Rationale, concepts and approach to the assessment

Callaghan, Terry V.; Björn, Lars Olof; Chernov, Yuri; Chapin, Terry; Christensen, Torben; Huntley, Brian; Ims, Rolf A.; Johansson, Margareta; Jolly, Dyanna; Jonasson, Sven; Matveyeva, Nadya; Panikov, Nicolai; Oechel, Walter; Shaver, Gus

Published in: Ambio

DOI: 10.1639/0044-7447%282004%29033%5B0393%3ARCAATT%5D2.0.CO%3B2

Published: 2004-01-01

Citation for published version (APA):
Callaghan, T. V., Björn, L. O., Chernov, Y., Chapin, T., Christensen, T., Huntley, B., ... Shaver, G. (2004). Rationale, concepts and approach to the assessment. Ambio, 33(7), 393-397. DOI: 10.1639/0044-7447%282004%29033%5B0393%3ARCAATT%5D2.0.CO%3B2
INTRODUCTION

A general recognition that the Arctic will amplify global climate warming, that UV-B radiation may continue to increase there because of possible delays in the repair of stratospheric ozone, and that the Arctic environment and its peoples are likely to be particularly susceptible to such environmental changes stimulated an international assessment of climate change impacts. The Arctic Climate Impacts Assessment (ACIA) is a four-year study, culminating in publication of a major scientific report (1) as well as other products. In this paper and those following in this Ambio Special Issue, we present the findings of the section of the report that focuses on terrestrial ecosystems of the Arctic, from the treeline ecotone to the polar deserts.

The Arctic is generally recognized as a treeless wilderness with cold winters and cool summers. However, definitions of the southern boundary vary according to environmental, geographical or political biases. This paper and the assessment in the following papers of this Ambio Special Issue focus on biota (plants, animals and microorganisms) and processes in the region beyond the northern limit of the closed forest (the taiga), but we also include processes south of this boundary that affect ecosystems in the Arctic. Examples are overwintering periods of migratory animals spent in the south and the regulation of the latitudinal treeline. The geographical area we have defined as the current Arctic is the area we use for developing scenarios of future impacts: Our geographical area of interest will not decrease under a scenario of the replacement of current Arctic tundra by boreal forests.

CHARACTERISTICS OF ARCTIC TUNDRA AND POLAR DESERT ECOSYSTEMS

The southern boundary of the circumpolar Arctic is the northern extent of the closed boreal forests. There is not a clear boundary but a transition from South to North consisting of the sequence: closed forest → forest with patches of tundra → tundra with patches of forest → tundra (2). The transition zone is relatively narrow (30–150 km) when compared with the forest and tundra zones in many, but not all, areas. Superimposed on the latitudinal zonation is an altitudinal zonation from forest to treeless areas to barren ground in some mountainous regions of the northern taiga. The transition zone from taiga to tundra stretches for more than 13400 km around the lands of the Northern Hemisphere and is one of the most important environmental transition zones on Earth (3, 4), as it represents a strong temperature threshold close to an area of low temperatures. The zone has been called forest tundra, sub-Arctic and the tundra-taiga boundary or ecotone. Vegetationally, it is characterized as an open landscape with patches of trees that have low stature and dense thickets of shrubs that together with the trees totally cover the ground surface.

The environmental definition of the Arctic does not correspond with the geographical zone delimited by the Arctic Circle at 66.5°N latitude, nor political definitions. Cold waters in ocean currents flowing southwards from the Arctic depress the temperatures in Greenland and the eastern Canadian Arctic whereas the northwards flowing Gulf Stream warms the northern landmasses of Europe. Thus, at the extremes, polar bears and tundra are found at 51°N in eastern Canada, whereas agriculture is practiced beyond 69°N in Norway. Arctic lands span some 20° of latitude reaching 84°N in Greenland and locally, in eastern Canada, an extreme southern limit of 51°N.

The climate of the Arctic is largely determined by the relatively low angles of the sun to the Earth. Differences in photoperiod between summer and winter become more extreme towards the North. Beyond the Arctic Circle (66.5°N), the sun remains above the horizon at midnight on midsummer’s day and remains below the horizon at midday on midwinter’s day.

Climatically, the Arctic is often defined as the area where the average temperature for the warmest month is lower than 10°C (5) but mean annual air temperatures vary greatly according to location, even at the same latitude. They vary from –12.2°C at Point Barrow, Alaska (71.3°N) to –28.1°C at the summit of the Greenland ice sheet (about 71°N) (6) and from 1.5°C at 52°N in sub-Arctic Canada to 8.9°C at 52°N in temperate Europe. The summer period progressively decreases from about 3.5 to 1.5 months from the southern boundary of the Arctic to the North, and mean July temperature decreases from 10–12°C to 1.5°C. In general, precipitation in the Arctic is low, decreasing from about 250 mm in the South to as low as 45 mm per year in the polar deserts of the north (7), with extreme precipitation amounts in maritime areas of the sub-Arctic, for example 1100 mm at 68°N in Norway. However, the Arctic cannot be considered to be arid because of low rates of evaporation: even in the polar deserts, air humidity is high and the soils are moist during the short growth period (8). The word “desert” refers to extreme poverty of life.

The Arctic is characterized by the presence of continuous permafrost, although there are exceptions such as the Kola Peninsula. Continuous, and deep (more than 200 m) permafrost is also characteristic south of the treeline in large areas of Siberia that reach to Mongolia. The depth of the soil’s active layer during the growing season depends on summer temperatures and varies from about 80 cm close to the treeline to about 40 cm in polar deserts. However, active layer depth varies according to local conditions within landscapes according to topography: it can reach 120 cm on south-facing slopes and be as little as 30 cm in bogs, even in the South of the tundra zone. In many areas of the Arctic, continuous permafrost becomes deeper and degrades into discontinuous permafrost in the South of the zone. Active layer depth, decreases in the extent of discontinuous permafrost and coastal permafrost will be particularly sensitive to climatic warming. Permafrost and active layer dynamics lead to patterning, such as polygons, in the landscape. Topography plays an important role in defining habitats in terms of moisture and temperature as well as active layer dynamics (9, 10) so that Arctic
landscapes are a mosaic of microenvironments. Topographic differences of even a few tens of cm are important for determining habitats, for example polygon rims and centers, whereas greater topographical differences of meters to tens of meters determine wind exposure and snow accumulation which in turn affect plant communities and animal distribution (11). Topographical differences become more important as latitude increases.

Ecosystem disturbances are characteristic of the Arctic. Mechanical disturbances include thermokarst through permafrost thaw, freeze-thaw processes, wind, sand and ice-blasts, seasonal ice oscillations, slope processes, snow load, flooding during thaw, changes in river volume and coastal erosion and flooding. Biological disturbances include insect pest outbreaks, peaks of grazing animals that have cyclic populations, and fire. These disturbances operate at various geographical and time scales (Fig. 1) and affect the colonization and survival of organisms and thus ecosystem development.

Arctic lands are extensive beyond the northern limit of the tundra-taiga ecotone where, according to the classification of Bliss and Matveeva (12) they amount to about 7 567 000 km². They cover about 2 560 000 km² of the former Soviet Union and Scandinavia, 2 480 000 km² in Canada, 2 167 000 km² in Greenland and Iceland, and 360 000 km² in Alaska (12). Figure 2, which is based on a classification of Walker (13) and mapped by Kaplan et al. (14), shows the distribution of Arctic and other vegetation types (this can be compared with a recent vegeta-

Figure 1. Schematic timescale of ecological processes in relation to disturbances in the Arctic. The schematic does not show responses expected due to anthropogenic climate change (based on Forbes et al. (30), Oechel and Billings (50), Shaver et al. (51)).

Figure 2. Present day natural vegetation of the Arctic and neighboring regions from floristic surveys. Vegetation types 1–5 are classified as Arctic, whereas types 6–8 are classified as boreal forest (modified from Kaplan et al. (14)).
most Finnmark, Norway, had been settled (20). Even earlier palaeolithic settlements (ca. 40,000 years BP) have been recorded from the eastern European Arctic (21). The impacts these peoples had on terrestrial ecosystems are difficult to assess but were likely to be small given their hunter-gatherer way of life and small populations. The prey species hunted by these peoples included the megafauna, such as the woolly mammoth, which became extinct. The extent to which hunting may have been principally responsible for these extinctions is a matter of continuing debate (22) but this possibility cannot be excluded (23). It is also uncertain to what extent the extinction of the megafauna may have contributed to, or been at least in part a result of, the accelerated northward movement of trees and shrubs, and consequent changes in vegetation structure (see ref. 2 and references therein). Although estimates of the population density of megafaunal species are fraught with uncertainties, it seems unlikely that these species were sufficient to constrain the spread of woody taxa in response to favorable environmental change.

During the last 1000 years, resources from terrestrial ecosystems have been central to the mixed economies of Arctic regions: many inland indigenous communities still derive most of their income from terrestrial ecosystems and their success in the Arctic determines their roles at lower latitudes (11). Physical and biogeochemical processes in the Arctic affect atmospheric circulation and the climate of regions beyond the Arctic (33). We know that ecosystems have responded to past environmental changes in the Arctic, we also know that current environmental changes are occurring (6, 34, 35). This understanding indicates that there will be future responses of Arctic ecosystems to changes in climate and UV radiation.
RATIONALITY FOR THE SPECIAL ISSUE

The effects of climate are specific to species, age/developmental stages of individuals and processes from metabolism to evolution (Fig. 1). Although there are many ways in which to organize an assessment of climate and UV-B impacts, throughout this Ambio Special Issue we follow a logical hierarchy of increasing organizational biological complexity to assess impacts on species, the structure of ecosystems, the function of ecosystems, and landscape and regional processes. A basic understanding of biological processes related to climate and UV-B radiation is required before we can assess impacts of changes in climate and UV-B on terrestrial ecosystems (44). Consequently, the structure of the Special Report progresses from a review of climate and UV controls on biological processes to an assessment of potential impacts of changes in climate and UV-B on processes at the species and regional levels. Some effects of climate change on ecosystems may be beneficial to people, while others may be harmful.

The changes in climate and UV-B that we use to assess biological impacts are of 2 types: i) those already documented; and ii) those established from scenarios of UV-B and climate derived from Global Climate Models (GCMs) (1). We know that mean annual and seasonal temperatures have varied considerably in the Arctic since 1965 (6). Western parts of North America and central Siberia have warmed by about 1.2°C (mean annual temperature and up to 2°C in winter) per decade while West Greenland and the eastern Canadian Arctic have cooled to the same extent.

Fennoscandia has seen little warming (about 1°C in the West to almost 0°C in the East (45)) over the past century. Precipitation has also changed. The duration of the snow-free period at high northern latitudes has increased by 5–6 days per decade and the week of the last observed snow cover in spring has become earlier by 3–5 days per decade over the period 1972–2000 (34). Stratospheric ozone has been depleted over recent decades, for example by a maximum of 45% below normal in the high Arctic in spring (35). This has probably led to an increase in UV-B radiation reaching the Arctic’s surface, although the measure of environmental change.

STRENGTHS, LIMITATIONS AND UNCERTAINTIES

APPROACHES USED FOR THE ASSESSMENT: STRENGTHS, LIMITATIONS AND UNCERTAINTIES

In the following papers in this Ambio Special Issue, we assess information on interactions between climate/UV-B radiation and ecosystems based on a wide range of sources derived from experimental manipulations of ecosystems and environments in the field; laboratory experiments; monitoring and observation of biological processes in the field; conceptual modeling using past relationships between climate and biota (paleo-analogs); and current relationships between climate and biota in different geographical areas (geographical analogs) to infer future relationships; and process-based mathematical modeling. Where possible, we include indigenous knowledge (limited to published sources) as an additional source of observational evidence.

We recognize that each method has uncertainties and strengths (49). By considering and comparing different types of information we hope to have achieved a more robust assessment. However, the only certainties of our assessment are that there are various levels of uncertainty in our predictions and that even if we try to estimate the magnitude of these effects, small changes in processes and their species to changes in climate and UV-B radiation are certain to occur.

References and Notes


---

**Terry Chaplin**
Institute of Arctic Biology
University of Alaska Fairbanks, AK 99775, USA
terry.chaplin@uaf.edu

**Torben Christensen**
Department of Physical Geography and Ecosystem Analysis
GeoBiobase Science Centre
Lund University, Sweden
torben.christensen@nateko.lu.se

**Brian Huntley**
School of Biological and Biomedical Sciences
University of Durham, UK
brian.huntley@durham.ac.uk

**Rolf A. Ism**
Institute of Biology
University of Tromsø
N-9037 Tromsø, Norway
ra.ism@bio.uio.no

**Margareta Johansson**
Abisko Scientific Research Station
Abisko SE 981-07, Sweden
schantran@ans.kiruna.se

---

**Terry V. Callaghan**
Abisko Scientific Research Station
Abisko, SE 981-07, Sweden
terry.callaghan@ans.kiruna.se

**Lars Olof Björn**
Department of Cell and Organism Biology
Lund University, Silvövägen 35
Lund, SE-22362, Sweden
lars_olof.bjorn@cob.lu.se

**Yuri Chernov**
A.N. Severtsov Institute of Evolutionary Morphology and Animal Ecology
Russian Academy of Sciences
Starmorenyom per. 29
Moscow, 109017, Russia
lsdc@e.ru