTIONS AND GLOBAL CHANGE

Chair: Robert L. Jefferies, Canada

Participants (alphabetically)

Louise Filion, Canada
Jesper Madsen, Denmark
Peter Scott, Canada
Bjartmar Sveinbjörnsson, Iceland

Preamble

Previous recommendations have not emphasised plant-herbivore interactions. Instead the potential effects of global climate change on animal populations have been examined. Given that there are large populations of different herbivores in tundra regions which forage on a broad range of plant species, one fruitful approach in the study of the effects of global change on plant-herbivore interactions is to examine changes in habitats in which forage species grow. A distinction can be made between direct human - induced disturbances which can be affected by policy decisions and natural disturbances (including global change which may be induced by anthrogenic effects) which are less amenable to control through policy decisions. The former types of disturbances include pipelines, roads, fires, settlements and hunting activities. These lead to habitat fragmentation and affect feeding areas for migrating and breeding populations of animals. The disturbance need not be located in the Arctic to cause a major effect on plant-herbivore interactions within this region. In the case of the lesser snow goose decreased mortality on the wintering grounds and on the flyways has led to a large population increase and habitat destruction through overgrazing in the Arctic. Natural disturbances (including global change) are increased lightening - caused fires, changes in snow and ice loads at different seasons and water-level changes. Time scales of animal life cycles are very different from time scales of habitat change.

Recommendations

1 Emphasis should be placed on short-term studies (years) complemented with long range investigations (decades) of habitats utilized by different herbivores. The long-term studies will enable non-linear processes and thresholds to be identified. Some of these studies may be carried out in conjunction with ITEX.

2 Two groups of organisms that are particularly important in plant-animal interactions in the Arctic are the lower plants (e.g. lichens) and invertebrates. The direct effects of weather and the indirect effects of foraging on these groups of organisms require study, in conjunction with studies of the population dynamics of the larger herbivores and vascular plants.

3 Changes in the chemical composition of plants, especially amounts of secondary chemical compounds in tissues may be expected, in the event of global climate change. As a consequence the palatability of forages may change. Hence, the interrelationships of the effects of climate change on plant-chemical composition and use of forage species by herbivores requires study.

4 Ecotones and edge effects are of special interest for global change studies in the context of plant-animal interactions because these borders and ecotones are particularly sensitive to climate, and because species diversity and herbivore

abundance are often high. We recommend that treelines, lake and river shores, shrub-meadow boundaries, glacier and snow bank boundaries be given special attention with respect to shifts in species assemblages overtime and the use of different forage species by herbivores.

5 Because of likely changes in the availability of forage species in different habitats, competitive interactions between different herbivores may change. This requires study as there are regions within the Arctic where strong competitive interactions between different groups of herbivores already occur.

6 There is considerable value in coordinating local studies across the Arctic. Inter- or multi-disciplinary studies of disturbance and of plant-animal interactions in which standardized methods and procedures are used will provide information on changes at the local, regional and continental scales.

7 We strongly recommend the integration of data obtained from long-term experimental field manipulative studies (coupled with baseline observations) and modelling procedures of population regulation of plants and animals as the most productive means to predict the effects of global climate change.

Group 8:

NEEDS FOR EXPERIMENTAL MANIPULATION: CO_2, NUTRIENTS, TEMPERATURE, U.V., AND WATER

Chair: Halldor Thorgeirsson, Iceland
Co-chair: George R. Hendrey, USA

Participants (alphabetically)

Henrik Saxe, Denmark
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Kari Anne Sølvernes, Norway

Research questions

The most fundamental questions now directed at the international scientific community studying the Arctic are:

- How will the arctic ecosystem respond to elevated CO_2 and altered temperatures?
- How will the arctic ecosystems contribute to C-fluxes and atmospheric CO_2 balance in a CO_2-richer world?

These questions, at our current level of knowledge, require long-term (five years or more) experimental manipulation of intact ecosystems. The direct effects of elevated CO_2 need to be studied. The fact that early indications are that physiological processes, such as photosynthesis, are only affected for a short period following CO_2 addition, should not be taken as indication of the absence of direct effects of CO_2 on ecosystem processes.

Evaluation of past conference recommendations

Group 5 at the 1990 Trondheim conference dealt with: "Direct Effects of Atmospheric CO_2 increase on vegetation and interspecific competition." This group pointed out several important interaction with elevated CO_2 and suggested priority research areas. These questions are just as important today but will not be repeated here.

This issue was also addressed by the working group on: "Terrestrial and Marine Ecosystems" at the International Arctic Science Committee Workshop on: "A Regional Research Programme in the Arctic on Global Change" in Reykjavik, 1993. This group suggested that manipulative experiments be carried out using a variety of experimental approaches and listed the parameters to be studied. This group suggested that FACE technology be "...phased in only after experience has been gained in simpler systems."

There is no contradiction between past conference recommendations and those presented below.

Research recommendations

What is needed now is a multiscale and multidiciplinary effort to supplement the ongoing smaller scale research projects. A whole-ecosystem free air CO_2 enrichment (FACE) experiment should be conducted at the boreal forest/tundra transition coupled with CO_2 flux measurements at the plot, patch and regional scales.

Such an effort should utilize the benefits of the free air CO_2 enrichment with strong links to studies using other approaches to CO_2 manipulation such as branch bags and open top chambers. The most effective scaling up of results will be achieved by using all the methods in a nested approach. A FACE experimental site also should be used to evaluate the characteristics (i.e. chamber effects) of other approaches.

Interactive effects of nutrient supply, water availability and UV-B radiation[1] should be studied along with studies of direct effects of CO_2.

The group notes the preparations underway for the establishment of the Boreal Forest Carbon Facility (BCF) under the auspices of the Center for Global Change and Arctic System Research at the University of Alaska, Fairbanks. This site could perhaps form the south end of a transect north from Fairbanks involving CO_2 and temperature manipulation as well multiscale measurements of CO_2 fluxes.

Recommended approaches and techniques

Several approaches can be taken to experimentally manipulate CO_2 partial pressure.

Branch bags (BBs)

Branch bags (BBs) have the advantage of low cost per experimental unit, they can be used on mature trees in their natural surroundings and treatments can be nested within individuals. They have the disadvantage of altering the microclimate, including temperature, while not providing strong enough effect to alter the carbon sink/source balance of large plants. This problem can be avoided by enclosing the entire plant in the bag.

Open Top Chambers (OTCs)

Open Top Chambers (OTCs) can be used to treat whole plants and small plots. They can also be used to manipulate other factors such as temperature in a factorial combination with CO_2. The disadvantage is that they alter the microclimate.

Free Air CO_2 Enrichment (FACE)

Free Air CO_2 Enrichment (FACE) has the advantage of no alteration of microclimate and the capability of treating large areas and providing the opportunity for many scientist to cooperate on the same experimental plots. Interactive effect of air temperature and CO_2 may be better studied by OTCs and branch bags experiments coupled with a FACE experiment, however.

There is no simple way to calculate the relative cost of each approach. This is dependent on the nature of the questions asked and on the number of investigators involved.

[1] It was not considered within the scope of this group to address the issue of UV-b radiation in general. At the plenary session this issue received considerable attention, however, since none of the groups had been given the task of addressing it. The predicted increase in UV-b radiation can have important consequences in the Arctic. The arctic ecosystem has evolved under low levels of UV-b radiation and can be expected to be quite sensitive to increases in UV-b radiation. For a comprehensive coverage of research needs in this area please refer to two recent SCOPE reports: "Effects of Increased Ultraviolet Radiation on Biological Systems" (1992) and "Effects of Increased Ultraviolet Radiation on Global Ecosystems" (1993). (SCOPE: Scientific Committee on Problems of the Environment, 51 bd de Montmorency, 75016 Paris, France).

Relationship to IGBP's GCTE Operational Plan

The study of the effects of elevated CO_2 is one of four activities within focus 1: "Ecosystem Physiology" in the GCTE Operational Plan (IGBP Report No. 21). This activity is divided into two tasks. The first task is to establish whole-ecosystem free air CO_2 enrichment (FACE) experiments including one at the boreal forest/tundra transition. The second is to integrate experiments on ecosystem CO_2 response through a network of investigators utilizing an array of experimental approaches.

GCTE has also called for the establishment of transect studies including process studies at key locations along the transect. One of these transects is the proposed Northern European Terrestrial Ecosystem Profile (NETEP). It is vital that studies of the effect of elevated CO_2 be included in this effort.

The suggestions of this group are therefore in close agreement with the GCTE Operational Plan.

Needs for international cooperation and linkages

Significant steps towards finding answers to the research questions stated above can only be taken through international cooperation. It should be noted that the nature and scope of the area covered by this group calls for more coordination than some of the other areas covered in this conference.

The group calls for a large-scale international effort in the Arctic and the Arctic-Boreal transition focusing on carbon fluxes and direct effects of elevated CO_2. Such an effort could be called the Tundra-Atmosphere Carbon Transfer and Storage (TACTS) initiative. This would involve a phased set of integrated experiments in several major tundra ecosystems of the world and would be linked to ongoing international efforts in measuring CO_2, water and energy fluxes in the boreal zone.

Fundamental to the success of such an effort is the establishment of an international network of scientists as well as an educational programme for graduate students and researchers. Strong links to the GCTE Long-Term Ecosystem Modelling Activity (LEMA) should also be ensured.

Group 9:

TEMPERATURE AND HUMIDITY MANIPULATIONS

Chair: Ulf Molau, Sweden
Rapporteur: Elisabeth J. Cooper, UK

Participants (alphabetically)

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State of the art

Humidity manipulation

There are currently no experiments designed to manipulate humidity, and we do not consider it particularly important. There are, however, often unintended changes in humidity in temperature manipulation experiments, particularly in closed chambers and tents, that make it difficult to attribute any changes to temperature alone. If humidity manipulation is necessary, it will require a power supply for air conditioning, and is probably only feasible in closed chambers. (Good commercial applications exist for greenhouses.) Such experiments then have to have simulated precipitation.

Interpreting humidity in a more general sense, as changes in precipitation, we also considered experiments that manipulate rain and snow inputs. General Circulation Models (GCMs) predict increases in winter precipitation over the Arctic. Although there are various experiments that mimic an increase in summer precipitation, there are very few manipulations simulating changes in winter precipitation inputs in the Arctic.

Temperature manipulations

Various techniques are currently in use, and will be considered in turn, taking into account cost, benefits and disadvantages.

Open Top Chambers (OTCs)

The design used in the International Tundra Experiment (ITEX) system, a hexagonal chamber with open-top chamber (OTC) with sloping sides, made of fiberglass or polycarbonate plastic, can be made in various sizes, from the 1m diameter chambers appropriate for the ragged microtopography in the Scandinavian mountains, up to a 2m diameter size used in tundra plains in Alaska, Canada and the Russia Far East. The chamber functions as a windshield and a solar trap, increasing temperature without an appreciable increase in humidity. It admits a high proportion of solar radiation, although its sides do intercept UV-B. It is relatively inexpensive, easily made, and will last up to 5 years *in situ*. No irrigation is necessary, as natural precipitation can enter the chambers. Temperature increases are relatively constant above ambient. The major limitation of these chambers is their relatively low stature, which makes them suitable for use on low growing plants, up to and including tussocks. Taller plants such as *Betula nana* will protrude. Some, but not all herbivores are excluded from the chambers, and wind pollinated plants may suffer from reduced pollination. insect-pollinated outbreeders show no decrease in seed set in the chamber.

Plastic tents

Various designs of plastic tents are in use, varying from complete domes to small triangular section tents, to domes with portions cut out at the apex and base (to increase air circulation.) Although these tents are very inexpensive to produce and can give a temperature increase of as much as ten degrees C, they suffer from a series of drawbacks. Both humidity and temperature can vary greatly within the tents, depending on the amount of air circulation and the degree of insolation. The amplitude of temperature variation can be high enough that plants burn inside (as seen in the Swiss Alps, Ch. Körner, pers. comm.). Depending on the type of plastic used for the tent, shading effects may be quite marked, reducing PAR to about 70 to 80% of ambient. UV-B may also be intercepted. Herbivores, pollinators and precipitation are all exluded to varying extents, depending on the design of the tent. Plastic tents can be made much larger than the ITEX OTCs, but are prone to wind damage (a major issue in arctic and alpine sites) and must be taken down in winter. Replacing tents in spring may be very time consuming, which means that plants may start their season out of their treatments.

Ground cover plastic nets

Horticultural insulating plastic ground cover is inexpensive and seductively easy to install. However, it excludes precipitation, dew, herbivores, pollinators and a large amount of light.

Greenhouses

Various sizes of greenhouses are in use, (sometimes combined with CO_2 manipulation) and represent a very thorough means of controlling temperature, especially when there is a chilling system in addition to heating. Mains power is essential, and they require constant maintenance, making these installations expensive to run, above and beyond the cost of building. A further expense is incurred if separate greenhouses must be installed for controls. Larger sizes of plants or greater portions of ecosystems can easily be accommodated, by building larger greenhouses. Small chambers must be dismantled for winter and reinstalled in spring, and snow is a hazard for the larger greenhouses. Greenhouses intercept both PAR and UV-B radiation (up to 30% of ambient PAR,) and precipitation, and exclude pollinators and herbivores.

Soil heating wires

While not as inexpensive as OTSs and plastic domes, soil heating cables are relatively cheap compared with greenhouse installations. They require a mains power supply, and a control system, but once installed, can be left in place for at least three years. Depending on where the wires are put, on the soil surface or within the soil, disturbance can be a major problem, making a parallel set of disturbance controls of installed wires without heat necessary. Local drying out around the wires may be an issue, and the system is completely incompatible with permafrost. Soil heating systems can be installed to heat large areas, potentially up to the size of small catchments. The system is switched off in autumn, if reduced snow cover is undesirable. A variation on this scheme is the system of pipes used by Grime's group in Sheffield, that circulates fluid in pipes on the surface of the soil. It shares many of the same problems as the heating wires, and takes up space among the plants.

Infrared lamps

One system is currently in use, in the Colorado alpine environment. The lamps supply an even 15 Watts/m^2, effectively simulating a warmer world, although the air temperature itself cannot be increased. In systems with open soil, it is perhaps the best simulation of global warming, but for the problem of spectral effects on plants due to irradiation in the infra red. Given the dependence of some arctic plants on red to far red for the signal for senescence, the potential for premature senescence is rather worrying. Cost is relatively low, as the lamps are readily available, and power costs quite modest. The plots are open, with no changes in precipitation, and giving free access to herbivores and pollinators. The system can be run all year, unlike most of the alternatives.

Recommendations for temperature manipulations

For inexpensive chambers to be used in low stature vegetation, use open top chambers. For large, catchment size experiments, soil heating cables are probably best, although infrared lamps may be better if spectral problems are shown to be negligable in the Colorado experiment. For multifactor experiments, such as combined CO_2 by temperature designs, greenhouses with piped precipitation and air conditioning are optimal.

Research needs

Scaling up

Ecosystem models give data for within system processes, but there are no predictions of output from catchments. We suggest a whole catchment heating manipulation to test model predictions and to generate data for the next generation of models.

Precipitation modification experiments

The recommendation in the ARCUS 1991 report to investigate interactions between snow cover and global and regional change, and to investigate how snow cover affects the arctic system remains important. We suggest snow removal and addition experiments, that lengthen and shorten the growing season.

Shading experiments

Current temperature experiments frequently have a shading treatment for comparison, due to the shading effect of plastic domes. We suggest that since GCMs predict an increase in cloudiness, more realistic shading experiments may be necessary.

Time scales

We are worried that our current generation of experiments run for an inappropriately short time period. We suggest much longer term experiments, since it is clear that many arctic systems are highly buffered. Furthermore, we suggest that inappropriately large treatments are currently the norm, and that experimenters should be much more concerned with the abrupt imposition of stepped "climate change" treatments. Given the individualistic nature of species' responses to treatments, the early loss of a particular species due to an abrupt imposition of treatment that might otherwise have remained in the system in a more gradual increase, is very worrying. Since species in "functional groups" have been shown to respond differently, we cannot assume that the role filled by one species will be filled by another if we impose very artificial treatments. How many of our results are artefacts of the way we impose our treatments?

Multifactor experiments

Multifactor experiments - We would like to reinforce the ARCUS 1991 recommendation for multifactor experiments, since the synergistic and non-additive effects of multiple factors have been amply demonstrated in this conference.

Organization

We recommend compilation of a list of sites on a circumpolar basis where temperature manipulations are being done. This should include sites in the Arctic, subarctic, and alpine systems.

Frequent, inexpensive meetings where scientists meet to present results and plan research are highly desirable. An umbrella organization to convene such meetings and collate material emerging from arctic studies is essential.

Group 10:
MODELLING, GIS AND REMOTE SENSING

Chair: Tagir Gilmanov, Russia
Co-chair: Douglas Stow, USA
Rapporteur: Tagir Gilmanov

Participants (alphabetically)

Rik Belmann, Germany
Gunnar Ch. Borg, Sweden
Allan S. Hope, USA
Douglas Kane, USA
Morten Lange, Norway
Preben Ottesen, Norway
Edward B. Rastetter, USA
Serguei Semenov, Russia

The theoretical and methodological foundation justifying the important role of mathematical modelling and geographic information technologies in studying the impacts of global change on natural ecosystems were formulated in the recommendations of the Trondheim meeting, November 27-29, 1990 (Impact of Climatic Change on Natural Ecosystems, 1990) and the GCTE documents (especially IGBP (1990, 1991, 1992b). The guidelines for GIS and Remote Sensing are presented in IGBP (1989, 1990, 1992a).

As a result of reviewing the state-of-the art of modelling arctic/alpine ecosystems and implementations of the recommendations of the Trondheim meeting ("Impact of climatic change on Natural Ecosystems", 1990) we agree that:

1 The first task in modelling arctic/alpine ecosystems remains the construction of integrated patch-level tundra ecosystem models with special emphasis on trace gas fluxes (CO_2, CH_4, ...) and water/energy exchange under Global Change (GCTE Focus 1, Activity 1.4, Task 1.4.1 "Integrated models of ecosystem physiology under global change").

2 The primary importance of hydrological and permafrost modelling of arctic/alpine ecosystems in the global change context is recognized due to the dominant role of the water/temperature regime in determining tundra ecosystem functioning. Furthermore, the hydrological outputs are significant for GCMs (e.g. evapo-transpiration, bulk surface conductance, etc.). This task is closely tied to the GCTE Focus 1, Activity 1.3, Task 1.3.1 "Effects of changes in vegetation water and energy fluxes and bulk surface conductance".

3 Phenomenological modelling as a means of providing "first-cut" estimates of ecosystem response is recognized and should provide valuable information for more extensive "mechanistic" modelling efforts designed for making long-term projections.

4 Development of models of vegetation composition dynamics under climate change conditions, including plant population dynamics, species/functional group competition, and the migratory processes is recommended in accordance with GCTE Focus 2, Activity 2.1, Task 2.1.3 "Patch models of ecosystem dynamics".

5 The problem of scaling, especially the utilization of the patch-scale information to estimate and predict properties at the landscape, regional, and global levels, require special attention. In this connection, models of landscape structure dynamics and interactions should be constructed and elaborated, in correspondence with GCTE

Focus 2, Activity 2.2, Task 2.2.1 "Ecosystem dynamics from patch to region, based on change in climate and atmospheric composition".

6 There is a tremendous need for the synoptic and large-area environmental data gathering capabilities that can be provided by remote sensing, that is driven by interests in scaling and monitoring arctic ecosystem and biogeochemical processes. Such data are required for:

- Input data and validation of ecosystem, landscape, and regional modelling.
- Extrapolation (scaling up) of localized measurements or model-simulation results to the regional or global scale.
- Monitoring impacts of global and land-use change.

However, there is a paucity of background research, research funding, and integrated research programmes involved with remote sensing of arctic tundra regions. Thus we recommend, that:

- Major organizations supporting global change (e.g. IGBP-DIS, GCTE) and remote sensing (e.g. NASA, ESA) research need to be urged to address the lack of focused studies of optical and microwave remote sensing applied to arctic tundra eco-systems.
- An ad hoc committee should be appointed ASAP to coordinate this initiative and a workshop should follow.
- Given the commitment of Canadian and US agencies to BOREAS, it is likely that leadership for this initiative will come from non-Canadian/US bodies, although the cooperation of North American agencies should be solicited.

7 The use of GIS technologies was also recognized as crucial to global-change studies in arctic/alpine ecosystems. In the recommendations provided at the Trondheim meeting it was suggested that monitoring activities should ensure wide geographical coverage and be integrated with GIS. This technology is also important for modelling, particular at the regional or circumpolar scale. Therefore it is sugges-ted that a circum-arctic GIS data base be established based on extant maps, digital data, and other environmental data. A possible location/organization for establishing such a data base is the UNEP GRID node at Arendal, Norway. Subnodes should be established at several regional facilities to coordinate regional development of digital data bases and the transfer of data to arctic scientists.

8 In the framework of the Long-term Ecological Modelling Activity (LEMA: Focus 2, "Integrated Activities"), an arctic/alpine LEMA Center should be established at an appropriate institution to achieve the following objectives:

- To facilitate collaborative research on the development and improvement of models of arctic/alpine ecosystems under global change.
- To focus the international modelling efforts on arctic/alpine ecosystems on a coherent and mutually agreed set of objectives.
- To synthesize results of GCTE arctic/alpine research into a set of robust models designed to meet GCTE objectives.
- To provide feedback to experimental, monitoring and GIS/Remote Sensing activities as priorities for model parameters, investigation of additional pheno-mena, and needs for model-testing information arise.

9 The need for comprehensive monitoring effort that will provide long-term data that can be used in model validation is recognized. This effort should grow naturally out of the US LTER program and other long-term international efforts.

Literature

IGBP (1989). Pilot studies for remote sensing and data management. Ed. by S.I. Rasool and D.S. Ojima. IGBP Report No. 8.

IGBP (1990). The International Geosphere-Biosphere Programme: A study of global change (IGBP). The initial core projects. IGBP Report No. 12.

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IGBP (1992b). Global Change and Terrestrial Ecosystems: The Operational Plan. Ed. by W.L. Steffen, B.H. Walker, J.S. Ingram and G.W. Koch. IGBP Report No. 21.

Impact of climatic change on natural ecosystems, with emphasis on boreal and arctic/alpine areas. Recommendations. Trondheim, Norway, November 27-29, 1990. Trondheim, Norwegian Institute for Nature Research and Directorate for Nature Management, 1990.

Group 11:

INTEGRATING EFFORTS OF ARCTIC ORGANIZATIONS AND PROGRAMMES

Chair: Patrick W. Flanagan, USA
Co-chair: Fred Roots, Canada

Participants (alphabetically)

Patricia Anderson, USA
Irina Bergström, Finland
Ellen Bielawski, Canada
Hugh Boyd, Canada
Jerry Brown, USA
Henrik Elling, Denmark
Bengt Giege, Sweden
Hans-Wolfgang Hubberten, Germany
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Loren W. Setlow, USA
Anna-Liisa Sippola, Finland

Recommendations

1 Each national IGBP Committee (or GCTE Committee if there is one) should be requested to designate a person to serve as a focus for national Arctic GCTE interests and action. The person should if possible be actively engaged in GCTE arctic science.

The designated national arctic GCTE representatives will collectively form a circumpolar Working Group for the arctic GCTE Programmes. The functions of the Working Group will include:

1.1 develop an international arctic GCTE implementation plan based on the outcome of the Oppdal working groups and the international science plan drawn up by the IASC working sroup. This implementation plan will be considered by national IGBP/GCTE committees for operation.

1.2 identify national and international sources of funding and support to achieve the long-term research and monitoring goals for Arctic GCTE, including resources needed to insure international or circumpolar GCTE actions.

1.3 establish linkages and communications between Arctic GCTE and other international science programmes related to the interests of GCTE, including the IASC, Global Change Office, MAB Northern Sciences Network, Arctic Environmental Protection Strategy,other regional and international arctic science programmes, and IGBP activities that may have arctic components, such as BAHC, LOICZ, IGAC,etc.

2 A small Task Force should be formed at Oppdal to review the science priorities identified by the workshops, and ensure that they are included in the "Scientific Plan for a Regional Research Programme in the Arctic on Global Change" co-ordinated by IASC for presentation to the IGBP Council and National Committees.

3 During planning and execution of the Arctic GCTE, environmental protection and the involvement of all residents of the Arctic should be emphasized.

4 Sites and stations where arctic research and long-term data relevant to terrestrial ecosystems has been undertaken (such as those being identified by MAB NSN) should be reviewed and considered as to their representativeness and suitability for GCTE studies, before new arctic sites and stations are established.

5 GCTE Arctic should develop and put into use a circumpolar science communication system, taking into account the systems already in use or planned by other IGBP programmes and other arctic science initiatives.

6 The circumpolar GCTE Arctic working group should recognize that long-term research and monitoring in the Arctic must involve industry, academic and government organizations as well as research funding bodies, and should vigorously cultivate a broad base of awareness, of the value to society, and the need for long term support.

7 To implement its goals,facilitate communications and insure momentum, the GCTE Arctic working group might find it useful to establish a small international secretariat within the IGBP structure.

CONFERENCE PROGRAMME

Saturday 21 August

Evening: Reception and Welcome (Hotell Oppdal)
- Karl Baadsvik (Norwegian Institute for nature research, Trondheim, Norway)

Sunday 22 August

Morning: Opening and Welcoming Addresses:
- Walter C. Oechel (Conference President): Goals of the conference
- Brian Walker (GCTE Core Project Office, Canberra, Australia) Global Change and Terrestrial Ecosystms: the GCTE Research Programme for the Arctic.
- Dwight Billings (Department of Botany, Duke University, Durham, NC, USA): Challenges for the future
- Ivar Isaksen (Geophysical Institute, Oslo University, Oslo, Norway): Chemical threats to the arctic atmosphere

Morning: Invited Papers: Context for Global Change (Chair: Jarle I. Holten, Norwegian Institute for Nature Research, Trondheim, Norway)

1. Recent climate patterns in the Arctic (Barrie Maxwell, Canadian Climate Centre, Downsview, Canada)

2. Global and regional patterns of climate change: recent predictions (Peter Rowntree, Hadley Climate Centre, The Meteorological Office, Bracknell, UK)

3. Paleoclimatic reconstructions (L. R. Serebryanny, A. Tishkov, A. Velichko, Institute of Geography, Russian Academy of Sciences, Moscow, Russia)

4. Implications for the soil physical environment (Douglas Kane, School of Engineering, University of Alaska, Fairbanks, AK, USA)

Afternoon: Contributed Paper Sessions: (Chair: Christian Körner, Department of Botany, University of Basel, Basel, Switzerland)

1. Context for Global Change

1. Estimates of the terrestrial net carbon flux using forestry databases (C. Bernabo, A. Auclair, P. Van Akkeren and B. Hood, Science and Policy Associates, Inc., Washington, USA)

2. Airborne measurement of greenhouse effect gases over Siberia in 1992 (G. Inoue, K. Izumi, M. Utiyama, S. Makshyutov, National Institute for Environmental Studies, Tsukuba, Ibaraki, Japan and N. Vinnichenko, A. Postnov, V. Galaktionov, Central Aerological Observatory, Moscow, Russia)

2. Effects on Organisms and Populations

1. Climatic change and species polymorphism in the Arctic (R.M. M. Crawford, H. M. Chapman, and R. J. Abbott, Plant Science Laboratories, St. Andrews University, Scotland)

2. Rates and controls of movement of plants and vegetation in high Alpine environments (Georg Grabherr, Michael Gottfried, and Harry Pauli, Department of Vegetation Ecology and Conservation Biology, Institute of Plant Physiology, University of Vienna, Austria)

3. Effects of surface disturbance on the movement of native and exotic plants under a changing climate (Bruce C. Forbes, Department of Geography, McGill University, Montreal, Quebec, Canada)

4. Transplantation of mountain plant communities (Frans E. Wielgolaski, Department of Biology, University of Oslo, Norway and Faye Benedict, Telemark College, Bø, Norway)

Evening: Poster sessions to include posters by national and international arctic organizations, research programmes, and commercial displays (See end of programme for list of posters)

Monday 23 August

Morning: Invited Papers: Effects of Anticipated Global Change on Organisms and Populations (Chair: David Murray, University of Alaska Museum, Fairbanks AK, USA)

1. Vascular plant photosynthesis and respiration (Walter C. Oechel, Department of Biology, San Diego State University, California, USA)

2. Photosynthesis and respiration of mosses and lichens (Bjartmar Sveinbjörnsson, Institute of Biology, University of Iceland, Reykjavik, Iceland and Mats Sonesson, Abisko Research Station, Abisko, Sweden)

3. Plant development and demography (Terry Callaghan, Merlewood Research Station, Institute of Terrestrial Ecology, Grange-over-Sands, Cumbria, U.K and Bengt Carlson, Department of Plant Ecology, University of Lund, Lund, Sweden)

4. Phenology, pollination and reproductive success in Arctic plants: susceptibility to climatic change (Ulf Molau, Department of Systematic Botany, University of Göthenborg, Sweden)

5. A kinetic approach to microbial ecology in arctic and boreal ecosystems in relation to global change (Nikolai Panikov, Institute of Microbiology, Russian Academy of Sciences, Moscow, Russia)

6. Responses of caribou and reindeer to global change (Anne Gunn, Department of Renewable Resources, Government of the Northwest Territories, Yellowknife, NWT, Canada and Terje Skogland, NINA, Trondheim, Norway)

7. Impacts on bird migration, populations and habitat (Jesper Madsen, National Environmental Research Institute, Kalö, Denmark and Hugh Boyd, Canadian Wildlife Service, Environment Canada, Quebec, Canada)

Afternoon: Contributed paper sessions: Effects on Organisms and Populations (continued)(Chair: Gen Inoue, National Institute of Environmental Studies, Tsukuba, Ibaraki, Japan)

1. The nature of water limitations for plants in a high arctic polar desert (Warren G. Gold and Lawrence C. Bliss, Department of Botany, University of Washington, Seattle, Washington)

2. Effects of simulated climatic change on the growth and flowering of *Cassiope tetragona* (Mats Havström, Department of Systematic Botany, University of Göthenborg, Sweden, Terence V. Callaghan, Merlewood Research Station, Grange-over-Sands, Cumbria, U.K and Sven Jonasson, Institute of Plant Ecology, University of Copenhagen, Denmark)

3. The effect of raised CO_2 and winter temperatures on growth and carbon balance in Norway spruce seedlings (Oddvar Skre, Norwegian Forest Research Institute, Bergen, Norway)

4 Response of methane emission from arctic tundra to climatic change (Torben Christensen, Scott Polar Research Institute, University of Cambridge, Cambridge, UK and Peter Cox, Hadley Centre, Meteorological Office, Bracknell, UK)

5. Forest insect activity and climate: larch sawfly activity reconstructed from tree-ring records along a latitudinal gradient in the high boreal and subarctic zones (Louise Filion, François Quinty, Yves Jardon and Serge Payette, Centre d'etudes nordiques, Université Laval, Quebec, Canada)

6. The effect of climate change on alpine and polar terrestrial arthropods (Lauritz Sømme, Department of Biology, University of Oslo, Norway)

7. Life history and ecophysiological responses to temperature in arctic terrestrial invertebrates (N. R. Webb, I. D. Hodkinson, S. Coulson, J.S. Bale, A.T. Strathdee, and W. Block, Furzebrook Research Station, NERC Institute of Terrestrial Ecology, Dorset, UK)

8. Recent trends toward earlier phenologies in the flight periods of British aphids (R. A. Fleming, Forest Pest Management Institute, Sault Ste. Marie, Ontario, Canada and G. M. Tatchell, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Herts, UK)

Evening: Poster sessions and commercial displays

Tuesday 24 August

Morning: Invited Papers: Effects of Anticipated Global Change on Ecosystem Structure and Ecological Complexity (Chair: Phil Johnson, Arctic Research Commission, Washington, DC, USA))

1. Impacts of global change on community composition and implications for ecosystem functioning (Terry Chapin, University of California, Berkeley, CA, USA)

2. Past vegetation changes and responses to past climate changes (Brian Huntley, Department of Biological Sciences, University of Durham, Durham, UK)

3. Effects of climate change on plant biodiversity (Boris Yurtsev, Botanical Institute, Russian Academy of Sciences, St. Petersburg, Russia)

4. Effects of climate change on animal biodiversity (Yuri Chernov, Institute of Evolutionary Morphology and Animal Ecology, Russian Academy of Sciences, Moscow, Russia)

5. Controls on current and future position of treeline (Peter Scott, Department of Zoology, University of Toronto, Toronto, Ontario, Canada and Bjartmar Sveinbjörnsson, Institute of Biology, University of Iceland, Reykjavik, Iceland, and others)

6. Modelling of future vegetation with climate change (Wolfgang Cramer, Department of Geography, University of Trondheim, Trondheim, Norway)

Afternoon: Contributed Papers: Effects on Ecosystem Structure and Function (Chair: Victor O. Targulian, Institute of Geography, Academy of Science, Moscow, Russia)

1. Biophysical remote sensing for global change studies in arctic terrestrial ecosystems (Allen S. Hope and Douglas A. Stow, Department of Geography, San Diego State University, California, USA)

2. Desertification and trophic cascades in arctic coastal ecosystems: a potential climatic change scenario? (R.L. Jefferies, F.L. Gadallah, D.S. Srivastava and D.J. Wilson, Department of Botany, University of Toronto, Ontario, Canada)

3. Fluxes of methane and nitrous oxides in forest soil as influenced by N deposition and soil acidification (Bishal K. Sitaula and Gunnar Abrahamsen, Department of Soil Sciences and Lars R. Bakken, Department of Biotechnological Sciences, Agricultural University of Norway, Ås, Norway)

4. Effects of climatic change on the soil floor of arctic ecosystems (Sergey V. Goryachkin and Victor O. Targulian, Institute of Geography, Academy of Science, Moscow, Russia)

5. Effects of climate change and dynamics of tundra plant communities in Far Eastern Asia (Vladimir Yu. Raszhivin, Komarov Botanical Institute, St. Petersburg, Russia)

6. Experimental warming increases net ecosystem CO_2 uptake in tussock tundra due to enhanced plant growth (Sarah E. Hobbie and F. Stuart Chapin, III, Department of Integrative Biology, University of California, Berkeley, California, USA)

7. CO_2 response of Alpine tundra (Christian Körner, Department of Botany, University of Basel, Basel, Switzerland)

8. Potential application of free-air CO_2 enrichment to arctic ecosystems (George R. Hendrey, Department of Applied Science, Brookhaven National Laboratory, Upton, NY, USA)

Wednesday 25 August

Morning: Invited Papers: Effects of Anticipated Climate Change on Ecosystem Function and Feedbacks to the Atmosphere (Chair: Terry Chapin)

1. Impacts of global change and vegetation change on productivity (Kim Peterson, Department of Biological Sciences, University of Alaska, Anchorage, Alaska)

2. Impacts of global change on nutrient cycling and decomposition (Knute Nadelhoffer and Gaius Shaver, Ecosystem Center, Marine Biological Laboratory, Woods Hole, MA, USA)

3. Buffering of arctic plant responses in a changing climate (Sven Jonasson, Department of Plant Ecology, University of Copenhagen, Denmark)

4. Impacts of climatic change on CO_2 flux (Walter C. Oechel, Systems Ecology Research Group and Department of Biology, San Diego State University, San Diego, CA, USA)

5. Past, present and future distribution and movement of radionuclides (Brit Salbu, Isotope Laboratory, Norwegian Agricultural University, Ås-NLH, Ås, Norway)

6. Phenomenological modelling of ecosystem productivity (Tagir Gilmanov, Center for Ecology and Productivity of Forests, Russian Academy of Sciences, Moscow, Russia)

7. Modelling nutrient and carbon dynamics under global change (Ed Ratstetter, Ecosystem Center, Marine Biological Laboratory, Woods Hole, MA, USA)

Afternoon: Workshops on future research directions, approaches, and techniques.
The workshops will:
- Evaluate past conference recommendations (i.e. progress towards answering questions raised, indicate what information gaps still remain);
- Consider the need for answering new questions;
- Suggest approaches and techniques appropriate for dealing with problems requiring additional attention, including GIS and modelling;
- Determine needs for international cooperation and linkages to other research groups.

Suggested topics (co-chairs in brackets):
1. Carbon stocks, fluxes and feedbacks. (N. Panikov, K. Peterson)
2. Nutrient cycling and decomposition. (K. Nadelhoffer, S. Jonasson)
3. Sensitive and risk ecosystems prone to climate change. (W.D. Billings, N. Matveyeva)
4. Species level effects on, and effects of, global change. (L. Sømme, F. S. Chapin)
5. Phenology, development, reproduction and plant establishment under global change. (T. Callaghan)
6 Arctic biodiversity of species, populations, and communities versus global change. (D. Murray)
7. Plant - herbivore interactions. (R.L. Jeffries)
8. Needs for experimental manipulation: CO_2, nutrient, temperature, U.V., and water. (H. Thorgeirsson)
9. Methods and needs for temperature and humidity manipulation and experimentation. (U. Molau)
10 Modelling and GIS. (T. Gilmanov, D. Stow)
11. Integrating efforts of arctic organizations and programmes. (P. Flanagan, F. Roots)

Thursday 26 August

Morning: Invited Papers: Relationships between Ecosystem Change and Humans (Chair: Frans-Emil Wielgolaski, Univ. Oslo Dept. of Biology Sect. Botany, Blindern, Oslo)

1. Ecosystem change and native land use (Ellen Bielawski, Arctic Institute of North America, Calgary, Canada)

2 Impacts of land use and industrial activity on the environment (V.V. Kryuchkov, Kola Science Centre, Russia Academy of Sciences, Apatity, Murmansk Region, Russia)

Conclusions of workshops

Reports of workshops: Future research directions, approaches, and techniques (Chair: Fred Roots, Environment Canada, Ottawa, Canada)

Panel Discussion: How national and international arctic programmes and organizations can assist the arctic research community (Chairs: Patrick Flanagan, Research and Graduate Program, University of Louisville, KY, USA

Friday 27 August

Field Trips

Posters

1. Organizations and Programmes

- International Arctic Science Committee (IASC)
- Center for Global Change and Arctic System Research: University of Alaska, Fairbanks
- International Tundra Experiment (ITEX)
- Ecology and Protection of East European Tundras
- Paleoenvironmental and Ecological Investigations on the Taymyr Peninsula, Siberia: a Joint Russian - German Project
- Arctic Centre: Mission, Current Activities and Future Perspectives
- Directorate for Nature Management (DN)
- MAB Northern Sciences Network
- Norwegian Institute for Nature Research (NINA)
- North European Terrestrial Ecosystem Profile (NETEP)

2. Research projects

- *Modelling the effects of a changing climate on the hydrological and thermal* properties in soil (Gunnar Ch. Borg, B. Ingvar Andersson and Hans Hultberg, Swedish Environmental Research Institute, Gothenburg, Sweden)
- Circumarctic map of permafrost and ground ice conditions (Jerry Brown, IPA Editorial Committee, Arlington, VA, USA, Oscar J. Ferrians, Jr., U.S. Geological Survey, Anchorage, AK, USA, J. Allan Heginbottom, Geological Survey of Canada, Ottawa, Canada, and Evgeny S. Melnikov, Institute of Hydrogeology and Engineering Geology, (VSEGINGEO), Moscow, Russia)
- Genetic polymorphism in the Arctic - a molecular approach (H. M. Chapman, R. M. M. Crawford, and R. J.. Abbott, Plant Science Laboratories, St. Andrews University, St. Andrews, Fife, Scotland)
- Soil organic matter dynamics in arctic ecosystems by radiocarbon data (Alexander E. Cherinsky, Institute of Geography, Academy of Sciences, Moscow, Russia)
- The importance of sexual reproduction in arctic clonal plants and their evolutionary potential (Ingibjörg S. Jonsdottir, Department of Botany, University of Gothenburg, Göthenborg, Sweden)
- The adaptation of vascular plants to low temperature and climate warming in the Arctic (Erik L. Kaipiainen and Tatjana V. Gerasimenko, Botanical Institute, Russian Academy of Sciences, St. Petersburg, Russia)
- Impact of climatic change on littoral-pelagic interactions in a mesohumic lake in the boreal region: description of the experimental system (Paula Kankaala, Anne Ojala, Tiina Tulonen and Lauri Arvola, University of Helsinki, Lammi Biological Station, Finland)
- Simulating the impact of changing climate, forest management and production alternatives on the carbon budget in boreal forests and wood products (Timo Karjalainen, University of Joensuu, Faculty of Forestry, Joensuu, Finland)
- Response of the boreal forest ecosystem to climatic change and its silvicultural implications (Seppo Kellomäki, University of Joensuu, Faculty of Forestry, Joensuu, Finland)
- The competition between methanogenic and acetogenic bacteria from tundra soil for H_2 and CO_2 at low temperature after long-term adaptation period (Oleg R. Kotsyurbenko and Alla N. Nozhevnikova, Institute of Microbiology, Russian Academy of Sciences, Russia)
- Anaerobic degradation of organic matter by psychrophilic microorganisms from tundra soil (Oleg R. Kotsyurbenko, Tatyana I. Soloviova, Alla N. Nozhevnikova and Georgy A. Zavarzin, Institute of Microbiology, Russian Academy of Sciences, Russia)

- The temperature threshold in the development of methanogenic versus acetogenic community from the tundra soil (Oleg R. Kotsyurbenko, Tatyana I. Soloviova, Alla N. Nozhevnikova and Georgy A. Zavarzin, Institute of Microbiology, Russian Academy of Sciences, Russia)
- Was there any forest limit advance in subarctic Quebec (Canada) associated with the XXth century warming? (Claude Lavoie and Serge Payette, Centre d'etudes nordiques and Departement de biologie, Université Laval, Sainte-Foy, Quebec, Canada)
- Germinable seed banks from polar desert stands on Central Ellesmere Island, Canada (Esther Levesque and Josef Svoboda, Department of Botany, University of Toronto, Toronto, Ontario, Canada)
- The influence of elevated CO_2 concentration on the growth of some plant species in growth chambers and in field plots (Leiv M. Mortensen, Særheim Research Station, Norway)
- Effect of climatic warming on carbon balance and geographical distributions of some tundra plants (Sergey K. Nazarov, Institute of Biology, Komi Scientific Center, Syktyvkar, Russia)
- CO_2 fluxes in East European wet sedge-moss and low shrub tundras (Elena V. Nekutchaev, Institute of Biology Komi Scientific Centre, Ural Department, Russian Academy of Sciences, Syktyvkar, Russia)
- Phytosociological and remote sensing studies of changes in vegetation patterns on a glacier forefield at Uversøyra, North West Spitsbergen (Lennart Nilsen and Sigmund Spjelkavik, Department of Ecological Botany, IBG, Tromsø University, Norway)
- Monitoring of current changes in the climate, upper permafrost and vegetation cover of the Arctic areas of West Siberia (A. V. Pavlov and N. G. Moskalenko, VSEGINGEO, Russia)
- GIS and climate modelling at the mesoscale (Aulis Ritari and Vesa Nivala, Rovaniemi Res. Stat., The Finnish Forest Research Institute, Finland)
- Biomass and composition of microbial communities in soils of Northern Russia (Maria V. Syzova and Nikolai S. Panikov, Institute of Microbiology, Russian Academy of Sciences, Moscow, Russia)
- Effects of increased CO_2 and temperature on changes in plant and soil processes (Kari Anne Sølvernes and Gunnar Ogner, Norwegian Forest Research Institute, Ås, Norway)
- Soil self-heating in Northern ecosystems as a cause of permafrost melting and CO_2 efflux to the atmosphere (S. Zimov, S.P. Daviodov, Y.V. Voropaev and S.F. Prosiannikov, North-East Scientific Station, Pacific Institute for Geography, Far-East Branch, Russian Academy of Sciences, Republic of Sakha, Yakutia, Cherski, Russia, L.P. Semiletov, Pacific Oceanographic Institute, Far-East Branch, Russian Academy of Sciences, Vladivostok, Russia; and M.C. Chapin, F.S. Chapin III, Department of Integrative Biology, University of California, Berkeley, California, USA)
- Northern lakes: a new methane source of global significance (S. Zimov, S.P. Daviodov, Y.V. Voropaev and S.F. Prosiannikov, North-East Scientific Station, Pacific Institute for Geography, Far-East Branch, Russian Academy of Sciences, Republic of Sakha, Yakutia, Cherski, Russia, L.P. Semiletov, Pacific Oceanographic Institute, Far-East Branch, Russian Academy of Sciences, Vladivostok, Russia; M.C. Chapin, F.S. Chapin III, Department of Integrative Biology, University of California, Berkeley, California, USA, and S. Trumbore and S. Tyler, Department of Geochemistry, University of California, Irvine, California, USA)
- Longitudinal and latitudinal patterns of phytomass reserves and primary productivity profiles of the Russian North from Cola Peninsula to Chukotka (Dmitri G. Zamolodchikov, Centre for Problems of Forest Ecology and Productivity, RAS, Moscow, Russia, and Dmitri V. Karelin and Olga V. Chesinykh, Moscow State University, Department of Biology, Moscow, Russia)

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