ICARP II – SCIENCE PLAN 8

TERRESTRIAL AND FRESHWATER BIOSPHERE AND BIODIVERSITY

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PREFACE

The Second International Conference on Arctic Research Planning (ICARP II) was held in Copenhagen, Denmark from 10 November through 12 November 2005 and brought together over 450 scientists, policy makers, research managers, indigenous peoples, and others interested in and concerned about the future of arctic research. Through plenary sessions, breakout sessions and informal discussions, conference participants addressed long-term research planning challenges documented in twelve draft research plans. Following the conference drafting groups modified the plans to reflect input from the conference discussions and input from the ICARP II web site. This science plan is the culmination of the process.

ICARP II Science Plans

Science Plan 1	Arctic Economies and Sustainable Development
Science Plan 2	Indigenous Peoples and Change in the Arctic: Adaptation, Adjustment and Empowerment
Science Plan 3	Arctic Coastal Processes
Science Plan 4	Deep Central Basin of the Arctic Ocean
Science Plan 5	Arctic Margins and Gateways
Science Plan 6	Arctic Shelf Seas
Science Plan 7	Terrestrial Cryospheric & Hydrologic Processes and Systems
Science Plan 8	Terrestrial and Freshwater Biosphere and Biodiversity
Science Plan 9	Modeling and Predicting Arctic Weather and Climate
Science Plan 10	A Research Plan for the Study of Rapid Change, Resilience and Vulnerability in Social-Ecological Systems of the Arctic
Science Plan 11	Arctic Science in the Public Interest
Background Document	Contaminants

8.1. Introduction

Arctic terrestrial and freshwater ecosystems are very extensive (more than 11.4 million km^2) and components of these ecosystems are important resources for arctic residents. While phytomass is generally low in tundra ecosystems, belowground carbon stores are very high. The biodiversity of the Arctic is low overall, but should not be seen in isolation as it is connected with other parts of the world. Changes in the interactions between northern temperate, boreal, and arctic ecosystems are, therefore, important elements of arctic ecosystem responses to climate change. Within the Arctic, ecosystem processes have important effects on climate and atmospheric chemistry, including snow patterns that affect energy exchange, wet tundra distribution, and greenhouse gas emissions. Ecosystem structure and function are already changing in the Arctic and are projected to change still further in response to changes in the Arctic's climate and other environmental factors. Permafrost is widespread in arctic regions and future thawing could result in very rapid changes to physical aspects of the landscape and ecosystem function. Assessments of these changes were made recently within the Arctic Climate Impact Assessment (ACIA, 2005; Callaghan et al., 2004) and the Millennium Ecosystem Assessment (Chapin et al., 2006), and are underway within the Fourth Assessment of the Intergovernmental Panel on Climate Change Working Group 2 (Polar Chapter) (Anisimov et al., in prep.).

Although there is therefore, a good knowledge of many aspects of the responses of arctic ecosystems to climate change, some key uncertainties and gaps remain and further field-based research and development of predictive models is a major necessity for allowing more detailed and comprehensive projections of change. Particular challenges are improved understanding of key processes and transient responses to climate change, upscaling from point measurements to regional scales, and the integration of climate feedback effects (net radiative forcing) at the landscape level (including interactions between ecosystems). This ICARP II science plan focuses on how the scientific community can improve its ability to identify, attribute, and project the impacts of climate change on terrestrial and freshwater ecosystems of the Arctic. The definition of climate used here includes the quality of radiation, in particular ultraviolet-B (UV-B) radiation, and the definition of the Arctic is wide and similar to that used by ACIA. This ICARP II science plan is not intended to be a source of literature: the major recent assessments listed above already contain the relevant literature sources.

The subject matter covered by this ICARP II science plan relates closely to that of several other ICARP II working groups. In particular, there has been coordination with ICARP II Working Group 7 to avoid overlap on issues relating to terrestrial permafrost dynamics.

8.2. Focus

Ecosystem function and ecosystem structure are the two major focal points for this ICARP II science plan. In practice, these topics are interlinked. Both are likely to respond to multiple drivers of change including the dominant climate drivers of change, such as temperature, precipitation, radiation and disturbance, and other drivers such as the wetting and drying of soils, permafrost changes, erosion, and deposition of dust. This section lists some key topics that are translated into research questions in section 8.3 and agendas in section 8.4.

8.2.1. Ecosystem Function

Understanding and predicting biospheric feedbacks with the atmosphere is the main issue related to ecosystem function for the near future. Two types of biospheric feedback are likely to have significant impacts on the atmosphere and climate at both local and global scales: impacts of biogenic trace gases, aerosols and dust, and exchanges of energy and water between the biosphere, hydrosphere, and atmosphere. Current understanding of the processes contributing to these feedbacks and their overall forcing of the climate system is limited. Particular focal activities include research and monitoring to achieve the following.

- To develop, improve and integrate observations and models of key biogeochemical species combined with studies and information on energy exchanges between the biosphere, hydrosphere and atmosphere. There should be a focus on linkages between ecosystems (particularly across the terrestrial/freshwater interface), on controls of multiple trace gases and aerosols, and on changes in albedo and surface roughness resulting from changes in plant canopy structure (e.g., at the treeline), disturbance, dust, and snow. There should also be a focus on experimental approaches that improve understanding of mechanisms and allow the quality of model simulations to be tested.

- To integrate the climate forcing of the various feedbacks, to integrate feedbacks from terrestrial and freshwater ecosystems with those from the cryosphere and marine systems, and to calculate the contribution of arctic feedbacks to the global climate and atmospheric chemistry.

8.2.2. Ecosystem Structure

The main focus relating to ecosystem structure is to gain better data on current and past changes in terrestrial and freshwater biodiversity, an improved understanding of the processes causing these changes, an ability to predict future changes, and a better understanding of the consequences of change for resource use and ecosystem function. There are several particular focal activities.

- To gain a better understanding of the impacts of multiple interacting drivers on species performance, abundance, distribution and interactions with other species.

- To link biodiversity with ecosystem function and focus particularly on belowground biodiversity and complementarity versus redundancy in species functions. There should be a particular focus on improving knowledge of the function of freshwater biota in order to interpret the detailed sediment records of dramatic changes in freshwater biota in the past 150 years that follow thousands of years of stability (Smol et al., 2005). Linking species and function will give insights into gradual climate change in the Arctic as well as into the consequences of rapid change.

- To improve models of ecosystem change. There needs to be a focus on variability in tundra landscapes, for example areas of potential paludification versus aridification resulting from permafrost thawing and geographical differences in drainage and evapotranspiration.

8.3. Key Scientific Questions

This section develops the focal topics by posing both overarching and detailed questions that must be resolved to reduce uncertainties in understanding responses of terrestrial and freshwater ecosystems to climate change.

8.3.1. Ecosystem Function

There are four key questions concerning ecosystem function, some of which can be sub-divided into more detailed components. These key questions are highlighted in italics and underlined.

What will be the magnitude and sign of the feedback between the carbon cycle and climate across terrestrial and freshwater systems at a pan-arctic scale in response to global change?

Spatial Variability

- *How is the large soil carbon pool distributed in the landscape? How are important large-scale features of the arctic landscape (such as the position of the treeline and the extent of wetlands) that affect carbon cycling and storage changing?* Remote sensing reveals both increases and decreases in the extent of wetlands. A systematic survey of the entire Arctic is required.

- *What will be the pan-Arctic carbon feedback from freshwater ecosystems?* The freshwater feedback occurs (a) through the loss from streams and lakes of carbon dioxide from soil, and (b) through the transformation of soil organic matter to methane. This has not been calculated for the pan-Arctic.

- *How does fine-scale environmental variability contribute to the regional carbon balance (or does it at all)?*

- *What are the lateral exchanges of carbon and other nutrients between terrestrial and freshwater ecosystems in relation to "vertical" surface-atmosphere exchange of carbon/nutrients and how will land physical changes and ecosystem function changes affect river discharge and water chemistry?* Loss of carbon from soil is usually measured as vertical flux of carbon dioxide. There is an additional large fraction of soil carbon that is lost horizontally through flux of soil water into streams – this is usually missed in measurements yet may tip the balance between an estimated carbon source and a carbon sink.

- *What is the overall balance between areas of drying and wetting in the Arctic and what impacts does regional heterogeneity of climate change have on overall arctic ecosystem responses?*

Temporal Variability

- *What are the roles of winter processes, long term trends and interannual variability in determining arctic biogeochemical cycles?*

- *What are the roles of episodic events in driving step changes in carbon dynamics; what are their frequency, magnitude and geographical location?* Examples are possible changes in the frequency and magnitude of disturbance events such as permafrost thawing, fire, insect pests, grazing and human activities on the carbon cycle.

- *What will be the transient integrated response of arctic terrestrial and freshwater ecosystems to global change, taking into account that key processes such as treeline migration, permafrost thawing and decay of soil organic matter might operate at different temporal scales?*

Drivers of the Carbon Cycle Feedback and Processes

- *What are the impacts on climate and atmospheric chemistry of a broader range of biogeochemical species and aerosols, particularly those that give a negative feedback on climate change in addition to carbon dioxide and methane?*

- *What will be the differential impact of land physical changes (e.g., thermokarst, ground subsidence, altered drainage patterns, aridification versus paludification; see Figure 8.1) and changes in vegetation and soil processes on soil organic matter chemistry and decay?* In some regions permafrost thaw is accelerating the movement of carbon-rich soils into lakes and wetlands where anaerobic conditions prevail. As well the death of freshwater biota, high amounts of methane are created and released to the atmosphere while unknown amounts of carbon are sequestered in sediments.

- *Which surface properties (e.g., normalized difference vegetation index, snow indices, soil moisture) can be used as indicators for carbon dynamics, and what are the processes that manifest in these indicators?* The relationship between soil moisture and decomposition of litter is crucial for predictions of future carbon storage or loss but few studies exist. Detailed studies are needed of the decomposition of different types of litter under natural conditions, rather than litter bag experiments.

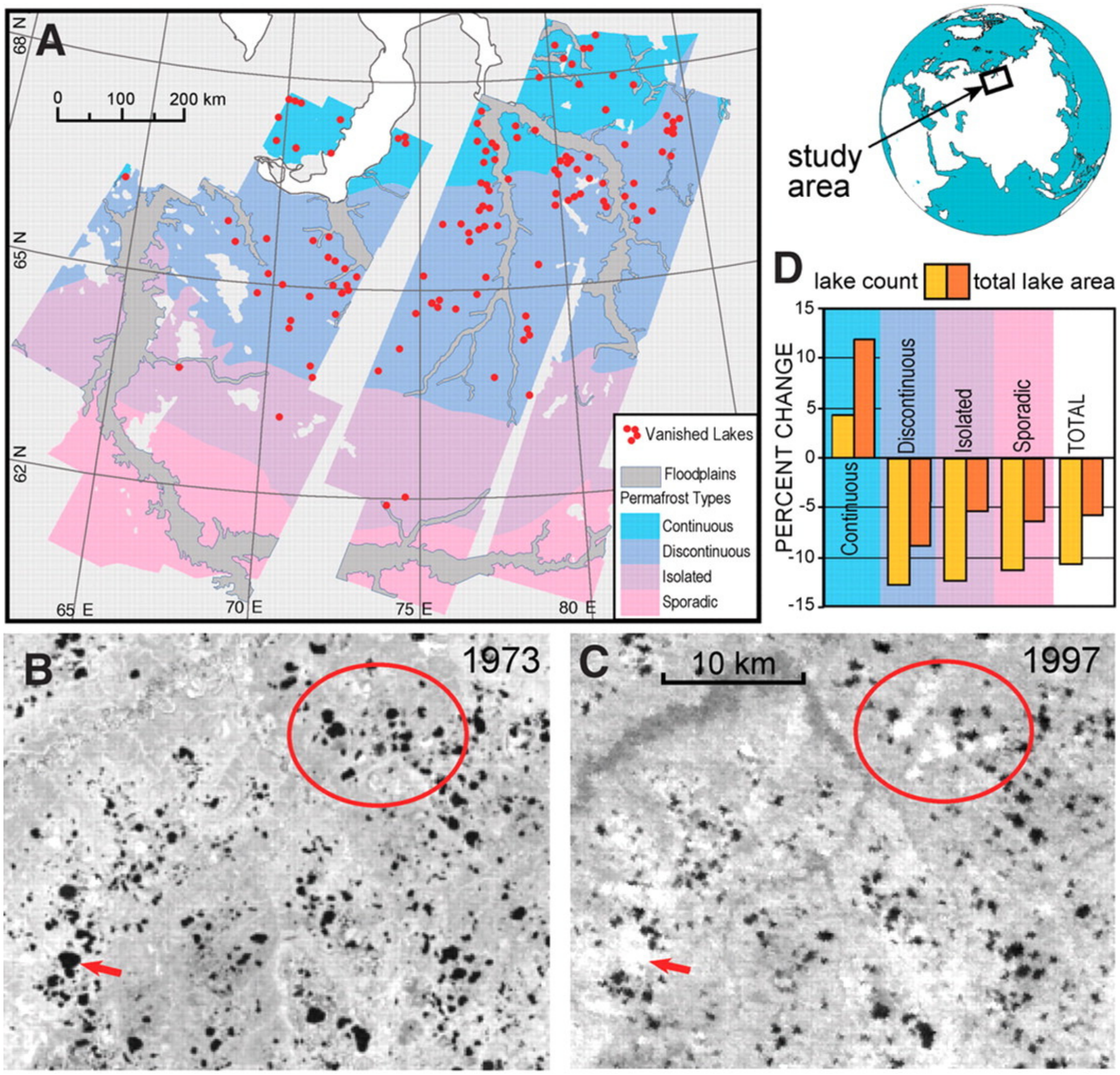

Figure 8.1. One example of the land physical changes that are occurring is the disappearance of Arctic lakes due to permafrost degradation (Smith et al., 2005).

- *What will be the impacts of concurrent increases in temperature and UV-B radiation on the carbon cycle in the terrestrial and freshwater ecosystems?* The effect of the interaction of higher levels of temperature and UV-B radiation on freshwater biota is unknown but amenable to an experimental approach. Increases in levels of UV-B radiation will affect the freshwater biota by accelerating the breakdown of dissolved organic matter. Impacts on the system as a whole are unknown, but could be approached experimentally.

- *How are changes in the arctic carbon cycle linked to, or modulated by changes in/regulation of other element cycles, especially nitrogen and phosphorus?*

Methodology

- *How well do the models of carbon cycling reflect observations?*

- *What upscaling tools are available (e.g., chamber-, tower- and aircraft carbon measurements, GIS-based landcover schemes) and how can they be improved?*

What will be the magnitude of changes in albedo, surface roughness, energy partitioning and momentum transfer at landscape to pan-arctic levels in response to climate change?

- *What will be the effect of changes in disturbance (thermokarst, fire, insect damage, infrastructure development) on albedo, surface roughness, energy partitioning and momentum transfer?*

- *What will be the effects of vegetation change on albedo, surface roughness, energy partitioning and momentum transfer?*

What is the net and relative influence on surface climate of the combined feedbacks from terrestrial and freshwater ecosystems?

What is the total contribution of arctic feedbacks to the global climate system?

8.3.2. Ecosystem Structure

There is one key question concerning ecosystem structure and this can be sub-divided into more detailed components.

How will terrestrial and freshwater biodiversity change and what will be the consequences for resource use and ecosystem function?

Vulnerability

- *Which arctic species, communities and ecosystems are most vulnerable to climate change?* Species at the edge of their distribution are vulnerable, and some ecotones are already showing changes in vegetation (e.g., Sturm et al., 2001). In freshwaters, fish and zooplankton distribution was often attained tens of thousands of years ago when high runoff from mountain and continental glaciers allowed biota to move throughout the Arctic. Now, when warming takes place and these populations become extinct, they cannot be replaced from populations further south.

Species Immigration

- *What species are likely to move into the Arctic and what will be their impact? What are the land physical and dispersal constraints affecting migration rates?*

- *What is the impact of climate change on migratory animals and what are the implications of these impacts for resource use by arctic residents?* (Key aspects are the synchrony of migration with availability of food sources and changes in the overwintering grounds for birds, and drastic changes in the lakes where fish overwinter.) Some populations of arctic char, important food resources for arctic residents, overwinter in lakes and migrate to the sea for a few months each summer. Changes in land use and climate will result in more nutrients reaching lakes, warmer lake temperatures in the summer, and a longer ice-free growing season for algae. Habitats where fish can live will be reduced because the increase in organic matter will lead to a reduction in under-ice oxygen for fish and because the thickness of the zone of cool water needed by the fish in the summer will shrink.

Taxonomic Groups of Organisms

- *How is the diversity of microbes related to their function within ecosystems and how does this vary among different freshwater habitats across environmental gradients?* The little information available about the diversity of microbes in arctic freshwaters indicates that species are widely distributed and not unique to the Arctic. However the genes used for species determination do not give information about temperature tolerances. Detailed studies of function, especially related to temperature, need undertaking for freshwater bacteria.

- *What are the impacts of climate change on soil organism diversity and soil processes, including decomposition, nitrogen cycling, mycorrhizal foraging, soil animal activities and food webs?* The indirect effects of climate change may lead to increased rates of nutrient movement into soils. Evidence from long-term experiments indicates that this change in nutrients will cause a dramatic increase in the decomposition rate of soil organic matter. This has the potential of being an important positive feedback for warming.

Interactions among Species, Populations, and Trophic Interactions

- *How will a change in tree cover (or other main structuring vegetation components) change living conditions for other ecosystem components?*

- *What are the impacts of climate change on multi-annual interaction cycles within the plant-based tundra food web (Ims and Fuglei, 2005)?*

- *What are the relative impacts of oscillatory versus long term climate variation and change on species performance, population dynamics and distribution?*

- *What are the effects of climate change on diseases, pests and parasites and what is the potential for the release of pathogens from thawing permafrost?*

Drivers of Changes in Biodiversity

- *What would be the impacts of concurrent increases in temperature and UV-B radiation on biodiversity (particularly at the genetic level, on microbes and in the freshwater systems)?* The effect of the interaction of higher levels of temperature and UV-B radiation on freshwater biota is unknown but is amenable to an experimental approach. Increases in the levels of UV-B radiation will affect the freshwater biota by accelerating the breakdown of dissolved organic matter. The impacts on the system as a whole are unknown, but could be approached experimentally.

- *What is the relative importance of climate change compared with other drivers of change and how do the drivers change throughout the Arctic?*

Consequences of Changes in Biodiversity (Excluding Feedbacks to Climate: see above)

- *What are the impacts of changes in species composition in both terrestrial and freshwater systems on important ecosystem services (e.g., subsistence hunting, commercial exploitation) and functions (productivity, nutrient cycling, trace gas fluxes) and resources for humans?*

- *What are the impacts of changes in ecosystem function on species composition and vice versa?*

- *What will be the new, potential no-analogue assemblages of species?*

8.4. Scientific Approach

Each approach has both strengths and limitations. Confidence increases when findings converge from a range of approaches (Callaghan et al., 2004). This ICARP II science plan recommends several fundamental approaches.

8.4.1. Observations

There is a fundamental need for improving sustained pan-arctic multidisciplinary observations in terrestrial and freshwater systems to further the understanding of baselines in the arctic system and to establish how the Arctic will continue to respond to change. Such observations are complementary to short-term hypothesis-driven research and offer a means by which the spatial, temporal and biological relevance of these mostly short-term studies can be maximized; they also increase the chance for serendipitous discovery. Improvements should build on existing infrastructure and initiatives (Figure 8.2) such as those conducted at major research sites (e.g., SCANNET, Scandinavian / North European Network of Terrestrial Field Bases, http://www.scannet.nu; and LTER, Long Term Ecological Research Network, http://www.lternet.edu), experimental sites (e.g., ITEX, International Tundra Experiment, http://www.itex-science.net), and other networks of observations (e.g., CALM, Circumpolar Active Layer Monitoring Network, http://www.udel.edu/Geography/calm), and should incorporate community based participation (e.g., CARMA, Circumarctic Rangifer Monitoring and Assessment Network) that will enhance the integration of traditional, local and scientific knowledge and the capacity for year-round observations. Such improvements should also enhance the capacity for networks such as the Arctic Monitoring and Assessment Programme, which requires samples for the analysis of contaminants to be collected from multiple sources across the Arctic. Networks focused on coordination and facilitation of observations in the Arctic, such as CEON (Circumarctic Environmental Observatories Network, http://www.ceoninfo.org/) and COMAAR (Coordination of Observation and Monitoring of the Arctic for Assessment and Research, http://www.ipy.org/development/eoi/proposal-details.php?id=305), could facilitate these developments.

Improved coordination of observations will require a combination of measurements conducted at new or existing intensive sites (e.g., Abisko, Barrow, Zackenberg, Ny Alesund, Cherski and Toolik Lake, Shaver et al., 2004) and extensive sites (e.g., remotely located automated stations) that will enhance the capacity for understanding spatial variability and patterns of change. Observations will also need to encompass traditional methods and protocols, and where appropriate, embrace state-of-the-art technology and new protocols to increase the efficiency, accuracy and resolution of measurements and the capacity to integrate multiple technologies and new fields of study. Combined, these improvements will help to overcome many of the existing limitations to observations, including:

- great variability in geographical coverage with large areas unrepresented;
- lack of winter measurements;
- lack of long-term measurements;
- little use of local knowledge;
- too few long-term research platforms; and
- lack of information on topics difficult to study (e.g., microbial processes).

Sustaining observational time series needs to cut across international borders and differences in national funding trends, capabilities and policies; differences in data ownership; and approaches to monitoring (research versus observatory platform managers) and needs to include traditional and local peoples of the north to ensure year round coverage of some measurements.

Future

To remedy this situation and improve the capacity for collecting sustained integrated time series observations in the Arctic, this ICARP II science plan recommends a progressive series of actions.

Short Term

- Use of the new techniques of molecular biology to define the expression of the potential functions of the microbial genome; one result being an understanding of the possible changes in the

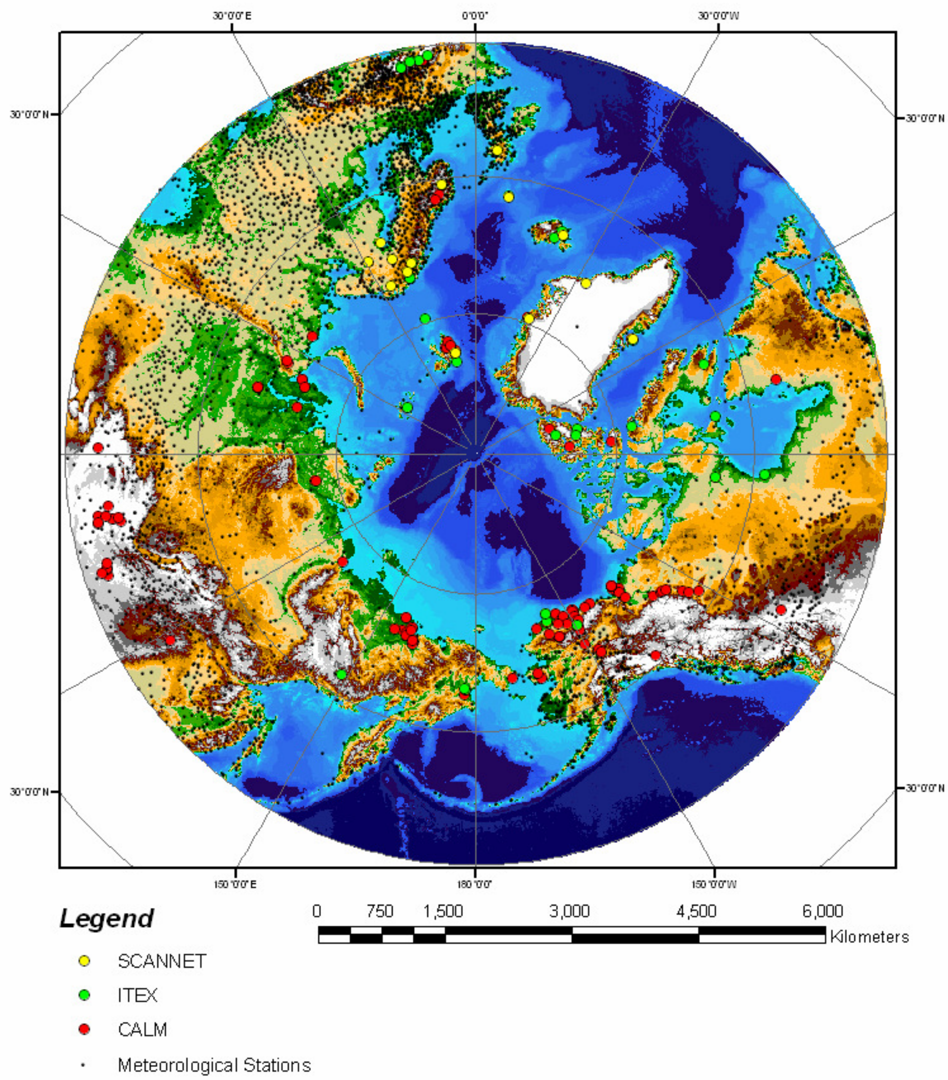

Figure 8.2. Current map of terrestrial monitoring and experimental sites as registered in the CEON database.

dominant decomposer organisms (i.e., the fungal and bacterial communities), and competition between them, during climate change; another, knowledge of changes in microbes when plant communities change.

- A broadening of the spectrum of compounds measured at existing monitoring and experimental sites to include, for example, nitrogen species, volatile organic compounds and biogenic aerosols.
- Integration of observations of the carbon cycle with experimental manipulations of the environment.

- Year round observations in order to include the important winter processes, which are currently underrepresented.
- An inventory of carbon content and quality for the many, varying types of plant litters, soils and permafrost.
- Design and orchestration of ground-based observations to maximize the potential for validating remotely sensed products.

Long Term

- Use of observations and experiments such as those listed above to generate a better process-based understanding that can be included in a new generation of models. Use of the models to develop hypotheses that can be tested by selected measurements at additional targeted field sites.
- Future observations and experiments to focus on the long term and operate year round.
- Regular syntheses and assessments to identify where gaps in the observational record can be filled and where the potential to integrate multiple observational time series can be improved.
- Addition of new time series observations to observational activities as new lines of uncertainty open up or discoveries are made, either through experimental research, other short-term studies or modeling.

8.4.2. Local Knowledge

Observations of changes in biodiversity, weather and landscape will be collated from local knowledge whereas knowledge from the science approach will be shared with arctic residents. There is a tremendous potential for terrestrial and freshwater ecosystem studies to harvest crucial information about ongoing and past environmental changes from local knowledge bases. There has been no systematic gathering of such information to date but ICARP II Science Plan 2 does address this issue, as do several IPY (International Polar Year) projects.

8.4.3. Experimental Manipulations

State-of-the-art

Experimental manipulations of the abiotic (physico-chemical, including climatic) environment, and biotic ecosystem components, are feasible in arctic terrestrial and freshwater systems, and across their interface. Such manipulations have been (and continue to be) used in this context for two principal reasons. First, to simulate environmental change drivers (e.g., climate warming, increased UV-B radiation fluxes to the surface, elevated carbon dioxide concentrations in the atmosphere, or increased deposition of airborne nitrogen-containing compounds) and their impacts upon organisms and ecosystem processes. Second, to answer fundamental ecological questions relating to, for example, how communities are assembled, how organisms utilize and partition resources, and how organisms interact with other species. Manipulation experiments are an important component of predictive modeling and offer the potential for model output to be tested against responses in nature (see Figure 8.3).

Manipulation experiments have particular strengths and weaknesses, and it is important to recognize these to ensure that the experiments are designed, implemented and interpreted optimally. Manipulation experiments are often justified as useful approaches to understanding short- to medium-term physiological and growth responses to change, and this has sometimes been extended to ecosystem processes such as nutrient cycling, and plant community changes and plant-herbivore interactions (e.g., Robinson et al., 1998; Arft et al., 1999; Cornelissen et al., 2001; Richardson et al., 2002; Sjögersten and Wookey, 2002; van Wijk et al., 2004; Wahren et al., 2005). Such approaches have been particularly successful where results are interpreted with reference to other sources of information (e.g., studies along environmental gradients/transects, longer-term observational data, and paleo-environmental information). A combined approach in which manipulation experiments are

Figure 8.3. Example of factorial experiments with increased temperature (infra red lamps and soil heating cables) and increased carbon dioxide concentration at Stordalen, subarctic Sweden (experiment operated by the Ecosystems Centre at Woods Hole).

conducted along/across environmental gradients/transects is best. In addition to the value of the manipulation experiments themselves, much additional information can be obtained from un-manipulated "control" plots (e.g., in terms of responses to interannual climatic variability, or biotic disturbances), although the value of this source of information is sometimes overlooked.

Manipulation experiments do have their limitations, however, and these are as much related to the potential longevity of the experiments (associated with, for example, research funding cycles) as to factors such as treatment artifacts (e.g., Wookey and Robinson, 1997), plot size, and problems of increasing physical disturbance through sampling and routine survey work. Short-term (two growing seasons) experimental manipulation of summer temperature at four sites in northern Alaska, for example, resulted in similar responses in plant community composition, species richness and vegetation height across all sites, while continued manipulation (for an additional three to five years) resulted in a divergence in response among the sites (Hollister et al., 2005). The authors concluded that "predictions of vegetation change due to climate warming based on manipulative experiments will differ depending on both the duration and plant community on which the study focuses".

Future

Experience to date with arctic ecosystems and manipulative experiments suggests that there remains enormous potential for this approach, but that there is considerable "value-added" by being part of broader networks (e.g., ITEX), or by ensuring that linkages exist between research teams that enable syntheses/meta-analyses to be undertaken (Arft et al., 1999; Cornelissen et al., 2001; van Wijk et al., 2004). If short-term "readjustment" responses to change imposed by manipulative experiments are to be translated into meaningful community and ecosystem-level responses (with relevance to predicting responses to global environmental change) then the duration of experiments is critical. Studies must be extended beyond traditional funding cycles, and mechanisms should be sought to achieve this. To date, the potential for manipulative experiments to be used in biodiversity-related research in the

Arctic has not been widely exploited, an exception perhaps being the experimental manipulation of plant community composition (e.g., Bret-Harte et al., 2004) and herbivory.

8.4.4. Remote Sensing

State-of-the-art

The current constellation of global earth observing satellites offers unprecedented coverage and monitoring capabilities for the Arctic. This network consists of a wide array of overlapping measurements, spatial and temporal scales, spectral wavelengths and sensitivities, and sensor and orbital configurations for biospheric monitoring. Advanced algorithms integrate synergistic remote sensing observations from multiple sensors to extract higher order information such as fractional vegetation cover, photosynthetic leaf area, net primary production (Figure 8.4), and land cover change. Many of these products are produced operationally and disseminated freely through online data archives by national agencies such as NASA to facilitate greater utility and public use of the data. These advanced products are often consistent with data collected from more rigorous, but spatially and temporally limited surface network observations, providing a means for regional comparisons and scaling of surface observations across the pan-Arctic.

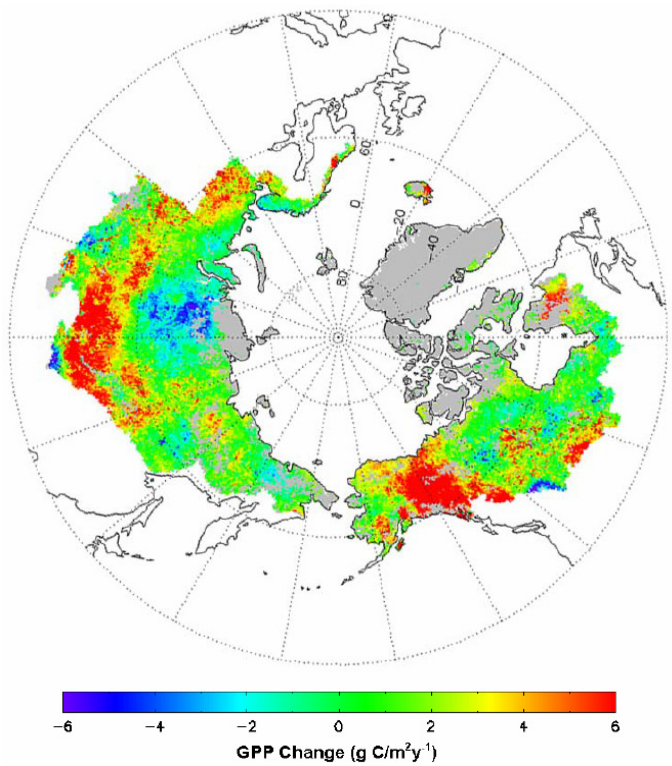

Figure 8.4. Long-term trends (1982-2000) in annual gross primary production (GPP), derived from NOAA AVHRR Pathfinder records and a production efficiency model described by Nemani et al. (2003) and Running et al. (2004) (Sitch et al., in press).

Detection of climate change and carbon cycle feedbacks from satellite remote sensing of the Arctic pushes the limits of measurement precision required to detect a meaningful signal due to the extreme natural variability of the system. The satellite remote sensing record is currently limited to the past 30 years and may be of insufficient length to distinguish climate change responses from natural cycles. The long-term remote sensing record is also derived from multiple generations of satellite sensors and platforms without the precise calibration and accuracy guidelines of newer sensors. Reanalysis of existing satellite data archives such as the NOAA AVHRR Pathfinder product mitigate many of the known problems and systematic errors in these data and provide improved long-term records for climate change analyses. Owing to the limited scope and period of record of satellite observations, these data are often integrated with surface network measurements and prognostic biophysical models for more comprehensive assessment of long-term trends and biophysical feedbacks. Newer sensors are generally well calibrated for global change research, but many are considered limited duration, “experimental” missions, while the potential for longer term monitoring is less certain. The current global satellite network is also supported by a diverse array of national, commercial and international entities, often with limited financial resources and conflicting agenda’s. International protocols and guidelines for public use and distribution of these data are also limited, restricting access to the full array of global satellite remote sensing products by the international science community.

Future

A series of short-term and long-term actions are recommended to ensure maximum use and benefit of the past, current and future wealth of satellite remote sensing information for arctic research.

Short Term

- In the near term, existing multi-scale satellite imagery and data sets relevant to biospheric feedbacks will be interrogated. Of particular interest are observational studies along regional thermal, moisture and vegetation gradients and transitional zones such as treeline and wetlands, where surface trends and biophysical feedbacks may be magnified and within the detection limits of existing satellite records.
- Episodic events of regional extent and limited duration, including fires and wetting and drying cycles will also be monitored to assess both short-term response and system recovery. Improved and continuous access to environmental satellite data specific to the Arctic domain is required.
- The community should identify and prioritize critical biophysical variables for long-term monitoring, which can be ranked according to their potential for remote sensing detection. These variables will form the basis for improved planning and coordination of satellite remote sensing and surface observational networks, and integration with prognostic biophysical modeling activities, where data from plots will be scaled up to targeted landscapes and then to the region.
- Stringent cross-platform radiometric calibration of remote sensing data and periodic reprocessing and reanalyses of long-term records should be conducted to increase signal to noise and ensure measurement accuracy and consistency of remote sensing data records.

Long Term

- In the long term there should be coordinated national and international prioritization of long-term monitoring of the Arctic.
- Satellite monitoring of surface properties relevant to physical drivers and biospheric feedbacks to the carbon cycle will be secured, developed and expanded for the pan-Arctic.
- International agreements will be secured for the provision and use of national satellite data archives for arctic research.
- Funding should also be identified for securing commercial satellite data; a potential model for this activity includes the NASA Data Buy, which provides NASA investigators access to commercially available remote sensing products free of charge.
- Existing public data archives should provide remote sensing and ancillary data bundles specific to the Arctic, with consistent, scaleable gridding and geographic projections, documentation, and portable data manipulation and analysis software to facilitate wider use and information extraction from the data.
- The development and implementation of new satellite remote sensing technologies designed for the Arctic should be encouraged to improve capabilities for regional detection, monitoring and evaluation of pan-arctic carbon cycle dynamics.

8.4.5. Modeling Biospheric Feedbacks

State-of-the-art

There are three types of terrestrial models; the biogeochemical models (e.g., TEM, http://www.mbl.edu/eco42/), the biogeography models (e.g., BIOME1, http://ocean.wff.nasa.gov/biome1/), and land surface models (e.g., MOSES, (UK) Met. Office Surface Exchange Scheme). Dynamic global vegetation models represent a merging and development of these three models. The biogeochemical models and the dynamic global vegetation models project past, current and future carbon dynamics. There are physical models of individual lakes that represent circulation and growing season length etc. but do not yet incorporate the carbon cycle. However, they do provide a basis for achieving this in the future.

Future

There are several needs that are urgent in the short-term to quantify the importance of biospheric feedbacks and some long-term goals for the development of more comprehensive biospheric feedback models.

Short Term

- Process level models understanding, for example soil decomposition (although the process understanding must be improved).
- Functional relationships derived from field experiments to test the models.
- Representation in models of organic soils, active layer dynamics, disturbance (thermokarst, fire, insect damage/herbivory, infrastructure/anthropogenic development) and non-vascular plants. Models also need to include the availability of suitable soils and the impact of geography on vegetation change as well as an improved representation of rates of vegetation change.
- Development of dynamic, process-based wetland models.
- Linkages of terrestrial-freshwater-cryosphere-marine systems at all scales.
- Evaluation, for example validation of the carbon pools, present-day treeline, seasonal dynamics of snow and carbon.
- Development of dynamic, process-based forest/shrub land models for the transition zone between boreal and arctic areas.
- Transient 3-dimensional modeling of land physical changes due to permafrost thawing.

Long Term

- The development of a set of community models for the Arctic, which includes dynamic vegetation, wetlands, and freshwater ecosystems. Community models have worked well for physical oceanographers as the factors affecting the movement of water are well known. This does not apply to dynamic models of vegetation, wetlands, and freshwaters.
- The coupling of community models with GCMs (general circulation models) and the running of fully coupled carbon cycle experiments to answer the feedback questions listed in section 8.3.
- The development of integrated landscape/catchment analysis and modeling that includes all biospheric and hydrologic feedbacks (surface albedo and roughness, greenhouse gas balance, river runoff).

Cooperation is needed among modelers, as well as some organization of the modeling, so that models do not continue to proliferate.

8.4.6. Data Analysis and Management

All participants should make efforts to archive their data and to make it freely available and in a timely fashion either through established national or international databases or by request. The development of information portals, meta-databases, and improved metadata and metadata search engines to increase the awareness and ease of accessing data is encouraged. Such activities will encourage data to be managed by specialists familiar with the intricacies and methods by which the data were attained and should improve the capacity for finding the data. All data, and research plots, should be geo-referenced as a resource for future use.

8.4.7. Development and Improvement of Methodologies, Technology, and Techniques

New satellite sensors and remote sensing algorithms are needed for improved regional assessment and monitoring of the major components of the arctic carbon cycle, including photosynthesis, respiration, and land-atmosphere carbon dioxide and methane fluxes, and the major biophysical controls on these processes, including soil moisture and its thermal state, and land cover composition and structure. New methods are also needed to determine soil carbon quality and spatial variability across the Arctic. Modern genomic methods need to be applied to arctic organisms (particularly microbes) to determine current population histories and trajectories. Standard protocols should be established for coordination, integration and spatial and temporal scaling of pan-arctic surface network observations using satellite remote sensing and biophysical modeling; these protocols should conform to approaches already in use by global carbon networks such as FLUXNET (http://www-eosdis.ornl.gov/FLUXNET). Development and application of alternative remote sensing technologies operating from field-based instrumentation, and underwater autonomous vehicles and other aircraft-based platforms are also needed to assess sub-grid scale landscape variability and facilitate spatial scaling of satellite remote sensing among plot, targeted landscape and pan-arctic domains.

In addition to the needs to develop new technologies and sensors, new methodologies are needed to answer some outstanding and important questions that cannot be addressed by applying current methods.

- Methods to determine soil carbon quality and residence time need to be improved and applied in the Arctic.
- Methods to determine the lability of contrasting soil organic matter fractions in response to changing soil conditions (this also requires improvements in the fractionation of soil organic matter pools).
- Estimation of above ground biomass and carbon storage by remote sensing techniques needs to be further developed and validated along gradients in productivity, forest cover, and species dominance.
- Modern genomic methodology needs to be applied to arctic organisms (particularly microbes).
- Development and application of remote sensing technologies other than conventional satellite observation are needed.

8.4.8. Interrogation and Exploration of Existing Data Sets and Metadata Analyses

Metadata analyses have recently proved a very powerful means of synthesizing comparable data collected at multiple locations (spanning a broad range of environmental conditions) and of identifying overarching and/or “emergent” properties, processes and responses. In turn, such information has potential to inform modeling activities and to improve fundamental understanding of ecosystem structure, function and dynamics. In the arctic context, meta-analysis was applied to the early ITEX data set in 1996 (at the National Centre for Ecological Analysis and Synthesis, NCEAS), and subsequently to an expanded dataset in 2001 (Arft et al., 1999; Walker et al., 2006). ITEX data were “predisposed” to this type of approach through the deployment of common protocols for the experiments and metrics obtained. There is still considerable potential to re-run analyses as the data set lengthens, and also to “mine” the data collected from control (un-warmed) plots to explore the relationship between interannual climatic variability and plant responses. In addition, meta-analytical or synthetic approaches to widely-dispersed, but related data have also been used successfully by Rustad et al. (2001), Cornelissen et al. (2001) and van Wijk et al. (2004). The potential to apply meta-analysis to datasets should be considered early in the research planning process, since not all datasets can be readily assimilated into a meta-analytical approach, although the potential benefits if this can be achieved are very high.

8.5. Linkages

Links are required with other ICARP II working groups. In particular, concerning work on snow under ICARP II Science Plan 9 to ensure the biospheric impacts on dust and aerosols are addressed, and the work on human dimensions associated with ICARP II Science Plans 1 and 2.

The results of implementing this ICARP II science plan will be useful to arctic residents as they use resources from terrestrial and freshwater ecosystems. They will become involved in sharing observation and monitoring data. The results will also be invaluable to the Arctic Monitoring and Assessment Programme (AMAP) in its follow-up work to the Arctic Climate Impact Assessment (ACIA, 2005) through its Climate Group and assessment of the carbon cycle.

This ICARP II working group could provide coordination of the terrestrial and freshwater components of ISAC (International Study of Arcic Change), IPY and the follow up to the Arctic Climate Impact Assessment (ACIA, 2005). This ICARP II working group could also serve as the international link for national arctic research efforts, such as ArcticNet in Canada, and as a link to an arctic component of the four programs (IGBP: International Geosphere-Biosphere Programme, WCRP: World Climate Research Programme, DIVERSITAS, and IHDP: International Human Dimensions Program) of the earth systems science partnership ESSP.

This ICARP II working group will interact with the Arctic Council’s new project COMAAR (Consortium for coordination of Observation and Monitoring of the Arctic for Assessment and Research) within IPY to facilitate co-ordination of relevant networks for research and observation and to increase data availability, and provide a basis for future assessments of terrestrial and freshwater ecosystem change.

The global community will benefit from knowledge of how changes in the feedbacks from arctic terrestrial and freshwater ecosystems will affect the climate system outside the Arctic.

Education and outreach must be integrated and addressed within the ICARP II process. Education and outreach are crucial to all research efforts. Preparation of future scientists and/or scientifically literate global citizens must start early, for example at elementary school and must not end with graduate school.

8.6. Outcome / Achievements

There will be a wide range of outputs over the next decade from research activities initiated through this ICARP II science plan. These include:

- specific scientific outputs published in international journals;
- thematic maps;
- new monitoring systems/observatories;
- new technologies and methodologies/and long-term experiments;
- improved standardization of protocols;
- a new generation of models scaling from the process level to the pan-arctic level;

- greatly improved understanding of the response of terrestrial and freshwater processes to a wide variety of changes in the arctic environment;
- a new generation of predictive models scaling from the process level to the pan-arctic level;
- continuous and updated information on achievement and development within the scientific field, including publication of results directed to the scientific community and the general public, via websites, printed reports and peer reviewed publications;
- improved web-based tools for searching, finding and archiving data; and
- widely available metadata bases.

8.7. Implementation

The implementation of this ICARP II science plan together with relevant IPY projects will be used to initiate and facilitate national and international efforts to gain funding for:

- The maintenance of existing research and monitoring platforms and the establishment of new platforms in areas with poor geographical coverage and where significant additional scientific information is likely to be gained by including more platforms. The central Canadian and Russian Arctic are key areas for extension and/or reestablishment of platforms, for example weather, ground and hydrological monitoring stations and plant phenology recording sites.
- Improved satellite remote sensing capabilities for the detection of change at the regional level, and monitoring and evaluation of the pan-arctic environment.
- Specialized state-of-the-art laboratories for applying molecular biology techniques.
- The development of miniaturization and transportability of analytical equipment and the development of new miniature sensors with low power needs.
- Improved logistical coordination of cross-disciplinary activities in the same geographical location.

8.8. Funding

This ICARP II science plan builds on the output from numerous research planning exercises and assessments for which funding was available. In contrast, the research itself is significantly impeded by lack of funding although the human resources are not currently a constraint for the proposed research.

There is a major requirement for international, coordinated funding that leads to the development and implementation of long-term research projects. The most cost-effective funding in the short-term is for the analysis of existing data sets and international collaboration on meta-analysis.

A number of the projects and research questions identified in this ICARP II science plan are included in IPY proposals, and IPY could serve as an important starting point for the research proposed here. In the longer term, it would be useful for the Arctic Council to consider methods for coordinating international funding for environmental research in the Arctic.

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