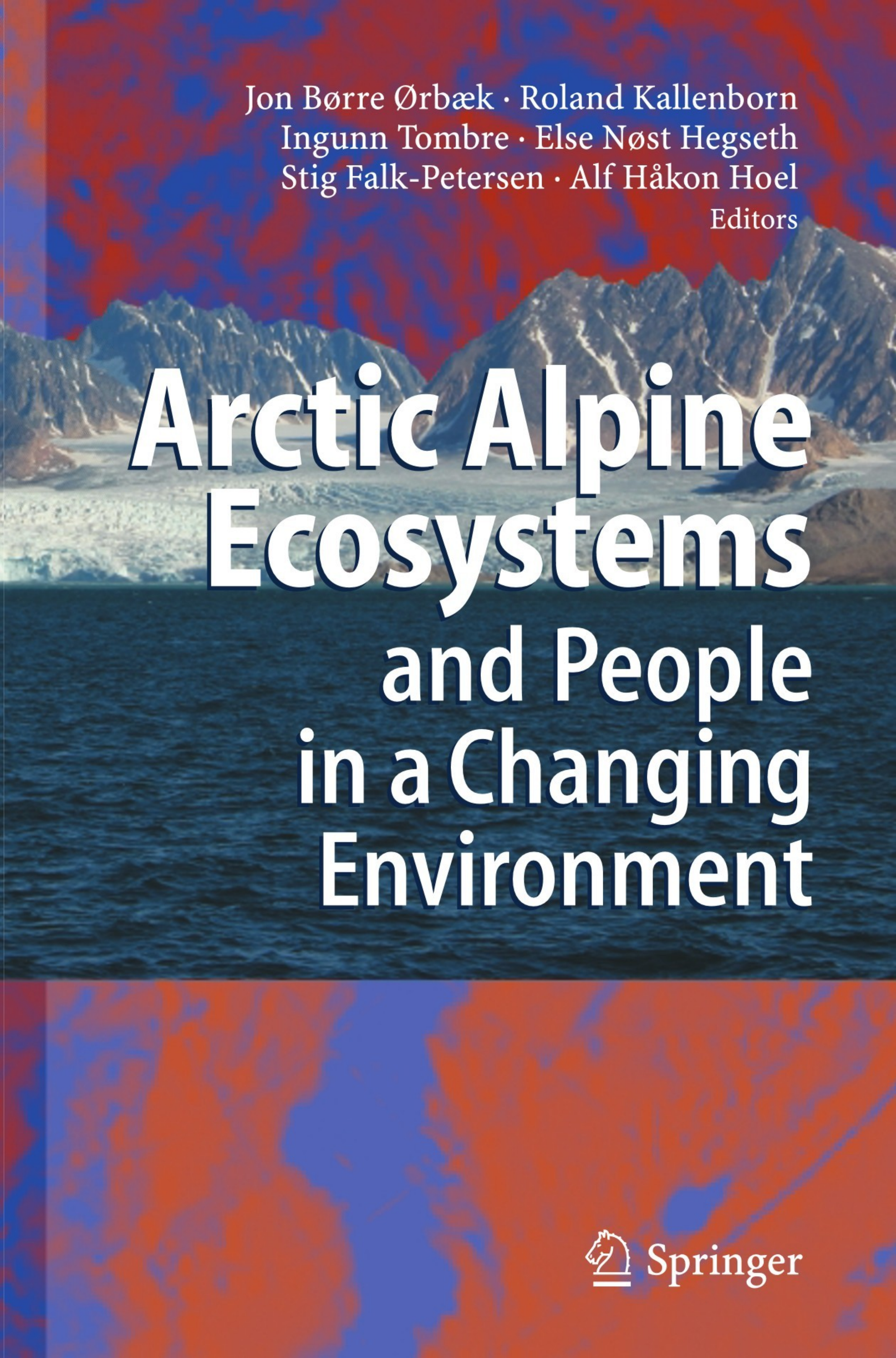

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Arctic Alpine Ecosystems and People in a Changing Environment

with 86 Figures and 10 Tables

Springer

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Preface

This book addresses the significant environmental changes experienced by high latitude and high altitude ecosystems at the beginning of the 21st century. Increased temperatures and precipitation, reduction in sea ice and glacier ice, the increased levels of UV-radiation and the long-range transported contaminants in arctic and alpine regions are stress factors that challenge terrestrial and aquatic ecosystems. The large natural variation in the physical parameters of these extreme environments is a key factor in structuring the biodiversity and biotic productivity, and the effect of the new stress factors can be critical for the population structures and the interaction between species. These changes may also have socio-economic effects if the changes affect the bio-production, which form the basis for the marine and terrestrial food chains.

The book is uniquely multidisciplinary and provides examples of various aspects of contemporary environmental change in arctic and alpine regions. The 21 chapters of the book are organised under the fields of •Climate change and ecosystem response, •Long range transport of pollutants and ecological impacts, and •UV radiation and biological effects, each also including aspects of the •Socio-economic effects of environmental change. The introductory chapter presents and explains the internal connection and integration of all chapters. The added value of these reviews and review-like manuscripts from different disciplines hopefully yields new information about the integrated aspects of environmental change.

The chapters are written on the basis of manuscripts presented at the international conference on “Arctic Alpine Ecosystems and People in a Changing Environment”, organized in Tromsø, Norway in February 2003. The conference was multidisciplinary in scope, aiming at creating new links and understandings across disciplinary boundaries and among researchers and research infrastructures, inviting the international marine, terrestrial and atmospheric environmental change research communities to meet and exchange recent research and monitoring results. The emphasis was on the European arctic and alpine environments. The conference was organized as a EURO-CONFERENCE supported by the European Commission. It also served as the final conference of the European Network for Arctic-Alpine Multidisciplinary Environmental Research (ENVINET), the final conference of the Nordic Arctic Research Programme (NARP), the last user meeting of the Ny-Ålesund Large Scale Facility, the first conference of the Arctic Seas Consortium and the final workshop of the EU-project UVAC (The influence of UV-radiation and climate conditions on fish stocks).

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•EUROCONFERENCE: High Level Scientific Conferences, European Commission IHP-programme, Contract HPCF-CT-2002-00238, •ENVINET: European Network for Arctic-Alpine Multidisciplinary Environmental Research, European Commission IHP-programme, Contract HPRI-CT-1999-40009. •NARP: Nordic Arctic Research Programme, Nordic Council of Ministers, •Ny-Ålesund LSF: Ny-Ålesund Large Scale Facility for Arctic Environmental Research, European Commission IHP-programme, Contract HPRI-CT-1999-00057, •UVAC: The influence of UV-radiation and climate conditions on fish stocks: A case study of the north-east Arctic cod, European Commission Environment-programme, Contract EVK3-CT-1999-00012, •Norwegian Ministry of Environment, •The University of Tromsø, including the Department of Political Science and the Norwegian College of Fishery Science, •Institute of Marine Research, Tromsø and the •Polar Environmental Centre, Tromsø, including the Norwegian Polar Institute, Norwegian Institute for Nature Research and Norwegian Institute of Air Research.

The editors wish to thank all authors and co-authors for their valuable set of complementary and multidisciplinary chapters, which together hopefully will add value to the reflection of the integrated scientific questions and environmental challenges faced by arctic-alpine environments. We would also like to thank the many reviewers that have provided valuable comments and advice to all manuscripts, as well as Mrs. Ingrid Storhaug for her very competent assistance in editing this volume.

Tromsø 2005, on behalf of the editors
Jon Børre Ørbæk, Norwegian Polar Institute

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Abbreviations

AARI	Arctic and Antarctic Research Institute
ACIA	Arctic Climate Impact Assessment
Ah	Aryl hydrocarbon receptor
AHDR	Arctic Human Development Report
Alt	Altitude (in meters above sea level - a.s.l.)
AMAP	Arctic Monitoring and Assessment Programme
AMOC	Atlantic meridional overturning circulation
AMOUR	Assessment Model for UV-radiation and Risks
AO	Arctic Oscillation
AOGCM	Atmosphere-Ocean General Circulation Model
a.s.l.	Above sea level
AVHRR	Advanced Very High Resolution Radiometer
AW	Atlantic Water
BCC	Basal Cell Carcinoma
BFR	Brominated flame retardant
BP	Before present
BWF	Biological weighting factor which expresses the relative damage incurred by exposure to UV radiation
CACAR	NCPs Canadian Arctic Contaminants Assessment Report
CAFF	Conservation of Arctic Flora and Fauna
CDOM	Colored dissolved organic matter
CFC	Chlorofluorocarbons
CFC's	Chloroflurocarbons, major ozone depleting substances
CHL	Chlordanes
Chl	Chlorophyll
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon dioxide
CPD	Cyclobutane-pyrimidine dimers
CYP	Cytochrome P450
D_1-protein	Reaction center protein of PS II
3-D	Three-dimensional
DDD	1,1-dichloro-2,2-bis ethane
DDE	1,1-dichloro-2,2-bis ethylene
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane

DEM	Digital elevation model
DF	Digital Filtration
DHA	Docosahexaenoic acid
DKr.	Danish Kroner
DNA	Desoxyribo Nucleic Acid
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
dw	Dry weight
EANET	Acid Deposition Monitoring Network in East Asia
EC_{50}	Effective concentration causing a response in 50 % of the treated organisms
EC AQFD	European Commissions Air Quality Framework Directive
ECHAM	Atmospheric general circulation model developed partly at the European Centre for Medium-range Weather Forecast and partly at the Max-Plank Institute for Meteorology in Hamburg
EGC	East Greenland Current
EIONET	European Environment Information and Observation Network
ENSO	El Niño-Southern Oscillation
ENVINET	European Network for Environmental Research
EPA	Eicosapentaeneoic acid
EROD	7-ethoxyresorufin-*O*-deethylase
ESOP	European Sub-Polar Ocean Programme
FCT method	Flux-Corrected Transport method
FS	Fram Strait
fT3	Free triiodothyronine
fT4	Free tetraiodothyronine
GAW	Global Atmospheric Watch
GEM	Gaseous Elemental Mercury
GIMMS	Global Inventory Modeling and Mapping Studies
GMES	Global Monitoring for Environment and Security
GMES-GATO	GMES-Global Atmospheric Observations
GSI	Global Solar Irradiiance
HadCM	The Hadley Centre coupled climate model
IABP	International Arctic Buoy Programme
HCA	Hydroxycinnamic acid
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HIV	Human Immunodeficiency Virus

IESA	Inside ellipse -species absent
IESP	Inside ellipse -species present
IgG	Immunoglobulin G
IgM	Immunoglobulin M
ind	Number of individuals
IPCC	Intergovernmental Panel on Climate Change
ISMO	Ice Statistical Model
K_{OA}	Octanol-air partition coefficient
KNMI	Royal Netherlands Meteorological Institute, de Bilt, the Netherlands
Lat	Latitude (in degrees North)
LHC	Light-harvesting complex
LHS	Left-hand side
LOAEL	Lowest observed adverse effect level
LOEL	Lowest observed effect level
LPJC	Lund-Potsdam-Jena dynamic global vegetation model
LRTAP-EMEP	Convention on Long-range Transboundary Air Pollution, European Monitoring and Evaluation Programme
lw	Lipid weight
MAA	Mycosporine-like amino acid
MeO	Methoxylated
$MeSO_4$	Methylsulfonyl
mRNA	Messenger ribonucleic acid
MTCLIM	Montane regional climate model
N	North (latitude)
N maps	The area actually occupied by a species as compared with the distribution as represented by a calculated ellipse
NAC	North Atlantic Current
NAMMCO	North Atlantic Marine Mammal Commission
NAO	North Atlantic Oscillation
NARP	Nordic Arctic Research Programme
NASA	National Aeronautics and Space Administration, USA
NCP	Indian and Northern Affair's, Northern Contaminants Program
NDVI	Normalised Difference Vegetation Index
NERI	National Environmental Research Institute (Denmark)
NIP	National Implementation Plans

NMSC	Non-Melanoma Skin Cancer
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No-observed adverse effect levels
NODC	National Oceanographic Data Centre
NOEL	No-observed effect levels
NPI	Norwegian Polar Institute
NwAC	Norwegian Atlantic Current
NwCC	Norwegian Coastal Current
OESA	Outside ellipse -species absent
OESP	Outside ellipse -species present
OH	Hydroxylated
OSPAR/CAMP	Oslo-Paris Commissions Comprehensive Atmospheric Monitoring Programme
OWSM	Ocean weather station
P maps	Maps showing bands of increasing probability of specified winter and summer temperature combinations being suitable for the survival of the species under discussion
PAH	Polynuclear aromatic hydrocarbons
PAR	Photosynthetically active radiation or visible light, 400-700 nm
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PCN	Polychlorinated napthalene
PFAS	Perfluorinated alkyl substances
PFOS	Perfluorooctane sulfonate
PNA	Pacific North American pattern
POP	Persistent organic pollutants
PS I	Photosystem I
PS II	Photosystem II
psbA	Gene sequence encoding for the D_1-protein
PSC	Polar Stratospheric Clouds
PUFA	Polyunsaturated fatty acid
Q_A	Plastquinon A, primary electron acceptor of PS II
Q_B	Plastquinon B, secondary electron acceptor of PS II
RAF	Radiation Amplification Factor, percent increase in effective UV for a one percent decrease in the atmospheric ozone column
rbcL	Gene sequence encoding for large subunit of

	RubisCO
RHS	Right-hand side
RIVM	The National Institute for Public Health and the Environment, Bilthoven, the Netherlands
ROS	Reactive oxygen species
RubisCO	Ribulose-1,5-bisphosphate carboxylase/oxygenase
SAT	Surface Air Temperature
SCC	Squamous Cell Carcinoma
SCUP-h	Skin Cancer Utrecht Philadelphia, biological action spectrum for skin cancer development in humans (de Gruijl and van der Leun, 1994)
SCUP-m	Skin Cancer Utrecht Philadelphia, murine biological action spectrum for skin cancer development derived from experiments in hairless mice (de Gruijl et al., 1993)
SLP	Sea level pressure
SOD	Superoxide dismutase
SST	Sea surface temperature
SZA	Solar zenith angle
T*	Weighted transparency. An index that expresses the UV-spectral effects of stratospheric ozone depletion and water column optical characteristics on a biologically relevant scale
T3	Triiodothyronine
T4	Thyroxin
T_a	Air temperature
T_e	Operative environmental temperature
TBT	Tri-butyl-tin
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TEQ	Dioxin equivalency quotient
Tmax	Maximum temperature (in degrees Celsius)
TOC	Total organic carbon
TOMS	Total Ozone Mapping Spectrometer
TS	Temperature and salinity
TT	Travel time
tT3	Total triiodothyronine
tT4	Tetraiodothyronine
UNEP	United Nation’s Environment Programme
US-EPA	United States – Environmental Protection Agency
UV	Ultraviolet
UVA	Ultraviolet A, wavelengths in the range: 315-400 nm
UVB	Ultraviolet B, wavelengths in the range: 280-315 nm

UVR	Ultraviolet radiation
VEINS	Variability of Exchanges in the Northern Seas
VEMAP	Vegetation/Ecosystem Modelling and Analysis Project
WMO	World Meteorological Organisation, Geneva, Switzerland
ww	Wet weight
WWII	World War II
XP	Xeroderma Pigmentosum, genetic skin disorder with extreme UV-sensitivity
Zmax	Max depth (in meters)

Arctic-Alpine Ecosystems and People in a Changing Environment - Introduction

1 Integrated aspects of environmental change: Climate change, UV radiation and long range transport of pollutants

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1.1 Introduction

Global warming, changes in climate variability, long-range transport of pollutants, and reduced stratospheric ozone, represent increasing challenges to the arctic and alpine ecosystems. Forced by natural and anthropogenic variability, these key environmental factors are amplified in polar (high latitude) and alpine (high altitude) environments. Climate change and ecosystem impact studies involve a number of different and related forcing factors and interaction processes in the atmospheric, terrestrial and marine environments. They represent multiple stress factors that add to harsh environments with large natural variability, and the changes are also connected through natural links and feedback processes.

The integrated physical and biological effects and interactions on marine and terrestrial ecosystems are complex to understand. UV radiation and its ecosystem effects are shaped by a number of physical parameters in the atmospheric, terrestrial and marine environments which contribute to its total biological impact. And so is true also for the long range transported pollutants. Their transport into the physical and biological environments, involve a number of pathways as well as physical, chemical and biochemical transformation processes. Their impact on ecosystems and humans are complex and cannot be treated in isolation. This introductory chapter provides a framework for the integration of the individual chapters of this book.

1.2 Climate change and ecosystem response

The arctic and alpine areas of Northwest Europe are especially sensitive to climate perturbations, due to the strong influence by the North Atlantic oceanic and atmospheric heat advection processes. As discussed by Furevik et al. (Chap. 8), abrupt climate changes with ~10ºC temperature variations over just a few decades occurred during the period of the last glacial maximum, with the termination of the Younger Dryas 11 600 years ago (Dansgaard et al., 1989) representing the last major climate perturbation in the region. They argue that observational evidence suggests that such abrupt changes in climate may be explained by sudden switches in the strength or positioning of the warm and saline Atlantic waters (AW) flowing into the Nordic Seas, forced by increased freshwater discharges making the surface waters fresh enough to inhibit the deepwater formation (Clark et al., 2001). It is therefore not unlikely that the current global warming trends, with enhanced melting of glacier ice and a general intensified hydrological cycle, may in a similar way influence the thermohaline circulation in the North Atlantic and contribute to a destabilization of the stable climate experienced since the last glacial period.

Scientific scenarios suggest that the Arctic temperatures increase almost twice as fast as average global warming (ACIA 2004). Increased summer temperatures leads to more effective ablation. While European alpine glaciers are receding quickly (Beniston et al. 2003), the mass balance of Arctic glaciers show a larger regional variation and variable response (Arendt et al., 2002; Lefeauconnier et al., 1999). The extent of summer melt of the Greenland ice sheet has significantly increased during the past 20 years or so (Steffen et al., 2002). Seasonal snow cover is reduced with increasing length of growing seasons (Høgda et al., Chap. 5), and the continued melt may induce large regional shifts in animal and plant distribution (Crawford and Jeffree, Chap. 6). According to Nuttall (Chap. 2), the results of scientific research and the observations from indigenous peoples suggest that the current climate changes are more pronounced in the Arctic than in any other region of the world (ACIA 2004).

Hansen-Bauer (Chap. 3) provides a review of the climate trends in the European Arctic during the 20th century and provides scenarios of future change. Large changes are seen in the climate records, of which the annual mean precipitation is the most pronounced with significant increase in large parts of the European Arctic. A positive warming trend in temperature is also evident but less significant, due to the large natural variability in this region. According to Hansen-Bauer (Chap. 3), the recent warming

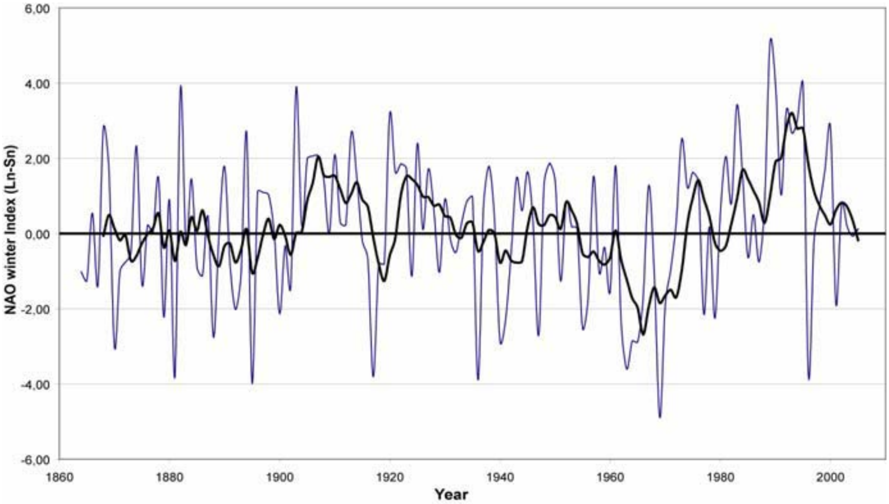

Fig. 1.1. North Atlantic Oscillation (NAO) Winter Index 1864-2003. Data provided by the Climate Analysis Section, NCAR, Boulder, USA, Hurrell (1995).

trend is associated with a positive North Atlantic Oscillation index (NAO, Hurrell 1995) and is evident during the last decades of the 20th century (see Fig. 1.1). This is especially emphasised in central and especially in eastern parts of the European Arctic, probably at least partly triggered by antropogenic forcing of the climate system.

According to Hansen-Bauer (Chap. 3), the Global Climate Models (AOGCMs) show rather different results for the projected changes in atmospheric circulation patterns and do not in general show the observed positive trend in the NAO. However, they project larger warming and precipitation increase in the Arctic than for the global average, with large projected reduction in summer sea-ice during for the 21st century. These projected changes are mainly in conformity with observed changes in temperature and sea-ice concentration during the last decades (Johannessen et al. 2004).

Arctic and alpine lake communities are well suited for studying ecological impacts of climate change, due to their simple structure, sensitivity to variation in ice and snow cover, and the availability of paleolimnological records. According to Primicerio et al. (Chap. 4), the ice phenology is an important driver of a number of ecological parameters for lake biota. Longer ice-free productive periods, induced by climate warming (Magnuson et al. 2000), prolong the seasonal activity of community members with expected increase in production. They claim that the seasonal dynamics of plankton and benthos is likely to change, leading to compositional and structural changes in plankton and benthos as well as the population and community structure of fish.

As for ice and aquatic environments, regional climate change impacts on snow melt and its distribution also significantly affects the length of the growing season. Høgda et al. (Chap. 5) have used the NOAA AVHRR GIMMS NDVI satellite dataset for the last two decades, producing maps for Fennoscandia that define the start and end of the growing season. Their results show that the estimated onset of spring is closely correlation with ground data on the onset of leafing of birch, with high regional differences. In the southern part of Fennoscandia, and on the oceanic west coast of Norway, the earlier spring fits with the pattern for western and central Europe. However, for the mountaineous areas in southern Norway and in the continental parts of northern Fennoscandia, the results indicate a stable or even a slightly delayed trend. Combined with the autumn trends, they find that the growing season is prolonged for the whole area, except the northern continental parts of Fennoscandia.

The tolerance of Arctic and alpine ecosystems to such climate changes can be studied by looking at the geographical limits of plant survival. Crawford et al. (Chap. 6) combine a map-modelling system that is sensitive to changing meteorological data, with comprehensive knowledge of the many interactions between physiology and environment, in their interpretation of plant distribution maps and the relating changing climates to species occurrence. They demonstrate that many species of woody plants of northern distribution have not only northern and southern limits to their distribution, but are restricted also in their east-west dispersal. Their probability models suggest that for some species, the migration patterns are also sensitive to existing temperature *seasonality,* and that the seasonality gradients may present barriers to the migration notwithstanding overall warming.

As plant distribution maps may connect large scale climate variability trends with ecosystem effects, similar variability can also be found on much smaller scales. Topography and the potentially large variability in the physical environmental parameters create a mosaic of microclimatic conditions at landscape scales. According to Armbruster et al. (Chap. 7), the variability in physical conditions, surface inhomogenities and radiation loads are important because all terrestrial biotic response to climate change is mediated by the local microclimate experienced by the organism. They argue that on the scale of meters, the spatial variability in temperature can be of the same order (>2^{o}C) as the estimate of the global warming expected to result from a future doubling of atmospheric CO2 (Houghton et al., 2001), or comparable to moving more than 400 m in elevation or 450 km in latitude. Classical physical climate parameters may therefore not be representative in topographically complex areas and in the high Arctic, where spatial rearrangements of indigenous species with different thermal requirements may in fact be a more prominent biotic response to climate warming than immigration of new species from other regions.

Marine related climate processes significantly force what happens in the atmosphere. Furevik et al. (Chap. 8) focus on the inflow of Atlantic Water (AW) to the Nordic Seas, its pathways and transformation within the Nordic Seas and the Arctic Ocean. These waters are of vital importance for the marine climate, water mass transformation and biomass production in the Nordic Seas. Together with the north-eastward heat flow transport with the numerous North Atlantic cyclones, this heat flow associated with the AW is responsible for the mild and favourable climate of northwest Europe.

The Nordic Seas are also a key area for the conversion of light surface water to dense deep waters, representing the Atlantic meridional overturning circulation (AMOC), or the Atlantic part of the "great conveyor belt" (Broecker, 1991). According to Furevik et al. (Chap. 8), most AOGCMs participating in the third assessment report of the Intergovernmental Panel of Climate Change suggested a 30-40% reduction in the strength of the AMOC during this century (Houghton et al., 2001).

Such dynamical patterns in the inflow of AW to the Arctic are of fundamental importance for Arctic primary production. Falk-Petersen et al. (Chap. 9) postulate that a warmer climate with reduced ice cover will shift zooplankton community structures towards a smaller size spectrum and with lower energy content per individual. This will also lower the potential for seasonal accumulation of lipid stores in their predators such as specialised seabirds. They claim that these effects are based on the very specialized process where carbon fixed photosynthetically in algal blooms is converted into high-energy lipid (oil) reserves by the major Arctic herbivores, a process which varies on all time scales during the Arctic summer, from days to decades and longer due to the variability in sea ice conditions. This lipid-based energy flux, increasing the lipid level from 10-20% of dry mass in phytoplankton to 50 to 70% in herbivorous zooplankton and ice-associated fauna, is probably one of the most fundamental specialisations in Arctic bioproduction (Falk-Petersen et al., 1990). It is therefore also the primary reason for the large stocks of fish and mammals in Polar waters and a key factor in the structuring the biodiversity of Arctic ecosystems.

Such changes in the marine environment and its exploitable resources can have a large impact on social systems. Drawing on recent research from the Arctic Climate Impact Assessment (ACIA 2004) in particular, Nuttall (Chap. 2) provides a brief assessment of climate change impacts on the local livelihoods and traditional resource use practices of arctic indigenous peoples. Rasmussen et al. (Chap. 10) discuss how social changes in Greenland have been heavily influenced by the environmental conditions, and how the social transformations reflect the interaction between different responses to the variations in the natural resource base. Such studies are important for our total understanding of living conditions for people and ecosystems in a changing environment.

1.3 UV radiation and biological effects

Atmospheric UV radiation has potential harmful effects on humans and ecosystems. The depletion of stratospheric ozone observed over the last two decades in the Arctic (Müller et al. 1997; Rex et al. 1997), as well as over parts of Europe (WMO 2003), is of serious concern, since this may lead to an increase in ambient UV radiation. Surface UVB radiation (280-315nm) may induce a wide range of harmful effects on humans (skin cancer, cataracts, suppression of the immune system) and on ecosystems by decreasing biomass and crop yields, growth conditions and algal distribution patterns in unique marine ecosystems ((UNEP 1999, Wiencke et al. 2000). The Vienna Convention (1985) and the Montreal protocol (1987) have successfully led to reduced production and emissions of ozone depleting substances, leading to an expected slow recovery of the ozone layer over the next century (UNEP 2003).

The link between atmospheric ozone and UV radiation is often referred to by Radiation Amplification Factors (Blumthaler et al., 1995), showing that the erythemally weighted UV radiation increases by about 1.1% when ozone decrease by 1%. However, due to its major dependence on other atmospheric and surface related parameters that are also highly variable, trends and future UV levels are difficult to identify. According to Blumthaler (Chap. 11), long term measurements of UVB radiation show a slight increase of a few percent per decade in the 80's and early 90's, most pronounced at high northern latitudes during spring. However, from their 20 years of measurements at a high alpine station, where the variability of UV irradiance under cloudless conditions is dominated by ozone and albedo variations, no significant increase was found.

Surface UV radiation is determined mainly by cloud cover, solar zenith angle, ozone and aerosols. In arctic and alpine environments, altitude and surface albedo are also significant. Blumthaler (Chap. 11) has derived quantitative relations between these parameters and the levels of UV radiation, showing that cloud cover, solar zenith angle, aerosols, altitude, and surface albedo significantly alter the surface UV radiation by the same order of magnitudes as can be the result of ozone variations.

These complex interaction patterns between atmospheric and surface parameters responsible for shaping the surface UV spectrum are important when assessing its ecosystem effects. Plants are expected to be vulnerable to UVB radiation, and according to Nybakken (Chap. 12), a large number of studies has been carried out at all levels of effects, from cellular investigations to large projects concerning the effects on entire ecosystems. Focussing on the possible negative effects of increased UVB radiation and the UV absorbing pigments of plants of both arctic and alpine origin, she contributes to this under-investigated field with only a few previous UVB response studies carried out on plants from arctic and alpine areas, as well as studies conducted in the field or with plants growing in their natural ecosystems (Caldwell et al. 1998). The analysis of screening pigments in a number of arctic and alpine plants agrees well with numerous field and growth chamber studies that show that the increased concentration of phenolic compounds in higher plants is a common response to UVB radiation (Searles et al. 2001).

The arctic and alpine environments also contain a range of waterbodies. In addition to the atmospheric parameters, a number of physiochemical and biological parameters are responsible for shaping the underwater UV spectrum (Ørbæk et al., 2002). Hessen (Chap. 13) focuses on observed and potential effects of UV radiation for the inhabitants of arctic and alpine freshwater ecosystems, as well as the various abiotic challenges that may be superimposed on the UV stress. He claims that the numerous small, shallow and transparent tundra ponds in high arctic localities may support a substantial benthic production, despite a scarcity or absence of benthic macrophytes and fish, with often dense populations of large-sized species of crustaceans. On the other hand, the few deeper (>3m) and larger lakes in the Arctic, which resembles the typically deep and oligotrophic alpine lakes, do not freeze to the bottom and may house populations of fish. In these ecosystems, short wave solar radiation may negatively affect both primary and secondary production. Whereas UV radiation is considered the most harmful part of the spectrum, visible photosynthetic active radiation (PAR) may also cause a suite of cellular damages (Hessen Chap. 13).

Vincent et al. (Chap. 14) show that arctic, antarctic and alpine aquatic ecosystems are particularly vulnerable to climate-induced shifts in underwater UV radiation, and that the controlling effect of snow, ice cover and coloured dissolved organic matter (CDOM) on the biological UV exposure under water, may be larger than those caused by moderate ozone depletion. Although UV radiation may be strongly attenuated in coastal waters by CDOM released from terrestrial ecosystems, the importance of snow and ice cover and the sparse catchment vegetation zones in the arctic typically result in low CDOM concentrations. Based on their paleo-ecological studies of fossil diatoms and UV-screening pigments preserved in lake sediments, a strong landscape influence on the underwater spectral light regime of high latitude and alpine lakes is indicated, in the past and present.

Hanelt et al. (Chap. 15) give a well documented presentation of the recent investigations on biological effects of UV radiation on marine ecosystems in the Arctic. In recent years they have carried out several studies on the distribution, physiology and UV radiation effects on several algal species like seaweeds growing in the Arctic environment (Hanelt et al. 1997a; Bischof et al. 1998). They point out that although the UV radiation is more intense in temperate zones, the polar algae are more sensitive to UV as compared to their temperate relatives. Potential negative effects on primary plant productivity may occur especially in spring, low temperatures and clear water conditions allowing harmful UV wavelengths to penetrate several meters into the marine water column. Hanelt et al. (Chap. 15) also point out that the summer discharge of turbid fresh water into the coastal waters overlays the more dense sea water, causing a stratification in the optical features, salinity and temperature of the water body that strongly attenuate solar radiation in the first meter of the water column. This effect is increased during warm summers with rainfall and intensified runoff from melting snow and ice covers. Organisms in deeper waters are thus more protected against harmful UVB radiation.

Ozone depletion and the induced increased UV radiation levels also have consequences in terms of health risks such as for example skin cancer. In their Assessment Model for UV Radiation and Risks (AMOUR), Slaper et al. (Chap. 16) evaluate the full source-risk chain from production and emission of halocarbons, the resulting stratospheric ozone depletion with changes in ambient effective UV doses, and the corresponding skin cancer risks. Updating his previous analysis of the kind (Slaper et al. 1996), the new model also takes into account the role of climate and ozone interactions in the arctic region on the future risks at mid-latitudes in densely populated areas in Europe. Their analysis predicts that a slow recovery of the ozone layer will occur with a return to 'normal' (1980) levels around 2050, and that skin cancer risks are expected to rise until 2050-2070.

1.4 Ecological impacts of long range pollutants transport

Contaminants are transported from industrialized source areas by ocean currents, sea ice and large scale wind patterns (Fig. 1.2). After entering these transport pathways, the contaminants reach the soils, snow and ice, biota and water of the remote environments in a number of different forms and phases. The soluble and particulate phases as well as the precipitation and scavenging processes involved are highly influenced by changing circulation patterns and other forms of climate change (AMAP 2003). As an example, arctic and alpine regions are especially vulnerable to temperature rise due to potential increased melting of snow and ice, and this phase change to water influence the redistribution and transfer of contaminants from the physical environment to the biota.

MacDonald (Chap. 17) describes thoroughly the processes involved in the long range transport of contaminants as well as the environmental systems that control the further metamorphosis of the pollutants after being deposited and brought into the biological systems. Climate change and variability strongly affect both pathways and the stationary phases (MacDonald et al. 2005), involving complex interaction with temperature, winds, precipitation, runoff patterns, snow and ice, organic carbon cycling, ocean circulation, and human activities.

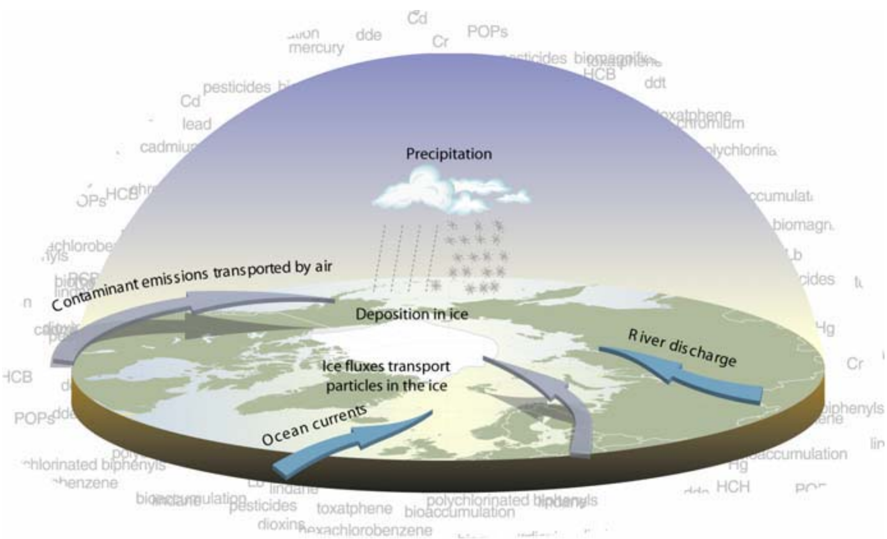

Fig. 1.2. Contamination pathways. UNEP-Grid-Arendal, Vital Arctic Graphics Source: AMAP (2002), ACIA (2004)

Sea ice and water currents in the Polar Ocean is also an important medium for pollutants transport (Korsnes 2002). These pathways undergo significant changes in the Arctic (AMAP 2003). Pavlov et al. (Chap. 18) have made several numerical experiments elucidating the spatial structure of contaminant spreading by water from potential sources in different parts of the coastal zone of the Arctic seas. The experiments have been carried out to estimate the transport of passive tracers by water and ice from potential sources of contaminants in the Arctic Ocean, especially from potential pollutant sources in the vicinity of river-mouths of major rivers flowing into the Arctic Ocean (Pavlov and Pavlov 1999). The numerical experiments, earmarking zones with maximum and minimum contamination, show that some regions, such as for example the northern and western parts of the Laptev Sea and Fram Strait, would be contaminated for all possible source locations in the coastal zone of the Arctic seas.

Kallenborn et al. (Chap. 19) argue that the global pathways of long-range contaminant transport and the principal atmospheric transport of inorganic and organic contaminants, nutrients, aerosols and particulate matter into the polar regions, can only be revealed by the concerted efforts from multinational atmospheric long-term pollution monitoring programs. Their empirically derived monitoring data, involving rapid and effective adaptation for the identification and implementation of priority contaminants, common sampling and analytical protocols etc., is at present the only way to evaluate the accuracy of the predictions calculated by modern models of future contamination scenarios.

As these monitoring programmes give important documentation on pollutant levels in the physical environment, they are a prerequisite to explain the levels of contaminants stored and bio-accumulated in the ecosystems. Gabrielsen et al. (Chap. 20) summarizes recent studies on the levels of heavy metals (HM) and persistent organic pollutants (POPs) in arctic animals, using data on biological effects related to POPs in polar bears *(Ursus maritimus)* and glaucous gulls *(Larus hyperboreus)* from the Svalbard archipelago. According to them, mercury, lead and calsium are the HM of most concern in the arctic environment. The monitoring programmes show that while the global emissions of cadmium and lead have decreased, the emission of mercury is increasing. For POPs, the levels are generally lower in the arctic environment than in more temperate regions. However, high levels of POPs exceeding the critical effect thresholds for effects on behavioural-, biochemical-, physiological- and immunological parameters, as found by laboratory and field studies, have been found in the marine food chain in glaucous gulls from Bjørnøya and in polar bears from Svalbard, Franz Josef Land and Kara Sea (Borgå et al. 2004).

The effective bio-accumulation of POPs in Arctic ecosystems are partly due to their lipid-rich food-chains, and pollutants are therefore also accumulate where Arctic people is at the top of these food chains. According to Gabrielsen et al. (Chap. 20), the levels of cadmium in arctic biota has been stable or is decreasing during the past 5-10 years, while the mercury level is increasing in most marine arctic species. In some arctic areas the levels of mercury and cadmium are high enough to cause health effects in animals and humans. Based on studies of the Greenland Inuit population, Mulvad (Chap. 21) explains that the traditional diet in Greenland to a large extend is based upon marine animals and fish, rich in fat. The partly isolated population with ethnic background provides good conditions for genetic and health impact studies under unique social circumstances, light and extreme cold weather.

1.5 Integrated aspects

Arctic and alpine areas are experiencing significant environmental change related to climate change, pollutant levels, changing pathways, stratospheric ozone depletion and surface UV radiation (AMAP 2003,2004; WMO 2003; ACIA 2004). The environmental changes and effects are in many cases amplified in these areas and closely coupled to the global climate change processes as documented in previous IPCC assessments (Houghton 2001). The Arctic biodiversity and indigenous peoples are vulnerable and constantly under pressure from these changes as well as from the effects of globalization (Nuttall Chap. 2). The decreasing sea-ice in the arctic ocean is one of the most pronounced features of climate change, with a decrease in spring and summer sea ice of the order 10-15% during the last 4 decades (Hougthton et al. 2001). According to Hansen-Bauer (Chap. 3), the variations in sea-ice concentration and air temperature during the last decades are partly accounted for by variations in atmospheric circulation indices such as the Arctic Oscillation (AO). The AO, which describes the general modes of large scale atmospheric circulation over the Northern Hemisphere, has gradually been more positive since the 1970s, with lower than normal surface air pressure anomalies over the Arctic (Thompson et al. 2000).

There is a close relationship between the atmospheric circulation patterns and the different global pathways bringing pollutants into the arctic and alpine environments. According to McDonald (Chap. 17), there is a general agreement that these changing pathways are caused by a combination of natural variability and anthropogenic forcing factors, and that the interdependence between contaminant pathways and climate change patterns, as manifested in anomalies of temperature, winds, precipitation, river flow and ocean circulation, ice and snow cover etc., involves a complex distribution of transport mechanisms, source regions, chemical transformation and magnifying processes.

The bio-accumulation of POPs in the arctic environment is high especially for the marine food chains, due to the fundamental specialisation of the lipid-based energy flux in Arctic bio-production, as discussed by Falk-Petersen et al. (Chap. 9). According to Gabrielsen (Chap. 20), the contaminant levels found in polar bears and glaucous gulls on Svalbard and Bjørnøya exceed critical effect thresholds and affect their health. Sea-ice both directly and indirectly challenge the polar bear population by reducing their habitat along with the forecasted future dramatic reduction of Arctic summer ice during this century (ACIA 2004), as well as by modifying the primary sea-ice related bio-production.

Indigenous peoples of the circumpolar North fundamentally depend on the health of arctic marine and terrestrial ecosystems. As discussed by Nuttall (Chap. 2), changes in climate, weather patterns, migration of animals and human actions all influence their traditional resource use, making e everyday life uncertain and unpredictable. Thus, the integrated effects of pollution, climate change and industrial development have consequences for the ecosystems, food security and human health that seriously may constrain their abilities to achieve sustainable livelihoods.

Atmospheric UV radiation is both physically, politically and biologically closely integrated with the problems of anthropogenic contaminant transport and climate change. The Vienna Convention (1985) with the Montreal protocol (1987) is a successful example of political countermeasures aimed at mitigating anthropogenic environmental change. This framework for reduction of both production and emission of ozone depleting substances are expected to lead to a slow recovery of the ozone layer over the next century (Madronich et al., 1999). However, more evidence of climate related interaction processes at stratospheric altitudes now suggests that ozone depletion is not purely chemically driven. Conditions with stronger and colder than normal polar stratospheric vortices, related to the persistent positive phase of the AO, have lead to an increased abundance of polar stratospheric clouds (PSCs) in the Arctic. And PSCs are effective catalysts in ozone depletion (Shindell et al., 1998). As pointed out by Slaper et al. (Chap. 16), it is therefore assumed that the ozone layer will need longer time to return to the “normal” 1980-levels, even with reduced active chlorine levels in the stratosphere.

This situation will certainly modify future UV levels especially in the Arctic. At the same time a number of atmospheric and surface physical parameters closely modified by climate change processes, significantly influence the surface UV radiation, as described by Blumthaler (Chap. 11). The surface albedo, as determined by the abundance of snow and ice, atmospheric aerosols and the amount and type of clouds represent parameters that are of almost equal importance in shaping the surface UV spectrum, as compared to the influence of ozone. In a similar way, ice cover, sediment particles and coloured dissolved organic matter (CDOM) are the primary controls of UV radiation under water, and these main controlling factors are highly responsive to climate warming or cooling trends. Vincent et al. (Chap. 14) argue that the climate induced shifts in underwater UV radiation can be of much greater magnitude than those caused by moderate ozone depletion. Arctic, antarctic and alpine aquatic ecosystems are particularly vulnerable to such effects because of the importance of snow and ice cover and the typically low CDOM concentrations in these regions. Hessen (Chap. 13) argue that the widespread small, shallow and highly transparent tundra ponds situated on permfrost in the circumpolar Arctic represent distinct ecosystems and unique biota that may be especially vulnerable to changes in UV-radiation, climate warming and changes in the hydrological cycle. Climate change interactions also affect the UV radiation conditions and primary production of seaweeds. According to Hanelt et al. (Chap. 15), organisms in the eulittoral and upper sublittoral zone are affected by UV radiation throughout the polar day. However, during the warm summer seasons with intense runoff, turbid melt water from glaciers and rivers significantly reduce the underwater UV transparency.

1.6 Conclusions

Obviously, the many challenges involving climate and stratospheric change, pollutant transport and social changes are related. A number of other significant dependencies also naturally exist between the various aspects of environmental change parameters and human activities in arctic and alpine areas. The scope here is not to give a complete review of all single processes but to outline the level of interaction between the main contemporary challenges in environmental change, on the basis of the studies presented in the book. Both with respect to the physical processes as well as dealing with their biological impacts and the anthropogenic forcing factors, the changes related to the climate change processes, long range transported pollutants and UV radiation, can not be treated alone or independently but need to be analysed as multiple pressures of the high latitude and high altitude, arctic and alpine environments.

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2 An environment at risk: Arctic indigenous peoples, local livelihoods and climate change

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2.1 Introduction

Over the last two decades the Arctic has emerged as a region of dramatic environmental change. This vast part of the planet, once seen as pristine and remote, is now represented increasingly as a vulnerable and fragile place, its biodiversity and peoples at risk from climate change, contaminants and globalization. These drivers of far-reaching change have a diffuse distribution around the globe, their origins often difficult to identify and almost impossible to allocate specific moral and legal responsibility to. They are also subject to a contested political debate over whether mitigation or adaptation are the most feasible or possible strategies for protecting Arctic ecosystems and human well-being.

Arctic marine and terrestrial ecosystems provide a variety of ecosystem services which are of fundamental importance to the livelihoods of indigenous peoples (Chapin *et al*., in press). Yet, the indigenous peoples of the circumpolar North increasingly perceive the Arctic as both an environment *of* risk and an environment *at* risk (Nuttall 1998: 170). It is an environment of risk in that climate variability and local weather events, changes in the movement and behaviour of animals, and human actions all influence traditional resource use activities and make everyday life uncertain and unpredictable. It is also an environment at risk from pollution, global climate change and industrial development. Such threats continue to influence the climate, have an impact on ecosystems, animal habitats and movement, and also have consequences for food security and human health, thus seriously constraining the abilities of indigenous peoples to achieve sustainable livelihoods.

Scientific scenarios suggest that the scale and nature of Arctic climate change in the coming decades may not only be greater than previous changes in the region's history, but within the context of global climate change northern regions will experience a greater degree of change than