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An assessment of the impacts of changes in climate and UV-B radiation on Arctic terrestrial ecosystems, made within the Arctic Climate Impacts Assessment (ACIA), highlighted the profound implications of projected warming in particular for future ecosystem services, biodiversity and feedbacks to climate. However, although our current understanding of ecological processes and changes driven by climate and UV-B is strong in some geographical areas and in some disciplines, it is weak in others. Even though recently the strength of our predictions has increased dramatically with increased research effort in the Arctic and the introduction of new technologies, our current understanding is still constrained by various uncertainties. The assessment is based on a range of approaches that each have uncertainties, and on data sets that are often far from complete. Uncertainties arise from methodologies and conceptual frameworks, from unpredictable surprises, from lack of validation of models, and from the use of particular scenarios, rather than predictions, of future greenhouse gas emissions and climates. Recommendations to reduce the uncertainties are wide-ranging and relate to all disciplines within the assessment. However, a repeated theme is the critical importance of achieving an adequate spatial and long-term coverage of experiments, observations and monitoring of environmental changes and their impacts throughout the sparsely populated and remote region that is the Arctic.

INTRODUCTION

An assessment of the impacts of changes in climate and UV-B radiation on Arctic terrestrial ecosystems has been made within the Arctic Climate Impacts Assessment (ACIA) (1). The assessment ranged from impacts on individual processes at the organism level, through biodiversity, to ecosystem function and biospheric feedbacks to the regional climate system (2–9). It highlighted the profound implications of projected impacts for future ecosystem services, biodiversity, and climate. However, the assessment is based on a range of approaches that each have uncertainties and data sets that are often far from complete.

Our current understanding of ecological processes and changes driven by climate and UV-B is strong in some geographical areas and in some disciplines, but is weak in others. Although the strength of our predictions has increased dramatically recently with increased research efforts in the Arctic and the introduction of new technologies, our current understanding is still constrained by various uncertainties: here, we focus on these uncertainties, rather than strengths of our knowledge that have been presented within the assessment (2–9), and recommend ways in which our uncertainties can be reduced.

UNCERTAINTIES

Uncertainties Due to Methodologies and Conceptual Frameworks

Uncertainties in methods of predicting impacts of changes in climate and UV-B on species and ecosystems

Each method has advantages and strengths and each has led to the important and extensive current knowledge base. However, each method also has uncertainties which need to be identified so that methods can be refined and uncertainties quantified.

The use of *paleo analogs* to infer future changes underrepresents the differences between past changes and those likely to occur in the future due to *i)* differences in the starting state of the environment and biota; and *ii)* the different nature of past and likely future changes. Major differences are the role of people, e.g. extent of land-use impacts, current and future stratospheric ozone destruction, and transboundary pollution that are probably unprecedented.

Using *geographical analogs* can indicate where communities and species *should* be in a warmer world, but they do not tell us at what rate species can relocate or if new barriers to dispersal such as fragmented habitats will prevent potential distributions from being achieved.

Observations and monitoring provide essential data on changes as they occur and can be used to test hypotheses and model predictions, but they have little predictive power in a changing climate during which many biotic responses are non-linear.

Experiments that simulate future environments of CO_2, UV-B, temperature, precipitation, snow depth and snow duration, etc., all have artifacts, despite attempts to minimize them. It is difficult in field experiments to include simulations of all likely eventualities: in warming experiments, it is very difficult to identify separate effects of seasonal warming and extreme events while most experiments are small in spatial extent, and are short term in the context of the life cycles of Arctic plants and animals. It is also difficult to identify the complex interactions among all the co-occurring environmental change variables and ecological processes determined in experiments in one geographical area may not relate sufficiently to other areas because of different ecological conditions and histories.

Indigenous knowledge, although a valuable contributor to our understanding (see below), is more qualitative than quantitative, and often characterized by relatively coarse measures, i.e. monthly and seasonal change rather than daily or weekly. The information available is sometimes limited to phenomena that fall within the cycle of subsistence resource use, and is more likely to be diachronic (long time series of local information) and not synchronic (simultaneously observed). It is often difficult to assign particular environmental changes to individual changes in biota, to determine mechanisms of change, and distinguish climate-related change from other changes occurring in the environment. Indigenous knowledge is variable between and within communities, and interpretation and verification processes are as important as collection and documentation. It is a knowledge system.

Uncertainties can be reduced when information from several methods converge. The ACIA assessment of climate and UV-B change impacts on terrestrial ecosystems (2–9) accepts all methodologies, knowing their limitations, and qualifies the information we present by the methodologies used to obtain it.

Uncertainties in measuring primary production and controlling factors

Key unknowns about primary productivity in the Arctic include root production and turnover and belowground allocation processes in general, including allocation to mycorrhizae and exudation. Also poorly understood are long-term (multiyear to multidecade) interactions between the C cycle and nutrient cycles, in which relatively slow changes in soil processes and nutrient availability interact with relatively rapid changes in photosynthesis in response to climate change. One major unknown is the control on dispersal, establishment and rate of change in abundance of species and functional types that are not now present or common in Arctic vegetation (e.g. trees and tall shrubs) that are more productive than current Arctic species.

There are two major approaches to assess NEP, *i)* classic weighing of biomass; and *ii)* round year CO_2 flux recording, but these are not always compatible. A particular gap in our estimates is the lateral transport of organic C from one ecosystem to another. The two methodologies give opposite results when accounting for the input of allochtonous OM (organic matter produced outside) to a particular ecosystem: CO_2 flux measurement gives negative NEP due to increased CO_2 emission from soil to atmosphere, while weighing gives a higher accumulation of organic C in the soil. Also, current estimates of buried C released to ecosystems due to soil erosion and thermokarst are poor (see plates 6 and 8 in Callaghan et al. (6)).

Uncertainties due to difficulties in studying microorganisms

We have a limited understanding of microbes that are critically important in many ecosystem processes. Knowledge of microbial diversity and function has been strongly constrained by lack of development in methodology and conceptual frameworks.

Bacteria and even more-advanced microscopic yeast and fungi cannot be characterized by visual observation alone due to their very simple shapes (rods, spheres, filaments). Typically, microbial strains must be cultivated in pure culture to reveal their various functional features and an appreciable amount of laboratory work is required to differentiate a microbe from close relatives. Only a small fraction of soil microorganisms are able to grow on artificial laboratory media, and less than 1% of the cells observed with a microscope form colonies on the plate. The main reasons for this "Great Plate Count Anomaly" (10) include *i*) metabolic stress of 'famine-to-feast' transition occurring when cells are brought from soil to artificial, nutrient rich media; *ii*) inadequacy of cultivation conditions compared with the natural environment; and *iii*) metabiotic interactions/cooperation in natural communities that are broken after cells have been separated by plating (11). This technical problem has resulted in an underestimation of diversity in natural habitats. Fortunately, new cultivation approaches are being developed that are helping to overcome this problem (12). However, it is not presently possible to make a fair comparison between the numbers of species of animals and plants *versus* bacteria given that these groups are defined differently (13).

Uncertainties due to incomplete databases

Length of time series of data. Although many long time series of relevant data, e.g. on species performance and phenology, exist, most information relates to short time series. This is a particular problem in the Arctic where complex population dynamics (e.g. cycles) need to be understood over periods long enough to allow trends to be separated from underlying natural dynamics. Also, observations of trace gas emissions require annual observations over time periods long enough to encompass significant climate variability. Experiments are usually too brief to capture stable responses to environmental manipulations and to avoid artifacts that are disturbance responses. Long time series of data are also necessary in order to identify extreme events and nonlinear system changes.

Geographical coverage and spatial scaling. The ecosystems and environments in the Arctic are surprisingly variable yet generalizations to the circumpolar Arctic are often made from few plot level studies. Sometimes, particular experiments, for example CO_2 and UV-B manipulations or observations are restricted to a few m^2 of tundra at just one or two sites. Uncertainties due to generalizing and scaling-up are thus significant. The International Biological Programme (IBP: 1960s and early 1970s) and the International Tundra Experiment (ITEX) are exceptional examples of how standardized experiments and observations can be implemented throughout the Arctic.

Coverage of species and taxa. Chapin and Shaver (14) and others have demonstrated the individualistic responses of species to experimental environmental manipulations, including climate, while Dormann and Woodin (15) have shown the inadequacy of the concept of "plant functional types" to generalize plant responses to such experiments. An approach has to be adopted to measure responses of a relevant range of species to changes in climate, and particularly UV-B. Plants studied were generally at their northernmost distributional limits and well adapted to high UV-B levels characteristic of southern parts of their ranges. Greater responses would be expected from species at their southern distributional limits where increased UV-B would exceed levels in the plants' recent "memory".

Some species and taxonomic groups are particularly difficult to study, or have little socioeconomic value, and so are underrepresented in databases. Examples are mosses, lichens, soil fauna and flora, and microorganisms (see below).

Uncertainties due to nomenclature and concepts

The restricted use of appropriate language often generates uncertainties. The nomenclature of vegetation and plant community types allows us to model changes in the *distribution* of these assemblages of species in a changed climate, but constrains our understanding of changes in the *structure* of the assemblages which is likely to happen because assemblages, of species do not move *en bloc.* This problem limits our understanding of novel future communities (16) and non-analogue communities of the past and emphasizes the uncertainties due to the lack of ability of quantitative models to predict qualitative changes in systems. Similarly, the concept of "line" to denote the limit of species' distributions such as treeline, is inadequate to express the gradient of changes from one zone to another that can occur over tens of kilometers.

The concept of "species" is particularly difficult in the context of microorganisms as discussed above, and even as applied to flowering plants. The traditional view that there are few rare and endemic Arctic plant species is challenged by recent studies of the flora of Wrangel Island and Beringia (Table 1 in Callaghan et al. (9)) but it is not known to what degree plant taxonomy is problematic (although the Pan Arctic Flora Project is addressing this problem). Such problems need to be resolved before we can assess the impacts of climate change on biodiversity.

Uncertainties Due to Surprises

Perhaps the only certainty in our assessment of impacts of changes in climate and UV on terrestrial ecosystems is that there will be surprises. It is difficult by definition to predict surprises. However, the possibility that climate *cooling* will occur because of a change in thermohaline circulation, is potentially the most dramatic surprise that could occur.

Regional cooling
The potential for a negative feedback arising from an increased freshwater flux to the GIN (Greenland, Icelandic and Norwegian) seas and Arctic basin, leading to a consequent partial or complete shut down of the thermohaline circulation of the global oceans, remains an area of considerable uncertainty; (Chapters 6 and 9 in ACIA (1)). Such an event would lead to marked and rapid regional cooling in at least Northwestern Europe. This region at present enjoys an anomalously warm climate given its latitude (50–72°N), enabling agriculture to be practiced and substantial settlements maintained at far higher latitudes than in any other Arctic/sub-Arctic region. Such cooling would qualitatively alter terrestrial ecosystems (17), agriculture and forestry over very large areas of Fennoscandia and Europe.

Mutations
Mutations are expected from UV radiation and also from aerosols and volatile chemical mutagens brought to the cool polar air from the mid- and low latitudes. The direct mutagenic effect is probably not strong, especially if we take into account the protecting shielding effects of soil particles and adaptive mechanisms discussed above. However, possible microbial mutants could lead to epidemic outbreaks that could have profound and unexpected consequences for the Arctic and elsewhere.

Desertification
Several approaches suggest an increase in productivity of Arctic vegetation with climate warming and a long-term net sequestration of CO_2. However, the complex interactions among warming, permafrost dynamics, hydrology, precipitation and soil type are generally lacking from our understanding. Desertification is a plausible outcome in some areas where scenarios suggest that warming will occur, permafrost will thaw, drainage will increase, and precipitation will *not* increase substantially. In areas of sandy soil and loess deposition, such as areas of eastern Siberia, there is a particular risk of desertification. In the polar deserts, herb barrens and heaths of northern Greenland, plant productivity is strongly correlated with precipitation and increased evapotranspiration could lead to a similar process (18). Locally, impacts of overgrazing and disturbance through human impacts can accelerate the process. A clear example of the effect of warming and drying on Alaskan tundra carbon balance is shown in Callaghan et al. (7), but the possible wider geographical scale of this process is unknown.

Changes in current distributions of widespread and rare species
Climate change could have counter-intuitive impacts on species distributions. Currently rare Arctic plant species, particularly those that are northern outliers of species with more southerly distributions, could expand during initial phases of climate warming. In contrast, currently widespread species, particularly lichens and mosses, could become more restricted in their abundance during warming. It is necessary to reassess the concept of ”threatened species” in the context of climate and UV change (9; Chapter 11 in ACIA (1)).

Uncertainties Due to Lack of Validation of Models

During the IBP period (late 1960s early 1970s) tundra research was characterized by extensive field observations but a general lack of modeling capability. Currently, a technological revolution has stimulated model generation and remote sensing of ecosystem change. However, in some cases, validation is insufficient. Models that predict NPP at a global or circum-Arctic level are insufficiently validated as recent measurements of NPP are rare and restricted to few localities. Also, lack of intercomparison between models and existing observations lead to potential errors in prediction: modeled displacement of the tundra by the boreal forest currently fails to relate to current observations of the southward retreat of the treeline in some areas and the expansion of “pseudotundra” in parts of Russia due to permafrost degradation, paludification and human activities.

Uncertainties Due to the Use of ACIA Scenarios

The future climate scenarios for ACIA were the B2 scenarios, but A2 scenarios have been used to a limited extent as a plausible alternative (19) (Chapter 1 in ACIA (1)). A2 scenarios have a greater economic emphasis, while B2 scenarios have a greater emphasis on environmental concerns: each has considerable uncertainties (Chapter 4 in ACIA (1)). In the present chapter, the B2 scenarios were mainly used to model changes in vegetation and carbon storage. Use of A2 scenarios would have resulted in higher temperatures than for those of B2 runs for a particular time period. The A2 changes would occur earlier by 5–10 years for the time slice 2050 and by 10–20 years for time slice 2080. Potential impacts on ecosystems would thus occur faster.

The major implication for ecosystems of a faster rate of temperature change is an increased mismatch between the rate of habitat change and the rate at which species can relocate to occupy new habitats in appropriate climate envelopes. The overall, generalized, difference between the B2 and A2 scenarios would be an increased risk of disturbance and disease in species that, under the A2 scenario, cannot relocate quickly enough. There would also be an increased mismatch between initial stimulation of soil respiration and longer-term vegetation feedbacks that would reduce carbon fluxes to the atmosphere under an A2 scenario.

The present-day climate simulated by GCMs is not yet good enough to use directly to drive a biosphere model, therefore the anomaly approach was used within the biosphere model (20). Data were downscaled from the GCM specific grid onto one at 0.5° resolution and GCM climate anomalies were normalized to the 1961–1990 observed average monthly CRU climatology (CRU CL 1.0; 21).

RECOMMENDATIONS TO REDUCE UNCERTAINTIES

Thematic Recommendations and Justification

The following section contains important thematic topics that require particular research. For each topic, we summarize the state of knowledge and important gaps, and give recommendations to fill these gaps (italicized text).

Mechanisms of species responses to changes in climate and UV-B. Changes in microbe, animal and plant populations are triggered by trends in climate and UV, exceeding thresholds and by extreme events, particularly during winter. However, information is uneven and dominated by trends in summer climate.

We need appropriate scenarios of extreme events and to deploy long-term experiments simulating extreme events and future winter processes in particular. We also need a better understanding of thresholds relevant to biological processes.

Biodiversity changes. Some groups of species are very likely to be at risk from climate change impacts, and the biodiversity of particular geographic areas such as Beringia are at particular risk. We do not know if currently threatened species might proliferate under future warming or which currently widespread species might decrease in abundance.

We need to reassess the nature of threats to species, including microbes, from long-term climate and UV-B change simulation experiments. We also need to identify and monitor currently widespread species that are likely to decline under climate change, and to redefine conservation and protection in the context of climate and UV change.

Relocation of species. The dominant response of current Arctic species to climate change, as in the past, is very probably relocation rather than adaptation. Relocation possibilities are very likely to vary according to region and geographical barriers. Some changes are already occurring. However, our knowledge of rates of relocation, impact of geographical barriers, and current changes is poor.

We need to measure and predict rates of species migration by combining paleo-ecological information with observations from indigenous knowledge, environmental and biodiversity monitoring and experimental manipulations of environment and species.

Vegetation zone redistribution. Forest is very likely to replace a significant proportion of the tundra and will very probably have a great effect on the composition of species. However, several processes including land use and permafrost dynamics are expected to modify the modeled response of vegetation redistribution related to warming.

We need to develop and link models of climate, hydrology (permafrost), ecosystems and land use. These models need to be based on improved information on the current boundaries of major vegetation zones, defined and recorded using standardized protocols.

Carbon sinks and sources in the Arctic. Current models suggest that the Arctic's vegetation and active-layer soils will be a sink for carbon in the long-term because of the northward movement of vegetation zones that are more productive than those they displace. Model output needs to be reconciled with observations that show that tundra C source areas currently exceed C sink areas, although the measurements of circum-Arctic C balance are very incomplete. Also, it is not known to what extent disturbance will reduce the C sink strength of the Arctic.

We need to establish long-term, annual carbon monitoring throughout the Arctic; to develop models capable of scaling ecosystem processes from plot experiments to landscapes; to develop observatories, experiments and models to relate disturbance such as desertification to carbon dynamics; to improve the geographical balance of observations by increasing high Arctic measurements. We also need to combine estimates of ecosystem carbon flux with estimates of carbon flux from thawing permafrost and methane hydrates.

UV-B and CO_2 impacts. Enhanced CO_2 and UV-B have subtle but long-term impacts on ecosystem processes that reduce nutrient cycling with the potential to decrease productivity. However, these are generalizations from very few plot-scale experiments, and it is difficult to understand impacts that include large herbivores and shrubs.

We need long-term experiments on CO_2 and UV-B effects on a range of Arctic ecosystems interacting with climate; short-term experiments stimulating repeated episodes of high UV exposure; long-term experiments that determine the consequences of high CO_2 and UV-B for herbivores and short-term screening trials to identify the sensitivity of a wide range of species, including soil microbes, to current and predicted UV-B levels.

Local and regional feedbacks. Displacement of tundra by forest will very probably lead to a decrease in albedo with a potential for local warming whereas carbon sequestration will probably increase with potential impacts on global greenhouse gas concentration. However, the timing of the processes and the balance between the processes are very uncertain. How local factors such as land use, disturbance, tree type and possible desertification will affect the balance, are also uncertain.

We need long-term and annual empirical measurements, analysis of past remotely sensed images and collection of new images together with the development and application of new models that include land use, disturbance and permafrost dynamics.

Recommendations for Future Approaches to Research and Monitoring

No one approach is adequate and confidence is increased when results from different approaches converge (2). We recommend the maintenance of current approaches and development of new approaches and even paradigms, for example when defining "threatened species" and "protected areas". Some important approaches are highlighted below.

Reducing uncertainty by increasing and extending the use of indigenous knowledge

Arctic indigenous peoples retain strong ties to the land through subsistence economies and they are "active participants" in ecosystems (*sensu* 22). Unlike a scientist, a hunter is not bound in his observations by a project time line, budget, seasonality, or logistical constraint (23, 24). Subsistence activities occur on a daily basis, year after year, and throughout the winter period when many scientists are south in home institutions. Indigenous peoples of Arctic regions therefore possess a substantial body of knowledge and expertise related to both biological and environmental phenomena. Such local expertise can highlight qualitative changes in the environment and provide pictures of regional variability across Arctic regions that are difficult to capture using coarser scaled models.

We present some of the first efforts at linking western science and IK to expand the range of approaches that inform the current assessment. However, the potential is far greater including for example local scale expertise, information on climate history, generation of research hypotheses, community monitoring and community adaptation (24).

Monitoring

Long term environmental and biological monitoring have been undervalued but are becoming increasingly necessary to detect change, to validate model predictions and results from experiments, and to substantiate measurements made from remote sensing. Present monitoring programs and initiatives are too scarce and are scattered randomly. Data from the Arctic on many topics are often not based on organized monitoring schemes, are geographically biased and are not long-term enough to detect changes in: - species' ranges, natural habitats, animal population cycles, vegetation distribution, and carbon balance. More networks of standardized, long-term monitoring sites are required to better represent environmental and ecosystem variability in the Arctic and particularly sensitive habitats. Because there are interactions among many co-varying environmental variables, monitoring programs should be integrated. Observatories should have the ability to facilitate campaigns to validate output from models or ground-truth observations from remote sensing. There should be collaboration with indigenous and other local peoples' monitoring networks where relevant. It would be advantageous to create a decentralized and distributed, ideally web-based meta-database from the monitoring and campaign results, including relevant indigenous knowledge.

Monitoring also requires institutions, not necessarily sited in the Arctic, to process remotely-sensed data. Much information from satellite and aerial photographs exists already on vegetation change, such as treeline displacement, and on disturbances such as reindeer overgrazing and insect outbreaks. However, relatively little information has been extracted and analyzed.

Monitoring carbon fluxes has gained increased significance since the signing of the Kyoto Protocol. Past temporal- and spatial-scales of measurement used to directly measure carbon flux have been a poor match for the larger scale of Arctic ecosystem modeling and extrapolation. It remains a challenge to determine if flux measurements and model output are complementary. The technological difficulties in extrapolating many nonlinear, complex, interacting factors that comprise fluxes at hundreds to thousands of square kilometers over time, space, and levels of biological and environmental organization in the Arctic have been significant (25, 26). Research is needed to better understand how the complex system behavior at the meter-scale relate to larger spatial scales that can be efficiently modeled and evaluated at the regional and circumpolar scale. To do this, extensive long-term and year-round eddy covariance sites and other long-term flux sites, including repeated aircraft flux measurements and remote sensing (27) provide the basis for estimating pan-Arctic net ecosystem CO_2 exchanges. Currently, the pan-Arctic region is disproportionately covered by current and recent measurements, with Canadian and high-Arctic regions particularly poorly represented.

Long-term and year-round approach to observations and experiments

Many observations and experiments are short term (< 5 years) and they are biased towards the summer period often because of commitments of researchers to institutions outside the Arctic during wintertime. However, throughout this assessment (2–9) it has become clear that long-term and year-round measurements and experiments are essential to our understanding of the slow and complex responses of Arctic organisms and ecosystems to climate change.

Long-term (> 10 years) observations and experiments are required to:
– enable transient responses to be separated from possible equilibrium responses;
– increase the chances that disturbances, extreme events and significant inter-annual variation in weather can be included in the observations;
– allow possible thresholds for responses to be experienced.

Year-round observations are necessary to understand the importance of winter processes in determining the survival of Arctic species and the function of Arctic ecosystems. Such observations are necessary to recognize the expected amplification of climate warming in wintertime and to redress the current bias of experiments to summer-only warming. For microbes, it is particularly important to understand changes in winter respiration and nutrient mobilizations during freeze-thaw in spring and late autumn.

It is important to improve the appropriateness of the timing of our observations and experiments. For example, current information on impacts of increased UV-B is mainly derived from general summer enhancements or filtration of UV-B although future increases in UV-B are likely to be highest in spring and during specific events. Also, frequency of observations can be fitted to the rate of change of the species/processes. Decadal measurement may suffice for some variables such as treeline movement.

Increasing the complexity and scale of environmental and ecosystem manipulation experiments

Single factor manipulation experiments now have limited applicability because it is clear that there are many interactive affects among co-occurring environmental change variables. There is need for well-designed large, *mutifactorial* environmental (e.g. climate, UV-B and CO_2) *and* ecosystem manipulation (e.g. species removal and addition) experiments that are long term and seek to understand annual, seasonal and event-based impacts of changing environments. The complexity of appropriate treatments and time scales is vast but the spatial scale is also a significant challenge as it is important to have manipulations that can be related to larger plants (e.g. trees, shrubs) and animals (e.g. reindeer).

Assessing the impacts of cooling on ecosystems

Warming scenarios dominate the approaches of predicting responses of ecosystems to future climates. However, cooling in some areas remains a possibility. As the impacts of cooling on terrestrial ecosystems and their services to people are likely to be far more dramatic than warming, it is timely to reassess the probabilities of cooling from GCMs and the appropriateness of assessing cooling impacts on ecosystems.

Modeling responses of Arctic ecosystems to climate and UV-B change and communicating results at appropriate geographical scales

High resolution models are needed at the landscape scale for a range of landscape types that are expected to experience different future envelopes of climate and UV-B. Modeling at the landscape-scale will simulate local changes that relate to plot scale experiments and can be validated by results of experiments and field observations. Also, visualization of model results presented at the landscape-scale will enhance the understanding of the changes and their implications by local peoples and decision-makers. A particular challenge is to provide scenarios for changes in climate and UV-B at the scale of tens of meters.

FUNDING REQUIREMENTS

It is inappropriate here to comment on levels of funding required to fulfill the recommendations discussed above. However, it is appropriate to highlight two essential aspects of funding.

i) Current short-term funding is inappropriate to support research into long-term processes such as ecosystem responses to climate change and UV-B impacts.

A stable commitment to long-term funding is necessary.

ii) Funding possibilities that are restricted to single nations or at best few nations, make it extremely difficult to implement coordinated research that covers the variability in ecosystems and expected climate change throughout the circumpolar north, even though the instruments for coordination exist for example within IASC, ICSU, IGBP. Limitation of international funding possibilities leads to geographical biases and gaps in important information.

Circum-Arctic funding is required so that coordinated projects can operate at geographically appropriate sites over the same time periods.

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