OSPAR Commission

for the Protection of the Marine Environment

of the North-East Atlantic

Quality Status Report 2000

Region I Arctic Waters

Quality Status Report 2000
Region I – Arctic Waters

Published by
OSPAR Commission, London 2000
ISBN 0 946956 47 2

Recommended reference format
OSPAR Commission 2000. Quality Status Report 2000, Region I – Arctic Waters. OSPAR Commission, London. 102 + xiv pp.

More information about OSPAR
The Convention for the Protection of the Marine Environment of the North-East Atlantic has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Union and Spain.

Visit the website at http://www.ospar.org

Illustration credits and copyrights

contents

Foreword		ix
The participants		x
Executive summary		xii

1 Introduction

1.1	Aim and scope	1
1.2	The assessment process	1
1.3	Guidance to the reader	3

2 Geography, hydrography and climate

2.1	Introduction	5
2.2	Definition of the region	6
2.3	Bottom topography	6
2.4	Geology and sediments	7
2.4.1	Bedrock geology	8
2.4.2	Quaternary–Recent sediments	8
2.5	Coastal characteristics	8
2.6	Catchment area	9
2.7	Water masses	9
2.7.1	Upper layers	9
2.7.2	Intermediate and deep water	10
2.7.3	Deep water formation	11
2.7.4	Estuarine and coastal waters	12
2.8	Circulation and volume transport	12
2.8.1	Circulation in the upper layers	12
2.8.2	Circulation in the deeper layers	14
2.8.3	Volume transport	15
2.9	Waves, tides and storm surges	16
2.10	Transport of ice	17
2.11	Meteorology and climate	18
2.12	Climate variability	19
2.13	Climate change	20
2.13.1	Global effects of deep water formation	20
2.13.2	Effects of the Atlantic inflow	20
2.13.3	Stability of the deep water formation	21
2.13.4	Potential impact of greenhouse gases	21

3 Human Activities

3.1	Introduction	25
3.2	Demography	26
3.3	Conservation	28
3.4	Tourism and recreation	28
3.5	Fishing and hunting	28
3.5.1	Fishing	28
3.5.2	Hunting	29
3.5.3	Harvesting	30
3.6	Mariculture/fish farming	30
3.7	Coastal protection and land reclamation	30
3.8	Sand and gravel extraction	30
3.9	Dredging, dumping and discharges	30
3.10	Offshore oil and gas	30
3.11	Shipping	31
3.12	Coastal and land-based industries	32
3.12.1	Industrial complexes	32
3.12.2	Mining and associated industries	33
3.12.3	Onshore petroleum activities	33
3.12.4	Urban settlements	33

3.13 Military activities 33
3.14 Agriculture and forestry 33
3.15 Regulatory measures and future developments 34

4 Chemistry

4.1 Introduction 37
4.2 Inputs of contaminants 40
4.2.1 Land-based inputs 40
4.2.2 Offshore inputs 40
4.2.3 Riverine inputs 40
4.2.4 Atmospheric long-range transportation 41
4.3 Background/reference values 42
4.4 Heavy metals 42
4.4.1 Cadmium 42
4.4.2 Mercury 45
4.4.3 Lead 46
4.4.4 Copper 47
4.5 Persistent organic contaminants 48
4.5.1 Tributyltin 48
4.5.2 Polychlorinated biphenyls 48
4.5.3 Polycyclic aromatic hydrocarbons 49
4.5.4 Other persistent organic compounds 51
4.6 Oil 54
4.7 Radionuclides 55
4.8 Nutrients and oxygen 56

5 Biology

5.1 Introduction 59
5.2 Overview of the ecosystems 60
5.2.1 Phytoplankton 60
5.2.2 Zooplankton 61
5.2.3 Benthos 62
5.2.4 Fish 65
5.2.5 Birds 70
5.2.6 Marine mammals 71
5.3 Impact of non-indigenous species and harmful algal blooms 73
5.4 Impact of microbiological pollution 74
5.5 Impact of fisheries 74
5.5.1 Effects on stocks 74
5.5.2 Discards 78
5.5.3 Benthos 78
5.6 Impact of whaling 79
5.7 Impact of mariculture 79
5.8 Impact of eutrophication 79
5.9 Impact of tourism and recreation 80
5.10 Impact of sand and gravel extraction 80
5.11 Impact of dredging 80
5.12 Impact of coastal protection and land reclamation 80
5.13 Impact of marine litter 80
5.14 Impact of offshore activities 80
5.15 Impact of shipping 81
5.16 Impact of contaminants 81
5.16.1 Introduction 81
5.16.2 Metals 81
5.16.3 Tributyltin 81
5.16.4 Polychlorinated biphenyls 81
5.16.5 Polycyclic aromatic hydrocarbons 82
5.16.6 Other persistent organic compounds 82
5.16.7 Radionuclides 82

6 Overall assessment

6.1	Introduction	85
	6.1.1 The assessment process	85
	6.1.2 Characteristics of the Arctic region	86
6.2	Assessment of human impacts	86
	6.2.1 Major effects	86
	6.2.2 Medium effects	88
	6.2.3 Lesser effects	89
6.3	Gaps in knowledge	90
6.4	Overall assessment	91
	6.4.1 Introduction	91
	6.4.2 The Barents Sea	91
	6.4.3 The Norwegian Sea	92
	6.4.4 The Iceland Sea and shelf area	92
	6.4.5 The Greenland Sea	93
6.5	Conclusions and recommendations	93
	6.5.1 Conclusions	93
	6.5.2 Recommendations	93

Species 94
Abbreviations 95
Glossary 96
References 98

FOREWORD

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention 1992) requires that Contracting Parties shall 'take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected'.

To provide a basis for such measures, the Contracting Parties are required to undertake and publish at regular intervals joint assessments of the quality status of the marine environment and of its development. These assessments should also evaluate the effectiveness of measures taken and planned for the protection of the marine environment and should identify priorities for action.

The Ministerial Meeting at which the OSPAR Convention was signed also issued an action plan for the OSPAR Commission, with a commitment to prepare a quality assessment of the whole maritime area by the year 2000. A comprehensive quality status report on this scale has not previously been produced.

To implement these commitments the OSPAR Commission decided, in 1994, to subdivide the maritime area into five regions and to prepare, coordinated by the Environmental Assessment and Monitoring Committee, five detailed quality status reports. As a result, five regional task teams were set up to produce reports for the following areas (see ***Figure 1.1***): Region I (Arctic Waters), Region II (Greater North Sea), Region III (The Celtic Seas), Region IV (Bay of Biscay and Iberian Coast) and Region V (Wider Atlantic). It was agreed that these reports should be developed in a scientifically sound manner and should be based upon an assessment plan and a scientific programme (covering monitoring, research and the use of assessment tools). It was also agreed that the information contained in the reports should reflect the outcome of the appropriate quality assurance procedures.

In 1995 the OSPAR Commission adopted a Joint Assessment and Monitoring Programme, to take over and build upon experience gained through its former Joint Monitoring Programme and the Monitoring Master Plan of the North Sea Task Force.

The findings of the five regional quality status reports ('the regional QSRs') form the basis of a holistic quality status report for the entire maritime area (the 'QSR2000'). This regional report is thus part of an overall quality status assessment for the North-east Atlantic in the year 2000. The QSR2000 will represent an integrated summary of the quality status of the entire OSPAR maritime area and will both fulfil the commitment made by the parties to the 1992 Convention and provide a basis upon which the future work programmes of the Commission can be decided. In the Sintra Statement, which concluded the 1998 Ministerial Meeting of the OSPAR Commission, importance was attached to the outcome of the QSR2000 as a basis for identifying and prioritising future tasks at the Ministerial Meeting of the OSPAR Commission to be held in 2003.

The term 'OSPAR Commission' is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were superseded by the 1992 OSPAR Convention when it entered into force on 25 March 1998.

The conclusions and recommendations contained in this report draw attention to problems and identify priorities for consideration within appropriate fora as a basis for further work. Within its sphere of competence, the OSPAR Commission will decide what follow up should be given to these conclusions, recommendations and priorities for action. The rights and obligations of the Contracting Parties are not therefore affected by this report.

THE PARTICIPANTS

Framework

The Environmental Monitoring and Assessment Committee (ASMO) has overall responsibility for the preparation of periodic quality status reports, assisted by a working group, the Assessment Coordination Group (ACG). ASMO outlined the basic arrangements for the quality status reports in the Joint Assessment and Monitoring Programme (JAMP). Further scientific and technical arrangements were prepared by ACG. Regional Task Teams (RTTs) were set-up for each of the regions of the maritime area. The lead countries for the respective RTTs were responsible for providing logistical support to the RTT.

Information relating to the entire maritime area was prepared in 1996 – 1998 by the following OSPAR working groups: the Working Group on Inputs to the Marine Environment (INPUT), the Working Group on Impacts on the Marine Environment (IMPACT), the Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (SIME) and its Ad Hoc Working Group on Monitoring (MON). This information constituted the basis of the five regional quality status reports, and was supplemented by relevant national information as appropriate.

Regional Task Team for the Arctic Waters

The RTT for the Arctic Waters had primary responsibility for drafting this report.

Denmark (including the Faroe Islands and Greenland), Iceland and Norway shared the work for the preparation of the report, with Norway taking the lead. The RTT functioned as an editorial group with a representative from the Institute of Marine Research in Bergen, Norway contracted a technical editor to draft the report. As of August 1999 the editorial group comprised the following persons:

Bogi Hansen (Fisheries Laboratory, Faroe Islands); Per Erik Iversen (Norwegian Pollution Control Authority), Chairman; Helgi Jensson (Environmental and Food Agency of Iceland); Jarle Klungsøyr (Institute of Marine Research, Norway), Technical Editor; Marit Nyborg (Norwegian Pollution Control Authority); and Mikkel Aaman Sørensen (Danish Environmental Protection Agency).

Several other representatives from Denmark, Iceland and Norway participated in the RTT for short periods of time:

Chapter 1

Per Erik Iversen (Norwegian Pollution Control Authority), Jarle Klungsøyr (Institute of Marine Research, Norway), Marit Nyborg (Norwegian Pollution Control Authority).

Chapter 2

Johan Blindheim (Institute of Marine Research, Norway), Reidulv Bøe (Norwegian Geological Survey), Bogi Hansen (Fisheries Laboratory, Faroe Islands), Jarle Klungsøyr (Institute of Marine Research, Norway), Harald Loeng (Institute of Marine Research, Norway), Jan R. Sulebak (Univ. Bergen, Norway).

Chapter 3

Bogi Hansen (Fisheries Laboratory, Faroe Islands), Per Erik Iversen (Norwegian Pollution Control Authority), Helgi Jensson (Environmental and Food Agency of Iceland), Jarle Klungsøyr (Institute of Marine Research, Norway), Einar Lystad (Triton Marinebiologists AS), Marit Nyborg (Norwegian Pollution Control Authority), Jan R. Sulebak (Univ. Bergen, Norway), Mikkel Aaman Sørensen (Danish Environmental Protection Agency).

Chapter 4

Rune Dietz (National Environmental Research Institute, Denmark), Helgi Jensson (Environmental and Food Agency of Iceland), Jarle Klungsøyr (Institute of Marine Research, Norway), Kari Stange (Institute of Marine Research, Norway), Tone Sørgård (Norwegian Pollution Control Authority).

Chapter 5

Asgeir Aglen (Institute of Marine Research, Norway), Padmini Dalpadado (Institute of Marine Research, Norway), Arne Ervik (Institute of Marine Research, Norway), Geir Wing Gabrielsen (Norwegian Polar Institute), Johan Glette (Institute of Marine Research, Norway), Arne Hassel (Institute of Marine Research, Norway), Jarle Klungsøyr (Institute of Marine Research, Norway), Vebjørn Melle (Institute of Marine Research, Norway).

Chapter 6

Bogi Hansen (Fisheries Laboratory, Faroe Islands), Per Erik Iversen (Norwegian Pollution Control Authority), Helgi Jensson (Environmental and Food Agency of Iceland), Jarle Klungsøyr (Institute of Marine Research, Norway), Marit Nyborg (Norwegian Pollution Control Authority), Hein Rune Skjoldal (Institute of Marine Research, Norway), Mikkel Aaman Sørensen (Danish Environmental Protection Agency).

Financial support from the Nordic Council of Ministers and various governmental directorates in Denmark, Iceland and Norway is gratefully acknowledged.

Scientific support and advice provided by the secretariat of the Arctic Monitoring and Assessment Programme is also gratefully acknowledged.

ACG and ASMO – representation by Contracting Parties

Chairmen of ACG: Ben van de Wetering (1994), Frank van der Valk (1995), Philip C. Reid (1996–1999)
Chairmen of ASMO: Georges Pichot (1994 – 1997), Roland Salchow (1998 – 2000)
Contracting Parties' delegates to ACG 1994–1999:
Belgium: Mia Devolder, Georges Pichot*, Wilfried Vyncke; Denmark: Jens Brøgger Jensen*, Henning Karup, Mikkel Aaman Sørensen; EC: Patrick McCutcheon*; France: Pascale Babillot, Marcel Chaussepied, Philippe Maire*, Jean-Marie Massin; Germany: Hartmut Heinrich*, Roland Salchow; Iceland: Helgi Jensson*; Ireland: Rick Boelens, Jacqueline Doyle*; The Netherlands: Lisette Enserink,

Frans Feith, Kees Kramer, Bob Oudshoorn, Folkert Post*, Frank van der Valk, Carien van Zwol; Norway: Per Erik Iversen, Hein Rune Skjoldal, Rune Vistad*; Portugal: Antonio Macieira Antunes, Maria E. F. Avila Goulart, Graça Noronha, Irene Pereira, Joaquim Pissarra, Tereza Vinhas*; Spain: Victor Escobar, Pilar García, Argeo Rodríguez de León*; Sweden: Stig Carlberg, Sverker Evans*, Ingrid Jansson; United Kingdom: Mike Burn, John A. Campbell, Stephen Churley, Theresa Crossley*, John M. Davies, Andrew Franklin, Andrew J. Osborne, Philip C. Reid.
* also acting as Head of Delegation during ASMO(2)1999 which adopted this report.

Observer organisations attending meetings of ACG and ASMO 1998 – 1999
Arctic Monitoring and Assessment Programme (AMAP), European Environment Agency (EEA), International Council for the Exploration of the Sea (ICES), Secretariat of the North Sea Conferences, Conseil européen des fédérations de l'industrie chimique (CEFIC), European Fertilizer Manufacturers Association (EFMA), Euro Chlor, World Wide Fund for Nature (WWF).

OSPAR Secretariat for ACG and ASMO (logistics, organisation, scientific and technical editing)
Stefan Hain (1994 – 1995), Carolyn Symon (1994 – 1998), Dornford Rugg (1998 – 2000), Gert Verreet (1995 – 2000), Ben van de Wetering (Executive Secretary 1995 – 2000).

Copy-editing: Carolyn Symon.

Technical support by Sylvie Ashe, Paula Creedon, Hélène Hughes, Corinne Michel, Barbara Middleton, Nicola Warden.

Design
Redhouse Lane Communications Ltd. (London).

OSPAR COMMISSION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH-EAST ATLANTIC

QUALITY STATUS REPORT 2000: REGION I – ARCTIC WATERS

EXECUTIVE SUMMARY

Introduction

This report is one of five regional quality status reports prepared by the OSPAR Commission as part of its commitment to produce the first quality status report of the North-east Atlantic by the year 2000.

The report presents an assessment of environmental conditions in that part of the maritime area which, for assessment purposes, is known as Arctic Waters or Region I. The area comprises the Barents Sea, the Norwegian Sea, the Iceland Sea and shelf and the south-east Greenland shelf, and the Greenland Sea. Region I also includes a sector of the Arctic Ocean.

This is the first time a quality status report has been prepared by OSPAR for the Arctic region. After an introductory chapter (Chapter 1), the report focuses on geography, hydrography and climate (Chapter 2), human activities (Chapter 3), chemistry (Chapter 4) and biology (Chapter 5). The report concludes with an overall assessment (Chapter 6).

Ecosystem characteristics

The climate in Region I is determined by the inflow of relatively warm Atlantic water. Where the Atlantic water meets the cold Arctic water to the north and west of the region, a sharp front separates the water masses. Climatic variability causes large interannual variability in ice and hydrographic conditions, which in turn affect plankton production and fish recruitment. The general circulation system within Region I is probably a major mechanism driving climate variability, both within Europe and globally.

Northern parts of the Iceland, Greenland and Barents Seas are ice-covered in winter. Most of the ice in the Barents and Iceland Seas is seasonal and melts during summer. The ice and ice-melt have significant effects on ecological conditions. Owing to these factors and to the high latitude of the region, the seasonal phytoplankton production is of short duration and limited extent. The primary production is conveyed efficiently to higher trophic levels and supports large populations of fish, marine mammals and seabirds.

Human population

Region I is sparsely populated with a total of only 2.6 million inhabitants. Their lives are closely linked to local resources, particularly in terms of their dependence on fishing and the harvesting of wildlife, which form the basis of their society, culture and economy. Other economically important activities include forestry, mining, the metals industry and petroleum exploitation.

Main human pressures

Owing to its remoteness and low population density, general environmental conditions within Region I are good. With regard to contaminants the region is one of the cleanest within the OSPAR Convention area. However, certain activities give cause for concern such as the impact of fisheries and the widespread occurrence of persistent organic contaminants in fish and marine mammals. In this report, human pressures on the marine ecosystems have been ranked on the basis of expert judgement according to the following classes: major effects, medium effects and lesser effects.

Major effects

Fisheries

The main impacts of fisheries result from the partial removal of target species. Although management actions over recent years have resulted in improvements and in the sustainable utilization of some stocks, fishing pressure on some other stocks is so high that they are close to or beyond the limits for sustainable utilization. The effects of fishing pressure on stock size and stock interactions may coincide with climatically driven variability.

Inadequate reporting of discards makes it difficult to establish the actual catches of target and non-target species. Discards can result in increased populations of scavenging species. This is likely to have contributed to population increases for some species of seabird.

Bottom trawling affects benthic species and habitats. Studies on deepwater corals off the coast of Norway indicate that trawling can cause extensive damage and the destruction of coral reefs.

Whaling

Whaling lead to the decimation of several whale species in the Arctic region. The recovery of some overexploited species has been very slow while others, such as fin and minke whales, have recovered well. It is likely that the patterns of energy flow and the dynamic properties of the ecosystems have been altered permanently by this former activity.

Medium effects

Persistent organic contaminants

An increasing number of persistent synthetic compounds have been detected in the biota, sediments, sea water and ice of Region I, indicating the global distribution of such compounds. They remain in the environment for extremely long periods due to their very low rates of degradation.

No quantitative estimates of the total input of persistent organic contaminants to Region I are available. A few local sources close to urban settlements are known. The concentrations in areas remote from human population cannot be explained by known uses or sources within the region. This implies that long-range transport from lower latitudes is important.

Long-term time trends for persistent organic contaminants in Region I are very few. It is therefore difficult to assess to what extent agreed measures and bans on the use of many of these compounds have resulted in decreased concentrations within the environment. Recent studies on glaucous gull and polar bear from Bear Island and Svalbard indicate that polychlorinated biphenyls (PCBs) and other persistent organic contaminants can cause biological effects in animals living within the region.

TBT

Imposex has been observed in dogwhelk and common whelk in coastal areas of Region I as a result of exposure to tributyltin (TBT) from TBT-based antifouling paints. Banning the use of TBT on small boats has resulted in some signs of recovery.

Mariculture

There is extensive mariculture in Region I, particularly in Norway. The spread of salmon lice from farmed to wild salmon stocks is an issue of concern since heavy infection may cause large mortalities. The genetic composition of wild stocks may be affected by salmon which have escaped from farms. Bacterial diseases in fish farms are now almost absent due to the use of effective vaccines and vaccination strategies. The use of pesticides and antibiotics in mariculture has decreased during recent years and these are not considered to cause significant effects on marine biota.

Oil

The only oil-contaminated areas in Region I are estuaries and harbours close to human settlements and industrial sites. Some oil is released from offshore production platforms, shipping and the transport of oil. Potentially, a large impact may occur if there is an overlap in time and space between an accidental oil spill and migratory animals such as seabirds, which congregate within relatively small areas at certain times. The difficulties associated with taking remedial actions in such cold environments are a cause for concern.

Lesser effects

PAHs

There is no information on polycyclic aromatic hydrocarbon (PAH) inputs to Region I. Industry and urban settlements within the region are local sources. Long-range transport via the atmosphere is also likely to be of some importance. PAHs are likely to have a local impact only, such as near oil wells, metallurgical plants and urban settlements. Owing to the generally low PAH concentrations within Region I, significant biological effects are unlikely to occur.

Metals

Anthropogenic effects of metals are only apparent in some areas close to point sources. Global discharges of cadmium, mercury, lead and copper from industrialised countries have declined for some years due to policy measures. Concentrations in Arctic sediments are mainly dependent on local geology. Cadmium and mercury occur in some seabirds and marine mammals at concentrations that may have health implications for both the animals and the human consumers. It is uncertain whether mercury poses a threat to the health of the most highly exposed marine mammals, such as pilot whales from the Faroe Islands, or to their human consumers. However, there are indications that selenium is present in concentrations that can protect against mercury poisoning.

Radionuclides

Contamination by artificial radionuclides is very low and has negligible radiological significance. Present inputs are mainly via global fallout from previous atmospheric nuclear weapons testing, fallout from the Chernobyl reactor accident and discharges from European nuclear fuel reprocessing plants. The greatest future threats to human health and the Arctic environment are associated with the potential release of radionuclides from local dumpsites and accidents within the civilian and military nuclear sectors.

Eutrophication

Population density in the land areas bordering Region I is very low and therefore the inputs of nutrients are generally low. Eutrophication is not an issue of concern for Region I.

Biological introductions

The introduction of non-indigenous species and the effects of microbiological pollution are considered insignificant problems in Region I. The only impact of this type observed is the introduction of the Kamchatka crab.

Physical impacts

Physical impacts include dredging and dumping, coastal protection and land reclamation, tourism, sand and gravel extraction and marine litter. These are all regarded as minor problems in Region I.

Gaps in knowledge

The following issues were identified as particularly important:

- there is a need to improve the scientific basis for linking climatic variability and climate change to the chemical and biological processes in Region I;
- the effect of fishing pressure may coincide with climatically driven variability and the information required to separate these processes is limited;
- the assessment process was difficult owing to limited data on trends in inputs and a lack of systematic contaminant monitoring data on geographical and temporal trends; and
- little information on the biological effects of contaminants made it difficult to draw conclusions about the impact of contaminants on the Arctic ecosystems.

Recommendations

Taking into account the human activities identified in this quality status report, their impact on the marine environment and the evaluation of existing measures, it is recommended that the following actions be considered by the appropriate authorities:

- Environmental management and the management of living resources should be based on science and any management action will need to be under constant review and modified as the scientific basis improves.
- To ensure continued improvement in the quality of the region adequate resources should be made available to implement the OSPAR Strategies.
- To improve the management of fish stocks there is a need for the development of better assessment tools regarding the effects of discards and by-catches and the effects of interaction between fish stocks.
- There is a need for more research on the effects of fishing gear on marine habitats.
- Qualitative and quantitative information on the inputs, sources and pathways of contaminants to the region should be improved.
- Research programmes on pathways and sources should be initiated together with monitoring programmes to identify critical regions and temporal trends.
- There is a need for more information on biological effects, particularly concerning the chronic exposure of persistent organic contaminants to organisms living in the region.
- More information and research are needed on the effects of mariculture on wild stocks, in terms of possible genetic effects and the spread of parasites and diseases.
- Environmental impact studies are required in relation to oil exploitation in or near ice covered areas.
- Research is required on the implications of climate change for the marine environment.

chapter 1

Introduction

1.1 Aim and scope

Assessments of the quality of the marine environment form a basis for measures to protect the marine and coastal environment. They provide an opportunity to gather together and assess the results of scientific research and monitoring as well as information on the many human activities that can, directly or indirectly, change or damage the natural attributes of the marine environment. In combination, this information can be used to evaluate the causes and implications of change and to identify impacts that require early attention by policy-makers and environmental managers. Assessments are also used to review the effectiveness of existing measures to prevent degradation of the marine environment, to protect species and communities and, when practicable, to restore previously damaged habitats and ecosystems.

The value of environmental assessments depends to a large extent on the availability of reliable and up-to-date information. Thus it is essential that monitoring and other systems of recording marine environmental information are both ongoing and designed to yield high-quality data amenable to interpretation. In this context, assessments provide a means of reviewing the performance of monitoring programmes and of identifying important gaps in knowledge.

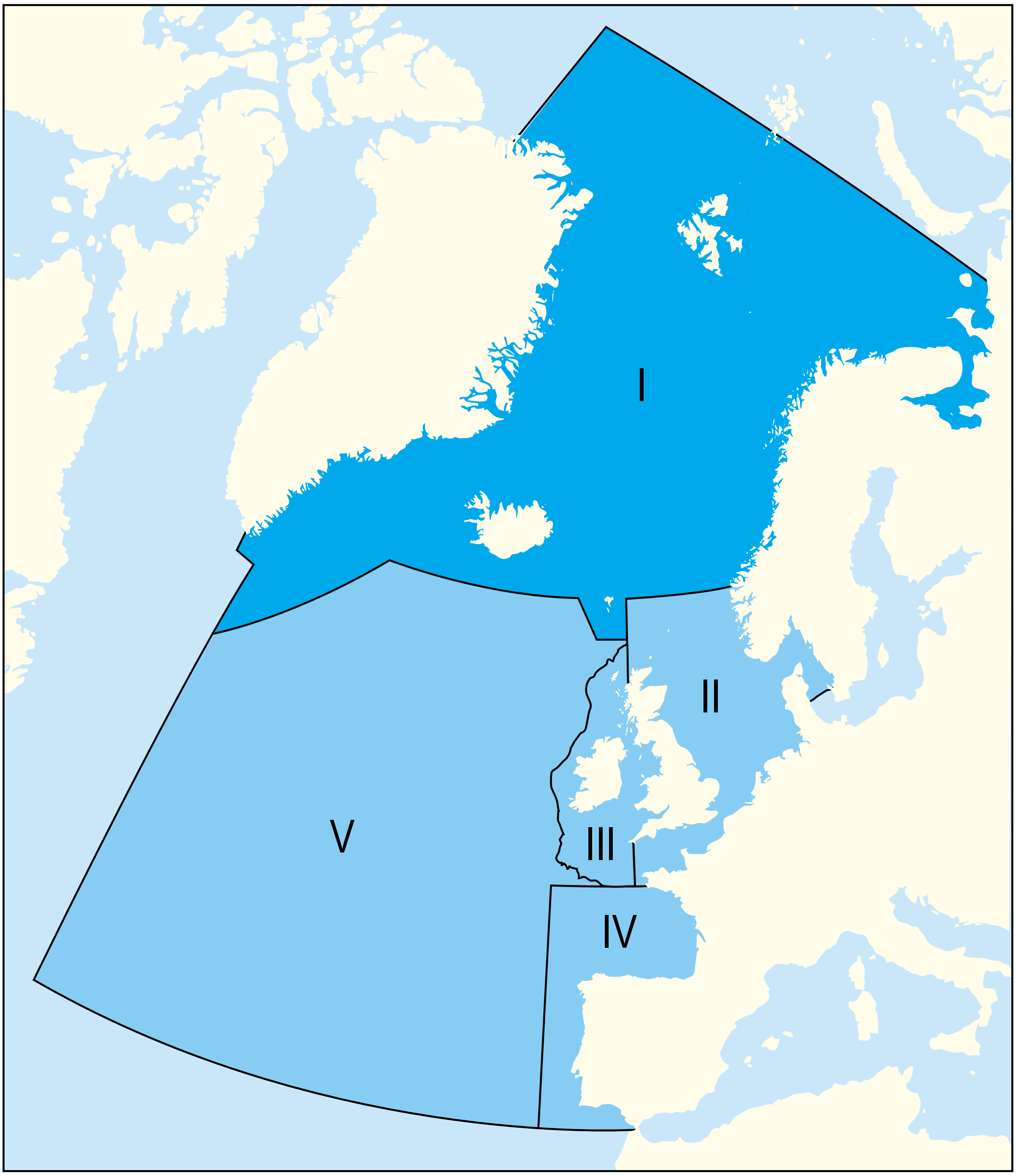
This report presents an assessment of environmental conditions in that part of the maritime area which, for assessment purposes, is known as the Arctic Waters or Region I *(Figure 1.1)*. Region I is the second largest OSPAR region and incorporates a wide range of environmental conditions and human activities. Most of the region is sparsely populated and appears relatively pristine. However, the long-range transport of contaminants and human activities such as fisheries, industry, petroleum production and military activities do impact upon the region. Region I can be divided into the following subregions based on ecological characteristics: the Barents Sea, the Norwegian Sea, the Iceland Sea and shelf and the south-east Greenland shelf, and the Greenland Sea. In addition, Region I also includes a sector of the Arctic Ocean. The five subregions have been used as the basis for the overall assessment of Region I. Together with similar quality status reports for the other four OSPAR regions, this report forms the basis of a holistic and integrated summary of the quality status of the entire OSPAR maritime area.

1.2 The assessment process

The assessment is based upon the most recent information available from national and international sources, including OSPAR committees and specialist working groups, the International Council for the Exploration of the Sea (ICES), the Arctic Monitoring and Assessment Programme (AMAP), published reports and the scientific literature. All material provided for AMAP assessments between 1995 and 1998 was made available for this report. Although most of the information relates to the 1990s, some topics required the use of earlier data, either because the recent record was sparse or because trend analysis involved a consideration of historical conditions. While every effort has been made to ensure the comparability of data from different times and locations, methodologies may have differed considerably and thus some comparisons will, inevitably, be tenuous. Where such uncertainties exist, they are indicated in the text.

There are several recent environmental assessments of the Arctic region, of which the most comprehensive was undertaken by AMAP (AMAP, 1998). In 1997 the Joint Norwegian–Russian Commission on Environmental Co-operation prepared a status report on the marine environment of the Barents Sea region (Lønne *et al.*, 1997); this focused on the various aspects of human impact. The Working Group on the Protection of the Arctic Marine Environment (PAME) summarised and assessed contaminant inputs to the Arctic from the various sources

Figure 1.1 Region I and the other regions of the OSPAR maritime area.



(PAME, 1996), while the Nordic Council of Ministers published information on human activities and ecological conditions in the Arctic sector of the Nordic countries (Bernes, 1996). The potential health and ecological risks from radionuclides in the Arctic Seas have been addressed by the Arctic Nuclear Waste Assessment Program of the US Office of Naval Research (Layton *et al*., 1997). Information on the state of the Arctic environment was also included in an assessment by the European Environment Agency (EEA, 1996). These reports are the main sources of information for the present assessment.

1.3 Guidance to the reader

Chapter two gives a description of the physical geography, hydrography and climate of the area, as these have an important bearing on the types and distributions of marine habitats and communities as well as on their sensitivity to environmental change. Region I is characterised by a severe climate, with extreme variations in light, temperature and ice-cover. The formation of deep water in the region is recognised as one of the important features of the global ocean circulation, and may be critical to the development of the global climate. Although climate change is not addressed by OSPAR, Chapter two gives a brief consideration to the subject following a more detailed description of water masses and circulation in Region I. Chapter two also provides information on bottom topography, geology and sediments, coastal characteristics, transport of ice, meteorology and climate variability.

Chapter three examines human activities that directly or indirectly impinge on marine areas, their amenities and resources, identifying localities most affected and assessing any apparent trends. As a result of the low population density in Region I, impacts on the marine environment related to urban settlements are relatively minor. The chapter therefore concentrates on the important regional fisheries, in addition to activities such as mariculture, petroleum exploration and production, industry, shipping, military activities, tourism, agriculture and forestry. Chapter three also includes an overview of international conventions and agreements relevant to the region.

Chapters four and five summarise existing information on the chemical and biological features of the various coastal and offshore ecosystems, focusing in particular on the causes and implications of the changes that are occurring. Chapter four presents information on sea-based, riverine and atmospheric inputs of contaminants, together with a consideration of spatial distribution and trends in concentration in different media. Chapter five comprises two major sections: a general description of the marine ecosystem and the associated impact of human activities. The impact of fisheries provides the main focus of the chapter, mariculture, offshore activities, contaminants, toxic algal blooms and the introduction of non-indigenous species are also considered. An attempt was made to prioritise the various human pressures and gaps in knowledge were highlighted.

Finally, Chapter six draws on the preceding chapters to identify the major causes of environmental degradation within the area and, where appropriate, makes recommendations for the managerial and scientific actions needed to redress them.

chapter 2

Geography, hydrography and climate

2.1 Introduction

Region I constitutes approximately 40% of the OSPAR Maritime area *(Figure 2.1)*. The region is characterised by a relatively harsh climate with extreme variations in light, temperature and ice cover. In addition to the north–south gradient, the current system in the region induces an east–west gradient with warmer conditions in the eastern part, influenced by inflow from the Atlantic. As a consequence, distinct differences are experienced in the geographical distribution of different types of living organisms. Most of these are adapted to the harsh conditions, but some live on the border of their tolerance.

In the surface layer, Region I receives inputs of water and various substances from both OSPAR Region V (the Wider Atlantic) through the inflow of Atlantic water and OSPAR Region II (the Greater North Sea), mainly through the inflow of coastal water. The return flow from Region I to Region V occurs both at the surface in the western part and in the deeper layers, where cold water penetrates southwards sinking to great depths and continuing through the Atlantic into the other major oceans as a major component of the so-called ‘Global Conveyor Belt’ contributing to the ventilation of the deep oceans of the world.

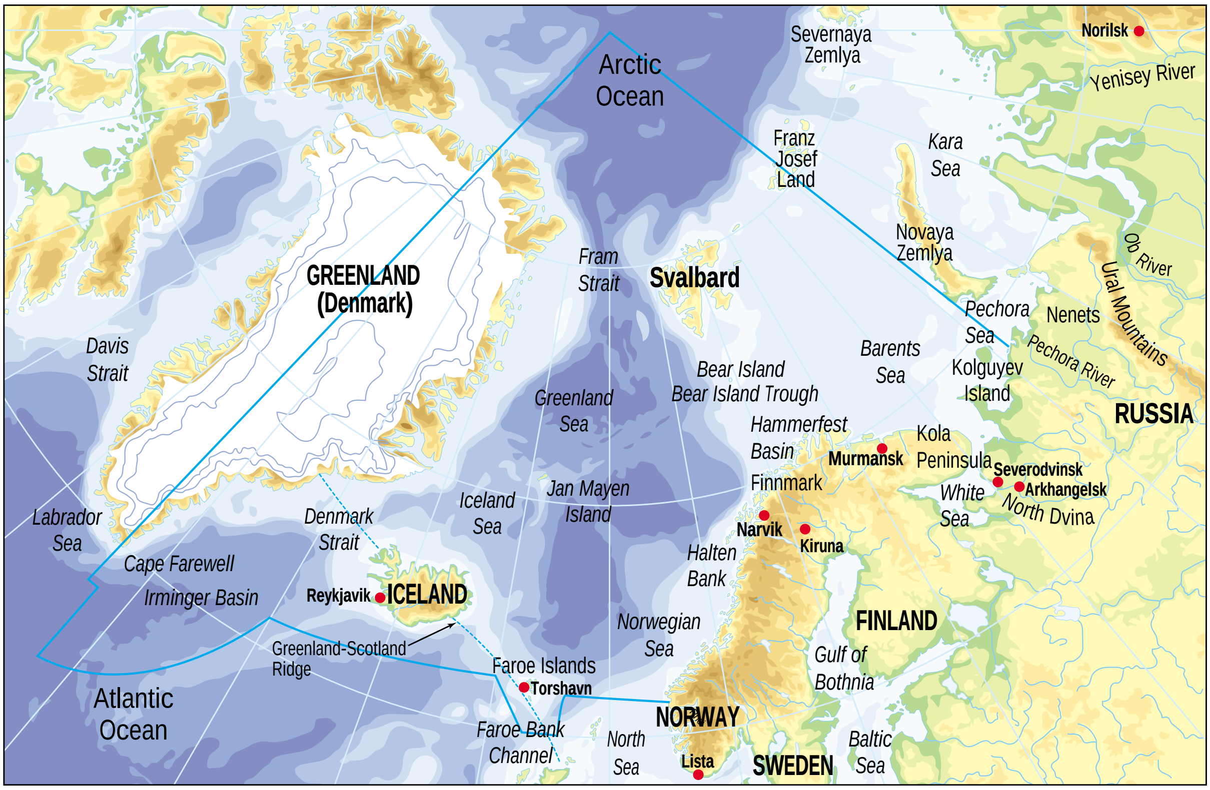


Figure 2.1 **Major geographical features of Region I. Source: adapted from AMAP (1998). Based on ETOPO5 dataset (NOAA, 1998).**

2.2 Definition of the region

Region I (Arctic Waters) represents the northern section of the OSPAR Maritime area *(Figure 2.1)*. The region encompasses the sea areas north of 62º N – the Norwegian, Iceland and Greenland Seas (collectively called 'the Nordic Seas'), the Barents Sea and a sector of the Arctic Ocean. South of 62º N Region I further comprises the area around the Faroe Islands and the East Greenland shelf area to Cape Farewell. The region is bordered to the east by northern Norway, the Kola Peninsula and Novaja Zemlya, and extends northwards via Franz Josef Land to the North Pole along the 51º E meridian. To the west, the region is bordered by the 42º W meridian and the east coast of Greenland. The approximate surface area, volume and mean depth of the major sea areas comprising Region I are shown in *Table 2.1*.

The total surface area of Region I amounts to approximately 5.5 x 10^6 km^2. That sector of the Arctic Ocean which falls within Region I represents only 8% of the total surface area of the Arctic Ocean, but due to its great depth represents around 25% of its total volume.

2.3 Bottom topography

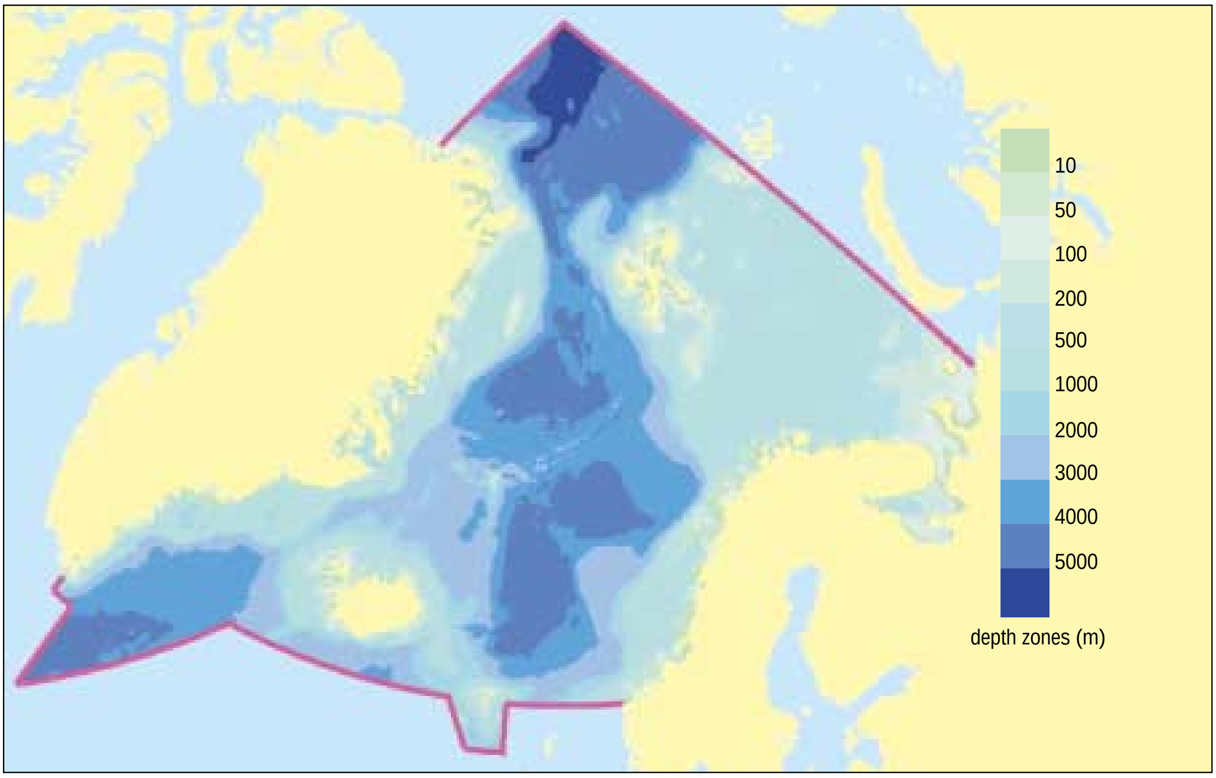
The most distinctive topographic feature of Region I is the submarine ridge extending from Greenland to Scotland – the Greenland–Scotland Ridge – from which Iceland and the Faroe Islands rise above the sea surface *(Figure 2.2)*. This ridge forms a barrier between the deep water masses of the ocean areas to its north and the rest of the Atlantic Ocean. The ridge has a sill depth of 620 m

Table 2.1 Area, volume and mean depth of the sea areas in Region I.

	Area (million km^2)	Volume (million km^3)	Mean depth (m)
The Arctic Ocean sector of Region I	0.8	2.8	3500
The Nordic Seas	2.6	4.1	1600
Barents Sea	1.6	0.37	230
Area south of the Nordic Seas	0.5	-	-

- not calculated.

Figure 2.2 **Bottom topography of Region I. Source of data: ETOPO5 dataset (NOAA, 1998).**



between Greenland and Iceland, 480 m between Iceland and the Faroe Islands and 840 m between the Faroe Islands and Scotland.

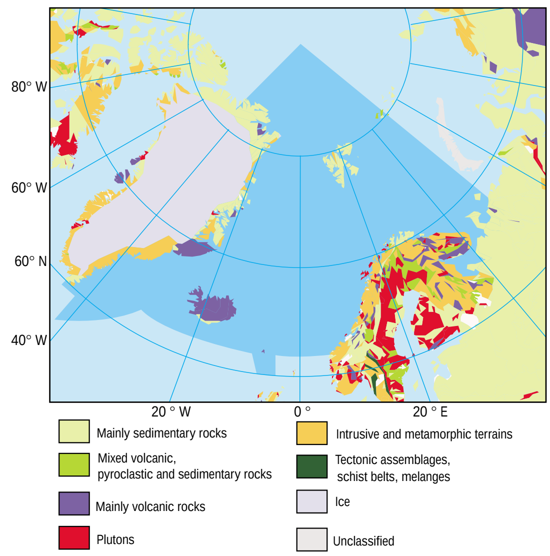
The Greenland, Iceland and Norwegian Seas north of the ridge are also defined by the topography. A platform extending northwards from Iceland to the latitude of Jan Mayen Island forms the floor of the Iceland Sea, with depths around 1500 m. The mid ocean ridge which crosses Iceland and continues across Jan Mayen north-eastwards and then northwards into the Arctic Ocean, forms the boundary between almost 4000 m deep basins in the Greenland and Norwegian Seas *(Figure 2.2)*. These basins have a relatively open connection to the Arctic Ocean through the 440 km wide Fram Strait which, with its sill depth of 2600 m, allows the exchange of deep waters. Some of the greatest depths in the area are found in the elongated rift valleys along the mid ocean ridge, with depths of up to 3400 m in the Nordic Seas. In the sector of the Arctic Ocean that belongs to Region I, rift valley depths exceed 5000 m.

The Barents Sea, one of the widest shelf areas in the World Ocean, is linked to the Nordic Seas through the gap between Norway and Svalbard and to the Arctic Ocean in the north and north-east. With its mean depth of 230 m there are wide areas shallower than 300 m, while the Bear Island Trough which cuts into the shelf south of Bear Island is the most important deeper structure.

2.4 Geology and sediments

The bedrock geology of the landmasses surrounding Region I is varied, both with respect to age and composition *(Figure 2.3)*. The area was strongly influenced by Caledonian folding, thrusting and mountain building,

Figure 2.3 **The major bedrock geology of the landmasses surrounding Region I. Source: AMAP (1998).**



which resulted during the collision between Greenland and Fennoscandia around 400 – 500 million years ago. The area experienced strong uplift and extension around 350 – 400 million years ago, while over the past 100 million years Norway and Greenland have again separated as a result of rifting and sea floor spreading in the North Atlantic. Sea floor spreading also occurs along the Arctic section of the mid ocean ridge.

2.4.1 Bedrock geology

Most of the Arctic Ocean (within Region I) and the North Atlantic are underlain by ocean floor basalts (Churkin and Johnson, 1983), which are in turn covered by Tertiary–Quaternary sediments. In the North Atlantic, basalts cover the areas from the escarpments east of Greenland in the west, to the escarpments along the eastern margins of the North Atlantic. Iceland has been created by volcanic activity along the Mid-Atlantic Ridge during the past 20 million years. New volcanic rock is constantly being added, and about one tenth of Iceland is covered by lava deposited since the last ice age. Jan Mayen and the Faroe Islands are also of volcanic origin. The Faroe Islands were formed about 50 million years ago, during the onset of volcanism and sea floor spreading in that region.

Precambrian metamorphic rocks (e.g. gneiss, schist and amphibolite) dominate in central and northern Norway (Sigmond, 1992). The northernmost part of Norway is dominated by Precambrian metasediments. Metasediments and metavolcanic rocks of early Palaeozoic age cover parts of central and northern Norway.

Mesozoic and Tertiary sediments dominate offshore Norway. The Barents Sea is also covered by Mesozoic sediments, although older sediments may crop out, e.g. on Bear Island (Sigmond, 1992). Along the southern coasts of the Barents Sea (in offshore areas, on many islands and peninsulas, and along the eastern coasts of the White Sea), sediments deposited in the late Precambrian and the late Palaeozoic Eras are common. Precambrian metamorphic and intrusive rocks predominate on the Kola Peninsula, while in the Hammerfest Basin, Tertiary sediments occur.

Western and northern Svalbard are dominated by Precambrian metamorphic rocks, locally with inliers of early Palaeozoic rocks deformed during the Caledonian mountain building period (Sigmond, 1992). The remaining parts of Svalbard are covered mainly by sedimentary rocks.

Eastern Greenland can be divided into several geological provinces (Escher and Watt, 1976). In the north-east, a whole suite of sedimentary rocks occurs, varying in age from Precambrian to Mesozoic. The East Greenland Mesozoic and Tertiary Province, north-west of Iceland, is covered by Tertiary basalt. Part of south-eastern Greenland is dominated by Precambrian gneisses.

2.4.2 Quaternary–Recent sediments

During the Quaternary ice ages, the land areas of Region I were severely denuded. The erosion products of this denudation were mainly deposited in the ocean. Very widespread and thick, coarse-grained deposits occur along the continental margins; at the outlet of the North Sea into the Norwegian Sea, offshore central Norway, at the outlet of the Barents Sea into the North Atlantic, and along the eastern coasts of Greenland. Finer grained sediments such as silt and clay were deposited in the deeper ocean basins. During late and post glacial times, redeposition and transport of glacial sediments into the deep ocean basins has taken place by subaqueous mass movements.

At present, deposition in the deep ocean basins is dominated by pelagic and hemipelagic, calcareous sedimentation, while the coastal stretches are dominated by terrigenous sedimentation. Most of the sediments derived from the land areas are trapped in deep fjords, without reaching the open ocean, and the sediment transport along the coasts is thus dominated by re-deposition of glacial sediments. The situation is different along the Russian coasts of the Barents Sea, where big rivers transport sediments directly into the open ocean. Sediments are also transported directly into the ocean where glaciers occur at or near the coasts of Iceland, Greenland and Svalbard. Along the spreading ridges in the Atlantic and Arctic Oceans there is a high input of volcanic and volcanoclastic sediments. The ridge areas are otherwise covered by a relatively thin veneer of sediments, deposited on top of the ocean floor basalts. The transport and deposition of fine-grained sediment within Region I is generally ruled by the major ocean currents.

2.5 Coastal characteristics

The dominant type of estuaries within Region I are fjords with river outlets in the inner parts. Sill fjords are found in numerous locations along the coasts of Norway, Greenland, the Kola Peninsula, Svalbard and northern Iceland. Rocky shores with a few sandy beaches dominate the Faroe Islands.

The coastal area of Norway north of 62º N consists of two main geomorphologic units: the strandflat and the fjords. The strandflat is a flat, uneven and partly submerged rocky platform extending seawards from the coastal mountains. The gently sloping land forms an uneven coastline with numbers of bays, coves, inlets, islands, islets and skerries. This kind of coast provides a protected shipping lane, possibilities for fish farming and good harbours. Inland the strandflat often ends sharply against steep slopes. From its outer boundary slopes lead down to the more even continental shelf. The width of the strandflat varies from zero to around 60 km.

The Norwegian fjords are relatively long and narrow, often curved or branching embayments with steep sides and considerable depths. The fjords are generally old valley systems that have been vigorously eroded by glaciers. Most fjords have a sill at the entrance, but exceptions are found, especially in the northernmost areas. These sills may have significant impacts on circulation and may contribute to making the fjords sensitive to contaminants. Most drainage from land is concentrated in the fjords, leading to estuarine circulation.

The coast of Iceland consists mainly of rock or sandy material. Rocky coasts predominate in the eastern, northern and western parts of Iceland. These are irregular in outline, cliffed and incised with numerous fjords and inlets. The main Icelandic fjords are more open and funnel-like than the Norwegian fjords. In many of the fjords curved shingle spits project from the shores, providing good natural harbours. Most settlements in the fjords are located on these spits. The coasts to the south and south-east of Iceland are dominated by a smooth shoreline and extensive river plains (sandurs). The rivers from inland glaciers supply the material that forms these sandurs. Enormous volumes of volcanoclastic sediments are transported across the sandurs and into the ocean during volcanic eruptions beneath the glaciers.

The coasts of the Faroe Islands mostly comprise vertical cliffs rising directly from the sea. This cliffed coastline is the result of intensive erosion by the ocean waves that break unabated against the rocks, making caves a common sight along the coast. In many places the cliffs are cut into deep, narrow ravines by fluvial erosion. Fjords in the Faroe Islands have been carved out by glaciers and most of the population has settled in their vicinity as the sea is relatively quiet and there are good natural harbours.

The eastern coast of Greenland is for the most part similar to the Norwegian coast. Deep fjords dominate the landscape and the outermost coastal area is strandflat-like. Huge glaciers from the inland ice sheets break through the coastal mountain barrier and terminate in the fjords. From this calving ice front, icebergs drift out of the fjords and follow the coastal current south-westwards along the coast and into the Atlantic Ocean.

2.6 Catchment area

The catchment area of Region I includes Iceland, the Faroe Islands and parts of Norway, Finland and the north-western part of the Russian Federation.

The Fennoscandian Arctic land area north of 62º N, including areas of Norway, Sweden and Finland, covers roughly 300 000 km^2. The catchment area of Norway to Region I covers 168 000 km^2. Most of these areas are subarctic due to the warming effect of the inflowing Atlantic water. This is also the situation for the Kola Peninsula with an area of approximately 145 000 km^2. The rivers Pechora and Dvina, with average annual discharges of 140 km^3 and 106 km^3 respectively (AMAP, 1998), contribute a significant proportion of the total freshwater input to Region I (see *Figures 2.1* and *4.4*). Svalbard and Franz Josef Land are Arctic archipelagos of 63 000 and 10 000 km^2, respectively. About 90% of these mountainous islands are covered by ice.

Greenland, described as the largest island in the world, actually comprises numerous mountainous islands almost entirely covered by a permanent ice cap up to 3000 m thick. The ice cap covers an area of 2 186 000 km^2. The main areas of ice-free land are along the south-west coast, i.e. outside the OSPAR Convention area. River run-off from the east coast of Greenland is minimal.

Iceland has a land area of 103 000 km^2. It is a mountainous and volcanically active island on the Mid-Atlantic Ridge. More than 50% of the land is without vegetation and 11% of its surface area is covered by glaciers. The Faroe Islands have a land area of 1399 km^2. The terrain is mountainous with vegetation covering most of the area.

Extreme events, such as the 1996 volcanic eruption below the glacier Vatnajøkull in Iceland, may contribute large quantities of solids to the area. The total amount of suspended solids from this event was estimated at 180 x 10^6 t, which is 90 times the annual contribution from the largest rivers on the Icelandic south coast (Egilson *et al.*, 1999).

2.7 Water masses

Within the oceans various bodies of water may be identified, principally on the basis of their temperature and salinity, although their concentrations of other dissolved components and transient tracers are also important. These bodies, termed ‘water masses’, are generally of different origin and may carry different contaminant loads. Their distribution and movement within a region may therefore help to explain contaminant concentrations and fluxes. A very detailed description of water masses in the North-east Atlantic is given by Hopkins (1991). Here, the focus is on the major water masses listed in *Table 2.2*, grouped according to the depths at which they are typically found.

2.7.1 Upper layers

Five water masses represent the surface and upper layer water *(Table 2.2)*. Two of these are warm, high salinity waters that enter Region I from the Atlantic. Modified North Atlantic Water derives from the open North Atlantic and mainly enters the Nordic Seas between Iceland and the Faroe Islands. It is somewhat colder and fresher than

Table 2.2 Typical properties of the main water masses in Region I.

Water mass	Temperature (°C)	Salinity
Upper		
North Atlantic Water	9 – 10	35.3 – 35.4
Modified North Atlantic Water	7 – 9	35.1 – 35.3
Norwegian Coastal Water	-1.8 – 14	30.0 – 34.7
Polar Water	-1.8 – 3	30.0 – 34.0
Arctic Surface Water	1 – 3	34.5 – 34.9
Intermediate		
Atlantic Intermediate Water	1 – 3	34.9 – 35.0
Arctic Intermediate Water	0 – 2	34.8 – 35.0
Modified East Icelandic Water	1 – 3	34.7 – 34.9
Deep		
Greenland Sea Deep Water	< -0.5	34.88 – 34.89
Eurasian Basin Deep Water	< -0.5	34.92 – 34.93

the North Atlantic Water that enters from the south-west, flowing along the continental slope. On entering the Nordic Seas, these Atlantic waters have temperatures ranging from 7 to 10 °C and salinities mainly between 35.1 and 35.4 *(Table 2.2)*. Within Region I the Atlantic water is cooled and diluted and may change considerably in character, although waters with a temperature and salinity in excess of 2 °C and 35.0 respectively are considered to be Atlantic water.

The Norwegian Coastal Water enters the region from the south-east, flowing northwards along the Norwegian coast. At its Baltic origin the salinity may be quite low, but when it enters Region I it has already mixed with other more saline water masses and its salinity generally exceeds 30. Due to further mixing with oceanic waters, its salinity increases further northwards to a maximum around the Lofoten Islands. Although there is a general temperature decrease northwards, seasonal temperature fluctuations are considerably greater.

Polar Water is formed in the Arctic Ocean where it occupies the 30 – 50 m thick surface mixed layer. Due to the sea ice cover its temperature is close to the freezing point, while its salinity is kept low by a large supply of river runoff, although it varies seasonally in connection with the freezing and melting of sea ice.

Arctic Surface Water is observed in the upper layers of the central Greenland and Iceland Seas. It derives largely from Atlantic water that has been recirculated within the Fram Strait and the Nordic Seas and therefore has relatively high values of salinity. Its temperature shows considerable seasonal fluctuations.

2.7.2 Intermediate and deep water

The sill depth of the Greenland–Scotland Ridge prevents all but upper layer water from entering the Nordic Seas from the south. Thus all intermediate and deep waters north of the ridge have formed there, mostly from Atlantic water that has been cooled and diluted by fresher waters. In this area, the term ‘intermediate water’ is generally used to describe water found at 500 – 1000 m in depth. In the scientific literature a large number of intermediate water masses have been defined with different areas of formation and slightly different properties (Swift, 1986; Hopkins, 1991). In this report, only three intermediate water masses are described *(Table 2.2)*.

A warm intermediate layer in the Arctic Ocean, known as the Atlantic Layer, derives from the Atlantic current system, entering through the Fram Strait and through the Barents Sea. These Atlantic waters subduct and eventually spread over the entire Arctic Ocean, and in Region I they may be observed as a layer with temperatures above 0 °C between about 200 and 900 m in depth (Andersen *et al.*, 1989). On entering the Arctic Ocean through the Fram Strait, the temperature is up to about 3 °C and the salinity is near 35. On leaving the Arctic Ocean through the western Fram Strait, the water in this layer joins with water which has recirculated from the West Spitsbergen and Norwegian Atlantic Currents to form a relatively warm intermediate water, Atlantic Intermediate Water, under the Polar surface waters of the East Greenland Current.

Arctic Intermediate Water is formed by winter convection in a similar manner to the deep water. Intermediate water is often formed when conditions for deep water formation are lacking. Under such conditions the product of the winter cooling may then spread over the body of older and denser bottom water. This may occur in both the Greenland and Iceland Seas. By sinking along the Arctic Front between the Arctic and Atlantic domains in the Nordic Seas, Arctic Intermediate Water may spread into the Norwegian Sea where it can be identified as a salinity minimum between the upper layer Atlantic water and the deep water (Blindheim and Ådlandsvik, 1995).

In the southern parts of the Norwegian Sea, a third intermediate water mass is found. It is formed north of Iceland and in the area of the Iceland–Faroe Front, from a number of different source waters (Stefánsson, 1962) and was denoted Modified East Icelandic Water by Read and Pollard (1992). This water sinks in the frontal zone and is found above the Arctic Intermediate Water. It also contributes to the overflow over the Iceland–Faroe Ridge.

Two major deep water masses are formed north of the Greenland–Scotland Ridge in Region I; Greenland Sea Deep Water and Eurasian Basin Deep Water *(Table 2.2)*. The names indicate the geographical origin of these waters, however they move from their formation areas and much of the southern and eastern parts of Region I north of the ridge are dominated by a mixture of the two, termed ‘Norwegian Sea Deep Water’.

South of the Greenland–Scotland Ridge the intermediate and deep layers of Region I are influenced by waters of highly different origins. At intermediate levels, water from the Labrador Sea is found as well as water from the Mediterranean. At greater depths, bottom water from the Antarctic influences the bottom water of Region I. In addition, intermediate and deep waters from northern parts flow over the ridge to enter the southern part of Region I.

2.7.3 Deep water formation

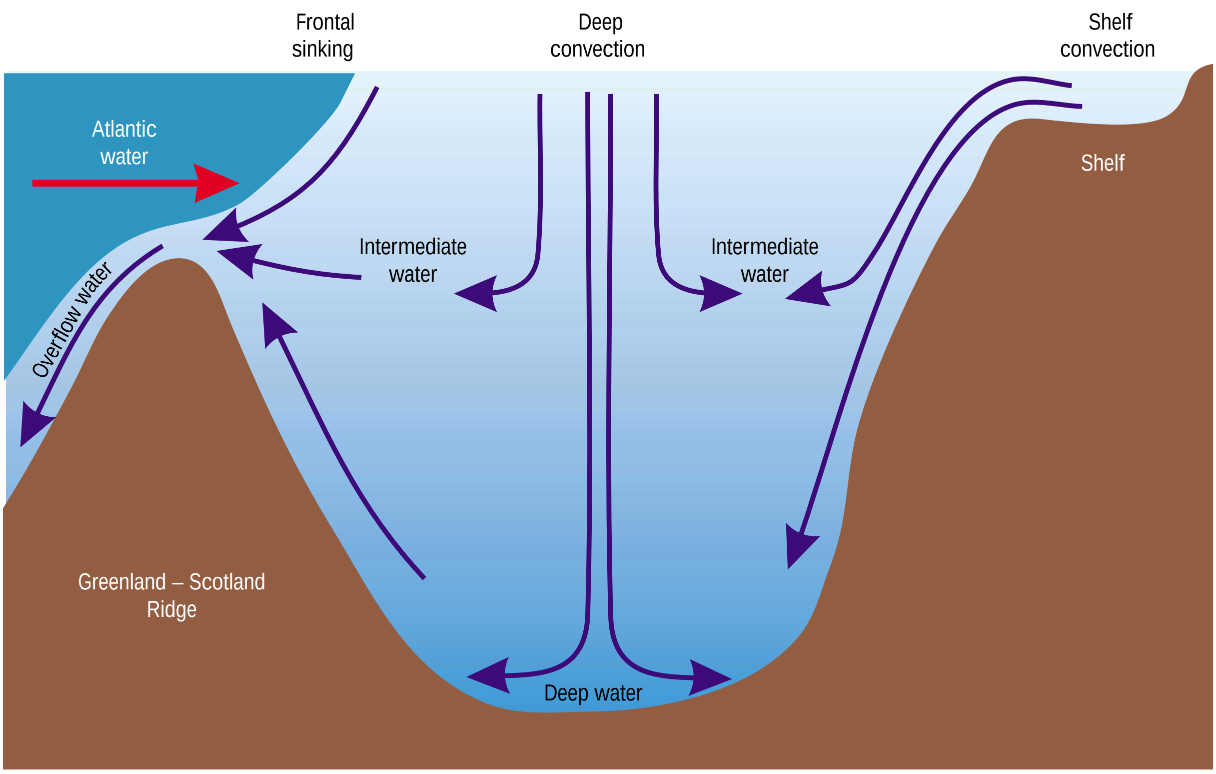
The formation of deep and intermediate waters in the northern parts of Region I is recognised as one of the most important features in the global thermohaline circulation. At least three different processes contribute to the formation of these waters, as illustrated in *Figure 2.4*. Greenland Sea Deep Water is formed by the first of these, termed 'deep convection', through cooling during winter, mainly in the centre of the Greenland Sea Gyre, which circulates cyclonically (anticlockwise) around the deep Greenland Basin. If the salinity of the Arctic surface water is close to the salinity of the deep water, there will be little salinity stratification. The density increase in the surface layer due to the winter cooling may then be sufficient for sinking of surface waters to great depth (Nansen, 1906), in extreme cases to the basin floor (deep winter convection). On the other hand, a low surface salinity will be associated with more stratified conditions and the cooled surface waters will only become sufficiently dense to sink to intermediate depths, even when the water reaches freezing point. Greenland Sea Deep Water is therefore not formed every winter.

Eurasian Basin Deep Water, on the other hand, is thought to derive from the second type of process, termed 'shelf convection', which involves the formation of bottom water on the adjacent shelves. For example, in the Barents Sea such water (of temperature < -1.7 °C and salinity > 35.0) is formed over shallow banks by winter cooling and brine rejection during ice formation (Midttun, 1985). This water will eventually leave the shelf area and sink into the Arctic Ocean. Warmer water of Atlantic origin is entrained during its descent down the slope (Aagaard *et al.*, 1985). Some bottom water from the Barents Sea also enters the Norwegian Sea through the Bear Island Trough (Blindheim, 1989) or from the Storfjord Deep (Quadfasel *et al.*, 1988).

The third formation process, termed 'frontal sinking', occurs in frontal zones, especially where Atlantic water meets colder and generally fresher water. It is characterised by tongues of mixed water sinking between the two primary water masses in the front (Blindheim and Ådlandsvik, 1995).

Deep convection and shelf convection may produce both intermediate and deep water masses, while frontal sinking mainly results in intermediate water. The waters

Figure 2.4 **Intermediate and deep water formation to the north of the Greenland–Scotland Ridge.**



which these processes continually transport downwards from the upper layers, leave the area by flowing over the Greenland–Scotland Ridge *(Figure 2.4)*. This ‘overflow’ contains both deep and intermediate waters from north of the ridge. In the Atlantic, all the overflow water descends to deep levels, and the term ‘deep water formation’ is commonly used to denote the processes producing both deep and intermediate waters in Region I.

2.7.4 Estuarine and coastal waters

In addition to the open ocean water masses previously discussed, a number of different waters are found in fjords and other estuaries along the coasts of Region I. Depending on the estuary type, residence time, freshwater input and mixing conditions etc., widely varying characteristics are found. Generally, the salinities of these water masses are lower than in the open ocean due to increased freshwater input from land. As the estuarine waters propagate offshore, they mix with the more saline ocean waters, and often a fairly well defined coastal water mass of intermediate salinity is formed in the shelf region. Examples of this type are the coastal waters around Iceland and around the Faroe Islands. Their relatively long residence times are due to the semi-closed circulation systems around these islands.

2.8 **Circulation and volume transport**

In contrast to most other oceanic areas, the circulation in Region I is truly three-dimensional. Both the upper and deeper layers have complicated systems of horizontal currents, but in addition the deep water formation *(Figure 2.4)* induces a vertical exchange. The areas north of the Greenland–Scotland Ridge therefore have a net inflow from the Atlantic in the upper layers and a net outflow to the Atlantic in the deeper layers.

2.8.1 Circulation in the upper layers

In the open ocean areas of Region I, circulation in the surface and upper layers is largely dominated by the inflow and spread of warm, saline Atlantic water. In addition, there are two currents that flow along the western and eastern borders of the region respectively, both carrying fresher waters. The first is the East Greenland Current, which transports Polar and Arctic water southwards along the East Greenland coast, while the other is the Norwegian Coastal Current, which flows northwards along the Norwegian coast. Due to the Earth’s rotation, the warm northerly Atlantic inflow and the Norwegian Coastal Current are concentrated in the east of the region, while the cold southerly East Greenland Current dominates the western part *(Figure 2.5)*. This is the main reason for the large temperature difference between the eastern and western parts of the Nordic Seas.

To some extent the upper layer circulation can be seen as one boundary current (Mauritzen, 1996), which enters the region close to the European continent as the inflow of Atlantic water, continues northwards along the Norwegian coast as the Norwegian Atlantic Current, enters and circles the Arctic Ocean and then leaves the region as the East Greenland Current, all the time hugging the continental slope to its right.

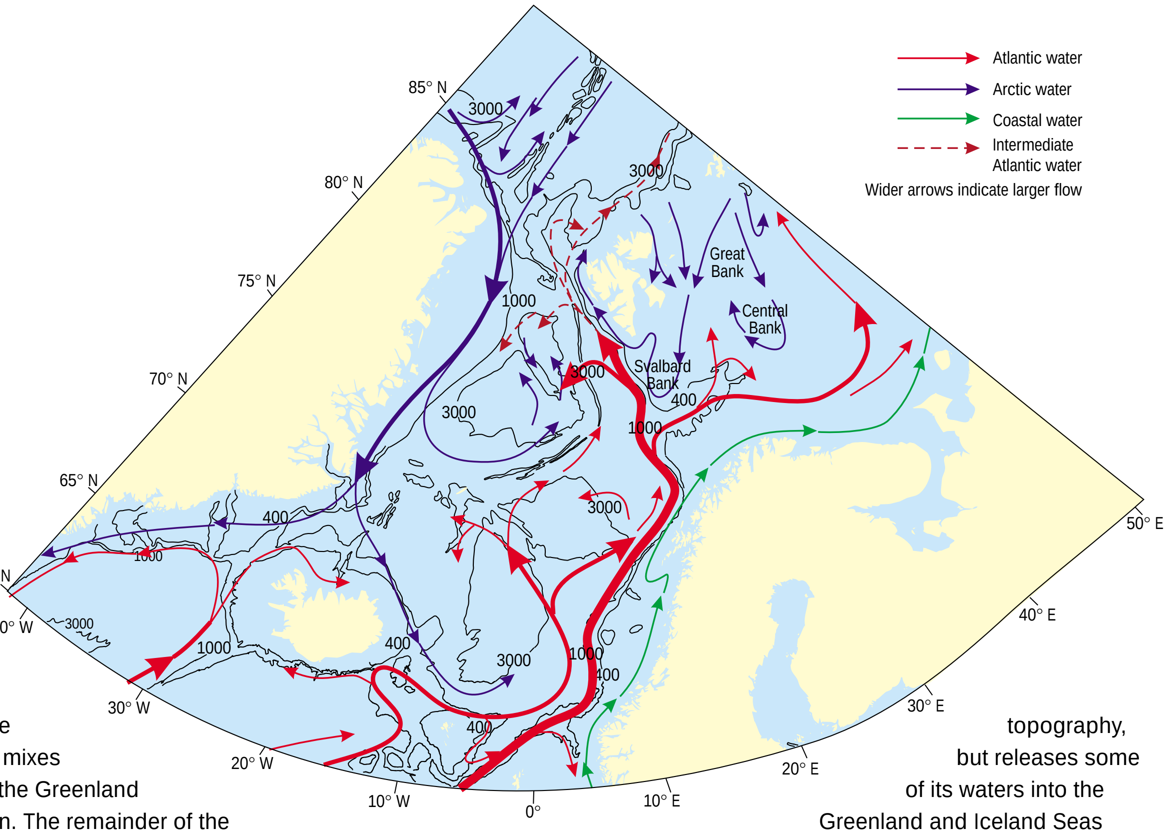
However, as shown in *Figure 2.5*, the Atlantic inflow is not restricted to the eastern border of the region. There is a branch of Atlantic water flowing into the region between Greenland and Iceland (the North Icelandic Irminger Current) and another inflow between Iceland and the Faroe Islands (the Faroe Current), in addition to the flow between the Faroe Islands and Scotland. Some of the water in the Faroe Current joins the Norwegian Atlantic Current to flow northwards while the rest recirculates in the southern Norwegian Sea. The water carried by the North Icelandic Irminger Current encounters intense mixing and cooling north of Iceland and rapidly looses its characteristics.

The two north-westernmost Atlantic inflows thus deliver a considerable proportion of their heat and salt content to the southernmost parts of the Nordic Seas, carrying Modified North Atlantic Water. The other Atlantic water mass, North Atlantic Water, only enters the region through the gap between the Faroe Islands and Scotland and is mostly carried by the Continental Slope Current. This branch affects the North Sea, the Norwegian Shelf and the Barents Sea more directly. The two Atlantic water masses thus to some extent influence different parts of Region I and, due to their different origins, may carry different contaminant loads.

Off the Barents Sea shelf, where the distance to the mid ocean ridge becomes short, the Atlantic water again merges into a narrower flow along the slope. But in the same area there are openings where branches can divert into the Barents Sea, the main one following the southern slope of the Bear Island Trough. This branch flows into the southern Barents Sea as the North Cape Current *(Figure 2.5)* where it mainly flows in an easterly direction towards Novaya Zemlya north of and parallel to the coastal current, progressively being diluted and cooled. Most of this water turns north near Novaya Zemlya to dwindle into the Kara Sea north of these islands.

The remainder of the Norwegian Atlantic Current continues northwards along the Barents Sea shelf. It sends branches westwards towards the Greenland Sea while the rest continues towards the Fram Strait, here known as the West Spitsbergen Current. In the Fram Strait much of its water leaves the main flow to circulate back into the Greenland Sea where most of it is found as intermediate water in the East Greenland Current, but where

Figure 2.5 **Upper layer circulation (0 – 500 m) in Region I.**



some also mixes into the Greenland Basin. The remainder of the West Spitsbergen Current continues into the Arctic Ocean, diving beneath the fresher and lighter surface layer, supplying new water to the Atlantic Layer below about 200 m in depth. In addition to the thin mixed layer of Polar Water in the upper 50 m, the surface layer at this point also includes the so-called halocline layer. This is a depth interval where much of the water derives from the surrounding shelves and where the salinity, and consequently the density, increases rapidly with depth (Aagaard *et al.*, 1981). The main flow here follows the bathymetry eastwards along the Siberian shelf.

In addition to the Atlantic inflow, two major currents enter Region I. From the south-eastern corner of the region the Norwegian Coastal Current carries Norwegian Coastal Water northwards along the coast, receiving inputs from the Norwegian fjords. From the opposite corner the East Greenland Current carries Polar Water and Arctic Surface Water towards the Denmark Strait.

The Norwegian Atlantic Current confines the coastal waters to the Norwegian shelf area and to the Finnmark and Murmansk coastal areas in the Barents Sea, although coastal water may be transported offshore particularly in the summer in a light surface layer and later mixed into the Atlantic water (Helland, 1963; Mauritzen, 1996).

The East Greenland Current also follows the bottom topography, but releases some of its waters into the Greenland and Iceland Seas influencing the hydrographic conditions to the north of Iceland. The different basins of the Nordic Seas tend to have cyclonic circulation cells, which in the eastern part mostly contain cooled and diluted Atlantic water in the upper layers, while the western gyres are dominated by Arctic Surface Water. In the Iceland Sea, the East Icelandic Current brings Arctic and occasionally Polar Water to meet the Atlantic water in the frontal region between Iceland and the Faroe Islands.

A front between water masses of Atlantic and Polar origin also occurs in the western part of the Barents Sea. The influx of Arctic water to the Barents Sea takes place along two main routes: between Svalbard and Franz Josef Land and, more importantly, through the opening between Franz Josef Land and Novaya Zemlya (Dickson *et al.*, 1970). The main part of the latter flows as the East Spitsbergen Current southwards along the coast of Svalbard. The current flowing south-westwards south of Franz Josef Land is called the Persey Current and splits north of Central Bank. The main part of the Persey Current flows south-westwards along the eastern slope of the Svalbard Bank as the Bjørnøya Current and plays an important role in the physical conditions of the area. A small inflow from the Kara Sea also occurs south of Novaya Zemlya.

The current directions shown in *Figure 2.5* are valid for the whole water column throughout most of the Barents Sea with a few exceptions such as in the areas to the west and south of Great Bank where Atlantic water sinks below the lighter Arctic water. Here, the current direction in the deeper layer is opposite to that at the surface.

The Norwegian Coastal Current and the East Greenland Current are both examples of coastal currents that carry water of relatively low salinity along the coasts, with the land to their right. Similar, although less pronounced, currents are found near islands in Region I, most notably the Icelandic Coastal Current that circles anticyclonically (clockwise) around Iceland.

2.8.2 Circulation in the deeper layers

The inflows of Atlantic water, Norwegian coastal water and river run-off to the region north of the Greenland–Scotland Ridge are to some extent compensated for by the outflows (e.g. the East Greenland Current) within the upper layer. As these outflows however are smaller than the inflows, the balance is restored by the conversion of Atlantic water into intermediate and deep waters and the outflow of these waters across the Greenland–Scotland Ridge. This is illustrated in *Figure 2.4.* These intermediate and deep water masses are colder and denser than water at corresponding depths in the North Atlantic. Their outflow therefore occurs as a bottom current that overflows the Greenland–Scotland Ridge and sinks to great depth in the Atlantic, from where it spreads into the rest of the World Ocean.

The information available does not allow a complete mapping of the deep currents in Region I, but *Figure 2.6* highlights the main features of the intermediate and deep water flow. Intermediate and deep water flows over the ridge both through the Greenland–Iceland gap and the Iceland–Scotland gap, although the ratio of deep to intermediate water appears to be highest for the overflow between the Faroe Islands and Scotland where the deepest passage across the ridge is located. Deep water formation does not occur everywhere in Region I and also occurs outside the region. Throughout most of Region I, the intermediate and deep water found in a particular area has not therefore been formed locally, but has travelled a considerable distance from its origin. The period of time since a water mass was in contact with the atmosphere and the surface waters, plus their contaminant loads, is denoted the 'age' of the water and this varies from one region to another, ranging from less than a decade to more than 200 years. The oldest water in Region I is the bottom water of the Eurasian Basin in the Arctic Ocean and its age has been estimated at 290 years

Figure 2.6 **Intermediate and deep water circulation in Region I.**

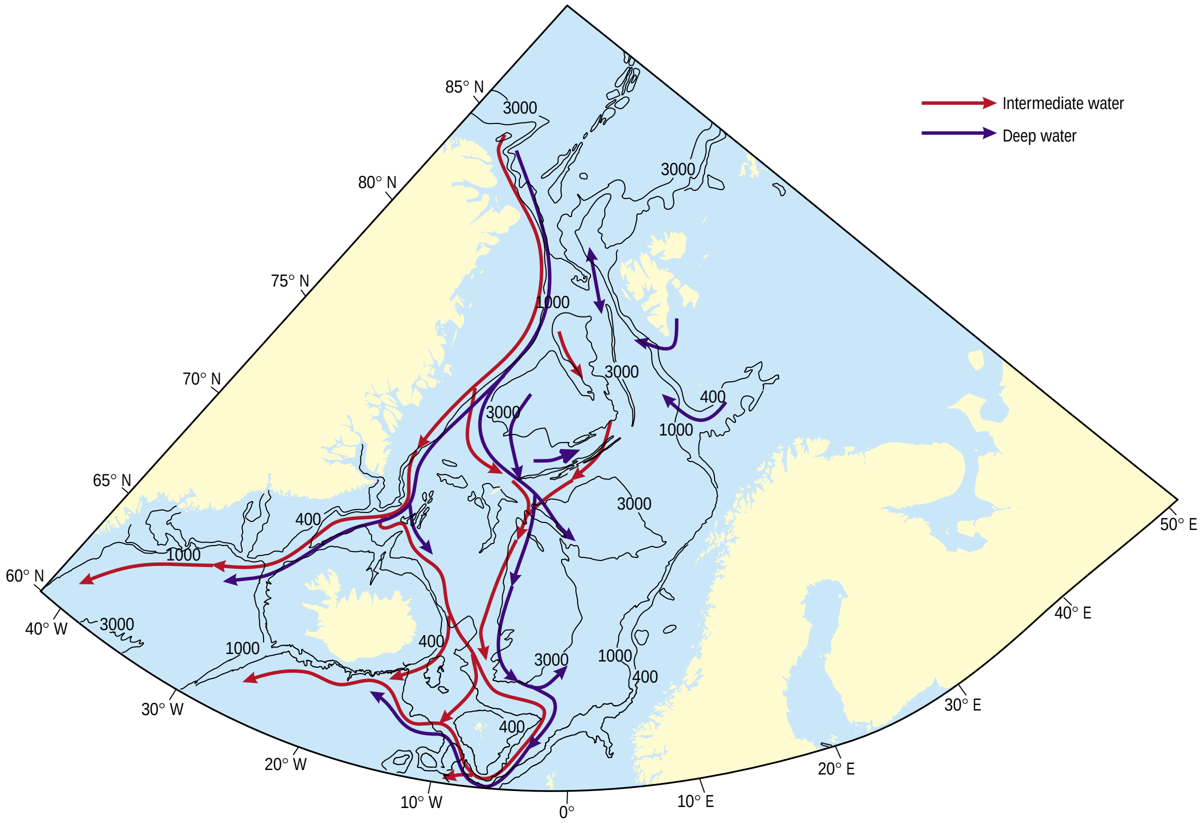
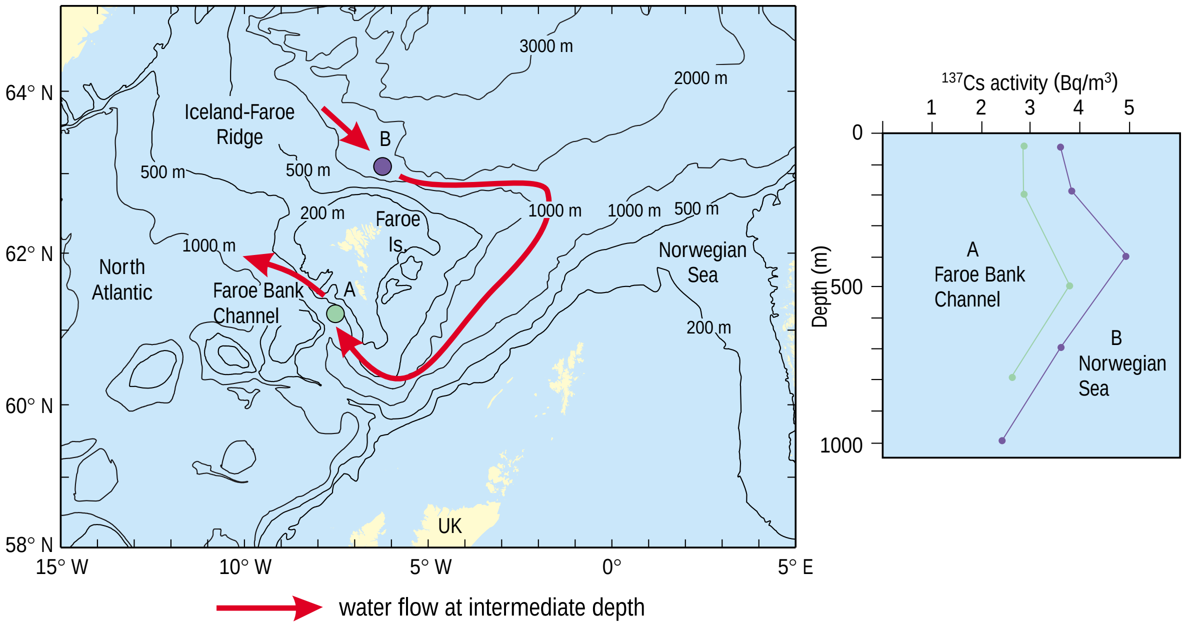


Figure 2.7 **Depth variation of ^{137}Cs activity to the north and south of the Faroe Islands. Source: adapted from Dahlgaard *et al.* (1998).**



(Heinze *et al.*, 1990; Bönisch and Schlosser, 1995). The intermediate waters belong to the younger varieties and the overflows, which are a mixture of deep and intermediate waters, contain waters of variable age.

The deep water formation in Region I and its overflow into the Atlantic Ocean is an important process for transporting dissolved contaminants from the upper layers into the deeper parts of the oceans. This is exemplified by *Figure 2.7* which shows a peak in ^{137}Cs activity at intermediate depths in the Norwegian Sea north of the Faroe Islands. This peak derives mainly from the Sellafield reprocessing plant and the Chernobyl accident and has travelled a long way, following the surface flows *(Figure 2.5)* almost north to the Fram Strait before turning southwards and sinking to intermediate depths. The water flow brings this peak to the Faroe Bank Channel and from there into the deep water of the World Ocean.

2.8.3 Volume transport

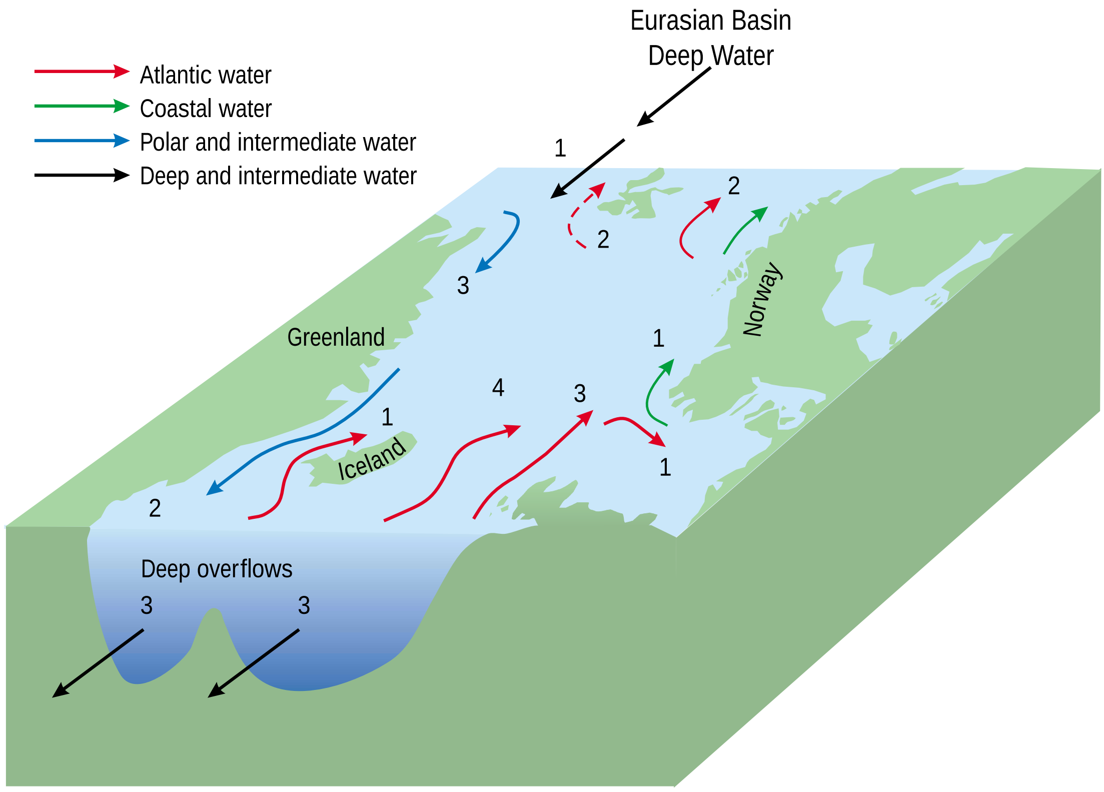
In the scientific literature, a number of estimates may be found for the volume transport of the various flows into and out of Region I. Most of these however are based on classical geostrophic computations using hypothetical reference levels or on other methods using uncertain assumptions or incomplete observations. Only recently have observational programmes been carried out with modern instrumentation that allows total budget estimates.

The results are still somewhat uncertain but do form a fairly consistent picture of the water balance of Region I as a whole. *Figure 2.8* illustrates the water budget of the Nordic Seas. A total of about 8 Sverdrup of Atlantic waters enter the region across the Greenland–Scotland Ridge (Hansen *et al.*, 1999); around 1 Sverdrup of this input making a detour into the North Sea and the Baltic before returning to Region I in a heavily diluted form via the Norwegian Coastal Current. From the Arctic Ocean there is an additional input, amounting to approximately 3 Sverdrup, in the upper layers (above 700 m) of the East Greenland Current (Foldvik *et al.*, 1988) and 1 Sverdrup of Eurasian Basin Deep Water (Bönisch and Schlosser, 1995).

The compensating outflows from the Nordic Seas occur mainly in the deeper layers in the form of the deep overflow through the Denmark Strait (Dickson and Brown, 1994) and the Iceland–Scotland gap. These gaps have approximately equal amounts of overflow, with a total volume transport amounting to around 6 Sverdrup. To balance the budget requires a total outflow of 6 Sverdrup from the Nordic Seas in the upper layers. This is consistent with available evidence and the upper layer outflow seems to be almost equally distributed between three gaps; 2 Sverdrup northwards through the Fram Strait (AMAP, 1998), 2 Sverdrup into the Barents Sea (Blindheim, 1989) and 2 Sverdrup southwards through the Denmark Strait. A reliable flux estimate for the East Greenland Current through the Denmark Strait using modern instrumentation is lacking, but the 2 Sverdrup needed for this flow to balance the budget is not inconsistent with older estimates (Malmberg *et al.*, 1972).

In the Barents Sea, little is known about the volume of

Figure 2.8 **Approximate transport (Sverdrup) for water flows into and out of the Nordic Seas.**



water transported via the different currents. Blindheim (1989) found a mean transport of about 3 Sverdrup into the Barents Sea between Norway and Bear Island *(Figure 2.8)* and about 1 Sverdrup out through this section. Most of the outflow needed to balance this inflow is likely to be located in the channel between Novaya Zemlya and Franz Josef Land. The variability in the fluxes is of the same magnitude as the mean transports.

2.9 Waves, tides and storm surges

Wave spectra in Region I are variable. The Arctic Ocean is mainly ice covered and waves are therefore generally small in this area. The largest waves occur in the southern parts of the area where oceanic swell enters from the North Atlantic. In this area the maximum significant wave height is about 17 m while the extreme height of single waves may exceed 30 m. The annual mean wave height is 3 – 4 m (based on wave statistics and operational model results provided by the Norwegian Meteorological Institute). Generally the wave lengths are greatest in the southern part of the region, decreasing northwards.

As for all oceanic areas, the longest waves are the tidal waves. The tides are generated by the orbital inertial force and the gravitational forces between the Earth and the other bodies in the stellar system to which it belongs, principally the moon and the sun. In the Nordic Seas the leading semidiurnal (principal lunar) tide circulates anti-clockwise around two amphidromic points; one in the Denmark Strait north-west of Iceland and one between Iceland and the Faroe Islands. Generally the tidal amplitude is thought to be zero on the amphidromic points and to increase outwards. The semidiurnal tidal wave in the eastern Nordic Seas appears to sweep northwards across the Norwegian and Greenland Seas with an almost constant amplitude of about 40 cm. This wave continues further into the Barents Sea and through the Fram Strait into the Arctic Ocean. The amplitudes (half the range between high and low tide) are largest along the coast of northern Norway and the Kola Peninsula where amplitudes are near or in excess of 1 m respectively.

The tidal waves along the south-east coast of Greenland circulate around an amphidromic point at about 50° N in the western part of OSPAR Region V and the amplitudes range between about 0.4 and 0.5 m. Tidal currents are strongest near the coasts, particularly where bathymetric features form constraints for the tidal waves.

Due to the relatively steep coasts in most parts of Region I, storm surges do not create great problems. Disasters have occurred in harbours and some low-lying areas however, particularly around the equinoxes when many tidal constituents act in the same direction and there may also be low atmospheric pressure and storms.

2.10 Transport of ice

Much of the central Arctic drift ice forms in winter in the marginal seas. Ice usually forms over the outer shelf region. The two main ice circulation systems are the clockwise Beaufort Gyre in the Amerasian Arctic and the Transpolar Drift in the Eurasian Arctic *(Figure 2.9)*. The Transpolar Drift transports ice primarily from the Kara, Laptev and East Siberian Seas, towards the Fram Strait, where it exits the central Arctic Basin (Colony and Thorndike, 1985).

Changes in ice circulation patterns may be related to fluctuations in continental discharge and ice extent, as well as to variations in atmospheric conditions. Icebergs released in the Siberian seas may be advected off the shelf to be transported in the Transpolar Drift across the Arctic to the East Greenland Current in the Fram Strait. Here, they join icebergs calved from East Greenland. Transport from the Laptev Sea to the Fram Strait typically takes about three years in the Transpolar Drift. Kara Sea

Figure 2.9 **Major patterns of ice circulation. Source: AMAP (1998).**

ice incorporated in the Transpolar Drift may exit through the Fram Strait in two years (Rigor, 1992), while transport to the Barents Sea takes less than a year. The main exit for ice in the central Arctic is through the Fram Strait *(Figure 2.9)*. Each year, about 2600 km^3 of sea ice (representing about 1 x 10^6 km^2) is exported through this region in the East Greenland Current (Kvambekk and Vinje, 1993).

There are seasonal variations in ice exchange. Both the Barents and Kara Seas export ice to the Arctic Basin in winter and import ice in summer (Zakharov, 1976). According to Vinje (1987), approximately 629 km^3 of ice is exported each winter from the Kara to the Barents Sea through the strait between Franz Josef Land and Novaya Zemlya. During June to September, 72 km^3 of ice are imported from the Barents Sea (Vinje, 1987), giving a net flux of 557 km^3 per year. Other sources indicate that the net annual flux from the Kara to the Barents Sea through this strait could be as low as 198 km^3 (Pavlov *et al.*, 1994).

Although much of the sea-ice in the Barents Sea forms locally, it also receives ice from the Kara Sea and the Arctic Ocean. More than 40% of the ice may be multi-year ice (Loeng and Vinje, 1979). According to Vinje (1985), the Barents Sea imports 37 km^3 from the Arctic Ocean each year and exports 72 km^3. Most of that imported from the Arctic Ocean is between April and June. Ice cores from the western Barents Sea in May 1989 confirm that much of the sea-ice sampled was imported from elsewhere. Pfirman *et al.* (1995a) suggest that some of the ice could have formed on the Siberian shelf in waters influenced by river discharge. On the basis of sea-ice diatom assemblages, Abelmann (1992) concluded that ice sampled to the east and north of Svalbard in 1987 probably originated in parts of the Kara or Barents Seas that had some river influence.

Ice forming over shallow Siberian seas often includes sediments and organic material. Because many contaminants of concern in the Arctic tend to adsorb onto particulate material (Stumm and Morgan, 1981), particle-laden ice may also be contaminant laden (Pfirman *et al.*, 1995b).

The main exit for Arctic sea-ice is through the Fram Strait. Between 50 to 85% of the ice discharge consists of multi-year and second-year ice (Vinje and Finnekåsa, 1986), which potentially contains accumulated contaminants. The marginal ice zone extends southwards from the Fram Strait, along the eastern slope off Greenland. In winter, ice also continues around the southern tip of Greenland and extends up into Baffin Bay.

2.11 Meteorology and climate

Most of Region I is characterised by low air temperatures. This is because, on an annual basis, it receives less solar radiation than at lower latitudes. However, the radiation levels vary greatly depending on the season; in the winter months, there is an almost total lack of incoming solar radiation, while in the summer, the poles receive higher levels of solar radiation than any other place on Earth.

The annual amount of solar radiation received however is less than that lost to space by long wave radiation. In addition, a large proportion of the solar radiation reaching the Earth is reflected by extensive cloud, snow and ice cover. This radiation imbalance produces low temperatures and results in a redistribution of heat from southern latitudes via air and ocean currents (Varjo and Tietze, 1987). This energy regime is the fundamental factor driving the climate in Region I.

The large-scale air circulation over the North Atlantic is determined by the Icelandic low pressure area (the 'Icelandic Low') and the high pressure areas over Greenland and the Central Arctic Basin. The prevailing winds are westerly or south-westerly between Iceland and Scandinavia, transporting warm and humid air from lower latitudes towards the Arctic. Further north, the circulation is generally anticyclonic around the pole with easterly and north-easterly prevailing winds. Strong winds over large areas are associated with intense depressions. These winds are most frequent in the Atlantic sector of the Arctic where they follow a track from Iceland to the Barents Sea in winter.

Climatic conditions in Region I are divided into maritime and continental subtypes. A maritime climate is characteristic of Iceland, the Norwegian coast and the adjoining parts of Russia. These areas have moderate, stormy winters. The summers are cloudy, but mild with mean temperatures of about 10 °C. The average winter temperatures are -2 to 1 °C in the Icelandic lowland, -2 °C in Bodø on the Norwegian coast and -11 °C in Murmansk on the Russia coast (Barry and Chorley, 1992; EEA, 1996). Over the ice-covered Arctic Ocean, both the ice and the underlying sea have a regulating effect on temperature.

Moving depressions, and heat transported by ocean currents, have a warming effect on the climate. The extent of this effect can be shown by comparing temperatures at sites of similar latitude. The average January temperature at a site on the Canadian Arctic Archipelago is approximately 20 °C lower than the January temperature at a site at the same latitude on Svalbard. Towards the east of Svalbard, the winter temperature decreases more slowly. The warming effect of the moving depressions extends as far as the north-eastern parts of the Barents Sea. During the summer, temperature variations along a given latitude are much reduced, due to the moderating effect of the heat of the sun.

As in the atmosphere, there is both annual and inter-annual variability in ocean temperature. This is most pronounced in the warmer water masses. Variability in cold Arctic waters is small, but important. The North

Atlantic appears to alternate between warm and cold states. The length of these states may vary, but fluctuations with periods of three to five years are most frequent. The temperature condition of the western North Atlantic is opposite to that of the eastern North Atlantic. This means that when the Barents Sea is in a warm state, the coast of Newfoundland is in a cold state.

The temperature state of the ocean appears to be closely linked to atmospheric circulation, with a positive feedback mechanism existing between the atmospheric and oceanic circulations. It seems that high atmospheric pressure is associated with low temperatures in the ocean, while low atmospheric pressure is related to a warmer ocean. Changes in ocean climate influence transport mechanisms and ice cover. In warm years, there is an increased transport of warm water masses to the Arctic, resulting in decreased ice cover. In cold years, transport of warm water to the Arctic is reduced and sea-ice cover is greater (Ikeda, 1990a,b; Ådlandsvik and Loeng, 1991).

The total annual precipitation in the Arctic is generally < 500 mm and typically between 200 and 400 mm (Loshchicov, 1965). In coastal areas of Region I, the precipitation is higher, and over the central Polar Basin it is lower. Cold air cannot contain much moisture, so although the frequency of precipitation may be high, the overall intensity is low. This explains why the total accumulation of snow is relatively low in winter over much of the Arctic.

Maritime areas in the subarctic have much higher precipitation. In southern Iceland, the annual precipitation ranges from < 800 mm to > 3000 mm, and on mountains and glaciers it is known to exceed 4000 mm (Einarsson, 1984). The precipitation decreases towards the east and north with 700 – 2000 mm in Bodø to < 400 mm in Murmansk, Russia and Longyearbyen, Svalbard.

In the marine environment, wind affects sea surface stability and increases mixing in the water column. It also influences ice drift (Vinje, 1976) and the formation of polynyas. Winds, or more precisely differences in air pressure which cause winds, are often closely related to ocean circulation (Ikeda, 1990b; Ådlandsvik and Loeng, 1991).

2.12 Climate variability

Climate is highly variable in the North Atlantic because of variations in the external forcing and internal instabilities. Two major processes drive circulation in the region; the northwards flow of surface water across the ridges between Scotland and Iceland into the Norwegian Sea, and the deeper outflows across the ridges. Dickson *et al.* (1996) linked this variability to the large-scale oscillations in atmospheric mass between the Icelandic Low and the Azores High, the so-called North Atlantic Oscillation (NAO). This oscillation is the dominant source of variability in atmospheric behaviour in the North Atlantic explaining 32% of the variance in monthly sea level pressure.

The index of NAO variability is determined from the difference between atmospheric pressure measured at Iceland and the Azores. When pressure is low over Iceland and high over the Azores the index is highest, and is low when this difference is reduced or even, on occasions, reversed in sign. Oscillations in the NAO index undergo long-term cycles with different periodicities. The index was particularly low during the 1880s and 1960s, and particularly high during the 1920s and 1990s. These oscillations have been linked to fluctuations in wind speeds, heat fluxes, wave heights, storm tracks, patterns of evaporation and precipitation, and quantities of sea-ice in the Labrador Sea. For example, during the late 1950s, winter convective mixing in the Greenland Sea became progressively deeper. Since the early 1970s, the depth of mixing has steadily diminished with the result that there has been no renewal of water below 1600 m, and none below 1000 m since the 1990s (Dickson *et al.*, 1996). Deep water in the Greenland Sea has become warmer and more saline since the early 1970s.

During the 1960s a major intrusion of fresher water was identified leaving the Greenland Sea. This became known as the ‘Great Salinity Anomaly’ and took fourteen years to circulate around the North Atlantic subpolar gyre, eventually re-entering the Norwegian Sea via the Norwegian Atlantic Current in the mid 1970s (Dickson *et al.*, 1988). Since then, high salinity anomalies have been reported from the English Channel, and also the turnover of the deep water in the Labrador Sea has increased. There is evidence that a similar cycle of events occurred in the 1920s. These strong climatic variations in the characteristics of the water masses in the North Atlantic appear to be generated by cyclic events rather than to represent progressive change.

A second Great Salinity Anomaly appeared in the West Greenland Current in 1982 and again circulated around the subpolar gyre (Belkin *et al.*, 1998). It finally re-entered the Norwegian Sea in 1987/8, reaching the Barents Sea in 1988/9 and the Iceland Sea in 1989/90. It thus took six to seven years to complete its circuit of the subpolar gyre. Another salinity anomaly has been circulating around the North-east Atlantic during the 1990s (Belkin *et al.*, 1998). The anomalies appear to have had different origins. The Great Salinity Anomaly of the 1970s resulted from a boost in inputs of freshwater and sea-ice from the Arctic into the North Atlantic via the Fram Strait. This coincided with a marked increase in the extent of sea-ice in both the Greenland Sea and the Iceland Sea. The two later anomalies formed locally in the Labrador Sea/Baffin Bay region and were the product of extreme winters, supplemented by abnormally high outflows of freshwater from the Canadian Archipelago driven by strong northerly winds. While the extent of sea-ice in the Labrador Sea increased at the time, there was no increase in the ice cover upstream in the Greenland Sea. Thus, these salinity anomalies may either be remotely forced or formed locally in the Labrador Sea.

2.13 Climate change

Climate change, as distinct from climate variability, reflects the effects of anthropogenic releases of carbon dioxide and other greenhouse gases on the global climate system. The deep water formation gives Region I a unique role in this respect. The cold deep and intermediate waters overflowing the Greenland–Scotland Ridge into the Atlantic are a key component of the deep circulation of the World Ocean as a whole, and form a link between the atmosphere and the deep ocean. The Atlantic water which flows into the Nordic Seas to compensate for the deep overflows is critically important in relation to the regional climate, making parts of Region I much warmer than would otherwise be the case. Processes occurring in Region I may therefore be critical to the development of the global climate, while changes in the global climate may affect Region I in ways not seen elsewhere. The importance of this point must be stressed, as this will form the basis of the future European climate.

2.13.1 Global effects of deep water formation

As discussed in Sections 2.7 and 2.8, deep and intermediate water masses are formed in the area north of the Greenland–Scotland Ridge by the sinking of water from the upper layers to the deeper levels. This water flows southwards *(Figure 2.6)* and passes over the ridge in several places in the form of an 'overflow' *(Figure 2.4)*. The overflow water is much colder than water at similar levels in the Atlantic. During and after its passage over the ridge the overflow entrains Atlantic water, approximately doubling its volume flux. Although this increases its temperature the resulting water mass is still considerably denser than the surrounding waters and it sinks to appreciable depths as it propagates southwards through the deeper parts of the Atlantic.

Together with a smaller and less dense component, derived from sinking in the Labrador Sea, this mixture becomes the North Atlantic Deep Water that propagates southwards through the Atlantic and on into the Indian and Pacific Oceans, forming the so-called Global Conveyor Belt *(Figure 2.10)*. The sinking of waters in Region I is therefore a key process in the global thermohaline circulation and is a dominant contributor to the renewal of the deep waters of the World Ocean as a whole. In this way, the process becomes a vital link between the atmosphere and the deep parts of the World Ocean, which contain by far the largest fractions of heat and carbon dioxide in the global climate system.

2.13.2 Effects of the Atlantic inflow

In comparison to the rest of the World Ocean, the eastern parts of the Nordic Seas are seen to have exceptionally mild temperatures at the surface *(Figure 2.11)*. Nowhere

Figure 2.10 **Schematic illustration showing the thermohaline circulation of the global ocean. Source: after Broecker (1991).**

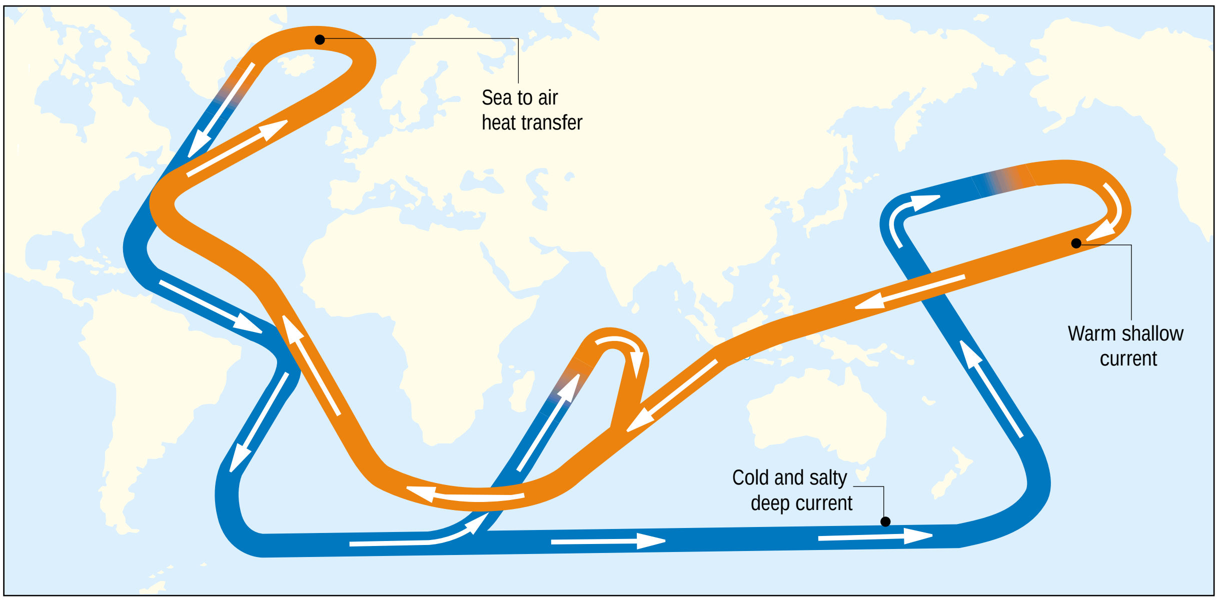
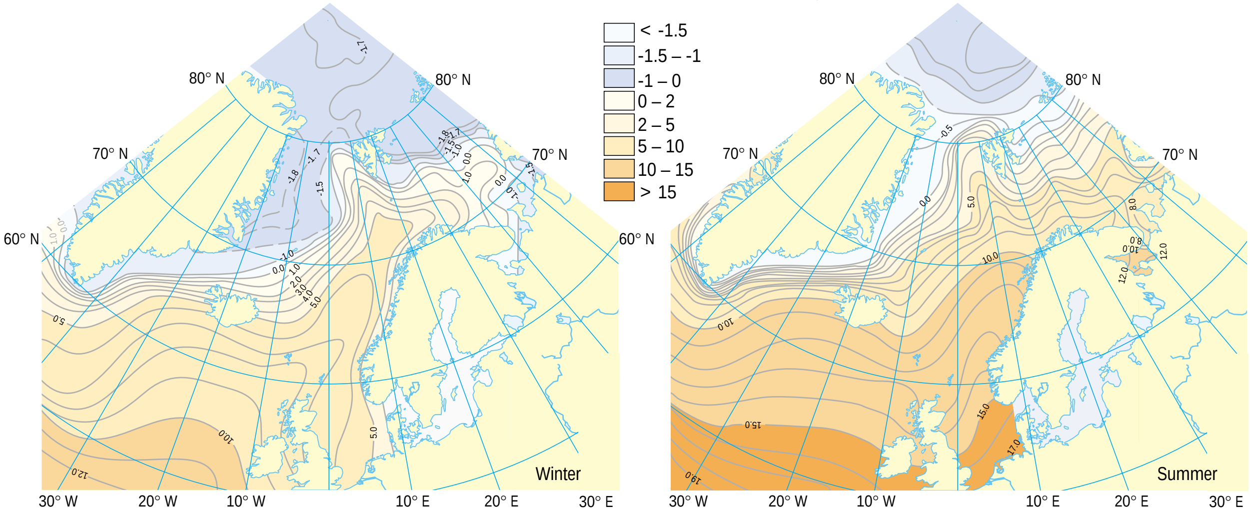


Figure 2.11 **Surface temperatures (°C) in the Nordic Seas.**



else are temperatures as warm found so close to a polar region. The main reason for this situation is the North Atlantic Current which brings warm waters into these areas from the south, increasing temperatures by 5 – 10 °C relative to waters at similar latitudes (N and S) elsewhere.

Two main forcing mechanisms affect the Atlantic inflow. The first of these is the wind. Wind blowing over the surface of the sea induces a drag on the water below. Although the force from the wind is in the direction of the wind, the Coriolis force from the Earth's rotation tends to deflect the flow towards the right (north of Equator) unless compensated for by other forces. The second driving mechanism comes from the pressure gradients set up by the deep water formation north of the Greenland–Scotland Ridge. This process transports cold waters from the upper layers downwards and so increases the density of the deeper layers. This creates a horizontal pressure gradient at depth between the Nordic Seas and the Atlantic and this drives the overflows across the ridge. The outflow of water at depth will, however, tend to lower the water surface north of the ridge which induces a pressure gradient at the surface in the opposite direction to that at depth and this drives the inflow of Atlantic water into the areas north of the ridge.

A quantitative assessment of the relative contributions from these two forcing mechanisms is not available and is to some extent meaningless anyway, since they are not independent. However, the water budget in *Figure 2.8* indicates the importance of the deep water formation for the Atlantic water inflow to Region I; of the 8 Sverdrup of Atlantic water estimated to cross the Greenland–Scotland Ridge, 6 Sverdrup are found to return through the deep overflows. If deep water formation north of the ridge were to diminish, the volume transport of the Atlantic water inflow would also be expected to diminish as well, unless the surface outflows increased.

2.13.3 Stability of the deep water formation

Deep water formation is one of the major forces driving the Atlantic water inflow. This inflow carries a surplus of salt towards the deep water formation areas and so increases the density of the upper layers, thus increasing the possibilities for deep water formation. This is one example of a positive feedback loop that could destabilise the deep water formation.

From palaeoceanographical investigations there are indeed indications that the deep water formation may not be stable. During the last glacial maximum, about 20 000 years ago, the production of dense North Atlantic Deep Water appears to have been less (Charles and Fairbanks, 1992) and abrupt (within less than 40 years) temperature drops of more than 5 °C have been identified within the Norwegian Sea (Lehman and Keigwin, 1992). More recent variations in the exchanges between the Atlantic and the Nordic Seas have also been implied (Bond *et al.*, 1997), and sediment cores south-west of Iceland have shown variations in the overflow from the Faroe Bank Channel (Bianchi and McCave, 1999). These results indicate that the overflow, and hence probably also the Atlantic water inflow, was at a minimum about 400 years ago when the regional climate was extremely cold ('the little Ice-age').

2.13.4 Potential impact of greenhouse gases

The indications of instability in the deep water formation system are a major concern, since an unstable system may respond more dramatically to external forcing than a stable system. Climate models predict exceptionally large warming of the areas close to the North Pole due to anthropogenic releases of carbon dioxide and other greenhouse gases with increased ice melting and fresh water supply (IPCC, 1995). If the increased amounts of freshwater are spread over large areas, they may decrease the salinity, and hence also the density, of the upper layers. This opens the possibility for reduced deep water formation north of the Greenland–Scotland Ridge, reduced production of dense North Atlantic Deep Water and a reduced inflow of Atlantic water to Region I.

Quantitative predictions about the probabilities of these changes and their severity require global models that couple the atmosphere, the ocean and the other components of the climate system. Although the present generation of such models supports the qualitative arguments for reduced deep water formation as a consequence of increased carbon dioxide releases, they all predict cooling instead of warming in areas affected by the reduced Atlantic inflow (IPCC, 1995). However, insufficient computer power and a lack of knowledge about basic physical processes restrict these models very severely and their predictions are currently hampered by large uncertainties.

The Intergovernmental Panel on Climate Change concluded in their 1995 assessment that: ‘The balance of evidence suggests a discernible human influence on global climate’. This influence includes a global warming through the Twentieth Century, but some of the areas in Region I which are most affected by heat transport from the Atlantic inflow in fact show the opposite trend. Thus, air temperature in the Faroe Islands has decreased since the 1930s (Cappelen and Vaarby Laursen, 1998). This cooling, as well as reports indicating reduced deep water formation, are consistent with the predictions of anthropogenically induced reduction in deep water formation, nevertheless purely natural causes cannot be excluded.

chapter 3

Human activities

3.1 Introduction

Region I is characterised by its low population density, with a total population of approximately 2.6 million *(Figure 3.1)*. As a result, impacts of human activities related to settlements are relatively small and mostly local. These activities are discussed briefly in this chapter, while human activities such as fishing and petroleum production are discussed in more detail.

The limit of territorial waters is 12 nm in Iceland and Russia and 4 nm in Norway, the Faroe Islands and Greenland in which national jurisdiction is fully adopted. Denmark represents the Faroe Islands and Greenland. The 200 nm exclusive economic zone is the area in which the exploitation of natural resources is regulated by the coastal state, and where these coastal states have sovereign rights *(Figure 3.2)*. Foreign fishery vessels are granted rights within the zone according to intergovernmental agreements. Norway has established a fishery protection zone around Svalbard. The legal status of the area is disputed. There are a few areas that lie outside the limit of national fishery jurisdiction, of which two are shown in *Figure 3.2* ('Loophole' and 'Loopocean').

3.2 Demography

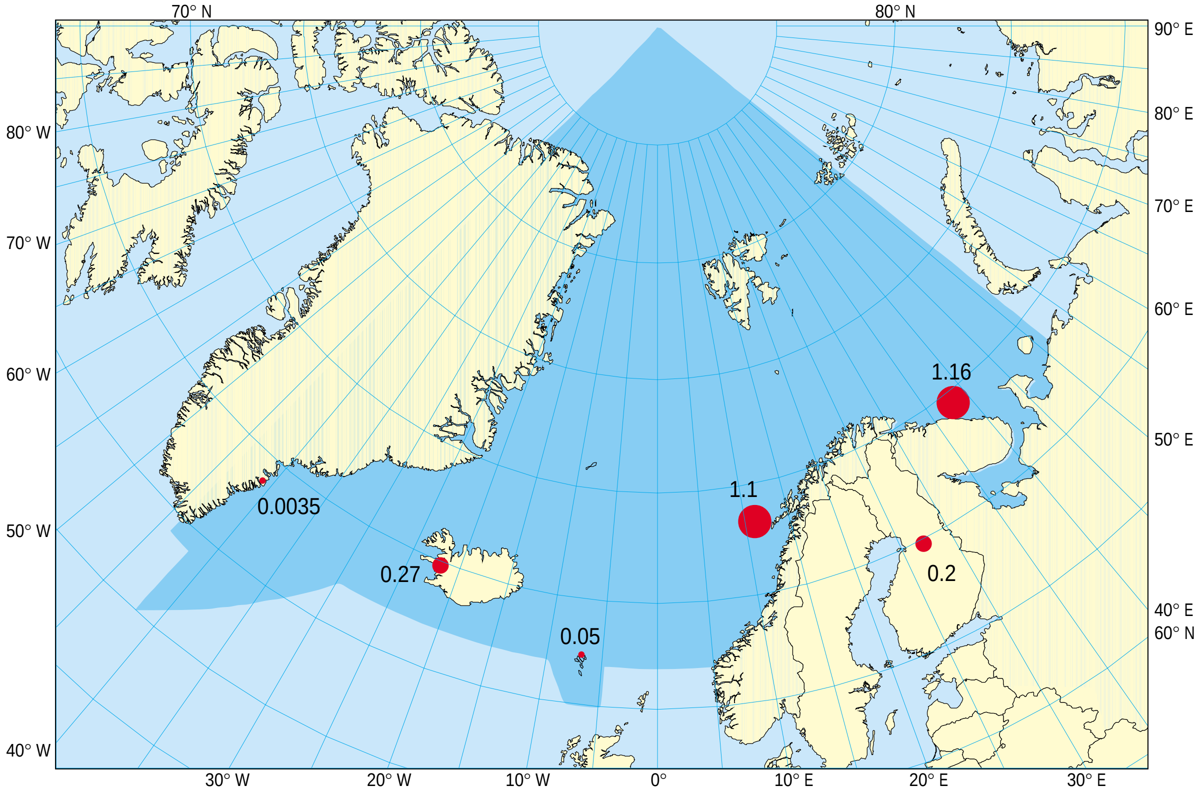
The Kingdom of Denmark consists of Denmark, Greenland and the Faroe Islands. In 1994, the total population of Greenland was 55 500. Inuits constitute 87% of the population. The rest of the population is mainly Danish. Only 3500 people live on the east coast, with most of the population on the west coast of Greenland, outside Region I. Of the total workforce, 14% are directly involved in hunting and fishing, 3% are self-employed and the remaining 83% are wage earners, mostly in the public sector. This high percentage is because the Home Rule Government owns a major share of the commercial fishing industry, transportation, technical plants and commercial warehouses.

Iceland was settled between the years 874 and 930. There has been little immigration to Iceland, and no coherent minority groups have formed. Iceland is the most sparsely populated country in Europe with an average of 2.4 inh/km^2. In 1996 the total population was 270 000. There are 31 towns of 1000 inhabitants or more. Approximately 92% of the population live in towns or villages of more than 200 people, while 8% live in rural districts. More than half the population lives in the greater Reykjavik area. 17.5% of the Icelandic workforce is employed in manufacturing industries; many in the fish processing industry. The fisheries sector, including both fishing operations and the fish processing industry, is the mainstay of the Icelandic economy. Fisheries also have indirect economic effects, since in many coastal communities fisheries are the only primary activity.

Of the eighteen islands in the Faroes, seventeen are inhabited. The capital, Torshavn, is placed on the largest island Streymoy. In 1990 the population of the Faroe Islands was 47 400. Due to an economic crisis, the population decreased to 43 400 in 1995, but has since increased. There are around 100 towns and villages in the Faroe Islands, of which the largest is Torshavn with a population of 15 000. The Faroese economy is very dependent on fish. Fishing, fish farming and fish processing account for 25% of the gross national income, and for nearly all exports. To a large extent, the other industries are suppliers to the fishing industry, and like the public sector, are highly dependent upon the income from the fishing industry.

North of 62° N Norway comprises six counties with a total area of approximately 160 500 km^2. In 1996, the population in these counties was approximately 1.1 million, a quarter of the total Norwegian population. Population density is low with an average of about 7 inh/km^2, varying from 2 inh/km^2 in the northernmost county to 17 inh/km^2 in the southern part of the region. Most people live along the coast in small villages, towns and cities. The increase in migration from remote areas,

Figure 3.1 **Population distribution (millions) in Region I.**



mainly to towns and cities in southern Norway, has been most pronounced for the three northernmost counties. In addition, there is a migration from smaller municipalities to larger municipalities and towns within northern Norway. Fishing is the most important industry and forms the economic base of the region. Some offshore petroleum industry is based in northern Norway, but the majority of the Norwegian petroleum industry is based further south in the North Sea area. The traditional homelands of the Saami are in parts of northern Norway, Sweden, Finland and north-western Russia.

Svalbard has nine settlements and in 1999 had a population of 2700. Mining and hunting have traditionally been the main activities, but the importance of new activities such as tourism and research is rapidly increasing.

The northernmost province of Finland – Lapland – has just over 200 000 inhabitants, with 50% living in the largest cities in southern Lapland. The population density is 2 inh/km^2. In 1997 around 9300 people lived in the catchment area of the Barents Sea. Service and tourism are the most rapidly growing industries in Lapland, often connected to natural attractions and winter sports. In rural areas traditional livelihoods include reindeer herding,

Figure 3.2 **Exclusive Economic Zones in Region I.**

animal husbandry, small-scale agriculture, forestry, fishing and service. Service comprises 65% of livelihoods, processing 22% and primary production 10%.

The Russian Federation has part of its coastline on the Barents Sea: the Murmansk administrative area and part of the Nenets administrative area. The Murmansk administrative area, including the Kola Peninsula, is approximately 145 000 km^2. The Nenets administrative area is 177 000 km^2. In 1989 the total population in the Murmansk administrative area was approximately 1.16 million, with around 470 000 living in the biggest city, Murmansk. Immigrants from other parts of Russia greatly outnumber the indigenous inhabitants. Less than 0.2% of the population are indigenous people (mainly Saami). In the Nenets administrative area the total population was approximately 54 000 in 1989. Indigenous people, mainly Nenets, comprised approximately 12%. Most immigrants arrived within the last century, live in cities and large towns, and are engaged in industrial activities and related support services. Mining and the smelting of non-ferrous metals are the major industries.

3.3 Conservation

Nature protection areas in Iceland, the Faroe Islands, Norway and Finland are mostly restricted to land-based areas. Information from the Russian Federation is not available. On the west coast of Iceland the inner part of Breidafjordur is protected by special law. In Norway, a total of seventeen river deltas are protected areas and three Norwegian biogeographical marine sub-provinces have been identified for protection. In 1999, an area outside central Norway was protected from fishing activity due to its unique deep-sea coral reefs. Svalbard is part of Norway. Norway has been given sovereignty to regulate activities in the Svalbard area within the framework of the Svalbard Treaty. National parks and nature protection areas constitute 56% of the total area of Svalbard.

3.4 Tourism and recreation

There is almost no tourism on the east coast of Greenland. In the Faroe Islands, there are approximately 25 000 tourist visits annually. Tourism is focused on experiencing nature (e.g. bird-watching). Tourism in the Faroe Islands has been increasing, but is still small in economic terms.

The number of foreign tourists visiting Iceland increased from 142 000 to 230 000 between 1990 and 1998. The total number of overnight stays was around 1.4 million. Tourism is focused on experiencing nature, such as visiting geysers, bird-watching and whale watching.

Specific statistics for tourism in the coastal area of northern Norway are not available, but generally the coastline is used for amenity purposes and ecotourism, for example fishing, whale watching, scuba diving, and visits to bird cliffs, fjords and coastal landscapes. The number of overnight stays in hotels in Norway has shown a general increase of 20 – 25% between 1992 and 1998. On Svalbard, tourism is limited but increasing. Although specific statistics are not available, tourism in northern Russia is probably limited and of little importance.

3.5 Fishing and hunting

3.5.1 Fishing

Ocean fisheries are among the major industries in Iceland, the Faroe Islands, Norway and the north-western part of the Russian Federation. Both Norway and Iceland are among the biggest fishing nations in the world, with an annual catch of approximately 2.6 million t and 1.5 – 2 million t, respectively.

Commercially, the most important demersal fish species in Region I is the Atlantic cod (*Gadus morhua*). The annual catches of cod have fluctuated widely in recent years *(Table 3.1)*. Fisheries for blue whiting (*Micromesistius poutassou*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and redfish (*Sebastes marinus*) are also important. Capelin (*Mallotus villosus*) and herring (*Clupea harengus*) are the most

Table 3.1 Landings (t x 10^3) of the major commercial fish species in Region I.

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Capelin	1022	1031	777	796	854	2077	1693	881	748	1495	1583
Halibut	66	71	81	62	65	44	53	47	47	49	39
Cod	976	875	743	591	514	707	834	984	941	962	1011
Haddock	214	165	137	109	87	116	134	199	211	244	213
Blue whiting	252	179	129	116	18	156	151	104	111	132	161
Redfish	221	231	171	190	187	184	194	206	162	222	193
Herring	193	220	195	175	160	238	342	630	1023	1308	1464
Mackerel	89	120	87	121	90	158	172	187	158	104	109
Shrimps	92	89	98	121	92	121	115	110	110	110	117

important pelagic fish species for the fishing fleet. There is a large shrimp fishery in the region, and in recent years test fishing for Kamchatka crab *(Paralithoides camtchatica)* has started along the northern coast of Norway. This fishery has been operating in Russia for some time.

An estimated 100 000 people in the north-west of the Russian Federation work directly in the fishing industry. There are around 10 000 full-time fishermen in northern Norway, with around 5000 people employed onshore in the fishing industry (Hoel, 1994). Fishing is the mainstay of the Icelandic economy. The fishery sector accounts for about 15% of the country's Gross National Product, over 70% of Iceland's exported goods and more than 50% of the total export revenue, although the actual number of people employed is low compared to other fishing nations. There are around 7000 full-time fishermen in Iceland, and around 9000 people employed in the shore-based fishing industry (AMAP, 1998). The total fish catch per capita, as well as per unit of Gross National Product, far exceeds that of the OECD (Organisation for Economic Cooperation and Development) countries.

The Faroe Islands and Iceland have modern deep sea fishing fleets consisting of longliners, many larger (> 50 m) shrimp, whitefish and factory trawlers, in addition to purse seiners which in many cases can also operate pelagic trawls. Both countries have smaller coastal vessels fishing near the coast. Russia has a big fleet of more than 300 larger trawlers (*c*. 60 – 100 m) which harvest most of the commercially viable fish species in the Nordic Seas and the Barents Sea. There is almost no smaller-scale coastal fishing in the Russian Arctic.

Norway has a very differentiated fishing fleet, both for coastal and deep sea fishing. The coastal fleet consists of smaller vessels for handlines, gillnets and longlines, Danish seining, trawlers and coastal purse seiners. Many of these vessels are rigged to operate several different types of fishing gears, such as gillnets, coastal purse seines and Danish seines. The deep sea fishing fleet consists of longliners, industrial trawlers, white fish trawlers, factory trawlers, shrimp trawlers, purse seiners and combination vessels for purse seines and pelagic trawls.

The main fishing activities in the Norwegian Sea are pelagic trawling for herring, blue whiting and mackerel (*Scomber scombrus*). Blue whiting are caught using big pelagic trawls by vessels with big holds (1500 – 2000 t), and are used mainly for industrial reduction to fish meal and oil. Herring and mackerel are caught mainly by purse seine of Faroese, Icelandic and Norwegian vessels. Big Russian trawlers and a number of EU vessels catch herring and mackerel in the Norwegian Sea and off the north-western coast of Norway with big pelagic trawls. Off Iceland, in the Greenland Sea, near Jan Mayen, along the coast of northern Norway and in the Barents Sea there are seasonal fisheries for capelin, mainly for industrial reduction to fishmeal and oil. Smaller quantities of 'roe' capelin are caught on the spawning grounds along the coast of northern Norway and Iceland for human consumption.

On the fishing grounds off the Faroe Islands, Iceland and in the Barents Sea there are major fisheries with passive gears, such as longlines and gillnets, and active gears such as bottom trawls and Danish seines for haddock, saithe and cod. Shrimp are caught using bottom trawls by smaller vessels in coastal areas, and by larger vessels (> 27 m) on the offshore fishing grounds.

Along the continental shelf surrounding the Norwegian Sea, the Faroe Islands and Iceland there are longline fisheries in deep water (200 – 1000 m) for tusk (*Brosme brosme*), halibut (*Hippoglossus hippoglossus*), blue ling (*Molva dipterygia*), ling (*Molva molva*) and Greenland halibut (*Reinhardtius hippoglossoides*). A few vessels catch these species using gillnets.

3.5.2 Hunting

Approximately 20% of the population of Greenland is directly or indirectly dependent on hunting activities. The most important resources for the hunters are ringed seal (*Phoca hispida*) and harp seal (*Pagophilus groenlandicus*), but a wide variety of other species are also caught. Whaling is part of the hunting tradition and is of great importance to the Greenland culture. Neither the fin whale (*Balaenoptera physalus*) nor the minke whale (*Balaenoptera acutorostrata*), the two species caught in accordance with International Whaling Commission (IWC) regulations, are endangered species. Small cetaceans such as the narwhal (*Monodon monoceros*) and the beluga (*Delphinapterus leucas*) are not under IWC authority, but hunting is regulated bilaterally with Canada. The areas and species used for hunting and fishing vary by location and season. The Management Committee of the North Atlantic Marine Mammal Commission (NAMMCO) accepted that for the Central Stock Area the minke whales are close to their carrying capacity and that catches of 292 animals per year (corresponding to a mean of catches between 1980 and 1984) are sustainable.

In the Faroe Islands, the traditional, non-commercial whaling for long-fin pilot whales (*Globicephala melaena*) has been carried out since the Norse settlement of the islands more than a thousand years ago, although new regulations have banned some of the traditional practices and equipment. Since 1709, annual killings have averaged 850 individuals out of a stock which today numbers nearly 800 000. Seabirds have been caught throughout Faroese history, and still are. The catch is regulated by law as regards species, periods and methods. Seabirds are also caught in Iceland.

In 1992, after a five-year ban on whaling, the

Norwegian Government decided to permit catches of the minke whale, based on new estimates of the population. The quota for 1999 was 753 animals. Norway has entered a formal reservation against the 1982 IWC moratorium on commercial whaling. There is a ban on exporting whale products from Norway and the whale meat is sold in Norway, where it is a traditional part of the diet. Most whaling vessels are ordinary fishing boats, specially equipped for whaling.

3.5.3 Harvesting

Kelp and other brown seaweeds are harvested for alginate production along the coast of Iceland and the west coast of Norway. Kelp is the most common with an average harvest of approximately 90 000 t/yr of large kelp (*Laminaria hyperborea*) in Norway and 3500 – 4000 t/yr of oarweed (*Laminaria digitata*) in Iceland. In 1997, knobbed wrack (*Ascophyllum nodosum*) had an outtake of approximately 17 000 t in Norway and 11 000 – 14 000 t in Iceland (Gunnarsson *et al.*, 1998; Toresen, 1999).

Locally, various types of mussels and gastropods are harvested for sale to consumers and used for bait in the longline fisheries. In Iceland, Iceland scallop (*Chlamys islandica*) is harvested mostly along the west and northwest coasts. The catch was 13 000 – 17 000 t during 1983 to 1987 but has now stabilised at about 10 000 t/yr. Ocean quahog (*Arctica islandica*) was first caught in Iceland in 1996 and the annual catch has been 4300 – 7700 t over the last few years (Anon, 1999).

3.6 Mariculture/fish farming

No mariculture or fish farming takes place along the east coast of Greenland. The number of mariculture sites in Iceland is presently very low, with a total production of approximately 2500 t/yr. In the Faroe Islands there were 26 farms in 1996 which produced around 14 000 t of salmon (*Salmo salar*) and 500 t of rainbow trout (*Oncorhynchus mykiss*) for export. Production is expected to increase greatly and approach 40 000 t in 2000. In 1996, production was 2% of the Gross National Product and 17% of the export. Salmon and trout are the most important species produced in Norway. The total Norwegian production in Region I was 220 000 t round weight in 1997. The farming of shellfish produces only very limited amounts of blue mussel (*Mytilus edulis*), scallops and oysters.

3.7 Coastal protection and land reclamation

Coastal protection and land reclamation are not common within Region I, due to a coastline dominated by rocky shores, fjords and sheltered bays providing natural protection. Coastal protection includes local enterprises such as the building of breakwaters and the construction of piers and jetties. Land reclamation is restricted to small landfills.

3.8 Sand and gravel extraction

In Iceland and the Faroe Islands, a limited amount of material is extracted for local construction. Sand and gravel extraction in northern Norway is extremely limited. No detailed information is available for Russia.

3.9 Dredging, dumping and discharges

Dredging is only carried out in harbours. There are discharges from settlements, the fishing industry and mariculture sites. Due to the low population density, discharges of sewage are very limited. Litter has been an increasing global problem which also affects Region I. In some areas currents and other conditions may concentrate floating litter onto beaches.

3.10 Offshore oil and gas

The offshore petroleum industry is of importance both in the Norwegian and Russian sectors of Region I. Most of Norway's petroleum reserves are found outside Region I, in the North Sea. However, a number of oil and gas reserves have been discovered in the Norwegian and Barents Seas. For Norway, 16% of estimated reserves are located in the Norwegian Sea (1.07 billion Sm^3 oil equivalents), while 3% are located in the Barents Sea (0.26 billion Sm^3 oil equivalents). The first production licences north of 62° N were awarded in 1980, while the first field came into production in 1993. In 1998 the Norwegian production of oil north of 62° N was 31.1 million Sm^3, with an estimated increase to 44.9 million Sm^3 in 1999. Production of gas north of 62° N was 0.6 billion Sm^3 in 1998, and estimated at 0.9 billion Sm^3 for 1999.

An overview of the oil and gas developments in the European, Arctic and adjacent areas is shown in *Figure 3.3*. In the Norwegian sector of Region I, production of oil and gas currently takes place at five fields: Njord, Draugen, Åsgard, Heidrun and Norne. Water depths are in the range of 240 to 380 m. Njord, Draugen and Heidrun have been developed with semi-submersible, mono-tower or concrete tension leg platforms, while Norne has been developed with a production and storage ship tied to subsea installations. Åsgard is being developed with a production ship and a floating gas platform. Oil is transported to shore in tankers, while gas is transported in pipelines.

Figure 3.3 **Offshore oil and gas production. Source: EEA (1996).**

Exploration wells are currently being drilled both in Haltenbanken and in the Barents Sea. The number of exploration wells has declined over the last few years due to low oil prices. In 1996, twenty-three exploration wells were drilled in the Norwegian sector of the Norwegian Sea and seven in the Barents Sea, while in 1998 only eight exploration wells were drilled in the Norwegian Sea and none in the Barents Sea. Results reported indicate small to medium oil reserves, none of which are currently considered economically viable, and some larger gas reserves. The largest gas reserve in the Norwegian sector, Snøhvit, is reported to contain around 110 billion m^3 of natural gas.

There is no offshore production in the Russian sector of the Barents Sea, but extensive exploration has been carried out *(Figure 3.3)*. In the Russian part of the Barents Sea, including the Pechora Sea, around nineteen fields have been drilled (Moe, 1994). Large gas reserves have been found at the Shockmanov and Murmansk fields north-east of Murmansk, which are some of the world's biggest offshore gas fields. These areas are covered by ice for six months of the year, making production difficult and expensive. Very large oil reserves have been discovered close to the shore in the Prirazlomnoye field in the southern Pechora area.

Off the Faroe Islands, the prospects for oil and gas exploitation are considered favourable. A number of companies have shown interest, seismic surveys have been carried out and exploratory drilling is expected to start around the turn of the century. There are currently no plans for oil and gas exploration off the east coast of Greenland or off Iceland.

3.11 Shipping

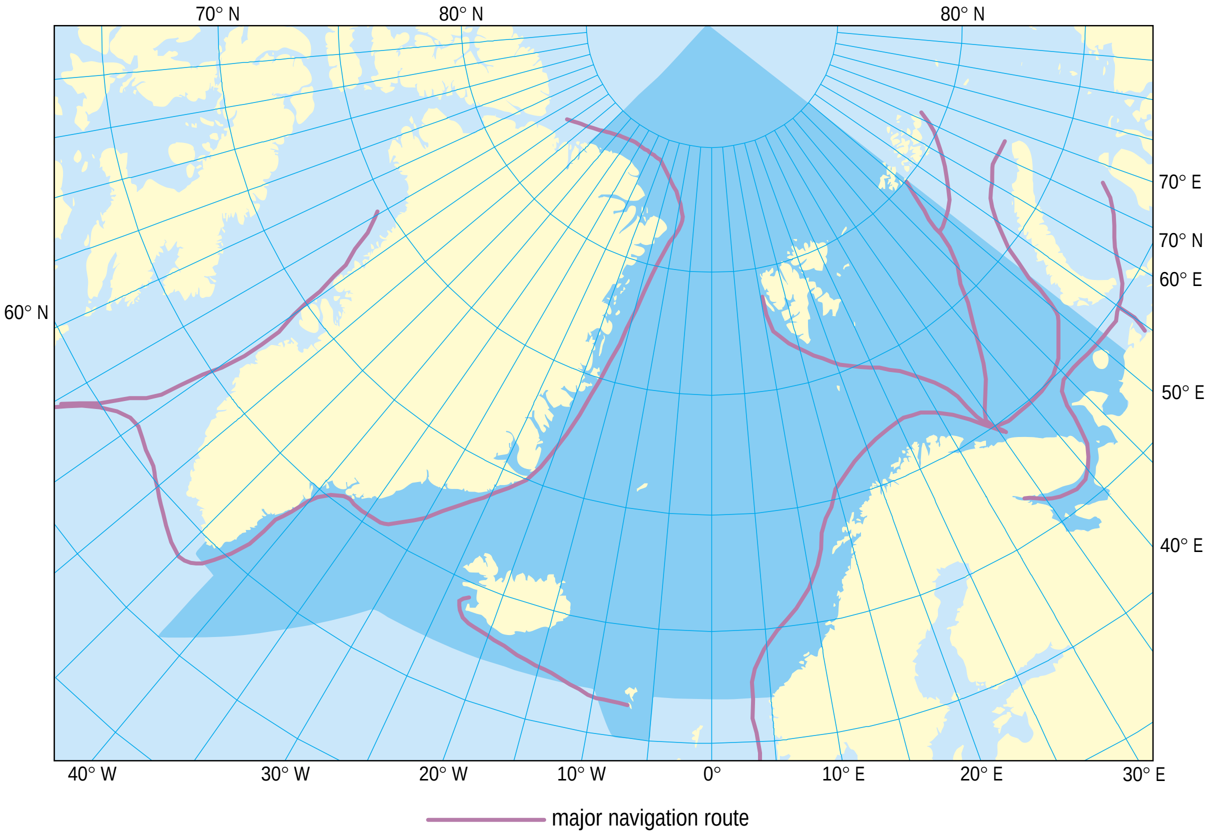
Shipping activities in Region I can be divided into the following major categories: shipping of cargo and passengers (including tourism), fishing, research, and shipping related to onshore and offshore petroleum activities and mining. Ongoing and potential projects indicate that shipping activities in the Arctic are likely to increase (PAME, 1996). Some of the major navigation routes in the region are shown in *Figure 3.4.*

Fishing represents the major component of Iceland's shipping activity. In 1994, there were > 117 000 fishing trips from Iceland, while the total number of voyages by passenger ships (mainly domestic ferries) was 6000. The number of cargo ship voyages to and from Iceland was around 600 (PAME, 1996).

Only a few of the eighteen islands in the Faroes have been connected by bridges, and most of the traffic between the islands is by ferry. Regular shipping routes connect the Faroe Islands to Iceland, Norway, Denmark, the United Kingdom and a few harbours in northern Europe.

Shipping in the Norwegian sector of Region I includes supply vessels to offshore installations and a number of fishing vessels. Ore from the mining industry in Kiruna in

Figure 3.4 **Major navigation routes in the Arctic.**



Sweden is shipped through the Norwegian port of Narvik. The Svalbard area is visited both by tankers and ordinary cargo vessels.

Detailed statistics about the shipping activity in the Russian part of Region I are not available. However, extensive national and international transport of cargo, oil and other goods takes place along the Murmansk coast.

3.12 Coastal and land-based industries

The main land-based activities that contribute to the pollution of the Arctic environment include industrial complexes, mining, petroleum exploration and production, urban settlements, ports, harbours and other coastal developments.

3.12.1 Industrial complexes

Industrial complexes include metallurgical operations, smelters, hydroelectricity developments and fish processing. Both Iceland and Norway have large hydropower reserves, which are used for electricity and heating, and in energy-intensive industries such as fertiliser production and aluminium smelting. Iceland also has several geothermal energy plants and vast geothermal energy reserves.

Iceland has established several heavy industry plants, producing ferroalloys, aluminium, cement, fertilisers and diatomite. Industrial complexes in the three northernmost counties of Norway include a secondary iron and steel plant, an aluminium plant and two ferroalloy plants. The most important are Hydro Aluminium in Sunndalsfjord and Elkem Mosjøen in Vefsnfjord, and these discharge around 3 t of polycyclic aromatic hydrocarbons per year to the fjords. One pulp and paper factory has outfalls in the Trondheimsfjord.

In addition, three fishmeal factories and around 300 fish processing plants are located in the three northernmost counties of Norway. Coastal industry in the Faroe Islands is restricted to fish processing from fisheries and mariculture. The input from shipyards and other small-scale industries causes local contamination of sediments in several harbours.

The Russian areas of Murmansk and Norilsk have the most concentrated industrial developments in Region I, and represent a major component of the industrial activity in the Arctic. The associated discharges are considerable and comprise a substantial proportion of the total industrial outputs in the area. These industrial complexes include petroleum and chemical industries, non-ferrous and ferrous metallurgy, pulp and paper industries, electricity production and food processing plants. No heavy industry is located in the Finnish section of the Barents Sea catchment area.

3.12.2 Mining and associated industries

The European Arctic is rich in mineral resources. Large-scale mining and metallurgical industries are found in the Russian Federation, particularly in the Murmansk administrative area. The mining companies of the Kola Peninsula produce a large proportion of the total Russian production, for example 80% of the total phosphate production and around 30% of the nickel production.

The Russian Federation and Norway each have three mines in operation on Svalbard. In 1994, the Norwegian coal production was 340 000 t, while the Russian production was 580 000 t. The coal is shipped to mainland Europe and the Russian Federation during summer.

The mining industries (minerals and coal) are the most significant coastal industries in the northern part of Norway and on Svalbard. A total of approximately 1.8 million t/yr of suspended matter is discharged to the fjords from the mining industry on the mainland.

At present, there is no exploitation of mineral resources in Greenland. In northern Greenland, a known zinc reserve may bring mining back to Greenland in the future. Known reserves of gold, platinum, uranium, oil and iron are not yet economically viable.

3.12.3 Onshore petroleum activities

Onshore petroleum exploitation in the European Arctic only takes place in the Russian Federation. The main onshore petroleum activity in the Russian Federation is in the Nenets area of the Arkangelsk administrative region, but oil is also extracted to a limited extent on Kolguyev Island. Although most of this activity lies outside or close to the border of Region I, it may still affect the environmental conditions of the region. The only oil field in full production is Kharyaga in southern Nenets. During 1963 to 1994, seventeen sites were explored for petroleum and gas on the Svalbard archipelago, without any important discoveries.

3.12.4 Urban settlements

Emissions and discharges from urban settlements generally represent a local problem. Although local problems can be severe, their contribution to the contamination of Region I is probably minor (PAME, 1996).

3.13 Military activities

No comprehensive information on military activities in Region I is available. Military uses of the sea in peacetime constitute a small proportion of the human activity in the area, and include patrols by the respective navies, control and enforcement of provisions concerning fisheries, monitoring of pollution and participation in emergency pollution control. The military activity in the Russian part of the region is considered the most significant in environmental terms.

Around 80 of the nuclear submarines of the former Soviet Union are currently in the Northern Fleet (PAME, 1996). More than two-thirds of the decommissioned submarines remain afloat and contain unloaded spent nuclear fuel. Submarine bases and construction and repair yards are situated on the Kola Peninsula and at Sverodvinsk in the White Sea.

There are proposals to destroy chemical weapons at the Novaya Zemlya nuclear test range using underground nuclear explosions, and plans to build a regional storage and disposal site for radioactive waste at Novaya Zemlya are being approved (PAME, 1996).

3.14 Agriculture and forestry

Along the eastern coast of Greenland there is no agricultural activity. Cultivated land covers only 1% of Iceland. Around 5% of the workforce is employed in the agricultural sector. Agriculture is based mainly on the cultivation of grass and animal husbandry. Sheep and dairy cattle are the main livestock. In the Faroe Islands, agricultural production consists mainly of dairy products, meat, eggs and potatoes. In 1996, agricultural production for local consumption was 0.8% of the Gross National Product.

Norway is the northernmost country in Europe and agriculture is characterised by a relatively short growing season. Arable land of about 3000 km^2 represents only 3% of the total land area of northern Norway. The coastal landscape is dominated by rocky shores and is unsuitable for most large-scale agricultural purposes. Farms are generally small, mainly producing dairy and meat products. Production is almost entirely for the national market. Agricultural activity in northern Russia is probably of low importance, but detailed information is not easily available.

Forestry has been an important economic activity, particularly in the Russian Federation and to some extent in the Nordic countries. The wood processing industry is important in the Russian Federation, Sweden, and

Finland. The Norwegian forestry industry in the Arctic is small, and primarily focused on the home market. Part of Iceland was once forested, but was cleared centuries ago. Presently, only small-scale production takes place. In Finland around 5 million ha of forests are suitable for forestry. Forestry is a significant contributor to Lapland's economy, comprising 50% of industrial production and 70% of its export revenue. By far the largest forest resources in the European Arctic are found in the Russian Federation; the boreal forests in the Archangels and Murmansk administrative areas and in the Karelian Republic represent a considerable proportion of the total forest reserves.

3.15 Regulatory measures and future developments

Until the mid 1980s, international co-operation on environmental protection in the Arctic was relatively poorly developed. This situation reflected both the generally clear delineation of national jurisdictions in the Arctic, and the strong national interests in a region of considerable economic, geopolitical and military-strategic importance. However, in the late 1980s this situation changed radically, as the developments in the political climate with respect to the former Soviet Union made possible an expansion of environmental cooperation.

A number of agreements call for global, regional and national efforts to prevent, reduce and control marine pollution, which form an important focus for efforts aimed at reducing impacts on the Arctic environment and its ecosystems.

The 1992 OSPAR Convention for the Protection of the Marine Environment of the North-east Atlantic is currently one of the most applicable international agreements addressing Arctic marine pollution from various sources. The 1972 Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, and the 1974 Paris Convention for the Prevention of Marine Pollution from Land-based Sources were superseded by the OSPAR Convention when it entered into force in March 1998. The OSPAR Convention has the general objective of preventing and eliminating pollution of the marine area covered by the Convention, to ensure that ecosystems are in sound condition and used in a sustainable manner, and to protect human health. The Convention covers prevention and elimination of pollution from land-based and offshore sources, dumping and incineration. A new annex to the Convention also contains provisions with regard to the protection and conservation of the ecosystems and biological diversity of the Maritime area.

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) is a combination of two treaties adopted in 1973 and 1978. The Convention covers all technical aspects of pollution from ships, except the disposal of waste to the sea by dumping, and applies to all kinds of ships. The Convention covers oil, chemicals, sewage, garbage and harmful substances carried in portable tanks and freight containers etc. The International Maritime Organization (IMO) is the UN agency responsible for improving maritime safety and preventing pollution from ships. The IMO Marine Environmental Protection Committee (MEPC) deals with issues relating to the prevention and control of pollution from ships.

The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the 'London Convention') is the primary international agreement regulating ocean dumping of wastes. The Convention has direct significance to several aspects of environmental protection of the Arctic, particularly in relation to radioactive waste disposal issues.

The juridical framework for sustainable use and protection of marine resources has been significantly improved since the 1982 UN Convention on the Law of the Sea (UNCLOS) entered into force in 1994. This Convention establishes the rights and duties of the states regarding resource management and protection of the marine environment. Other important agreements include the Conservation and Sustainable Use of Marine and Coastal Biological Diversity, which was adopted under the Convention on Biological Diversity in 1995, and the Code of Conduct for Responsible Fisheries adopted by the UN Food and Agriculture Organization (FAO) in 1995.

The first Arctic Ministerial Conference in 1991 represented a breakthrough in the development of international cooperation for the protection of the Arctic, with its most significant outcome being the adoption of the Arctic Environmental Protection Strategy (AEPS, 1991). The objectives of the AEPS are to protect the Arctic ecosystems, to provide for the protection of environmental quality and sustainable utilisation of natural resources, to recognise the traditional values and practices of indigenous peoples, to review the state of the Arctic environment and to identify, reduce and as a final goal eliminate pollution. To implement the AEPS, the following five programmes were instituted:

- The Arctic Monitoring and Assessment Programme (AMAP);
- Conservation of Arctic Flora and Fauna (CAFF);
- Emergency Prevention, Preparedness and Response (EPPR);
- Protection of the Arctic Marine Environment (PAME); and
- Sustainable Development and Utilisation (SDU).

In 1996, the government of the eight Arctic countries established the Arctic Council (Arctic Council, 1996). The Arctic Council assumed responsibility for the AEPS in 1997.

The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities was developed by the UN Environment Programme (UNEP) in 1995, in response to the Rio Declaration and Agenda 21. A negotiating committee has been established under the Global Programme of Action to prepare a global, legally binding agreement on at least twelve persistent organic pollutants, an initiative of special significance in addressing the threats to the Arctic environment.

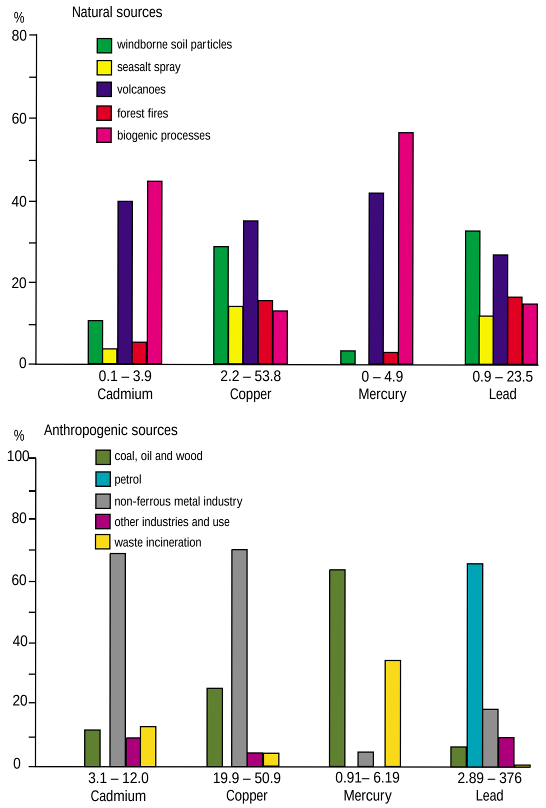
chapter 4

Chemistry

4.1 Introduction

This chapter presents a summary of available data for Region I on the input and environmental concentrations of selected metals, persistent organic contaminants, nutrients, radionuclides and oil. The first section deals in general terms with the inputs and properties of contaminants and the processes governing the fluxes into the region. Subsequent sections discuss concentrations and trends of contaminants in water, sediments and biota.

Figure 4.1 **Global emissions of trace metals to the atmosphere from natural and anthropogenic sources at the beginning of the 1980s. The numbers under the columns reflect the range in the estimates of emissions (t x 10³/yr). Source: based on Nriagu (1989); Nriagu and Pacyna (1988).**



Metals are components of the Earth's crust, and occur naturally in all biotic and abiotic compartments of the environment. Metals enter the marine environment through multiple pathways, including atmospheric deposition (particles and gas exchange), transport by rivers, drainage from agricultural land and the weathering of rocks and soils. Anthropogenic sources include fossil fuels, coal and oil, and the non-ferrous metal industry. Natural sources include volcanoes, forest fires and windborne soil particles. *Figure 4.1* illustrates the most important natural and anthropogenic emission sources of cadmium, copper, mercury and lead. The atmospheric pathway plays a particularly significant role for anthropogenic inputs of lead, mercury and cadmium to the ocean.

Persistent organic contaminants, such as polychlorinated biphenyls (PCBs) and the organochlorine pesticides DDT, hexachlorocyclohexanes (HCHs) and toxaphene have no natural sources, and are thus entirely anthropogenic in origin. These compounds are transported to Region I via the atmosphere, ocean currents and rivers. In addition to long-range transport from areas further south, some local sources of persistent organic contaminants are found within Region I.

Polycyclic aromatic hydrocarbons (PAHs) have both natural and anthropogenic sources. Natural sources of PAHs to the Arctic marine environment include oil seeps from the ocean floor and atmospheric inputs from forest fires. Inputs of anthropogenically derived PAHs from the use of oil and from various combustion processes reach Region I via similar routes to the other persistent organic compounds, with long-range atmospheric transport a major pathway.

Global fallout from atmospheric nuclear weapons testing in the 1950s and 1960s was a major source of anthropogenic radioisotopes in Region I. Underwater nuclear tests contributed to radioactive contamination of water and sediments. Potential sources for future radioactive contamination are found within the Arctic in the form of inappropriately stored nuclear waste. However, long-range transport of radioactive isotopes from the North Sea and the Baltic Sea via ocean currents is today the most significant source to the Arctic marine ecosystems.

Once in the water column, contaminants may sink to the bottom associated with inorganic or biogenic particles, or be taken up by organisms and incorporated into the marine food web. Many of the contaminants of concern in the marine environment have low water solubility and a high affinity for particulates. Contaminants are taken up by the primary producers, the base of the food chain. Primary production in the Arctic marine environment is highly seasonal, with most of the assimilation taking place during a few weeks of phytoplankton blooms in the spring. Contaminants associated with phytoplankton can be transferred to organisms higher in the food chain via grazing or may sink to the bottom and become incorporated into the bottom sediments.

Through biomagnification, which refers to the accumulation of contaminants by successive trophic levels, contaminants build up to higher levels in predator species relative to their prey. High biomagnification factors indicate efficient transfer from prey to predator. Conversely, low biomagnification factors indicate little transfer between trophic levels. Cadmium is not biomagnified from the zooplankton *Parathemisto* sp. to Polar cod (*Boreogadus saida*), while mercury concentrations are six to sixteen times higher in Polar cod than *Parathemisto* sp. Cadmium is efficiently transferred further to the birds, seals and whales which feed on Polar cod (AMAP, 1998). Polar bears (*Ursus maritimus*) are very low in cadmium due to their preference for seal blubber, which is low in cadmium. Mercury is low in Polar bear muscle, similar in liver and higher in kidney relative to ringed seal. The limited data available for lead indicate low biomagnification factors for this element in Arctic marine biota. PCBs are efficiently transferred and biomagnified from Polar cod to birds and seals. HCH is efficiently accumulated by species at low trophic levels, while the biomagnification potential is low at the upper end of the food chain. In *Figure 4.2* data for six major classes of organochlorine contaminants are plotted for each compartment or species as the percentage of the organochlorine contaminant in that compartment or species. This illustrates the variable importance of the different contaminants in their transfer between compartments and bioaccumulation in the marine mammal food chain. PAHs are less prone to biomagnification than most of the other persistent organic contaminants. Vertebrates have the ability to metabolise and excrete PAHs, and the biomagnification factors for these compounds are low.

Important factors in the accumulation of contaminants by organisms are the uptake rates and excretion rates. Contaminants are taken up through the skin, lungs and gills, and via the intestine. Once absorbed by the body, contaminants are distributed to various organs by the circulatory system. Persistent organic contaminants, which are highly lipophilic, will accumulate in body fats. The highest levels are thus often found in liver tissue and in blubber. Metals are preferentially accumulated in proteinaceous tissues. Heavy metals tend to accumulate in specific organs. For example, high cadmium concentrations are found in the kidneys of mammals experiencing chronic cadmium exposure. Mercury is accumulated in mammalian liver, while lead is deposited and stored in bony tissue.

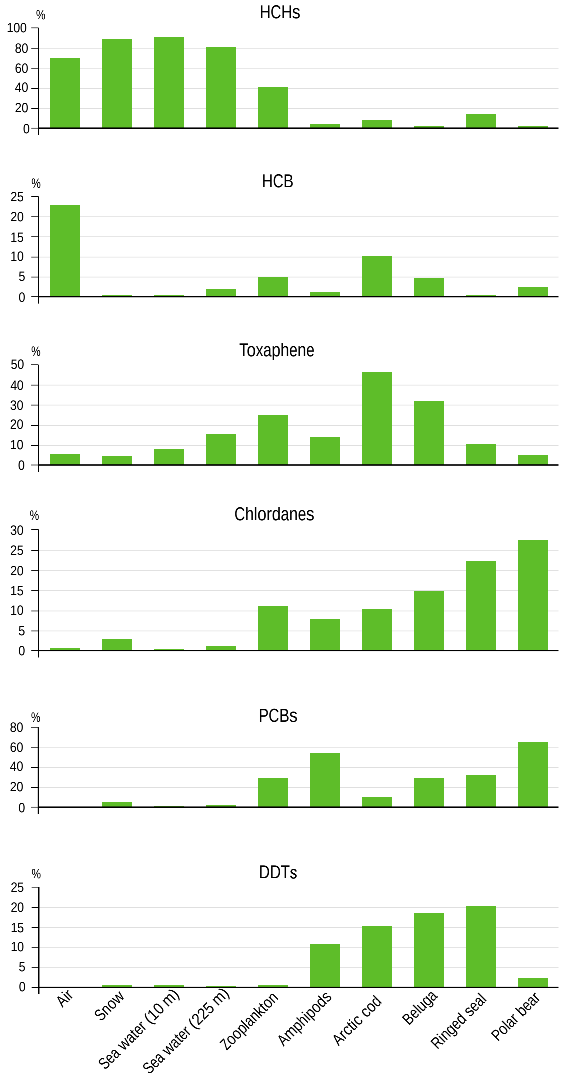
Species vary in their ability to take up and eliminate contaminants via the different routes of exposure. Invertebrates and fish take up only small amounts of metals through the gills, while the intestinal uptake is large. The uptake efficiency in the intestine depends on the form of the metal. Methyl mercury is taken up more than six times more efficiently than inorganic mercury. Lead is readily excreted from internal organs, and is therefore found in moderate levels in liver and kidney. Cadmium and mercury, however, are excreted slowly. This partly explains why these metals are found in high levels in the internal organs of long-lived species.

Many of the persistent organic contaminants of concern in the Arctic marine environment are no longer produced or in use. Reductions in the concentrations of PCBs and DDT since these compounds were banned in the 1970s have been observed in marine biota, for example in the Swedish monitoring programme in the Baltic Sea (Olsson and Reutergårdh, 1986; Bignert *et al.*, 1993). Few such long-term time series exist for the Arctic marine environment. Analysis of cod liver from Iceland and seabird eggs from northern Norway and Svalbard indicate a decline in the levels of organochlorine compounds over recent years (Barrett *et al.*, 1996; Egilson *et al.*, 1999).

Although these compounds are no longer produced, or their use is significantly restricted, large reservoirs of some persistent organic contaminants still exist. Sources include for example, PCBs deposited on soil and vegetation, old equipment and PCB-containing materials still in use, and landfills. Results from the long-term Swedish monitoring programmes indicate that the initial decrease in environmental concentrations, which was observed after the restrictions in the 1970s, has now levelled off (Bignert *et al.*, 1993).

Lead has been significantly enriched in the Arctic as a result of anthropogenic inputs. Concentrations of lead in the Greenland ice sheet are currently 300 times higher than in prehistoric times. However, phasing out the use of leaded petrol has led to a recent decrease (Boutron *et al.*, 1991).

Figure 4.2 **Distribution of organochlorine contaminants in Arctic snow, sea water and the marine mammal food chain. Source: Norstrom and Muir (1994).**



4.2 **Inputs of contaminants**

4.2.1 Land-based inputs

Land-based activities of importance for the input of contaminants to Region I include urban settlements, ports and harbours, oil and gas exploration, production and transportation, industrial complexes, mining, forestry, nuclear activities, government facilities and coastal developments.

With few exceptions, residential settlements are small. Emissions and discharges to the marine environment consist primarily of untreated sewage and wastewater. The impact on the environment from these sources is relatively local, with elevated concentrations of nutrients, heavy metals, persistent organic contaminants and hydrocarbons occurring within tens of kilometres of the source.

Mining operations are currently in operation in Norway (including Svalbard) and the Russian Federation only. Mining was important in Greenland, but these operations are now closed. Coal mining occurs on Svalbard. These activities are not thought to be important direct sources of pollution to the marine environment. Elevated concentrations of heavy metals in nearshore coastal waters are the major concern associated with mining.

Land-based nuclear activities of relevance to Region I are located only in the Russian Federation. These include power generation, waste treatment and storage, and the naval and commercial nuclear fleet. The environmental impact of the normal operation of nuclear installations is considered minimal and acceptable. However, the potential exists for accidents with significant releases of radionuclides from areas within the Russian Federation to the marine environment (AMAP, 1998).

Iceland, Norway and the Russian Federation have large industrial complexes. There are heavy industry plants producing ferroalloys, aluminium, cement, fertiliser and diatomite in Iceland. Secondary iron and steel plants, and aluminium and ferroalloy plants occur in northern Norway. The industrial developments in the Russian Federation include smelters, petroleum and chemical industries, non-ferrous and ferrous metallurgy, power generation and food processing. The emissions to the marine environment from the industrial operations in Iceland and northern Norway are considered small and are thought to have a local impact only.

Government facilities, which include research, military and transportation facilities, also contribute to the contamination of Region I. The impact of these sources on the Arctic marine environment is uncertain. The limited information available indicates that the environmental effects are mainly local. Landfills around the settlements on Svalbard are sources of both PAHs and PCBs. It is not known how much hazardous waste is buried on Svalbard. The impact on the local environment may be significant.

Most harbours within Region I are small-scale fishing ports. Contamination is associated with major harbours and ports. Onshore sites that support offshore oil and gas drilling have the potential to affect the marine environment. The biggest ports are found in the Russian Federation.

4.2.2 Offshore inputs

Exploration for oil and gas resources indicates that the Norwegian and Barents Seas contain some of the world's largest reserves. Oil and gas production has taken place offshore of central Norway since 1993 and major projects for the development of oil and gas resources are planned for the future in the Barents and Kara Seas. Offshore petroleum activities may result in operational or accidental discharges of oil and chemicals.

The production of oil and gas in the Norwegian sector of Region I results in discharges from drilling and well operations and from the production process. The bulk of the chemical discharges (92%) are from drilling operations. Water-based drilling fluids are mostly used, but a few wells have been drilled with synthetic drilling fluids. Cuttings drilled with oil-based drilling fluids are not discharged.

The oil discharges from the petroleum sector mainly stem from ordinary operations. The main source of oil released into the sea from daily operations is the discharge of water that has come up with the oil and gas from the well (i.e. produced water). In addition, discharges occur in connection with accidents and spills. In 1997 there were 31 accidental oil spills from the five Norwegian fields north of 62º N (two spills larger than 1 m^3) and twenty accidental discharges of chemicals and drilling fluids (SFT, 1998).

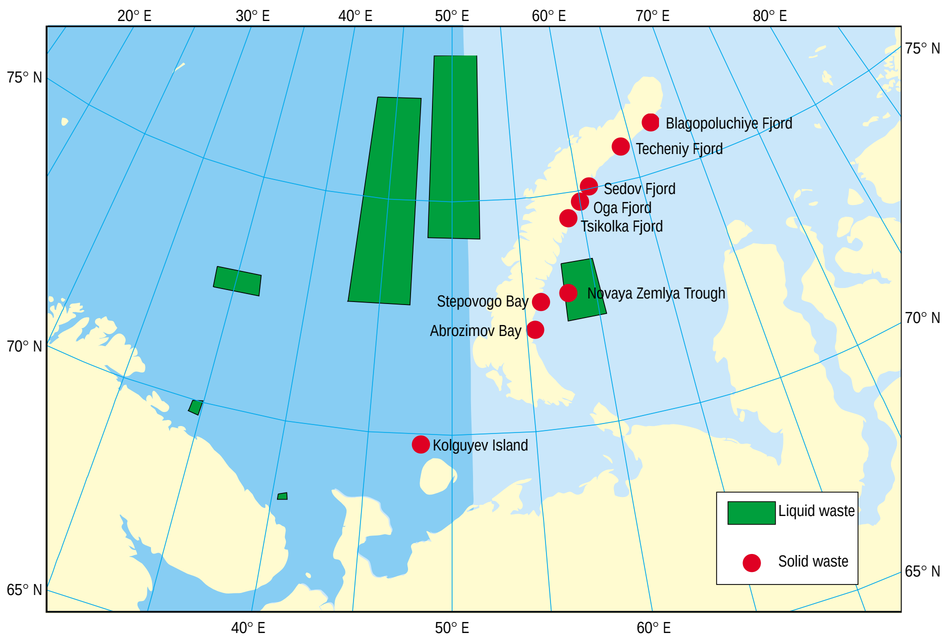
Discharges of hazardous substances from Norwegian petroleum production north of 62º N are small compared to other sources. In 1997, discharges included 8 kg of lead, 66 kg of copper, 51 kg of organotin and 187 kg of organohalogens (SFT, 1998).

None of the countries within Region I have reported the dumping of industrial wastes during the last ten years. Dredged material and vessels are among categories of waste still being dumped at sea. The Kara Sea and the Barents Sea have been dumping grounds for radioactive waste from the former Soviet Union *(Figure 4.3)*.

4.2.3 Riverine inputs

Riverine inputs related to activities outside the Arctic are thought to be a significant source of contaminants to the Arctic Ocean (AMAP, 1998). However, little is known about the magnitude of this pathway in relation to the other transport routes for the various contaminants. Rivers discharging into the Kara, Laptev and East Siberian Seas have a drainage area of 9 000 000 km^2, encompassing

Figure 4.3 **Dumping grounds for radioactive waste in the Russian Arctic. Source: AMAP (1998).**



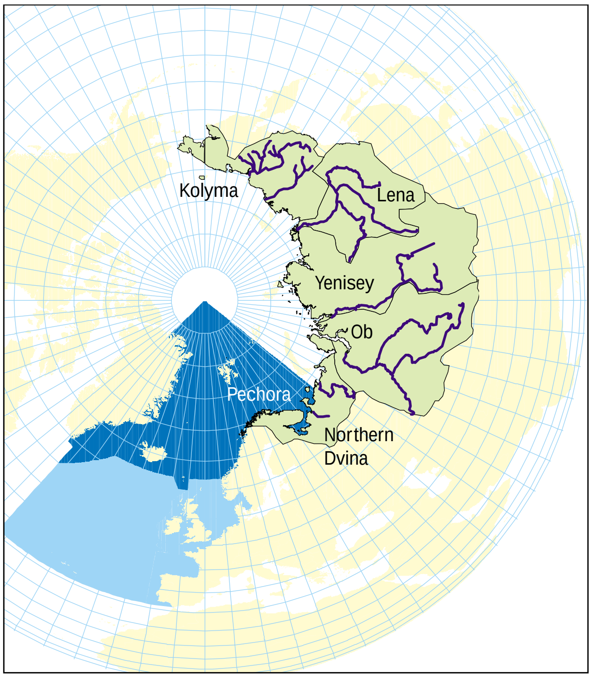
many industrial and agricultural regions. The rivers Yenisey, Ob and Lena (see *Figure 4.4*) are ranked fifth, sixth and seventh in the world in order of annual freshwater discharge (Goldberg, 1976). Known contaminants in these major rivers include oil, metals, persistent organic contaminants, radionuclides and nutrients. For some of these groups it is difficult to separate natural sources from anthropogenic contributions. Freshwater discharges from rivers in Greenland, Iceland, the Faroe Islands and Norway are small compared to the Russian rivers draining into the Arctic Ocean. The limited information on riverine and direct inputs reported to OSPAR shows that the levels of trace metals, PCBs and nutrients are low and stable, and no trends are evident (OSPAR, 1998).

Although significant amounts of petroleum hydrocarbons have been discharged to some Russian rivers, relatively little is transported to the river mouth due to the self-purification and sedimentation processes that occur along the course of the river. For example, little of the oil spilled in 1994 in the Komi Republic of the Pechora basin reached the river mouth (Wartena *et al.*, 1997).

4.2.4 Atmospheric long-range transportation

Barrie *et al.* (1992) investigated the long-range pathways to the Arctic for radionuclides, metals and persistent organic contaminants. Where sufficient information was available to make an assessment, the atmosphere was found to be the major pathway. Unlike transport by ocean currents which can take years or even decades, long-range atmospheric transport of contaminants can occur on a daily or weekly basis. The atmosphere can deliver not only volatile and semi-volatile contaminants, but also aerosols containing particle-reactive contami-

Figure 4.4 **Major rivers discharging in the Russian Arctic.**



nants such as PAHs. These contaminants accumulate in and on snow, ice and sea water, and in northern drainage basins.

Atmospheric emissions of most metals (except mercury) occur on particles. Following their release into the atmosphere, particles and associated heavy metals are subject to long-range transport via air masses. Factors such as particle size, the height of emission and meteorological conditions influence the atmospheric transport. Models of long-range metal transport show that emissions from sources in Eurasia contribute to more than half of the air pollution measured in the Arctic (Pacyna, 1991). The major source regions include the Urals, the Kola Peninsula, the Norilsk area, and the industrial regions of Central and Eastern Europe. Contributions from the European and North American continents seem to be lower in the winter than the contributions from the Russian sources, while the European contribution is more significant in the summer months, depending on the meteorological conditions. Air concentrations of heavy metals in the high Arctic are usually lower than concentrations measured in the sub-Arctic region by at least an order of magnitude.

Concentrations of persistent organic contaminants in air from northern Norway are generally an order of magnitude lower than in air from more southern locations in Norway. PCB levels were about ten times higher at Lista in southern Norway than on Svalbard (Oehme *et al.*, 1995a). A similar trend was seen for γ-HCH. In Iceland, the concentrations of PCBs, DDT and γ-HCH in air are similar to or slightly lower than those on Svalbard (Egilson *et al.*, 1999). Elevated levels of persistent organic contaminants in Arctic air are positively correlated with long-range transport episodes from use areas in the mid-latitudes of North America, Europe and Asia. During transport episodes with air masses originating mainly in Europe, elevated levels of PCBs and HCHs were observed at an air monitoring station on Svalbard (Oehme *et al.*, 1996). This is illustrated in *Figure 4.5.* The levels of trans-chlordane on Svalbard were higher when air masses originated mainly in North America, with the lowest concentrations of all organochlorine compounds found in air coming in over the Arctic Ocean.

4.3 Background/reference values

Background/Reference Concentrations (BRCs) and Ecotoxicological Assessment Criteria (EACs) have been adopted by OSPAR as tools for assessing the impact of some groups of contaminants. These values are based on a limited amount of data for Region I. This implies that the values must be used carefully for metals and other naturally occurring compounds in Region I. References to background concentrations have been made under the different sub-headings.

For metals, background concentrations are related to the normal chemistry or geochemistry of the areas concerned. Metals such as cadmium and mercury are found at higher concentrations in areas around Greenland and Iceland than in other parts of the OSPAR Convention area. The anthropogenic point sources of these metals in the western parts of Region I are not known, and the higher levels can only be explained by natural factors such as sediments of different geological origin and different physical/chemical conditions.

In the case of synthetic substances, such as many of the persistent organic contaminants, there is no natural concentration, which implies that the natural background level should in principle be zero. However, due to their ubiquitous presence in marine media, background concentrations have also been defined for some of these compounds.

4.4 Heavy metals

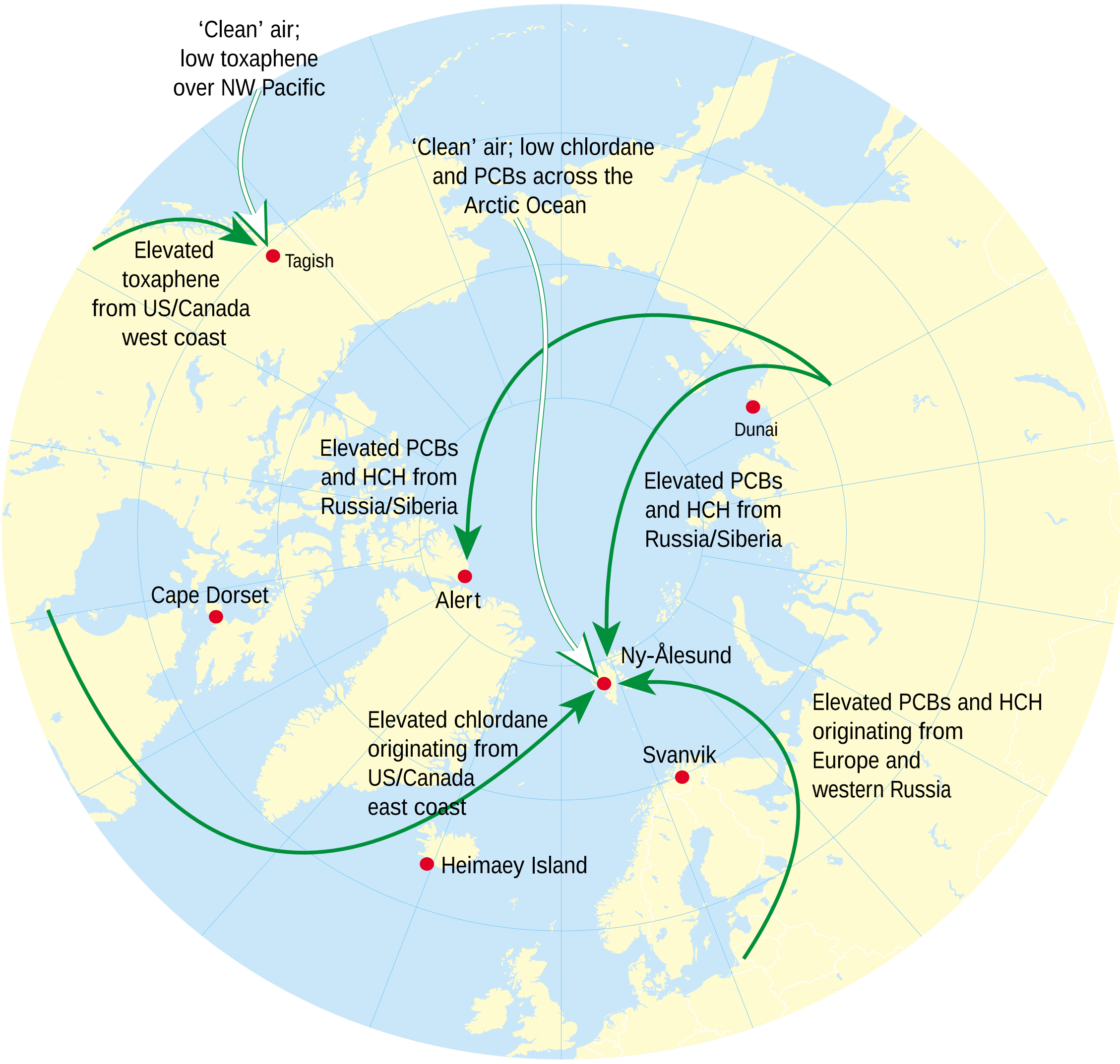
4.4.1 Cadmium

Volcanic activity and biogenic processes are considered the major natural sources of cadmium to the atmosphere (Nriagu, 1989). On a global scale, the natural atmospheric inputs are exceeded by the anthropogenic inputs by a factor of approximately 1:9. Total atmospheric emissions of cadmium were estimated at 8900 t/yr in the early 1980s (Nriagu and Pacyna, 1988). The most significant anthropogenic sources of cadmium to the environment are non-ferrous metal industries, such as copper–nickel production and zinc–cadmium production *(Figure 4.1)*. Other sources include municipal refuse incineration and coal combustion. The total European emissions are estimated to have decreased considerably since the 1960s *(Figure 4.6)*.

Elemental cadmium and its oxide are the predominant chemical forms of cadmium emitted to the atmosphere from major sources. These, together with cadmium chloride which is found in emissions from refuse incineration, appear to be the most toxic cadmium species. In the marine environment, cadmium is present mainly as soluble chloride complexes. The species most readily accumulated by organisms is the free ionic form Cd^{2+}.

Cadmium concentrations of 8 ng/l have been measured in the surface waters of the eastern Arctic Ocean (Campbell and Yeats, 1982). At greater depths, concentrations ranged from 13 to 21 ng/l. Similar concentrations were measured in the surface waters of the Norwegian Sea; 22 ng/l (Danielsson *et al.*, 1985), and in deeper layers of the Central Arctic Ocean; 20 ng/l (Moore, 1981). Cadmium levels of between 20 and 260 ng/l have

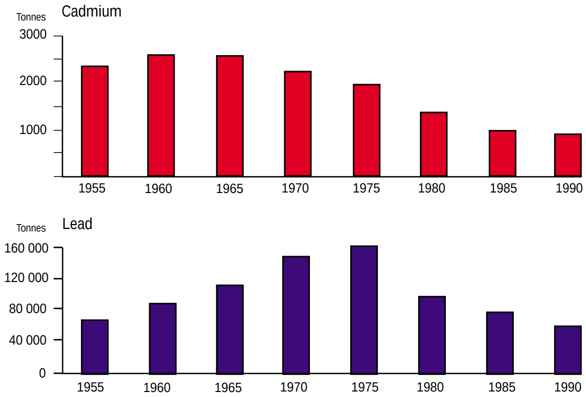
Figure 4.5 **Source regions for HCH, chlordane and PCBs in Arctic air based on 5-day back-trajectories for elevated air concentrations at various Arctic stations. Source: AMAP (1998).**



been reported for the Pechora and Kara Seas (Rosgidromet, 1995). The Norwegian Sea shows no significant mid-oceanic differences for cadmium (Mart and Nurnberg, 1984). In the relatively warm surface waters of the North-east Atlantic, cadmium concentrations are lower in surface water than in deep water, indicating uptake of cadmium by organisms at the surface, and the release of cadmium from sinking organic matter in subsurface layers. Local cadmium contamination occurs in the Arctic close to point sources. Surface concentrations of cadmium ranged between 18 and 252 ng/l close to the Ivittuut mining area in South Greenland (Johansen *et al.*, 1995).

Cadmium levels are generally low in the surface sediments of Region I. The concentrations are dependent on the content of fine-grained material in the sediment.

Figure 4.6 **Variations over time in European atmospheric emissions of cadmium and lead. Source: Olendrzynski *et al.* (1995).**



There is no indication that cadmium accumulates in the upper layers of sediments in Region I away from point sources (Loring and Asmund, 1996; AMAP, 1998).

In deep water Greenland Sea sediments, average cadmium concentrations were 0.12 ± 0.05 mg/kg dw (AMAP, 1998). Cadmium concentrations measured at 43 sites in the Barents Sea averaged 0.08 ± 0.08 mg/kg dw. Similar levels were found in Norwegian Sea sediments with cadmium concentrations ranging from 0.08 to 0.19 mg/kg dw. Cadmium concentrations in Icelandic sediments average 0.22 mg/kg dw (range 0.05 – 0.74 mg/kg dw) (Egilson *et al.*, 1999) which is somewhat higher than in the sediments of the Norwegian and Greenland Seas. This is probably due to volcanic activity.

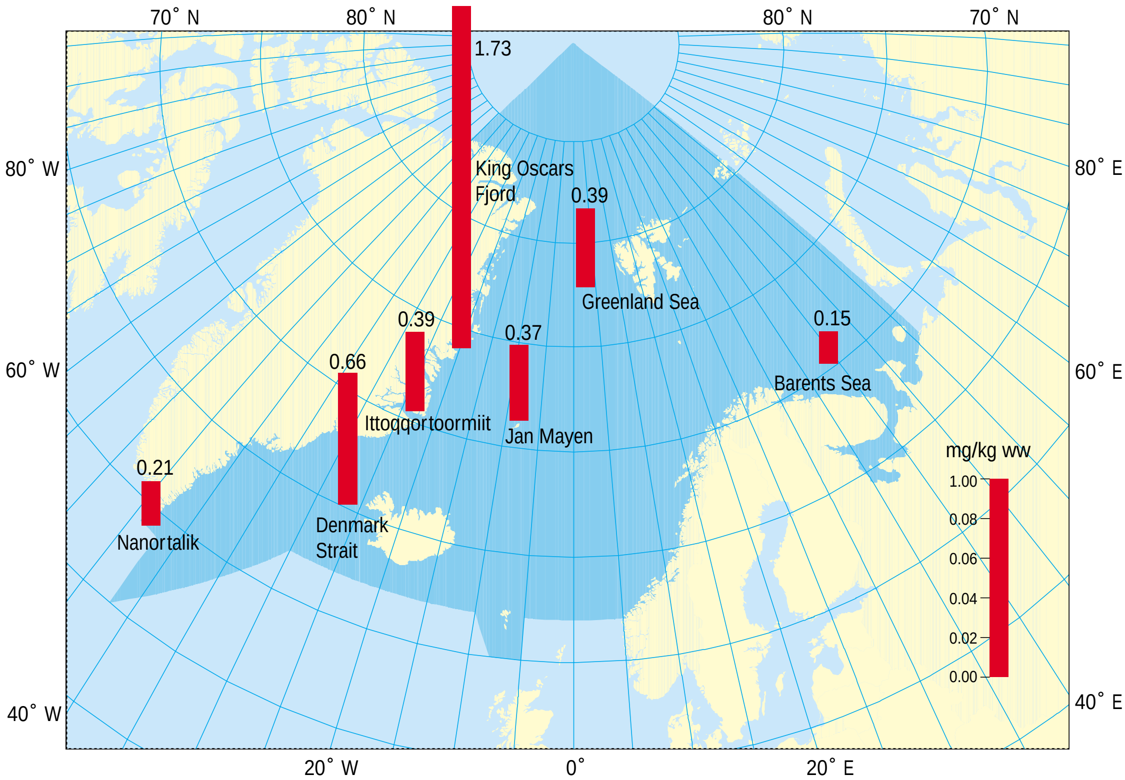
Concentrations of cadmium in seaweed range from 0.14 to 3.50 mg/kg dw in Greenland waters. Small-scale geographical differences are observed. Concentrations are higher near the open sea than in fjords, a phenomenon explained by the relationship between the dissolved cadmium concentration and the salinity of the water (Riget *et al.*, 1993).

Cadmium concentrations in blue mussel are generally lower in Faroese and Norwegian waters (range 0.12 to 0.35 mg/kg ww) than in Greenland waters (range 0.56 to 1.25 mg/kg ww) (AMAP, 1998). Mussels from Icelandic waters have levels similar to or lower than those from Greenland waters (range 0.09 to 0.43 mg/kg ww) (Egilson *et al.*, 1999). The highest concentrations are found in the largest mussels, and concentrations tend to be higher closer to the open sea than in the inner regions of large fjords (Riget *et al.*, 1996).

High cadmium concentrations have been found in crustaceans such as the amphipod *Parathemisto libellula*, a key species in the Arctic pelagic food chain. At Uummannaq, West Greenland, cadmium concentrations in *P. libellula* ranged from 1.38 to 4.60 mg/kg ww (Dietz *et al.*, 1996). Higher concentrations are reported in the same species from Arctic Canada (Macdonald and Spraque, 1988).

Cadmium concentrations have been investigated in the different tissues of a large number of fish species in Arctic waters (AMAP, 1998). With few exceptions, the highest concentrations are found in liver tissue (see *Figure 4.7*), while muscle concentrations are often lower than 0.001 mg/kg ww and close to the detection limit. In cod and dab (*Limanda limanda*) collected during 1990 to 1996 from Icelandic waters the mean concentrations (and range) of cadmium in liver were 0.15 mg/kg ww (0.018 – 0.84 mg/kg ww) and 0.47 mg/kg ww (0.27 – 0.87 mg/kg ww), respectively (Egilson *et al.*, 1999). Liver concentrations of cadmium can be high in deep-water fish with a long life span. Of a large number of species investigated in Greenland waters, the highest cadmium levels were

Figure 4.7 **Distribution of cadmium concentrations in liver tissue of Polar cod. Source: AMAP (1998).**



found in Greenland halibut, golden redfish (*Sebastes marinus*), shorthorn sculpin (*Myoxocephalus scorpius*) and spotted wolffish (*Anarhichas minor*), with maximum concentrations of 3.3 (Nuuk), 2.7 (Nanortalik), 8.4 (Maniitsoq) and 18.7 (Uummannaq) mg/kg ww, respectively (Riget *et al.*, 1997; AMAP, 1998). Levels of up to 19 mg/kg ww were found in deep-sea redfish (*Sebastes mentella*) from the Irminger Basin (Stange *et al.*, 1996). These values are considerably higher than levels commonly reported in commercial fish species in areas such as the North Sea. The recommended limit for cadmium in food for human consumption is 0.3 to 0.5 mg/kg ww (NSTF, 1993).

In Arctic seabirds, cadmium concentrations in muscle tissue are generally below 0.6 mg/kg ww (AMAP, 1998). Some high values (up to 29 mg/kg ww) were reported in northern fulmar (*Fulmarus glacialis*) from Svalbard. Cadmium accumulates primarily in the kidney of seabirds. For some species there is a clear tendency for cadmium to accumulate with age. Cadmium levels of up to 77 mg/kg were found in kidneys of older glaucous gulls (*Larus hyperboreus*) from West Greenland (Overgaard and Dietz, 1989; Dietz *et al.*, 1997a,b).

In marine mammals, cadmium concentrations tend to be higher in kidney than in liver and muscle, while blubber concentrations are low. An increase in cadmium concentrations with age has been observed in seals, whales and Polar bear. High concentrations were found in the kidneys of ringed seals and narwhals from north-west Greenland and the Pond Inlet in the Canadian Arctic; 111 and 63.5 mg/kg ww respectively (AMAP, 1998). On Svalbard, most of the concentrations reported for liver and kidney of ringed seals are in the range of 1.5 to 34 mg/kg ww. Cadmium concentrations of up to 93 mg/kg were found in the kidneys of pilot whales from the Faroe Islands (Caurant *et al.*, 1994). Despite being a top predator, Polar bears generally have lower levels of cadmium in their tissues than other marine mammals. Concentrations of up to 8.1 mg/kg were found in the kidneys of Polar bear from Svalbard (Norheim *et al.*, 1992). Values for Polar bear from Greenland are higher, whereas liver levels from Canadian Polar bears are lower (Braune *et al.*, 1991; Dietz *et al.*, 1998).

The concentrations of cadmium in ringed seals from Region I are considerably higher than the levels in ringed seals from areas more influenced by anthropogenic inputs, such as the Gulf of Finland and the Gulf of Bothnia (Frank *et al.*, 1992). Different feeding habits, in terms of the availability of prey species, together with slow growth rates, are theories proposed to help explain the high concentrations in Arctic marine mammals (e.g. Muir *et al.*, 1996).

4.4.2 Mercury

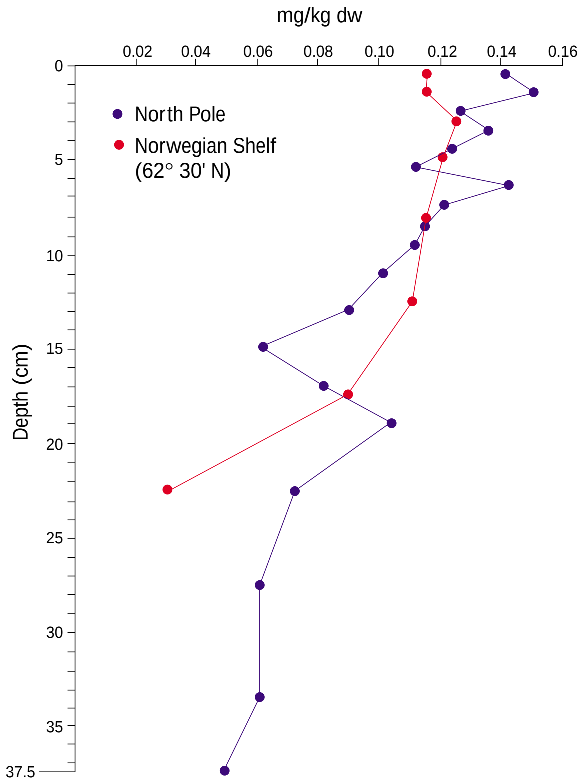
Preliminary results indicate that global annual emissions to the atmosphere are between 1300 and 2150 t (Pacyna and Pacyna, 1996). The major emission sources of mercury to the atmosphere are coal combustion at power plants, and industrial, commercial and residential burners, followed by gold production and waste disposal. A decreasing trend in mercury levels in the atmospheric deposition in Scandinavia has been observed over the last few years (Iverfeldt *et al.*, 1995).

There is little information on mercury concentrations in sea water in the Arctic. There are apparently small differences in the concentrations of mercury in unpolluted water in the different oceans of the world. Total dissolved mercury concentrations in unpolluted ocean water are within the range 0.2 to 1 ng/l, with higher concentrations in coastal waters and at pycnoclines (up to 2 ng/l) (AMAP, 1998).

Mercury concentrations in Arctic sediment cores indicate a general pattern of higher concentrations in the surface layers of Arctic sediments (AMAP, 1998) (see also *Figure 4.8*). Loring and Asmund (1996) reported average mercury concentrations in Greenland sediment of 0.045 ± 0.045 mg/kg dw. Sediment mercury levels were < 0.06 mg/kg dw at open ocean sites in the Norwegian and Barents Seas (Stange *et al.*, 1996).

Marine mammals at high trophic levels are consumed by people living within Region I. Levels of mercury and other heavy metals have been measured primarily in the

Figure 4.8 **Concentrations of mercury in Arctic marine sediment cores. Source: AMAP (1998).**



organs and tissues used for human consumption, which may not coincide with the tissues of most significance from an animal toxicity point of view. Within Region I relatively high levels of methyl mercury have been found in kidney, liver and muscle of some fish species and mammals (AMAP, 1998). Few data exist for mercury in brain tissue, which is considered important for evaluating toxicological effects. Much of the mercury in the environment is unavailable to organisms, as it is strongly bound to sediment or organic material.

Blue mussels readily accumulate mercury. This species is used in marine monitoring programmes, and data are therefore available from several areas within the Arctic, including coastal regions of Greenland, Iceland, the Faroe Islands and Norway. Mercury levels vary little between the different areas, with most values reported between 0.01 and 0.02 mg/kg ww (AMAP, 1998; Egilson *et al.*, 1999).

Tissue concentrations of mercury increase with age in both freshwater and marine fish (Dietz *et al.*, 1996; Stange *et al.*, 1996; Riget *et al.*, 1997). In contrast to other heavy metals for which the highest levels are found in liver tissue, mercury accumulates primarily in the proteinaceous muscle tissue of fish. Cod and dab muscle collected from the Iceland Sea contained mean mercury concentrations of 0.034 and 0.036 mg/kg ww respectively (Egilson *et al.*, 1999). Mercury concentrations in Arctic marine fish are generally within the range of 0.01 to 0.10 mg/kg ww (AMAP, 1998) (see *Figure 4.9*). Somewhat higher levels, up to 0.21 mg/kg ww, were found in deep-sea redfish in the Irminger Basin (Stange *et al.*, 1996).

In seabirds, mercury is usually found in higher concentrations in liver tissue than in kidney and muscle. Reported values in liver from Arctic seabirds range from 0.1 to 3 mg/kg ww (AMAP, 1998). In muscle, mercury levels are low; from below the detection limit to 1 mg/kg ww. Mercury has also been measured in seabirds and concentrations in eggs from seven species in the Barents Sea region ranged from 0.06 to 0.34 mg/kg ww (Barrett *et al.*, 1996).

In mammals, the highest concentrations are usually found in liver tissue, followed by kidney and muscle. The primary route of mercury uptake is through the diet. Mercury is present in their prey largely as methyl mercury, which is readily absorbed in the mammalian intestine. Mercury can pass from mother to foetus during gestation. As is the case for cadmium, mercury levels increase with age. This tendency has been seen in seals, whales and Polar bear (AMAP, 1998).

In ringed seals from Jarfjord in Finnmark, Norway, mercury concentrations in liver and kidney were in the range of 0.2 to 0.5 mg/kg ww (Skaare, 1994). Similar levels are reported in ringed seals from Svalbard, but with a few exceptions where liver concentrations were as high as 4 mg/kg ww. Higher levels, 23 to 30 mg/kg ww, were found in livers of five-to-fifteen year old ringed seals from King Oscars Fjord on the east coast of Greenland (Dietz *et al.*, 1998) and in adult grey seals (*Halichoerus grypus*), 22 mg/kg ww, in Jarfjord, Norway (Skaare, 1994).

Baleen whales generally have low levels of mercury in their tissues. Liver concentrations of up to 0.54 mg/kg have been reported in fin whale, while lower levels were found in bowhead whale (*Balaena mysticetus*) and minke whale (AMAP, 1998). Toothed whales have comparatively high mercury levels, with the highest concentrations reported in pilot whale. This species is used for human consumption in the Faroe Islands. Recent mercury levels in the muscle tissue of pilot whales ranged from 0.70 to 2.54 mg/kg ww, which is high relative to standards set for mercury levels in food from the marine environment for human consumption (0.3 – 0.5 mg/kg). Liver concentrations as high as 84 mg/kg were reported in samples collected in 1987 (Caurant *et al.*, 1994), while older data show even higher levels of mercury in the livers of pilot whales (Julshamn *et al.*, 1987).

Polar bear from Svalbard had average liver and kidney mercury concentrations ranging from 1.9 to 2.6 mg/kg ww and from 1.9 to 4.9 mg/kg ww, respectively (Norheim *et al.*, 1992). Higher values are reported in Polar bear from Greenland and the Canadian Arctic, with liver concentrations of up to 53 mg/kg ww (e.g. Braune *et al.*, 1991; Dietz *et al.*, 1995).

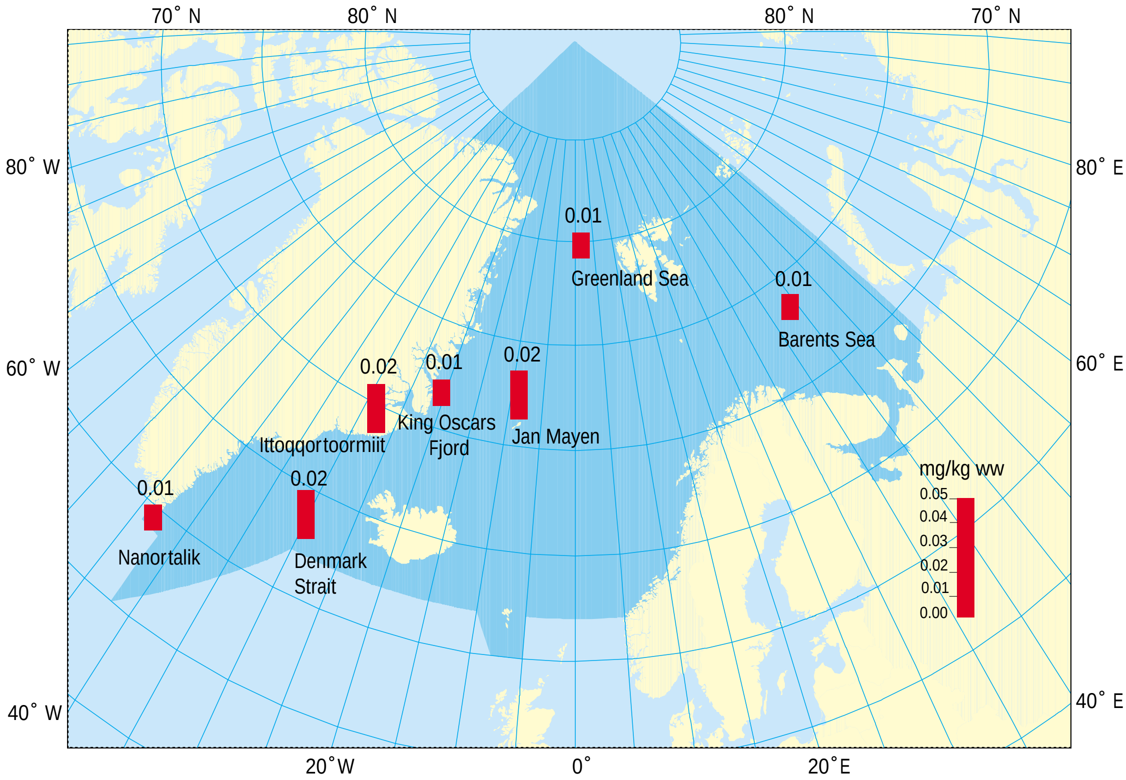
4.4.3 Lead

The atmosphere is the major route of lead entry into maritime areas. In Arctic areas, lead is considered to be of less toxicological importance than cadmium and mercury (AMAP, 1998). In a recent revision of the global emission inventory for lead, a maximum annual emission of approximately 209 000 t was estimated for 1989. Petrol combustion accounted for 62% of the emissions, and non-ferrous metal production for 26% (Pacyna *et al.*, 1993). The manufacture of ceramics is a source of lead to the aquatic environment. Lead in the environment is strongly adsorbed onto particles and sediment, and is therefore not readily bioavailable. Of the different species of lead in the environment, Pb^{2+} is most readily absorbed by biota. Global emissions of lead have decreased in recent years, including in Europe (see *Figure 4.6*).

Lead concentrations are consistently higher in oceanic surface waters than in deeper layers. In the Arctic Ocean, lead concentrations of 15 ng/l in surface waters and 3 to 4 ng/l at 1500 – 2000 m have been reported (Mart and Nurnberg, 1984). Lead levels in the surface waters of the Norwegian Sea in the 1960s ranged from 29 to 41 ng/l (AMAP, 1998).

Lead levels in surface sediments in the Norwegian Sea at sites far from point sources ranged from 7 to 22 mg/kg dw (AMAP, 1998). A similar concentration range was found in the Barents Sea with concentrations of 5 to

Figure 4.9 **Distribution of mercury concentrations in muscle tissue of Polar cod. Source: AMAP (1998).**



32 mg/kg dw. The mean concentration of lead in sediments around Iceland is 11.7 mg/kg dw (range 2.7 – 77.4 mg/kg dw) (Egilson *et al.*, 1999). Lead is not enriched in the upper layers of sediments in Region I.

Reported lead levels in blue mussels from Norwegian waters range from 0.10 to 0.48 mg/kg ww (Green, 1997). Similar ranges are observed in Iceland and Greenland (Egilson *et al.*, 1999). Deep sea prawns (*Pandalus borealis*) from East Greenland show generally low levels of lead, with mean muscle values ranging from 0.008 to 0.050 mg/kg ww.

Lead levels in fish from Region I are generally low. Concentrations in liver are typically higher than in muscle. Atlantic cod, Polar cod and long rough dab (*Hippoglossoides platessoides*) from the Barents Sea had average muscle and liver concentrations of less than 0.03 and 0.06 mg/kg ww, respectively (Stange *et al.*, 1996). Similar concentrations were found in the same species in the Norwegian Sea. Redfish (*Sebastes marinus* and *S. mentella*) had higher levels of cadmium and mercury than Atlantic cod, Polar cod and long rough dab, but this species difference was not observed for lead (Stange *et al.*, 1996). Cod and dab from Icelandic waters contain very low levels of lead (below the detection limit) (Egilson *et al.*, 1999).

Lead levels in the muscle tissue of Arctic seabirds are generally < 0.4 mg/kg ww (AMAP, 1998).

The highest lead levels reported in Arctic marine mammals are 0.5 to 1.0 mg/kg in liver and kidney of Polar bear from Svalbard (Norheim *et al.*, 1992). Tissue concentrations in seals are generally < 0.05 mg/kg ww. The highest values reported for ringed seal are 0.06 mg/kg (Dietz *et al.*, 1997a,b) from East Greenland and 0.05 to 0.1 mg/kg ww from Kongsfjorden on Svalbard (AMAP, 1998). Whales generally have low levels of lead in their tissues. Differences in concentration between tissues are not as apparent for lead as for cadmium and mercury.

4.4.4 Copper

Pyrometallurgical processes in the non-ferrous metal industries are the major sources of atmospheric copper *(Figure 4.1)*. Two major industrial complexes, the Pechenganikel smelters and the Severonikel smelter on the Kola Peninsula, are significant sources of copper to the Arctic region. The copper emissions have been estimated at approximately 310 t and 3000 t from the two industrial complexes, respectively. Ship building and maintenance are important sources of copper to the aquatic environment.

As is the case for the other trace elements, copper concentrations in sediments depend on the local geology, particle size, the organic carbon content, and on anthropogenic influences. The concentration of copper in marine sediments increases with increasing levels of fine-grained material. The mean copper concentration in sediments around Iceland is 55.5 mg/kg dw (range 22 – 122 mg/kg dw) (Egilson *et al.*, 1999). Both in Iceland and the Faroe Islands copper levels reflect the natural levels in rock of volcanic origin. Copper concentrations ranging from 18 to 59 mg/kg were measured in surface sediments in the Norwegian Sea, while the levels in the Barents Sea ranged from 2 to 36 mg/kg (Stange *et al.*, 1996). The influence of local geology is evident in sediments from Greenland, where copper concentrations ranged from 90 to 140 mg/kg in areas containing tertiary volcanic rock, and from 10 to 40 mg/kg in areas with non-volcanic rock (Loring and Asmund, 1996).

Copper is not considered to be an element of concern for the marine environment in Region I and few data are reported on this element in biota. Copper and several other trace elements were analysed in muscle and liver tissue of Atlantic cod, Polar cod, long rough dab and redfish from the Barents Sea and the North-east Atlantic (Stange *et al.*, 1996). Concentrations were similar in the three species, with muscle levels of 0.1 to 4.0 mg/kg ww and liver levels of 2 to 9 mg/kg ww. The highest concentrations were found in the livers of Polar cod. Mean copper levels in Atlantic cod and dab liver in Icelandic waters are 3.9 and 5.5 mg/kg respectively (Egilson *et al.*, 1999).

4.5 Persistent organic contaminants

4.5.1 Tributyltin

Organotin compounds including tributyltin (TBT) have been widely used as antifouling agents in the marine environment. In the last decade much attention has been paid to the induction of male characteristics in female snails, known as imposex. This phenomenon is mainly observed in negastopods. The dogwhelk (*Nucella lapillus*) is found to be an especially sensitive species. Populations of dogwhelk have disappeared or declined in areas where they experience TBT exposure, such as around harbours or along shipping lanes.

The most significant sources of TBT to marine waters were directly from surfaces treated with TBT; boat hulls, mariculture equipment, moorings and industrial cooling pipes. Additional sources include municipal wastewater and sewage sludge, run-off from agricultural land and shipyards. Although severe negative effects on marine organisms have been documented, TBT is still in use due to its superior properties as an antifouling agent. In Europe, its use has been regulated since 1990. It is no longer permitted to use TBT-based antifoulants on boats smaller than 25 m, or on aquaculture pens.

TBT released to the water will degrade to dibutyltin and monobutyltin. Breakdown in sediments is much slower than in water, with half-lives of 100 to 800 days, depending on the oxygen conditions (Watanabe *et al.*, 1995). Sediments are thus an important environmental compartment and sink for TBT. TBT has a high affinity for particles and is strongly bound to the sediment. It is lipophilic and can accumulate in marine organisms. Half-lives have been estimated at 69 days in blue mussel (Page *et al.*, 1995) and from one to four weeks in three species of marine fish (Yamada and Takayanagi, 1992).

Little is known about the fate of TBT in the Arctic environment. Half-lives may be longer than in temperate zones due to the low temperatures. A pathway of concern in the Arctic may be the direct, short food chain from benthic organisms to walrus (*Odobenus rosmarus*).

Harbours on the Norwegian coast have sediments with highly variable levels of TBT. Most of the sites investigated had concentrations of < 100 µg/kg dw, while sixteen sites had levels of > 1000 µg/kg dw (Berge *et al.*, 1997).

Imposex characteristics have been found in mussels and snails from the coasts of Norway, Iceland, the Faroe Islands and Svalbard. Some degree of imposex occurred in dogwhelk at almost all the sites investigated along the Norwegian coast (Berge *et al.*, 1997). At about half the sites, a proportion of the females were sterile. The concentrations of TBT in affected populations were in the range 50 to 2676 µg/kg dw, while unaffected populations from northern Norway had levels of < 17 µg/kg dw (the detection limit). The concentrations of TBT in blue mussels from 63 stations along the Norwegian coast varied from < 10 µg/kg ww to about 3000 µg/kg ww. The highest concentrations were found in close proximity to harbours. However, concentrations of up to 150 µg/kg ww were found in mussels from open waters (Berge *et al.*, 1997). Seasonal fluctuations in levels of TBT were observed in both dogwhelk and blue mussel in Icelandic waters, with summer levels being approximately five to ten times higher than the winter levels (Skarphedinsdottir *et al.*, 1996). These changes were related to seasonal variations in the feeding and resting of dogwhelk and the feeding of blue mussel, with seasonal changes in shipping activity insignificant.

4.5.2 Polychlorinated biphenyls

Polychlorinated biphenyls are synthetic compounds that were used extensively because their physical/chemical properties made them ideal for a variety of industrial products, such as transformer and capacitor oils, hydraulic and heat exchange fluids, lubricating and cutting oils, and as a plasticiser in paints, plastics and sealants. However, their resistance to degradation and their semi-volatile, lipophilic and toxic characteristics make them environmentally polluting. There are 209 chlorinated biphenyl congeners with different chlorine substitutions on the biphenyl rings. The number and positioning of the chlorines influences both toxicity and physical properties such as solubility and vapour pressure.

The total world production of PCBs has been estimated at 1.5 million t. PCBs have not been deliberately spread through the environment like pesticides. Releases occur via different routes including leaks from sealed transformers and heat exchangers, accidental losses and spills, vaporisation of carelessly disposed PCB-containing equipment, and emissions from PCB-containing materials such as paints, coatings, sealants and plastics.

The production and use of PCBs have been banned or severely restricted in most circumpolar countries since the 1970s. However, the use of PCBs in closed systems was allowed in several countries until recently.

Once released to the environment PCBs can move from the point of emission and be distributed globally. According to global fractionation theory, chemicals released in warmer climates vaporise and are transported via air currents to colder regions where they are deposited onto land and water (Wania and Mackay, 1993).

PCBs emitted and deposited during the years of intensive production and use are still a diffuse source to the global environment. Re-volatilisation from polluted soils and waters has been shown to be a significant source to the atmosphere. Examples are the Great Lakes in North America (Hornbuckle *et al.*, 1993) and soils in England (Harrad *et al.*, 1994). Once in the atmosphere, PCBs re-enter the global circulation, and can be transported to the Arctic. Several studies from the terrestrial environment show a decline in PCB levels since the 1970s. A reduction in the atmospheric deposition of PCBs in Norway was identified by studying PCB levels in moss (*Hylocomium splendens*) (Lead *et al.*, 1996).

A problem when comparing and interpreting PCB data is that different scientists measure and report varying numbers of PCB congeners. The reported sum of PCBs can refer to as little as seven or as many as 60 congeners.

PCBs are hydrophobic compounds; i.e. they have extremely low water solubility. Concentrations in ocean water are generally very low, and this makes reliable quantification difficult. PCB levels in filtered ocean water are usually reported in the low pg/l range. High levels in the ng/l order of magnitude were reported in whole (unfiltered) sea water in the Russian Arctic (AMAP, 1998). These levels seem unrealistically high, but are consistent with high levels of PCBs measured in suspended sediments in Russian rivers.

Concentrations of PCBs are generally very low (near the detection limit) in marine sediments from offshore areas. Most of the locations included in the AMAP assessment have PCB concentrations of < 1 µg/kg dw (AMAP, 1998). Nearshore locations along the Norwegian coast had PCB concentrations ranging from 0.1 to 5.4 µg/kg dw, while concentrations at sites in the Norwegian Sea ranged from 0.35 to 1.1 µg/kg dw. In nearshore locations in Iceland (in the vicinity of Reykjavik and Akureyri) elevated PCB concentrations of up to 30.6 µg/kg dw have been found reflecting local sources (Egilson *et al.*, 1999).

A number of Norwegian harbours have sediments that are contaminated by PCBs. Levels of > 100 µg/kg dw have been found in the most severely contaminated harbours in northern Norway. Several of the harbours investigated had sediments with PCB levels in the range of 25 to 100 µg/kg dw (Konieczny, 1996).

Of marine invertebrates in Arctic waters, most information on PCB levels is available for the blue mussel. Levels of PCBs in blue mussels in coastal waters are generally low with values ranging from 0.5 to 1.4 µg/kg ww (AMAP, 1998).

Organochlorine contaminant levels in zooplankton and pelagic amphipods vary according to trophic position and life span. While most levels of PCBs in Arctic invertebrates included in the AMAP assessment were < 10 µg/kg ww, PCB levels in zooplankton from the central Arctic Ocean ranged from 31 to 67 µg/kg ww (AMAP, 1998; Egilson *et al.*, 1999).

PCBs have been investigated in several species of marine fish from Arctic waters for the AMAP assessment (see *Figure 4.10*). Polar cod is a key species in the pelagic food chains of Region I and was selected as an essential species for the AMAP programme. Reported levels of PCBs in Polar cod livers are 33 µg/kg ww in Greenland (Cleemann *et al.*, 1997), 25 to 72 µg/kg ww in the Norwegian Sea (Stange *et al.*, 1996), 47 to 82 µg/kg ww in the Barents Sea (Stange and Klungsøyr, 1997) and 19 to 58 µg/kg ww west of Svalbard (Killie and Dahle, 1996). As a predatory fish, Atlantic cod is at a higher level in the food chain than Polar cod. This is reflected in higher levels of PCBs in Atlantic cod than in Polar cod. Average concentrations of PCBs reported in Atlantic cod livers range from 63 µg/kg ww in the Faroe Islands to 392 µg/kg ww off the coast of Norway in the Barents Sea (Stange *et al.*, 1996; Stange and Klungsøyr, 1997). Other species investigated in the same studies included redfish from the North-east Atlantic (22 – 159 µg/kg ww) and long rough dab from the Barents Sea and off Iceland (15 – 57 µg/kg ww). Average PCB levels in shorthorn sculpin from Greenland waters were 17 µg/kg ww (Cleemann *et al.*, 1997). Icelandic data show a mean PCB concentration in cod liver of 87 µg/kg ww and in dab liver of 64 µg/kg ww (Egilson *et al.*, 1999).

4.5.3 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons include aromatic molecules containing three or more fused aromatic rings. Often di-aromatic compounds such as alkylated naphthalenes are also included in the PAHs. In general, the two main sources of PAHs to the environment are fossil fuels, including crude oil, and the incomplete combustion of organic materials such as wood, coal and oil. Some naturally synthesised compounds can be reduced to PAHs under anaerobic conditions. Among the PAHs formed by natural processes are perylene, retene and phenanthrene homologues. PAHs are also formed naturally during forest fires and volcanic eruptions. PAHs in aquatic environments rapidly become associated with particulates due to their hydrophobic nature. Sediments are the most important reservoir of PAHs in the marine environment. Anthropogenic activities are generally accepted as the most important source of PAHs released into the environment. Estimates of total PAH inputs to Region I are not available.

Little information exists on the levels of PAHs in sea water from Region I. Generally the levels in the open ocean are in the low ng/l range. The concentrations of total PAHs in the Russian Arctic marine environment range from below the detection limit to 88 ng/l (AMAP, 1998). Phenanthrene and naphthalene are the most abundant PAH compounds in samples collected in the Pechora, White and Kara Seas. Naphthalene is most common in river estuaries and coastal areas where some anthropogenic influence is most likely.

PAH concentrations in surface sediments from the Russian marine environment are generally lower than 500 µg/kg dw (range 4 – 3400 µg/kg dw) (AMAP, 1998).

Sediments near Svalbard contain total PAH concentrations of 1600 to 8100 µg/kg dw, probably due to contamination by petroleum and petroleum products, as indicated by the predominance of alkylated naphthalenes.

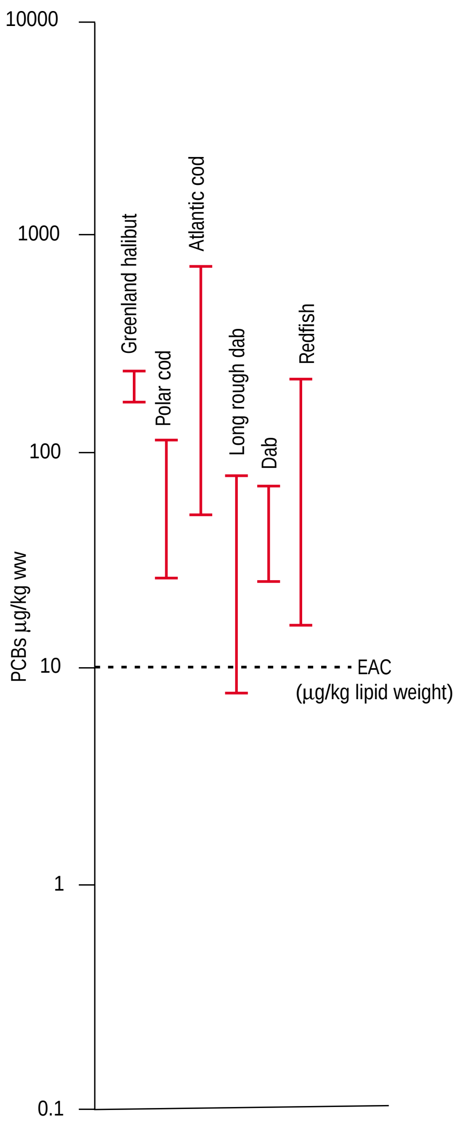
Total PAH concentrations in sediments from several locations along the northern Norwegian coast occur over a wide range (44 – 46 000 µg/kg dw), with the highest concentrations found in some contaminated harbour areas (Konieczny, 1996). The high molecular weight (combustion) PAHs were most abundant. Total PAH concentrations measured within two cores (of approximately 50 cm) from coastal areas provided uniformly low values (3 – 39 µg/kg dw) below an enriched surface layer (44 – 274 µg/kg dw) (Næs *et al.*, 1995).

On a worldwide basis, background values for sediments appear to fall within the range of a few tens to approximately 500 µg/kg dw (Windsor and Hites, 1979). Consequently, some areas of Region I have elevated levels of PAHs relative to global background concentrations.

PAHs are less prone to bioaccumulation or biomagnification than the organochlorines, since fish and organisms higher in the food web tend to metabolise and excrete the compounds relatively rapidly (e.g. Macdonald and Bewers, 1996). In marine invertebrates such as blue mussel the metabolism of PAHs is usually slower and these organisms are therefore considered more suitable for the monitoring of PAHs.

Only limited information is available on PAHs in marine biota from Region I. The results reported indicate levels similar to those thought to reflect global background conditions in biota (AMAP, 1998). A few blue mussel samples collected from the northern coast of Norway during 1992 to 1995 contained total PAH concentrations in the range of 18 to 76 µg/kg ww, with two- and three-ring aromatics being the most common (Killie and Dahle, 1995). Cod and haddock liver obtained during 1993 to 1994 from the Norwegian and Barents Seas, contained 77 to 110 µg/kg ww of PAHs, again with two- and three-ring aromatic hydrocarbons the most common (Klungsøyr and Johnsen, 1997).

Figure 4.10 **Range in PCB concentrations (µg/kg ww) in the livers of various fish species from Region I.**



4.5.4 Other persistent organic compounds

Organochlorine pesticides

There is no specific information available on the total inputs of persistent organic compounds to Region I. However, several studies have indicated that compounds such as HCHs, hexachlorobenzene (HCB), DDTs and chlordanes are widespread within Arctic maritime areas. *Table 4.1* shows the global use of certain pesticides. Bidleman *et al.* (1990) reported that the relative abundance in sea water is often α-HCH > HCB > γ-HCH = toxaphene > chlordanes = PCBs > DDTs. The same groups of compounds are also widespread in sea-ice and surface sediments, generally at very low concentrations. In surface sediments from offshore sites there is no apparent geographical trend (AMAP, 1998). Coastal sediments at some locations along the northern coast of Norway have been reported to contain slightly elevated levels of persistent organic contaminants compared to offshore sites (AMAP, 1998).

The levels of HCB, HCHs, DDTs and chlordanes in Atlantic cod liver from the Barents Sea were slightly lower than the levels found in cod from Haltenbanken in the Norwegian Sea and in cod from the northern parts of the North Sea (Stange *et al.*, 1996). The lowest levels were found in livers of cod from different stocks in Icelandic and Faroese waters. The range in concentrations of HCHs and DDTs reported in Arctic biota is shown in *Table 4.2*. Levels of persistent organic compounds in liver from deep sea Arctic fish species were similar to or slightly higher than concentrations in Atlantic cod from the north-western Atlantic (Berg *et al.*, 1997). Egilson *et al.* (1999) reported very low mean concentrations of HCB, HCHs and DDE in cod and dab liver from Icelandic waters, ranging from < 1.6 to 48 µg/kg ww (see also *Figure 4.11*).

Polar cod from the Canadian Arctic Archipelago had around two- to three-fold higher levels of HCHs than Arctic cod from the Barents Sea (AMAP, 1998). HCHs in

Table 4.1 Global use of selected pesticides, 1948 to 1993. Source: Voldner and Lie (1993, 1995).

	t x 10^3
DDT	1500
Technical HCH	550
Technical lindane	720
Toxaphene	450

Canadian Arctic ringed seals are higher than in the same species from Greenland and Svalbard. A similar situation is the case for thick-billed murre (*Uria lomvia*). These elevated levels of HCHs are consistent with higher HCH levels in sea water in the Canadian Arctic.

Surveys of contaminants in eggs and tissues of Arctic seabirds show that seabirds breeding in the Arctic are contaminated by a similar suite of organic contaminants as those breeding in temperate regions. Glaucous gull, herring gull (*Larus argentatus*), black-legged kittiwake (*Rissa tridactyla*), cormorant (*Phalacrocorax carbo*) and puffin (*Fratercula arctica*), generally have the highest levels of persistent organic compounds (AMAP, 1998). DDE concentrations were highest in glaucous gulls from the Canadian Arctic, herring gulls from northern Norway and Brünnich's guillemot from Svalbard (AMAP, 1998). These levels are comparable, on a lipid weight basis, to concentrations in seals from the same areas.

A picture that emerges from the analyses of Arctic seabirds is that the Barents Sea may be more contaminated by DDTs (and PCBs) than the Canadian Arctic. Lipid weight levels of DDTs in black-legged kittiwake eggs from Svalbard are higher than in eggs from a site in Canada, the same is the case for thick-billed murre eggs in which concentrations are higher in samples from Svalbard, Hornøya and the Kola Peninsula than from the Canadian Arctic. However, HCH levels are higher in thick-billed murre from Canada than from Norwegian sites (AMAP, 1998).

Figure 4.11 **Trends in the concentrations of selected persistent organic contaminants in cod liver from Icelandic waters.**

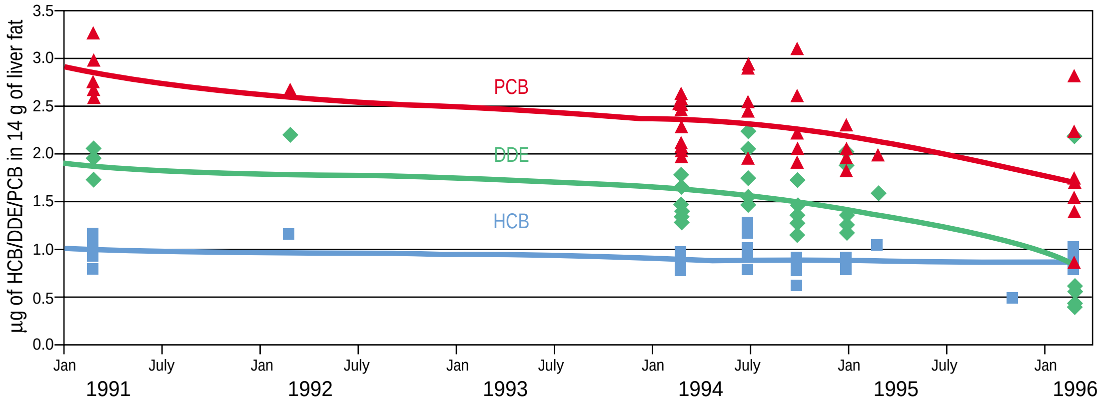


Table 4.2 Range in concentrations for selected organochlorine compounds in biota (µg/kg ww).

	Location	Dates	Tissue	HCHs	DDTs	PCBs	Source
Mussel							
blue mussel	Iceland	1990–6	soft tissue	< 0.5	0.05 – 2.9*	1.6 – 26.5	Egilson *et al.* (1999)
	Norway	1996–7	soft tissue	0.1 – 0.2	0.2 – 1*	2 – 7	Green *et al.* (1999)
	Greenland	1994–5	soft tissue	0.82	0.43	0.86	Cleemann *et al.* (2000b)
Fish							
Polar cod	Barents Sea	1991–4	liver	7 – 15	21 – 54	36 – 114	Stange and Klungsøyr (1997)
	Norwegian Sea	1991–4	liver	6 – 10	12 – 83	21 – 111	Stange *et al.* (1996)
	Greenland Sea	1991–4	liver	8 – 16	23 – 35	39 – 114	Stange *et al.* (1996)
	Greenland Sea	1994	liver	40	42	35	Cleemann *et al.* (2000b)
Atlantic cod	Barents Sea	1991–4	liver	3 – 17	67 – 344	115 – 685	Stange and Klungsøyr (1997)
	Norwegian Sea		liver	4 – 9	42 – 452	52 – 519	Stange *et al.* (1996)
	Iceland Sea	1991–6	liver	< 1 – 153	12 – 118*	28 – 406	Egilson *et al.* (1999)
long rough dab	Barents Sea	1991–4	liver	1 – 5	6 – 43	-	Stange and Klungsøyr (1997)
	Iceland Sea	1991–4	liver	4.3 – 5.6	34 – 63	30 – 47	Stange and Klungsøyr (1997)
common dab	Iceland Sea	1991–6	liver	< 0.6 – 5.3	3.6 – 150*	14 – 501	Egilson *et al.* (1999)
redfish	Norwegian Sea	1991–4	liver	2 – 6	26 – 148	31 – 136	Stange *et al.* (1996)
	Iceland Sea	1991–4	liver	2 – 4	13 – 39	14 – 38	Stange *et al.* (1996)
	Greenland Sea	1991–4	liver	1 – 3	54 – 130	35 – 149	Stange *et al.* (1996)
Seabirds							
kittiwake	Barents Sea	1991	liver	0.2 – 25	3 – 279	23 – 2 378	Savinova *et al.* (1995)
	Barents Sea	1992	liver	-	-	12 – 285	Henriksen *et al.* (1996)
common eider	Barents Sea	1991	liver	0.2 – 1.3	0.5 – 18	0.8 – 54	Savinova *et al.* (1995)
glaucous gull	Barents Sea	1991	liver	0.9 – 14	65 – 432	116 – 2 989	Savinova *et al.* (1995)
Marine mammals							
harp seal	Greenland Sea West Ice	1990	blubber	nd – 220†	340 – 1 800†	540 – 1 470†	Espeland *et al.* (1997)
	Barents Sea		blubber	50 – 190	550 – 7 870	750 – 9 810	Kleivane *et al.* (1996)
hooded seal	Greenland Sea West Ice	1990	blubber	43 – 79†	1 550 – 5 800†	2 090 – 10 200†	Espeland *et al.* (1997)
harbour seal	Iceland	1988	blubber	17	1 550	5 220	Luckas *et al.* (1990)
	Barents Sea	1989–90	blubber	-	-	5 200	Skaare (1996)
	Norwegian Sea	1990	blubber	-	-	3 400	Skaare (1996)
grey seal	Barents Sea	1989	blubber	-	-	5 700	Skaare (1996)
ringed seal	Barents Sea	1990	blubber	-	1 070	1 130	Daelemans *et al.* (1993)
	Greenland Sea	1994	blubber	152	1 410	1 010	Cleeman *et al.* (2000a)
walrus	Barents Sea	1991–2	blubber	-	4 340	11 500	Skaare (1996)
harbour porpoise	Barents Sea	1988–9	blubber	473	15 400	24 500	Kleivane *et al.* (1995)
minke whale	Barents Sea	1992	blubber	-	1 400	2 000	Skaare (1996)
Polar bear	Barents Sea	1990–4	fat	nd – 1 150	-	2 900 – 90 000	Bernhoft *et al.* (1997)

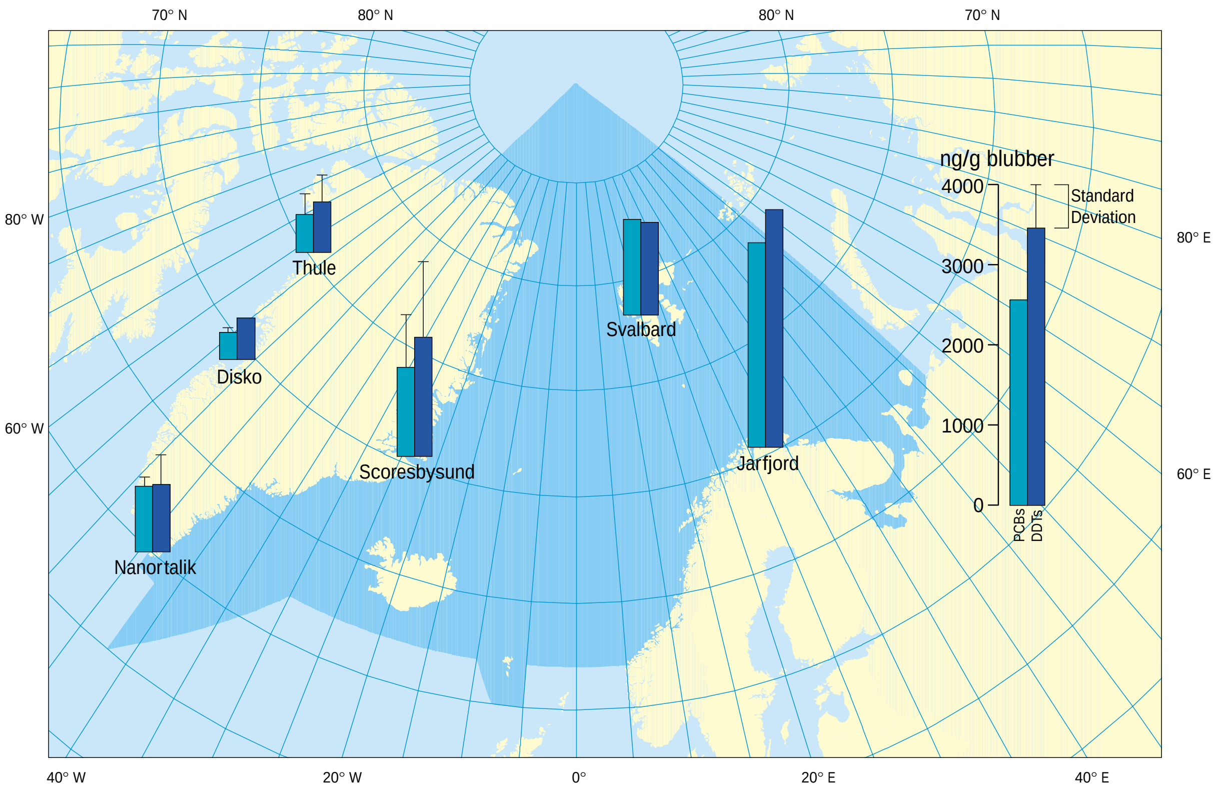
* *p,p'*-DDE only; † µg/kg lipid; nd not detected.

A west to east increase in levels of DDTs (and PCBs) from North America to western Russia is apparent in the blubber of harp seals and possibly also in that of ringed seals (AMAP, 1998) (see *Figure 4.12*). DDTs in harp seals from north-eastern Greenland were about two- to three-fold lower in concentration than those from northern Norway (Jarfjord, Skjånes) and western Russian waters.

Levels of persistent organic compounds in Polar bear tissues have been the focus of detailed studies on Svalbard and in the Canadian Arctic. Chlordanes and HCB in Polar bears are more uniformly distributed over the study area than DDTs (and PCBs). This is consistent with the finding of lower geographical variation in chlordanes and HCB concentrations in air and sea water (AMAP, 1998).

The circumpolar study of persistent organic contaminants in Polar bear fat by Norstrom *et al.* (1998) shows

Figure 4.12 **PCBs and DDTs in ringed seal blubber. Source: based on AMAP (1998).**



generally increasing concentrations from west to east; similar to that observed in several other marine species for DDTs (and PCBs). This trend may be due to the combined influence of long-range atmospheric transport from North America and Europe. Another possible factor is the transport of contaminants in sea-ice and overlying snow or associated with sediment particles embedded in sea-ice derived from the Russian continental shelf.

Dioxins and dibenzofurans

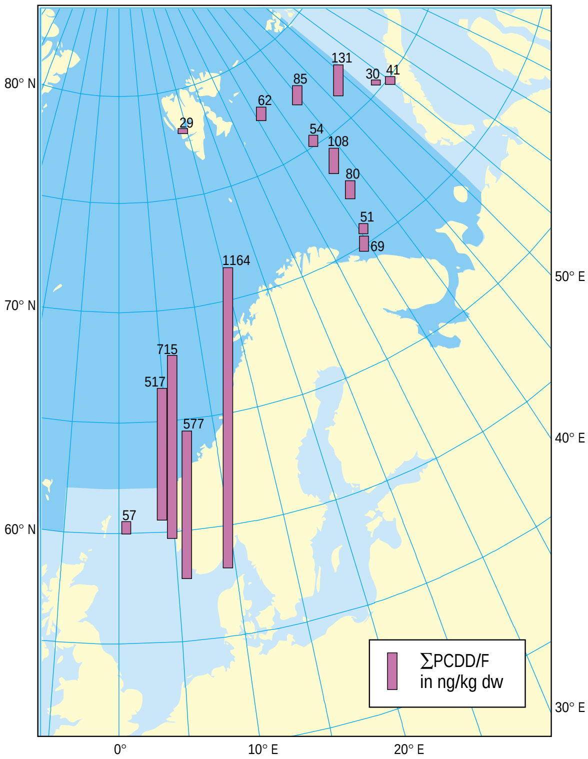
The major sources of polychlorinated dibenzodioxines and -furanes (PCDD/Fs) to air are waste incineration, particularly through incomplete combustion, wood burning and other combustion, and metallurgical industries. Smelters, the secondary iron and steel industry, the aluminium industry, the ferroalloy industry and the pulp and paper mill industry may be sources of PCDD/Fs in Region I.

Information about PCDD/Fs in sea water from the Arctic is not available. Oehme *et al.* (1993) analysed surface sediments from the Barents Sea for PCDD/Fs and compared the results with samples from the North Sea/Norwegian Sea (*Figure 4.13*). PCDD/F concentrations in the Barents Sea were low and fell within a relatively narrow range (12 – 32 ng/kg dw for PCDDs; 16 – 102 ng/kg dw for PCDFs). The relative proportion of more volatile PCDD/F congeners was higher in the Barents Sea than the North Sea. Concentrations of PCDD/Fs in the Barents Sea were ten to twenty times lower than those in the northern North Sea.

Information on levels of PCDD/Fs in marine biota from Region I is limited. Schlabach and Skotvold (1996a,b) found low ng/kg ww levels of PCDD/Fs in horse mussel (*Modiolus modiolus*) samples within the vicinity of a smelter near Kirkenes in northern Norway. TCDD TEQ concentrations in mussels ranged from 0.61 ng/kg ww near the smelter to 0.2 ng/kg ww at the reference site. Atlantic cod caught in the area also had low TCDD TEQs in muscle (0.02 – 0.04 ng/kg ww).

In ringed seals from the Barents and Greenland Seas, concentrations of 2,3,7,8-TCDF and PeCDF tend to be equal to or higher than concentrations of TCDD and PeCDD, slightly different to the pattern for mammals from the Canadian Arctic (Oehme *et al.*, 1988, 1995b; Bignert *et al.*, 1989). Concentrations of 2,3,7,8-TCDF in Canadian ringed seals ranged from < 2 to 7 ng/kg ww, which were lower than values reported for Svalbard ringed seals (9 – 13 ng/kg) (Oehme *et al.*, 1988). Concentrations of 2,3,7,8-TCDD in ringed seal blubber from Svalbard ranged from < 2 to 8.2 ng/kg ww (Oehme *et al.*, 1988) and from 2 to 37 ng/kg ww in pooled blubber samples from various locations in the Canadian Arctic (Norstrom *et al.*, 1990). In

Figure 4.13 **Concentrations of total PCDD/Fs in marine sediments from Norwegian waters and the Barents Sea. Source of data: Oehme *et al*. (1993).**



general, concentrations of PCDD/Fs in Arctic seals are lower than in animals from the Baltic Sea and the North Sea (Oehme *et al.*, 1988; Bignert *et al.*, 1989), but higher than those found in Antarctic seals (Oehme *et al.*, 1995c).

Toxaphene

Toxaphene, a complex mixture of polychlorinated camphenes, was first introduced in 1945 by Hercules Co. Until the mid 1980s, it was mass produced and widely used as an insecticide, particularly in the cotton growing industry. It was also used as a piscicide to control fish in various water systems. The lipophilic, persistent and volatile nature of toxaphene, has contributed to its global dispersion throughout the freshwater and marine environment (e.g. Kidd *et al.*, 1995; Norstrom and Muir, 1994; Oehme *et al.*, 1996). It has even been detected in remote areas such as the Arctic where the pesticide was never used (Bidleman *et al.*, 1989). Toxaphene was banned by the US Environmental Protection Agency in 1982, this example was followed by many countries. However, in the early 1990s the detection of toxaphene in marine fish in Europe caused concern with regard to human consumption.

There are very few measurements of toxaphene in sea water from Region I. Chernyak *et al.* (1995) reported toxaphene levels of 14 pg/l in Barents Sea coastal waters. Measurements of toxaphene in the Canadian Archipelago (Bidleman *et al.*, 1995; Hargrave, 1996) and on oceanographic cruises across the Polar cap (Jantunen and Bidleman, 1998) showed toxaphene concentrations to increase from 15 – 30 pg/l in the Bering/Chukchi Seas (outside Region I) to 90 – 120 pg/l at higher latitudes. A similar northwards increase was also found for HCHs.

Relatively few measurements of toxaphene have been made in marine biota from Region I. Toxaphene was determined in zooplankton in the central Arctic Ocean during a Russian/Canadian transpolar cruise in 1994 (AMAP, 1998). Toxaphene concentrations were 15 to 31 µg/kg ww, and together with PCBs were the main organochlorines in the samples.

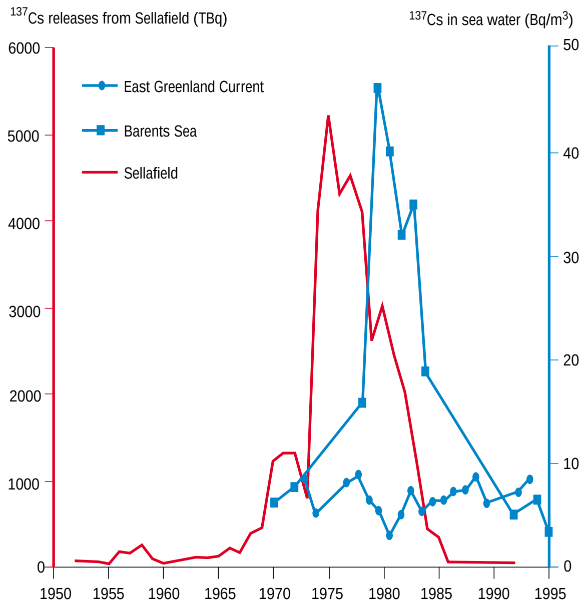
Analyses of Greenland halibut and Arctic cod in the Canadian Arctic indicate that toxaphene is a significant persistent organic contaminant in fish (Muir and Lockhart, 1996). Toxaphene was also prominent in Atlantic cod liver from northern Norway and eastern Canada (Paasivirta and Rantio, 1991; Musial and Uthe, 1983). Toxaphene was measured in landlocked Arctic char (*Salvelinus alpinus*) from Greenland (Cleeman *et al.*, 1997). The char showed levels that were significantly higher on the east coast relative to areas on the west coast, however overall the levels of toxaphene in muscle were low with a geometric mean of 13 µg/kg ww for the whole group analysed. Müller *et al.* (1988) reported that toxaphene concentrations in mackerel and herring caught west and north-west of Ireland and the Shetland Islands exceeded the German tolerance level (which at that time was 0.1 mg/kg on a lipid basis or 0.01 mg/kg ww).

There are few published data on toxaphene in Arctic marine mammals from Greenland, Norwegian and Russian waters. Some results from mammals collected in the Canadian Arctic are therefore used to illustrate toxaphene levels in mammals. High levels of toxaphene have been reported for white-beaked dolphins (*Lagenorhynchus albirostris*) and pilot whales collected during 1980 to 1982 from the coast of Newfoundland (Muir *et al.*, 1988). Toxaphene levels were higher than for the other organochlorines measured (PCBs, DDTs etc.). Toxaphene was also the major organochlorine contaminant detected in belugas and narwal (Muir *et al.*, 1990, 1992). Toxaphene was measured in ringed seals from Greenland (Cleeman *et al.*, 1997). The seals displayed no significant geographical variation, the geometric mean being 0.26 mg/kg ww.

4.6 Oil

Inputs of petroleum hydrocarbons to Region I are the result of sea-based activities, discharges from land, riverine inputs, atmospheric deposition and natural seeps.

Figure 4.14 **Sea water concentrations of ^{137}Cs in the Barents and East Greenland Seas compared to annual discharges from Sellafield. Source: AMAP (1998).**



No quantitative estimates of total inputs to Region I have been made and data on temporal trends in inputs are not available. In 1997, the installations in the Norwegian Sea discharged 25.3 t of oil in total (SFT, 1998), mostly via production water. Owing to a lack of information it has not been possible to discuss the relative importance of different sources. GESAMP (1993) stated that land-based discharges and run-off are a major source of petroleum hydrocarbons to the global marine environment. Of the total amount of oil entering the marine environment from all sources, it has been estimated that at least 15% comes from natural oil seeps (GESAMP, 1993).

Oil is a complex mixture of aliphatic and aromatic hydrocarbons and small amounts of other compounds. This section describes the total concentrations of hydrocarbons reported in different media. Levels of aromatic hydrocarbons are discussed in Section 4.5.3.

Specific information about oil hydrocarbons in sea water from Region I is very limited. The solubility of oil in sea water is low and levels reported from areas not influenced by point sources are generally low. Elevated levels can be found in harbours and river estuaries. Accidental oil spills at the sea surface result in elevated concentrations under the oil slick in the upper part of the water column.

Total petroleum hydrocarbon concentrations in marine sediments from open parts of the Barents Sea range from 5 to 60 mg/kg dw (dos Santos *et al.*, 1996). In 1994 sediments from fourteen harbours in northern Norway showed elevated levels of petroleum hydrocarbons and some of the concentrations exceeded 1000 mg/kg dw (Konieczny, 1996). A similar situation is probably also the case in harbours from other parts of Region I. Elevated concentrations of oil hydrocarbons can also be found close to (< 500 m) oil installations off the Norwegian coast.

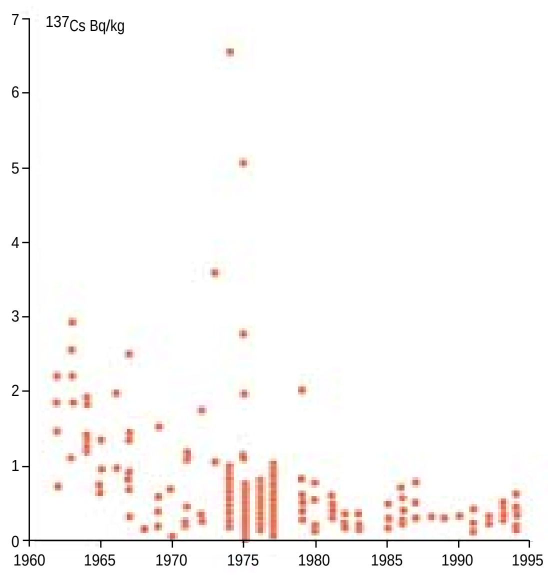
Information about background levels of total oil hydrocarbons in biota from Region I is very limited, and it is often difficult to differentiate between the naturally occurring hydrocarbons in the organisms and those which are anthropogenically derived. Oil spills will result in elevated concentrations of hydrocarbons in affected organisms, and may cause detrimental effects either due to physical smothering or due to the toxic effects of oil hydrocarbons.

4.7 Radionuclides

The anthropogenic sources of radionuclides contributing to the contamination of Region I are mainly from former nuclear weapons fallout, releases from the Sellafield and Cap de La Hague reprocessing plants, and the Chernobyl accident. Other potential sources include releases from nuclear reactors into cooling water streams, leakage from dumped solid wastes and the direct dumping of liquid wastes.

Figure 4.14 illustrates how the pattern of ^{137}Cs releases from Sellafield are reflected in the levels of ^{137}Cs measured in the Barents Sea, with a time lag due to transportation of approximately four to five years. The peak in ^{137}Cs activity of around 50 Bq/m^3 measured in the Barents Sea in the early 1980s is probably the highest

Figure 4.15 **Variations over time in levels of ^{137}Cs activity in marine fish from Greenland waters. Source: AMAP (1998).**



activity concentration that has occurred in this sea area. Before the increase in discharges from Sellafield in 1960s, the only major source contributing ^{137}Cs to the Barents Sea was fallout from nuclear weapons testing.

Surface concentrations of ^{137}Cs in sediments have been measured at many locations in Region I (AMAP, 1998). For most locations ^{137}Cs activity is < 10 Bq/kg dw. A few locations in the Norwegian Sea had concentrations of up to 100 Bq/kg dw, probably reflecting unusual sedimentation rates or sediment characteristics. On the southern coast of Novaya Zemlya similar levels have been found (AMAP, 1998).

Levels of radionuclides in fish from Region I have been monitored since the 1950s. The highest levels of ^{137}Cs in fish muscle (max. 80 Bq/kg ww) were found in the early 1960s at the time of nuclear bomb testing in the atmosphere. At present, the levels of ^{137}Cs in fish and mammals are very low (0.2 – 0.5 Bq/kg) and of low radiological significance (AMAP, 1998) (see *Figure 4.15*).

4.8 Nutrients and oxygen

Nutrients are natural constituents of sea water which play an important role since they form a basis for primary production in phytoplankton. Anthropogenic influences resulting in elevated nutrient concentrations can result in eutrophication and oxygen depletion. Such problems have not been observed in Region I, and nutrients are therefore not considered a pollution problem in the region. Typical winter values for nitrate, phosphate and silicate in the open ocean areas of Region I are 11 – 12 µmol/l, 0.8 – 0.9 µmol/l and 5 – 5.5 µmol/l, respectively. During phytoplankton blooms the levels in the upper water column show a natural decrease and can approach zero.

chapter 5

Biology

5.1 Introduction

The purpose of this chapter is to provide a general description of the marine ecosystems in Region I, to provide details about changes that have occurred during recent years and to discuss to what extent these can be attributed to different types of human activity. Section 5.2 gives an overview of the ecosystems in the different sea areas of Region I, while the subsequent sections provide an overview of the impact of different human activities. OSPAR adopted its Joint Assessment and Monitoring Programme (JAMP) in 1995 (OSPAR, 1995). This is based on a number of issues organised according to six main categories. These issues were intended as a guide to focus the monitoring and assessment activities within the OSPAR Convention area. This chapter is structured so as to try to provide answers to both general and specific questions raised in association with the JAMP.

5.2 Overview of the ecosystems

Parts of Region I are ice-covered in winter and the ice and ice-melt have a large influence on ecological conditions as well as on pollutant transport. Ice limits light and thus primary production by phytoplankton. When the ice melts, there is typically a sudden increase in light and a burst of plant growth in the form of an ice edge bloom in spring and summer. Owing to its association with melting ice, and the high latitude location, the seasonal plant production is short and of limited extent. The primary production is conveyed to higher trophic levels, often through short food chains within simple food webs. This allows for efficient transfer and supports large stocks of fish, mammals and seabirds.

The high latitude ecosystems of the Arctic region are characterised by large natural variability. This is due to high variability in recruitment to fish stocks combined with strong biological interactions in relatively simple food webs (Skjoldal *et al.*, 1992). That many species are close to their limits of distribution is also important. Region I comprises the transition zone between the boreal and true Arctic biogeographic regions. This transition zone is very sharp, in some areas as a distinct Polar Front, and is more gradual in other areas where the mixing of water masses occurs. The relatively warm Atlantic water that flows into the Arctic region, will in many places submerge and continue as an intermediate flow under the lighter Arctic surface water into the Greenland Sea and the Arctic Ocean. This mixing and transport makes the export of plankton an important feature of the Arctic region. Climatic variability causes large interannual variability in ice and hydrographic conditions, which again affects plankton production and fish recruitment.

5.2.1 Phytoplankton

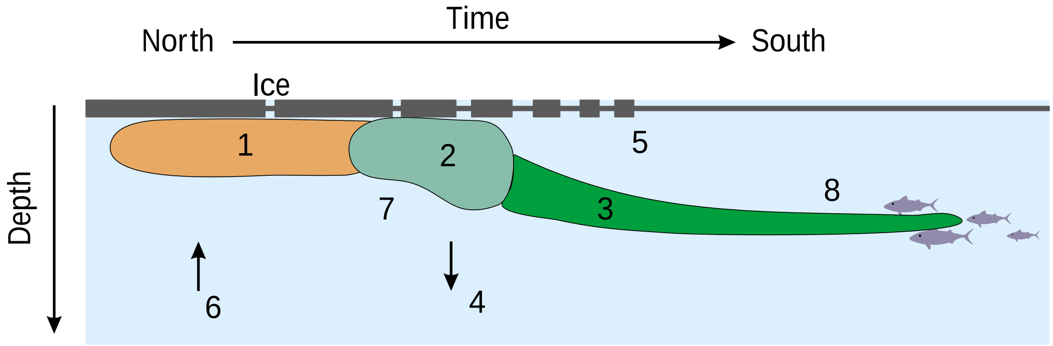
The Nordic Seas contain around 200 to 300 species of phytoplankton, the primary producers of the sea, and half of these belong to the diatoms (Zenkevitch, 1963). Diatoms are very important during the spring bloom and their numbers may reach several billion cells per cubic metre of sea water. The size varies from a few micrometres up to several hundred micrometres, the most important species in terms of primary production measure 10 – 50 µm in diameter. *Chaetoceros socialis* is the most abundant species, other common diatoms belong to the genera *Nitzschia* and *Thalassiosira*. Another group of phytoplankton is the naked flagellates; the colony-forming *Phaeocystis pouchetii* and the diatom *Chaetoceros socialis* are the two most important phytoplankton species in the Nordic Seas. The third group is the dinoflagellates, where the cells have two flagella for locomotion. Many of the species are heterotrophic, which means they feed on organic material and thus act as animals.

Vertical mixing of the water column is the most important process controlling the growth of phytoplankton. During winter, surface cooling combined with windstress causes deep mixing that brings nutrient salts up into the surface waters where they are available for the phytoplankton during the spring bloom. Where stratification is already present the spring bloom will usually start when the light level is sufficient. Although in the northern Nordic Seas this light level is attained in March, the bloom cannot start until at least a month later when the stable surface layer forms, reducing vertical mixing and thus the time spent by the phytoplankton in deeper water with insufficient light for growth. The stability of the water column is generated in different ways (Loeng and Rey, 1985). In areas covered by ice during winter the melting of the ice forms a shallow surface layer of relatively fresh and gradually warmer water on top of denser and saltier water below. This leads to a rapid and concentrated phytoplankton bloom that stops when the nutrient salts are depleted. The melting of the ice, which may start in April or even earlier, can result in an early bloom compared to those of the surrounding open waters. During periods with low air temperatures or persistent, strong winds from the ice towards the open sea, the winter ice may cover the warmer Atlantic water where an exceptionally early melt forms a stable surface layer and so an early bloom.

In open sea areas not affected by ice, the stable surface layer is formed by atmospheric warming. This process can be delayed by wind-induced mixing. This process takes some time and the bloom, at least in the northern and western regions of the Nordic Seas, will usually start later than the melt water blooms. In the open areas the mixed layer is deeper and more diffuse than the melt water layer, and the bloom is slower and lasts longer. Because the transition layer is deeper and less pronounced, the upper layer contains more nutrients. At the same time nutrients can be also mixed up from the layer below, which makes the production higher than in ice-covered areas. Temperature-induced stability starts in the Atlantic regions of the Nordic Seas and spreads towards the Arctic during summer. The ice-edge bloom is a dynamic process which follows the ice edge as it recedes, and stops in late summer when the melting of the ice comes to an end or light becomes a limiting factor *(Figure 5.1)*.

During the bloom the phytoplankton biomass is homogeneously distributed throughout the surface mixed layer. Later in the productive season, when nutrients become exhausted in the surface layer, the biomass is found within or just below the transition layer where nutrients can be reached from the deeper layer and the levels are still sufficient for production. The total integrated biomass during the bloom, expressed as chlorophyll *a*, may reach values of between 300 and 400 mg/m^2 in coastal waters and shelf regions, and is usually

Figure 5.1 **Schematic illustration showing the different successional stages of an ice-edge bloom. Source: Sakshaug *et al.* (1992).**



1. nutrient-rich water (pre-bloom)
2. nutrient-rich water (bloom)
3. layer of chlorophyll *a* (post-bloom)
4. sedimentation of phytoplankton
5. surface water (nutrient-depleted)
6. over-wintering zooplankton migrating to the surface
7. zooplankton spawning
8. capelin feeding migration

< 100 mg/m^2 in the open sea (Rey 1981, 1993; Melle and Skjoldal, 1998).

Primary production based on nutrients brought to the surface layer by vertical mixing during winter is referred to as ‘new production’. In the Barents Sea, this production amounts to around 50 and 55 g C/m^2 in Arctic and Atlantic water masses, respectively (Rey, 1993). When the phytoplankton is grazed or dying and the nutrient salts are regenerated, additional primary production occurs. The total annual production was calculated to be around 90 g C/m^2 in the Barents Sea between 1979 and 1989. In the Greenland Sea the total production between May and August was around 70 g C/m^2, new production comprising 57 g C/m^2. Production in the Norwegian and Icelandic Seas is similar. Along the Norwegian coast total production was estimated at 90 to 120 g C/m^2 (Rey, 1981).

A substantial fraction of the primary production is lost from the pelagic food web by sedimentation before it is grazed by the zooplankton. The amount grazed depends on the coupling between the time of the phytoplankton bloom and the zooplankton grazing. When these are closely coupled, most of the bloom is grazed, when they are not, most is lost. Sedimentation also tends to be greater when the bloom is short and intense. The amount and composition of the overwintered zooplankton will affect the extent of grazing and sedimentation, the phytoplankton species present are also an important factor. For example, colonies of *Phaeocystis pouchetii* contain a substance that inhibits grazing, especially when the colonies are healthy and fast growing (e.g. Estep *et al.*, 1990; Weisse *et al.*, 1994). The degree to which the primary production is removed from the pelagic system by sedimentation governs the extent of the mesopelagic and benthic production.

5.2.2 Zooplankton

Zooplankton, small animals drifting around in the sea, are the link between the phytoplankton and the higher organisms in the food web. They form a very heterogeneous group of animals. In size, they range from a few micrometres to several centimetres. Some species only exist as plankton during their juvenile stages, while others are planktonic during their whole life cycle. The zooplankton of the Nordic and Barents Seas is characterised by a few dominant species.

Crustaceans form the most important group of zooplankton, among which the copepods of the genus *Calanus* play a key role in the sub-Arctic and Arctic ecosystems. The 3 to 4 mm long *Calanus finmarchicus* is by far the most important contributor to the biomass of the Nordic and Barents Seas. It has a unique position as the main food source for herring, capelin, mackerel and other plankton feeders. *C. finmarchicus* is predominantly oceanic with two centres of distribution; the subpolar gyre south of Greenland and the gyre of the southern Norwegian Sea (Jaschnov, 1970; Aksnes and Blindheim, 1996). Both are cyclonic gyres dominated by mixed Atlantic and Arctic water masses. *C. glacialis* and *C. hyperboreus* are Arctic calanoid copepod species, about 4 and 6 mm in adult length, respectively. *C. glacialis* is the dominant contributor to zooplankton biomass in the Arctic region of the Barents Sea, and *C. hyperboreus* is the most abundant *Calanus* species within the Arctic Ocean. The *Calanus* species are predominantly herbivorous, feeding on phytoplankton, especially diatoms. However, the importance of heterotrophic microplankton in their diet has received much attention lately. Other large copepods common in the area are *Metridia longa* and *Euchaeta norvegica*, the latter feeding on other copepods. *Pseudocalanus elongatus*, *Microcalanus* spp. and *Oithona* *similis* are examples of smaller copepods, which are abundant in both the open sea and on the continental shelves.

Krill (euphausiids) is another group of crustaceans playing a significant role in the pelagic ecosystem as food for both fish and marine mammals. They appear in large schools and continuous layers, often remaining at deeper levels in the day and ascending at night. *Meganyctiphanes norvegica* can reach 45 mm in length and is the predominant species in Atlantic water. The smaller *Thysanoessa inermis* is also common and is the predominant species over the continental shelves surrounding the deep basins of the Nordic Seas. *T. longicaudata* is also frequently found in the Nordic Seas. Krill prey range in size from microorganisms to fish larvae. *T. inermis* is mainly herbivorous, while *M. norvegica* and *T. longicaudata* are omnivorous, feeding on both phytoplankton and zooplankton.

The hyperiid amphipods are represented in the North Atlantic by a few important species. *Themisto abyssorum* is Atlantic, and *T. libellula* is related to Arctic water. The latter can reach 60 mm. Both feed on copepods and on other small plankton.

Other main groups are jellyfishes and ctenophores, often referred to as gelatinous plankton. They feed on other plankton and can respond rapidly to favourable food conditions with a bloom-like growth. The common jellyfish *Aurelia aurita* from coastal water is a good example. The 10 to 20 mm medusae *Aglantha digitalis* is found in both Atlantic and Arctic water. The Arctic *Sarsia princeps* is another example of medusae with rapid blooms. Ctenophores such as *Mertensia ovum* also have a large potential to graze the smaller planktonic forms.

The arrow worms form a well-defined group with a few species. These carnivorous transparent animals, 20 to 90 mm long, are found in the whole area, *Sagitta elegans* being the most common. Planktonic molluscs are represented by two species occurring in high numbers; the pteropods *Limacina retroversa* and *L. helicina*, the latter being a true Arctic species.

In the Nordic and Barents Seas the total zooplankton biomass varies considerably, both seasonally and between years (1 – 20 g/m^2 dw). This is illustrated in ***Figure 5.2***. Zooplankton production is governed by phytoplankton production and the grazing of the zooplankton by predators. The nature of the interactions between the zooplankton and the other trophic levels varies for the different water masses and biological regions. In the northern areas, capelin and herring are the key pelagic fish species, while blue whiting, herring and mackerel are the most important zooplankton predators in the central and southern regions. They are migratory fish and herbivorous zooplankton are a major component of their diet. Demersal fish such as cod feed to a large extent on other fish, however, during their pelagic larval and juvenile stages, they depend mainly on copepods as their food source. In addition, marine mammals and seabirds are major zooplankton predators.

The Nordic Seas are the feeding area for several large pelagic fish stocks, including herring, blue whiting and mackerel. The feeding migrations of these stocks are closely linked to the seasonal production cycles of *Calanus* (Fernö *et al.*, 1998). During winter, *C. finmarchicus* is advected from the waters over the continental shelves into the deep Norwegian Sea basin where it winters mainly below 1000 m. The herring feeding migration is closely linked to the time for reproduction of *C. finmarchicus*, and may be directed specifically towards the overwintered generation returning from the deep wintering depths. Mackerel, as well as herring later in the summer, mostly feed on the older stages of the new generation of *C. finmarchicus*, and their feeding area normally extends to 75º N.

Copepods, krill and amphipods are also major prey of capelin. Their relative importance varies with season, year and capelin size. The importance of copepods decreases with increasing capelin length, and krill and amphipods are most important for adult capelin. Recent results indicate clear predator-prey interactions between capelin and their major prey, such as krill and amphipods, and suggest that these zooplankton populations are controlled to a large extent by capelin predation (Dalpadado and Skjoldal, 1996) (see also ***Figure 5.3***).

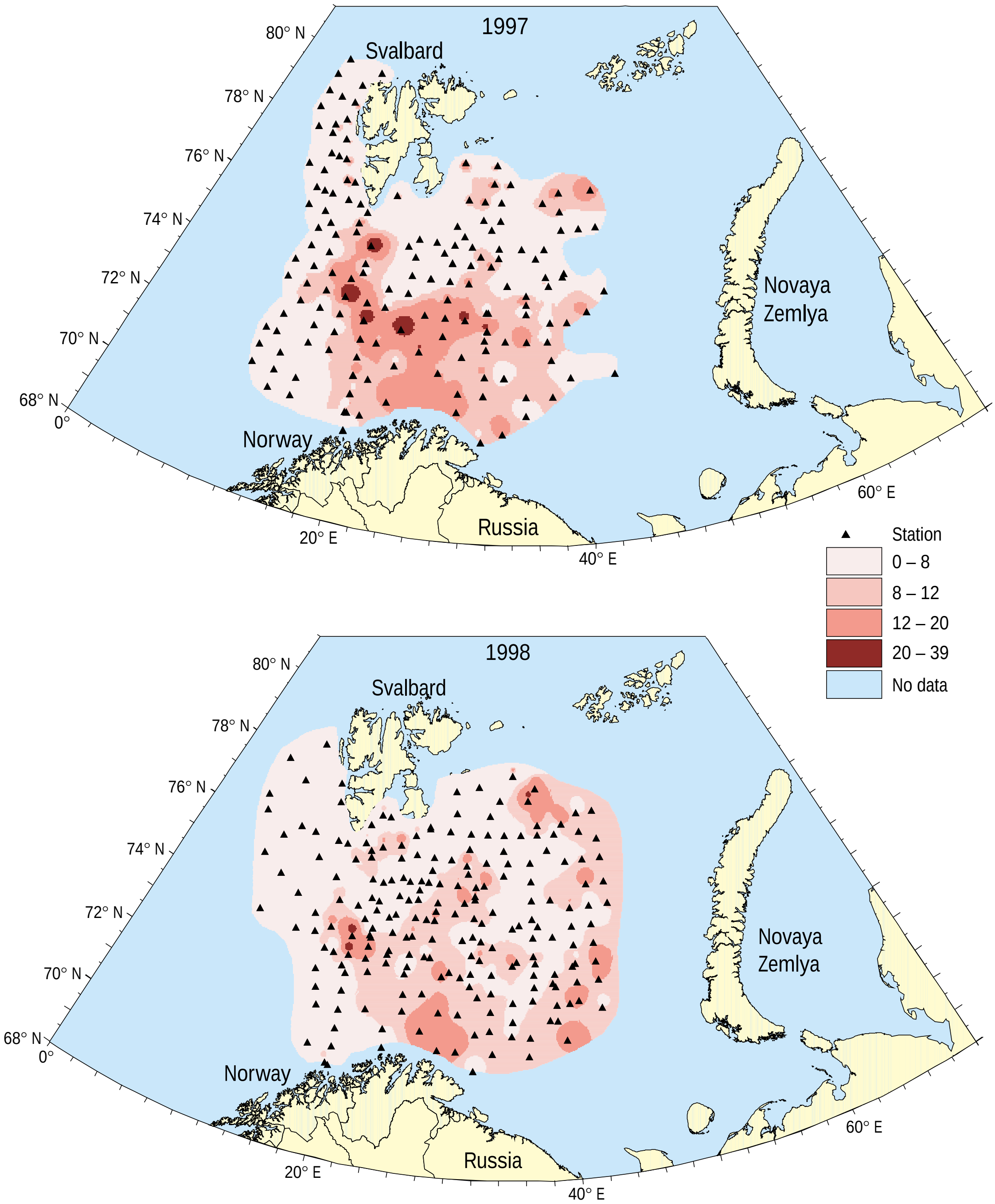
Capelin was the most important prey of cod when the stock size of capelin in the Barents Sea was large. A shift in the diet of cod was observed when capelin stock size was at very low levels. Krill (*Thysanoessa* spp. and *Meganyctiphanes norvegica*) and amphipods (mainly *Themisto* spp.) increased in importance in the diet of cod during 1994 to 1997 (Bogstad and Mehl, 1997).

5.2.3 Benthos

The benthos, organisms in and on the sediments, is an integral part of marine ecosystems and represents a major link between pelagic production and sedimentary deposition (Graf, 1992). This is of particular interest for the sequestration of excess CO_2 released to the atmosphere. Benthic and deep-sea remineralisation are also the major means of remineralizing organic matter to the nutrients necessary for primary production. The benthos has several other ecological functions, including the burial and redistribution of organic matter and contaminants in the sediments, conditioning disturbed sediments, and as an indicator of pollution, biogeographic boundaries and environmental change. The benthos is also a food source for zooplankton and fish such as cod, and so plays a key role in regulating the bioavailability of food and thus contaminants in marine ecosystems.

The major basins of the Nordic Seas as well as the

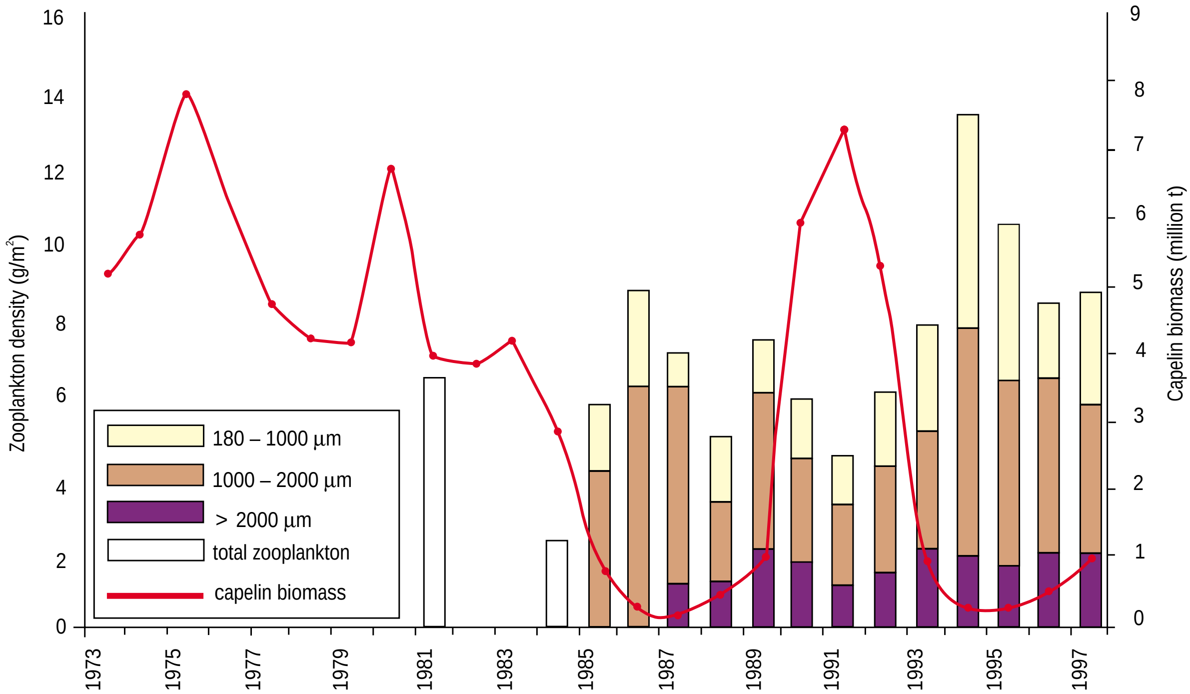
Figure 5.2 **Zooplankton biomass (g/m2) distribution in the Barents Sea, 1997 and 1998.**



Barents Sea represent biogeographical provinces with specific taxonomic and metabolic characteristics. The underlying features which appear to determine community structure are temperature and sediment type. Accordingly, the benthic communities are closely related to water masses delineated by topography.

The Shetland–Faroe–Iceland Ridge represents a biogeographical boundary separating warm- from cold-water species. There is also a temperature gradient from the south to Svalbard. The number of species with a ‘southern’ distribution decreases northwards. There is a faunal gradient across the continental shelf and slope from Atlantic Water to Norwegian Sea Deep Water. This transition zone in the slope region is rich in fish, hyperbenthos and micronekton. On the continental slope off the Norwegian Trench, Atlantic Water converges with the cold

Figure 5.3 **Fluctuations in zooplankton biomass together with capelin stock size in the Barents Sea during 1981 to 1997. Source: Gjøsæter *et al*. (2000).**



deep water of the Norwegian Sea at 500 to 600 m in depth, and this fauna-rich transition zone between the two water masses almost encircles the Nordic Seas.

Knowledge of the benthic species composition and biomass, especially in the deep waters of the Nordic and Barents Seas, is limited. Nevertheless, investigations indicate that the numbers of species (crustaceans > polychaetes, molluscs > echinoderms) in large ecosystems of the Nordic Seas are fairly similar, both within the Nordic Seas as well as in most Canadian and high Arctic regions (Dayton, 1990).

The mid-Norwegian shelf has received little attention with regard to benthic investigations. Coral communities are now recognised as important benthic features along the coast. Extensive banks of *Lophelia* are common (Fosså and Mortensen, 1998).

In soft sediments of the Vøring Plateau polychaetes predominate followed by crustaceans. Infauna are generally small although some exceptions exist, such as metre-long enteropneusts. 'Rich' and 'poor' zones of benthic biomass have been identified in relation to a stationary gyre on the Vøring Plateau (Jensen *et al.*, 1992). On slopes, tube dwellers feeding at the sediment surface may predominate. On plateaus, deposit feeders predominate. Romero-Wetzel (1989) investigated the distribution of macrofauna along a section from the Vøring Plateau to Jan Mayen. At 43 sites, 101 species were identified; these were dominated by polychaetes followed by crustaceans. A decrease in species diversity correlated with increasing depth. With the exception of large enteropneusts and echiurids, the infauna consisted of small organisms, whereas a large fraction of the epifauna was of megafauna size. The abundance and biomass of the infauna were relatively constant between the shelf, slope and plateau. In contrast, from the outer plateau towards the deep sea, abundance and biomass decreased with increasing depth.

In recent years the Icelandic BIOICE (Benthic Invertebrates of Icelandic Waters) programme (1992 to 1996) has collected data on the distribution of benthic organisms, especially the hyperbenthos. In the Iceland Sea and the westernmost part of the Norwegian Sea, the diversity of the isopods increased with depth to about 320 to 1100 m, below which the diversity again decreased. Major faunistic changes appear to be associated with the Greenland–Iceland–Faroe Ridge, possibly due to rapid changes in temperature. Low diversity in the deep sea areas of this region is a regional rather than large-scale phenomenon (Svavarsson, 1997). Further investigations on peracarid crustaceans showed large differences in composition to the east and west of the Kolbeinsey Ridge and identified four communities of organisms – deep water, eastern slope, western slope and ubiquitous (Brandt and Piepenburg, 1994) – with the greatest abundance and diversity on the western slope. These communities are presumably related to sediment type and food supply.

Over 1000 species of animals have been identified in waters near Svalbard, and the number could easily double if Barents Sea species are included (Gulliksen and Gjøsæter, 1992). Intensive studies on hard-bottom benthos in fjords and on the shelf using underwater photography showed strong correlation with sediment type, water temperature and ice exposure. Dramatic shifts in the distribution limits of some large fauna in Svalbard shelf waters have been attributed to changes in bottom temperature (Blacker, 1957), and decapod fauna in Isfjorden (Svalbard) changed remarkably over about 60 years for the same reason (Christiansen and Christiansen, 1962). In the Barents Sea at the Norwegian continental margin, two habitat types have been identified: shallow shelf banks and deeper trenches.

Considerable work has been done on the north-eastern Greenland shelf. Brittle stars, i.e. *Ophiocten* and *Ophiura*, dominate the megafauna of coarse sediments (Piepenburg and Schmid, 1996), and were separated into different communities on shallow shelf banks and in deep water. Furthermore, three communities – shelf break, slope and lower slope – have been described for epibenthos along 75º N (Mayer and Piepenburg, 1996) and appear to be related to sediment type.

In summary, the benthos is rich and diverse in the Arctic region, where ecological provinces are often topographically determined and characterised by differences in temperature and food supply. The latter is largely dependent upon pelagic primary production, although important coastal ecotopes are also associated with kelp and cold-water coral reefs. Long-term historical changes in benthic composition have been documented and attributed to changes in the physical environment. Current and future modifications to benthic ecotopes, arising from natural variability and resulting from human activities, are likely to be reflected in changes in the benthic biomass, composition and diversity. These can, for example, have negative repercussions with respect to the harvesting of marine resources such as fish, shellfish and kelp, as well as endanger the present level of biodiversity.

The total number of macroalgae decreases northwards within the Atlantic cold temperate biogeographical region and the Atlantic Arctic region (Lüning, 1990). There is also a decrease in the ratio between Rhodophyta (red macroalgae) and Phaeophyta (brown algae) (Hawkins *et al.*, 1992). The main depth to which seaweeds grow is generally lower at high latitudes than in temperate regions (Lüning, 1990).

There are marked differences between the macroalgae on the eastern and western sides of the North Atlantic. This is mainly due to differences in sea water temperature and to different spreading rates for the various species across the North Atlantic Ocean. Along the Norwegian coast sea water temperature is higher than at similar latitudes along the north-western Atlantic. This results in a more northern distribution for many macroalgae along the north-eastern part of the Atlantic Ocean relative to the western part (Lüning, 1990). During the Pleistocene glacial periods a greater extinction of macroalgae took place on the western side of the North Atlantic. The absence of many species on the north-western side of the Atlantic is probably due to their low ability to spread across the North Atlantic (Hoek and Breeman, 1989).

The predominant macrophytes of Region I are large, brown algae (Phaeophyta) belonging to the orders of Laminariales and Fucales. Characteristic macrophytes of the littoral zone along the eastern part of Region I are the brown algae *Fucus vesiculosus, F. spiralis, F. serratus, F. distichus, Pelvetia canaliculata* and *Ascophyllum nodosum* (Lüning, 1990). The Fucales predominate particularly in the sheltered parts, while a mixture of brown and small red and green algae is found in more wave-exposed littoral areas. From the Kola Peninsula and eastwards the fucoids disappear, and apart from one species (*Fucus distichus*) they are also absent on Svalbard. In the western part of Region I, *Fucus distichus* is abundant in the littoral zone, while *F. spiralis, F. serratus* and *Pelvetia canaliculata* are absent. *Ascophyllum nodosum* and *Fucus vesiculosus* occur in the south-western part of Region I (Greenland).

In the sublittoral zone, species belonging to the order Laminariales dominate the vegetation on both sides of the North Atlantic (Lüning, 1990). *Laminaria saccharina* and *L. digitata* are widely distributed in nearly all of Region I, but *Laminaria digitata* is less abundant in the north-western part of the Atlantic relative to the north-eastern part. The distribution of *Laminaria hyperborea* is confined to Iceland, and the north-eastern Atlantic to the eastern part of the Kola Peninsula (Schoschina, 1997). The distribution of the Arctic species *Laminaria solidungula* in Region I is confined to the coast of Greenland and Svalbard.

5.2.4 Fish

In Region I, there are six species of fish that support major fisheries in the Nordic and Barents Seas: cod, saithe, haddock, blue whiting, herring and capelin. The continental shelves along the Nordic countries are the spawning areas for many commercially important fish species. From the spawning grounds the larvae are spread into the open ocean. Some of the species perform long annual migrations between the feeding and overwintering areas.

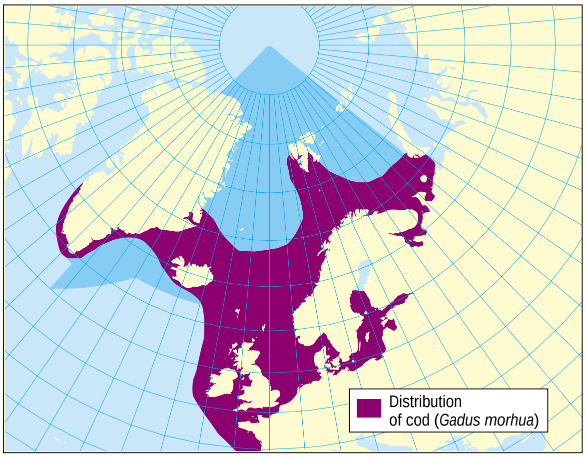
Cod

Cod is a common and economically very important species in the region. The size of cod from fisheries at Iceland and northern Norway is usually 80 to 110 cm with a weight of 5 to 15 kg. However, it can grow to a size of more than 150 cm with a weight of 40 to 50 kg. Cod is found along the coasts on both sides of the Atlantic Ocean *(Figure 5.4),* from the Barents Sea to the Bay of Biscay, along the coast of Iceland and Greenland, and along the North American coast. Historically, the main stocks have been the North-east Arctic cod in the Barents Sea, the Icelandic stock and the northern cod off Newfoundland. Besides these, there are cod stocks in the North Sea, around the Faroe Islands, at west Greenland and off Canada and the USA. There seems to be little contact between the different populations. This can be explained by the current pattern in the Atlantic, the depth distributions and the temperature barriers.

The North-east Arctic cod is potentially the largest cod stock in the world, with annual catches historically reaching around 1 million t. The stock biomass has fluctuated considerably over the last 50 years. From 3 to 4 million t in the 1950s a minimum was reached in the 1980s. The stock size increased over the following years. In 1997, the total stock was 1.8 million t and the catch was around 750 000 t. During winter the North-east Arctic cod is found in the southern Barents Sea. Maturity occurs at 6 to 8 years old. In December to January, the mature part of the population starts migrating to the spawning areas along the coast of Norway. The Lofoten area in northern Norway is the main site of spawning. The spawning peak occurs in March to April, and the larvae are transported by the surface water of the North Atlantic Current into the Barents Sea. In rich years the larvae are spread as far as Novaya Zemlya and the Norwegian Sea to the west of Svalbard. During the late autumn the 0-group settles on the bottom. The immatures feed both at the bottom and in the midwater layers and make seasonal migrations. The distribution area of cod is extended to the north and east in warm years, with the fish concentrating in the south-western part of the Barents Sea during colder years.

The Icelandic cod stock has fluctuated during the last years. In 1930, the stock was estimated at more than 2.5 million t and in the period 1935 to 1960 the biomass was 1.5 – 2.0 million t. The juveniles migrate from Iceland to the east and west coast of Greenland and fluctuations in stock size after 1960 are partly due to returning of cod from Greenland. The fishable stock reached a minimum level of 550 000 t in 1992. Since then it has increased and reached a level of 990 000 t in 1997 (Anon, 1999). The spawning stock was about 450 000 t and the catch was 200 000 t in 1997. The Icelandic cod stock has its main spawning area in the south western part of the Icelandic shelf, and its nursery area mainly along the northern coast. Recruits from the Icelandic stock have also, at certain times, largely supported the cod fishery in the East and West Greenland waters. The local stock in this area is at present very small, and the catch in 1997 was only about 1000 t.

Figure 5.4 **Distribution of Atlantic cod showing feeding, spawning and overwintering areas in the North-east Atlantic and Baltic Sea.**



Cod in the waters off the Faroe Islands are treated as two separate stocks; one at the Faroese Bank and one at the Faroese Plateau. The latter is the largest, with a spawning stock in 1997 estimated at around 95 000 t and landings of 34 000 t.

Saithe

Saithe is a true Atlantic species which can be up to 120 cm long and up to 20 kg in weight. In the eastern Atlantic the saithe is found over the continental shelf from the Bay of Biscay to Svalbard and Novaya Zemlya, as well as around Iceland. Within this distribution area several stocks are found. The major stocks live in Norwegian waters (the North-east Arctic saithe stock), around Iceland and around the Faroes. Common to most of the stocks is that spawning takes place in February to April at about 200 m depth. Within the first two months after metamorphoses the 0-group concentrates along the coastline where they form schools and spend the next two to three years. At age 2 and 3 the saithe move to somewhat deeper water at the coastal and offshore banks. Saithe reaches maturity at 5 to 7 years. In 1997, 143 000 t of North-east Arctic saithe were caught from a total population of around 500 000 t. The catches of saithe in Icelandic waters in 1997 totalled 37 000 t and the spawning stock was estimated at around 90 000 t. Catches off the Faroe Islands in 1997 totalled 22 000 t, and the spawning stock was around 60 000 t.

Haddock

Haddock is present in most parts of Region I. It is a bottom-living species which may become 110 cm long and weigh up to 20 kg. Spawning mainly occurs in April to May in deep water along the continental slope west of Tromsøflaket to Røst, and off the south and west coast of

Iceland. The eggs are spread over vast areas. In 1997, the total stock of North-east Arctic haddock was 430 000 t, and 145 000 t were caught. In Faroese waters the catches of haddock in 1997 totalled 18 000 t, and the spawning stock was estimated at about 118 000 t. The Icelandic fishable stock is currently around 100 000 t, and around 40 000 t are caught each year (Anon, 1999)

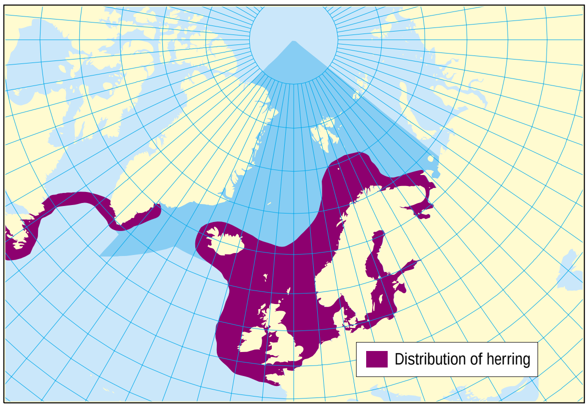
Blue whiting

The blue whiting is a small gadoid species reaching 50 cm in length, and is widespread in the Nordic Seas. The stock has a northern component reaching south to south-west Ireland and a southern component from south-west Ireland to the Bay of Biscay and Gibraltar. Both components spawn in the area to the west of the British Isles in March and April. Spawning also occurs south of Iceland. Several Norwegian fjords, and the continental slope south of Svalbard, are known areas of local spawning. Like other pelagic fishes the blue whiting performs diurnal vertical migrations, staying deep in the day and moving closer to the surface at night. In early summer, it is found in dense concentrations in Atlantic and mixed waters of the Nordic Seas from east of Iceland to the Norwegian coast and from the Faroe Islands to Svalbard. In 1997, the spawning stock was estimated at 2.0 million t. The catch increased from 634 000 t in 1997 to around 1.1 million t in 1998.

Herring

The herring is a small pelagic fish reaching 40 cm in length and weighing 500 g. It is a plankton eater with the copepod *Calanus finmarchicus* as one of its main prey items. Herring reaches maturity at 3 to 5 years, and the eggs are spawned on the bottom where they attach to the substrate. The herring of the North Atlantic is divided into many populations differing in growth pattern, spawning locations and time of spawning *(Figure 5.5)*. The main stocks are the North Sea stocks, the Norwegian spring spawning stock and the Icelandic spring and summer spawners. The Norwegian spring spawning herring is the largest of the stocks with a potential total biomass of more than 15 million t, and has constituted the largest single fish stock unit in the North Atlantic. However, great fluctuations in abundance have taken place, and spawning sites, feeding areas and migration routes have been subject to dramatic changes throughout history. In the 1950s and early 1960s, the stock spawned in March at several places along the Norwegian west coast north to Lofoten. After hatching the larvae rose into the upper water layers and were transported northwards with the coastal current into the Barents Sea and along the west coast of Svalbard. Larvae drifted into the fjords. The 0-group herring remained in these areas during the following two to three years before migrating into the Norwegian Sea to join the mature stock. The main feeding area was in the Norwegian Sea from around 64º N to 74º N and in the warm Atlantic water north of Iceland. During the winter the herring were concentrated off the east coast of Iceland, from where spawning migrations to the Norwegian coast started in January. In the 1960s, a new and separate feeding area was established south-west of Bear Island. The stocks from the southern and northern areas were later joined.

Figure 5.5 **Distribution of herring showing feeding, spawning and overwintering areas in the North Atlantic and Baltic Sea.**



After the stock collapse at the end of the 1960s, the feeding area changed to the continental shelf off Norway, and Norwegian fjords became wintering areas. In the 1990s only a few north Norwegian fjords served this purpose, especially the Tysfjord and Ofotfjord. In the early 1990s the Norwegian spring-spawning herring reoccupied the Norwegian Sea as its main feeding area. However, the stock has continued to winter in Norwegian coastal waters.

The total catch of Norwegian spring spawning herring was consistently high during the 1950s and 1960s. During this period the stock size of spawners declined gradually from about 14 million t to a minimum after the collapse in the late 1960s, and the fisheries were down until the rich 1983 recruitment started a new growth in the herring population. The catch was almost 1.4 million t in 1997, and the population of spawners in 1997 was estimated at 12 million t.

The Icelandic stocks have also undergone great fluctuations in abundance, with a collapse in the fisheries in the late 1960s. The stock of summer spawners gradually recovered in the late 1970s. The spawning stock estimate for 1997 was 415 000 t, and the catch 65 000 t (Anon, 1999). The Icelandic stock of spring spawning herring has still not recovered. The Icelandic summer spawners spawn along the southern coast of Iceland, and the main feeding area is east and north of Iceland where the Norwegian spring spawners also fed in the 1950s and early 1960s.

Capelin

The capelin is a small pelagic salmonid fish, reaching a length of around 18 to 20 cm. It is found along the Atlantic coast of North America, on both sides of Greenland, at Iceland and Jan Mayen, and in the Barents Sea *(Figure 5.6)*. In the North Atlantic there are several stocks; the stocks off Newfoundland and Labrador, the West Greenland stock, the Iceland stock and the Barents Sea stock. The Barents Sea stock is potentially the largest.

Capelin lay their eggs on sand and gravel bottoms, where the eggs adhere to the substrate. The capelin at Newfoundland are mainly beach-spawners while the stocks in the North-east Atlantic spawn along the coasts at shallow depths. The spawning season is in spring. Upon hatching, the larvae ascend to near surface layers and are transported with the currents from the coasts. Both the capelin living in the Barents Sea and those living in the Iceland–Greenland–Jan Mayen areas grow to a maximum size of around 20 cm in approximately four to six years. Maturity is reached at a length of around 13 to 15 cm at an age of 3 to 4 years. Most capelin die after spawning and so few are larger or older than this (Vilhjámsson, 1994; Gjøsæter, 1998).

Capelin is a plankton feeder. The larvae catch copepod eggs and nauplii. Young capelin mainly feed on *Calanus* spp., while larger plankton such as krill and amphipods become increasingly important with age. During summer and autumn, the capelin perform feeding migrations to the plankton-rich Polar Front areas to the north of Iceland and the northern Barents Sea, respectively.

The capelin fishery in the Barents Sea was large until the stock collapse of the mid 1980s. Strong year classes in 1988 and 1989 caused an increase in the spawning stock in 1990. The stock size dropped again in 1993 and has been low in recent years, although it is now slowly increasing. In 1997, the Barents Sea stock was estimated at 800 000 t, which is only 10% of its size in 1975. From 1994 to 1998 there was no fishing on capelin in the Barents Sea, but in 1999 a small fishery on mature capelin for human consumption was permitted.

The Icelandic capelin stock collapsed in the early 1980s but recovered in two years following a fishing ban. The total stock in January 1997 was estimated at 2.8 million t, and approximately 1.25 million t were fished during autumn 1996 and winter 1997.

Polar cod

Polar cod has a circumpolar distribution and is a true Arctic gadoid with a maximum length of about 25 cm. Its distribution is associated with cold water and ice. The largest stock is found in the Barents Sea. Spawning takes place during the winter from December to March at temperatures close to or below 0 °C at the ice edge or under the ice cover. Spawning grounds have been recorded near Novaya Zemlya, but spawning probably also occurs in the western Barents Sea, east of Svalbard. The large pelagic eggs (1.9 mm) develop slowly in the surface layer and hatch after one to three months according to temperature. Polar cod is a plankton eater and plays an important role in the Arctic food web. Its prey are copepods, amphipods and krill. The stock size is estimated at around 0.5 – 1 million t. The annual catches

Figure 5.6 **Distribution of capelin showing feeding, spawning and overwintering areas in the North Atlantic.**

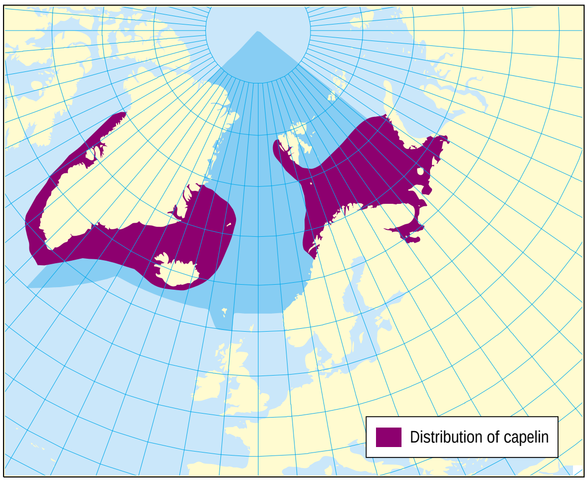


Table 5.1 Breeding populations (x 10^3) of seabirds in Region I.

	Iceland	Faroe Islands	East Greenland
Fulmar	100 – 1000*	100 – 1000*	100 – 500*
Cormorant	3.5	? *	0*
Shag	6.6*	1 – 10*	-
Herring gull	10*	1.2*	-
Glaucous gull	+ *	3.5*	0.1*
Great black-backed gull	1*	1*	-
Kittiwake	100 – 1000*	100*	0.7‡‡
Common guillemot	1600¶	300¶	0*
Brünnich's guillemot	2000¶	-	35¶
Razorbill	500¶	3¶	0*
Black guillemot	50¶	2¶	15¶
Little auk	< 0.01¶	500*	3500**
Puffin	3000¶	500¶	0.1¶

* Evans (1984a,b);
† Mehlum and Gabrielsen (1995);
‡ Gjerstad *et al.* (1994), estimate for the whole of Norway;
§ Mehlum and Bakken (1994);
ΩΩ Isaksen and Bakken (1995), estimate for the whole of Svalbard;

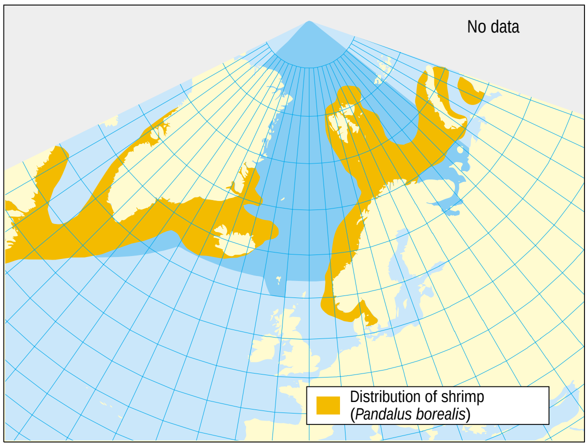
have fluctuated widely during recent years; 30 000 t were caught by the Russians in 1995.

Redfish

The redfish in Region I consist of four closely related species, of which two are commercially exploited – *Sebastes marinus* and *S. mentella*. The two species are difficult to distinguish at the larval and juvenile stages, and this has led to some difficulties in distinguishing between the populations in the nursery areas. The redfish has internal fertilisation, and the eggs hatch before they are released from the female. Copulation takes place in autumn. The females carry the sperm and delay fertilisation until the winter. The larvae are released in April and May.

Redfish grow slowly and can become very old. *S. marinus* may reach 60 years old and up to 100 cm in length. It is common at bottom depths of between 100 and 300 m. The temperature preference is 4 – 5 ºC. *S. mentella* has a maximum length of approximately 50 cm. It is found at greater depths than *S. marinus* and in colder water (down to 2 ºC). The main spawning areas for *S. marinus* in the North-east Atlantic are south-west of Iceland and along the Norwegian shelf. The larvae produced along the Norwegian shelf are spread by the currents to the western Barents Sea and to the west of Svalbard, where the juveniles settle at 8 – 10 cm long. The larvae produced south-west of Iceland spread over to East Greenland and to the northern and eastern part of the Icelandic Shelf. In 1997, *S. marinus* catches in the North-east Atlantic totalled 17 000 t, while catches from the Faroe Islands, Iceland, Greenland area totalled 40 000 t.

Figure 5.7 **Distribution of shrimp (*Pandalus borealis*) in the North Atlantic.**



S. mentella tends to concentrate along continental slopes, but it is also oceanic (pelagic) in the Irminger and Norwegian Seas. The oceanic *S. mentella* in the Irminger Sea is considered as a separate stock from the *S. mentella* (the 'Deep Sea Mentella') found along the continental slope of the Faroe Islands, Iceland and Greenland. In addition, there is a separate stock in the North-east Atlantic. The oceanic *S. mentella* in the Irminger Sea is the

	Bear Island	Hopen	Southern Svalbard	Northern Norway	Kola	Novaya Zemlya	Franz Josef Land	Total
	15†	5†	2†	0.1†	-	2.5†	2.5†	327.6 – 2500
	-	-	-	21‡	-	-	-	24.5
	-	-	-	15‡	-	-	-	22.6 – 32.6
	< 0.01§	-	-	200‡	-	-	-	211.2
	2†	1†	0.5†	-	-	8.5†	-	15.6
	-	-	0.1ΩΩ	40‡	-	-	-	42.1
	85†	40†	60†	450†	73†	21†	3†	932.7 – 1932
	245†	-	-	10†	11†	-	-	2166
	105†	105†	300†	2†	5†	1000†	50†	3602
	0.1†	-	-	30‡	2†	-	-	535.1
	0.5†	-	-	-	1.2†	5†	3.5†	77.2
	5†	5†	300†	-	-	20†	250†	4580
	-	-	10††	2000‡	12†	0.3†	-	5522.4

¶ Nettleship and Birkhead (1985); Petersen (1994a,b);
** Kampp *et al*. (1987), perhaps up to 10 million pairs;
†† Mehlum (1990);
‡‡ Falk and Møller (1995), only North-east Greenland.

Table 5.2 Main species of whale in the Nordic and Barents Seas.

	Length (m) (females/males)	Abundance estimate (sightings)	Year	Area
Baleen whales				
Greenland right whale	20	10	1982	Norwegian Sea/Barents Sea
blue whale	33	700	1989	Iceland
minke whale	10	184 255	1996	North-east Atlantic
fin whale	24	22 789	1995	North-east Atlantic
sei whale	20	9 249	1995	North-east Atlantic
humpback whale	18	1 025/700	1988/89	northern Norwegian Sea/ southern Barents Sea
Toothed whales				
sperm whale	14/22	5 200	1989	Norwegian Sea
killer whale	8.5/10	-		
bottlenose whale	10	-		
pilot whale	5.5/6.5	214 840	1995	North-east Atlantic
white-beaked dolphin	3	-		
white-sided dolphin	2.8	-		
white whale	5.5/4.1	-		
narwal	5.0/4.2	-		
harbour porpoise	1.9/1.6	-		

largest of these stocks (of the order of 2 million t). The catches from this stock in 1997 totalled 122 000 t, compared to 43 000 t of the Deep Sea Mentella and 8000 t from the north-east Arctic stock.

Other resources

The only shrimp species of economic importance is the deep water shrimp (*Pandalus borealis*). It prefers soft bottom habitat and stays close to the bottom at temperatures ranging from < 0 to 10 ºC. Suitable habitats with rich shrimp fields are found around Iceland, along East Greenland, around Svalbard and in the Barents Sea, as well as in the Norwegian fjords ***(Figure 5.7)***. The largest shrimp fisheries are in Icelandic waters, where 70 000, 75 000 and 56 000 t were landed in 1996, 1997 and 1998 respectively (Anon. 1999). The fishing grounds stretch from the north-west to the east coast of Iceland. The shrimp catch in the North-east Atlantic was 32 000 t and in East Greenland waters 9000 t in 1996.

Squid are used as bait as well as for human consumption. The European flying squid (*Todarodes sagittatus*) can reach 0.3 m in length. It occurs very irregularly at the Norwegian coast, feeding on the migrating herring. Another abundant species, the boreoatlantic gonate squid (*Gonatus fabricii*), lives in the deep North Atlantic after spending its first year in the surface layers. It is an important prey for the bottlenose whale (*Hyperoodon ampullatus*) and sperm whale (*Physeter macrocephalus*), and is also consumed by cod, herring and salmon. The biomass of this species in the Nordic Seas is estimated at 4 million t (Dalpadado *et al*. 1988).

5.2.5 Birds

The European Arctic is one of the most important seabird regions in the word. The breeding population of seabirds in Norway, the Faroe Islands, Iceland, East Greenland, Svalbard, Bear Island, Hopen, Franz Josef Land, Novaya Zemlya, and Kola, is more than 25 million individuals ***(Table 5.1)***.

Seabirds are constrained in their diets by their morphology and diving capability. In the European Arctic, seabird species may be grouped into surface feeders and pursuit diving subsurface feeders. Gulls and fulmars are surface feeders, but may make shallow dives. Alcids are good divers that actively swim underwater to catch their prey. The Brünnich’s guillemot, which is one of the largest alcid species, is known to dive down to 210 m. However, most dives are around 40 to 50 m deep (Croll *et al.*, 1992). The diversity of prey species is dominated by certain key species. In northern areas Polar cod and the amphipod *Themisto* sp. predominate. The diet of the smallest species, the little auk (*Alle alle*), consists mainly of copepods. Further to the west and south herring, capelin and sandeels (*Ammodytes* spp.) are important prey species for seabirds.

The seabirds are not distributed at random. For example, the Alcids tend to concentrate in areas of pack ice, close to the breeding site in the breeding seasons, and in areas where major water masses meet. That means, towards the boundaries of marine zones and along the Polar Front where the marine production is high. The importance of seabird populations as components of the Arctic marine ecosystem is not fully known. However, the annual food requirement of seabirds in the Barents Sea has been estimated at about 25% of that for mammals inhabiting the same area (Mehlum and Gabrielsen, 1995).

Seabird populations are affected by changes in prey-fish stocks. The breeding population of common guillemot (*Uria aalge*) on Bear Island was reduced from 245 000 pairs in 1986 to 36 000 pairs in 1987, due to lack of food; a reduction of 85% (Mehlum and Bakken, 1995). The number of breeding pairs at Bear Island has increased since 1987, but in 1995 the population was still < 50% of that in 1986. The puffin along the Norwegian coast is another example. The numbers of puffins have dropped dramatically since 1960 as a direct result of the earlier collapse in the stock of Norwegian spring-spawning herring (Barrett, 1994). Seabird populations in Iceland are in general stable or increasing indicating good feeding grounds for the birds in the Iceland waters (Petersen, 1994).

Not all the effects on seabird populations owing to changes in prey populations or fishing are negative. The fulmar has dramatically increased its geographical range from the high Arctic southwards over the past two hundred years. The population increase over this period is at least partly due to the rapid increase in food available via discards from fishing (Ollason and Dunnet, 1988).

5.2.6 Marine mammals

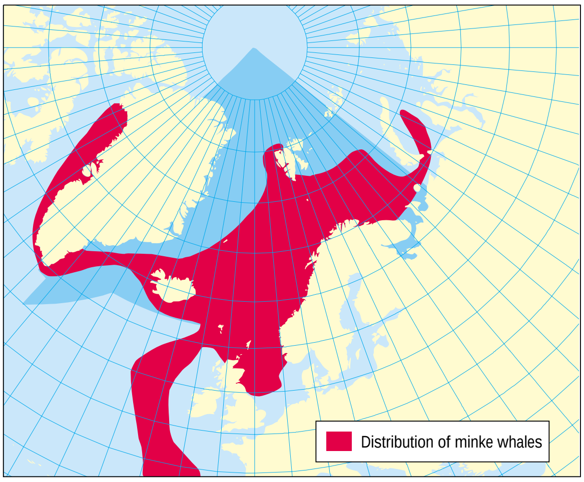
Whales

The whales inhabit all seas of the world, from warm waters to Arctic and Antarctic waters. Many baleen whale species are known to perform long and regular breeding migrations to warm and temperate waters during the winter, and to migrate to cold water at higher latitudes to feed on the rich zooplankton supplies during the summer season. They breed once every two to four years, and usually have only one calf. Fin whales become sexually mature at 6 to 12 years old, and their life span is probably at least 40 years.

Whales are divided into two main groups: baleen whales and toothed whales. The baleen whales are primarily plankton feeders, using their numerous baleens or whale bones to sieve plankton from the sea, but they may also eat fish. The toothed whales prey on fish, squid and seals. The Norwegian Sea, the Barents Sea and the Arctic areas include the species of whale listed in *Table 5.2*.

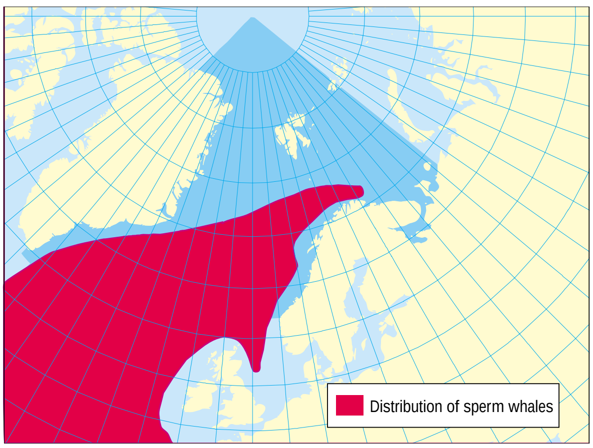
The baleen whales are grouped into the fin whales and the right whales. The bowhead whale or Greenland right whale is the one example of the latter. It is an Arctic species which was heavily decimated during whaling up to the beginning of the century. The population size of the blue whale (*Balaenoptera musculus*), the largest animal on Earth, also dropped severely during the period of intensive whaling, but the stock is now increasing since the blue whale was protected in 1966. It has been

Figure 5.8 **Distribution of minke whales in the North-east Atlantic. Source: EEA (1996), based on North Atlantic Sightings Surveys (NASS).**



observed regularly in the area in recent years and the stock is growing worldwide. The world's total population of blue whale is about 10 000 animals. The humpback whale (*Megaptera novaeangliae*) is another example of a species affected by heavy exploitation in the past. It spends the summer and autumn in the waters between Bear Island and Hopen Island in the Barents Sea. The fin whale has also been subject to hunting, especially to the north of Norway, but the population size is still reasonably high. The minke whale is a relatively small species that has been particularly important to the modern Norwegian whaling *(Figure 5.8)*. The main whaling areas were in the North-east Atlantic: the North Sea, along the Norwegian coast, in the Barents Sea, and along the coast of Svalbard. The Norwegian minke whaling was stopped

Figure 5.9 **Distribution of sperm whales in the North-east Atlantic. Source of data: EEA (1996).**



between 1988 and 1992. Between 1993 and 1996 the annual catches varied between 218 and 388 individuals. The north-eastern Atlantic minke whale population size was estimated at 184 000 individuals in 1997.

The sperm whale is the largest of the toothed whales. It belongs primarily to warm water between 50º N and 30º S, which is also the breeding area. Sperm whales encountered in the northern Atlantic are usually males. The sperm whale is often seen west of the steep continental slope off mid and northern Norway *(Figure 5.9)*. They are capable of diving to 3000 m in depth, and the dive may take up to 180 minutes. The main prey is squid, but redfish and lumpsucker (*Cyclopterus lumpus*) are also caught. The sperm whale was of little interest to the industry during the first period of modern whaling off northern Norway, but its importance increased with the decline in catch of the large baleen whales. The sperm whale was protected worldwide in 1988. The number of individuals in the area is calculated at about 20 000.

The highest concentrations of killer whale (*Orcinus orca*) occur in temperate and cold waters, and it is common along the Norwegian coast all year around. It does not perform long breeding migrations like the baleen whales. Its main prey is fish, and it is often associated with the migrating schools of herring. The killer whale typically occurs in schools consisting of 5 to 15 individuals.

The bottlenose whale is a migratory species found in deep water on both sides of the North Atlantic, at Labrador, from Greenland to Iceland, from Iceland to Jan Mayen, at the Faroe Islands, off the coast of Norway, Bear Island and Svalbard. Like the sperm whale it can dive deeply to catch squid and fish. The bottlenose whale has been protected since 1975 by the IWC, and NAMMCO calculated the North Atlantic population to be around 40 000 animals in 1995. The long-fin pilot whale is distributed north to Greenland, Iceland and the Barents Sea. It is known to occur in large schools. Newfoundland and the Faroe Islands have been traditional hunting areas. In addition to the bowhead whale, the beluga (or white whale) and narwhal are the only species to live in Arctic waters throughout their entire life. The white whale may occasionally be observed in large numbers on feeding migrations to the northern coast of Norway, eating capelin, salmon, squid and benthic animals. The smallest whale in the area under consideration is the harbour porpoise (*Phocoena phocoena*), this occurs along the coast of Norway, especially to the south. The white-beaked dolphin and the white-sided dolphin (*Lagenorhynchus acutus*), also common along the coast, are both members of the dolphin family together with the common porpoise.

Seals

Six species of seal, as well as the walrus, are found in the North Atlantic north of 62º N; the common harbour seal (*Phoca vitulina*), grey seal, harp seal, hooded seal (*Cystophora cristata*), ringed seal and the bearded seal (*Erignathus barbatus*). Both the harbour seal and the grey seal are widely distributed along the coasts of Region I, while the other species occur further north. These are adapted to the sea ice and never come to the shore. During the spring, most seals aggregate in large groups to breed and mate, they also gather during the moulting period. All seals are carnivorous, feeding on fish, krill, amphipods or bottom animals.

The harbour seal is common along the coasts of the northern hemisphere, but only a small colony occurs on Svalbard. It is a relatively stationary fish eater, and the mean length is about 1.6 m. The grey seal is also adapted to the coast where it lives in the most exposed areas, especially in mid Norway. It has a mean length of 2.3 m, and preys on fish and crabs.

The harp seal lives in the open sea in the ice zone from Baffin land to the Kara Sea. The maximum length is 2 m. In early spring the harp seal migrates to the breeding areas near Newfoundland, the Greenland–Jan Mayen area (the West Ice), and in the White Sea (the East Ice). As with all other seals, one pup is the rule, and it is born on the ice some distance from the open sea. The pup gains weight very fast and is soon able to live on its own. Two months later the seals gather again, this time to moult. During the breeding and moulting periods the harp seals stay very close together and for this reason they have traditionally been the object of extensive hunting. The pups, which are born with white fur (known as the ‘white coats’) have been particularly important economically. Today, the Barents Sea and the White Sea are the most important sealing areas, from where 41 000 animals were landed in 1996. The catch from the West Ice was about 6400 individuals. The estimated number of pups and older seals in the West Ice in 1996 was 60 000 and 286 000 respectively, while the numbers for the East Ice are uncertain.

The hooded seal has a similar life history and distribution to that of the harp seal, except for the East Ice and White Sea where only a few individuals have been observed. The hooded seal can reach 2.5 m in length and weigh up to 400 kg. The pup is born without the woolly coat of the harp seal pup. Its fur is short and stiff (‘blue back’) like that of the adults. Krill and amphipods are the prey of the young seals, while the adults catch fish and squid.

The ringed seal is common along the coasts in the Arctic, as well as along the coast of northern Norway. It is the smallest of the seal species in the area reaching a maximum of 1.4 m in length. Except for the breeding and moulting periods these species have a solitary habit. Its diet comprises herring, cod, haddock, krill and crabs.

The bearded seal has an Arctic distribution. It is found close to the shore or in shallow waters near Svalbard, Franz Josef Land, Novaya Zemlya, along the coasts of

Greenland and in Baffin Bay. Its prey is benthic and consists of fish, crabs, shrimps, mussels and snails. Because it is a solitary species with a scattered distribution it is rarely hunted. The maximum length attained is 2.5 m.

The walrus is the giant among the seals in the Arctic and has a circumpolar distribution. At a length of 3.6 m the weight can be up to 2000 kg. It has been heavily exploited in the past, and was long considered endangered in the North-east Atlantic. The walrus is a highly social species that haul-out on land and on the ice in big groups. Walrus feed on the bottom in shallow waters less than 100 m deep. Their diet is mussels, snails, polychaetes and other benthic species, which they remove from the substrate with their tusks. Females and males often live in separate areas. The number of walruses between East Greenland and Franz Josef Land is around 3000 (Born *et al.*, 1995).

Polar bear

Polar bears have a circumpolar distribution, and are confined to ice covered areas of the Arctic. The occurrence of bears between East Greenland and Franz Josef Land is largely determined by the extension of the pack ice. In autumn, bears move south-westwards with the expanding winter ice. At Bear Island, which is at the very edge of the Svalbard pack ice area, most observations of bears occur during February and March. During spring and summer, the bears follow the retreating ice. However, many bears also stay on land during the summer period.

The Svalbard–Barents Sea population is believed to have fully recovered from the overexploitation that occurred up to 1973. The population is unique in that it is the only population that has no ongoing harvest. Harvesting occurs in Greenland and illegal hunting is known to occur in Russia (Derocher *et al.*, 1998).

Studies by satellite telemetry have shown that bears may roam over huge areas but tend to be confined to the same area each year (e.g. Wiig, 1995). Paetkau *et al.* (1999) concluded that there is a small genetic difference between polar bears at East Greenland, on Svalbard and in western Russia, indicating movements between the areas.

Polar bears breed in April and May. A fertilised egg ‘sleeps’ until September/October when it implants into the wall of the uterus and starts to develop. The pregnant females dig a snow den in October/November on land near the coast. The cubs, usually two, are born in late December/early January and weigh < 1 kg. The family group leaves the den in late March/early April. At this time the cubs weigh around 10 kg. The females have fasted since entering the snow den five to six months previously. They now start feeding on seals on the sea-ice. The cubs follow their mother for 2.5 years before they are weaned. Consequently, the reproductive interval for most females is three years. They have their first cubs at five years old and may continue to have cubs until their twenties. The main food of polar bears is seals, which they catch on the ice. The distribution of Polar bears is therefore highly dependent upon the distribution of seals.

Polar bears rely on a thick coat of hair and fat to protect them from the cold. Grooming is necessary to maintain the thermal efficiency of their pelt. The pelt is often soiled after feeding and the bear usually cleans itself by licking its paws and rolling or pushing its face and neck against the snow.

5.3. Impact of non-indigenous species and harmful algal blooms

Non-indigenous species

A compilation of information about non-indigenous species introduced to the OSPAR Maritime area identified 104 non-indigenous species, plus fifteen species of uncertain origin and nine non-established species. The majority of species originate from unintentional introductions associated with shipping and mariculture.

Only a very limited number of non-indigenous species have been reported in Region I. In terms of flora: *Bonnemaisonia hamifera* (Rhodophyta), *Codium fragile* (Chlorophyta), *Colpomenia peregrina* (Pheophyta) and *Fucus evanescens* (Pheophyta). In terms of fauna: *Balanus improvisus* (Crustacea), *Lepas anatifera* (Crustacea), *Molgula manhattensis* (Tunicata), *Mya arenaria* (Mollusca), *Paralithoides camtschatica* (Crustacea), *Petricola pholadiformis* (Mollusca) and *Teredo navalis* (Mollusca).

The most significant ecological effects of non-indigenous species are competition (for food, space or light) with indigenous and/or commercially important species, and pathogenic effects. There are few quantitative estimates of ecological or economic impacts available. For Kamchatka crab, studies on annual output in northern Norway have been made (Olsvik, 1996). Studies of effects on, or interactions with native species that have no apparent economic significance are lacking.

Harmful algal blooms

Relatively few harmful algal blooms have been reported in Region I. Problems with harmful algal blooms along the Norwegian coast north of 62º N are not serious compared to the situation along the southern coast bordering the North Sea and Skagerrak. Farmed fish are particularly vulnerable to harmful algal blooms. Most of the problems for the farming industry are related to the natural phytoplankton bloom in spring, mostly dominated by diatoms, that occasionally results in clogging or physical damage to fish gills. Only a few harmful blooms have developed in northern Norway over the last ten years. These have mostly been local blooms of *Chrysochromulina* sp. This genus has a widespread distribution in Norwegian coastal waters, with around 26 species and grows well in the 15 – 35 salinity range and the 15 – 20 ºC temperature range. The most dramatic episode occurred in May 1991 when a bloom of *Chrysochromulina leadbeateri* in the Vestfjord area caused losses of around 740 t of farmed fish. In 1998, a limited bloom of an unidentified *Chrysochromulina* species caused losses of around 200 t in one particular fjord area off the Tromsø region. Harmful algal blooms on the Faroe Islands have also caused the occasional mass mortality of farmed fish. The most important events were in 1984 and 1987 caused by the dinoflagellate *Alexandrium excavatum*, in 1988 caused by *Heterosigma akashiwo* (Raphidophyceae), and in 1998 in connection with the naked form of the silicoflagellate *Dictyocha speculum.*

Dinoflagellates can also occasionally be present in large amounts causing Diarrethic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP). However, in the northern part of Norway the problems are of minor importance in comparison with those in the southern part of the country. On the Faroe Islands, local outbreaks of PSP have been found repeatedly due to the presence of *Alexandrium excavatum*, while DSP outbreaks seem more scarce.

5.4 Impact of microbiological pollution

The EC Bathing Water Quality Directive (76/160/EEC) was adopted in December 1975. As a consequence the microbiological quality of bathing water is monitored to protect against human health effects. Contamination by bacteria resulting in poor bathing water quality is not considered a serious problem in Region I. Population density is generally low and bathing activities in the sea tend to be low all year round due to the very low water temperatures.

Council Directive 91/492/EEC (the Shellfish Directive) lays down health conditions for the production and marketing of bivalve molluscs for human consumption. Permissible limits are given for the number of faecal coliforms and *Salmonella*, for example. In relation to the dinoflagellate toxins that accumulate in bivalve molluscs, particularly the blue mussel, a qualitative standard based on the bioassay of choice is applied for shellfish poisoning (DSP, PSP). In Region I the presence of faecal coliforms in bivalve molluscs is a minor problem. The accumulation of algal toxins associated with DSP and PSP has only been a problem along parts of the Norwegian coast.

5.5 Impact of fisheries

Humans are often considered predators at the highest trophic level in the marine ecosystem. For a long time, it was assumed that we could harvest the unlimited fish resources without concern. In modern times, with rapidly increasing demands for food and the development of modern and highly efficient fishing vessels and equipment, this situation has changed. Even the most inaccessible fish stocks in remote areas of the open sea are now exploited, and catches have doubled several times over the last hundred years. It has long been known that natural variability has been responsible for large fluctuations in the abundance of certain fish species. These natural fluctuations may be intensified by the large-scale commercial fishing of such stocks. Many of the species in the northern regions live and spawn at the limits of their distribution, and even moderate changes in temperature will have profound effects on their distribution, growth and spawning success. The fisheries are regulated through various international fisheries management bodies and the assessment process is briefly explained in *Boxes 5.1 and 5.2.*

5.5.1 Effects on stocks

Several commercial fisheries have suffered from a dramatic decline in population size in recent years. The fluctuations in stock size are a result of a combination of

Box 5.1 Stock assessment

Stock size can either be measured directly by research vessel surveys or estimated indirectly from catch statistics or tagging programmes. The status of fish stocks are assessed regularly, usually once a year, in the fishery management process. Analytical assessment provides estimates of the abundance and mortality of the various age groups from different year classes in the stock. This requires a data basis with information on age structure in the catches. Such catch-at-age information can be used to reconstruct the recent stock development through virtual population analysis (VPA) or similar analysis.

There are two major difficulties in using catch data to estimate stock size and composition. The first is the quality of the data. Incomplete data or misreporting of catches may lead to serious limitations and errors in the estimates of stock history from catch data. The second difficulty is the inherent limitation in estimating the number of fish remaining in the sea from the number of fish taken out of the sea. Even with 100% correct catch statistics, this limits the predictive ability to detect ongoing changes in the stock size from catches.

Stocks can also be measured acoustically by echosounders or by systematic sampling with pelagic or bottom trawls. Acoustics may provide estimates of absolute stock size abundance while trawl surveys generally provide a relative measure of stock size. Stock size can also be estimated by back-calculation from surveys of the total amount of eggs spawned.

Box 5.2 Biological reference points and safety margins

Biological reference points have been established for several fish stocks and are used in fish stock assessments. A biological reference point is a value of fishing mortality or stock size estimated through agreed scientific procedures. The values correspond to states of the fishery or the stock. Two types of precautionary reference points are used: conservation or limit reference points, and management or target reference points. Limit reference points set boundaries (lower boundary for spawning stock size and upper boundary for fishing mortality) which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. A parallel set of target reference points is intended to meet management objectives – they refer to harvesting strategies which may optimise the fishery.

A precautionary approach has been developed which prescribes certain requirements with regards to information on stock size and fishing mortality. ICES has operationalised this approach by taking into account reference points relating to both spawning stock biomass and fishing mortality.

Safety margins have also been set so that in general there should be less than a 5% probability that the estimates of stock size and fishing mortality fall outside the reference point values due to the statistical uncertainty in the estimates. In principal, the percentage probability (the risk) is a management decision and 5% is used as the default if management authorities do not request a different probability. There are thus the dual requirements that the spawning stock size should not be below a minimum level and that the fishing mortality should not exceed a maximum level. In this way, both the stock size and the rate of change in stock size due to fishing are taken into account. While this is a considerable improvement, the precautionary reference points are still mainly based on limit reference points. These limits should not be exceeded, and there is a need for further improvement to move towards target reference points.

Precautionary reference points have not been determined for the stocks where no assessment is done. For some of the stocks that are assessed, one or both reference points have not yet been determined (see *Table 5.3*).

large natural variability and pressure from fisheries. A collapse in fish stocks has thus been explained as a combined effect of recruitment failure, increased natural mortality, reduced growth and over-exploitation. The problems increase when the exploited species is a food source for other commercial species. The three largest and economically most important fish populations in Region I – herring, cod and capelin – are good examples.

Years with good recruitment of herring and cod, have resulted in poor capelin recruitment and have subsequently given rise to weak capelin stock size *(Figure 5.10)*. In years when the herring stock was very low, capelin stock recruitment was higher. Hence, the development of the herring cod and capelin stocks in Region I are biologically strongly linked. For several years, models have been used to regulate the fisheries of these stocks.

Figure 5.10 **Stock size variations for cod, capelin and herring in the Barents Sea during 1973 to 1999. Source: Gjøsæter (1997); ICES (1999).**

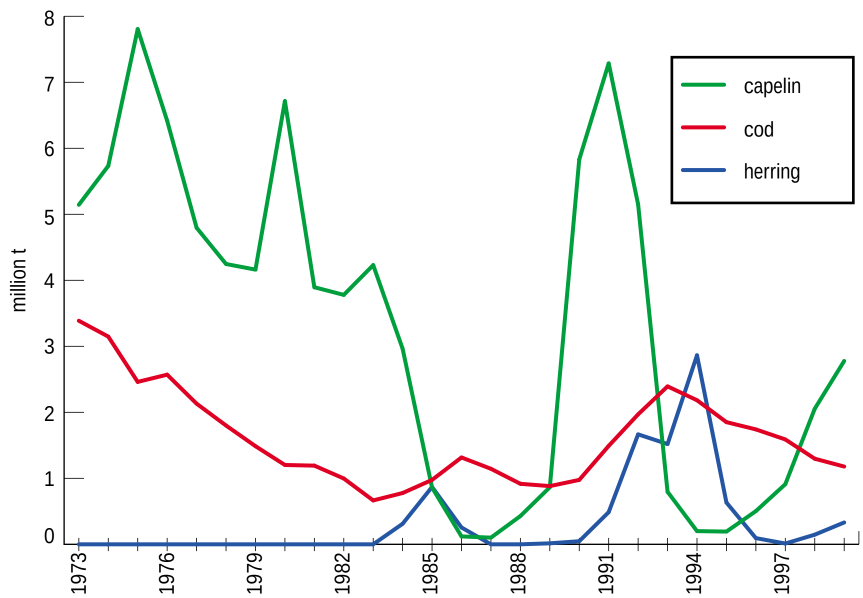


Table 5.3 Basis for the assessment of fish stocks in 1998.

Sub-region/ species	ICES stock name	Assessment	Data basis*
Barents Sea			
cod	North-east Arctic cod	analytical	caa, sur, cpu
cod	Coastal cod	survey based	caa, sur
haddock	North-East Arctic haddock	analytical	caa, sur, cpu
capelin	Barents Sea capelin	survey based	caa, sur
deep water shrimp		none	sur, cpu
polar cod		none	sur
long rough dab		none	sur
Norwegian Sea			
saithe	North-east Arctic saithe (Sub-areas I and II)	analytical	caa, sur, cpu
Sebastes mentella	Sebastes mentella in Sub-areas I and II	analytical	caa, sur, cpu
Sebastes marinus	Sebastes marinus in Sub-areas I and II	survey based	caa, sur, cpu
Greenland halibut	Greenland halibut in Sub-areas I and II	analytical	caa, sur, cpu
herring	Norwegian spring-spawning herring	analytical	caa, sur, cpu, tagging
cod	Faroe Plateau cod (Sub-division Vb1)	analytical	caa, cpu
cod	Faroe Bank cod (Sub-division Vb2)	none	caa, sur
haddock	Faroe haddock (Division Vb)	analytical	caa, sur, cpu
saithe	Faroe saithe (Division Vb)	analytical	caa, cpu
blue whiting	Blue whiting combined stocks (Sub-areas I-IX, XII and XIV)	analytical	caa, sur, cpu
salmon	Atlantic salmon in the North-East Atlantic Commission Area	none	c
ling	Ling	none	c, cpu
blue ling	Blue ling	none	c
tusk	Tusk	none	c
Greater silver smelt	Greater silver smelt	none	c
lumpsucker		none	c
angler fish		none	c
elasmobranchs		none	c
bluefin tuna		none	c
Icelandic Sea			
cod	Icelandic cod (Division Va)	analytical	caa, sur, cpu
cod	Greenland cod (Sub-area XIV and NAFO area 1)	analytical	caa, sur, cpu
haddock	Icelandic haddock (Division Va)	analytical	caa, sur, cpu
saithe	Icelandic saithe (Division Va)	analytical	caa, sur, cpu
Greenland halibut	Greenland halibut (Sub-area V and XIV)	analytical	caa, sur, cpu
Sebastes marinus	Sebastes marinus (in Sub-areas V, VI and XIV)	none	caa, sur, cpu
Sebastes mentella	Deep-sea Sebastes mentella (in Sub-areas V, VI and XIV)	none	c, sur, cpu
herring	Icelandic summer-spawning herring (Division Va)	analytical	caa, sur, cpu
capelin	Capelin in the Iceland-East Greenland-Jan Mayen area	analytical	caa, sur

* c: catch, caa: catch at age, cpu: catch per unit effort, sur: survey.

The Norwegian spring spawning herring is currently the largest fish population in European waters and has probably been so for some time. The traditional fishery was conducted in coastal areas with small vessels. After the Second World War, fishing capacity increased, and the echo sounder made the search for herring an easier task. In the 1960s, the fleet was equipped with purse seines and later with power blocks, operating all year round in the North Atlantic. The fishing fleets of Norway, the Soviet Union and Iceland took most of the catches. An increase

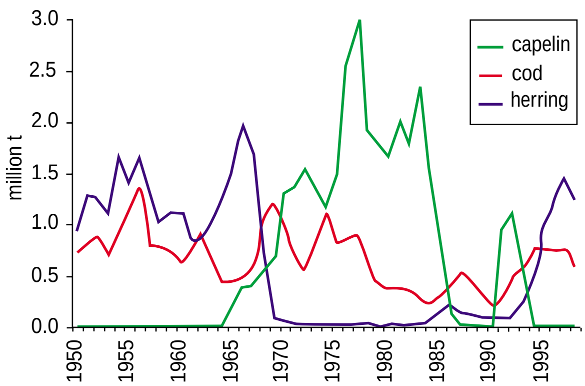
State of stock relative to precautionary reference points		Stock
biomass	fishing mortality	(t x 10³)
inside	outside	631
not def.	not def.	no estimate
inside	outside	219
outside	not def.*	254
not. def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
inside	outside	211
outside*	not def.	no estimate
not def.	not def.	no estimate
outside*	not def.	37
inside	inside	9836
inside	outside	no estimate
not def.	not def.	no estimate
outside	outside	50
outside	outside	50
inside	inside	2718
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
not def.	not def.	no estimate
inside	inside	529
not def.	not def.	21
not def.	outside	67
outside	outside	91
outside	outside	63
not def.	not def.	no estimate
not def.	not def.	no estimate
inside	inside	486
inside	not def.	400

in the strength of the East Icelandic Current in 1965, with very low temperatures in the western part of the Norwegian Sea and to the north of Iceland, together with an increasingly efficient fishery, resulted in a decrease in the population of spawners in 1969 to < 1% of the original; more than 10 million t in the early 1950s. Fishing for juvenile herring in the 1950s and 1960s may have contributed to the collapse of the stock.

The herring catch in Icelandic waters during 1960 to 1966 was around 600 000 t, including catch from the Norwegian spring spawning herring. The Icelandic stocks collapsed at the same time as the Norwegian spring spawning herring and during 1972 to 1974 no catch was allowed in Icelandic waters. Since then the Icelandic summer spawning stock has built up. The catch is around 100 000 t/yr. In the 1970s and early 1980s, the quotas of Norwegian spring spawning herring were also set very low and the fishery was partly closed in order to give the population a chance to recover. The 1983 season gave high spawning success for the Norwegian spring spawners, and at the end of the 1980s the spawning population had reached about 4 million t. Today, this has increased to more than 10 million t, and the total catch is almost 1.3 million t. The herring population has now partly resumed the old migration pattern.

The decline in the herring fisheries increased interest in the capelin fishery. Norway and the Soviet Union started an extensive fishery on the Barents Sea capelin stock in the 1960s, and by volume this soon took over the herring's role as the most important fishery in Europe. Because the capelin has a life span of only three to four years, and few individuals survive the first spawning, the capelin stock is more subject to rapid changes than the herring stock. In the 1970s and early 1980s reproduction was good, and a spawning stock in the range of 1 to 4 million t maintained an annual catch of 1 to 3 million t *(Figure 5.11)*. The stock collapsed between 1984 and 1986, mainly as a result of recruitment failure. Later investigations have shown that juvenile herring of the rich 1983 year class fed on capelin larvae, and that the decline in the capelin stock was not a result of overfishing, although catches larger than the recommended quotas in 1985/6

Figure 5.11 **Development of the total catch (landings) of capelin, cod and herring in the Barents Sea during 1950 to 1994. Source: IMR (1999).**



contributed to the collapse (Gjøsæter, 1995; Huse and Toresen, 1995). From 1987 to 1990, and from 1994 to 1998, the capelin fishery was banned.

The recovery of the Norwegian spring spawning herring caused problems for capelin recruitment. When the young herring from the 1983 year class left the Barents Sea in 1986, the capelin once more recruited rich year classes for a few years, allowing the population to grow fast until a new decline was observed in 1993, with a resulting halt in catches the following year. This new decline resulted from new strong year classes of herring in the Barents Sea in 1991 and 1992. From 1995, the population of young herring in the area was again small and the capelin stock began to recruit strong year classes. The stock quickly recovered and the fishery started again on a small scale in 1999.

From the late 1970s until the present, the annual catches of the Iceland–East Greenland–Jan Mayen stock of capelin have varied from about 900 000 t to 1.6 million t. Only in 1982/3 and in 1991 have the catches been < 300 000 t because of poor recruitment and temporary drops in the stock abundance.

The collapse of the capelin stock in the mid 1980s had dramatic effects on other components of the Barents Sea ecosystem. Some examples are:

- the shift in the diet of cod from capelin to zooplankton (krill and amphipods) which led to a decrease in growth rate and weight at age of cod;
- an increase in the migration of harp seals to the Norwegian coast during 1986 to 1988, probably in search of other prey; and
- the collapse of the common guillemot population on Bear Island in 1986.

Cod, harp seals and guillemots all depend on capelin as their major prey.

For centuries, the cod fisheries have been the most important economically for the Nordic countries. The traditional fishery is aimed at the spawners migrating to the Lofoten area in northern Norway during late winter. The fishery in the Barents Sea for young cod was intensified with trawlers after the Second World War, and by the 1950s negative effects on the spawning stock were observed in the Lofoten fishery. Nevertheless, the fishing effort was not reduced, and in a 30-year period the stock decreased by more than 75%. The decline was accelerated by low recruitment and low temperatures impeding growth in 1976 to 1980. The next few years were warm and gave hope for new growth and increased catches. But in 1986, the main prey of cod – capelin and herring – almost disappeared from the Barents Sea. Cod growth decreased dramatically, and the mean weights of several age groups dropped to about half their previous level.

The Icelandic cod is the second largest cod population in the area. Heavy exploitation from many nations led to a strong decline in the 1970s. The introduction of national 200 mile exclusive economic zones was not sufficient to compensate for the increasing catches. National regulations of fisheries in the 1980s have resulted in an increase in stock size since 1990, and although the fishing has been sustainable over the last few years, the spawning population has not yet reached the levels of the early 1950s.

5.5.2 Discards

Discards of fish from catches have not been investigated in detail for Region I. Discards may be grouped according to two main categories. The first reflects the effects of regulations. In this case fish are discarded when marketable species smaller than the minimum size are caught, or when the quota of the target species is reached, or the by-catch percentage of protected species is overrun. Fish are also discarded if fishing for that particular species has been stopped. The second category comprises the discard of fish that do not offer the prospect of adequate financial return to the fishermen. These may be either marketable species or non-marketable species, including a long list of fish and invertebrates, as well as marine mammals and seabirds. Catching a mixture of species using non-selective gear may result in high discard percentages. One example is the shrimp fishery where cod, haddock, Greenland halibut and redfish are a common by-catch, although this has now been minimised by the use of selective sorting grids. Fishing for a single species that occurs in large schools, such as capelin and herring, results in low discards.

Discards vary in quantity and quality depending on the fishing technique employed. The correct choice of gear and its technical condition are crucial in reducing discards. In general, trawls are less selective and result in more discards than longlines.

When large schools of herring or mackerel are caught in nets, the nets sometimes tear. At such times large numbers of fish die (‘slipping’). For herring the survival rate is close to zero.

By-products from fisheries, such as gonads, guts, heads, skin and bones, are usually thrown away. Discards provide food for scavengers. It is difficult to obtain exact figures on the extent of discards. Only landing data are used to calculate the actual catches, and the unreported discards make management of the fish stocks difficult.

5.5.3 Benthos

Bottom trawling and dredging may have negative effects on benthic communities and habitats. The extent of damage within Region I is not well known. In recent years, particular attention has been paid to decreased biodiversity in the benthos caused by fisheries. Recovery after a disturbance may take years. The effects of disturbance on vulnerable species and habitats, for example deep water coral reefs, will be assessed along the Norwegian coasts in the coming years.

5.6 Impact of whaling

Whaling, from the Seventeenth Century to the Nineteenth Century, lead to the decimation of several whale species in the Arctic region. The recovery of the overexploited species has been very slow. Only very limited whaling takes place at present.

5.7 Impact of mariculture

In 1997, the total production of farmed salmon and rainbow trout in Region I resulted in discharges of approximately 10 000 t nitrogen and 2000 t phosphorus. In some local areas this represented the largest anthropogenic input. Relative to the volume and assimilative capacity of the receiving water body however, the discharges are considered to be of minor importance, and no eutrophication has been reported. Overloading of fish farm locations by organic matter however does occur. Such overloading results in a degradation of the benthic community at the site, which may in turn have significant effects on the fish. To prevent such situations a regulatory framework, including a newly developed monitoring programme, is being implemented in Norway.

There has been no systematic mapping of diseases in wild fish stocks in Region I. Thus there are no statistics on the prevalence of diseases in wild fish populations. However, occasional incidents of disease have been reported. Among the bacterial diseases the most common is vibriosis, caused by various serotypes of *Vibrio anguillarum*. This disease has been detected in coal fish (*Pollachius virens*) and Atlantic cod caught in Norwegian waters. Little is known about viral diseases in wild fish stocks, mainly due to the lack of systematic studies. However, the Infectious Pancreatic Necrosis (IPN) virus has been detected in fish and shellfish. This virus is not species-specific and can be transferred from one species to another. As it is detected in shellfish without causing any disease problems it is not unlikely that such organisms act as vectors for its transmission. Fungal infections have also been reported in wild fish stocks. The best known case concerns the infection of herring by *Ichthyophonus hoferi* (Holst, 1994). Such infections may contribute to a decrease in the population of this species. *Ichthyophonus hoferi* may also be transmitted from one species to another and has been reported in different species of flat fish.

Parasites, ectoparasites as well as endoparasites, may cause problems in wild fish stocks. Various species of lice have been reported on Atlantic cod and other white fish species. Salmon lice (*Lepeophtheirus salmonis*) have been detected on wild Atlantic salmon and on sea trout (*Salmo trutta*). Sea trout populations seem to be particularly heavily infected and this may be one of the reasons for the decrease observed in the populations of sea trout and salmon in Norwegian waters.

Bacterial diseases at fish farms are currently almost absent due to the use of effective vaccines and vaccination strategies. The most serious disease problems are caused by the IPN virus after the sea transfer of Atlantic salmon, and by infections with salmon lice. Vaccines against IPN do exist but are less effective than the vaccines for bacterial diseases. To control the lice infections, several species of wrasse (Labridae), together with the use of chemicals, seems to be the most effective strategy. Even though many of the potential diseases are controlled by vaccination and other prophylactic treatments, cultured fish are still a potential reservoir of pathogens (bacteria, viruses and parasites) which may be transferred to wild fish stocks. The spread of salmon lice from farmed fish to wild fish is currently one of the most serious problems connected with fish farming.

Due to the low occurrence of bacterial diseases in farmed fish over the last five years, antibiotic use by the industry has been low. In 1987, around 40 t were used in Norway to control such diseases, in 1997 this had dropped to around 500 kg. Over the same period, salmon production increased from 50 000 t to > 300 000 t. The improved disease situation has decreased the environmental problems caused by the use of antibiotics at fish farms.

Over the last ten to fifteen years attention has been given to the possibilities for genetic interactions between farmed and wild salmon stocks. However, there is still very little information available on this topic. There is insufficient genetic information about the wild and farmed salmon stocks to enable an understanding of the genetic processes taking place. The size of the wild salmon stocks is currently decreasing, while the farmed salmon stocks are increasing rapidly. In Norway the production volume of farmed salmon is now more than 150 times greater than for wild salmon.

5.8 Impact of eutrophication

Eutrophication results from nutrient enrichment. Typical effects include increased production and biomass of phytoplankton, changes in species composition including the occurrence of harmful algae, changes in benthic community structure and increased oxygen consumption in the water and sediments, sometimes leading to oxygen deficiency. Eutrophication can to some extent occur naturally. It is only considered polluting when it results from anthropogenic inputs. In Region I, eutrophication effects only occur locally close to urban settlements. Eutrophication is generally considered to be a minor problem in the Arctic.

5.9 Impact of tourism and recreation

Tourism and recreation in Region I are generally limited. Most of the region has a low population density and there are relatively few tourists. Owing to their remoteness and extreme environmental conditions some areas are not visited by tourists at all. However, some parts of the region are subject to tourism. Fishing, whale watching, scuba diving, visiting bird cliffs and viewing fjords and coastal landscapes are typical tourist activities. Tourism and recreational activities may disturb the natural functioning of the coastal zone as being a habitat for the breeding, moulting, resting or feeding of seabirds and seals. Quantitative estimates of environmental damage by tourism and recreation in Region I have not been made.

5.10 Impact of sand and gravel extraction

The extraction of marine aggregates in Region I is very limited and therefore expected to result in only minor environmental problems. Activities resulting in sediment removal and disturbance can result in negative local effects on the benthic communities.

5.11 Impact of dredging

In Region I, dredging only occurs in a few harbour areas and is usually to maintain navigation channels. Dredging increases turbidity and affects the sand and mud balance locally. Sediments in harbour areas often carry a high contaminant load. The dumping of dredged material in open sea areas may thus result in the transport and remobilization of the sediment-associated contaminants.

5.12 Impact of coastal protection and land reclamation

Coastal protection and land reclamation activities in Region I are usually restricted to the development of ports and harbours. These are mostly small-scale fishing ports or urban settlements. Locally, this can result in habitat changes. The impact of coastal protection and land reclamation in Region I is of minor importance compared to the situation in more densely populated areas such as the southern North Sea.

5.13 Impact of marine litter

Marine litter represents a global pollution problem. No investigations have been undertaken to quantify the amount of marine litter entering Region I, and no attempts have been made to quantify the associated biological or ecological impacts. It has been estimated that most marine litter is derived from land. Important land-based sources include refuse disposal sites, sewage-derived debris and items discarded by humans at beaches and along the coast. Important marine sources include shipping and the fishing industry. In Region I, litter represents a local problem close to urban areas and, to a certain extent, in some sheltered bays where plastics and other floating debris can collect. The presence of litter is unsightly and the material may affect several areas by drifting around. Seabirds are considered particularly vulnerable to marine litter, due to its ingestion or as a result of physical injury. Seabirds, marine mammals and some species of fish and mobile shellfish such as crabs may become entangled with larger pieces of marine litter.

5.14 Impact of offshore activities

Pollution from the offshore oil and gas industry is primarily related to the potential for accidental oil spills and to operational discharges of oil and chemicals. In terms of volume, operational discharges arising during production processes may exceed accidental spills, particularly where safety standards are low, as is currently the case in parts of the Russian land-based oil industry. The transport of oil by ships normally implies small operational discharges of oil. In the Arctic, particular environmental conditions such as ice will also increase the general risk of accidents.

Seabirds in Arctic areas are considered particularly vulnerable to oil pollution. Relatively small amounts of oil can reduce the insulative capacity of the feathers to the extent that the animal will die from the cold directly or because it is unable to obtain enough energy (food) to maintain its body temperature. Oil can also be toxic. An oil spill that reaches flocks of moulting birds in late summer/autumn, feeding birds in winter darkness, or areas close to bird cliffs, may potentially kill a large number of birds. The potential effects on seabirds and marine mammals of petroleum activity in the Barents Sea has been evaluated (e.g. Isaksen *et al.,* 1998). Both birds and marine mammals like the polar bear are vulnerable to such activity.

The potential harm to animal populations of an oil spill entering drift ice areas can be significant. Under such conditions, the oil will be protected against degradation, dilution and evaporation of the lighter fractions by ice floes that counteract wave action. The oil is easily trapped under and between ice floes and is thus conserved for much longer periods than under warmer conditions. Oil will also be transported from the underneath to the surface of ice floes by capillary effects. These factors may thus prolong the 'life' of an oil spill considerably, and so increase the period over which environmental damage occurs. The drift ice, and in particular the marginal ice-edge, is important for Arctic marine life. In the spring when seabirds, polar bears and seals concentrate in these areas, an oil spill can potentially affect large numbers of animals.

5.15 Impact of shipping

The impact of normal operational discharges of oil, sewage and other wastes from MARPOL compliant vessels are likely to be low at current levels of shipping operations. Future increases in ship traffic will also increase the risk of pollution. Significant environmental impacts are most likely to occur from large, concentrated, accidental releases. There are a number of sensitive sites in Region I, associated with critical habitats such as wildlife breeding areas. Accidental spills in these areas may have serious long-term effects, particularly given the low breeding rates of many Arctic species.

Shipping activities in the Arctic pose a greater risk in terms of accidents than activities further south, owing to the extreme climatic conditions in this area (i.e. ice, darkness and fog). These climatic conditions also complicate clean-up procedures and thus increase the risks of environmental damage. Other impacts related to shipping are the introduction of non-indigenous species (see Section 5.3) and the effects of antifoulants (see Section 5.16.3). The environmental impact of increased levels of shipping in the Arctic was recently evaluated in depth in relation to the opening of the Northern Sea Route from Europe to Japan along the Siberian coast (e.g. Brude *et al.*, 1998).

5.16 Impact of contaminants

5.16.1 Introduction

This section gives an overview of existing information with regard to the actual or potential effects of contaminants on organisms inhabiting coastal and offshore areas of Region I, and attempts to address the issues raised in the JAMP related to contaminants. Persistent organic contaminants, trace metals, oil and radionuclides are considered important within Region I. Sources both outside and within the Arctic contribute to the loads of these contaminant groups. Low temperatures and extreme seasonal variations in light are two of the physical characteristics of the region which cause environmental stress to organisms in Region I, making them potentially more vulnerable to environmental contaminants than in other areas.

There is considerable variability among species in their exposure to and response to different contaminants. It is often difficult to make direct links between the occurrence of a particular contaminant and particular biological effects. Assessing ecosystem effects and human health impacts in terms of exposure to specific contaminants is a very difficult task. Animals and humans are always exposed to mixtures of compounds within the ecosystem, never to single compounds. Hence, toxicological risk assessments that make use of animal test data on individual chemicals rather than on mixtures of chemicals will always give indications of risk only, no definite answers. Only in very few cases have biological effects been measured directly.

5.16.2 Metals

Anthropogenic effects of metals are only apparent locally in areas close to point sources. To date, biological effects of metals have not been investigated in Arctic biota. Cadmium and mercury are probably the most important metals because they occur in biota at concentrations that may affect the health of individual animals or may have implications for human consumers. Cadmium levels in seabirds and marine mammals from north-west Greenland may be sufficiently high to cause kidney damage. It is also uncertain whether mercury poses a threat to the health of the most highly exposed marine mammals, such as pilot whales from the Faroe Islands. However, there are indications that selenium is present in concentrations that can protect against mercury poisoning. Lead levels in marine organisms from the Arctic are well below food safety standards. This is not the case in local 'hot spots' such as mining areas and some Russian estuaries.

5.16.3 Tributyltin

Exposure to antifouling paints containing TBT is responsible for the development of imposex in female snails. Imposex has been observed in dogwhelk and common whelk (*Buccinum undatum*) in harbours in Iceland, Norway and Svalbard (see Section 4.5.1). The ban on the use of TBT on small boats has resulted in some signs of recovery for invertebrate species near marinas and other heavy use areas.

5.16.4 Polychlorinated biphenyls

PCBs can disturb enzyme systems in marine mammals. Specific information on this topic for Region I is not available. A study from the western Canadian Arctic has shown there is a strong correlation between liver microsomal enzymatic activities (e.g. EROD, AHH) and PCB residues in beluga whale blubber. This indicates that the current body burdens of PCBs in whales may be associated with biological effects. A relationship between enzymatic activities and the presence of PCBs in ringed seal from Arviat and hooded seal from the West Ice has also been found.

Few studies on the biological effects of PCBs in seabirds within Region I have been carried out. A recent study on glaucous gull from Bear Island found high PCB concentrations and indications of biological effects (Skaare *et al.*, 2000).

A recent study on polar bears found no correlation between PCB concentrations and reproductive success (Skaare *et al.*, 1994). A negative correlation was found however between retinol concentrations and PCBs in polar bear plasma. Recently, effects of high PCB levels on the immune system of polar bears have been found (Skaare *et al.*, 2000) and Wiig *et al.* (1998) suggested that the finding of pseudohermaphrodite polar bears at Svalbard could have been caused by high pollution levels. These results indicate that PCBs can potentially cause biological effects within Region I.

A small group of PCBs, the non-*ortho* and mono-*ortho* PCBs (planar PCBs), have dioxin-like toxicity. Intake of contaminated seafood is a major source of exposure to planar PCBs in humans living in the Arctic. The question has been raised as to whether high concentrations of planar PCBs in seafood pose a risk to human health. Available information on PCB levels in the tissues of northern residents shows significantly elevated levels in the tissues of several ethnic groups. Epidemiological studies on the effects of PCBs in residents of Region I are not available however.

Data obtained from epidemiological studies on infants from Michigan and North Carolina suggest adverse neurobiological effects from *in utero* exposure to PCBs (AMAP, 1998). High cord blood concentrations were associated with low birth weight and small head circumference. It is not clear whether PCB exposure is the sole factor leading to neurodevelopmental deficits, or if other contaminants such as mercury, or socio-demographic factors might also be associated with these results. Caution must be exercised when comparing people from different areas. The mixtures of contaminants to which the Lake Michigan infants were exposed may be very different to those occurring in the Arctic ecosystems. Dietary differences may also lead to significantly different exposure profiles.

One study has shown that birth size among male Inuit infants was inversely related to PCB concentrations in maternal breast milk (AMAP, 1998). Perinatal exposure to planar PCBs may impair immune responses to infections, as suggested by a 20-fold higher incidence of infectious diseases (e.g. meningitis, measles) and ear infections among one-year old Inuit with higher PCB exposures than the less exposed controls.

5.16.5 Polycyclic aromatic hydrocarbons

Fish and other organisms from open sea areas contain very low levels of PAHs due to both low exposure and rapid metabolism. PAHs have been detected at generally low levels in mussels along coasts. Elevated levels of PAHs have only been found in mussels and shellfish affected by direct discharges (e.g. harbours, industrial sites). This has resulted in advice against consumption of mussels in two Norwegian fjords in Region I: Vefsfjorden and Ranafjorden.

Information concerning the biological effects of PAHs in Region I is not available. Due to the generally low levels of PAHs in Region I, significant biological effects are unlikely to occur. The sources of exposure to PAHs for the human population are the inhalation of tobacco smoke, wood smoke and smoke from fuel, and the ingestion of PAHs through the consumption of smoked, fried or broiled food.

5.16.6 Other persistent organic compounds

All persistent organic compounds that have been detected in organisms in temperate waters have also been detected in the same species living in Region I. The effects of these low residue levels are presently unknown.

5.16.7 Radionuclides

The levels of artificial radionuclides in Region I are generally very low. Following the cessation of widespread atmospheric nuclear weapons testing in the early 1960s, the levels of artificial radionuclides have decreased. The present levels of radionuclide contamination are of negligible radiological significance (Layton *et al.*, 1997). The greatest future threats to human health and the environment in the Arctic are associated with the potential for accidents in the civilian and military nuclear sectors.

chapter 6

Overall assessment

6.1 Introduction

6.1.1 The assessment process

An environmental assessment consists of an analysis of the quality status of a marine area or ecosystem and the extent of impacts from human activities. A major challenge is to distinguish effects of human activities from natural variability, due for instance to climatic forcing. A second challenge is to distinguish an effect of a given human activity from effects resulting from other human activities. A successful environmental assessment therefore depends on a good basic understanding and description of the natural processes and variability within the ecosystem together with quantitative information on the human activities and their relationships to the processes and components of the ecosystem.

Basic knowledge about the functional properties and variability of marine ecosystems is limited. This in turn limits the ability to carry out conclusive environmental assessments (EEA/IRF, 1998; EEA, 1999).

Several environmental assessments have been prepared for the Arctic region over the last few years. These have been used as major sources of information for the present quality status report:

- AMAP Assessment Report: Arctic Pollution Issues (AMAP, 1998);
- PAME Working Group on the Protection of the Arctic Marine Environment (PAME, 1996);
- Arctic environment in the Nordic Countries (Bernes, 1996);
- Status Report on the Marine Environment of the Barents Region (Lønne *et al*., 1997);
- Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks (Layton *et al*., 1997); and
- The State of the European Arctic Environment (EEA, 1998).

This chapter builds upon Chapters 2 to 5 where information was presented on the geography, hydrography and climate; human activities; chemistry; and biology and ecology of Region I. An assessment of human impacts is made in Section 6.2 for the issues identified in the Joint Assessment and Monitoring Programme (OSPAR, 1995). A simple ranking system was used in the assessment process. Section 6.4 presents an overall assessment on a sub-regional basis and Section 6.5 presents conclusions and recommendations.

6.1.2 Characteristics of the Arctic Region

The ocean climate and the climate of Region I is largely determined by inflow of relatively warm Atlantic water. The circulation system – with inflow of Atlantic water, its transformation into Arctic water, deep water formation in the Arctic and the exit of Arctic water into the North Atlantic – is probably a major mechanism for climate variability, both within Europe and globally.

The northern and western parts of the Iceland and Greenland Seas and the northern and eastern parts of the Barents Sea are ice-covered in winter. Most of the ice in the Barents and Iceland Seas is seasonal and melts during summer. The ice and ice-melt have a large influence on ecological conditions and pollutant transport. The northern seas are home to some of the largest fish stocks in the world, which in turn support large stocks of seals, whales, and seabirds.

Climatic variability causes large interannual variability in ice and hydrographic conditions, which in turn affect plankton production and fish recruitment. Strong biological interactions in relatively simple food webs, as well as many species being close to their limits of distribution, imply that large natural variability is a typical feature of the ecosystems of the area.

The high natural variability is both a problem and an advantage when it comes to environmental assessments. On the one hand, the high natural variability makes it difficult to detect changes due to anthropogenic effects (e.g. resulting from fishing activity or pollution), while on the other hand, such variability indicates the importance of the physical driving forces and the relatively short food webs, which makes it easier to understand the dynamic properties of the high latitude ecosystems.

Region I is very large and heterogeneous in both its physical and biological features, and is mostly a clean and unspoiled area, except in some local areas where pollution problems may occur. The region is sparsely populated with a total population of only 2.6 million inhabitants, which to a large degree are dependent on fishing and hunting. Ocean fisheries are very important for all countries within Region I. In addition there are some activities related to forestry, agriculture, hunting, mining, the metallurgical industry, petroleum exploration and exploitation, military activity and tourism.

6.2 Assessment of human impacts

Due to its remoteness and low population density, the general environmental conditions within Region I are quite good. It is one of the least contaminated regions of the OSPAR Convention area. Natural fluctuations in fish stocks may be intensified by large-scale commercial fishing activities on such stocks and stringent fisheries management actions over the last decades have played an important role in increasing the stock size of some fish species. There are, however, certain causes for concern within Region I such as the impact of fisheries and the ubiquitous presence of persistent organic contaminants in fish and marine mammals.

Anthropogenic inputs in Region I range in scales from local, to regional, to global. The impacts at the largest scale, such as global climate change related to the increase in atmospheric carbon dioxide and in UV-B radiation, will require wider international action. Such impacts tend to be longer, larger in scale and harder to reverse. Also, some of the heavy metal and organochlorine inputs come from sources outside the OSPAR area and to reduce them would necessitate agreement with other international bodies. This assessment mainly considers those human impacts that are predominantly internal and which fall within the OSPAR sphere of influence.

In order to assess the environmental state of Region I the effects of human activities have been ranked into three classes:

- major effects (i.e. those which have been well documented or observed and which are of great impact);
- medium effects (i.e. those with medium to small observed effects and which are of potential impact); and
- lesser effects (i.e. those with small or no observed effects and which are of low or no impact).

This ranking was based on the information presented in Chapters 2 to 5, especially the impacts considered in Sections 5.3 to 5.16. The result of the ranking is shown in *Table 6.1*. No prioritisation has been made within the three classes.

Although such an approach may be considered simple and not completely objective, an assessment of the relative importance of the different types of human impact is necessary as a basis for decision makers to take action. This classification system should not be directly compared to classification systems used for the other OSPAR Regions. Impact types and issues are discussed according to their order of appearance in *Table 6.1*.

6.2.1 Major effects

Fisheries

The effects of fisheries have been well documented in Region I. The status of several fish stocks which are assessed and for which precautionary reference points have been determined, fall outside the limit for either the spawning stock or the fishing mortality or both. In the Norwegian Sea, this is the case for cod, haddock, saithe, redfish and Greenland halibut. In Icelandic waters, similar situations occur for haddock, saithe, and Greenland halibut. In many cases the fishing pressure is so high that the state of the stocks are beyond or close to the biological reference points, which are to be considered as warning signals. Management actions that have been in operation for some years have resulted in an improvement of the situation for some stocks, such as for Icelandic cod and the Norwegian spring-spawning herring.

Fishing mortality, stock size and the age and size composition of the stock are related. With the currently high fishing mortality for many of the stocks, fewer fish will grow to maturity. Both the total stock and the spawning stock will be reduced, and the proportion of young fish will be higher in the spawning stock as well as in the total stock. A higher proportion of small and young fish in the spawning stock may cause reductions in the reproductive potential and in the resilience towards fishing and other stresses on the stock. This has to some extent been demonstrated for the North-east Arctic cod.

In addition to direct effects, fishing can also have indirect effects on fish stocks through trophic interactions. Interactions between fish stocks can be strong through predator-prey relationships, such as has been documented for cod and capelin and for juvenile herring and capelin larvae in the Barents Sea. Reduced size of predatory fish populations will therefore have a positive effect on their prey species. Conversely, reduced size of prey populations may negatively affect predator populations. Because the effect of fishing pressure on stock size and stock interactions may coincide with climatically driven variability, the indirect effects of fishing are generally not well documented.

Table 6.1 Ranking of impacts in Region I.

Major effects
fisheries
Medium effects
PCBs
other persistent organic compounds
TBT
mariculture
oil
Lesser effects
PAHs
metals
radionuclides
eutrophication
biological introductions*
physical impacts†
shipping

* includes the impacts arising from the introduction of non-indigenous species, and microbiological pollution; † includes the impacts arising from dredging and dumping, coastal protection and land reclamation, tourism, sand and gravel extraction, and marine litter.

Discards from fisheries represent food and can cause increases in populations of scavenging species. This is likely to have contributed to population increases for some species of seabird in Region I. This is not well quantified, however, due to a lack of data on discards and limited time series data on population sizes of seabird populations.

Bottom trawling affects benthic species and habitats. There can be direct effects on organisms, i.e. they may be damaged or killed by the trawl. Organisms may also be mixed out of the sediment and made available to predators. Trawling also affects the bottom substrate. Sediments will be disturbed and resuspended. In Norway there have been investigations into the effect of trawling on deepwater corals (e.g. *Lophelia pertusa*) over the last few years. The investigations suggest that there could be extensive damage to coral reefs by fishing activities. Such investigations have not been done in other parts of Region I, but similar effects are expected due to the intensive fishing activities.

Other benthic habitats and species could also be sensitive to and affected by bottom trawling. Sponge communities are widely distributed in some areas, like the Barents Sea, and are affected by trawling. To what extent this results in lasting damage with the risk of losing species and habitats, has not yet been investigated.

Seabird populations can be indirectly affected by fisheries through effects on the fish species on which they prey. During the late 1980s there were large mortalities and sharp declines in several seabird colonies in the Barents Sea. This was due to the lack of food caused by the collapse of the capelin stock. While fishing contributed to and aggravated the situation, the collapse was mainly a natural event caused by climatic variability and biological interactions.

The former days of whaling lead to the decimation of several whale species in the Arctic region. The recovery of some overexploited species, such as the Greenland whale and blue whale, has been very slow, while the fin whale has recovered well. The Greenland whale feeds primarily on copepods in Arctic water, while the blue whale feeds on aggregations of krill during summer. It is likely that the pattern of energy flow and the dynamic properties of the ecosystems in Region I have been altered permanently by the previous whaling activities, but the extent of this situation has not yet been quantified.

The minke whale has been important in modern Norwegian whaling. Although Norwegian minke whaling resumed in 1993, the current level of whaling is not considered a threat to the minke whale population. There is a traditional catch of pilot whales by the local population of the Faroe Islands. The scale of this activity is limited and it is not considered to be a threat to the pilot whale population. Except for minke whales and pilot whales, all other whale species are protected and not subject to hunting.

The harp seals in the Barents Sea and the Greenland Sea and the hooded seals in the Greenland Sea are hunted commercially. The populations are presently at high levels and the catches are considered to be well within the limits of sustainable utilisation. Small cetaceans and seals may be entangled and killed in gillnets. The magnitude of such incidental catches is limited and does not appear to represent a threat to these populations in Region I.

6.2.2 Medium effects

PCBs

Assessing the ecosystem and human health effects of exposure to PCBs is very difficult. Organisms are always exposed to mixtures of contaminants within the ecosystem, never to single compounds. Hence, toxicological risk assessments that make use of animal test data on individual chemicals rather than mixtures of chemicals will only give indications of risk, not definite answers.

No quantitative estimates of the total input of PCBs to Region I are available. A few local sources close to urban settlements are known. The levels of PCBs cannot be explained by known use or releases from sources within Region I. This implies that long range transport from lower latitudes is important. Levels of PCBs seem to be higher in both biotic and abiotic media around Svalbard, the southern Barents Sea, and eastern Greenland, than in the Canadian Arctic. Causes and mechanisms for this are not fully understood. Very high levels of PCBs have been reported in polar bears from Svalbard.

Long-term time trends for PCBs in Region I are few. It is therefore difficult to judge to what extent agreed measures and the ban on the use of PCBs have resulted in decreased concentration levels in the environment. Data for 1991 to 1996 indicate a decreasing trend in concentrations in fish from Icelandic waters. Data from the subarctic indicate decreasing trends in PCB concentrations between the 1970s and 1990s.

Very few studies have been carried out on the biological effects of PCBs within Region I. Recent studies on glaucous gulls from Bear Island showed high PCB concentrations and indications of biological effects. In a study on polar bears no correlation could be found between PCB concentrations and reproductive success. A few studies on marine mammals from other parts of the Arctic have shown correlations between the body burden of PCBs and microsomal enzymatic activities. These studies indicate that PCBs can cause biological effects in animals living within Region I. However, scientific proof is presently very limited.

A small group of PCBs, the non-*ortho* and mono-*ortho* PCBs (planar PCBs), have dioxin-like toxicity. Intake of contaminated seafood is a major exposure route to planar PCBs for humans living in the Arctic. The question has been raised as to whether high concentrations of planar PCBs in seafood pose a risk to human health. Information on PCB levels in the tissues of residents living in Region I shows significantly elevated levels in the tissues of some ethnic groups. However, epidemiological studies on the effects of PCBs on people living within the region are not available. A study undertaken outside Region I (Michigan) suggests links between PCB exposure and neurobiological effects, low birth weight and small head circumference in newborn children. Another study found that birth size among male Inuit infants was inversely related to PCB concentrations in the breast milk of the mother.

Other persistent organic compounds

All persistent organic compounds, organochlorines as well as brominated organics, that have been detected in temperate waters have also been detected in Region I, showing the global distribution of such compounds. Organochlorine pesticides such as HCHs, HCB, DDTs, chlordanes and toxaphene are widespread in marine biota from Region I. These compounds are also found in sea ice and surface sediments, but generally at very low concentrations. In surface sediments from offshore sites no apparent geographical trend for persistent organic compounds seems apparent.

Results generally indicate slightly higher levels of DDTs, PCBs and dioxins and furanes in biota from eastern compared to western parts of Region I, at all trophic levels. For HCHs the opposite occurs with the highest concentrations found in animals from western parts of the region. This may be due to the combined influence of long-range atmospheric transport from North America and Europe. Another possible factor is the transport of contaminants in sea ice and the overlying snow or in association with sediment particles embedded in sea ice derived from the Russian continental shelf.

Very few biological effect studies have been carried out on persistent organic compounds in Region I. Reports from other areas indicate the potential for biological effects and negative impacts on the environment.

TBT

Exposure to antifouling paints containing TBT is responsible for the development of imposex in female snails. Development of imposex has been documented in dogwhelk and common whelk in and outside numerous harbour areas in Region I. Recent data show some signs of recovery, due to the decreased use of antifouling paint containing TBT and the ban on the of use of TBT on smaller boats.

Mariculture

The wild salmon stocks appear to have been decreasing over the last few decades while salmon farming has shown a marked increase. Genetic effects of mariculture on wild stocks are mainly an issue for Atlantic salmon. Escaped salmon have been found to make up more than 50% of the individuals in several rivers in Norway where the natural stocks are low. The amount of escaped salmon makes it likely that there are effects on the genetic composition of wild stocks. This may contribute to a loss of genetic diversity in the wild salmon stocks and to their ability to adapt to local environmental conditions. The extent of such effects on genetic composition is not well documented.

The spreading of salmon lice from farmed to wild stocks of salmon is an issue of concern in Region I, especially in Norway. Heavy infection may cause large mortality. The problem with salmon lice appears to have increased. The extent to which cultured salmon contribute lice to wild salmon is not well documented, however. A lack of information on the role of natural factors and on natural variability makes a quantitative assessment very difficult.

Bacterial and viral diseases may also spread from farmed to wild stocks. Bacterial diseases in fish farms are presently almost absent due to the use of effective vaccines and vaccination strategies. The most serious disease problem at present, besides salmon lice, is caused by the IPN virus which affects cultured salmon. There is a potential risk of the spread of this disease to wild stocks but there is at present no evidence that this has occurred.

The use of pesticides and antibiotics in mariculture has decreased during recent years due to increased environmental awareness and improved hygiene. Apart from very locally, pesticides and antibiotics are not considered to cause significant effects on marine biota.

Oil

The most oil contaminated areas in Region I are estuaries and harbours close to human settlements, and industrial or military sites. Hydrocarbon levels in the region associated with anthropogenic inputs are generally relatively low and of low ecological significance. Local problems have occurred in connection with accidental releases of oil.

Anthropogenic sources of oil include offshore production platforms, shipping and the transport of oil, local discharges from human settlements, and long range atmospheric transport from temperate and subarctic areas. New projects for the development of oil and gas resources are presently underway or planned for the near future on the mid Norwegian Shelf, the Faroe Islands and the Barents Sea. These developments will increase the potential for accidental releases of oil.

The environmental risks associated with oil and gas development, production and transport in Region I are primary local and/or regional. Potentially, a large impact may occur if there is overlap in time and space between an oil spill and migratory animals such as seabirds, which congregate at certain times within relatively small areas. Primary concerns associated with the major new oil and gas developments involve the risks of accidents and the difficulties of taking remedial actions in such cold environments. Drilling at greater water depths will take place and the effects of a potential deep water blowout are not presently known.

6.2.3 Lesser effects

PAHs

PAHs are present in petroleum, and can have pyrogenic or biogenic sources. Anthropogenic activities are generally the most important source of PAHs released into the environment. Estimates of total inputs of PAHs to the Arctic are not available. Industry and urban settlements within Region I are considered important local sources. Long-range atmospheric transport is probably of some importance.

PAHs are less prone to biomagnification than most of the other persistent organic contaminants and there is less concern about disperse, long range inputs from atmospheric sources. PAHs are most likely to have a local impact in regions where direct inputs occur, such as near oil wells, metallurgical plants and urban settlements.

PAHs accumulate in and are usually found at highest concentrations in sediments. Sediments in deep parts of the Greenland, Iceland and Norwegian Seas show low background concentrations of PAHs. Areas of the Barents Sea near Svalbard contain elevated concentrations of PAHs, probably due to contamination by petroleum. It is not known whether this is a natural phenomenon (seepage) or partly caused by human activities. Levels of PAHs in other parts of the Barents Sea are generally low. Low concentrations of PAHs have been detected in mussels in coastal areas. However, elevated levels of PAHs have been found locally in mussels and shellfish affected by direct discharges.

There has been limited attention given to studies on the biological effects of PAHs on fish and shellfish from Region I. Most of the data for acute and sublethal toxicity have been acquired from studies on acute oil spills from places outside Region I. Biomagnification has not been observed for PAHs. Due to the generally low levels of PAHs in Region I, it is unlikely that significant biological effects occur.

Metals

Background levels of metals in sea water from Region I generally fall within the global range for ocean areas. The concentrations of lead, cadmium, mercury and copper in Arctic marine sediments are mainly dependent on local geology. An anthropogenic influence is only apparent in areas close to point sources. Mercury concentrations in Arctic sediments show an increase over time, even though anthropogenic discharges of mercury have not increased in recent years. This indicates a regional or global process that is not fully understood.

Cadmium levels in marine organisms from large parts of the Arctic exceed common global background concentrations, mainly due to natural processes. Mercury (and selenium) levels in some marine mammals are high, while lead levels in large parts of the Arctic are relatively low. Traces of metals have been found in fish, with few large scale geographical differences. For seabirds and marine mammals including polar bears, cadmium and mercury levels have been shown to be highest in western parts of Region I. Geology, food and growth processes linked to temperature are most likely explanations for these differences.

Temporal trend data are scarce for biota from Region I. There is some evidence of mercury increasing by a factor of 2 to 3 in some marine mammals over the last two decades. Only liver, and in certain cases kidney, shows such an increase. It remains unclear, however, whether this is a real increase or reflects year to year variation.

Biological effects of metals have so far not been investigated in biota from Region I. Cadmium and mercury are probably the most important metals because they occur in some seabirds or marine mammals at concentrations that may have health implications both for individual animals and for human consumers. It is unclear whether mercury poses a health threat to the most highly exposed marine mammals such as pilot whales from the Faroe Islands. However, there are indications that selenium is present in concentrations that can protect against mercury poisoning. Lead levels in marine organisms from the Arctic are well below food standard limits.

Radionuclides

Contamination of the Arctic by artificial radionuclides derives primarily from two historical sources – global fallout from past atmospheric nuclear weapons testing and fallout from the Chernobyl reactor accident – and one ongoing activity – releases from European nuclear fuel reprocessing plants.

The additional contamination of the Arctic by radionuclides from local sources, such as spent fuel storage sites and radioactive wastes dumped at sea, is at present of negligible radiological significance. The greatest future threats to human health and the environment in the Arctic are associated with the potential release from dumpsites and accidents in the civilian and military nuclear sectors.

Levels of artificial radionuclides in Region I are generally very low. The maximum values were recorded during 1950 to 1970 as a consequence of atmospheric nuclear weapons testing. Following the cessation of widespread atmospheric weapons testing in the early 1960s, the relative importance of other sources, such as releases from European nuclear fuel reprocessing plants, increased. A second, but lower, peak in fission product radionuclides occurred in the early 1980s as a consequence of increasing radionuclide discharge from Sellafield in the mid 1970s. Fallout from the Chernobyl accident in 1986 made an additional contribution to radionuclide contamination in the Arctic. Since then, the levels of artificial radionuclides have been decreasing.

Eutrophication

The population density of the land areas bordering Region I is very low and therefore the inputs of nutrients are generally low. The aquaculture industry contributes about 10 000 t of nitrogen and 2000 t of phosphorus annually, the main part being from Norwegian salmon farming. This production is spread along a long coastline and the nutrient input constitutes an insignificant component (less than 1%) of the nutrient budgets in fjords and coastal waters. In fjords with shallow sills and restricted water exchange, the discharges of nutrients and organic material from feeds and faeces may cause local problems. As the location of aquaculture plants is regulated by the authorities according to the conditions and capacity of local areas, such problems are generally avoided.

Transboundary inputs of nutrients via the atmosphere or ocean currents, such as from the North Sea, have no detectable influence on nutrient concentrations in Region I. It is concluded that eutrophication is not an issue of concern and that the whole of Region I can be regarded as a non-problem area in terms of the negative effects of nutrients.

Impact of biological introductions

Impacts of biological pollution include both the introduction of non-indigenous species and the effects of microbiological pollution. The only observed impact that could have a possible effect on the ecosystem of Region I is the introduction of the Kamchatka crab.

Impact of physical disturbance

Physical disturbances include the impact of dredging and dumping, coastal protection and land reclamation, tourism, sand and gravel extraction and marine litter. All these impacts are regarded as minor problems in the region and are therefore not further discussed in this chapter.

6.3 Gaps in knowledge

The lack of data and limitations in information that were demonstrated in Chapters 2 to 5 hampered the assessment process and prevented definitive conclusions. Information from the ice-covered Arctic Ocean is very limited. Information on human activities and data from environmental monitoring in the Russian Federation was not easily available.

Natural fluctuations in the physical properties of the ocean are the main factor influencing variability in the marine ecosystems. There is consequently a need to improve the scientific basis for linking the physical processes with the chemical and biological processes. Key factors are how the ecosystems will respond to changes in ocean climate and how to extend the predictability of the ocean conditions, including climatological forecasting. The physical numerical models are now close to operational development and should be generalised to incorporate both chemical and biological parameters.

Fisheries

There is a lack of knowledge about several fish stocks, since only the most important fish stocks are assessed on a regular basis. The effects of fisheries on non-commercial fish species are not well known. The effect of fishing pressure may coincide with climatically-driven variability, and the information required to separate these processes is limited, making it difficult to quantify the effects of fisheries on the size and composition of total fish stocks.

Data on discards from fisheries are not available, making an assessment of the effects on the size of fish stocks difficult. Discards can be linked to increases in seabird populations. However, due to a lack of data on discards and limited time series on population sizes of seabirds, the effects have not been quantified, although discards are likely to have contributed to population increases for seabirds in Region I.

The effects of different types of fishing gear on benthic habitats have not been sufficiently investigated. There is a lack of information on the fishing intensity by trawls in different parts of Region I. Whether trawling causes lasting damage with the risk of losing species and habitats is therefore not well known.

There is insufficient information to quantify the effects of the previous whaling activities on the energy flow and dynamic properties of the marine ecosystems.

Contaminants

There is a general lack of knowledge concerning the total inputs of the different groups of contaminants from their various sources to Region I and concerning the influence of Arctic conditions on the transformation and fate of these contaminants. It is very difficult to quantify the inputs, for example those via the atmosphere, rivers and ocean currents. Current understanding of the importance of the different transport processes is limited. This results in a poor understanding of contaminant focusing zones. One element that is not fully understood is the role played by ice in contaminant transport.

Information on contaminant levels is lacking both for certain contaminants and for different media in some areas. Time series data sets for detecting long-term trends in levels of contaminants in different media are very limited. This results in a very limited ability to judge to what extent measures for the reduction of contaminant inputs have been effective.

There is a need for a better understanding of biological effects of contaminants on humans and on species identified as being at highest risk. In particular, it is important to undertake further studies on the effects of persistent organic compounds on the development of offspring and/or immunosuppression and on endocrine disrupting properties. Knowledge about the combined effects of contaminants on biota and humans, both at the individual and the ecosystem level, is also very limited.

Mariculture

The effects of escaped salmon on the genetic composition of wild salmon stocks are not well documented. This is also the case as to the extent to which cultured salmon contribute lice to wild salmon. Lack of information on the role of natural factors and on natural variability makes a quantitative assessment very difficult. There is also limited information concerning the risk of diseases spreading from mariculture to wild stocks.

6.4 Overall assessment

6.4.1 Introduction

Region I was subdivided into sub-regions based on ecological characteristics, namely: the Barents Sea, the Norwegian Sea, the Iceland Sea and shelf area and the south-east Greenland shelf, and the Greenland Sea. These subregions were used as the basis for the overall assessment in which priorities have been given to the various issues. No overall assessment has been made for the sector of the Arctic Ocean in Region I due to a lack of information.

6.4.2 The Barents Sea

The following issues of concern have been identified:

- high fishing pressure on targeted fish stocks and possible indirect ecological effects and effects on benthic habitats;
- high concentrations of persistent organic contaminants and possible biological effects at high trophic levels;
- the risk of pollution and disturbances from oil exploration and development;
- the spread of radioactive substances from dumpsites, storage sites and accidents; and
- possible ecological effects of the non-indigenous species Kamchatka crab.

Fisheries

The main concern in the Barents Sea is the risk of overfishing targeted stocks and the associated indirect effects on other parts of the ecosystem. Heavily fished stocks are likely to be more variable, reducing the resilience of the ecosystem. The effect of trawling on benthic habitats and species is also a cause for concern although quantitative studies to indicate the magnitude of such effects are lacking.

Persistent organic contaminants

High levels of PCBs and some other persistent organic contaminants have been found in polar bear and some species of seabird from the Svalbard area and Bear Island. Some biological effects are indicated and the persistent organic contaminants could potentially have negative effects on organisms in the Arctic marine environment, particularly those at the top of the marine food chains. Persistent organic contaminants are transported via the atmosphere to the Arctic region. Deposition over the Arctic Ocean may be transported with the transpolar ice drift to enter the sea as the ice melts in the northern Barents Sea. It is important to quantify this transport and to establish temporal trends. In addition to classical contaminants such as PCBs and DDT, there are new and possibly as yet unknown substances that may also be important.

Oil exploration

Norwegian and Russian oil exploration and development of the petroleum industry in the Barents Sea pose future risks for the environment. Low temperatures and ice may make the consequences of accidental or routine discharges of oil and chemicals more severe than in more temperate environments.

Radionuclides

The Barents Sea contains very low levels of radioactive substances from anthropogenic sources. The spread of radioactive substances from dumpsites or storage facilities and from routine or accidental releases from nuclear power plants and atomic weapons, however, pose a long-term threat to the marine environment.

Non-indigenous species

The Kamchatka crab has been introduced to the Barents Sea. It is now increasing in abundance and spreading westwards. It could possibly have ecological effects on other species in the Barents Sea ecosystem.

6.4.3 The Norwegian Sea

The following issues of concern have been identified:

- the impact of fisheries on deepwater coral reefs and other benthic habitats and the impact of high fishing pressure on targeted fish stocks;
- pollution and the impact of oil and gas exploration and production in deep water on benthic habitats and the effects of produced water discharges on marine organisms;
- potential biological effects of persistent organic contaminants; and
- effects on the genetic composition and survival of wild salmon stocks by escapees and salmon lice from salmon farms.

Fisheries

Extensive damage and destruction of deepwater coral reefs have been indicated. Several fish stocks are close to or outside the biological reference points and it likely that they are or may become overfished. There are also many commercial fish species for which no reference points and no assessment of stock size are made.

Oil industry

The oil industry is expanding its activities into deep water along the slope to the Norwegian Sea. There is a risk of deep sea blowouts, from which large amounts of oil may remain in the water column and affect pelagic and benthic organisms. There are also discharges of toxic compounds in produced water from oil and gas exploration. These represent chronic exposure to low concentrations of toxic compounds. It is of concern that the consequences of these regular discharges have not been adequately assessed due to insufficient scientific information.

Persistent organic contaminants

Levels of persistent organic contaminants are relatively low compared to those in more urbanised areas. Higher levels may be found near the coasts. However, the potential for effects is still considered a matter of concern.

Mariculture

Escaped salmon from Norwegian mariculture may have an effect on the genetic composition and ability for local adaptation of wild salmon stocks. Salmon lice from farms may also infect juvenile salmon migrating from the rivers through fjords and coastal waters, resulting in increased mortality. The extent of such effects has not yet been determined.

6.4.4 The Iceland Sea and shelf area

The following issues of concern have been identified:

- the effects of fisheries on targeted stocks and on benthic habitats; and
- potential biological effects of persistent organic contaminants.

Fisheries
Some fish stocks (haddock and Greenland halibut) are at or below the biological reference points. This suggests that the stocks are or may become overfished.

Persistent organic contaminants
Levels of persistent organic contaminants are relatively low. Higher concentrations are found near the most populated areas in Iceland although they are still low compared to those in more urbanised areas. However, the potential for effects is still considered a matter of concern.

6.4.5 The Greenland Sea

The following issue of concern has been identified:

- elevated concentrations of persistent organic contaminants and possible biological effects in organisms at high trophic levels.

Persistent organic contaminants
Persistent organic contaminants may be transported to the Greenland Sea via the atmosphere and ice from the Arctic Ocean. Relatively high concentrations in seals and polar bear indicate that biological effects may occur.

6.5 Conclusions and recommendations

6.5.1 Conclusions

In general the environmental quality of the Arctic waters is good and Region I is among the least contaminated parts of the OSPAR Convention area. Several issues, such as the levels of metals and radioactivity, are not presently creating problems and others such as eutrophication are of low environmental significance in the region (see *Table 6.1*). However, there are several reasons for concern.

Fisheries
There are clear indications that fisheries have the greatest observed effects on the ecosystems in Region I.

Contaminants, oil and mariculture
The potential impacts of persistent organic contaminants, potential problems connected to the future development of offshore petroleum resources, and problems related to mariculture on the Norwegian coast are of concern.

Gaps in knowledge and lack of information
The assessment process has been difficult due to the limited availability of data on trends in inputs and systematic contaminant monitoring data on geographical and temporal trends.

A lack of data on the biological effects of contaminants has made it difficult to draw conclusions about the impacts of contaminants on the Arctic marine ecosystems.

The region is very large, with huge natural variability within the region. Processes governing inputs of contaminants to the area is not well known. Processes and activities outside the region are probably also of importance in explaining the present levels of contaminants in different parts of Region I.

Global effects
The effects of global warming have not been considered in detail in this report. However, global warming can potentially influence the hydrographical conditions in Region I. The climate in Europe is highly dependent on the physical conditions in the Nordic Seas.

6.5.2 Recommendations

Taking into account the human activities identified in the QSR, their impact on the marine environment and the evaluation of existing measures, it is recommended that the appropriate authorities consider the following :

- Management of living resources and the environment should be based on science and any management action will need to be under constant review and modified as the scientific basis improves.
- To ensure continued improvement of the quality of the region adequate resources should be made available to implement the OSPAR Strategies.
- To improve the management of fish stocks there is a need for the development of better assessment tools regarding the effects of discards and by-catch, and the effects of interactions between fish stocks.
- There is a need for more research on the effects of fishing gear on marine habitats.

- Qualitative and quantitative information about the inputs, sources and pathways of contaminants to the region should be improved.
- That research programmes into pathways and sources be initiated together with monitoring programmes to identify critical regions and temporal trends.
- There is a need to obtain more knowledge about the biological effects of in particular the low chronic exposure to persistent organic contaminants of organisms living in the region.
- More information and research is needed on the possible genetic effects and the spread of parasites and diseases from mariculture to wild stocks.
- Environmental impact studies are required in relation to oil exploitation in or near ice covered areas.
- Research is required on the implications of climate change for the marine environment.

SPECIES

Reference list of species mentioned in this report (sorted by common (English) name within categories)

Common (English) name	Scientific name
Mammals	
Bearded seal	*Erignathus barbatus*
Beluga (White whale)	*Delphinapterus leucas*
Blue whale	*Balaenoptera musculus*
Bottlenose whale	*Hyperoodon ampullatus*
Common harbour seal	*Phoca vitulina*
Fin whale	*Balaenoptera physalus*
Greenland right whale (Bowhead whale)	*Balaena mysticetus*
Grey seal	*Halichoerus grypus*
Harbour porpoise	*Phocoena phocoena*
Harp seal	*Pagophilus groenlandicus*
Hooded seal	*Cystophora cristat*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Long-fin pilot whale	*Globicephala melaena*
Minke whale	*Balaenoptera acutorostrata*
Narwhale	*Monodon monoceros*
Polar bear	*Ursus maritimus*
Ringed seal	*Phoca hispida*
Sei whale	*Balaenoptera borealis*
Sperm whale	*Physeter macrocephalus*
Walrus	*Odobenus rosmarus*
White-beaked dolphin	*Lagenorhynchus albirostris*
White-sided dolphin	*Lagenorhynchus acutus*
Birds	
Black guillemot	*Cepphus grylle*
Black legged kittiwake	*Rissa tridactyla*
Common eider	*Somateria mollissima*
Common guillemot	*Uria aalge*
Cormorant	*Phalacrocorax carbo*
Glaucous gull	*Larus hyperboreus*
Great black-backed gull	*Larus marinus*
Herring gull	*Larus argentatus*
Little auk	*Alle alle*
Northern fulmar	*Fulmarus glacialis*
Puffin	*Fratercula arctica*
Razorbill	*Alca torda*
Shag	*Phalacrocorax aristotelis*
Thick-billed murre (Brünnich's guillemot)	*Uria lomvia*
Fish	
Anglerfish	*Ceratias hollboelli*
Arctic char	*Salvelinus alpinus*
Atlantic bluefin tuna	*Thunnus thynnus*
Atlantic cod	*Gadus morhua*
Atlantic halibut	*Hippoglossus hippoglossus*
Blue ling	*Molva dipterygia*
Blue whiting	*Micromesistius poutassou*
Capelin	*Mallotus villosus*
Dab	*Limanda limanda*
Deep-sea redfish	*Sebastes mentella*
Great silver smelt	*Argentina silus*
Greenland halibut	*Reinhardtius hippoglossoides*
Haddock	*Melanogrammus aeglefinus*
Halibut	*Hippoglossus hippoglossus*
Herring	*Clupea harengus*
Ling	*Molva molva*
Long rough dab	*Hippoglossoides platessoides*
Lumpsucker	*Cyclopterus lumpus*
Mackerel	*Scomber scombrus*
Polar cod	*Boreogadus saida*
Rainbow trout	*Oncorhynchus mykiss*
Redfish/golden redfish	*Sebaster marinus*
Saithe	*Pollachius virens*
Salmon	*Salmo salar*
Sandeel	*Ammodytes* sp.
Sea trout	*Salmo trutta*
Shorthorn sculpin	*Myoxocephalus scorpius*
Spotted wolffish	*Anarhichas minor*
Tusk	*Brosme brosme*

Common (English) name	Scientific name
Lower animals	
American piddock	*Petricola pholadiformis*
Amphipod	*Themisto abyssorum*
Amphipod	*Themisto libellula*
Amphipod	*Themisto* sp.
Amphipod	*Parathemisto libellula*
Arctic medusa	*Sarsia princeps*
Arrow-worm	*Sagitta elegans*
Barnacle	*Balanus improvisus*
Common goose barnacle	*Lepas anatifera*
Blue mussel	*Mytilus edulis*
Brittlestar	*Ophiocten* sp.
Brittlestar	*Ophiura* sp.
Common jellyfish	*Aurelia aurita*
Common whelk (whelk)	*Buccinum undatum*
Copepod	*Calanus finmarchicus*
Copepod	*Calanus glacialis*
Copepod	*Calanus hyperboreus*
Copepod	*Euchaita norvegica*
Copepod	*Metridia longa*
Copepod	*Microcalanus* sp.
Copepod	*Oithona similis*
Copepod	*Pseudocalanus elongatus*
Deep sea coral	*Lophelia pertusa*
Deep sea coral	*Lophelia* sp.
Deep sea prawn (Deep-water shrimp)	*Pandalus borealis*
Dogwhelk	*Nucella lapillus*
European flying squid	*Todarodes sagittatus*
Great shipworm	*Teredo navalis*
Horse mussel	*Modiolus modiolus*
Iceland scallop	*Chlamys islandica*
Kamchatka crab	*Paralithoides camtschatica*
Krill	*Meganyctiphanes norvegica*
Krill	*Thysanoessa inermis*
Krill	*Thysanoessa longicaudata*
Krill	*Thysanoessa* sp.
Medusa	*Aglantha digitalis*
Ocean quahog	*Arctica islandica*
Salmon louse	*Lepeophtheirus salmonis*
Sea jelly	*Mertensia ovum*
Soft shell clam (clam)	*Mya arenaria*
Squid	*Gonatus fabricii*
Tunicate	*Molgula manhattensis*
Winged snail	*Limacina helicina*
Winged snail	*Limacina retroversa*
Crustacean	*Parathemisto* sp.
Plants	
Bladder wrack	*Fucus vesiculosus*
Brown seaweed	*Colpomenia peregrina*
Channelled wrack	*Pelvetia canaliculata*
Micro alga	*Alexandrium excavatum*
Micro alga	*Chaetoceros socialis*
Micro alga	*Chrysochromulina leadbeateri*
Micro alga	*Dictyocha speculum*
Micro alga	*Heterosigma akashiwo*
Micro alga	*Nitzschia* sp.
Micro alga	*Phaeocystis pouchetii*
Micro alga	*Thalassiosira* sp.
Flat wrack	*Fucus distichus*
Green seaweed	*Codium fragile*
Kelp	*Laminaria saccharina*
Kelp	*Laminaria solidungula*
Knotted wrack	*Ascophyllum nodosum*
Kelp	*Laminaria hyperborea*
Moss	*Hylocomium splendens*
Oarweed	*Laminaria digitata*
Red seaweed	*Bonnemaisonia hamifera*
Serrated wrack	*Fucus serratus*
Spiral wrack	*Fucus spiralis*
Wrack	*Fucus evanescens*
Other organisms	
Bacteria	*Vibrio anguillarum*
Fungus	*Ichthyophonus hoferi*

ABBREVIATIONS

µ (prefix)	micro, 10^{-6}
∑ (prefix)	Sum (of concentrations)
°C	Degrees Celsius
ACFM	Advisory Committee on Fisheries Management (ICES)
ACG	Assessment Coordination Group (OSPAR)
AEPS	Arctic Environmental Protection Strategy
AHH	Aryl hydrocarbon hydroxylase
AMAP	Arctic Monitoring and Assessment Programme
ASMO	Environmental Assessment and Monitoring Committee (OSPAR)
atm	1 atmosphere = 1.013 x 10^5 Pascal
BC	Before Christ
Bq	Becquerel (1 disintegration per second)
BRC	Background / Reference Concentration
cm	Centimetre
d	Day
DBT	Dibutyltin
DDE	1,1-dichloro-2-(2-chlorophenyl)-2-(4-chlorophenyl)ethene
DDT	4,4'-dichlorodiphenyl-1,1,1-trichloroethane
DSP	Diarrhetic Shellfish Poisoning
dw	Dry weight
EAC	Ecotoxicological Assessment Criteria
EC	European Commission
EEA	European Environment Agency
EROD	Ethoxyresorufin-*O*-deethylase
EU	European Union
FAO	UN Food and Agriculture Organization
fw	Fat weight
G (prefix)	Giga, 10^9
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
IMPACT	Working Group on Impacts on the Marine Environment (OSPAR)
IMR	Institute for Marine Research (Norway)
INPUT	Working Group on Inputs to the Marine Environment (OSPAR)
IPCC	UN Intergovernmental Panel on Climate Change
IPN	Infectious Pancreatic Necrosis virus
ITQ	Individual Transferable Quota
IUCN	International Union for Conservation and Natural Resources
IWC	International Whaling Commission
JAMP	Joint Assessment and Monitoring Programme (OSPAR)
kg	Kilogramme
km	Kilometre
km^2	Square kilometre
km^3	Cubic kilometre
lw	Lipid weight
M	Molar mass
M (prefix)	Mega, 10^6
MARPOL	International Convention for the Prevention of Pollution from Ships (1973/1978)
MEPC	Marine Environmental Protection Committee (IMO)
mm	Millimetre
mo	Month
MON	Ad Hoc Working Group on Monitoring (OSPAR)
n (prefix)	nano, 10^{-9}
NAMMCO	North Atlantic Marine Mammal Commission
NAO	North Atlantic Oscillation
NASS	North Atlantic Sightings Surveys
NIVA	Norwegian Institute for Water Research
nm	Nautical mile
OECD	Organisation for Economic Cooperation and Development
OSPAR Commission	The term 'OSPAR Commission' is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were replaced by the 1992 OSPAR Convention when it entered into force on 25 March 1998
p (in pCO_2)	Partial pressure
p (prefix)	pico, 10^{-12}
PAH	Polycylic Aromatic Hydrocarbon
PAME	Working Group on the Protection of the Arctic Marine Environment
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorodibenzodioxins
PCDF	Polychlorodibenzofurans
PeCDD	Pentachlorodibenzodioxins
PeCDF	Pentachlorodibenzodifurans
PSP	Paralytic Shellfish Poisoning
PSU	Practical Salinity Unit (replaces 'parts per thousand' – ppt)
QSR	Quality Status Report
QSR 2000	Quality Status Report for the entire OSPAR maritime area published by OSPAR in 2000
RTT	Regional Task Team (OSPAR)
s	Second (time)
SFT	Norwegian Pollution Control Authority (Statens forurensningstilsyn)
SIME	Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (OSPAR)
Sv	Sievert (1 J kg^{-1} x (modifying factors))
t	Tonne
T (prefix)	Tera, 10^{12}
TBT	Tributyltin
TCDD	Tetrachlorodibenzodioxins
TCDF	Tetrachlorodibenzofurans
TEQ	Toxic equivalent
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	UN Educational Scientific and Cultural Organization
UV-B	Ultraviolet radiation with wavelenght of 315 – 280 nm
W	Watt
ww	Wet weight
yr	Year

GLOSSARY

Advection	The transfer of heat or matter by horizontal movement of water masses
Anthropogenic	Caused or produced by human activities
Background/Reference Concentrations (BRCs)	The following operational definitions have been used by OSPAR to determine Background/Reference Concentrations (BRCs): concentrations reflecting geological times (obtained from layers of buried marine sediments) or concentrations reflecting historical times (obtained from measurements carried out prior to significant anthropogenic inputs of the respective substance; relevant for nutrients only) or concentrations from pristine areas (preferably areas far from known sources and normally having very low concentrations)
Benthos	Those organisms attached to, living on, or in the seabed. Benthos is categorised by its diameter into: - nanobenthos: passes through 63 µm mesh - microbenthos: passes through 100 µm mesh - meiobenthos: within the 100 – 500 µm range - macrobenthos: passes through 1 cm mesh but is retained on 1000 – 500 µm mesh - megabenthos: visible, sampled using trawls and sieves
Bioaccumulation	The accumulation of a substance within the tissues of an organism. This includes 'bioconcentration' and uptake via the food chain
Bioassay	The use of an organism for assay purposes. Generally referring to a technique by which the presence of a chemical is quantified using living organisms, rather than chemical analyses
Bioavailability	The extent to which a substance can be absorbed into the tissues of organisms. Possibly the most important factor determining the extent to which a contaminant will enter the food chain and accumulate in biological tissues
Bioconcentration	The net result of the uptake, distribution and elimination of a substance by an organism due to water-borne exposure
Biomagnification	The process whereby concentrations of certain substances increase with each step in the food chain
Biomass	The total mass of organisms in a given place at a given time
Biota	Living organisms
Bloom	An abundant growth of phytoplankton, typically triggered by sudden favourable environmental conditions (e.g. excess nutrients, light availability, reduced grazing pressure)
By-catch	Non-target organisms caught in fishing gear
Cascading	Cascading occurs when a large volume of dense shelf water slides down slope into deep water
Climate	The long-term average conditions of the atmosphere and/or ocean
Contaminant	Any substance detected in a location where it is not normally found
Continental margin	The ocean floor between the shoreline and the abyssal plain, including the continental shelf, the continental slope and the continental rise
Continental shelf	The shallowest part of the continental margin between the shoreline and the continental slope; not usually deeper than 200 m
Continental slope	The steeply sloping seabed from the outer edge of the continental shelf to the continental rise
Coriolis effect	This is the apparent force generated by the rotation of the Earth that is produced by the conservation of angular momentum. In the northern hemisphere this imparts a clockwise rotation to a body of moving air or water
Crust	Rocks overlying the Earth's mantle; in the oceans, crust is formed along mid-ocean ridges
Discards	Fish and other organisms caught by fishing gear and then thrown back into the sea
Diversity	The genetic, taxonomic and ecosystem variety in organisms in a given marine area
Dumping	The deliberate disposal in the maritime area of wastes or other matter from vessels or aircraft, from offshore installations, and any deliberate disposal in the maritime area of vessels or aircraft, offshore installations and offshore pipelines. The term does not include disposal in accordance with MARPOL 73/78 or other applicable international law of wastes or matter incidental to, or derived from, the normal operations of vessels or aircraft or offshore installations (other than wastes or other matter transported by or to vessels of offshore installations for the purpose of disposal of such wastes or other matter or derived from the treatment of such wastes or other matter on such vessels or aircraft of offshore installations)
Ecotoxicological assessment criteria (EAC)	The concentrations that, according to existing scientific knowledge, approximate to concentrations below which the potential for adverse effects is minimal
Ecosystem	A community of organisms and their physical environment interacting as an ecological unit
Emission	A release into air
Eutrophication	The enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients
Exclusive Economic Zone (EEZ)	An area in which a coastal state has sovereign rights over all the economic resources of the sea, seabed and subsoil (see Articles 56 – 58, Part V, UNCLOS 1982)
Fisheries management	In adopting Annex V to the 1992 OSPAR Convention, on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area, OSPAR agreed that references to 'questions relating to the management of fisheries' are references to the questions on which action can be taken under such instruments as those constituting: - the Common Fisheries Policy of the European Community; - the corresponding legislation of Contracting Parties which are not Member States of the European Union; - the corresponding legislation in force in the Faroe Islands, Greenland, the Channel Islands and the Isle of Man; or - the North East Atlantic Fisheries Commission and the North Atlantic Salmon Commission; whether or not such action has been taken. For the avoidance of doubt, in the context of the OSPAR Convention, the management of fisheries includes the management of marine mammals
Food web	The network of interconnected food chains along which organic matter flows within an ecosystem or community
Fossil fuel	Mineral fuels (coal and hydrocarbons) rich in fossilised organic materials which are burnt to provide energy
Geochemical	Relating to the natural chemistry of the Earth
Glacial periods	Cool to cold climatic periods, characterised by advancing ice sheets and caps, within the Quaternary Period
Great Salinity Anomaly (GSA)	Large-scale advective features that take several years to progress around the subpolar gyre in the North Atlantic
Gyre	Large-scale ocean circulation pattern generated by the interaction of winds and the rotation of the earth
Harmful Algal Blooms (HAB)	Blooms of phytoplankton that result in harmful effects such as the production of toxins that can affect human health, oxygen depletion and kills of fish and invertebrates and harm to fish and invertebrates e.g. by damaging or clogging gills
Hazardous substances	Substances which fall into one of the following categories: (i) substances or groups of substances that are toxic, persistent and liable to bioaccumulate; or (ii) other substances or groups of substances which are assessed by OSPAR as requiring a similar approach as substances referred to in (i), even if they do not meet all the criteria for toxicity, persistence and bioaccumulation, but which give rise to an equivalent level of concern
Hydrography	The study of water characteristics and movements
Hydrothermal	Related to the circulation of fluids in the crust driven by pressure and geothermal heat. In the ocean this results in the discharge from underwater vents of chemically modified and often superheated water
Imposex	A condition in which the gender of an organism has become indeterminate as a result of hormonal imbalances or disruption, as in the case of the effect of tributyltin on gastropods
Intrusion	Water that is intermediate in density between two contiguous water masses and so flows between them
Isotope	A form of an element chemically identical to another but with a different atomic weight
Key species	A species whose loss would have a detrimental or disproportionate effect on the structure, function and/or biological diversity of the ecosystem to which it belongs
London Convention	The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter. The Convention is administered by the International Maritime Organization
MARPOL 73/78	The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
Mesopelagic	The depth zone of the oceanic water column between 200 and 1000 m. Also an adjective describing organisms which occur in the mesopelagic zone.
Meteorology	The study of weather and climate
Micronekton	The larger pelagic animals that are routinely sampled by large trawls (usually with mesh sizes of 3 – 5 cm)
Nordic Seas	Collective term for the Norwegian, Iceland and Greenland Seas
North Atlantic Oscillation (NAO)	The North Atlantic Oscillation index is defined as the difference in atmospheric pressure at sea level between the Azores and Iceland and describes the strength and position of westerly air flows across the North Atlantic
Nutrients	Dissolved phosphorus, nitrogen and silica compounds

Ocean Conveyor	A popular term for the global ocean circulation pattern, which results in the exchange of water between all the major oceans
Organohalogens	Substances in which an organic molecule is combined with one or more of the halogen group of elements (i.e. fluorine, chlorine, bromine, iodine)
Overflow waters	Cold high density waters that spill over the relatively shallow sills that lie between Greenland, Iceland and Scotland, or flow through the deep channels dissecting these sills
Phytoplankton	The collective term for the photosynthetic members of the nano- and microplankton
Plankton	Those organisms that are unable to maintain their position or distribution independent of the movement of the water. Plankton is categorised by its diameter into: - picoplankton: < 2 µm - nanoplankton: 2 – 20 µm - microplankton: 20 – 200 µm - macroplankton: 200 – 2000 µm - megaplankton: > 2000 µm
Pollutant	A substance (or energy) causing pollution
Pollution	The introduction by man, directly or indirectly, of substances or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea
Production, primary	The assimilation of organic matter by autotrophs (i.e. organisms capable of synthesising complex organic substances from simple inorganic substrates; including both chemoautotrophic and photoautotrphic organisms). Gross production refers to the total amount of organic matter fixed in photosynthesis and chemosynthesis by autotrophic organisms, including that lost in respiration. Net production is that part of assimilated energy converted into biomass and reflects the total amount of organic matter fixed by autotrophic organisms less that lost in respiration
PSP biotoxins	Toxins of the saxitoxin group produced by some phytoplanktonic species of microalgae that, if transmitted through the food chain, cause a syndrome known as Paralytic Shellfish Poisoning (PSP) because it is mainly caused after the ingestion of shellfish and with respiratory paralysis as the most serious symptom
Pycnocline	A density discontinuity in a water column. This is commonly used to refer to the narrow depth zone at the base of the relatively uniform surface mixed layer within which the density of the water increases sharply either because of a decrease in temperature (thermocline) or an increase in salinity (halocline)
Pycnostad	A layer of water within which density remains constant
Radionuclide	Atoms that disintegrate by emission of electromagnetic radiation, i.e. emit alpha, beta or gamma radiation
Recruitment (fisheries)	The process by which young fish enter a fishery, either by becoming large enough to be retained by the gear in use or by migrating from protected areas into areas where fishing occurs
Remineralisation	The conversion of a substance from an organically bound form back to a water-soluble inorganic form, resulting in the release of inorganic nutrients (e.g. nitrate, phosphate), carbon dioxide or methane back into solution
Safe biological limits	Limits (reference points) for fishing mortality rates and spawning stock biomass, beyond which the fishery is unsustainable. Other criteria which indicate when a stock is outside safe biological limits include age structure and distribution of the stock and exploitation rates. A fishery which maintains stock size within a precautionary range (a range within which the probability of reaching any limits is very small) would be expected to be sustainable.
Salinity	A measure of the total amount of dissolved salts in sea water
Sequestration	The long-term storage of material or energy
Shelf break	The outer margin of the continental shelf marked by a pronounced increase in the slope of the seabed; usually occurring at around 200 m in depth along European margins
Slope current	A current that follows the shelf break along a continental margin
Sverdrup	A unit of transport used in oceanography to quantify flow in ocean currents. It is equivalent to 10^6 m^3/s.
Terrigenous	Derived from land
Thermohaline circulation	Oceanic circulation caused by differences in density between water masses, which is itself determined primarily by water temperature
Topography	The land forms or surface features of a geographical area
Toxaphene	A chlorinated insecticide with an average chemical composition of $C_{10}H_{10}C1_8$. Primarily used in cotton farming
Toxin	A biogenic (produced by the action of living organisms) poison, usually proteinaceous
Trench	A narrow, elongated U-shaped depression of the deep ocean floor between an abyssal plain and the continental margin where subduction of oceanic crust occurs
Trophic	Pertaining to nutrition
Water column	The vertical column of water extending from the sea surface to the seabed
Water mass	A body of water within an ocean characterised by its physicochemical properties of temperature, salinity, depth and movement
Zooplankton	The animal component of the plankton; animals suspended or drifting in the water column including larvae of many fish and benthic invertebrates

REFERENCES

Chapter 1 References

AMAP 1998. *AMAP assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 859 pp.

Bernes, C. (Ed.) 1996. Arktisk miljø i Norden – urørt, overutnyttet, forurenset? Nord 1996:23. 240 pp.

EEA 1996. *The state of the European Arctic environment.* Ed. by J.R. Hansen, R. Hansson and S. Norris. European Environment Agency, Copenhagen. EEA Environmental Monograph No. 3. 135 pp.

Layton, D., Edson, R. and Napier, B. 1997. *Radionuclides in the Arctic seas from the former Soviet Union: potential health and ecological risks.* Arctic Nuclear Assessment Program (ANWAP), Office of Naval Research, USA. 119 pp.

Lønne, O.J., Sætre, R., Tikhonov, S., Gabrielsen, G.W., Loeng, H., Dahle, S. and Svevljagin, K. (Eds.) 1997. *Status report on the marine environment of the Barents region.* The Joint Norwegian-Russian Commission on Environmental Cooperation. Department of Environment, Oslo. 97 pp.

PAME 1996. PAME Working Group on the Protection of the Arctic Marine Environment. Report to the Third Ministerial Conference on the Protection of the Arctic Environment 20-21 March. Ministry of Environment, Oslo. 159 pp.

Chapter 2 References

Aagaard, K., Coachman, L.K. and Carmack, E.C. 1981. On the halocline of the Arctic Ocean. *Deep-Sea Res.* 28: 529–45.

Aagaard, K., Swift, J.H. and Carmack, E.C. 1985. Thermohaline Circulation in the Arctic Mediterranean Seas. *J. Geophys. Res.* 90(C5): 4833–46.

Abelman, A. 1992. Diatom assemblages in Arctic sea ice – indicator for ice drift pathways. *Deep-Sea Res.* 39: 525–38. Special Issue.

AMAP 1998. *AMAP assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 859 pp.

Andersen, L.G., Jones, E.P., Koltermann, K.P., Schlosser, P., Swift, J.H. and Wallace, D.W.R. 1989. The first oceanographic section across the Nansen Basin in the Arctic Ocean. *Deep-Sea Res.* 36(3): 475–82.

Barry, R.G. and Chorley, R.J. 1992. *Atmosphere, weather and climate.* Routledge.

Belkin, I.M., Levitus, L., Antonov, J. and Malmberg, S.-A. 1998. 'Great Salinity Anomalies' in the North Atlantic. *Prog. Oceanogr.* 41: 1–68.

Bianchi, G.G. and McCave, I.N. 1999. Holocene periodicity in North Atlantic climate and deep ocean flow south of Iceland. *Nature*, 397: 515–7.

Blindheim, J. 1989. Cascading of Barents Sea bottom water into the Norwegian Sea. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 188: 49–58.

Blindheim, J. and Ådlandsvik, B. 1995. Episodic formation of intermediate water along the Greenland Sea Arctic Front. *ICES CM 1995/Mini: 6.* International Council for the Exploration of the Sea, Copenhagen.

Bond, G., Showers, W., Cheeseby, M., Lotti, R., Almasi, P., de Menocal, P., Priore, P., Cullen, H., Hajdas, I. and Bonani, G. 1997. A pervasive millenial-scale cycle in North Atlantic holocene and glacial climates. *Science*, 278: 1257–66.

Bönisch, G. and Schlosser, P. 1995. Deep water formation and exchange rates in the Greenland/Norwegian Seas and the Eurasian Basin of the Arctic Ocean derived from tracer balances. *Prog. Oceanogr.* 35: 29–52.

Broecker, W.S. 1991. The great ocean conveyor. *Oceanography*, 4: 79–89.

Cappelen, J. and Vaarby Laursen, E. 1998. The climate of the Faroe Islands with climatological standard normals, 1961–1990. Danish Meteorological Institute. Tech. Rep. No. 98–14. 62 pp.

Charles, C.D. and Fairbanks, R.G. 1992. Evidence from Southern Ocean sediments for the effect of North Atlantic deep-water flux on climate. *Nature*, 355: 416–9.

Churkin, M. and Johnson, L. 1983. Arctic – Sheet 19, 1/16 000 000. In: Geological world atlas, 1/10 000 000. Ed. by G. Choubert, A. Faure-Muret and P. Chanteux. UNESCO and the Commision for the Geological Map of the World. UNESCO, Paris.

Colony, R. and Thorndike, A.S. 1985. Sea ice motion as a drinkard's walk. *Geophys. Res.* 90: 965–74.

Dahlgaard, H., Hansen, B. and Joensen, H.P. 1998. Observations of radioactive tracers in Faroese waters. *ICES Coop. Res. Rep.* No. 225. 162–71. International Council for the Exploration of the Sea, Copenhagen.

Dickson, R.R. and Brown, J. 1994. The production of North Atlantic Deep Water: sources, rates and pathways. *J. Geophys. Res.* 99: 12319–41.

Dickson, R.R., Midttun, L. and Mukhin, A.I. 1970. The hydrographic conditions in the Barents Sea in August-September 1965–1968. In: International 0-group fish surveys in the Barents Sea, 1965–1968. Ed. by O. Dragesund. *ICES Coop. Res. Rep.* Ser. A, No. 18. International Council for the Exploration of the Sea, Copenhagen.

Dickson, R.R., Meincke, J., Malmberg, S.-A. and Lee, A.J. 1988. The 'Great Salinity Anomaly' in the northern North Atlantic 1968–1982. *Prog. Oceanogr.* 20: 103–51.

Dickson, R., Lazier, J., Meincke, J., Rhines, P. and Swift, J. 1996. Long-term coordinated changes in the convective activity of the North Atlantic. *Prog. Oceanogr.* 38: 241–95.

EEA 1996. *The state of the European Arctic environment.* Ed. by J.R. Hansen and S. Norris. European Environment Agency, Copenhagen. EEA Environmental Monograph No. 3. 135 pp.

Egilson, D., Ólafsdóttir, E.D., Yngvadóttir, E., Halldórsdóttir, H., Sigursson, F.H., Jónsson, G.S., Jensson, H., Gunnarsson, K., Rájnsson, S.A., Stefánsson, A., Indriðason, H.D., Hjartarson, H., Thorlacius, J., Ólafsdóttir, K., Gíslason, S.R., and Svavarsson, J. 1999. *Mælingar á mengandi efnum á og við Ísland. Niðurstöðurvöktunarmælinga.* Starfshópur um mengunarmælingar, mars 1999, Reykjavík. 138 pp.

Einarsson, M.A. 1984. Climate of Iceland. *World survey of climatology*, Vol. 15. Elsevier.

Escher, A. and Watt, W.S. 1976. Geology of Greenland. Geological Survey of Greenland.

Foldvik, A., Aagaard, K. and Tørresen, T. 1988. On the velocity field of the East Greenland Current. *Deep-Sea Res.* 35: 1335–54.

Hansen, B., Larsen, K.M.H., Østerhus, S., Turrell, B. and Jonsson, S. 1999. The Atlantic Water inflow to the Nordic Seas. The International WOCE Newsletter. Univ. Bergen. 3 pp

Heinze, Ch., Schlosser, P., Koltermann, K.P. and Meincke, J. 1990. A tracer study of the deep water renewal in the European polar seas. *Deep-Sea Res.* 37(9): 1425–53.

Helland, P. 1963. Temperature and salinity variations in the upper layers at Ocean Weather Station M (66° N, 2° E). Årbok. Univ. Bergen. Mat. Naturvitens. Ser. 16. 26 pp.

Hopkins, T.S. 1991. The GIN Sea – A synthesis of its physical oceanography and literature review 1972–1985. *Earth-Sci. Rev.* 30: 175–318.

Ikeda, M. 1990a. Decadal oscillation of the air-sea-ocean system in the northern hemisphere. *Atmosphere-Ocean*, 28: 106–39.

Ikeda, M. 1990b. Feedback mechanism among decadal oscillations in the northern hemisphere atmospheric circulation, sea ice and ocean circulation. *Ann. Glaciol.* 14: 120–3.

IPCC 1995. *The science of climate change.* International Panel on Climate Change. Cambridge Univ. Pr. 572 pp.

Kvambekk, A.S. and Vinje, T. 1993. The ice transport through Fram Strait. Paper presented at the Nansen centennial symposium, Bergen, Norway, 21–25 June. (unpubl.).

Lehman, S.J. and Keigwin, L.D. 1992. Sudden changes in North Atlantic circulation during the last deglaciation. *Nature*, 356: 757–62.

Loeng, H. and Vinje, T.E. 1979. On the sea ice conditions in the Greenland and Barents seas. In: Proc. Fifth Int. Conf. on Port and Ocean Engineering under Arctic Conditions. POAC Vol. 1.

Loshchicov, V.S. 1965. Snow cover on the ice of the central Arctic. *Probl. Arktiki*, 17: 36–45. (In Russian).

Malmberg, S.-A., Gade, H.G. and Sweers, H.E. 1972. Current velocities and volume transports in the East Greenland Current off Cape Nordenskjold in August-September 1965. In: Sea Ice Conf. Proc., Reykjavik. pp. 130–9.

Mauritzen, C. 1996. Production of dense overflow waters feeding the North Atlantic across the Greenland-Scotland Ridge. *Deep-Sea Res.* 43(6): 769–835.

Midttun, L. 1985. Formation of dense bottom water in the Barents Sea. *Deep-Sea Res.* 32(10): 1233–41.

Nansen, F. 1906. Northern waters. Captain Roald Amundsen's oceanographic observations in the Arctic seas in 1901. Videnskaps-Selskabets Skrifter, I. Mathematisk ñ Naturvitenskapelig Klasse, 1906. Dybvad, Christiania, 1. 145 pp.

NOAA 1998. Data announcement 88-MGG-02; digital relief of the surface of the Earth. NOAA, National Geophysical Data Centre, Boulder, Colorado.

Pavlov, V.K., Timohov, L.A., Baskakov, G.A., Kulakov, M.Y., Kurazhov, V.K., Pavlov, P.V., Pivovarov, S.V. and Stanovoy, V.V. 1994. Hydrometeorological regime of the Kara, Laptev and East Siberian Seas. Arctic and Antarctic Research Institute, St Petersburg, Russia. Manuscript, 179 pp.

Pfirman, S.L., Koegler, J. and Anselme, B. 1995a. Coastal environments of the western Kara and eastern Barents Seas. *Deep-Sea Res.* 42: 1391–412.

Pfirman, S.L., Eicken, H., Bauch, D. and Weeks, W. 1995b. The potential transport of pollutants by Arctic sea ice. *Sci. Total Environ.* 159: 129–46.

Quadfasel, D., Rudels, B. and Kurz, K. 1988. Outflow of dense water from a Svalbard fjord into the Fram Strait. *Deep-Sea Res.* 35: 1143–50.

Read, J.F. and Pollard, R.T. 1992. Water masses in the region of the Iceland-Faroes Front. *J. Phys. Oceanog.* 22: 1367–77.

Rigor, I. 1992. Arctic Ocean buoy program. *Argos Newsl.* 44: 1–3.

Sigmond, E.M.O. 1992. Bedrock map of Norway and adjacent ocean areas. Scale 1:3 million. Geological Survey of Norway, Trondheim.

Stefánsson, U. 1962. North Icelandic Waters. Rit Fiskideildar 3. 269 pp.

Stumm, W. and Morgan, J.J. 1981. *Aquatic chemistry.* J. Wiley.

Swift, J. 1986. The Arctic Waters. In: *The Nordic Seas*, pp. 129–53. Ed. by B.G. Hurdle. Springer.

Varjo, U. and Tietze, W. (Eds.) 1987. *Norden, man and environment.* Gebrüder Bornträger. 535 pp.

Vinje, T. 1976. Sea ice conditions in the European sector of the marginal seas of the Arctic, 1966-1975. *Norsk Polarinst. Årbok*, 1975: 163–74.

Vinje, T. 1985. Physical environment western Barents Sea: drift, composition, morphology and distribution of the sea ice field in the Barents Sea. *Norsk Polarinst. Skr.* 179C: 1–26.

Vinje, T. 1987. Morphology and dynamics of the Barents Sea ice field. Port and Ocean Engineering under Artic Conditions; POAC vol. 77, Univ. Alaska.

Vinje, T. and Finnekåsa, O. 1986. The ice transport through the Fram Strait. *Norsk Polarinst. Skr*. 186, 39 pp.

Zakharov, V.F. 1976. Cooling of the Arctic and ice cover of the Arctic seas. *Trudy Trans.* 337: 96.

Ådlandsvik, B. and Loeng, H. 1991. A study of the climate system of the Barents *Sea. Polar Res.* 10(1): 45–9.

Chapter 3 References

AEPS 1991. Arctic Environmental Protection Strategy. Arctic Environment, Rovaniemi. 45 pp.

AMAP 1998. *AMAP assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 859 pp.

Anon 1999. State of marine stocks in Icelandic waters 1998/1999. Prospects for quota year 1999/2000. Hafrannsóknastofnunin. Fjölrit No. 72. 172 pp. (In Icelandic. Summary and figure text in English).

Arctic Council 1996. Declaration on the establishment of the Arctic Council. Ottawa, Canada, Sept. 1996. Dept. Foreign Affairs Int. Trade, Ottawa. 3 pp.

EEA 1996. *The state of the European Arctic environment.* Ed. by J.R. Hansen, R. Hansson and S. Norris. European Environment Agency, Copenhagen. EEA Environmental Monograph No. 3. 135 pp.

Gunnarsson, K., Jónsson, G. and Pálsson, Ó.K. 1998. Sjàvarnytjar vid Ìsland. Màl og menning, Reykjavìk. 282 pp.

Hoel, A.H. 1994. The Barents Sea: fisheries resources for Europe and Russia. In: *The Barents region. Cooperation in Arctic Europe.* Ed. by O.S. Stokke and O. Tunander. SAGE Publications. 15 pp.

Moe, A. 1994. Oil and gas: future role of the Barents region. In: *The Barents region. Cooperation in Arctic Europe.* Ed. by O.S. Stokke and O. Tunander. SAGE Publications, 15 pp.

PAME 1996. PAME Working Group on the Protection of the Arctic Marine Environment. Report to the Third Ministerial Conference on the Protection of the Arctic Environment 20–21 March. Ministry of Environment, Oslo, Norway. 159 pp.

Toresen, R. (Ed.) 1999. Havets ressurser 1999. Fisken og Havet. Særnr, 1.

Chapter 4 References

AMAP 1998. *AMAP assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 859 pp.

Barrett, R.T., Skaare, J.U. and Gabrielsen, G.W. 1996. Recent changes in levels of persistent organochlorines and mercury in eggs of seabirds from the Barents Sea. *Environ. Pollut.* 92: 13–18.

Barrie, L.A., Gregor, D., Hargrave, B., Lake, R., Muir, D., Shearer, R., Tracey, B. and Bidleman, T. 1992. Arctic contaminants: sources, occurrence and pathways. *Sci. Total Environ.* 122: 1–74.

Berg, V., Ugland, K.I., Hareide, N.R., Aspholm, P.E., Polder, A. and Skaare, J.U. 1997. Organochlorine contamination in deep-sea fish from the Davis Strait. *Mar. Environ. Res.* 44: 135–48.

Berge, J.A., Amundsen, R., Berglind, L., Brevik, E.M., Følsvik, N., Green, N., Knutzen, J., Konieczny, R. and Walday, M. 1997. Levels and environmental effects of TBT in marine organisms and sediments from the Norwegian coast. A summary report. Norwegian State Pollution Monitoring Programme, Report 693/97. 36 pp.

Bernhoft, A., Wiig, Ø. and Skaare, J.U. 1997. Organochlorines in polar bears (*Ursus maritimus*) at Svalbard. *Environ. Pollut.* 95(2): 159–75.

Bidleman, T.F., Falconer, R.L. and Walla, M.D. 1995. Toxaphene and other organochlorine compounds in air and water at Resolute Bay, NWT, Canada. *Sci. Total Environ.* 169/161: 55–63.

Bidleman, T.F., Patton, G.W., Hinkley, D.A., Walla, M.D., Cotham, W.E. and Hargrave, B.T. 1990. Chlorinated pesticides and chlorinated biphenyls in the atmosphere of the Canadian Arctic. Ch. 23. In: *Long range transport of pesticides.* pp. 347–72. Ed. by D.A. Kurtz, Lewis Publ. Michigan.

Bidleman, T.F., Patton, G.W., Walla, M.D., Hargrave, B.T., Vass, W.P., Erickson, P., Fowler, B., Scott, V. and Gregor, D.J. 1989. Toxaphene and other organochlorines in Arctic Ocean fauna: evidence for atmospheric delivery. *Arctic*, 42: 307–13.

Bignert, A., Göthberg, A., Jensen, S., Litzén, K., Odsjö, T., Olsson, M. and Reutergårdh, L. 1993. The need for adequate biological sampling in ecotoxicological investigations: a retrospective study of twenty years pollution monitoring. *Sci. Total Environ.* 128: 121–39.

Bignert, A., Olsson, M., Bergquist, P.-A., Bergek, S., Rappe, C., de Wit, C. and Jansson, B. 1989. Polychlorinated dibenzo-*p*-dioxins (PCDD) and dibenzofurans (PCDF) in seal blubber. *Chemosphere*, 19: 551–6.

Boutron, C.F., Görlach, U., Canderlone, J.-P., Bolshov, M.A. and Delmas, R.J. 1991. Decrease in atmospheric lead, cadmium and zinc in Greenland snow since the late 1960s. *Nature*, 353: 153.

Braune, B.M., Norstrom, R.J., Wong, M.P., Collins, B.T. and Lee, J. 1991. Geographical distribution of metals in livers of polar bears from the Northwest Territories, Canada. *Sci. Total Environ.* 100: 283–99.

Campbell, J.A. and Yeats, P.A. 1982. The distribution of iron, nickel, copper and cadmium in waters of Baffin Bay and the Canadian Arctic Archipelago. *Oceanol. Acta*, 5: 161–8.

Caurant, F., Amirad, J.C., Amiardtriquet, C. and Sauriau, P.G. 1994. Ecological and biological factors controlling the concentrations of trace elements (As, Cd, Hg, Se, Zn) in delphinids *Globicephala meals* from the North Atlantic Ocean. *Mar. Ecol. Prog. Ser.* 103(3): 207–19.

Chernyak, S.M., McConnell, L.M. and Rice, C.P. 1995. Fate of some chlorinated hydrocarbons in Arctic and far eastern ecosystems in the Russian Federation. *Sci. Total Environ.* 160/161: 75–85.

Cleemann, M., Riget, F., Paulsen, G.B., de Boer, J. and Dietz, R. 2000a. Organochlorines in Greenland ringed seals. *Sci. Total Environ.* 245: 103–16.

Cleemann, M., Riget, F., Paulsen, G.B., Klungsøyr, J. and Dietz, R. 2000b. Organochlorines in Greenland marine fish, mussels and sediments. *Sci. Total Environ.* 245: 87–102.

Cleemann, M., Paulsen, G.B., Pritzl, G., Riget, F., Poulsen, M.E., de Boer, J. and Klungsøyr, J. 1997. Organochlorines in sediments and biota from Greenland. *Organohalogen Compounds*, 32: 268–71.

Daelemans, F.F., Mehlum, F., Lydersen, C. and Schepens, P.J.C. 1993. Mono-ortho and non-ortho substituted PCBs in Arctic ringed seal (*Phoca hispida*) from the Svalbard area: analysis and determination of their toxic threat. *Chemosphere*, 27: 429–37.

Danielsson, L.G., Magnusson, B. and Westerlund, S. 1985. Cadmium, copper, nickel and zinc in the North-east Atlantic Ocean. *Mar. Chem.* 17: 23–41.

Dietz, R., Nørgaard, J. and Hansen, J.C. 1998. Have Arctic marine mammals adapted to high cadmium concentrations? *Mar. Pollut. Bull.* 36(6): 490–2.

Dietz, R., Riget, F. and Johansen, P. 1996. Lead, cadmium, mercury and selenium in Greenland marine animals. *Sci. Total Environ.* 186: 67–93.

Dietz, R., Born, E.W., Agger, C.T. and Nielsen, C.O. 1995. Zinc, cadmium, mercury and selenium in polar bears (*Ursus maritimus*) from Central East Greenland. *Polar Biol.* 15: 175–85.

Dietz, R., Johansen, P., Riget, F. and Asmund, G. 1997a. Heavy metals. In: *AMAP Greenland 1994–1996.* pp. 119–62. Ed. by A. Aarkrog, P. Aastrup, G. Asmund, P. Bjerregaard, D. Boertmann, L. Carlsen, J. Christensen, M. Cleemann, R. Dietz, A. Fromberg, E. Storr-Hansen, N.Z. Heidam, P. Johansen, H. Larsen, G.B. Paulsen, H. Petersen, K. Pilegaard, M.E. Poulsen, G. Pritzl, F. Riget, H. Skov, H. Spliid, P. Weihe and P. Waahlin. Environmental Project No. 356. Ministry of Environment and Energy, Danish Environmental Protection Agency, Copenhagen.

Dietz, R., Johansen, P., Riget, F. and Asmund, G. 1997b. Data on heavy metals from Greenland before 1994: contaminants in the Greenland marine environment. In: *AMAP Greenland 1994–1996.* pp. 247–350. Ed. by A. Aarkrog, P. Aastrup, G. Asmund, P. Bjerregaard, D. Boertmann, L. Carlsen, J. Christensen, M. Cleemann, R. Dietz, A. Fromberg, E. Storr-Hansen, N.Z. Heidam, P. Johansen, H. Larsen, G.B. Paulsen, H. Petersen, K. Pilegaard, M.E. Poulsen, G. Pritzl, F. Riget, H. Skov, H. Spliid, P. Weihe and P. Waahlin. Environmental Project No. 356. Ministry of Environment and Energy, Danish Environmental Protection Agency, Copenhagen.

Egilson, D., Ólafsdóttir, E.D., Yngvadóttir, E., Halldórsdóttir, H., Sigursson, F.H., Jónsson, G.S., Jensson, H., Gunnarsson, K., Ráinsson, S.A., Stefánsson, A., Indriðason, H.D., Hjartarson, H., Thorlacius, J., Ólafsdóttir, K., Gíslason, S.R., and Svavarsson, J. 1999. *Mælingar á mengandi efnum á og við Ísland. Niðurstöðurvöktunarmælinga*. Starfshópur um mengunarmælingar, mars 1999, Reykjavík. 138 pp.

Espeland, O., Kleivane, L., Haugen, S. and Skaare, J.U. 1997. Organochlorines in mother and pup pairs in two Arctic seal species: harp seal (*Phoca groenlandica*) and hooded seal (*Cytophora cristata*). *Mar. Environ. Res.* 44(3): 315–30.

Frank, A., Galgan, V., Roos, A., Olsson, M., Petersson, L.R. and Bignert, A. 1992. Metal concentrations in seals from Swedish waters. *Ambio*, 21(8): 529–38.

GESAMP 1993. *Impact of oil and related chemicals and wastes on the marine environment.* Joint Group of Experts on the Scientific Aspects of Marine Pollution, Reports and Studies No. 50. 180 pp.

Goldberg, E.D. 1976. *The health of the oceans.* UNESCO, Paris. 172 pp.

Green, N.W. 1997. Joint Assessment and Monitoring Programme (JAMP). National Comments to the Norwegian Data for 1995. Norwegian State Pollution Control Authority Monitoring Programme, Rep. No. 685/97. 124 pp.

Green, N.W., Berge, J.A., Helland, A., Hylland, K., Knutzen, J. and Walday, M. 1999. Joint Assessment and Monitoring Programme (JAMP). National Comments Regarding the Norwegian Data for 1997. Norwegian State Pollution Control Authority Monitoring Programme, Rep. No. 752/99, 144 pp.

Hargrave, B.T. 1996. Sources and sinks of organochlorines in the Arctic marine food web. In: *Symposis of research conducted under the 1994/95 Northern Contamination Program*. Indian and Northern Affairs Canada, pp. 135–8. Ed. by J.I. Murray and R.G. Shearer. *Environmental Studies*, 73.

Harrad, S.J., Sewart, A.P., Alcock, R., Boumphrey, R., Burnett, V., Duartedavidson, R., Halsall, C., Sanders, G., Waterhouse, K., Wild, S.R. and Jones, K.C. 1994. Polychlorinated biphenyls (PCBs) in the British environment – sinks, sources and temporal trends. *Environ. Pollut.* 85(2): 131–46.

Henriksen, E.O., Gabrielsen G.W. and Skaare, J.U. 1996. Levels and congener pattern of polychlorinated biphenyls in kittiwakes (*Rissa tridactyla*), in relation to mobilization of body lipids associated with reproduction. *Environ. Pollut*. 92: 27–37.

Hornbuckle, K.C., Achman, D.A. and Eisenreich, S.J. 1993. Over-water and over-land polychlorinated biphenyls in Green Bay, Lake Michigan. *Environ. Sci. Technol.* 27(1): 87–98.

Iverfeldt, A., Munthe, J., Brosset, C. and Pacyna, J. 1995. Long-term changes in concentration and deposition of atmospheric mercury over Scandinavia. *Water Air Soil Pollut.* 80: 227–33.

Jantunen, L.M.M. and Bidleman, T.F. 1998. Organochlorine pesticides and enantiomers of chiral pesticides in Arctic Ocean water. *Arch. Environ. Contam. Toxicol.* 35(2): 218–28.

Johansen, P., Asmund, G. and Rigert, F. 1995. Miljøundersøkelser ved Ivittuut 1982–1992. Grønlands Miljøundersøgelser, Copenhagen. Rapport serie No. 7. 60 pp.

Julshamn, K., Andersen, A., Ringdale, O. and Mørkøre, J. 1987. Trace elements intake in the Faroe Islands I: element levels in edible parts of pilot whales (*Globicephalus melaenus*). *Sci. Total Environ.* 65: 53–62.

Kidd, K.A., Schindler, D.W., Muir, D.C.G., Lockhart W.L. and Hesslein, R.H. 1995. High concentration of toxaphene in fishes from a subartic lake. *Science*, 269: 240–2.

Killie, B. and Dahl, S. 1995. Metaller og organiske miljøgifter i sediment fra Kvitsjøen. Akvaplan-NIVA Rep. No. 414.95.687.01, Tromsø, Norway. 10 pp.

Killie, B. and Dahle, S. 1996. PCB, kloroganiske pestisider og metaller i polartorsk (*Boreogadus saida*) hentet vest og norvest for Spitzbergen. Akvaplan-NIVA, Rep. No. 414.95.677/SFT 95172, Tromsø, Norway.

Kleivane, L., Skaare, J.U., Bjørge, A., Deruiter, E. and Reijnders, P.J.H., 1995. Organochlorine pesticide-residue and PCBs in harbour porpoise (*Phocoena phocoena*) incidentally caught in Scandinavian waters. *Environ. Pollut*. 89(2): 137–46.

Kleivane, L., Espeland, O., Fagerheim, K.A., Hylland, K., Polder A. and Skaare, J.U. 1996. Organochlorine pesticides and PCBs in the east ice harp seal (*Phoca groenlandica*) population. *Mar. Environ. Res.* 43: 117–30.

Klungsøyr, J. and Johnsen, S. 1997. Oil hydrocarbons in fish from Norwegian waters 1993–95, Fisken og Havet 17. 22 pp.

Konieczny, R.M. 1996. Sonderende undersøkelser i norske havner og utvalgte kystområder. Fase 3: Miljøgifter i sedimenter på strekningen Ramsund-Kirkenes. Norwegian Instutute for Water Research Rep. No. 34231-96, Oslo. 117 pp.

Lead, W.A., Steinnes, E. and Jones, K.C. 1996. Atmospheric deposition of PCBs to moss (*Hylocomium splendens*) in Norway between 1977 and 1990. *Environ. Sci. Technol*. 30: 524–30.

Loring, D.H. and Asmund, G. 1996. Geochemical factors controlling accumulation of major and trace elements in Greenland coastal and fjord sediments. *Environ. Geol.* 28(1): 2–11.

Luckas, B., Vetter, W., Fischer, P., Heideman, G. and Plötz, J. 1990. Characteristic chlorinated hydrocarbon patterns in the blubber of seals from different marine regions. *Chemosphere*, 21: 13–19.

Macdonald, C.R. and Sprague, J.B. 1988. Cadmium in marine invertebrates and Arctic cod in the Canadian Arctic. Distribution and ecological implications. *Mar. Ecol. Prog. Ser.* 47: 17–30.

Macdonald, R.W. and Bewers, J.M. 1996. Contaminants in the Arctic marine environment priorities for protection. *ICES J. Mar. Sci.* 53: 537–63.

Mart, L. and Nurnberg, H.W. 1984. Trace metal levels in the easten Arctic Ocean. *Sci. Total Environ.* 39: 1–14.

Moore, R.M. 1981. Oceanographic distributions of cadmium, copper and aluminium in waters of the central Arctic. *Geochim. Cosmochim. Acta*, 45: 2475–82.

Muir, D.C.G. and Lockhart, W.L. 1996. Contamination trends in freshwater and marine fish. In: *Synopsis of research conducted under the 1994/95 Northern Contaminants Program*. pp. 189–94. Ed. by J.L. Murray and R.G. Shearer. Indian and Northern Affairs Canada, Ottawa, Environmental Studies 73.

Muir, D.C.G, Wageman, R., Grift, N.P., Norstrom, R.J., Simon, M. and Lien, J. 1988. Organochlorine chemical and heavy metal contamination in white-beaked dolphins (*Lagenorhynchus albirostris*) and pilot whale (*Globicephala malaena*) from the coast of Newfoundland, Canada. *Arch. Environ. Toxicol. Chem.* 17: 613–29.

Muir, D.C.G., Ford, C.A., Grift, N.P., Steward, R.E.A. and Bidleman, T. 1992. Organochlorine contaminants in narwhal (*Monodon monoceros*) from the Canadian Arctic. *Environ. Pollut*. 75: 307–16.

Muir, D.C.G., Ford, C.A., Stewart, R.E.A., Smith, T.G., Addison, F.R.F., Zinck, M.E. and Béland, P. 1990. Organochlorine contaminants in belugas, *Delphinapterus leucas*, from Canadian waters. *Can. Bull. Aquat. Fish. Sci.* 224: 165–90.

Muir, D., Braun, B., DeMarch, B., Norstrom, R., Wagemann, R., Gamberg, M., Poole, K., Addison, R., Bright, D., Dodd, M., Duschenko, W., Eamer, J., Evans, M., Elkin, B., Grundy, S., Hargrave, B., Hebert, C., Johnston, R., Kidd, K., Koening, B., Lockhart, L., Payne, J., Peddle, J. and Reimer, K. 1996. Chap 3. In: *Ecosystem uptake and effects*, pp. 183–294. Ed. by J. Jensen, K. Adare and R. Shearer. Canadian Arctic Contaminants Assessment Report. Indian and Northern Affairs, Ottawa.

Müller, R., Lach, G. and Parlar, H. 1988. Comparative studies on the presence of toxaphene residues. *Chemosphere*, 17: 2289–98.

Musial, C.J. and Uthe, J.F. 1983. Widespread occurrence of the pesticide toxaphene in Canadian east coast marine fish. *Int. J. Environ. Anal. Chem.* 14: 117–26.

Næs, K., Knutzen, J. and Berglind, L. 1995. Occurrence of PAH in marine organisms and sediments from smelter discharge in Norway. *Sci. Total Environ.* 163: 93–106.

Norheim, G., Skaare, J.U. and Wiig, Ø. 1992. Some heavy metals, essential elements and chlorinated hydrocarbons in polar bear (*Ursus maritimus*) at Svalbard. *Environ. Pollut*. 77: 51–7.

Norstrom, R.J. and Muir, D.C.G. 1994. Chlorinated hydrocarbon contaminants in Arctic marine mammals. *Sci. Total Environ.* 154: 107–28.

Norstrom, R.J., Simon, S. and Muir, D.C.G. 1990. Polychlorinated dibenzo-*p*-dioxins and dibenzofurans in marine mammals in the Canadian north. *Environ. Pollut.* 66: 1–19.

Norstrom, R.J., Belikov, S.E., Born, E.W., Garner, G.W., Malone, B., Olpinski, S., Ramsay, M.A., Schliebe, S., Stirling, I., Stishov, M.S., Taylor, M.K. and Wiig, Ø. 1998. Chlorinated hydrocarbon contaminants in polar bears from eastern Russia, North America, Greenland and Svalbard: biomonitoring of Arctic pollution. *Arch. Environ. Contam. Toxicol.* 35(2): 354–67.

Nriagu, J.O. 1989. A global assessment of natural sources of atmospheric trace metals. *Nature*, 338: 47–9.

Nriagu, J.O. and Pacyna, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils with trace metals. *Nature*, 333: 134–9.

NSTF 1993. *North Sea Quality Status Report 1993.* North Sea Task Force, Oslo and Paris Commissions, London. 132 pp.

Oehme, M., Haugen, J.-E. and Schlabach, M. 1995a. Ambient levels of persistent organochlorines in spring 1992 at Spitzbergen and the Norwegian mainland: comparison with 1984 results and quality control measures. *Sci. Total Environ.* 160/161: 139–52.

Oehme, M., Schlabach, M. and Boyd, I. 1995c. Polychlorinated dibenzo-p-dioxins, dibenzofurans, and coplanar biphenyls in Antarctic fur seal blubber. *Ambio*, 24(1): 41–6.

Oehme, M., Klungsøyr, J., Biseth, A. and Schlabach, M. 1993. Quantitative determination of ppb-ppt levels of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in sediments from the Arctic (Barents Sea) and the North Sea. *Anal. Method Instrum*. 1: 153–63.

Oehme, M., Schlabach, M., Kallenborn, R. and Haugen, J.E. 1996. Sources and pathways of persistent polychlorinated pollutants to remote areas of the North Atlantic and levels in the marine food chain: a research update. *Sci. Total Environ.* 186: 13–24.

Oehme, M., Fürst, P., Krüger, C., Meemken, H.A. and Groebel, W. 1988. Presence of polychlorinated dibenzo-*p*-dioxins, dibenzofurans and pesticides in Arctic seal from Spitzbergen. *Chemosphere*, 18: 1291–399.

Oehme, M., Schlabach, M., Hummer, K., Luckas, B. and Nordøy, E.S. 1995b. Determination of levels of polychlorinated dibenzo-*p*-dioxins, dibenzofurans, biphenyls and pesticides in harp seals from the Greenland Sea. *Sci. Total Environ.* 162: 75–91.

Olendrzynski, K., Andeberg, S., Bartnicki, J., Pacyna, J.M. and Stigliani, B. 1995. Atmospheric emissions and depositions of cadmium, lead and zinc in Europe during the period 1955–1987. International Institute for Applied Systems Analysis, Laxenburg, Austria, Working Paper WP.95-35.

Olsson, M. and Reutergårdh, L. 1986. DDT and PCB pollution trends in the Swedish aquatic environment. *Ambio*, 15: 103–9.

Overgaard, N.C. and Dietz, R. 1989. Heavy metals in Greenland seabirds. Meddr. Grønland, Bioscience, 29. 26 pp.

Paasivirta, J. and Rantio, T. 1991. Chloroterpenes and other organochlorines in Baltic, Finnish and Arctic wildlife. *Chemosphere*, 22: 47–55.

Pacyna, J.M. 1991. Chemical tracers of the origins of Arctic air pollution. In: *Pollution of the Arctic atmosphere.* Ed. by W.T. Sturges. Elsevier Science.

Pacyna, J.M. and Pacyna, P.E. 1996. Global emissions of mercury to the atmosphere. Emissions from anthropogenic sources. Internal report to the Norwegian Institute for Air Research, June 1996. Kjeller.

Pacyna, J.M., Shin, B.D. and Pacyna, P.E. 1993. Global emissions of lead. Atmospheric Environment Service, Environment Canada, Ottawa.

Page, D.S, Dassanayake, T.M. and Gilfillan, E.S. 1995. Tissue distribution and depuration of tributyltin for field exposed *Mytilus edulis. Mar. Environ. Res.* 40: 409–21.

Riget, F.F., Dietz, R. and Johansen, P. 1997. Zinc, cadmium, mercury and selenium in Greenland fish. Meddr. Grønland, Bioscience, 48. 29 pp.

Riget, F.F., Johansen, P. and Asmund, G. 1993. Naturlig variasjon av kobber, cadmium, bly og zink i blæretang og blåmusling ved Nuuk. Grønlands Miljøundersøkelser, Copenhagen. Teknisk rapport. 40 pp.

Riget, F.F., Johansen, P. and Asmund, G. 1996. Influence of length on element concentrations in blue mussels (*Mytilus edulis*). *Mar. Pollut. Bull.* 32(10): 745–51.

Rosgidromet 1995. Results of chemical-analytical studies of the Russian AMAP National Implementation Plan. Regional Centre (Monitoring of the Arctic), St Petersburg.

Santos, J. dos, Dale, S., Næs, K., Fredriksen, K.R., Gulliksen, G. and Matishov, G. 1996. Baseline studies of contaminants in sediments: Svalbard, Barents Sea and Franz Josef Land 1992. Tech. Rep. AMAP. Akvaplan, NIVA Report no. 414.92.242. Tromsø, Norway. 32 pp.

Savinova, T.N., Poldner, A., Gabrielsen, G.W. and Skaare, J.U. 1995. Chlorinated hydrocarbons from the Barents Sea area. *Sci. Total Environ.* 160/161: 497–504.

Schlabach, M. and Skotvold, T. 1996a. Undersøkelse av PCDD/PCDF i omgivelsene rundt Pelletsverket ved Aktieselskapet Sydvaranger. Norwegian Institute for Air Research, Lillestrøm, NILU-rapport OR 11/96, 111 pp.

Schlabach, M. and Skotvold, T. 1996b. Undersøkelse av PCDD/PCDF i næringsmidler i Sørvaranger. Norwegian Institute for Air Research, Lillestrøm, NILU-rapport OR 29/96. 74 pp.

SFT 1998. Utslipp av olje og kjemikalier på norsk kontinentalsokkel. State Pollution Control Authority Norway. SFT Report 98: 26. 26 pp.

Skaare, J.U. 1996. Organochlorine contaminants in marine mammals from the Norwegian Arctic. In: *Whales, seals, fish and man*, pp. 589–98. Ed. by A. Schytte-Blix, L. Walløe and Ø. Ulltang. Proc. Int. Symp. on the Biology of Marine Mammals in the North East Atlantic, Tromsø, Norway. 29 Nov. – 1 Dec. 1994. Elsevier.

Skaare, J.U., Degre, E., Aspholm, P.E. and Ugland, K.I. 1994. Mercury and selenium in Arctic and coastal seals of the coast of Norway. *Environ. Pollut.* 85: 153–68.

Skarphédinsdóttir, H., Olafsdottir, K., Svavarsson, J. and Johannesson, T. 1996. Seasonal fluctuation of tributyltin (TBT) and dibutyltin (DBT) in the dogwhelk, *Nucella lapillus* (L.), and the blue mussel, *Mytilus edulis* L., in Icelandic waters. *Mar. Pollut. Bull.* 32: 358–61.

Stange, K. and Klungsøyr, J. 1997. Organochlorine contaminants in fish and polycyclic aromatic hydrocarbons in sediments from the Barents Sea. *ICES J. Mar. Sci.* 54: 318–32.

Stange, K., Maage, A. and Klungsøyr, J. 1996. Contaminants in fish and sediments in the North Atlantic Ocean. NMR Report Tema: Nord 1996: 522. Nordic Council of Ministers, Copenhagen. 79 pp.

Voldner, E.C. and Li, Y.F. 1993. Global usage of toxaphene. *Chemosphere*, 27(10): 2073–8.

Voldner, E.C. and Li, Y.F. 1995. Global usage of selected persistent organochlorines. *Sci. Total Environ.* 160/161: 201–10.

Wania, F. and Mackay, D. 1993. Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. *Ambio*, 22(1): 10–18.

Wartena, E., Evenset, A., Dahl-Hansen, G.A., Skolsky, V. and Chibisson, S. 1997. Did the the Komi oil spill in 1994 pollute downstream areas of the Pechora River? AMAP Int. Symp. Environ. Pollut. in the Arctic. Tromsø, June 1–5. Extended abstracts, pp. 270–2.

Watanabe, N.S., Sakai, S., Takatsuki, H., 1995. Release and degradation half lives of tributyltin in sediment. *Chemosphere*, 31: 2809–16.

Windsor, J.G. and Hites, R.A. 1979. Polycyclic aromatic hydrocarbons in Gulf of Maine sediments and Nova Scotia soils. *Geochim. Cosmochim. Acta*, 43: 27–33.

Yamada, H. and Tagayanagi, K. 1992. Bioconcentration and elimination of Bis(tributyltin)oxid (TBTO) and tributyl chloride (TPTC) in several marine fish species. *Wat. Res.* 26: 1589–95.

Chapter 5 References

Aksnes, D.L. and Blindheim, J. 1996. Circulation patterns in the North Atlantic and possible impact on population dynamics of *Calanus finmarchicus*. *Ophelia*, 44: 7–28.

AMAP 1998. *Assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP). Oslo. 859 pp.

Anon 1999. State of marine stocks in Icelandic waters 1998/1999. Prospects for quota year 1999/2000 Hafrannsóknastofnunin. Fjölrit No. 72, 172 pp. (In Icelandic. Summary and figure text in English).

Barrett, R. 1994. Seabirds – their past and future. In: *Bird life.* Ed. by R. Barrett, J. Møller and I. Bjørklund. Tromsø: Way North, Tromsø Museum, Univ. Tromsø. 80 pp.

Blacker, R.W. 1957. Benthic animals as indicators of hydrographic conditions and climatic change in Svalbard waters. *Fishery Invest. Lond.* 20: 1–49.

Bogstad, B. and Mehl, S. 1997. Interactions between Atlantic cod (*Gadus morhua*) and its prey species in the Barents Sea. In: *Forage fishes in marine ecosystems*, pp. 591-612. Proc. Int. Symp. on the Role of Forage Fish in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97–01. Univ. Alaska.

Born, E.W., Gjertz, I. and Reeves, R.R. 1995. Population assessment of Atlantic walrus. *Norsk Polarinst. Meddelelser*, 138: 1–100.

Brandt, A. and Piepenburg, D. 1994. Peracarid crustacean assemblages of the Kolbeinsey Ridge, north of Iceland. *Polar Biol.* 14: 97–105.

Brude, O.W., Moe, K.A., Bakken, V., Hansson, R., Larsen, L.H., Løvås, S.M., Thomassen, J. and Wiig, Ø. 1998. Northern sea route dynamic environmental atlas. *Norsk Polarinst. Meddelelser*, 147: 1–58.

Christiansen, M.E. and Christiansen, B.O. 1962. The crustacea decapoda of Isfjorden. A comparison with the Swedish Spitsbergen expedition in 1908. *Acta boreal. A. Scientia*, 19: 1–53.

Croll, D.A., Gaston, A.J., Burger, A.E. and Konnoff, D. 1992. Foraging behaviour and physiological adaptation for diving in thick-billed murres. *Ecology*, 73(1): 344–56.

Dalpadado, P. and Skjoldal, H.R. 1996. Abundance, maturity and growth of the krill species *Thysanoessa inermis* and *T. longicaudata* in the Barents Sea. *Mar. Ecol. Prog. Ser.* 144: 175–84.

Dalpadado, P., Ellertsen, B., Melle, W. and Skjoldal, H.R. 1988. Distribution and biomass of macrozooplankton and micronekton in the Nordic Seas. *Sarsia*, 83: 313–31.

Dayton, P.K. 1990. Polar Benthos. In: *Polar Oceanography.* Part B: Chemistry, Biology and Geology, pp. 631–76. Ed. by W.O. Smith Jr. Academic Pr.

Derocher, A.E., Garner, G.W., Lunn, N.J. and Wiig, Ø. 1998. *Polar bears.* Proc. Twelfth Working Meeting of the IUCN/SSC Polar Bear Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. v + 159 pp.

Estep, K.W., Nejstgaard, J.C., Skjoldal, H.R. and Rey, F. 1990. Predation by copepods upon natural populations of *Phaeocystis pouchetii* as a function of the physiological state of the prey. *Mar. Ecol. Prog. Ser.* 67: 235–49.

Evans, P.G.H. 1984a. The seabirds of Greenland: their status and conservation. In: *Status and conservation of the world's seabirds.* Ed. by J.P. Croxall, P.G.H. Evans, R.W. Schreiber. pp. 49–84. ICBP Technical Publication.

Evans, P.G.H. 1984b. Status and conservation of seabirds in northwest Europe (excluding Norway and the USSR). In: S*tatus and conservation of the world's seabirds.* Ed. by J.P. Croxall, P.G.H. Evans, R.W. Schreiber. pp. 293–321. ICBP Technical Publication.

Falk, K. and Møller, S. 1995. Colonies of northern fulmars and black-legged kittiwakes associated with the northeast water polynya, northeast Greenland. *Arctic*, 48(2): 186–95.

Fernö, A., Pitcher, T.J., Melle, W., Nøttestad, L., Mackinson, S., Hollingworth, C. and Misund, O.A. 1998. The challenge of the herring in the Norwegian Sea: making optimal collective spatial decisions. *Sarsia*, 83(2): 149–67.

Fosså, J.P. and Mortensen, P.B. 1998. Artsmangfoldet på Lophelia-korallrev og metoder for overvåkning. *Fisken og havet*, 17: 1–95.

Gjerstad, J.O., Thingstad, P.G., Eldøy, S. and Byrkjeland, S. 1994. Norsk fugleatlas, Hekkefuglenes utbredelse og bestandsstatus i Norge 1994.

Gjøsæter, H. 1995. Pelagic fish and the ecological impact of the modern fishing industry in the Barents Sea. *Arctic*, 3: 267–78.

Gjøsæter, H. 1997. The Barents Sea capelin stock: a brief review, pp. 469–84. Proc. Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program, AK-SG-97-01.

Gjøsæter, H. 1998. The population biology and exploitation of the Barents Sea capelin stock. *Sarsia*, 83(6): 453–96.

Gjøsæter, H., Dalpadado, P., Hassel, A. and Skjoldal, H.R. 2000. Growth of the Barents Sea capelin (*Mallotus villosus*, Müller). *In*: Gjøsæter, H. PhD Thesis.

Graf, G. 1992. Benthic–pelagic coupling: a benthic view. *Oceanogr. Mar. Biol. Ann. Rev.* 30: 149–90.

Gulliksen, B. and Gjøsæter, H. 1992. Havbunnens organismer. Chap. 11, In: *Økosystem Barentshavet, Mesna Trykk*, pp. 169-80. Ed. by E. Sakshaug, A. Bjørge, B. Gulliksen, H. Loeng and F. Mehlum, Lillehammer.

Hawkins, S.J., Hartnoll, R.G., Kain (Jones), J.M. and Norton, T.A. 1992. Plant-animal interactions on hard substrata in the North-east Atlantic. In: *Plant-animal interactions in the marine benthos*, pp. 1–32. Ed. by D.M. John, S.J. Hawkins and J.H. Price. Clarendon Pr.

Hoek, C. van den and Breeman, A.M. 1989. Seaweed biogeography of the North Atlantic: Where are we now? In: *Evolutionary biogeography of the marine algae of the North Atlantic*, pp. 55–86. Ed. by D.J. Garbary and G.R. South. Springer-Verlag.

Holst, J.K. 1994. The precision of two macroscopic screening procedures relative to a microscopic procedure for screening of the fungus *Ichthyophorus hoferi* in herring (*Clupea harengus* L.). *Fish. Res.* 19: 187–90.

Huse, G. and Toresen, R. 1995. Predation by juvenile herring (*Clupea harengus* L.) on the Barents Sea capelin (*Mallotus villosus* Müller) larvae. In: *Precision ad relevance of pre-recruitment studies for fisheries management related to fish stocks in the Barents Sea and adjacent waters*, pp. 14–17. Proc. sixth IMR-PINRO symp. Ed. By A. Hylen.

ICES 1999. Report of the northern pelagic and blue whiting fisheries working group. *ICES CM 1999/ACFM:* 18.

IMR 1999. Havets ressurser 19999. Fisken og Havet – Saernummer 1 – 1999. 153 pp.

Isaksen, K. and Bakken, V. 1995. Seabird populations in the northern Barents Sea. Source data for the impact assessment of the effects of oil drilling activity. Norwegian Polar Institute, Oslo. Rep. No. 153.

Isaksen, K., Bakken, V. and Wiig, Ø. 1998. Potential effects on seabirds and marine mammals of petroleum activity in the Northern Barents Sea. *Norsk Polarinst. Meddelelser*, 154: 1–66.

Jaschnov, W.A. 1970. Distribution of *Calanus* species in the seas of the northern hemisphere. *Nit. Rev. Ges. Hydrobiol. Hydrogr.* 55: 179–212.

Jensen, P., Rumohr, J. and Graf, G. 1992. Sedimentological and biological differences across a deep-sea ridge exposed to advection and accumulation of fine-grained particles. *Oceanol. Acta*, 15: 287–96.

Kampp, K., Meltofte, H. and Mortensen, C.E. 1987. Population size of the little auk *Alle alle* in East Greenland. *Dansk Orn. Foren. Tidskr.* 81: 129–36.

Layton, D., Edson, R. and Napier, B. 1997. Radionuclides in the Arctic seas from the former Soviet Union: potential health and ecological risks. Arctic Nuclear Assessment Program (ANWAP), Office of Naval Research, USA. 119 pp.

Loeng, H. and Rey, F. 1985. The influence of ice and hydrographic conditions on the development of phytoplankton in the Barents Sea. In: *Marine biology of polar regions and effects of stress on marine organisms*, pp. 49–63. Ed. by J.S. Gray and M.E. Christiansen. Proc. 18th European Marine Biology Symp. Oslo.

Lüning, K. 1990. *Seaweeds. Their environment, biogeography and ecophysiology.* J. Wiley.

Mayer, M. and Piepenburg, D. 1996. Epibenthic community pattern at the continental slope of East Greenland at 75° N. *Mar. Ecol. Prog. Ser.* 143: 151–64.

Mehlum, F. 1990. *Birds and mammals of Svalbard.* Norwegian Polar Institute, Polarhåndbok No. 5.

Mehlum, F. and Bakken, V. 1994. Seabirds in Svalbard (Norway): status, recent changes and management. In: *Seabirds on islands: threats, case studies and action plans*, pp. 155–71. Ed. by D.N. Nettleship, J. Burger and M. Gochfeld.

Mehlum, F. and Bakken, V. 1995. Seabird population in the Barents Sea. Source data for the impact assessment of the effects of oil drilling activity. Norwegian Polar Institute, Rep. No. 135. Oslo.

Mehlum, F. and Gabrielsen, G. 1995. Energy expenditure and food consumption by seabird populations in the Barents Sea region. In: *Ecology of fjords and coastal water*, pp. 457–70. Tromsø, Norway. Ed. by H.R. Skjoldal, C. Hopkins, K.E. Erikstad and H.P. Leinaas. Elsevier Science.

Melle, W. and Skjoldal, H.R. 1998. Reproduction and development of *Calanus finmarchicus, C. glacialis* and *C. hyperboreus* in the Barents Sea. *Mar. Ecol. Prog. Ser.* 169: 211–28.

Nettleship, D.N. and Birkhead, T.R. 1985. *The Atlantic alcidae. The evolution, distribution and biology of the auks inhabiting the Atlantic ocean and adjacent water areas.* Academic Pr. 574 pp.

Ollason, J.C. and Dunnet, G.M. 1988. Variation in breeding success in Fulmars. In: *Reproductive success. Studies of individual variation in contrasting breeding systems.* Ed. by T.H. Clutton-Brock. Univ. Chicago Pr. 538 pp.

Olsvik, P.A. 1996. The red king crab, *Paralithodes camtschatica* (Tilesius 1815), in the Barents Sea: Life history and future stock progress. *Fauna (Blindern)*, 49(1): pp. 20–33.

OSPAR 1995. The Joint Assessment and Monitoring Programme. OSPAR Commission London. 22 pp.

Paetkau, D., Amstrup, S.C., Born, E.W., Calvert, W., Derocher, A.E., Garner, G.W., Messier, F., Stirling, I., Taylor, M.K., Wiig. Ø. and Strobeck, C. 1999. Genetic structure of the world's polar bear populations. *Molec. Ecol.* 8(10): 1571–84.

Petersen, Æ. 1994a. Potential mortality factors of auks in Iceland. *CAFF Circumpolar Seabird Bulletin*, 1: 3.

Petersen, Æ. 1994b. Status and population changes of auks in Iceland. *CAFF Circumpolar Seabird Bulletin*, 1: 4.

Piepenburg, D. and Schmid, M.K. 1996. Distribution, abundance, biomass and mineralization potential of the epibenthic megafauna of the northeast Greenland shelf. *Mar. Biol.* 125: 321–32.

Rey, F. 1981. The development of the spring phytoplankton outburst at selected sites off the Norwegian coast. In: *The Norwegian Coastal Current, vol. II*, pp. 649–80. Ed. by R. Sætre and M. Mork. Proc. Norwegian Coastal Current Symp. Geilo.

Rey, F. 1993. Planteplanktonet og dets primærproduksjon i det nordlige Barentshavet. *Fisken og havet*, 10: 1–39.

Romero-Wetzel, M.B. 1989. Struktur und Bioturbation des Makrobenthos auf dem Vöring-Plateau (Norwegische See). Berichte aus dem Sonderforschungsbereich 313 'Sedimentation im europäischen Nordmeer', No 13: 1–204.

Sakshaug, E., Bjørge, A., Gulliksen, B., Loeng, H. and Mehlum, F. 1992. The Barents Sea ecosystem (PROMARE). Norwegian Scientific Council, Norwegian Ministry of Environment. 304 pp. (In Norwegian).

Schoschina, E. 1997. On *Laminaria hyperborea* (Laminariales, Phaeophyta) on the Murman coast of the Barents Sea. *Sarsia*, 82: 371–3.

Skaare, J.U., Wiig, Ø. and Bernhoft, A. 1994. Klorerte organiske miljøgifter; Nivåer og effekter på isbjørn. *Norsk Polarinstit. Rapportserie*, 86: 1–23.

Skaare, J.U., Bernhoft, A., Derocher, A., Gabrielsen, G.W., Goksoyr, A., Henriksen, E., Larsen, H.J., Lie, E. and Wiig, Ø. 2000. Organochlorines in top predators at Svalbard – occurrence, levels and effects. *Toxicol. Letters*, 112: 103–109.

Skjoldal, H.R., Gjøsæter, H. and Loeng, H. 1992. The Barents Sea ecosystem in the 1980s: ocean climate, plankton and capelin growth. *ICES mar. Sci. Symp.* 195: 278–90.

Svavarsson, J. 1997. Diversity of isopods (Crustacea): new data from the Arctic and Atlantic Oceans. *Biodiversity and Conservation*, 6: 1571–9.

Vilhjámsson, H. 1994. The Icelandic capelin stock. Capelin *Mallotus villosus* (Müller) in the Iceland-Greenland-Jan Mayen area. *Rit Fiskideildar*, 13(1): 281 pp.

Weisse, T., Tande, K., Verity, P., Hansen, F. and Gieskes, W. 1994. The trophic significance of *Phaeocystis* blooms. In: *Ecology of Phaeocystis-dominated ecosystems.* Ed. by C. Lancelot and P. Wassmann. *J. Mar. Systems*, 5: 67–79.

Wiig, Ø. 1995. Distribution of polar bears (*Ursus maritimus*) in the Svalbard area. *J. Zool. Lond.* 237: 515–29.

Wiig, Ø., Derocher, A.E., Cronin, M.M. and Skaare, J.U. 1998. Female pseudohermaphrodite polar bears at Svalbard. *J. Wildlife Diseases*, 34: 792–6.

Zenkevitch, L. 1963. *Biology of Seas.* George Allen & Unwin. 955 pp.

Chapter 6 References

AMAP 1998. *AMAP assessment report: Arctic pollution issues.* Arctic Monitoring and Assessment Programme (AMAP), Oslo. 859 pp.

Bernes, C. (Ed.), 1996. Arktisk miljø i Norden – urørt, overutnyttet, forurenset? Nord 1996:23. 240 pp.

EEA 1998. *Europe's environment: the second assessment.* European Environment Agency, Copenhagen. 293 pp.

EEA 1999. *Environment in the European Union at the turn of the century.* European Environment Agency, Copenhagen. 446 pp.

EEA/IRF 1998. Inter-Regional Forum Second Meeting Report of European Marine Conventions. Rome, 6–7 November 1997. Ed. by M. Dalla Costa. European Environment Agency, Copenhagen. 56 pp.

Layton, D., Edson, R. and Napier, B. 1997. Radionuclides in the Arctic Seas from the former Soviet Union: potential health and ecological risks. Arctic Nuclear Assessment Program (ANWAP), Office of Naval Research, USA. 119 pp.

Lønne, O.J., Sætre, R., Tikhonov, S., Gabrielsen, G.W., Loeng, H., Dahle, S. and Svevljagin, K. (Eds.), 1997. Status report on the marine environment of the Barents region. The Joint Norwegian-Russian Commission on Environmental Cooperation. Department of Environment, Oslo 97 pp.

OSPAR 1995. *The Joint Assessment and Monitoring Programme.* OSPAR Commission, London. 22 pp.

PAME 1996. PAME Working Group on the Protection of the Arctic Marine Environment. Report to the Third Ministerial Conference on the Protection of the Arctic Environment 20-21 March. Ministry of Environment, Oslo. 159 pp.