Global International
Waters Assessment

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Arctic Greenland
East Greenland Shelf
West Greenland Shelf

GIWA Regional assessments 1b, 15 and 16

Pedersen, S.A., Madsen, J. and M. Dyhr-Nielsen

Global International Waters Assessment

Regional assessments

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Regional assessment
1b – Arctic Greenland
15 – East Greenland Shelf
16 – West Greenland Shelf

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UNEP Collaborating Centre on Water and Environment

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Preface

Globally, people are becoming increasingly aware of the degradation of the world's water bodies. The need for a holistic assessment of transboundary waters in order to respond to growing public concern and provide advice to governments and decision makers regarding management of aquatic resources has been recognised by several international bodies focusing on global environment. To compile a global overview, the Global International Water Assessment (GIWA) has been implemented by the United Nations Environment Programme (UNEP) in conjunction with the University of Kalmar, Sweden (www.giwa.net).

The importance of the GIWA has been underpinned by the UN Millennium Development Goals adopted by the UN General Assembly in 2000 and the Declaration from the World Summit on Sustainable Development in 2002. The development goals aimed to halve the proportion of people without access to safe drinking water and basic sanitation by the year 2015. WSSD also calls for integrated management of land, water and living resources and, by 2010 the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystems should be implemented by all countries that are party to the declaration.

This report presents the results of GIWA assessments of the three Greenlandic GIWA regions – Arctic Ocean (1), East Greenland Shelf (15), and West Greenland Shelf (16). The report is the Greenland contribution to GIWA and it is funded by the Danish Environmental Protection Agency as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. The report has been carried out in collaboration between National Environmental Research Institute (contractor), Greenland Institute of Natural Resources, and UCC-Water.

The report is based on the GIWA Methodology: "STAGE 1: Scaling and Scoping" and "Causal chain analyses" (see www.giwa.net).

Two task team meetings were held in 2003:

1) August 15, at the National Environmental Research Institute in Roskilde, Denmark, and

2) September 3, at the Greenland Institute of Natural Resources in Nuuk, Greenland.

A number of selected experts were participating in these task team meetings. Other selected experts were unable to attend to the meetings. The experts consulted for inputs and reviews of this report are presented in Annex 1. The report was peer-reviewed by Dr. Henrik Sparholt and Dr. Raphael V. Vartanov.

The report has been compiled and edited by:

- Søren Anker Pedersen, GINR (Compiler and editor)
- Jesper Madsen, NERI (Co-editor)
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Executive summary

Greenland and its surrounding marine waters comprise a unique arctic and fairly undisturbed ecosystem of global significance. 85% of Greenland is covered by a continuous icecap, and the population of less than 60,000 lives in small towns and settlements along the coast. The population is traditionally highly dependent on the marine ecosystems, and also today, the economy of Greenland is strongly related to the productivity of the marine waters. In the 20th century, Greenland has experienced two major transitions, from seal hunting to cod fishery, then from cod to shrimp fishery. Both affected the human population centers of West Greenland and the economy. The economic transitions reflected large-scale shifts in the underlying marine ecosystems, driven by interactions between climate and human impacts.

Accordingly, the coastal and marine waters hold by far most of the international environmental aspects in relation to the Global International Water Assessment, whereas land and river issues are of minor or no importance. The eastern waters are characterized by southern currents from the Arctic basin, and in the spring and summer large amounts of sea ice drifts south. The western waters are influenced by a northern current, mixed by the cold eastern current and the warmer waters from the Irminger current. The oceanographic and sea ice conditions are closely linked to climate variability. The last decades warming of the northern hemisphere has reduced summer ice cover and increased open-water periods in East Greenland. But in the same period regional lower temperatures has increased ice cover, and reduced open-water periods in West Greenland. The arctic ecosystems are fragile and their stability is closely related to ocean temperature and to changes in ice cover.

A major environmental concern of the marine waters around Greenland have been identified to be chemical and toxic pollutants. Long-range transport of toxic contaminants reach the coastal waters of Greenland, where they are bioaccumulated in tissues of animals. Because these are important local diet items, both animals and human health might be affected. Over the next 20 years, environmental and human health impacts from pollution are expected to increase, unless strict regulations and internationally adopted environmental protection measures are implemented.

With the large importance of the fishing sector (locally as well as internationally), unsustainable exploitation of fish has also been identified as a key concern in both East Greenland Shelf and West Greenland Shelf. Southern Greenland waters are moderately impacted, and – due to the remoteness –, the Northern waters are not affected at all.

In the Northern and eastern waters, changes in ice cover and water temperature due to climatic heating cause increasing impacts on these unique ecosystems, in particular the habitats of endangered species like the polar bear.

The key causes for the toxic pollution are related to toxic emissions to water and air in industrial areas in Northern Asia, Europe and America. These sources are outside the control of the Greenland authorities and can be controlled by international agreements only.

The issue of overexploitation is caused by inappropriate management, due to a lack of understanding of how the marine resources react to the combined pressures of fisheries and climate change. The disappearance of the cod and the replacement by shrimp has been related to changes in water temperature, but the actual impact of the fisheries are difficult to determine. Accordingly, there is a need to improve the scientific understanding of the marine ecosystems around Greenland, and to use these results in an ecosystems approach to fisheries management.

It is also apparent that the potential future impacts of global warming on the fragile arctic ecosystems can be mitigated only by control of the release of greenhouse gasses by the larger consumers of fossil fuels in the developed world. A continued international effort to control these sources is mandatory to save the ecosystems of the Northern waters, including the large mammals like the polar bear and the walrus.

Regional definition

This section describes the boundaries and the main physical and socio-economic characteristics of the region in order to define the area considered in the regional GIWA assessment and to provide sufficient background information to establish the context within which the assessment was conducted.

Boundaries of the regions

The marine waters of Greenland holds by far most of the international aspects in GIWA, whereas land and river issues are of minor or no importance. Greenland holds three GIWA regions: Arctic (1), East Greenland Shelf (15), and West Greenland Shelf (16) (Figure 1). It was agreed among task team experts to assess Greenland waters in these three predefined regions in order to maintain the comparability with the other UNEP/GIWA regions and to use the GIWA methods. However, there are major differences between ecosystems from south to north within regions 15 and 16 due to differences in physical characteristics, species compositions, and community structures on both the East and West Greenland Shelf.

Physical characteristics

Geography (location, geology, climate)

Geographically, Greenland is part of the North American continent, geopolitically, a part of Europe. Greenland is the biggest island in the world. It stretches from Nunap Isua (Kap Farvel) in the south at 59°46' N lat to Odaap Qeqertaa (Odak Island) at 83°40' N lat (Figure 1). Odaap Qeqertaa lies only 700 km from the North Pole, and Kap Farvel, 2 600 km further south, is at the same latitude as Oslo in southern Norway (180 km south of Anchorage, Alaska, USA). The ice-free parts alone have a topography dominated by alpine areas and cover an area of 2 175 600 km^2.

85% of Greenland is covered by a continuous, slightly convex ice cap, which is the world's second-largest ice sheet. In a borehole drilled in the central part of the ice cap, the drill reached the bedrock in a depth of 3 030 m. The remaining 15% of the island is a narrow stretch of land between the ice cap and the sea, where flora and fauna exists and the people live – mainly in the coastal areas, with access to open water.

The coast around Greenland is dominated by bedrock shorelines with many skerries and several archipelagos. Very large differences in depths can be found within a short distance in the coastal zone. Some of the world's largest fjord complexes are found in East Greenland, e.g. Kejser Franz Josephs Fjord and Scoresby Sund, leading out north of the Denmark Strait. In several places the icecap reaches the coast as glaciers at the heads of fjords; so called icefjords. Deep fjords often continue as deep channels outside the coastal line, dividing the offshore banks.

Greenland is located in the Arctic. That means that the average temperature in July does not exceed 10°C, that there is permafrost in most regions, so only the top layers of soil thaw in the summer, and there are no forests. In southwest, however, there is generally no permafrost and at a few locations close to the inland ice the average temperature in July may exceed 10°C. The country can be divided from south to north into sub-arctic, low-Arctic and high-Arctic climate zones. The mean summer temperatures on both the west and the east coast differ by only a few degrees from south to north, despite a distance of more than 2 600 km. The reason for this is the vast iceshield on the one hand, and the summer midnight sun in north Greenland on the other. Conversely, winter darkness and the absence of warm sea currents from North and East Greenland mean that the temperature during the winter

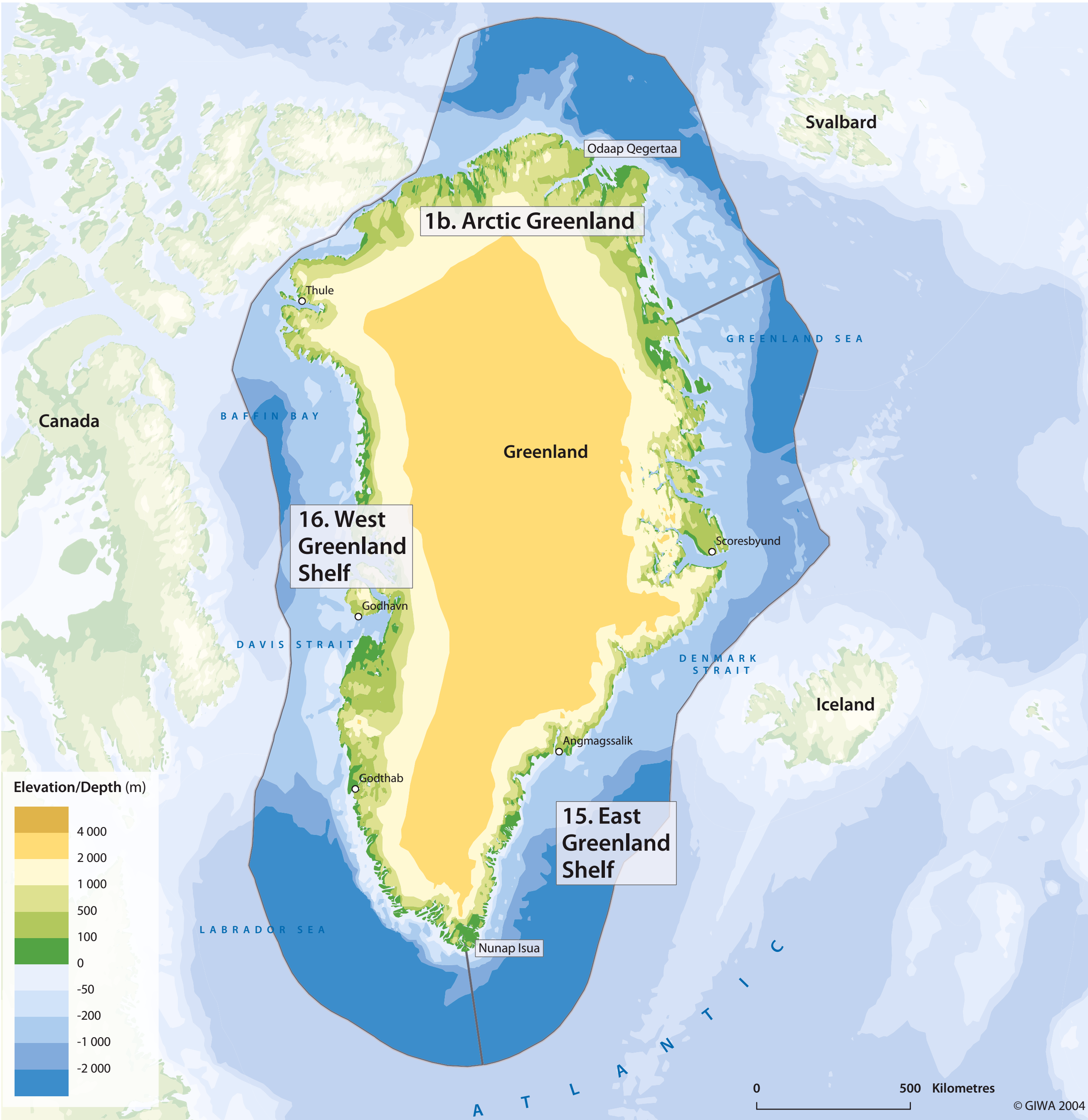


Figure 1 Boundaries of the Arctic Greenland, East Greenland Shelf and West Greenland Shelf regions.

period differs considerably from north to south, average temperatures in February 1961-1990: -30.9°C in the north and -3.9°C in the south (see www.dmi.dk).

The highest temperature officially recorded in Greenland since 1958 is 25.5°C. It was recorded near the "ice cap" in Kangerlussuaq (West Greenland) in July 1990. In Greenland, frost can occur in principle in all the months of the year except deep inside the large fjords in southern and western Greenland during the summer months. The "frostfree" period in southern Greenland varies from 60 to 115 days per year.

The coldest place in Greenland is naturally on the ice cap, where the temperature can fall to below -70°C. Temperatures in Greenland have shown a slightly increasing trend for the last 125 years, although, on a shorter time scale, temperatures have generally fallen since the 1940s (Anon, 2003a, Figure 2.10). This has been most marked on the west coast, where a temperature rise trend has only been seen over the last few years. On the east coast, however, there has been an increasing trend since the 1970s.

Recorded precipitation in Greenland decreases with rising latitude and from the coast to the inland area. In the south and particularly in the southeastern region, precipitation is significant with average annual precipitation ranging from 800 to 2 500 mm along the coasts. Further inland, towards the ice cap, considerably less precipitation is recorded.

In the northern regions of Greenland there is very little precipitation, from around 250 mm down to 125 mm per year. In the northeastern most coastal areas there are "arctic deserts", i.e. areas that are almost free of snow in winter, and where evaporation in summertime can exceed precipitation.

Not surprisingly, snow is very common in Greenland. In principle, in the coastal region it can snow anytime during the year without snow cover necessarily forming. The winter snow depth is greatest in southern Greenland, averaging from one to more than two metres in all the winter months and sometimes reaching up to six meters.

The prevailing patterns of wind direction, especially in winter, transport air masses from industrialised areas to the Arctic. The cold Arctic climate seems to create a sink for pollutant compounds (certain heavy metals and persistent organic pollutants), resulting in a so-called bio-accumulation in higher animals (fish, sea birds, marine mammals), causing concern for human health of Greenlanders consuming these animals.

The Greenland ice cap, icebergs, and sea ice

The Greenland ice cap (1.7 million km^2) holds 9 % of the world's freshwater. The Greenland ice cap produces about 300 km^3 of icebergs per year. About 10 % of all Greenland's icebergs stem from one particularly active glacier near the town Ilulissat ("Icebergs" in Greenlandic) in Disko Bay, This glacier (Sermeq Kujalleq) – is the most prolific glacier in the Northern Hemisphere and produces 22 million tonnes of ice each day (Chisholm and Parfit, 2002).

The extensive sea ice is one of the most characteristic and most important features of the Arctic Ocean, North Greenland and adjacent waters. Sea ice plays a decisive role for marine productivity and life in Arctic Greenland (e.g., Rysgaard et al., 2003; Born et al., 2003; Wiig et al., 2003; Heide-Jørgensen and Laidre, 2004). In the white stretch of frozen Arctic Sea, there exist many winter refugia or "microhabitats" for air-breathing marine animals. Several species seek access to open water leads and productive foraging opportunities for many months of the year. The refugia range widely in size, from a few hundred meters to many kilometres of vast open water. They remain ice-free during even the coldest period of winter and are generally surrounded by solid sea ice. Often these areas are annual recurrent 'polynyas' (the Russian word for 'open water area surrounded by ice'), variable shore leads and cracks, or tidal- and/or wind-driven openings in the consolidated pack ice. What defines these microhabitats is that they occur predictably in the same locations year after year, independent of how they are generated and maintained. This geographical and temporal predictability permits numerous Arctic sea birds and marine mammals to utilise open water during winter, when survival in the Arctic sea ice is most critical. Many of these open water habitats demonstrate conspicuous levels of production, generally due to large-scale upwelling events along the ice edge driven by the absence of ice providing early availability of light for photosynthesis. This widely attracts sea birds and marine mammals that seek to benefit from zooplankton production and associated fish abundance in these areas (Heide-Jørgensen and Laidre, 2004).

Species that utilise open water winter refugia include Arctic cetaceans, pinnipeds, sea birds and polar bears and their winter behavioural preferences are specific to requirements for survival and reproductive success (Heide-Jørgensen and Laidre, 2004). One of the largest winter refugia is the North Water Polynya (NOW) found during winter in Smith Sound and the northernmost Baffin Bay (Figure 2). NOW is utilised during winter and spring by approximately 13 000 belugas or white whales (*Delphinapterus leucas*) (who undertake a northbound migration to this locality from Lancaster Sound in the fall), thousands of narwhals (*Monodon monoceros*), and 30 million little auks (*Alle alle*) feeding in the area prior to the breeding season. Alternate and smaller open water localities of great importance are situated over shallow banks, such as Store Hellefiske Bank in West Greenland, containing vast benthic resources utilised by species such as king eiders (*Somateria spectabilis*) and common eiders (*Somateria mollissima*) and walrus (*Odobenus rosmarus*) with limited diving abilities. Hundred of thousands of thick billed murres (*Uria lomvia*) from Canada, Greenland and Svalbard over winter in smaller regions along the productive coastal open water area in West Greenland.

Oceanography

Comprehensive descriptions of the physical oceanography of the Greenland waters have been given by Buch (1990), Valeur et al. (1996), Buch et al. (2004), and Rudels et al. (2002).

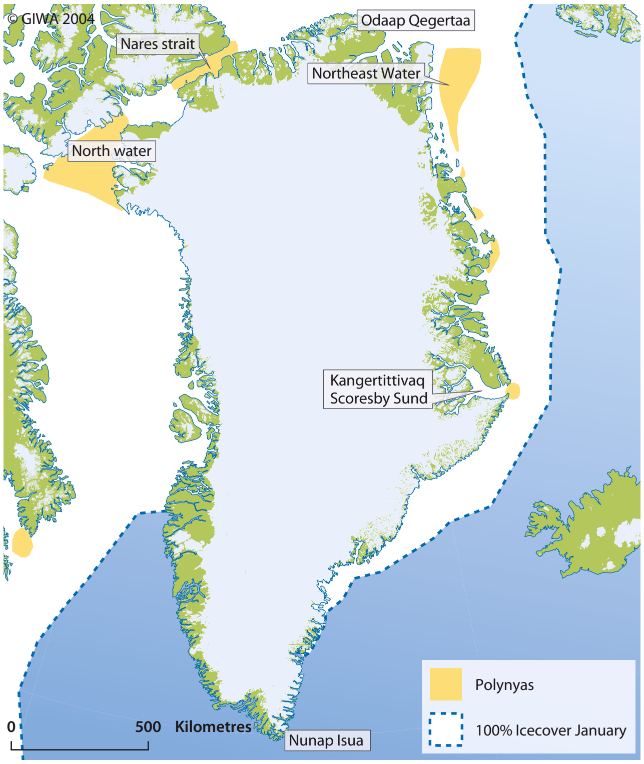


Figure 2 Greenland map showing a typical situation during the winter. The locations of the larger polynyas around Greenland are shown. 'Polynyas' is the Russian word for 'open water area surrounded by ice'.
(Source: Born and Bøcher, 2001)

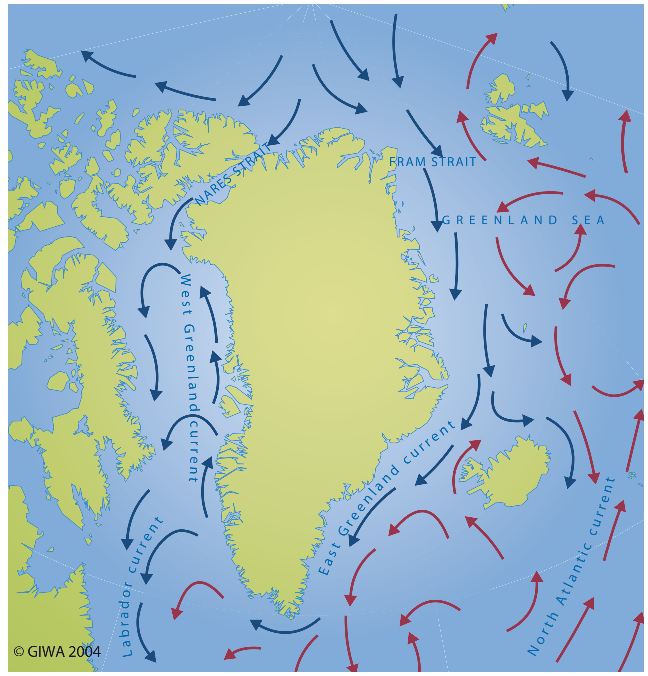


Figure 3 Ocean surface currents. Blue arrows indicate cold currents and red arrows show warm ones.
(Source: Modified from Born and Bøcher, 2001)

East Greenland

The surface layer in the eastern part of the Greenland Sea is dominated by the northward flowing Norwegian Atlantic Current, an extension of the North Atlantic Current. Waters from the Arctic Basin are transported southward through the Fram Strait along the east coast of Greenland to the Greenland Sea (Figure 3). The East Greenland Current flows over the Greenland shelf. During spring and early summer it carries large amounts of pack ice along with it.

The East Greenland Current flows southward along the coast of East Greenland and rounds Cape Farewell. A branch of the North Atlantic Current, known as the Irminger Current, turns westward along the west coast of Iceland. Part of the current turns further towards Greenland, where it flow southward parallel to the East Greenland Current down to Cape Farewell, where it joins the East Greenland Current (Figure 3), and flows up the west coast, securing largely open water in the harbours of Southwest and West Greenland.

Southwest and West Greenland

The water masses flowing northward along the West Greenland coast originate partly from the cold East Greenland Current, and partly from the warmer Irminger Current. These two water masses mix intensely. The hydrographic conditions along West Greenland depend greatly on the relative strengths of these two currents. The West Greenland Current, which flows over the Greenland shelf, continues northward until it reaches a latitude of about 65-66° N in the Davis Strait. At this point, a part of it turns westward and unites with the south flowing Baffin Current along the Canadian east coast, and a part continues northward in Baffin Bay.

North Greenland

Baffin Bay receives polar water from the Arctic Ocean through the Nares Strait and the Canadian Archipelago. This polar water flows southward along the eastern Canadian coast. Baffin Bay is covered by ice during winter, and in very cold winters, the ice can cover the whole Davis Strait. In summer the ice breaks up and drifts south along Canada's east coast.

Climate-oceanography-sea ice

The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere (e.g. Buch et al., 2001, 2004; Serreze et al., 2000; Johannesen et al., 2002; Macdonald et al., 2003). For example the winter (December-March) North Atlantic Oscillation Index (NAO-index) tends to be positively correlated with next years winter sea ice concentrations in West Greenland, but negatively correlated with next years sea ice concentrations in Northeast Greenland (Stern and Heide-Jørgensen, 2003). The last decades warming of the northern hemisphere has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods has been observed in West Greenland (e.g. Stern and Heide-Jørgensen, 2003).

Marine ecosystems

Basic information on biological diversity and marine ecosystems in Greenland has been given in Jensen (1999) and Born and Bøcher (2001). Specific research and reviews of potential environmental impacts and status of species and their habitats have recently been given in reports and scientific papers e.g. Heide-Jørgensen and Johnsen (1998), Riget et al. (2000), Buch et al. (2001), Petersen et al. (2001), Glahder et al. (2003), Mosbech et al. (1996, 1998), Mosbech (2002), Pedersen (2003), Møller et al. (2003), Born et al. (2003), Wiig et al. (2003), Buch et al. (2004), Rysgaard et al. (2003), Hansen et al. (2003), Heide-Jørgensen and Laidre, 2004).

Primary production

The annual pelagic primary production in the low arctic south Greenland waters averages 40-80 g C/m of sea surface. Annual productions as high as 605 g C/m have been registered. This is more than in most boreal and tropical waters, but still compares poorly with annual productions of 5.5 kg C/m near Antarctica and over 3.5 kg C/m off the Peruvian coast. Sea ice, ocean currents, light, nutrients, temperature, and grassing by herbivores are primary factors determining the distribution of marine productivity and animal life. Areas, in which water masses are vertically mixed, with a continuous supply of nutrients to the surface, are especially productive. One example is the front area between polar and Atlantic water masses that predominates off the southeast coast of Greenland. Another is the mixed water mass on the banks off West Greenland, where the surface layers are well supplied with nutrients throughout the summer (Figure 4).

The annual cycle in primary production in the seas of Greenland is normally initiated in May reaching peak biomasses in June. Large diatoms dominate the spring bloom, but depending on the nutrient availability, the flagellate *Phaeocystis* may also contribute. After the spring bloom where silicate or nitrate is depleted from the surface layer, the phytoplankton biomass is low and dominated by autotrophic flagellates < 10 µm.

Obviously there are significant regional differences in the timing and composition of the spring bloom within the northern North Atlantic.

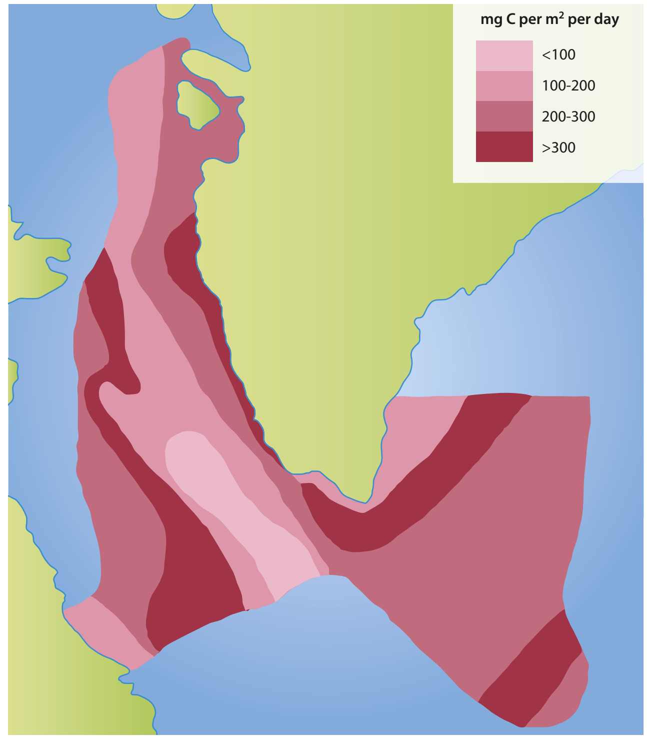


Figure 4 Gross primary production from July to August is greatest along edge of the ice off East Greenland and Labrador and near the coast where bottom water is brought to the surface by upwelling.
(Source: Nielsen, 1958 in Born and Bøcher, 2001)

While the surface community in the open water is nutrient depleted in the late summer, the continuous supply of nutrients from the melt water at the marginal ice zone can support a high phytoplankton biomass. Thus blooms can be observed at the ice edges throughout the season while it is more episodic in the open water.

To understand the carbon drawdown, it is essential to have a good description of the structure and succession of the zooplankton of the area. The zooplankton influences the carbon dynamics in several ways; by vertical migration, through grazing activity and by acting as accelerators of sedimentation of organic matter through production of faecal material. During the last decade, the views on high latitude pelagic food web structure have changed.

Pelagic food web

The present knowledge of pelagic food chain structure in high latitude ecosystems is primarily based on sampling with coarse nets (>200 µm) ignoring the smaller components of the food web. However, use of nets with smaller mesh size has documented that the smaller copepod species can contribute significantly to standing stock of the grazer community, especially after the oldest *Calanus* stages have left the surface layer. During the recent cruises in connection to the Danish Global Change Program in the Greenland Sea, a pronounced shift in the copepod community was observed from June to August; in June *Calanus* dominated while the small copepod species and developmental stages of *Calanus* took over in August. It is important to keep in mind that the *Calanus* species have a 2-4 year life cycle while the smaller species likely go through 2-3 generations per year. So the turnover of the copepod community and grazing rates in August is much higher than in June.

Knowledge of the role of the microbial food web in the Arctic has been limited because the microbial loop in cold water ecosystems has been considered less important than at lower latitudes. However, recent comprehensive investigations in Disko Bay, West Greenland, have documented that bacterioplankton and unicellular zooplankton also play a prominent role in the food web of Arctic ecosystems (Hansen et al., 2003).

Young Sund

Since 1994 there has been an extensive research activity in the high Arctic fjord Young Sund (74°N) on the northeast coast of Greenland (Rysgaard et al., 2003). In the Young Sund estuary, sea ice algae, primarily diatoms, were heterogeneously distributed in the sea ice both vertically and horizontally. Annual ice algal production at the sea ice-water interface in Young Sund may be highly variable and regulated by the thickness of snow cover. Primary production was <0.01 g C/m during 1998-1999. Compared to other coastal fast ice areas in the literature this rate seems low but comparable to measurements further out in the Greenland Sea. The low biomass and productivity in Young Sund was caused by a combination of poor light conditions due to snow cover and freshwater drainage from melt ponds and river discharge removing and/or inhibiting the algae at the sea ice-water interface through physical disturbance and exposure to freshwater. Thus, seen on an annual scale, the primary production of sea ice algae in Young Sund was <1% of the pelagic primary production.

In Young Sund the phytoplankton community was dominated by diatoms in the surface samples as well as in the subsurface bloom succeeding the spring bloom. Pelagic primary production was limited by light during sea ice cover. After break-up of the sea ice, silicate initially limited primary production in the surface water due to a well established pycnocline, and maximum photosynthesis occurred in a subsurface layer at 15-20 m depth. In August, production was displaced to deeper water layers presumably due to nitrogen limitation. The carbon budget describing the fate of the annual pelagic primary production revealed that the pelagic production was tightly coupled to the grazer community since total consumption by the grazer community. The classical food web dominated this northeastern Greenlandic fjord and it was estimated that copepods account for >80% of the grazing pressure upon phytoplankton (Rysgaard et al., 1999). Based on this study and other values of annual pelagic primary production and sea ice cover found in the literature, annual pelagic primary production in the Arctic was found to increase with the length of the open water light period (Figure 5). Rysgaard et al. (2003) proposed future increase in the annual pelagic primary production, secondary production, and hence food production for higher trophic level animals in a wide range of Arctic marine areas, as a consequence of reduction and thinning of sea ice cover due to global warming. The reduction in sea ice may be a benefit to some marine mammals e.g. Atlantic walruses (Born et al., 2003), but probably not for others e.g. polar bears (*Ursus maritimus*) (Wiig et al., 2003).

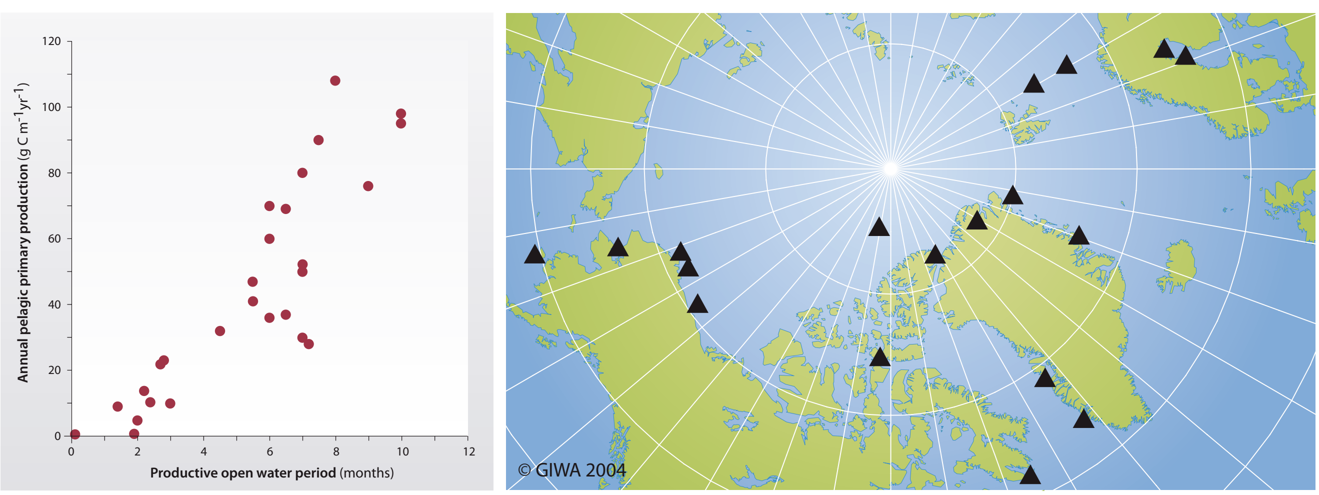
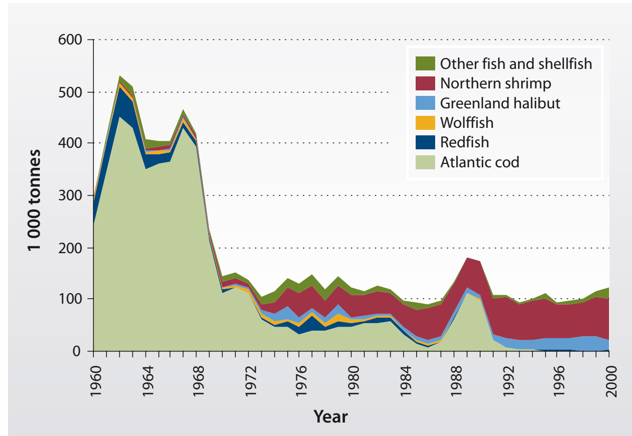


Figure 5 (a) Annual pelagic primary production versus length of productive open water period. b) Geographical location of investigations.
Further details are given by Rysgaard et al. (1999)

Due to physical differences and because different species have different ranges of temperature and habitat tolerance there are differences in species composition and community structure of the marine ecosystems from south to north along East and West Greenland. Water temperatures and sea ice distributions play a decisive role in determining the distribution of fish, sea birds and marine mammals. For example the distribution of a fish species is limited not only by the temperatures at which the species can survive, but especially by the narrow temperature interval in which reproduction is successful. Accordingly, the geographical range of Greenlandic fish species is primarily determined by the distribution of cold water of polar origin and warmer water of Atlantic origin.

Southwest and southeast Greenland

With respect to commercial fisheries resources, the marine ecosystems of Southwest and Southeast Greenland waters are the most productive in Greenland and the best investigated ones. They are intermediate between the cold polar water masses of the Arctic region and the temperate water masses of the Atlantic Ocean and they are characterised by relatively few dominant species (e.g. Jensen, 1939; Hansen, 1949; Rätz, 1999; Pedersen and Zeller, 2001). Ocean currents that transport water from the polar and temperate regions affect the marine productivity in the Greenland shelf areas, and changes in the North Atlantic circulation system therefore have major impact on the distribution of species and fisheries yield (Rätz, 1999; Rätz et al., 1999 Pedersen and Rice, 2002; Pedersen et al., 2002, 2003; Wieland and Hovgaard, 2002; Buch et al., 2004). The relative strengths of the warm vs. cold water currents contribute to the definition of the habitat of the flora and fauna.



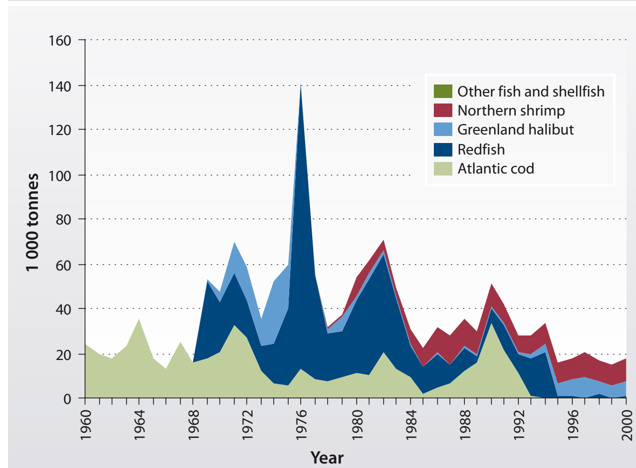


Figure 6 Catches of fish from region 16, West Greenland Shelf (upper figure) and region 15, East Greenland (lower figure).

(Data from Horsted, 2000; NAFO, 2003; ICES, 2003; and Greenland Institute of Natural Resources. Data for catches of fish in "LME: East Greenland" other than cod is lacking before 1969)

Fish

Since the beginning of the 20th century, cod (*Gadus morhua*) has been the most important commercial fish species in Greenland waters, with annual catches peaking at levels between 400 000 and 500 000 tonnes in the 1960s (Mattox, 1973; Horsted, 2000). Until the introduction of the 200 mile EEZ in 1977, most of the catch was taken by foreign vessels. During the late 1960s, the annual catches of cod and other commercially important fish species - mainly taken as by-catch in the cod fishery, e.g., redfish (*Sebastes marinus*), Atlantic halibut (*Hippoglossus hippoglossus*) and wolffish (Atlantic wolffish, *Anarhichas lupus*, and spotted wolffish, *A. minor*) declined drastically (Figure 6).

After 1970 the catches of cod and redfish showed fluctuations at much lower levels compared to the 1960s (Figure 6). Except for a temporary improvement of the cod fishery during 1988-1990, the catches of cod, redfish, Atlantic halibut and wolffish showed decreasing trends towards the present very low levels (Rätz, 1999; Buch et al., 2004). During the same period, however, catches (inshore and offshore combined) of two other important species, Greenland halibut (*Reinhardtius hippoglossoides*) and northern shrimp (*Pandalus borealis*) increased and annual catches are presently about 25 000 tonnes and 100 000 tonnes, respectively.

Other living resources

In addition to the fisheries yields from mainly the West Greenland, but also the East Greenland large marine ecosystem, one has to add the hunting (and consumption) of more than 100 000 seals, several hundred whales and several hundred-thousand seabirds per year on average (e.g. Mosbeck et al., 1998; Greenland Institute of Natural Resources, 2000; Namminersornerullutik Oqartussat, 2002). The seal hunt targets primarily ringed seals (*Phoca hispida*) and harp seals (*Phoca groenlandica*), but also other species including the walrus (*Odobenus* *rosmarus*). The whale hunt is mainly on fin whales (*Balaenoptera physalus*), minke whale (*B. acutorostrata*), beluga (*Delphinapterus leucas*), narwhal (*Monodon monocerus*) and occasionally others. The seabird hunt is primarily on Brünnich's guillemot / thick-billed murre (*Uria lomvia*), king eider (*Somateria spectabilis*), common eider (*S. mollissima*), little auk (*Alle alle*) and kittiwake (*Rissa tridactyla*). Polar bear (*Ursus maritimus*) is hunted and a total of about 170 animals are killed in Greenland per year with approximately an equal number in West- and East Greenland (Namminersornerullutik Oqartussat, 2002).

Transboundary aspects

The marine animal resources, e.g. fish, sea birds and sea mammals, generally have an extensive distribution area, involving the waters of several nations. This means that fishery, hunting and other influences on one part of a population will eventually affect the rest of it, within as well as outside of Greenland waters. International cooperation on management and protection of marine species and resources is thus imperative if sustainable yields and protections of endangered species are to be attained. Accordingly, Greenland is member of several international organisations that advise a sustainable use of Greenland's marine resources, e.g. North Atlantic Fisheries Organisation (NAFO), International Council for the Explorations of the Sea (ICES), North East Atlantic Fishery Commission (NEAFC), North Atlantic Salmon Conservation Organisation (NASCO), Joint Commission for the Conservation and Management of Narwhal and Beluga (JCNB), North Atlantic Marine Mammal Conservation Organisation (NAMMCO), and International Whaling Commission (IWC).

Greenland's membership of e.g. ICES and IWC is through Denmark and Greenland has an active Greenlandic representation/participation. Greenland is a self-governing part of the Kingdom of Denmark. In 1979 the Home Rule Act transferred the mandate of legislation to the Greenland Parliament in all areas defined to be issues of self-government. Hence, regulations issued in Denmark or international conventions ratified by her are not automatically in force also in Greenland.

In 1991, the eight Arctic countries – Canada, Denmark, Finland, Iceland, Norway, Sweden, Russia, and the United States – initiated the Arctic Environmental Protection Strategy. Under this framework, the countries pledged to work together on issues of common concern. Recognising the importance of the environment to the indigenous communities of the Arctic, the countries at that time included three indigenous organisations in their cooperative programs. In 1996, the eight Arctic countries created the Arctic Council, incorporating the Arctic Environmental Protection Strategy and expanding it to include sustainable development issues. They have also included three more indigenous organisations for a total of six permanent participants. One of the programs created under the Arctic Environmental Protection Strategy and continued under the Arctic Council is the Arctic Monitoring and Assessment Programme (AMAP). AMAP was designed to address environmental contaminants and related topics, such as climate change and ozone depletion, including their impacts on human health (AMAP, 2002). In 2000, the Arctic Council approved the Arctic Climate Impact Assessment, overseen by AMAP, its sister working group on Conservation of Arctic Flora and Fauna (CAFF), and the International Arctic Science Committee. According to AMAP (2002), this impact assessment will deliver a report to the Arctic Council in 2004.

Greenland has responded to threats to the freshwater systems and the fauna and flora these habitats support by establishing protected areas and designating important wetland areas under the Convention on Wetlands of International Importance (Ramsar) (Figure 7; Egevang and Boertmann, 2001).

The objective of the UNESCO Convention concerning World Heritage is to help protecting irreplaceable expressions of former cultures and of natural landscapes of great importance and beauty. The foundations for two international conventions were laid in the mid-1960s and later,

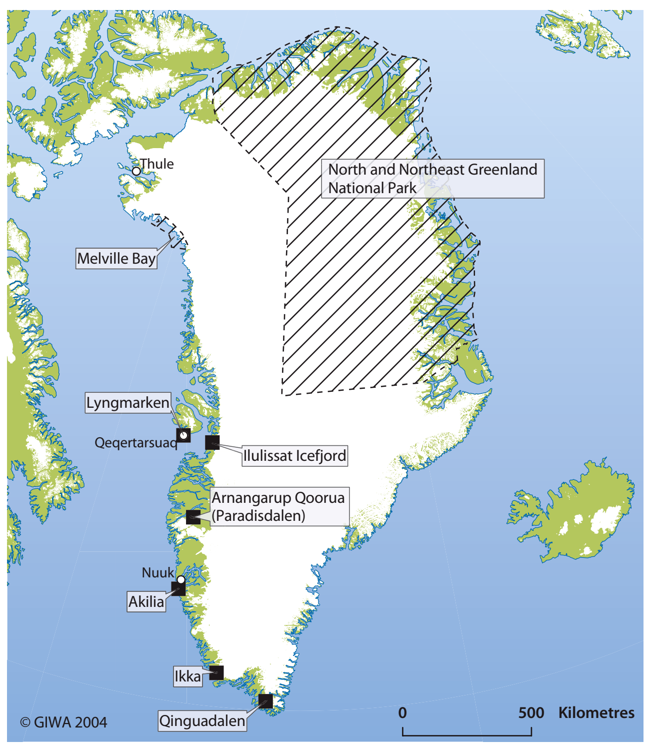


Figure 7 National parks and protected areas indicated by their name.
(Greenland Home Rule, 2004).

in 1972, merged into one, the UNESCO World Heritage Convention. The five Nordic countries, among others, ratified the convention between 1977 and 1995. As Greenland is not a sovereign state, in these matters Greenlandic interests are upheld through the Danish government.

After a request by the Danish Ministry of the Environment in 1988, the Greenland government has selected natural heritage areas and cultural monuments in Greenland for inclusion in the UNESCO World Heritage List (Mikkelsen and Ingerslev, 2002). This work was properly organised in 1995 when cooperation was established between the Greenland Department of Culture, Education and Ecclesiastical Affairs, the Department of Health, Environment and Research, the Greenland National Museum and Archives, and the Greenland Institute of Natural Resources. The Greenland National Museum selected culturally significant historical objects and the Institute of Natural Resources pointed out areas of special interest for the natural environment. Subsequently, these proposals comprised sites of both natural and cultural history.

The icefjord of Ilulissat/Jakobshavn, West Greenland, which covers an area of 796 km^2 are being evaluated to become the first UNESCO World Heritage area in the Arctic (Mikkelsen and Ingerslev, 2002). The result of this evaluation will be announced in 2004. The icefjord contains the Jakobshavn Glacier, which is a floating, calving ice cap glacier. The glacier is presently located about 40 km east of the town of Ilulissat. Because of the relatively easy access to the glacier from the settlements in the immediate vicinity, the fjord and glacier are well known. The glacier is particularly famous for its high speed of 1 m/h and its production of calving ice which amounts to about 30 km^3/year. This is more than any other glacier and comprises about 10% of the entire production of calving ice from the Greenland ice cap (Mikkelsen and Ingerslev, 2002).

Socio-economic characteristics

Political structure

Greenland has been a colony of Denmark since 1728, and obtained home rule in 1979, so it is at present a semi-independent province of Denmark. The Home Rule Government consists of a directly elected parliament (the Landsting), comprising 31 members. A general election is held every four years. The Landsting elects a government (the Landsstyre), which is responsible for the central administration under the Prime Minister (the Landsstyreformand). The members of the government head the various ministries. As Greenland is part of the Kingdom of Denmark, some fields of responsibility remain under the Danish state, including the Constitution, the right to vote, eligibility for election of justice, the concept of citizenship, inspection and enforcing of jurisdiction in territorial waters, as well as all foreign policy and monetary affairs.

The Home Rule Government is responsible for all other administrative areas, including transport and communication, and the environment and nature. The rights to Mineral and Petroleum are shared between the Danish Government and the Greenland Home Rule. Greenland is not a member of the EU, but has an OCT scheme (Overseas Countries and Territories) that ensures the country open access to the European market for its fish products.

Population

The population of Greenland was 56 542 in 2002 of which ~88% were born in Greenland, which is the official proxy measure for Greenlandic (Inuit) ethnicity (Anon, 2003b). Most of the remainder of the population (~12%) comes from Denmark. The population pyramid for the indigenous population is relatively broad based until the age group 30-34. Around 1970, a very high fertility rates decreased rapidly which, in combination with relatively few women of childbearing age, resulted in small birth cohorts (Figure 8). After the dramatic decrease, the size of the birth cohorts increased steadily from 1974 to 1995 but is now once more on the decrease (Bjerregaard, 2003).

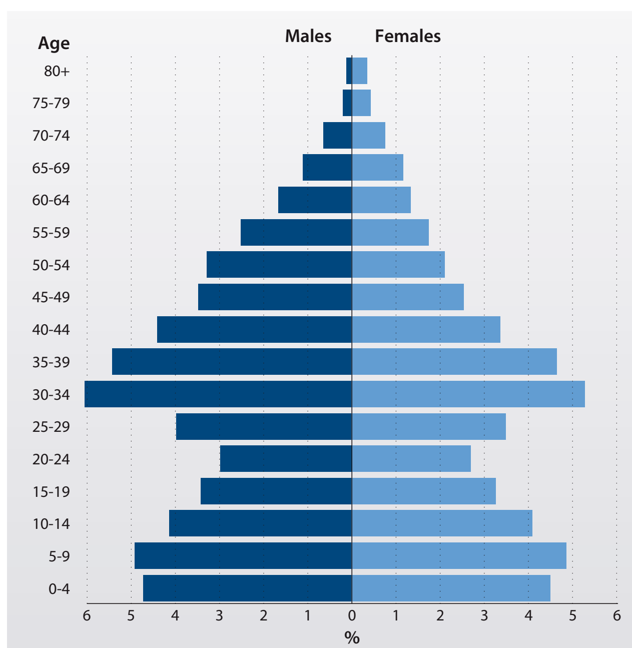


Figure 8 Population pyramid for Greenland, 2001.
(Source: Greenland Statistics; AMAP, 2003)

East Greenland is inhabited by only about 3 600 people. West Greenland is inhabited by the majority of the Greenland population, about 53 000 people, and the Greenland fishing industry and all major cities including the Capital Nuuk are situated in West Greenland. In the capital, Nuuk, lives 13 500 people. 80% of the population lives in coastal towns and settlements in Southwest Greenland and the Disko Bay, where also most of the commercial fishing takes place and the fish processing plants are located. Outside this area subsistence hunting and fishing are predominant occupations. The fishery in East Greenland is performed by offshore fishing vessels, both Greenlandic and foreign vessels, whereas the local and coastal fishery is small, but of cultural and sociological importance.

Culture

The Danish/Norwegian colonisation of West Greenland started in 1721, and what today is termed the traditional Greenlandic culture is a mixture of Inuit and European culture. The traditional occupation of the Greenlanders until the early 20th century was the hunting of marine mammals (seal, whales, and walrus). During the 20th century hunting was increasingly substituted by fishing, first from small dinghies but later from large sea-going vessels using the most modern equipment. The Greenlandic culture today is still very much centred around traditional Greenlandic food (kalaalimernit), which is understood as the meat and organs of marine mammals and fish often eaten raw, frozen or dried. Seal meat, for instance, is usually ascribed several positive physical as well as cultural qualities, and asking a person whether he or she likes seal meat is equivalent to asking whether he or she considers himself/herself to be a true Greenlander (Bjerregaard, 2003).

Traditional sealing and whaling still plays an important role in the life of people especially in Northwest, North, and East Greenland although it is not the dominant industry in economic terms. Leisure time hunting and fishing is a very common activity.

The consumption of marine mammals, fish and sea birds is high, but the young and the population in towns eat considerably less than the elderly and the population in the villages. Seal is the most often consumed traditional food item followed by fish. On average, 20% of the Greenlanders eat seal 4 times a week or more often while 17% eat fish similarly often. Traditional food is valued higher than imported food; the highest preference is given to mattak (whale skin), dried cod, guillemot, and blackberries. Almost all value traditional food as important for health and less than one percent (in 1993-94) restricted their consumption of marine mammals or fish because of fear of contaminants (Bjerregaard, 2003).

Lifestyle

A sedentary lifestyle is becoming increasingly common among the Greenlanders. In the villages, only 7% are self-reported sedentary while this increased to 23% among the well-educated residents of the capital, Nuuk. Overweight is an increasing problem among the Greenlanders; 35% and 33% of men and women, respectively, are overweight (BMI 25.0-29.9) and 16% and 22% are obese (BMI=> 30) (Bjerregaard, 2003).

The consumption of alcohol and tobacco has increased considerably during the last 30-40 years but is now stagnant (Bjerregaard, 2003). The impact of alcohol on social and family life is marked. Among those born after 1960, more than 50% state that they experienced alcohol related problems in their parental home.

According to import statistics, the average consumption of cigarettes increased from 5 cigarettes per day in 1955-59 to 9 in 1990-94. Recent population surveys estimate the proportion of cigarette smokers to be 70-80% among both men and women compared with 40% in Denmark, but the proportions of heavy smokers are similar in the two countries. Young people start smoking very early, often well before the age of 15, and the lowest smoking prevalence is found among the elderly.

Economy

In 1998 gross national income (GNP) was more than 7.5 billion Dkr, corresponding to 134 000 Dkr per capita. (Dkr = Danish Crowns; 1 Euro equals approximately 7.4 Dkr) (Anon., 2003b). Principal income for the Home Rule Government comes from a block grant from the Danish state, which constitutes about 2/3 of the Greenland economy. The remaining 1/3 is overwhelmingly based on fishery and its products. In addition, the Home Rule Government and the municipalities have revenue from personal and corporate taxes, indirect taxes, and licences. In addition, Greenland receives payment from the EU for access by EU fishermen to Greenland's fishing waters.

Exports

In 2001, 87% of Greenland's exports of 2 251 million Dkr consisted of fish products, 60% of which were shrimps (Anon., 2003b). The export value of fish products is heavily dependent on the prices on the world market. Although there was a considerably larger production of shrimps in 2001 than ever, falling prices on the world market considerably reduced the export value.

Imports

Apart from fish and hunting products, only few goods are produced in Greenland. Imports therefore include almost all goods used in households, business and institutions. In 2001 imports amounted to 2 466 million Dkr.

Industry

Fishing is the main industry, and it is estimated that about 2 500 people are directly employed by it. In addition, around 3 000 people work in the fisheries industry and derivative occupations. Hunting is of direct or indirect significance for about twenty percent of the population, and is the principal occupation Northern and Eastern Greenland. Sheep and reindeer are raised in South Greenland. For many years it was expected that tourism and the extraction of raw materials eventually would become leading industries, supplementing fishing as major sources of income. So far, however, the expectations have not been met.

The fisheries in Greenland are characterised by three main sectors with distinct differences between large-scale offshore, intermediate and small-scale inshore activities. This is not only due to structural and economic patterns, but also caused by political relations of importance for the development process. The large-scale sector is dominated by a capital rationale, with concentration and centralisation through large-scale projects and economy of scale as the fundamental mechanisms, giving access to resources otherwise inaccessible, and the major contributor to the national economy. The intermediate sector of the regional fisheries is partly based on capital rationality, partly on a life form which has become a backbone of many of the larger settlements, but also present in many smaller settlements. This sector is important for the regional economies. The small-scale sector, relying on small boats, dog-sledges and skidoos, is vital for the small settlements, and consequently constituting the backbone of the cultural heritage, and important for the direct and indirect political attempts to maintain reasonable living conditions for the smaller places. At the same time its contribution to the maintenance of the informal and subsistence sector is certainly not negligible (Rasmussen, 1998c; Caulfield, 1997; Marquardt and Caulfield, 1995).

Fishing and hunting

Northern shrimp (*Pandalus borealis*) constitute the most important commercial export. The annual catches of around 100 000 tonnes contribute more than 1 billion Dkr to the Greenland economy. However, this contribution is depending on e.g. the world marked prize for shrimp products.

Cod (*Gadus morhua*) previously played a central role in the development of the economy, but the cod landings have fallen to <2 000 tonnes and cod fishing in Greenland today is of very low economic importance compared to former periods.

Greenland halibut (*Reinhardtius hippoglossoides*) on the other hand, has in the last 2 decades become important to the economy of the country. The yearly catch of more than 20 000 tonnes comes first and foremost from the northwesterly districts.

Redfish, catfish, Atlantic halibut, salmon and char are of minor economical importance, however, important to the local socio-economy in towns of Southwest Greenland.

A number of marine mammals are essential for the survival of the traditional hunting communities. The most important of these are the five species of seal which are found in the waters around Greenland. The most common is the ringed seal, and the Greenlanders still harvest around 80 000 of these every year whereas they also harvest 80 000 of all the other species put together. A number of walruses and whales are also caught (see Assessment, Unsustainable exploitation of fish and other living resources). Considerable sums are involved in the lively trade in meat which is only used locally. The only commercial use of the seals comes from the sale of skins to the Great Greenland tannery in Qaqortoq (Julianehåb). The Home Rule Government provides generous subsidies to the sealers because of the difficulty in selling the skins on the world market. Polar bear hunting and the sale of polar bear skin are socio-economical important locally in West and East Greenland.

The rich bird life around the coasts has also played a role in the life of the Greenlanders. In addition to a number of different types of gulls and ducks, of which the most important is the common eider, uses have also been found for a number of colony birds, not least Brünnich's guillemot, known commonly as the polar guillemot.

The fishing and marine mammal hunting in Greenland is founded on resource assessments and quotas given by international advisory organisations and committees on fishery and marine mammal management (NAFO, ICES, NASCO, NEAFC, JCCM, NAMMCO, and IWC) of which Greenland is a member. The Greenland Institute of Natural Resources is responsible for providing scientific advice on the level of sustainable exploitation of the living resource to the Greenland Government, including long-term protection of the environment and biodiversity. As of today, the scientific advice to the Greenland Government of sustainable use of the renewable resources is entirely based on single-species assessments given for one year. However, for northern shrimp (the most important commercial fishery) an analytical assessment framework using a stochastic version of a surplus-production model that included an explicit term for predation by cod was applied for the first time in 2002.

Today cooperation between Greenland and EU is dominated by fisheries agreements. Within these agreements EU pays Greenland for rights to fish parts of the quotas of the Greenland fish stocks. However, from 2007 Greenland and EU are expected to make a wider partnership agreement.

The Greenland Government regulates the utilisation of renewable resources by quotas, license's and technical measures (e.g. mesh sizes or closed seasons) (Namminersornerullutik Oqartussat, 2002; www.nanoq.gl). To enforce the decided regulations and laws on fishing and hunting, Greenland has established the "Greenland Fishing License Control" (GFLK) and "Greenland Hunting Patrol" (Jagtbetjentordningen).

Farming and land use

Geographically, Greenland's agriculture is placed in the south. It consists mainly of sheep farming, and 25 000-30 000 lambs are produced each year. There are also two farms with domesticated reindeer. The number of sheep has remained relatively stable since 1990, whereas the number of domesticated reindeer has more than halved. The area farmed has increased by 85% since 1990 due to cultivation of heath lands for hay cutting.

There is no forestry in Greenland apart from four experimental plantations with conifers, with a total area of 100 ha.

In Greenland there are no roads connecting towns. Therefore all traffic between towns and settlements is either by ship, boat, dog-sledge (seasonally), snowscooter (seasonally) or by fixed-wing aircraft or helicopter. In the towns most goods are transported by car. The main gateways to Greenland are the international airports (former American military bases) in Narsarsuaq (South Greenland) and Kangerlussuaq (West Greenland). From here traffic to all Greenland destinations is being distributed – either by small airplanes or by helicopters. The two towns in East Greenland are accessible by air from Iceland.

Almost all goods transport, both to and within Greenland, is by sea. A small proportion, mainly mail and perishable goods, is transported by air. Only the areas from Paamiut (Frederikshåb) to Sisimiut (Holsteinsborg) on the west coast is open water all year round, and therefore accessible by boat. South of Paamiut (Frederikshåb) drift ice from the east coast can cause trouble for fisheries and transportation in the summer months. North of Sisimiut (Holsteinsborg), ice conditions limit navigation during winter. On the east coast ice may cause troubles year round, as the east coast can only be navigated for a few months in the summer.

Conclusion

The GIWA regions of Greenland, Arctic (1), East Greenland Shelf (15), and West Greenland Shelf (16), cover huge areas, but they are sparsely populated. The development of modern Greenland has been based on fishing and hunting natural resources. Besides the importance of transfers from Denmark, the society of Greenland, including the local economies, depends on living resources from the sea, and more than 90% and Greenland's total export value stems from fish products. Likewise, the social and physical health of Greenlanders, notably those living in the more isolated areas, depends to a high degree on the collection and consumption of traditional food.

Assessment

This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Table 1.

Table 1 Scoring tables for the Arctic Greenland, East Greenland and West Greenland regions.

	Arctic Greenland						East Greenland						West Greenland					
	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	0* →	0 →	0 →	0 →	0	4	0* →	0 →	0 →	0 →	0	5	0* ↗	+1 →	0 →	0 →	0	5
Modification of stream flow	0						0						1					
Pollution of existing supplies	0						0						1					
Changes in the water table	0						0						0					
Pollution	2* ↗	0 →	0 →	0 →	2	3	3* ↘	0 →	3 ↘	3 ↘	3	1	2* →	0 ↗	3 ↘	0 ↘	2	2
Microbiological pollution	0						0						0					
Eutrophication	0						0						0					
Chemical	2						3						2					
Suspended solids	0						0						0					
Solid waste	0						0						1					
Thermal	0						0						0					
Radionuclide	0						0						0					
Spills	0						0						0					
Habitat and community modification	0* →	0 →	0 →	0 →	0	2	1* ↘	0 →	1 →	0 →	1	3	2* →	0 →	0 →	0 →	2	3
Loss of ecosystems	0						0						0					
Modification of ecosystems	0						1						2					
Unsustainable exploitation of fish	0* →	0 →	0 →	0 →	0	5	*3 ↗	0 ↘	2 →	0 →	3	2	3* ↗	0 ↘	0 →	0 ↘	3	1
Overexploitation	0						3						3					
Excessive by-catch and discards	0						1						1					
Destructive fishing practices	0						3						3					
Decreased viability of stock	0						0						0					
Impact on biological and genetic diversity	0						0						0					
Global change	2* →	0 →	0 →	0 →	2	1	1* →	0 →	0 →	0 →	1	4	1* →	0 →	0 ↘	0 ↘	1	4
Changes in hydrological cycle	2						1						1					
Sea level change	0						0						0					
Increased UV-B radiation	1						1						1					
Changes in ocean CO_2 source/sink function	1						1						1					

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)

IMPACT 0 No known impacts · IMPACT 1 Slight impacts · IMPACT 2 Moderate impacts · IMPACT 3 Severe impacts

The arrow indicates the likely direction of future changes.

↗ Increased impact · → No changes · ↘ Decreased impact

* This value represents an average weighted score of the environmental issues associated to the concern. ** This value represents the overall score including environmental, socio-economic and likely future impacts. *** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

The Greenland ice cap contains nine percent of the world's freshwater. Greenland's water is renowned as some of the finest in the world. The purity of the water has been measured at various locations in Greenland in order, so to speak, to set the instruments used for measuring pollution at zero (Pedersen, 2002).

Environmental impacts

Modification of stream flow

One river has been regulated due to build a hydropower dam outside of Nuuk, the Capital of Greenland, situated in West Greenland (region 16). However, modification of stream flows in Greenland is generally considered an environmental problem of minor concern. Hydropower was considered as a socio-economic benefit for Greenland as the country has no own oil or gas resources. A few other hydro power plants are planned.

Pollution of existing supplies

Although clean water is plentiful there are special factors in Greenland that have to be taken into account when water is piped into the towns for use by households and the fishery industry (Pedersen, 2002).

In all towns, the water is chlorinated at the waterworks to combat harmful bacteria in the drinking water. When the content of humus and silt is high, so-called trihalomethanes sometimes form in connection with chlorination. Trihalomethanes are suspected of being carcinogenic, so there is every reason to try to prevent them from forming. Therefore, the local authority in Ilulissat (Jabokshavn) adds aluminium sulphate to the water at the same time as it is aerated, whereby the humus and silt are removed before the water is chlorinated (Pedersen, 2002).

Surface water is only chlorinated in towns. In settlements, where the water is not chlorinated, this can mean that food products cannot be directly processed for export. The EU's Drinking Water Directive demands a water quality that is free of micro-organisms, parasites and substances in quantities or concentrations that present a potential risk to health. All new waterworks are designed and constructed to meet the EU's requirements for reasons of public health and the export of Greenlandic food products (Pedersen, 2002).

Changes in the water table

No evidence that use of water from aquifers exceeds natural replenishment.

Socio-economic impacts

Economic impacts

West Greenland (region 16) a hydro power plant outside the Capital of Greenland, Nuuk, has been positive for the economic development.

Health impacts

No known impact.

Other social and community impacts

In several settlements the access to a continuous flow of drinking water is limited throughout the year. In some settlements in the north the supply of freshwater during winter is based on the melting of ice, which is expensive and may open up for contamination. In a few settlements in the south the sources of drinking water can become scarce during summer, and can then be limiting for commercial fish processing (Friis and Rasmussen, 1989). In several settlements freshwater is so scarce that supplies are produced from seawater by osmosis.

Conclusions and future outlook

Freshwater shortage is generally not a problem of major concern for Greenland at present or in the foreseeable future. Greenland holds plenty of unpolluted water in the ice cap and in lakes and rivers. However, the surface of the ice-cap can be contaminated with persistent organic pollutants (see later, Jacobsen et al.(2003)).

Pollution

The experts agreed that pollution and almost exclusively chemical pollution has a moderate to severe impact and it is an issue of major concern for Greenland at present.

A comprehensive assessment of the levels and trends of contaminants in the Greenland marine environment, their effects in the environment, particularly in sea-birds, ringed seals, polar bears and to human health have recently been made in connection with the Arctic Monitoring and Assessment Programme (AMAP) (Riget et al. 2003; Deutch and Hansen, 2003; AMAP, 2002, 2003).

In general, people in Greenland are more exposed to contaminants from their diet than people in Europe and North America, who eat processed foods under strict standards. The reason is that marine traditional food items (fish, seabirds, seals and whales) are much more important in the Greenland diet, and at the same time some of these food items have high levels of contaminants, i.e. metals such as mercury and cadmium and organochlorines such as PCBs. Within the Arctic, Greenlanders have the highest concentrations of mercury and PCBs (Hansen, 1998).

Since the Arctic lies far from the industrialised world, one would not expect environmental problems to be serious. However, the presence of chlorinated organic compounds and heavy metals in arctic food chains testifies to the fact that certain pollutants are transported over long distances to the Arctic. Pollutants enter the Greenland marine environment via the atmosphere and ocean currents. The importance of sources and pathways are not fully understood, but in general the anthropogenic contribution to the contaminant levels is expected to be dominated by pollutants originating from sources outside Greenland.

Numerous inorganic and organic pollutants occur in the industrial products of daily use, leading to a current emission into the environment, where they will be transported by the atmosphere and the sea. Studies in the Arctic region have shown that long-range transport of compounds produced and emitted in industrialised countries to the remote regions of the Arctic takes place. Additionally, the use of imported industrial products in the Arctic has also been indicated to lead to a certain emission of pollutants.

Coal burning, waste incineration and industrial processes around the world emit mercury to the atmosphere, where natural processes transport the metal. The Arctic is vulnerable because unique pathways appear to concentrate mercury in forms that are available to the food web. Environmental changes, e.g. increase in the distribution of wetlands due to melting of permafrost may have made these pathways more efficient in recent years (AMAP, 2002). However, the pathways for contaminants between its deposition to surfaces, and its concentration in apex aquatic feeders are very poorly known (AMAP, 2002).

Environmental impacts

Chemical pollution

Heavy metals

Metals are naturally occurring elements. They are found in elemental forms and in a variety of other chemical compounds. Each form or compound has different properties, which affect how the metal is transported, what happens to it in the food web, and how toxic it is. Some metals are vital nutrients in low concentrations.

The metals raising most concern in the Arctic are mercury and cadmium. They have no known biological function but bioaccumulate, can be toxic in small quantities, and are present at high levels for a region remote from most anthropogenic sources.

The rise of the sun after the polar winter is a time of celebration in the Arctic. The lengthening days herald warmer weather and the return of migratory animals. But the recent discovery that the Arctic may be an important global sink for atmospheric mercury casts a shadow over polar sunrise (AMAP, 2002).

Each spring, a substantial amount of airborne mercury is deposited on Arctic snow and ice as a result of reactions spurred by sunlight (AMAP, 2002; Macdonald et al., 2003). Once in the snow, some of the mercury is present in reactive, biologically available forms. As the snow melts, some of the mercury can enter the food web just as the burst of spring productivity begins, a time when life in the region is vulnerable.

In mammals, mercury causes nerve and brain damage, especially in foetuses and the very young (AMAP, 2002). It can also interfere with the production of sperm. In birds, high levels of mercury can cause erratic behaviour, appetite suppression, and weight loss. At lower levels, egg production and viability are reduced, and embryo and chick survival are lower. Outside the Arctic, some seabirds show signs of kidney damage from accumulated mercury. Fish exposed to high mercury levels suffer from damage to their gills and sense of smell, from blindness, and from a reduced ability to absorb nutrients through the intestine. Plants with high concentrations of mercury show reduced growth.

Sonne-Hansen et al. (2003) compiled the available knowledge of contaminant effects in the Greenland environment. Although histopathological changes were observed in 10% of the ringed seal kidneys these were not specific enough to be concluded as cadmium induced. No demineralisation in the skeletal system could be linked to cadmium levels and/or nephropathological changes in selected ringed seals from northwest Greenland with high cadmium levels in the kidney. Furthermore the degree of mineralisation of the skeleton was not correlated with gender but was highly significant correlated to age.

The knowledge of heavy metals in the Greenland environment is summarised in Table 2.

Persistent organic pollutants (POPs)

The evidence that persistent organic pollutants affect Arctic wildlife is accumulating (AMAP, 2002). The class of POPs covers a large number of chemicals with some common characteristics that make them potential problems in the environment. By definition, POPs are persistent, which means that they break down slowly in the environment. Persistent chemicals are more likely to be transported over long distances and reach remote regions such as the Arctic. Once in the Arctic, some compounds may last even longer in the cold and

Table 2 Heavy metals in the environment in Greenland.

Heavy metals	
Freshwater environment	Mercury (Hg) concentrations in landlocked Arctic char in Greenland are relatively high especially in southwest Greenland. No significant difference was found in Hg concentrations in Arctic char from southwest Greenland between 1994/95 and 1999.
Marine environment	Recently observed cadmium (Cd), mercury (Hg) and selenium (Se) levels in marine biota were generally within the range observed previously in the mid 1980'ies. The recent Cd data confirms the previously observed relatively high level in the marine biota from Qeqertarsuaq (central west Greenland) compared to other Arctic regions. Beside that, no pronounced difference in Cd levels between marine biota from west and east Greenland was observed. Hg levels tended to be higher in east Greenland than in west Greenland for shorthorn sculpin, black guillemot (egg) and ringed seals, whereas polar bears appear to show the opposite pattern. Only few time series of Cd and Hg data covering the recent 20 years are available so no firm conclusions can be made concerning trends. Cd in ringed seals from Avanersuaq and Ittoqqortoormiit tended to have lower levels in 1994 and 1999/2000 than in the mid 1980'ies. In Qeqertarsuaq Cd levels tended to be higher in 1994 than in 1999/2000 in ringed seals, and Hg concentrations in blue mussels and ringed seals tended to have higher levels in 1994 than in 1999. In Avanersuaq, Hg levels in ringed seals showed an increasing trend from the mid 80'ies to mid 90'ies and again to 1999/2000. In Ittoqqortoormiit, no apparent trend in Hg levels was observed in ringed seals and polar bears. Seabirds hunted with lead shot have significantly elevated lead levels in their muscle tissues. This probably constitutes the most important single lead source in Greenland human diet (Johansen et al., 2004). Greenland marine sediments are not enriched by arsenic as reported for large areas of the Barents Sea.

(Source: Riget et al., 2003a,b)

dark environment than they would in more temperate climates (e.g. Jacobsen et al., 2003).

Many POPs are taken up by organisms, either directly from their surroundings or via food. If the chemicals cannot be broken down or excreted as fast as they are taken up, they will accumulate in the organisms' tissues. Most POPs are poorly soluble in water but readily soluble in fat and therefore become concentrated in the fat of animals. At high enough levels, many POPs can have adverse effects on wildlife and on human health, including effects on reproduction, development, and resistance to disease.

POPs have a range of potential effects on animals. A sensitive target is the immune system, where new information reveals that effects are apparent among some Arctic populations of polar bear, northern fur seals, and glaucous gulls. Current contaminant levels may also pose a threat to reproduction and brain development in wildlife. POPs interacting with hormones, especially during development in the womb or at a very young age, is probably a common link between many effects. The knowledge of POPs in the Greenland environment is summarised in Table 3.

Other contaminants of concern

Up to now the main focus on long range transported POPs has been on strongly hydrophobic organic pollutants such as polychlorinated biphenyls (PCBs) and chlorinated pesticides. Due to the hydrophobic character of the compounds they will primarily be linked to organic matter of similar polarity and thus be likely to concentrate in sediment and/or to accumulate in animal lipids. The compounds have been found to bioaccumulate in animals and the highest levels are found in the top predators of the Arctic. As marine food, including tissues from the top predators, contributes significantly to the diet of many people in the Arctic, humans are exposed to a high intake of organochlorines and metals, which may affect their health.

However, other groups of organic chemicals could also be of concern in the Arctic (Table 4). Brominated and fluorinated compounds are examples. These compounds have many physical and chemical properties in common with their chlorinated counterparts and can therefore be expected to increase in the Arctic environment in the same manner as the chlorinated substances. Some compounds might be more persistent at higher latitudes than further south. This may be a problem if the compounds are toxic at very low concentrations.

Radionuclide pollution

Concentrations of ^{99}Tc, ^{137}Cs and ^{90}Sr in seawater are decreasing in the order North East Greenland and the coastal East Greenland Current > Southwest Greenland > central West Greenland and Northwest Greenland > Irminger Sea ~ Faroe Islands (AMAP, 2002; Riget et al., 2003b). This is caused by the general large-scale oceanic circulation combined with European coastal discharges and previous contamination of the Arctic Ocean. The same tendency is seen in marine biota. The peak ^{99}Tc discharge from Sellafield 1994-1995 has

Table 3 Persistent organic pollutants (POPs) in the environment in Greenland.

POPs	
Freshwater environment	Organochlorine (CO) levels in landlocked Arctic char were in the same range as found in marine fish species. No consistent geographical pattern of OC concentrations was observed. Concentrations of ∑DDT, ∑HCH and ∑CHL were lower in a southwest Greenland Arctic char population in 1999 than in 1994. No significant changes were found of ∑PCB-10 and HCB concentrations between 1999 and 1994.
Marine environment	In marine fish the highest organochlorine (OC) levels were found in bottom fish-eating species such as Greenland halibut. In seabirds, the highest OC levels were found in opportunistic feeders such as glaucous gull and in species wintering off North America and Europe such as kittiwake. The highest OC levels in marine mammals were found in narwhals, beluga and polar bear. Considerable evidence now exists of higher OC levels in marine biota from east Greenland than from west Greenland. In general, OC levels in biota from west Greenland were comparable with OC levels found in similar species from east Arctic Canada, whereas biota from East Greenland were intermediate the levels in west Greenland and Svalbard or at the same level as found in Svalbard. Circumpolar patterns of ∑PCB, ∑DDT, ∑CHL in ringed seal, minke whales and polar bears generally increase eastward from east Arctic Canada, west Greenland to east Greenland and Svalbard, whereas the opposite trend was found for ∑HCH. OC concentrations in biota from Qeqertarsuaq showed no consistent changes from 1994 to 1999/2000. In shorthorn sculpin from Ittoqqortoormiit ∑PCB and ∑HCH were significantly lower in 1999/2000 than in 1994. This was also the case ∑HCH in male ringed seals. In polar bears from Ittoqqortoormiit in 1999/2000, ∑PCB and ∑CHL levels were considerably lower than in 1990.

(Riget et al., 2003a,b)

Table 4 Other contaminants of concern.

Other contaminants	
Tributyltin (TBT):	TBT and degradation products were detected in the marine environment in mussels sampled outside Nuuk and in harbour sediments. The TBT levels in mussels were low compared to Danish coastal waters.
Dioxins, furans and coplanar PCBs:	Dioxins, furans and coplanar PCBs were detected in polar bears. Compared to marine mammals in other Arctic regions the concentrations were relatively low.
Toxaphene:	Toxaphene concentrations in the Greenland marine biota were within the range observed in other Arctic regions. Toxaphene levels in Greenland terrestrial biota were lower than in marine biota. The highest toxaphene levels were found in marine mammals especially narwhals.
Chlorobenzene:	The highest chlorobenzene concentrations were found in blubber of narwhal and beluga. The by far dominating chlorobezene in Greenland biota is hexachlorobenzene (HCB).
New chlorinated pesticides:	The highest levels of aldrin, dieldrin, endrin, heptaclor, endosulfan, methoxychlor and mirex were comparable to levels detected elsewhere in the Arctic. Data on levels of endosulfan and methoxychlor, two chlorinated pesticides still in use, in Arctic biota are sparse. The concentrations found were lower than observed in more industrialised parts of the world.
Polybrominated diphenyl ethers (PBDE):	PBDEs are found in all organisms analysed, as a result of not only long-range transport but also local sources. The concentrations measured are lower than found in industrialised parts of the world and below levels that can acutely affect organisms detrimentally.
Polycyclic aromatic hydrocarbons (PAH):	PAH levels in south Greenland are of the same magnitude as levels measured in more urbanised parts of the world, even exceeding the EAC values (OSPAR) for e.g. anthracene. The highest levels were found in fish, e.g. shorthorn sculpin indicating a higher potential for bioaccumulation than seen in the temperate zone.
Contaminants of future concern:	The compound groups PFOS, synthetic musks, polychlorinated naphthalenes, other brominated flame retardants (HBCD, TBBPA and PBB), polybrominated dibenzodioxins and dibenzofurans, aromatic amines and the biocide triclosan are examples of high volume chemicals of high international concern found in the environment at lower latitudes. Studies have indicated the presence of some of these compounds in the Arctic.

Pécseli et al. (2003) analysed a range of compounds not previously included in the Danish AMAP programme. Their conclusions are given in this Table. According to Pécseli et al. (2003) the groups of contaminants considered are not new strictly speaking. The group of polycyclic aromatic hydrocarbons (PAHs) has for instance been analysed in the environmental samples from Temperate Zone for the last thirty years but data from the Arctic are sparse. Other compounds have not been analysed previously in samples from Greenland.

only been slightly visible in year 2000. Although, the concentrations are expected to increase in the future, especially in East Greenland, this issue is not considered a problem of concern, and it will have no impact on the biota now or in the future.

On 21 January 1968 a B-52 bomber carrying four nuclear weapons crashed on the ice in Bylot Sound near Thule, North Greenland. The impact triggered conventional explosives, which led to fragmentation of the nuclear weapons on board, and the plutonium spread over the ice. Not all the plutonium was recovered (one bomb is still missing), and an unknown amount fell to the bottom of Bylot Sound. In the plutonium contaminated Bylot Sound, biological activity has mixed plutonium efficiently into the 5-12 cm new sediment resulting in continued high surface sediment concentrations 3 decades after the accident in 1968. Transfer of plutonium to benthic biota is low – and lower than observed in the Irish Sea. This is supposed to be caused by the physico-chemical form of the accident plutonium. A recent study indicates that "hot particles" hold considerably more plutonium than previously anticipated and that the Bylot Sound sediments may account for the major part of the un-recovered amount, i.e. around 3 kg (Riget et al., 2003b). However, transfer of plutonium to the biota is low and at present not considered a problem of concern. Riget et al. (2003b) recommend that the plutonium contamination should be monitored regularely, e.g. every 5 years.

Oil spills

Oil exploration in Greenland (regions 1, 15, and 16) is likely in the future. However, the Arctic is particularly vulnerable to oil pollution. The speed with which oil spills disappear depends on the type of oil and various climatic and biological conditions: winds, currents, temperatures, light, and microbial activity (bacteria). Oil is a mixture of hundreds of different carbon compounds. The simplest of them usually evaporate rapidly, but because temperatures in the Arctic are low, evaporation takes place slowly. The oil products used by communities in Greenland is mainly light oils which relatively fast disperse or evaporate if they are spilled at sea, while the worst environmental threat is the heavy crude or heavy fuel oils where oil slicks can persist on the ocean surface or in pack ice for many weeks. Oil spills at sea can be deadly for many animals and large marine spills has the potential to affect sensitive populations (Mosbech et al., 1996, 1998; Mosbech, 2002). According to Mosbech (2002), a large spill of crude oil or heavy oil in Greenland could lead to long-term contamination of certain habitats.

There is now one offshore oil exploration license and an increased level of offshore oil exploration is expected. In relation to oil exploration, and oil production and transport of crude oil, careful planning of activities and oil spill contingency preparedness can minimise the environmental risk related to oil spills. However, the risk cannot be eliminated and efficient response to an oil spill in heavy seas or in pack ice is still a technological problem. Because of the risk of oil spills one should develop strategies for long-term monitoring programs to assess oil concentrations and effects in the environment in case of a spill. This would consist primarily of performing chemical analyses on oil composition and monitoring of oil induced stress on biota.

A Circumpolar assessment of "Petroleum Hydrocarbons in the Arctic" has been initiated by the Arctic Council and is planed to be finished in 2006. It is planned to be a comprehensive and wide-ranging assessment of the environmental impacts of oil and gas developments in the Arctic, and of pollution of petroleum hydrocarbons and PAHs from other sources, also including possible impacts on human health.

Solid wastes

Pollution with solid wastes was locally considered a minor problem in the towns and settlements. It is, however, a problem for most of the towns, and in several of the towns combustion plants have been established in order to reduce the solid waste problem, and instead produce heat for warming of houses. This has contributed to solving one problem, but there have been reporting of local pollution due to fumes and potentially also contaminations with dioxins due to combustion plant management problems, i.e. maintenance of a suitable combustion environment in the oven (Pedersen, 2002).

Similarly ongoing and abandoned military installations and base activities add to the potential pollution level (Glahder et al., 2003). Abandoned materials, extensive use of paints with PCB's, and large number of drums with oil residues and undetermined substances both add to the health hazards in connection with cleaning activities, and contaminations of the surrounding environment (Rasmussen and Jensen, 2000; Glahder et al., 2003).

Suspended solids

Pollution from mining activities includes contamination in connection with exploration activities, production activities, and due to waste materials from abandoned mines. With only one small gold mine in South Greenland, and most of the exploration activities taking place far from other human activities, they only contribute marginally to the pollution risks. Similarly the abandoned mines only contribute locally to the pollution level and contaminant levels at these are decreasing (Johansen and Asmund, 1999). However, at three closed mines, at which environmental monitoring is conducted, lead pollution from the mining operations (ore, waste rock, and concentrate handling) still is important (Johansen and Asmund, 1999, 2003).

Microbiological

No known impact.

Eutrophication

No known impact.

Thermal

No known impact.

Socio-economic impacts

Economic impacts

Pollution can seriously affect the economy if natural resources became polluted with contaminants. Greenland's main exporting income is from fish and shellfish export, and an important trademark is the clean products from a pollution free sea. In case of oil spill and other types of contamination this reputation may be threatened and result in much lower prices (Friis and Rasmussen, 1989; Rasmussen, 1998e). At present this is not considered a problem of concern, but future oil spills may have a negative impact on the Greenland economy. However, oil activity also has a positive impact on the economy.

Human health impacts

Food is the major exposure route for contaminants in the human Arctic populations. The combination of environmental conditions and biomagnification in the marine food webs result in accumulation of certain persistent contaminants in traditional food of the Greenland people. As a consequence Greenlanders are much more highly exposed through the diet than most populations in the temperate zone (AMAP, 1998, 2002, 2003; Deutch and Hansen, 2003). The AMAP, Human Health, monitoring programme has recently been extended to cover all geographic regions of Greenland (Table 5).

Although levels of mercury (Hg), cadmium (Cd), and persistent organic pollutants (POPs) are relatively low compared to industrialised areas, these compounds are of concern because of their ability to bio-magnify, and because in Greenland marine mammals and seabirds constitute a significant part of the human diet. The cold Arctic climate seems to create a sink for certain pollutant compounds. The high concentrations of contaminants, heavy metals (especially Hg, and Cd), and POPs found in fish, seabirds, marine mammals, and humans, causes concern for animals

Table 5 Human health impacts of contaminants in Greenland.

Human health
A geographical survey has revealed that the highest human blood levels of POPs in particular of PCB are to be found in East Greenland, with close to 100 % in excess of the Canadian blood-guidelines for PCB-aroclor1260 for both men, women of fertile age, and pregnant women. Exposures to methyl mercury are more geographically uniform. In several areas close to 100% of the samples exceed the blood concentration corresponding to the strict US-EPA guideline and a considerable part also exceeds the WHO guidelines. Selenium gives some protection against the toxic effects of some forms of mercury. Selenium intake through the diet is high among Greenlanders, however, there is at the moment not sufficient information on a protective effect against POPs and methyl mercury. It has so far not been possible to assess time trends in POPs exposure, due to too short an observation period. There are no indications of declined exposures to methyl mercury, whereas the blood levels of lead are continuing to decrease. New data on contaminant concentrations in animals used for food, in combination with improved dietary surveys have made exposure estimates possible with identification of species and organs with the highest contributions to human exposure. On country wide basis seal blubber followed by whale blubber are the predominant sources of POPs whereas seal meat is the main source of methyl mercury. However, in areas where polar bear is consumed that can be a major additional source of POPs. It is known that POPs negatively influence the immune system. As the exposure to POPs in some Greenland districts is among the highest ever measured it is reasonable to expect an influence on the immune status in these populations. As POPs are only one of several influential factors, causality is difficult to establish in these small populations. There is no epidemiological evidence from Greenland to correlate pregnancy outcomes, neonatal mortality, or prevalence of infectious diseases to POP exposure. No overt health effects of endocrine disrupting POPs have so far been confirmed. The exposure level is very high in some communities, in excess of e.g. Canadian guidelines. Because the possible effects should be viewed in a perspective of several generations the present situation warrants public health measures to be taken in order to reduce the exposure without jeopardising the nutritional values of the traditional diet.

(Deutch and Hansen, 2003)

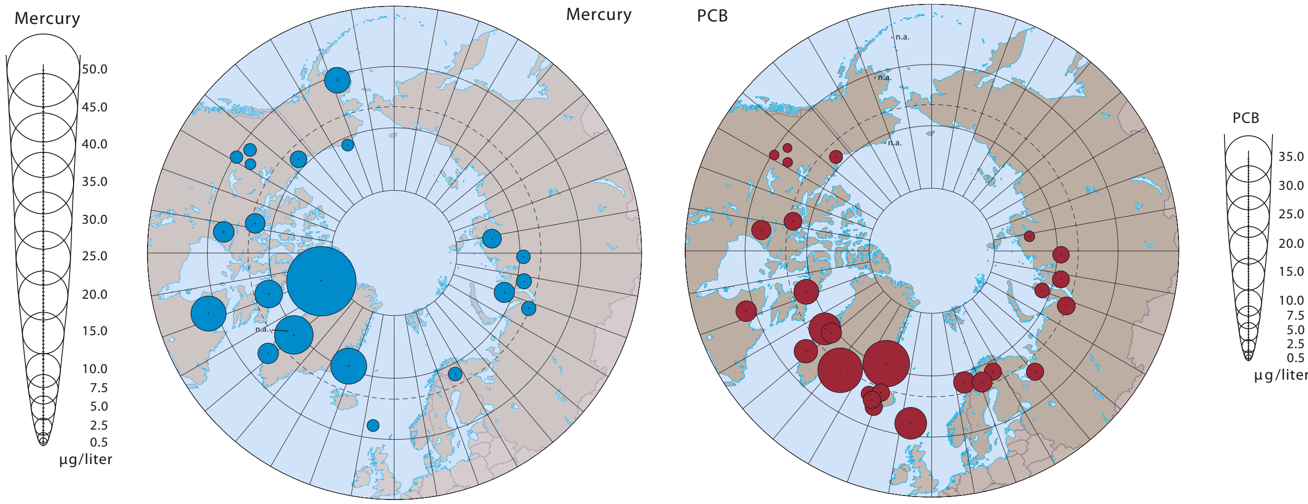


Figure 9 Mercury (left) and PCB (right) concentrations in human blood.
(Source: AMAP, 2002)

and human health in Greenland (Figure 9). The present levels of mercury and some POPs in sea animals have a negative effect on the health of Greenlanders, because these animals are an important part of their diet (Grandjean et al., 1998; AMAP, 2002, 2003; Deutch and Hansen, 2003).

In Greenland, diet is the main source of exposure to most contaminants. Dietary intake of mercury and PCBs exceeds established national guidelines in a number of communities in Greenland, and there is evidence of neurobehavioral effects in children in some areas of the Arctic. In Greenland, a local public health intervention has achieved a reduction of exposure to mercury by providing advice on the mercury content of available traditional foods. The physiological and nutritional benefits of traditional food support the need to base dietary recommendations on risk-benefit analyses. The health benefits of breast-feeding emphasise the importance of local programs that inform mothers how adjustments within their traditional diet can reduce contaminant levels in their milk without compromising the nutritional value of their diet.

Other social and community impacts

A suggested change in diet to reduce human contaminant intake will affect lifestyle and culture of people in Greenland (see Deutch and Hansen, 2003).

Conclusions and future outlook

For the Major Concern Pollution as a whole, the present levels of environmental impact were considered to be of a moderate degree. A major concern is long range transport of contaminants, which are bioaccumulated in tissues of animals, and because these are important local diet items, both animals and human health might be affected.

Over the next 20 years, environmental and human health impacts from pollution are considered to remain moderate or to be increased, unless strict regulations and internationally adopted environmental protection measures are implemented (see The Arctic Monitoring and Assessment Programme: Recommendations in AMAP, 2002, 2003).

Over the next 20 years pollution of radio-nuclides and oil spill have a potential to increase, e.g. due to leakage from radioactive waste stored in interim depots (outside Greenland) and offshore oil activities, respectively. Increasing shipping, oil exploration, and the transport of oil have heightened the risk of oil spills. Other local environmental pollution issues were considered of no or little concern today and in 20 years.

Habitat and community modification

Since the two issues are closely connected, the assessment focused on the modification of ecosystems or ecotones. This issue was considered to have a moderate environmental impact.

Environmental impacts

Global climate change

The recent significant reduction in sea ice cover in East and North Greenland and the increase in ice cover observed in some areas of West Greenland are most probably related to warming and global climate change (Serreze et al., 2000; Johannesen et al., 2002; Stern and Heide-Jørgensen, 2003). Increased open water period will increase annual pelagic primary production and food production for higher trophic level animals in a wide range of Arctic marine areas (Rysgaard et al., 1999, 2003).

The reduction in sea ice and increased open water period may be a benefit to some marine mammals e.g. Atlantic walrus which may get improved feeding conditions (Born et al., 2003). However, polar bear may have reduced habitats and feeding areas (Wiig et al., 2003).

North and East Greenland (region 1 and 15)

In Northeast Greenland the expected global warming is predicted to result in severe changes and in reductions of ice thickness and prolonged open-water periods – up to halving in the fjords and a doubling of the ice-free period (Johannesen et al., 2002; Ryesgaard et al., 2003). As a result, more light will penetrate down in the water column, which will stimulate the production of both plankton algae and bottom-living algae. However, the increased precipitation (snow) will impair the light conditions in the ice in early spring and probably have an adverse effect on the production of sea-ice algae and the animals that benefit from the early production. All in all, however, production is predicted to increase (Rysgaard et al., 1999, 2003; Meltofte et al., 2003).

Algae, water copepods, mussels, and walruses

An increased freshwater supply as a consequence of increased precipitation and melting of the ice cap in the inner parts of the fjords is likely to increase the water exchange in the fjords and bring more nutritious water in from the open sea and thus contribute still further to increased primary production. The increased production is predicted to have a powerful effect in the top levels of the food chain. Today, water copepods (crustaceans that live on algae) are limited by food (Rysgaard et al., 2003), and stimulation of plankton production will immediately mean increased grazing and growth of copepods).

Figure 10 Polar bears live in ice-covered fjords and seas, their most important prey being ringed seals. It has been estimated that the polar bears of Baffin Bay and Davis Strait eat about 160 000 ringed seals each year.
(Source: Born and Bøcher, 2001) (Photo: Oliver Gilg)

Sedimentation of the copepods' faeces will therefore increase, thereby increasing the quantity of food for bottom-living animals. This will, for example, increase growth in mussels, which are today very limited by food. The increased mussel growth will benefit for example walruses (Born et al., 2003). Rising winter temperatures will mean that the ice does not reach the same thickness as today and will therefore break up earlier in spring and that the walruses could seek food on the mussel banks for longer periods.

*Problems for polar bear*s

The polar bear, on the other hand, is facing an uncertain future in East Greenland. The effects of global warming on East Greenland polar bears have not been documented. However, with reference to what has been found in other parts of the Arctic (e.g. Hudson Bay and Svalbard) polar bears in East Greenland may be negatively affected (Lunn et al., 2002; Wiig et al., 2003). In areas where the ice disappears fast it reduces the bears' hunting grounds and the bears' will probably follow the ice northwards. However, another possible scenario is that starving bears seek land and become an easy hunting target for bear hunters (E.W. Born, Greenland Institute of Natural Resources, pers. comm.). Seals, which are attached to the ice, will presumably become concentrated in smaller areas with ice and may therefore be more easily accessible to the bears, but in the longer term, the number of bears will decrease. In addition, the polar bears are not good at hunting seals in water.

Fish

Rising surface temperatures will also have a major effect on the composition of fish in the high-Arctic zone (i.e. region 1). In the case of Arctic char, reproduction ceases when the temperature rises above 5°C because the enzymes in the egg sacs denature when the temperature is just a little over 5°C. As a result, the eggs rot in the body and the fish dies. At the same time, a number of Arctic fish species will be more exposed to parasites and bacterial and fungal attack, and their immune defence system will be reduced with rising temperatures.

Crabs, copepods, and sea birds

There are no crabs in areas with temperatures below 0.5ºC, which characterises large areas off East Greenland. The temperature rises in the future will perhaps mean that crabs will migrate into the area and thus distinctly change the composition of bottom-living fauna. According to Soto (2002) temperature directly affects the metabolic rate and

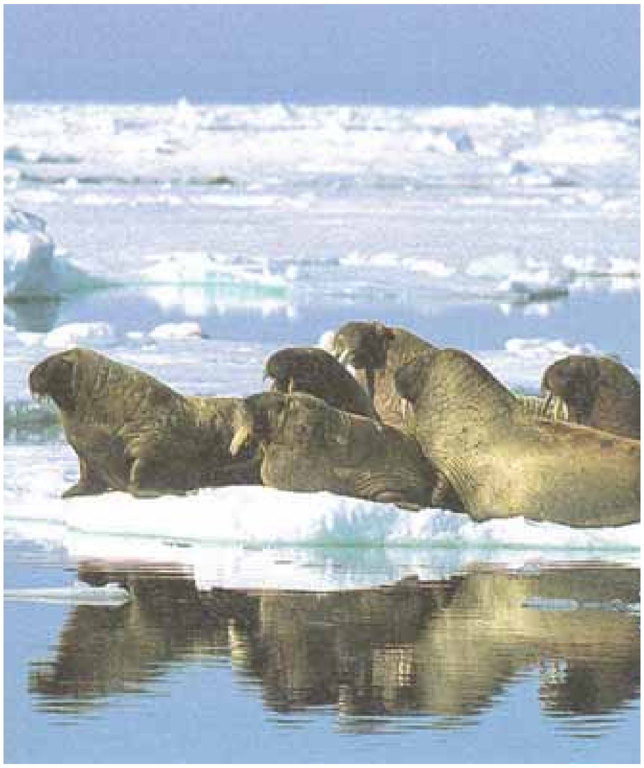


Figure 11 Walruses occur in coastal waters. They often rest on small, sturdy ice floes. Thus, these floes are part of their habitat.
(Source: Born and Bøcher, 2001) (Photo: Lars Åby)

other physiological features such as growth rate and incubation time on invertebrates and fish. Increased temperatures increased growth rate, while decreasing incubation time (Soto, 2002), the direct effects of temperature on the species will change species compositions in the systems.

Another marked change that could happen is a change in currents, so that North Atlantic seawater containing a smaller species of copepod *(Calanus finmarchicus)* could penetrate areas that are today dominated by polar water with larger and longer-living species of copepod (*C. glacialis and C. hyperborus)*. If *C. finmarchicus* ousted the larger species it will have very serious consequences for little auks, which breed in millions in the Thule area and around Scoresbysund, and which are specialised in foraging along the edges of ice with high concentrations of food animals (Egevang et al., 2003). The little auk lives almost exclusively from the large species of copepod and can probably not sustain on the smaller species (Egevang and Falk, 2001). Conversely, the Atlantic guillemot may be able to immigrate in large numbers, just as a number of other sea bird species may benefit from the increased marine production and the reduced ice cover.

West Greenland (region 16)

Sea ice and open-water refugia are of crucial importance for marine productivity and the occurrence, distribution and abundance of sea birds and marine mammals in the Arctic marine ecosystems of the Northwest Atlantic (Heide-Jørgensen and Laidre, 2004). The timing and extent of primary production is strongly related to the ice formation. Late break up of sea ice may delay phytoplankton production and modify connections between phytoplankton and copepod grazers that ascend from the depth at specific times of the year. In Disko Bay, West Greenland, the behavioural adaptations of *Calanus* spp. to climate change may have strong effects on the food web structure, generating trophic cascades and eventually influence sea birds, marine mammals, and the fisheries (Hansen et al., 2003). The cascading effects of sea ice coverage and marine productivity on the Arctic trophic web is difficult to assess in remote areas. According to Heide-Jørgensen and Laidre (2004) both the cetaceans (Bowhead whales, narwhals, and belugas) and sea birds (king and common eider, little auk, thick-billed murre) are vulnerable to an increase in sea ice and decrease in open water, as observed during the last decades. For example the migrating cetaceans are vulnerable to decrease open-water because they need oxygen after dives that can rarely exceed 25 minutes (Heide-Jørgensen and Laidre, 2004). It seems most likely that the above described decrease in temperature in West Greenland is only a small variation from the general trend in the arctic area of a significant temperature increase in the future.

Fish and shellfish

In the last 30 years, cod and a number of other boreal fish species in South and West Greenland marine waters have decreased substantially as a consequence of generally colder climate combined with unsustainable exploitation. Today, more cold-adapted populations of shrimp, crab, and halibut constitute the main commercial fishing resources in Greenland (Buch et al., 2004). A change in sea currents and a rise in temperature as a consequence of the climate changes are assumed to improve the conditions of life for cod and other boreo-atlantic commercial fish species in Southeast and West Greenland, while impeding arctic species such as Greenland halibut. In addition, a larger cod population will most probably reduce the shrimp population due to predation (e.g. Pedersen, 1994a,b; Pedersen and Zeller, 2001; Hvingel, 2002a). It can therefore be envisaged that there will be a change in the fishing resources from today's dominance by shrimp to dominance by cod under a warmer ocean climate. However, it may be that shrimps and other shrimp habitat associated organisms will be distributed more to the north without a reduction in stock size or productivity. The latter is but one possible and speculative scenario which need to be further investigated.

Resource exploitation

Modification of bottom habitats and community structures in Southeast and West Greenland due to bottom trawl fishery was seem as an environmental problem. The bottom trawl fishery for shrimp in the Davis Strait, West Greenland, is one of the world's largest cold water shrimp fisheries, with an annual catch of about 80 000 tonnes in recent years, corresponding to an area of 16 000 km^2 trawled each year. From other areas of the North Atlantic e.g. direct and indirect effects of fisheries on marine ecosystems has been reported as a major concern (see e.g. Svelle et al., 1997). However, in Greenland no or little data exists to evaluate the extent of e.g. modification of bottom habitats and community structures due to fisheries.

Human disturbance of breeding sites for seabirds was also seen as a threat to local seabird populations. Hunting affects seabird populations not only by killing birds. Delayed effects on fitness may arise due to embedded shots and disturbance factors, such as disruption of breeding activities, interrupted feeding opportunities, displacement from preferred feeding habitats, and increased energetic expenditures due to flying – which eventually may affect body condition and subsequently reproductive success (Merkel, 2002a).

There is no documentation where disturbance impacts on seabird populations breeding in Greenland have been separated from hunting impacts. But experience from other areas show that disturbance is closely linked to hunting activities, both in terms of the activities as such, and also in terms of how birds react to disturbance (e.g. Fox and Madsen 1997, Madsen 1998). Therefore disturbance impacts will be dealt with elsewhere.

Socio-economic impacts

Economic impacts

Large-scale tourism development is generally absent in Greenland, except maybe for Disko Bay where several research projects assess the environmental impact of tourism that has been increasing rapidly over the past few years. Two other existing forms of tourism are expensive tourism in the hunting districts on the one hand, mainly interacting with specially developed services mimicking the traditional hunting communities (Danielsen et al., 1998), and hiking tourism mainly in South Greenland, often connected to rod fishing and farm stays, supplying an additional income to sheep farmers. These services appear not to be influenced by changes in resource usage patterns (Rasmussen and Hansen, 2002). According to Kaae (2003) there is a need for improved interactions between tourism, management of natural resources, and the local societies in Greenland.

Health impacts

No known impact.

Other social and community impacts

No known impact.

Conclusions and future outlook

The knowledge about the way the water ecosystems function is constantly improving, but to predict the biological impacts of the large-scale reductions in ice cover etc., observed in the East Greenland Shelf ecosystems in summer 2002 and 2003, more knowledge on the coupling between physics and biology is needed. These fast changes in the habitats for the Greenland biota will have a high impact on life cycles, productivity, and probability of survival for all animals e.g. polar bears and walruses.

One of the biggest uncertainties in connection with the marine environment in South Greenland is the extent to which the sea currents and thus sea temperatures follow changes in air temperature. The balance between the part of the seawater in Southwest Greenland that comes from the cold East Greenland Current and the warm Irminger Current, and the cold water masses in Baffin Bay and Davis Strait, thus totally determine the ecological conditions off Southwest Greenland, where most of Greenland's human population live.

In conclusion there is a need for development of coupled climate-ocean-biological models and ecosystem based management of natural resources in Greenland waters. A research programme to establish a scientific basis for a long-term ecosystem-based management of natural resources in West Greenland waters was outlined in 2001 (Jarre, 2002). This programme is currently under development and planning by the Greenland Institute of Natural Resources and several other international partner institutes (Greenland Institute of Natural Resources, 2002).

Unsustainable exploitation of fish and other living resources

Environmental impacts

Overexploitation

Fishing

In West Greenland, overexploitation has been reported for Atlantic cod, Atlantic halibut, redfish, wolfish, starry ray, long rough dab (e.g. Buch et al. 1994; ICES, 2003; NAFO, 2003; Greenland Institute of Natural

Resources, 2000). In East Greenland, overexploitation has been reported for Atlantic cod, Greenland halibut, and redfish (ICES, 2003).

Many of the Greenlands fish resources are unstable because temperature limits their distribution. Even small changes in ocean circulations and sea temperatures can have profound effects on species productivity and distribution (see causal chain analysis). At present cod is very sparse in both offshore and inshore areas of West Greenland. ICES recommends no fishing on cod until a substantial increase in recruitment and biomass is evident (ICES, 2003). According to ICES (2003), a recovery plan for both inshore and offshore components should be developed in order to take advantage of strong year classes when they occur and to protect all inshore spawning components. For other fish species such as redfish, wolfish, starry ray, and long rough dab, NAFO similarly recommends no fishing until a substantial increase in recruitment and biomass is evident (NAFO, 2003).

Sea bird hunting

Several species of seabird populations belonging to the West Greenland ecosystem, Brünnich's guillemot, king eider, common eider, and Arctic tern have been reduced due to human activities, and in most cases hunting, egg collection, and associated disturbance has been assigned as the main impact factors (Frich, 1997; Mosbech et al., 1998; Jensen, 1999; Falk and Kampp, 2001; Merkel and Nielsen, 2002; Merkel et al., 2002; Merkel, 2002a,b; Egevang and Boertmann, 2003; Greenland Institute of Natural Resources, 2000). Catch statistics are given in Table 6.

At least 57 000 common eiders are bagged annually in Greenland, which corresponds to app. 12% of the total winter population estimated for West Greenland (Merkel, 2002a). According to a population model (Gilliland et al. in prep.; Merkel, 2002a) the West Greenland winter population can sustain a take of app. 8%. As a consequence of the overexploitation, the model predicts the West Greenland breeding population to decline by 3.2% per year, which is close to survey figures detected at some breeding grounds.

Beluga, narwhal and walrus hunting

In West Greenland the declining abundances of walrus, narwhal, and beluga are believed to be mainly caused by overexploitation (Born et al., 1994; Greenland Institute of Natural Resources, 2000; Heide-Jørgensen, 2001; Heide-Jørgensen and Acquarone, 2002). Catch statistics are given in Table 6.

Of marine mammals the reductions in the Northwest Greenland beluga population have caused concern (Table 7).

Table 6 Reported number of individuals by part-time and full-time hunters, 1996-2000.

	1996	1997	1998	1999	2000
Sea birds					
Brünnich's guillemot	254 728	236 466	221 783	227 121	176 760
Common eider	83 810	76 991	72 109	71 041	61 702
King eider	5 557	4 030	3 362	3 535	2 694
Little auk	64 494	49 220	21 017	25 296	44 871
Small whales					
Narwhal	738	797	822	775	597
Beluga	542	577	746	493	609
Harbour porpoise	1 662	1 550	2 051	1 830	1 607
Pilot whale	67	208	365	115	5
Seals					
Ringed seal	90 309	80 387	82 108	83 453	80 265
Harp seal	74 645	69 663	82 491	95 097	99 847
Hooded seal	9 906	7 500	6 328	7 458	5 834
Bearded seal	2 134	2 349	2 354	2 336	2 695
Harbour seal	256	295	217	148	124
Walrus	305	317	610	311	329

(Source: Namminersornerullutik Oqartussat, 2002)

Table 7 Calculated number of belugas in the area Qeqertarsuaq og Maniitsoq, West Greenland. From aerial observations.

Year	Number of belugas
1982	19 689
1994	10 230
1999	7 941

(Source: Greenland Institute of Natural Resources, www.natur.gl)

Excessive by-catch and discards

Fish

In addition to reported landings one will have to add an unknown amount of unreported fish and shrimp catches discarded at sea. Large amounts of small fish, especially redfish, are discarded or die due to contact with the fishing gear in the sea (e.g. Pedersen, 1995).

Although little quantitative information on the by-catch and discards of fishes in the West Greenland shrimp fishery is available, the considerable fishing effort of shrimp fishery (e.g. 164 000 trawl hours in 2001, see Hvingel, 2002b) seems to affect the demersal fish community (Kingsley et al., 1999; Buch et al., 2004; Siegstad et al., 2003a,b).

Sorting grids (22 mm) have, however, been mandatory in the shrimp fishery since October 1, 2000, in order to reduce the by-catch of juvenile fish. Results of experimental fishing with 22mm sorting grids shows a nearly complete protection to finfish larger than about 20 cm, but poor protection of the smallest fish (Engelstoft et al., 2001). Besides the introducing of sorting grids Greenland shrimp trawling regulations require ships to change grounds by at least 5 miles as soon as by-catch exceeds certain limits. To reduce by-catch and discards in e.g. the Greenland Commercial shrimp fishery, the Greenland Home Rule Government has introduced by-catch regulations and laws, and inspectors onboard large trawlers to ensure that the fishing laws and regulations are enforced.

In 2003, ICES advises that technical measures to avoid the by-catch of juvenile cod in the shrimp fishery should be maintained (ICES, 2003). This advice was partly based on a cod recruitment model which indicates a significant effect on potential stock recovery of even low fishing mortality on pre-recruits.

Sea birds

Current studies indicate that by-catch of eiders in gillnets is a problem during late winter and spring in southwest Greenland. In Nuuk around 16% of all eiders sold at the local market in 2000/2001 originated from gillnet by-catch (Merkel pers.com). Nearly all the by-catch came from the lumpsucker fishery in March and April.

There is also an unaccounted mortality of seabirds wounded by gunshots but not retrieved during hunting. The number of wounded birds, which later die of the wounds is unknown. However, that wounded birds is not uncommon is indicated by the estimate that about 30% of the adult eiders caught as by-catch in gillnets in Nuuk Fjord carry lead pellets from gun shots (Merkel, pers. comm.)

Destructive fishing practices

The high effort of bottom trawling in the Greenland shrimp fishery was considered to have a moderate environmental impact. The main concern was modification of bottom habitats and community structures due to bottom trawl fishery. However, to date no data exists to evaluate the extent of modification of bottom habitats and community structures.

Decreased viability of stock through pollution and disease

In spite of the considerable degree of chemical pollution detailed above, this is at present not a problem of concern for Greenland.

Impact on biological and genetic diversity

Not known – no data.

Socio-economic impacts

Economic impacts

There was some discussions and doubt about the economic score impact of overfishing and discards of small fish and shellfish in the bottom trawl fishery. By-catch and discard data are largely missing However, based on very preliminary trophic modelling and comparisons with experience in similar systems, for example the Newfoundland shelf, it was judged that there was a moderate economic impact (score 2) of by-catch of small fish and shellfish in region 15 and 16.

The fisheries in Greenland are characterised by three main sectors with distinct differences between large-scale offshore, intermediate and small-scale inshore activities. This is not only due to structural and economic patterns, but also caused by political relations of importance for the country's development process. A series of social science studies related to the Greenland fisheries sector were carried out in the 1980s (e.g., Winther, 1988; Roth 1988; Roth 1989; Vestergaard and Christensen 1993; Vestergaard et al. 1993), and business cultures, particularly related to the political wish for further independence, of Denmark, have recently been analysed (e.g., Winther, 2000, 2001).

The large-scale sector dominated by a capital rationale, with concentration and centralisation through large-scale projects and economy of scale as the fundamental mechanisms, giving access to resources otherwise inaccessible, and the major contributor to the national economy.

The intermediate sector of the regional fisheries, partly based on capital rationality, and partly based on a life form which has become a backbone of many of the larger settlements, but also present in many smaller settlements. This sector is important for the regional economies.

Greenland does not a priori appear to be an exception to the general pattern of potentially excessive effort. Continued renewal of the coastal fleet is constantly being discussed in public despite decreasing prices for northern shrimp, and rapidly increasing effort has been documented, e.g., in the fisheries for Greenland halibut and snow crab. In a large, sparsely populated country, incentives that increase the probability of rule compliance have been recognised of overriding importance to the implementation of a management system (e.g., Heilman 1998).

The small-scale sector, relying on small boats, dog-sledges and/or snowscooters, is vital for the small settlements, and constituting the backbone of the cultural heritage, and important for the direct and indirect political attempts to maintain reasonable living conditions for the smaller places. At the same time its contribution to the maintenance of the informal and subsistence sector is certainly not negligible (Rasmussen, 1998c; Caulfield, 1997; Marquardt and Caulfield, 1995).

A general obstacle to a rational evaluation of the different scales of activities is the way the economy of the different sectors of fisheries is perceived. An evaluation of the total output per person (output=Dkr) involved in fisheries (Rasmussen, 1994) demonstrates the dominance of the off-shore fisheries with an outcome 10 times the medium-scale fisheries and 200 times the output of the small-scale fisheries. But an evaluation of the output in relation to the invested capital shows a very different pattern, with the off-shore sector as the least capital efficient activity, the small-scale fisheries being ~1½ times more efficient than the off-shore sector, and the medium-scale fleet the most capital efficient activity being ~2½ times more efficient than the off-shore sector (Rasmussen, 1998a; Rasmussen et al., 1998; Rasmussen, 2000a).

Although the potentials of participatory ownership are emphasised and elaborated (Winther, 2001), concrete examples also exist that highlight the gap between private and cooperative interest in a developing context (Olsen, 2001).

Health impacts

No known impact.

Other social and community impacts

Unsustainable fishery and hunting may lead to 1) unemployment, social, cultural, and economic loss (e.g. Hamilton et al., 2000; Rasmussen and Hamilton, 2001), 2) changes in human diet and lifestyle, and 3) tourism may also potentially be adversely affected, because many tourists expect to see a well-managed, relatively unspoilt nature in Greenland with plenty of wildlife – typically species that are top predators in the respective food webs (Kaae, 2003).

Conclusions and future outlook

The task team experts found unsustainable exploitation of fish and other living resources to have severe impact in East Greenland Shelf (15) and West Greenland Shelf (16), but no impact in Arctic North Greenland (1).

Overexploration and by-catch of fish and shellfish in South Greenland (region 15 and 16) were assessed to have moderate economic impact.

In a preliminary analysis, the Danish government's Advisory Committee on Greenland's Economy, emphasises the importance of optimising the fishery policy in Greenland from a national economics perspective and list a number of issues for which a balanced solution needs to found, e.g. maximising economic efficiency, safeguarding employment and cultural values (Det rådgivende udvalg vedrørende Grønlands økonomi, 2002). A more detailed analysis is presently carried out.

A comprehensive research programme into the structure and functioning of the marine ecosystem in West Greenland, including both natural and social sciences, is currently being developed (Jarre 2002, Greenland Institute of Natural Resources 2002, and see below) in order to contribute towards improved management of human activities in the respective ecosystems.

Modeling and predicting the optimal outcome of exploitation of marine resources depends on many factors of which some of the most important are to be found in good/adequate knowledge about resource dynamics, exploitation (fishing/hunting, technology, gear) and socio-economics. This knowledge is especially important for the Greenland society facing changing climatic conditions, because the dynamics and productivity of marine resources, follows climatic conditions. The dynamic impact on the two main forces on the marine resources, 1) climate and 2) exploitation, are not well described and addressed in the present management of Greenland's marine resources.

Global change

Environmental impacts

Changes in oceanography

Global changes in climate, oceanography, and sea ice, and the possible impacts on marine biota in Greenland have been described and addressed in e.g. Jensen (1939), Smidt (1989); Heide-Jørgensen and Johnsen (1998), Buch et al. (2001), Petersen et al. (2001), Rudels et al. (2002), Johannesen et al., (2002), Buch et al. (2004), Meltofte et al. (2003), Hansen et al. (2003), Stern and Heide-Jørgensen (2003) and Heide-Jørgensen and Laidre (2004). The influence of global change on contaminant pathways to, within, and from the Arctic has been described in Macdonald et al. (2003).

Changes in atmospheric pressures over the past 3-4 decades have caused changes in ocean circulation, water temperatures, sea ice extent, etc, which have generated changes in the marine ecosystems of Greenland.

These changes have been most clearly seen in the changes in the exploited natural resources - from mainly cod fishery before 1970 to a gradually increasing shrimp fishery after 1970 - reflecting a shift in the ocean climate from generally "warm" conditions before 1970 to generally "cold" conditions after 1970 (Figure 12).

The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere. The North Atlantic Oscillation Index (NAO-index) reflects climate changes in the North Atlantic region (Hurrell, 1995; Dickson et al., 2000). During positive NAO phases, the planetary westerly winds intensify, and the North Atlantic storm track shifts to the north. These changes lead to milder conditions in the western Atlantic and east coast of the United States; colder, stormier conditions in the northwest Atlantic and Greenland; and milder conditions in the northeast Atlantic and coasts of northern Europe and Great Britain. In contrast, during negative phases of the NAO, the westerly winds diminish in intensity and the storm track shifts to the south. These changes lead to colder, stormier conditions in the western Atlantic and east coast of the United States; milder conditions in the northwest Atlantic and Greenland; and colder, drier conditions in the northeast Atlantic and coasts of northern Europe and Great Britain.

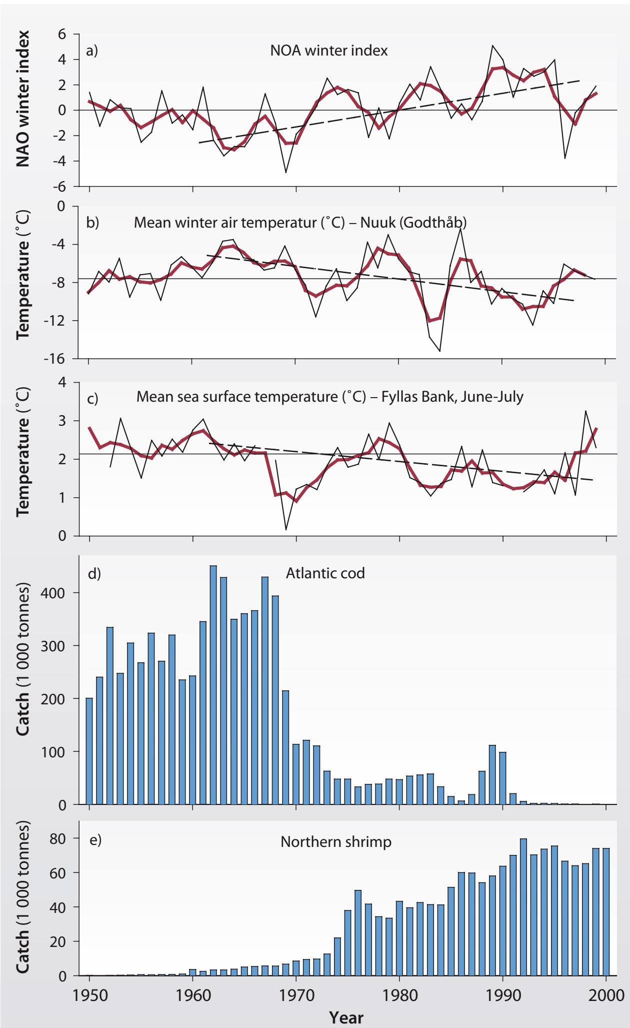


Figure 12 Time series of the winter NAO index (a), winter air temperature (b), sea temperature (c), landings of Atlantic cod (d), and northern shrimp (e) in the West Greenland LME (16), 1950-2000.

(Source: S.A. Pedersen, Greenland Institute of Natural Resources, unpubl.; redrawn from Petersen et al., 2001)

The winter (December-March) NAO-indeces tend to be positively correlated with next year's winter sea ice concentrations in West Greenland, but negatively correlated with next year's sea ice concentrations in Northeast Greenland (Stern and Heide-Jørgensen, 2003).

The warming of the northern hemisphere during the last decades has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods have been observed in West Greenland. These changes have major impacts on species distributions and fisheries as described under Physical characteristics of Greenland and Habitat and community modification.

Sea level change

Only one water level (WL) recorder in Nuuk, West Greenland, has measured WL over a long period. A slight increase in WL since 1960 has been registered, but it is insignificant and of no importance for Greenland (E. Buch, Danish Meteorological Institute).

Increased UV-b radiation as a result of ozone depletion

UV-b mesurements have been made in Greenland over several years. Changes in ozone concentrations have been compensated by an increase in cloud cover and there have therefore been no changes in the UV-b radiation.

Changes in ocean CO_2 source/sink function

The east and west Greenland shelf areas (region 15 and 16) and the Arctic ocean (region 1) are remote areas with few observations of the marine carbon chemistry. However, the open ocean area in the Nordic Seas are one of the globally most efficient regions per area in sequestering CO_2 from the atmosphere (e.g., Takahashi et al., 2002), and therefore significant changes would be expected in the near shore surface pCO_2 field around Greenland and in the Arctic ocean as a consequence of global change, in particular the rising atmospheric CO_2 level. Therefore the assessment is: Some reasonable suspicions that current global change is impacting the aquatic system sufficiently to alter its source/sink function for CO_2.

Socio-economic impacts

Economic impacts

The interactions between climate and human resource use have large socio-economic impact. The combination of climate variation and fishing pressure, for example, proved fatal to West Greenland's cod fishery (e.g. Smidt, 1989; Buch et al., 1994; Horsted, 2000; Hamilton et al., 2000). The socio-economic consequences may differ substantially due to different response patterns, both regionally and sectoral (Rasmussen and Hamilton, 2001). The resilience of the social systems, however, may contribute to solving some of the adverse effects of climate change, for instance enabling a continuous consumption of traditional food products, in spite of attempts to globalise the consumption patterns (Rasmussen, 2002).

Health impacts

No known impact.

Other social and community impacts

For the Greenland society, a warmer climate would probably mean increased fishing in the form of more boreo-atlantic species such as cod, and haddock, but fewer shrimps. The possibilities for hunting ring seals and polar bears would probably be reduced in the long run, while the occurrence of several other game animals would depend more on the pressure of hunting itself. Transport conditions would be much better because the period of open water would be longer, making it easier for boats to call at many towns and villages. There would probably be far less field ice, but on the other hand, a reduced possibility of using the ice to get from place to place. Retraction of glaciers and the ice cap, together with less "Arctic wilderness" could adversely affect the tourist industry, but the improved communication – including a longer summer season – could have a beneficial effect.

Conclusions and future outlook

The task team assessed a moderate impact of global change in the High Arctic, North Greenland (1) and a slight impact in East – (15) and West Greenland (16). The Arctic is vulnerable to global environmental threats, such as the greenhouse effect. Even small changes in average temperatures will probably have profound consequence in an environment where many organisms are adapted to specific distribution patterns of ice.

Although climate change was assessed to have slight impact in East- and West Greenland, decadal climate variability is a very important factor for the distributions and productivity of Greenland's natural renewable resources. Climate is a driving force for habitat modifications and linked to overexploitation of resources and pollution.

In the 20th century Greenland has experienced two great transitions, from seal hunting to cod fishery, then from cod to shrimp fishery, both affected the human population centers of West Greenland and the economy. The economic transitions reflected large-scale shifts in the underlying marine ecosystems, driven by interactions between climate and human resource.

Model predictions of future climate change and its impact on the habitats, communities, living resources, pollution, and socio-economics are needed for Greenland.

Priority concerns

The result of the impact assessments of GIWA issues in the three Greenland regions are summarises in Table 8.

The environmental factors were considered to be far most important and the sum of present and future score were used as the overall score of Major Concern (0 lowest and 5 highest overall score).

Table 8 Prioritisation of impacts of Major Concern at present and in 2020 in Arctic Ocean (1), East- and West Greenland Shelf (15 and 16).

Major Concern	Impact/ Present	Impact/2020	Overall Score	
			Sum	weight%
Arctic North Greenland (region 1)				
I Freshwater shortage	No known (0)	No known (0)	0	0
II Pollution	Moderate (2)	Slight (1)	3	10
III Habitat and community modification	No known (0)	No known (0)	0	45
IV Unsustainable exploitation of fish	No known (0)	No known (0)	0	0
V Global change	Moderate (2)	Moderate (2)	4	45
East Greenland Shelf (region 15)				
I Freshwater shortage	No known (0)	No known (0)	0	0
II Pollution	Severe (3)	Slight (1)	4	30
III Habitat and community modification	Slight (1)	Moderate (2)	3	10
IV Unsustainable exploitation of fish	Severe (3)	Moderate (2)	5	30
V Global change	Slight (1)	Slight (1)	2	30
West Greenland Shelf (region 16)				
I Freshwater shortage	No known (0)	Slight (1)	1	0
II Pollution	Moderate (2)	Moderate (2)	4	20
III Habitat and community modification	Moderate (2)	Moderate (2)	4	10
IV Unsustainable exploitation of fish..	Severe (3)	Moderate (2)	5	50
V Global change	Slight (1)	Slight (1)	2	20

Habitat modification and overexploitation at West Greenland Shelf (16)

Far most of the Greenland population lives on the west coast of Greenland, about 53 000 people. "Unsustainable exploitation of fish and other living resources", "Pollution" and "Habitat and community modifications" were assessed to have severe and moderate impact, respectively. Overexploitation and chemical pollution were given high priority issues partly because harvesting the natural resources is the backbone of the Greenland society and culture. In addition fishing and hunting are the main or only income for many Greenlanders.

Chemical Pollution at East Greenland Shelf (15)

East Greenland is inhabited by only about 3 600 people. "Pollution", "Unsustainable exploitation of fish and other living resources", and "Habitat and community modifications" were assed to have severe and moderate impact, respectively. The system was assessed severely impacted by the issues chemical pollution and overexploitation by offshore fishing vessels from West Greenland and foreign countries.

Chemical pollution was considered to be a high priority problem because contamination of the Greenlanders natural food sources (fish, sea birds and marine mammals) causes human health problems and changes in the Greenlandic life style.

Habitat and Community modification in Arctic North Greenland (1)

Although "Habitat and community modification" was given zero score at present and in 2020, "Habitat and community" modification caused by climate change was considered to be high priority issue under both present and future conditions. The reduced ice-cover and increased open water period in Northeast Greenland and vice versa for Northwest Greenland most probably have a profound impact on the ecosystem dynamics and the unique high Arctic biota (e.g., polar bear, beluga and walrus). However, at present much too little information exists to document these impacts and changes. There is therefore a need for continued and increased research.

Major concern issues were the future changes in climate, melting of sea ice, ice cover, ocean circulation, and the resulting effects on biota, habitats, contamination and ecosystem dynamics. The biota was moderate impacted by chemical pollution. However, very few people live in this region.

Causal chain analysis

This section aims to identify the root causes of the environmental and socio-economic impacts resulting from those issues and concerns that were prioritised during the assessment, so that appropriate policy interventions can be developed and focused where they will yield the greatest benefits for the region. In order to achieve this aim, the analysis involves a step-by-step process that identifies the most important causal links between the environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible and, finally, the root causes that determine the behaviour of those sectors. The GIWA Causal chain analysis also recognises that, within each region, there is often enormous variation in capacity and great social, cultural, political and environmental diversity. In order to ensure that the final outcomes of the GIWA are viable options for future remediation, the Causal chain analyses of the GIWA adopt relatively simple and practical analytical models and focus on specific sites within the region. For further details, please refer to the chapter describing the GIWA methodology.

Introduction

Based on the assessment results it was decided to perform a causal chain analysis of the high priority issues overexploitation, chemical pollution, and habitat modification. Overexploitation and fish/seafood habitat modification were high priority issues in West and Southeast Greenland. Chemical pollution has severe impact in East Greenland and moderate impact in North and West Greenland. Habitat modifications due to climatic change in high Arctic Greenland are a high priority problem.

Climate is a key driving force for problems of overexploitation, chemical pollution and habitat modification and therefore, climate change is of great concern for the biota and Greenland society. However, in the GIWA context, it is considered as an environmental driving force, as it is basically related to activities outside the Greenland region.

Immediate causes

Immediate causes are the direct reasons behind the environmental concerns and issues. It is important to identify the main direct causes as a scientific basis for policies and activities to achieve an improved environment.

Overexploitation and fish/seafood habitat modification in GIWA region 16, West Greenland

Fishing

The main immediate causes of overfishing and the associated habitat modification are a combination of several factors: increasing fishery due to higher efficiency (new catch technology), inadequate resource management, and vulnerable resources due to climate variability. The impact of these factors is illustrated in the historically variable fishery for cod, the former most important fisheries resource.

The cod fisheries decline: The fluctuations in cod populations are well-known, as shown in Figure 12. The presence of cod in Greenland waters has a periodic character. The changes in the temperature conditions in West Greenland in the 20th century generally coincide with the change of the cod fishery, indicating the existence of a relatively strong climatic effect on the cod stock. When biological fisheries research began in West Greenland in 1908-09, only small, local fjord populations of cod were present. A climatic change in the 1920's caused ocean temperatures to rise and during the following years cod became abundant along the coast of West Greenland and they dispersed northward. The general warming of the northern hemisphere around 1920 evidently lead to the establishment of a self sustaining and very abundant West Greenland cod population. From about 1930 to the late 1960s this stock produced good year classes at relatively short intervals. The drastic decline in the cod stock in the late 1960s was attributed to a combination of unfavorable cold climatic conditions and a too high fishing take in the offshore international fishery (Buch et al., 1994; Horsted, 2000). No good year classes were produced by the West Greenland population after the late 1960s due to generally lower and more fluctuating water temperatures in the West Greenland area (Figure 12). All important cod year classes in West Greenland from 1970 to the present time seem to have been of Icelandic origin (Buch et al., 1994). The most recent of these, the 1984 and 1985 years classes sustained relatively high catches during 1988-1990 but evidently left West Greenland thereafter (e.g., ICES, 2003). Today there are only very small local fjord populations of cod in West Greenland.

Increasing shrimp abundance: The Greenland economy, formerly being highly dependant on a rich cod fishery, is today almost entirely dependant on northern shrimp fishery. As seen from Figure 12, the decline of cod fisheries was replaced by a corresponding increase in shrimp fisheries.

In the beginning of the 1970s new deepwater fishing technology made it possible to develop an offshore West Greenland fishery for shrimp. An inshore fishery for Greenland halibut has been taking place in Northwest Greenland fjords since the beginning of the last century. This fishery developed gradually during the 1980s and 1990s and catches are at present around 20 000 tonnes annually.

During the last two decades shrimp and Greenland halibut have been the commercially most important fishery resources in West Greenland. Export of shrimp to e.g. Japan, has provided a high-value economic alternative to cod, comprising 73% of Greenland's total exports in 1995. However, new fisheries on snow crabs, started in late 1990s, and scallops, started in the mid 1980's, and other mainly coastal and local fisheries on cod, salmon, redfish, wolffish, halibut, herring and others are also important for the Greenland society.

Today's low abundance of cod and high abundance of shrimp most probably have the following main causes:

1) *A general cold climate after 1970.* Since 1970 the Greenland climate has been considerably colder than during the more stable warm period between 1920 and 1970. The cold and variable conditions after 1970 have been unfavourable for growth, reproduction and survival of cod.
2) *Continuing absence of the West Greenland cod spawning stock.* The spawning stock at the banks off West Greenland is virtually absent since the collapse in the 1970s.
3) *Reduced inflow of cod larvae from Icelandic spawning grounds.* Since the collapse of the West Greenland spawning stock in the early 1970s, cod stocks at Greenland have been entirely dependant on recruiting year-classes from Iceland. In addition to local production significant inflow of cod larvae from Iceland occurred almost every year in the 1950s and early 1960s; this inflow disappeared thereafter except for the big 1973 and 1984 year classes.
4) *Reduced predation on shrimp.* The low abundance of shrimp predators, mainly cod, but also other fish species has probably improved the survival success and productivity of shrimp in recent years.
5) *Overexploitation of cod.* Fishing mortality on cod has been too high due to by-catch in the shrimp fishery and due to unregulated fishery directed for cod in the fjords. The resource management has been unable to adequately protect the few remaining cod spawning populations during periods of cold climate and low cod productivity.

Apparently, climatic and oceanographic changes play a very important role in the modification of the habitats and in the sustainability of the fisheries sector. This is further aggravated by overfishing in the fragile and highly variable ecosystems (Rätz et al., 1999; Buch et al., 2004).

Changes in the ocean climate are probably the main cause to changes in productivity and structures of the marine ecosystems. For example, for many of Greenland's fish species, the seas off Greenland limit their dispersal, for example, cod, redfish, striped catfish, halibut and herring, which have their northern limit there. Conversely, too high sea temperatures set a southern limit for the dispersal of Arctic species, such as polar cod, and Arctic ray. Therefore, relatively small variations in the temperature of the sea could result in considerable fluctuations in the dispersal and productivity of many fish species, as also observed earlier (Jensen, 1939). The trend in cod distribution by-and-large follows the average sea temperature (Horsted, 2000).

In South Greenland many years of bottom trawling is believed to have impacted species compositions and community structures. By-catch of shrimp predators mainly cod, redfish, Greenland halibut and others in the steady growing fishery for shrimp during the last part of the 20th century has been suggested to be an important factor in the shift from cod dominated to shrimp dominated ecosystems by modifications of habitats and community structures (e.g. Buch et al., 2004).

A general characteristic of the mainly long-lived resources exploited in Greenland waters has been a population structure with many large, old individuals when the fishery begins. However due to slow reproduction and growth rate in cold and/or deep water, the population age structure shifts downwards as fishing intensifies, and the large older fish are removed. This trend has been observed not only with cod, but also with halibut, wolfish, scallops and other species. In the case of isolated stocks, even a short period of overfishing leads to a drastic reduction. For example, some Greenland halibut stocks appear resident in certain fjord complexes, although reproduction occurs elsewhere (Riget and Boje, 1989). Such stocks are particularly vulnerable to overfishing, on the offshore spawning grounds.

Sea bird hunting

The breeding populations of Brünnich's guillemot and common eider have both declined significantly in West Greenland during the 20th century. The immediate cause is ascribed to overexploitation (Kampp et al., 1994; Meltofte, 2001; Merkel et al., 2002). The life strategy of both species are characterised by a slow population turn-over making the stability of the population dependant on a high adult survival. This makes the populations particularly sensitive to exploitation in periods when adult birds are exposed (mainly in spring and summer). The present annual levels of harvest as expressed by the official bag records system is about 84 000 common eiders and. 255 000 Brünnich's guillemots (maximum recorded numbers over the period 1994-2001) (Namminersornerullutik Oqartussat, 2002).

The main reasons for overexploitation in the last century is the increased human population in West Greenland and the technical development of the hunt (more efficient weapons, faster and more far-reaching boats) combined with the low productivity of the exploited species. However, besides the hunting harvest, climatic changes, as for example the extension and duration of winter sea ice, by-catch in gillnets and disturbance (mainly hunting related) at colonies and moulting sites may also have had an impact on the populations.

Since 1930 the breeding population of Brünnich's guillemot has decreased by 80 % in West Greenland, and by 35 - 50 % in Greenland as a whole (Falk and Kamp, 2001; Kampp et al., 1994). Only in the northernmost part of the breeding range (in Qaanaaq in North Greenland) the population seems stable (Falk and Kampp, 2001). The population is migratory, wintering in the open waters of Southwest Greenland and in Newfoundland waters (Kampp, 1988; Lyngs, 2003). In both areas the guillemots are exposed to hunting and significant numbers are taken. But it is difficult to assess the impact on the Greenland breeding population because the winter quarters are shared with Brünnich's guillemot populations from other breeding areas, such as Svalbard, Northeast Canada and Iceland. However, the winter hunt primarily takes juvenile and immature birds, while hunt in spring and summer near the breeding sites mainly takes local adult birds.

In the early 1970s by-catch in salmon gill-nets took huge numbers of Brünnich guillemots in Davis Strait in autumn. This by-catch declined to insignificant levels in the late 1970s, because the salmon quota was reduced and timing and location of the fishery were changed, eliminating much of the overlap with the occurrence of the Brünnich's Guillemots (Falk and Durinck, 1991).

The part of the Brünnich guillemot breeding population wintering in Newfoundland waters is exposed to chronic oil polluting from the heavy shipping activities in these waters (Wiese and Ryan, 2003), but the impact on the population is not known.

The common eider breeding population was very large in West Greenland late in the 1800s, documented by eider down trade figures. As early as in the beginning of the 1900s concern was expressed for the status of the population due to overexploitation (Boertmann et al., 2004). Locally the population has been reduced by 80% since 1960, when the population already was reduced compared to earlier in the century (Merkel and Nielsen, 2002). Exploitation is mainly hunting, and as much as 32% of the hunting bag has been taken in the spring months when the population is particularly vulnerable. The open hunting season has been reduced since 2002. The high hunting pressure is documented by the fact that a high proportion of the common eiders carry embedded lead shots in their tissues (Falk and Merkel, unpubl.). Egg collection and previously also down collection also impact the population as well. Preliminary studies indicate that by-catch in gill-nets (mainly for lumpsucker) also contribute to the mortality (Merkel, 2002b), but the impact is not known. King eiders at moulting sites also show population declines (Mosbech and Boertmann, 1999).

Marine mammals: Beluga, narwhal and walrus hunting

A number of marine mammals have been exploited commercially in Greenland in recent times, either by whalers or by organised hunting cooperations that have sold their products on the national and international market. Subsequently, several species were and are exploited by local hunters whose hunting techniques and economic motivations resemble those of commercial whalers. This has been particularly obvious in cases where the hunting of marine mammals has been part of an overall pattern of exploitation that included fishing. Examples of this are belugas, narwhals, and walruses (Born et al., 1994; Heide-Jørgensen, 2001).

The hunting of walruses in West Greenland during the 20th century is an example of how increasingly efficient hunting methods and lack of regulation may rapidly lead to overexploitation of a group of marine mammals in which the innate capacity of increase is relatively low.

Beginning in 1911, hunting expeditions using government schooners were sent to the walrus haul-outs in West Greenland. Private motorboats soon began to participate in the hunt. The most obvious result of this intensified and uncontrolled hunting pressure was the complete disappearance after about 30 years of walruses from their haul-outs in West Greenland. They have not since returned to these haul-outs.

Since 1932, walruses have also been hunted during the spring in the West Ice off Sisimiut/Holsteinsborg to Aasiaat/Egedesminde and west of Qeqertarsuaq/Disko. The vessels used were likewise partially financed by public funds. The walrus hunt thus had the character of a commercial activity that was subsidised by the government. Great amounts of hides, tusks, and blubber were sold to the Royal Greenland Trade Company, which continued to buy these products long after it became difficult to sell them on the international market. For a number of years catches were very large; in West Greenland alone at least 12 000 walruses were landed between 1900 and 1987. The actual number of animals killed was probably much higher, because not all catches were reported and because many animals sank and were lost during hunting. Furthermore, mainly females with young were hunted in the West Ice because they were more accessible than males. The males preferred to stay in the dense pack ice further offshore. Moreover, during spring females have a relatively greater content of blubber, making them a more attractive commodity.

Even though the decrease of the walrus population in these areas was obvious relatively early, hunting regulations were not introduced until around 1950, finally affording the walruses a certain degree of protection.

The population is still far below earlier levels. Aerial surveys between 1981 and 1994 indicated that during the spring there are less than 1 000 animals in the West Ice between Sisimiut/Holsteinsborg and Qeqertarssuatsiaq/Hare Island. During this period, in which hunting continued, there have been no signs of growth in the stock.

In a "traditional" hunting community without the mechanisms of a market economy, the hunting effort is reduced as soon as the number of animals decreases, allowing the population to recover. This "feedback" regulation mechanism was put out of operation in the case of the walruses of West Greenland, because public funds were used to increase hunting effort and maintain it at a high level, even though there were signs that the population was being overexploited. Today hunting is not self-regulating mainly do to efficient transportation and hunting equipment.

The above historic example emphasises the necessity of monitoring and regulating hunting efforts; this is especially true when it becomes technically and economically feasible to intensify the hunt on a population of marine mammals.

Chemical pollution

Long range transport and climate

The vast majority of chemical pollution in Greenland is due to long-transported contaminants from outside Greenland (AMAP, 2002; Macdonald et al., 2003).

Main sources of marine pollution are the industrialised areas in Europe, Russia and USA (AMAP, 1998, 2002; Christensen et al., 2003). Pollutants are transported to Greenland by the atmosphere and by the marine currents, however, transportation by ice may also play a role. The prevailing patterns of wind direction, especially in winter, transport air masses from industrialised areas to the Arctic (Figure 13). The cold Arctic climate seems to create a sink for e.g. Hg and POPs (AMAP, 1998, 2002; Macdonald et al., 2003; Christensen et al., 2003).

Three major mines have been in production in Greenland, and elevated heavy metal levels have been observed in fjord areas within approximately 40 km from the mine sites (Riget et al., 2000). However, local sources of pollutants in the marine environment around Greenland play a minor role, except for lead pollution from the use of lead shot (Johansen et al., 2004).

Heavy metals

The heavy metals assessment in AMAP focuses on mercury, lead, and cadmium. Of the metals, mercury (Hg) pollution generate the greatest concern because levels in the Arctic are already high, and are not declining despite significant emissions reductions in Europe and North America (Macdonald et al., 2003).

Coal burning, waste incineration, and industrial processes around the world emit Hg to the atmosphere, where natural processes transport the metal. The Arctic is vulnerable because unique pathways appear to concentrate Hg in forms that are available to the food web. Environmental changes may have made these pathways more efficient in recent years. In the Arctic, Hg is removed from the atmosphere and deposits on snow in a form that can become bioavailable. A recently

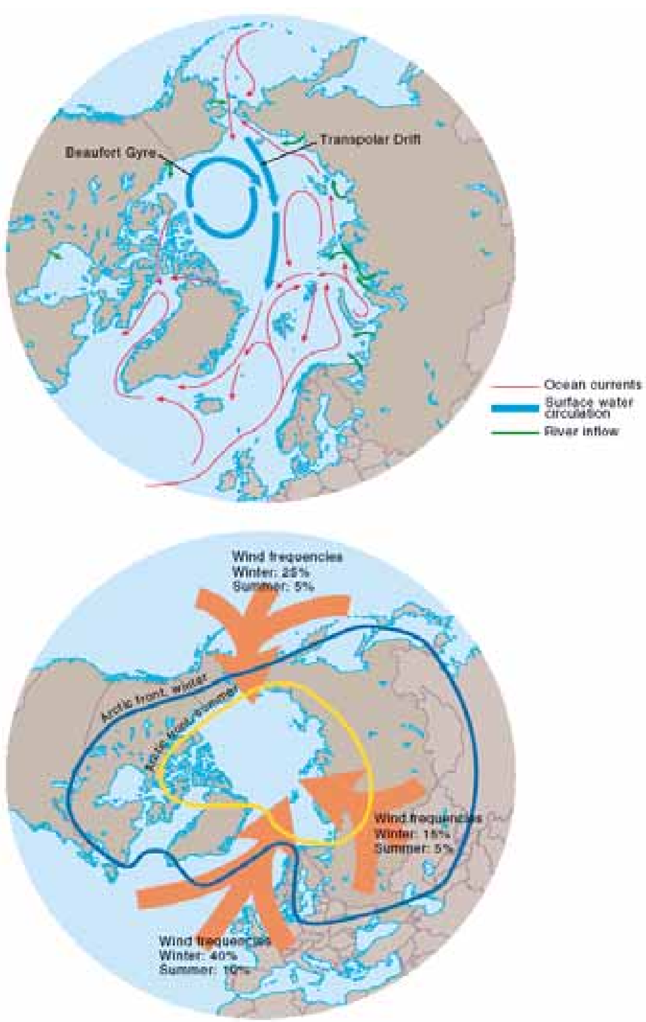


Figure 13 Pathways for pollutants transported to Greenland.
Upper map: Rivers and ocean currents are important pathways for water-soluble contaminants and those that are attached to particles in water.
Lower map: Winds provide a fast route for contaminants from industrial areas to the Arctic, especially in the winter.
(Source: AMAP, 2002)

discovered process links enhanced deposition of Hg to the polar sunrise, which is unique to high latitude areas. The resulting enhanced deposition may mean that the Arctic plays a previously unrecognised role as an important sink in the global Hg cycle (AMAP, 2002). Some of the deposited Hg is released to the environment at snowmelt, becoming bioavailable at the onset of animal and plant reproduction and rapid growth. Although poorly understood, this process may be the chief mechanism for transferring atmospheric Hg to Arctic food webs.

Despite declining anthropogenic emissions, at least in the period between the 1980s and the 1990s, the Arctic ecosystem appears to be increasingly exposed to Hg (Macdonald et al., 2003). It is unclear why this is so because the complete Hg pathway has not been adequately studied. The connection between atmospheric transport and deposition to Arctic surfaces (Hg depletion events) shows the Arctic to possess a unique, climate-sensitive process that may explain much of its susceptibility to Hg contamination. However, the pathway for Hg between its deposition to surfaces, especially following polar sunrise, and its concentration in apex aquatic feeders is very poorly known. AMAP recommends that studies continue on the Hg cycle in the Arctic with emphasis on the processes implicated in Hg depletion events and in the biogeochemical cycling of Hg in ice-covered environments (Macdonald et al., 2003).

POPs

Most of the total quantity of POPs found in the Arctic environment is derived from distant sources (Figure 14). Most POPs are semi-volatile and their transport is complex.

In temperate and tropical regions, they are picked up by the winds as gases. When temperatures drop, they condense onto atmospheric particles and other surfaces, reaching the ground via rain, snow, or direct deposition onto land and water. The role of atmospheric transport varies with the seasons. Generally, atmospheric long range transport to the Arctic from source areas in North America and Eurasia is much higher in winter and early spring than in summer (Macdonald et al., 2003).

The precise importance of ocean transport for each compound depends on the physical properties of the substance (AMAP, 2002; Macdonald et al., 2003). The role of ocean currents in transport is

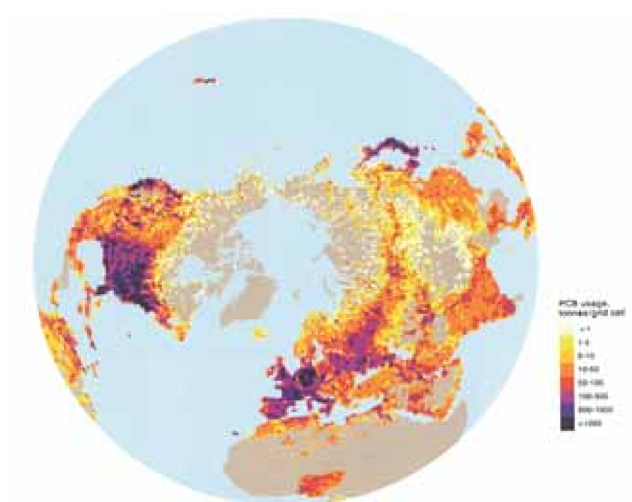


Figure 14 Estimated cumulative global usage of PCBs (1930-2000). Most of the use was in the northern temperate region.
(Source: AMAP, 2002)

probably more important for contaminant levels in the Arctic than was previously thought. Water soluble chemicals that are efficiently removed from the air by precipitation or air-to-sea gas exchange may reach the Arctic primarily via ocean currents.

The POPs are transported to the Arctic by regional and global physical processes, and are then subjected to biological mechanisms that lead to the high levels found in certain species. Given the length and complexity of the POP pathways into top predators of aquatic systems in the Arctic, exposure to these chemicals is particularly sensitive to global change (Macdonald et al., 2003).

Habitat modification in GIWA region 1, Northern Greenland

Climate change

The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere. The last decades warming of the northern hemisphere has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods has been observed in West Greenland (e.g. Stern and Heide-Jørgensen, 2003). These changes have major impact on the marine ecosystems and the habitats for the Arctic animals.

In Northeast Greenland, Rysgaard et al. (1999) expects future increase in the annual pelagic primary production, secondary production, and hence food production for higher trophic level animals in a wide range of Arctic marine areas, as a consequence of reduction and thinning of sea ice cover due to global warming. However, the reduction in sea ice may be a benefit to some marine mammals e.g. Atlantic walruses (Born et al., 2003), but probably not for others e.g. polar bears (Wiig et al., 2003).

In West Greenland, Heide-Jørgensen and Laidre (2004) found the increased ice cover and reduction in open water refugia to be a threat to a number of sea birds and marine mammals.

The above described changes in ice cover and open water occur and impact the habitats of mainly the northern high Arctic areas of East and West Greenland. In these areas the impact of climate change are predicted to be most severe whereas in South Greenland changes in climate are expected to have less impact on habitats and ecosystems.

Root causes

The root causes are the more fundamental reasons behind the direct causes for environmental decline. Experience has shown that addressing the direct, immediate causes is not sufficient to achieve sustainable results. It is equally – and sometimes more - important to identify and consider actions related to the root causes.

Examples of some fundamental root causes are population growth, unsustainable economic development, social and cultural conditions. But lack of knowledge, inadequate governance, and lack of awareness may also be important root causes. Of special importance for the fragile ecosystems of Greenland are the basic root causes related to natural and man-induced climatic changes.

Overexploitation of living resources

Climate change

Overexploitation of fish and shellfish in Greenland is linked to global changes in climate and ecosystem functioning as illustrated in the above description of historic fluctuations in the cod populations and fisheries yields. A more detailed description is given in Buch et al. (2004). Changes in the thermal regime can have a considerable impact on the abundance of fishes and shellfish. Fore example Northern shrimp, snow crab and Icelandic scallop prefer relatively cold temperatures in the range of 1-5°C and especially their larvae are less vulnerable to low temperatures compared to e.g. cod. The better ability of shellfish larvae to cope with low temperature environment partly explain the positive reaction of the shrimp and snow crab stocks to the changed climatic conditions observed in West Greenland in last decades. However, the shift in the underlying marine ecosystems at Greenland may have been amplified by the declining cod stock due to a release in predation pressure on e.g. sandeel and shrimp as observed in Eastern Canada (Koeller, 2000; Lilly et al, 2000).

Inadequate management

An overall difficulty in fisheries and hunting assessment is to assess whether changes in the stocks are due to overexploitation or environmental changes (changes in climate, ocean circulation, turbulence etc.). Up until now the fisheries assessment and the subsequent management methods used have generally been inadequate (e.g. Maguire, 2001).

During the task team meeting in Nuuk a number of root causes for overexploitation of fishes, shellfish, sea birds and marine mammals were mentioned and discussed. They are listed according to the four dimensions of a fishery system as used by the ICES Working Group on Fishery Systems (WGFS, 2003), i.e., scientific, political, related to monitoring, control and surveillances (MCS), and user group related.

(a) Scientific documentation

- Inadequate data: For example for inshore cod.
- No quantitative and analytical biological assessment and advice: For example offshore snow crab.
- Inadequate stock assessment: For example cod. The biological advice for and management of the cod fishery off Greenland is based on a combined assessment of cod in its distribution area East and West Greenland. However, the cod populations in these areas are partly separate and additionally connected to the Icelandic cod stock in a complicated way, resulting in a complex stock structure (e.g., Wieland and Hovgaard, 2002; Stein et al., 2002; Anon., 2003c). The complexity of the stock structure is not considered in the assessment as it is done today by ICES. There is a need for improved assessments by a better use of the available biological and hydrographic knowledge in the assessments not only for cod but also for several other exploited resources of fish, shellfish, sea birds and marine mammals.
- There is a need for improved regional stock assessments by development of coupled models of the dynamic relationship between climate, ocean circulation, and variability in key species abundance not only for cod but also for several other exploited resources of fish, shellfish, sea birds and marine mammals (e.g. Pedersen et al., 2002; Pedersen and Bergström, 2003; Ribergaard et al., 2004; Heide-Jørgensen and Laidre, 2004).

(b) Political constraints

- No regulations or inadequate regulations: This mostly applies to widely distributed fish stocks such as Greenland halibut. Often, inefficient and uncoordinated management measures lead to an uncontrolled and most probably high exploitation of the resource as is the case for Greenland halibut in East Greenland and Iceland. No formal agreement on the management of the shared Greenland halibut stocks exists among the three coastal states, Greenland, Iceland and the Faroe Islands. The regulation schemes of those states have previously resulted in catches well in excess of TAC's advised by ICES.
- The Government subsidises fishing and hunting gear, boats and engines.
- Foreign nations that are non-members of commissions are not restricted by regulations and measures set up by the respective coastal nations or commissions that have taken the responsibility to regulate international fisheries. Examples of this is seen in the pelagic redfish fishery in the Irminger Sea and adjacent areas, where vessels belonging to a member state of the Northeast Atlantic Fisheries Commission, re-flag under a non-member country, thereby avoiding restrictions in the fishery.
- Variable market prize differentiate fishing and hunting pressure on resources.
- Lack of transparency and accountability in the process of balancing between natural resource conservation, social and economic issues. Lack of management plans.
- Partly lack of political will to listen to biological advice.

(c) Administrative constraints

- Lack of control or inadequate control: In the wide areas of the North Atlantic schemes of control and enforcement are most often hard to accomplish, although introduction of satellite devices and a vessel monitoring system have improved control and enforcement substantially.
- Inadequate logbook reporting: For example inshore cod.
- No gear registration and no lost gear registration (in contrast to practice in, e.g., the Faroe Islands), resulting, e.g., in the possibility of ghost fishing by gill nets.
- Inadequate fishery administration: Fishery and hunting controls too costly or not prioritised.

(d) User-group related

- Many local communities and settlements are dependent on the harvest of marine resources because there are no other income possibilities.
- Improved fishing and hunting technology over the years.
- No flexibility in the medium- and large-scale fishery e.g. seasonal shifts in target species.
- Overcapitalisation (e.g., snow crab fishery).
- The need of monetary income (after change of the society to a money-based economy) increases pressure on vulnerable resources.
- Disagreement about the current resource situation between on the one hand biologists and on the other hand fishers and hunters.

Socio-economic problems

A discussion among task team members on root causes revealed the necessity to discriminate between recreational and professional fishing and hunting. For recreational fishermen and hunters a root cause may be inadequate knowledge about the resources and inadequate understanding of the importance of observing rules and restrictions. For local professional fishermen and hunters the main root cause is probably the lack of alternatives to fishing and hunting. In families with annual income of about 50 000 Dkr per family (i.e., well below the poverty line), it is naturally difficult to reduce exploitation and thereby family budgets. Therefore, to rebuild overexploited resources, alternative income possibilities must be offered to the professional fishermen and hunters.

Chemical pollution in East Greenland

Lack of knowledge

In spite of recent progress, in particular due to the findings of the AMAP programme, there are still considerable uncertainties about the sources, the transport mechanisms and the impacts of the arctic food chains of chemical pollutants. In particular, documentation to pinpoint key international causes is needed to form a better scientific basis for reduction of the impacts

Lack of international governance

The major sources for the chemical contamination of the waters and the ecosystems around Greenland can be found in the pollutant releases in Europe, Asia and North America. The only possibility of reducing these sources is a continued focused and significant international effort to control these emissions, and to enforce existing agreements.

Socio-economic conditions

The combination of environmental conditions and biomagnification in the marine food webs result in accumulation of certain persistent contaminants in traditional food of the Greenland people. For many reasons, traditional food still plays an important role in the diet of the population, in particular in the settlements

The consumption of marine mammals, fish and sea birds is high but the young and the population in towns eat considerably less than the elderly and the population in the villages. Seal is the most often consumed traditional food item followed by fish. On average, 20% of the Greenlanders eat seal 4 times a week or more often while 17% eat fish similarly often. Traditional food is valued higher than imported food; the highest preference is given to mattak (whale skin), dried cod, guillemot, and blackberries. Almost all value traditional food as important for health and less than one percent (in 1993-94) restricted their consumption of marine mammals or fish because of fear of contaminants (Bjerregaard, 2003).

Habitat modification

Climate change

The main root cause for habitat modifications in the Northern waters is variability in climate, and hence, global climate change. In addition to the natural variations, anthropogenic climate change is one of the major emerging environmental problems. Although the climate system is complex and large uncertainties exist in the understanding and prediction of climate change, the question is no longer if we will experience climate change, but how large anthropogenic and natural changes will be, how fast they will appear and their regional variations (Jørgensen et al., 2001).

Analyses with global climate models show the following general trend for the climate in Greenland in 2100 in relation to 1990 (Anon., 2003a):

- In South Greenland a rise in mean annual temperature of just over 2°C, slightly more in winter and slightly closer to 2°C in summer, and in North Greenland, a rise in temperature of 6-10°C in winter but only small rises in summer;
- A general increase of 10-50% in precipitation, but little or no increase in Southeast Greenland. In winter, however, a considerably bigger increase in North Greenland, locally up to more than 100%.

Such changes will cause significant impacts on the oceanographic conditions and on the stability of the ice cover. It is questionable if the present arctic ecosystems will be able to accommodate these changes.

Lack of knowledge

There is a considerable lack of both data and understanding of how the arctic ecosystems will react to possible drastic changes in the climate and ice-cover.

Conclusion

Overexploitation of the marine resources, in particular in West Greenland, GIWA region 16, partly due to climate change, inadequate knowledge of the living resource dynamics, and management, and partly due to the ability or inability of the municipality to react and adapt to changes, is a severe problem and one of the large challenges for Greenland now and in the future (Figure 15).

Chemical pollution from outside Greenland is a threat to the biota at higher trophic levels, human health and the culture of the Arctic people, in particular in East Greenland, GIWA region 15 (Figure 16).

And finally, habitat and community modifications due to climate change, but also overexploitation are threats to many unique Arctic animals, (e.g., polar bears, walrus) in particular in the North, GIWA region 1

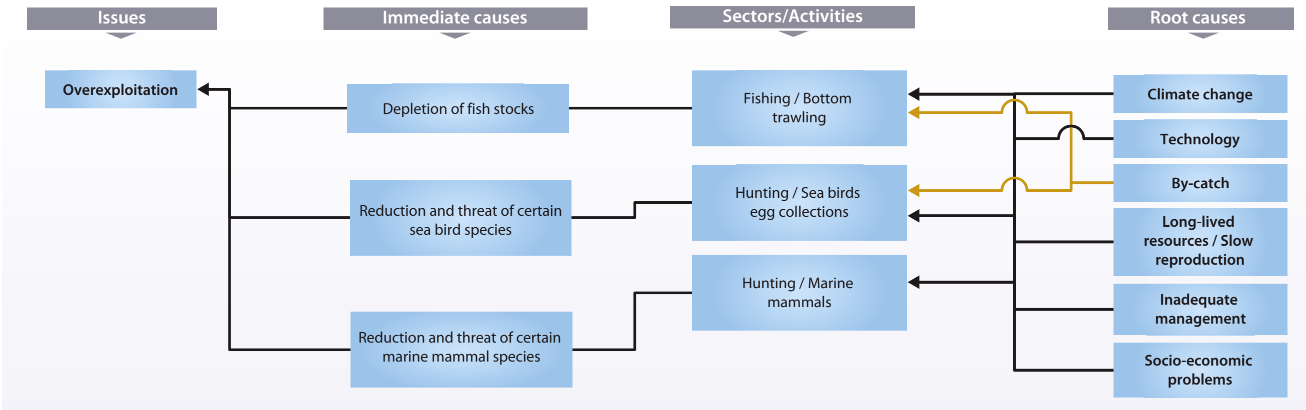


Figure 15 Causal chain analyses regarding overexploitation.

Complex models of interactions are not easily tractable and it will be necessary to extract from complex interactions, those processes which are the most important in the causal-chain analyses. The essential task is to discover how to combine social and natural science scale analyses to understand the impact of natural systems on people and the impact of people on natural systems (Perry and Ommer, 2003). The causal-chain analysis represents a general picture. Overexploitation in Greenland is a complex function of many factors, which interact in complex ways. Key factors are: 1) a climate with large short-term variability and long-term changes which affects the productivity and distributions of natural resources, 2) a technology which constantly is developed and becoming more effective, 3) by-catch of non-target species, 4) long-lived resources with slow growth in a cold environment, slow reproduction and therefore vulnerable to fishing and hunting, 5) inadequate management due to e.g. lack of knowledge, economy and political will, 6) socio-economic problems due to increased human needs of modern equipment and technology (e.g. TVs, motor boats, etc.) and lack of natural resources to support economical development due to overexploitation, 7) gradual societal shift from commercial to recreational exploitation.

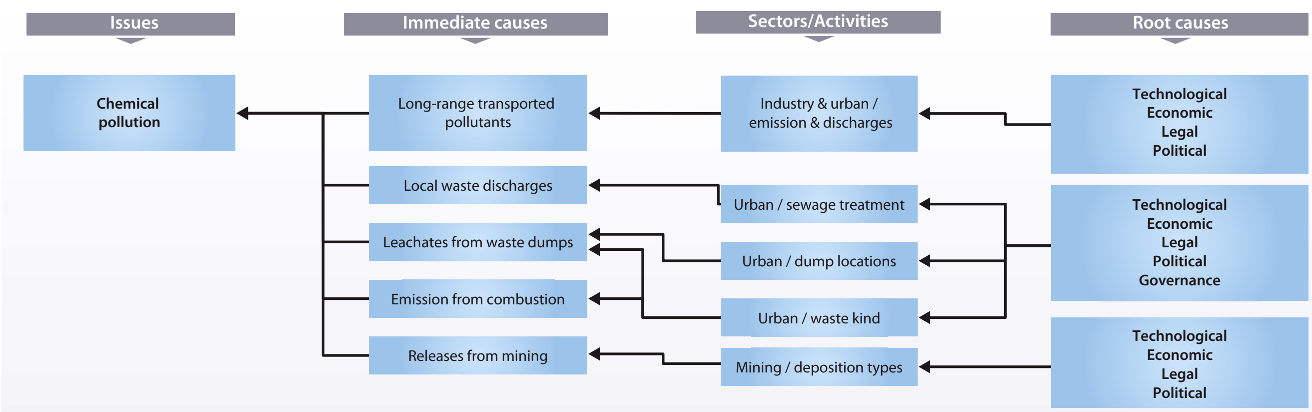


Figure 16 Causal chain analyses regarding chemical pollution.

The major sources for the chemical contamination of the waters and the ecosystems around Greenland can be found in the pollutant releases in Europe, Asia and North America (Macdonald et al., 2003). The only possibility of reducing these sources is a continued focused and significant international effort to control these emissions, and to enforce existing agreements. Local pollution is generally a minor problem in Greenland. For example there is a need to reduce the leaching from several locations all over Greenland.

Some of the root causes for the key environmental concerns of Greenland's marine resources are to be found and solved within Greenland. However, climate change greatly influences the natural resources and is a very important factor for Greenland's ability to manage natural resources and socio-economics relationships in the society.

Hence, the main international problems for the waters around Greenland, the biota and the society are chemical pollution and climate change. Both these problems are caused by the industrialised world and they are global international problems to be solved in international cooperation.

Policy options

This section aims to identify feasible policy options that target key components identified in the Causal chain analysis in order to minimise future impacts on the transboundary aquatic environment. Recommended policy options were identified through a pragmatic process that evaluated a wide range of potential policy options proposed by regional experts and key political actors according to a number of criteria that were appropriate for the institutional context, such as political and social acceptability, costs and benefits and capacity for implementation. The policy options presented in the report require additional detailed analysis that is beyond the scope of the GIWA and, as a consequence, they are not formal recommendations to governments but rather contributions to broader policy processes in the region.

Key issues and causes

The assessments and the causal chain analysis identified the following key issues:

- West Greenland (GIWA region 16) suffers from overexploitation of the marine resources, due to climatic changes, inadequate knowledge about the resource dynamics and productivity of the ecosystems, inappropriate management frameworks, and a lack of population awareness and ability on how to best adapt to the changes.
- East Greenland (GIWA region 15) - and to a certain degree West Greenland - suffers from the impacts of chemical pollution, transported by the air and ocean currents from Europe, Asia and North America, and building up in the food webs of the arctic marine ecosystems. There is a need to further improve the understanding of the transport processes and to improve the international cooperation to reduce emission of hazardous chemicals.
- North Greenland (GIWA region 1) is presently fairly undisturbed, but it is expected that global climatic changes related to emission of green house gases may cause significant threats to the arctic ecosystems, in particular the unique arctic mammals (polar bears, walrus, etc.). There is a need to further understand these impacts, and to use this information in the international climate negotiations.

Options for policy intervention

The politicians and the administration in Greenland are fully aware of the issues and the threats they pose to the socio-economic development. Accordingly, a large number of policy initiatives – both nationally and internationally have been initiated. The following sections will highlight some of particular importance to the issues identified above, and also point out some additional options for intervention.

Addressing Overexploitation of marine resources in West Greenland

In 1987 the "Brundtland Report" (World Commission on Sustainable Development 1987), also known as Our Common Future, alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. The report provided a key statement on sustainable development, defining it as: development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

There is great awareness in Greenland about the urgency of sustainable development in the society (see www.nanoq.gl/sustainability). Quoting Jonathan Motzfeldt, former Premier, Greenland Home Rule Government (Greenland Institute for Natural Resources 2002: Foreword):

"The marine ecosystem is the life-blood of Greenland. There is a tight connection culturally, socially, and economically, and mankind is, more significantly than anywhere else, integrated into the ecosystem.

The wide-spread realms of the Arctic marine region have, through the centuries, drawn fishermen and hunters from far and wide. But human influence, and rapid climatic change, have induced marked shifts in the ecosystem, and the focal points of exploitation have changed through time.

Rapid climatic shifts and a low level of complexity make the Greenland marine ecosystem uniquely suitable for the study of the effects of climate change. At the same time, the situation of the ecosystem within a single economic zone gives good possibilities for studying the interactions between it and society. Together, these factors make this a unique study area, of international interest for investigating the effects and interactions between mankind, climate, and ecosystem."

Improved knowledge

In their discussion of the concept of sustainability in fisheries, Steele and Hoagland (2003) argue that one of the main difficulties in fisheries management is the "ratchet" effect (Ludwig et al., 1993). When the abundance of a stock increases, the fishing capacity goes up. But when later the stock decreases – often by natural causes - , the effort stays the same, usually with disastrous consequences for the stock and the economy. This general sequence occurs on top of a trend for "improved" gear technology. The critical scientific problem is to distinguish between these two causes: natural environmental variability and changes in effort, fishing boats and gear. According to Steele and Hoagland (2003) the time scale of natural changes in the sea - a few decades - is comparable to the economic scales of human adaptation; specifically the "lifetime" of a fishing vessel. It is this resonance in time scales that makes the attribution of cause to the quasi-cycles in stock abundance more than a purely scientific problem. There is a need to understand the natural physical and ecological causes of these "cycles" in marine ecosystems and subsequently devise sufficiently long-term management to ameliorate rather than amplify the economic consequences (Steele and Hoagland, 2003).

Much of this and related discussion was taken up by the Food and Agriculture Organisation (FAO) of the United Nations in discussions related to the Convention relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN, 1994) and the Code of Conduct for Responsible Fishing (FAO, 2001), and recently resulted in Technical Guidelines for an Ecosystem Approach to Fisheries Management (FAO, 2003). These guidelines have been adopted to reflect the merging of two different but related and – it is hoped – converging paradigms. The first is that of ecosystem management, which aims to meet its goal of conserving the structure, diversity and functioning of ecosystems through management actions that focus on the biophysical components of ecosystems (e.g. introduction of protected areas). The second is that of fisheries management, which aims to meet the goals of satisfying social and human needs for food and economic benefits through management actions that focus on the fishing activity and the target resource. Up until recently, these two paradigms have tended to diverge into two different perspectives, but the concept of sustainable development (World Commission on Environmental and Development, 1987) requires them to converge towards a more holistic approach that balances both human well-being and ecological well-being. Ecosystem Approach to Fisheries (EAF) is, in effect, a way to implement sustainable development in a fisheries context (FAO, 2003).

The Greenland Institute of Natural Resources is the Greenland Home Rule Government's centre for research on living natural resources. It advises the government on sustainable use of resources, including conservation of the environment and biological diversity. The Institute's vision is to understand the interrelationship between ecosystem, climate and human impact.

The Greenland Institute for Natural Resources wishes to initiate a long-term research programme towards its vision, in order to meet the increasing interest in ecosystem-based advice for management (Jarre, 2002). The focus will be the marine ecosystem off West Greenland, both economically and socially most important to Greenland's society.

The goal of the "Ecosystem West Greenland" (ECOGREEN) research programme is to establish a scientific basis for a long-term ecosystem-based management of natural resources in West Greenland waters"

Through the research programme ' ECOGREEN', Greenland expects to attract international expertise within the natural- and social-science research communities, which in fellowship with Greenlandic institutions can create a scientific basis for holistic management of a marine ecosystem.

The results from ECOGREEN could well become the basis for developments in more complex systems, and its perspective therefore extends far beyond Greenland.

Improved management

Key questions concerning management of human use of natural resources and the need for socio-economic research in the West

Greenland ecosystem were discussed during a workshop at Greenland Institute of Natural Resources in 2001. The following is quoted from the workshop report (Jarre, 2002, p77-78):

The need for communication on management issues: "In the end it is the person with the finger on the trigger or the person setting the net, who decides whether their action is complying with, or violating the law." said Paviaraq Heilman, then member of the Home Rule Government, during the seminar on Greenland's living resources conducted by the Greenland Institute of Natural Resources in 1998. In a country where it is practically impossible to control compliance with hunting and fishing regulations, it is the people's knowledge, understanding and acceptance of management measures that leads to compliance with regulations. In connection with strategies for sustainable exploitation, experts and practitioners have been analysing for a number of years how the needed change of behaviour can be achieved. Consensus is growing that active participation in the management process is one of the necessary conditions.

Solution co-management: In International Union for Conservation of Nature (IUCN), World Wildlife Fund (WWF) and the Arctic Council, co-management is propagated as the best solution to management issues. In the report "Arctic Flora and Fauna. Status and conservation" (CAFF (ed.) 2001, Edita, Helsinki. 272 p.- free online version: www.caff.is it is concluded that "One of the most notable recent innovations is the involvement of hunters and fishers in wildlife management. In theory, hunters and fishers who help develop the regulations will better understand the rationale for them and be more willing to abide by them. In practice this approach has enjoyed success in North America, where support for co-management has grown widely, although difficulties remain."

However, efforts like "better communication" by themselves may not solve the problems. There are genuine divergence of interests and a major problem in fishery management is lack of organisation among fishers and lack of confidence among them: If an individual fisher restrict himself in his fishing he will not receive the benefits himself. Thus the individual fisher has little incentive to restrict himself.

There are genuine conflicts of interests among stakeholders. Shrimp and cod fishers might have different interests. Environmentalists and fishers clearly have different interests as well. Thus, only a socio-political realistic approach to "comanagement" will be efficient.

Acknowledging that co-management in Greenland is only in its infancy, the Directorate for Environment and Nature of the Home Rule Government published a "programme proposal for local engagement in management of natural resources in Greenland" (Greenland Home Rule, www.nanoq.gl). Quoting from the proposal:

"The programme's aim of seeking a broader basis for management principles - and letting the process of reaching agreement on the basic principles become a part of the programme, thereby creating local awareness of the consequences of a general natural resource policy - is new in Greenland".

"One of the conditions for solving these problems is that a real alternative is created to enable many of those who are today dependent on the very direct utilisation of our live resources to earn a living. Moreover, subsidies to the fishing industry and the hunting trade should be arranged so that they do not contribute to maintaining the existing pattern".

"In order to counter any negative development there is a distinct need for two concrete initiatives: 1. an information campaign and an open and honest dialogue about the problems in this country, and 2. the formulation of an overall policy for the solution of the problems, resulting in an actual strategy and action plan"

According to Greenland Home Rule (www.nanoq.gl), the purpose of the campaign is to ensure better dialogue between interest groups and to disseminate factual information about the status of living resources, the objective being to create a common understanding of what is needed to conserve the natural environment for future generations.

At the same time the campaign is hoped to enable Greenland to live up to its obligations in terms of information to the public about environmental issues and protection of the natural environment as required in two international conventions:

- The Biodiversity Convention, which Greenland has signed and according to which signatory countries are obliged to initiate public education and awareness programmes; and
- The Aarhus Convention on access to information about environmental matters, which Greenland stated it would endeavour to observe when Denmark ratified it. According to the Aarhus Convention citizens are not only entitled to information about environmental matters: public authorities have an obligation of pro-active dissemination of information. With the new nature conservation act which is expected to be adopted within the next twelve months. Greenland lives up to the spirit of the Aarhus Convention in a number of areas: the establishment of an environmental complaints board and the potential establishment of a nature protection council.

According to Sejersen (2003) the Greenland society should continue discussions and reevaluations of the terms optimal and sustainable use of the natural resources under the changing environment.

In relation to development of tourism in Greenland, Kaae (2003) suggests priority to projects integrating tourism, natural science, and sustainable use of nature. For example project cooperation between research institutions and the tourist business, and projects which better integrate and make use of local Greenlandic expertise.

Addressing chemical pollution in West and East Greenland

Environmental chemical contaminants are a global problem. Their presence and role in the Arctic reflects the physical, biological, and social characteristics of the region, as well as the way the Arctic interacts with the rest of the world.

The pollution stemming from the industrialised world is caused by a complex of causes and the solution is to stop/reduce the chemical pollution which leads to problems for the biota in Greenland. The latter needs international actions such as AMAP and the OSPAR Commission (see AMAP, 2002; OSPAR Commission, 2000). However, pollution from mining and hunting is mainly a "local Greenland" problem, as the use of lead shot contaminates bird's meat, which subsequently is a significant lead source to bird eaters (Johansen et al., 2004). This problem may be solved by replacing lead with non-toxic alternatives.

Improved knowledge

Current concern about Arctic contaminants began with discoveries of high levels of persistent organic pollutants (POPs) in some indigenous inhabitants of the Arctic. Subsequent research confirmed that Arctic animals have elevated levels, posing a threat not only to the people who eat them but also to the animals themselves, and their ecosystems.

In 1991, the eight Arctic countries – Canada, Denmark, Finland, Iceland, Norway, Sweden, Russia, and the United States – initiated the Arctic Environmental Protection Strategy.

Under this framework, the countries pledged to work together on issues of common concern. Recognising the importance of the environment to the indigenous communities of the Arctic, the countries at that time included three indigenous organisations in their cooperative programs. In 1996, the eight Arctic countries created the Arctic Council, incorporating the Arctic Environmental Protection Strategy and expanding it to include sustainable development issues. They have also included three more indigenous organisations for a total of six permanent participants.

One of the programs created under the Arctic Environmental Protection Strategy and continued under the Arctic Council is the Arctic Monitoring and Assessment Programme. AMAP was designed to address environmental contaminants and related topics, such as climate change and ozone depletion, including their impacts on human health (AMAP, 2002). Its specific task in Phase I of its existence was to prepare a comprehensive scientific assessment on these matters.

The conclusions and recommendations from the first scientific assessment led to substantial progress in addressing the problem of contaminants. They raised the profile of environmental contamination in the Arctic as a public policy issue, and helped in the preparation of dietary guidelines in several countries.

Improved international cooperation

At the time AMAP began its work, the United Nations Economic Commission for Europe (UN ECE) Convention on Long-range Transboundary Air Pollution was already considering whether it should take action on POPs and heavy metals. The data compiled by AMAP over the next several years established a strong case for restricting or eliminating several POPs.

Several important steps have already been taken to address the threats POPs pose to the Arctic environment, such as the Stockholm Convention and the UN ECE POPs Protocol. The AMAP (2002) assessment shows the continued need to bring Arctic concerns about POPs to the attention of these international policy fora to ensure continued emphasis on Arctic needs.

Conventions regulate some POPs

At a national level, the use and emissions of many POPs have been restricted since the 1970s. In 1998, the United Nations Economic Commission for Europe (UN ECE) negotiated a regional protocol on POPs under the Convention on Long-range Transboundary Air Pollution, the Aarhus POPs Protocol, which covers Europe, all states of the former Soviet Union, and North America. All AMAP countries except Russia are signatories to this convention. As of August 1, 2002, the following AMAP countries had ratified the POPs Protocol: Canada, Denmark, Norway, and Sweden. They were able to do so in part because they had learned much from AMAP concerning transboundary contaminants in the Arctic. Indeed, the preamble to the Stockholm Convention explicitly recognises the risks POPs pose to Arctic ecosystems and indigenous health and well-being.

The regional UN ECE agreement paved the way for global negotiations on banning POPs under the auspices of the United Nations Environment

Programme. The Stockholm Convention on Persistent Organic Pollutants was opened for signature in May 2001. All AMAP countries have signed the Stockholm Convention. As of July, 2002, Canada, Iceland, Norway, and Sweden had ratified it.

Both agreements identify a number of specific POPs to be banned or whose use or emissions are to be restricted. They include industrial chemicals and by-products, such as PCBs, dioxins, furans, and hexachlorobenzene. Also included are a number of organochlorine pesticides: aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, mirex, and toxaphene. Together, these are often called the 'dirty dozen'. Some POPs, most notably the pesticide hexachlorocyclohexane (HCH), are covered in the UN ECE Protocol but not the Stockholm Convention. For several of the listed substances, some limited use is allowed, for example DDT for fighting malaria.

The conventions also define criteria for including new chemicals based on their persistence, bioaccumulation, potential for long-range transport, and adverse effects. The Arctic is well suited as an indicator region for long-range transport. Monitoring data that provide information about the fate of chemicals in the Arctic will therefore be critical in identifying new POPs to be considered under the agreements.

In addition to national regulations concerning emissions and use of heavy metals, some significant steps have recently been taken internationally to address the heavy metals. The United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution adopted a Protocol on Heavy Metals in 1998. The protocol targets mercury, lead, and cadmium. Countries that are party to the protocol will have to reduce total annual emissions to below the levels they emitted in 1990.

As of June 15th, 2002, there were 36 signatories to the protocol, including all the Arctic countries except Russia. Of these, 10 had ratified it, including Canada, Denmark, Finland, Norway, Sweden, and the United States. For the protocol to enter into force, sixteen countries must ratify it. At its meeting in 2000, the Arctic Council called on the United Nations Environment Programme (UNEP) to initiate a global assessment of mercury that could form the basis for appropriate international action. This request was based on the findings of AMAP's first assessment.

In 2001, the UNEP Governing Council agreed to undertake such a study. At the same time, UNEP agreed to tackle the issue of lead in gasoline. The study on mercury will summarise available information on the health and environmental impacts of mercury, and compile information about prevention and control technologies and practices and their associated costs and effectiveness. In addition, the UNEP Governing Council requested, for consideration at its next session in February 2003, an outline of options to address any significant global adverse impacts of mercury. These options may include reducing and or eliminating the use, emissions, discharges, and losses of mercury and its compounds; improving international cooperation; and enhancing risk communication.

The Arctic Council also decided to take cooperative actions to reduce pollution of the Arctic. In 1998, the Regional Programme of Action to Prevent Pollution of the Arctic Marine Environment from Land-Based Activities was adopted. As a direct follow-up of the AMAP scientific assessment, the Arctic Council Action Plan to Eliminate Pollution of the Arctic was created to address sources identified by AMAP. This plan was approved in 2000 and several projects have begun.

In addition to its recommendations on contaminants, the AMAP assessment recommended further work on climate change and ultraviolet radiation. In 2000, the Arctic Council approved the Arctic Climate Impact Assessment, overseen by AMAP, its sister working group on Conservation of Arctic Flora and Fauna (CAFF), and the International Arctic Science Committee. According to AMAP (2002), this impact assessment will deliver a report to the Arctic Council in 2004.

Addressing habitat modification in North Greenland

As described above

Addressing global climate change

Habitat modification due to climate change is a global problem, and climate change is dealt with by UN Intergovernmental Panel on Climate Change (IPCC) (e.g., Jørgensen et al., 2001; Anon., 2003a).

The Kingdom of Denmark comprises Denmark, Greenland and the Faroe Islands. The UN Framework Convention on Climate Changes has been ratified on behalf of all three parts of the Kingdom (Anon., 2003a).

The ultimate objective of international climate cooperation is described in Article 2 of the UN Framework Convention on Climate Change, namely to achieve a "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

In September 2001, the UN Intergovernmental Panel on Climate Change (IPCC) presented its Third Assessment Report. The report shows that there is now stronger evidence for a human influence on the global climate than previously assumed, and that most of the observed warming at the Earth's surface over the last 50 years is likely to have been due to human activities.

The climate changed during the twentieth century, and larger changes are expected in the twenty-first century. No one knows the exact scope of future climate change. However, today no one can doubt the risk that climate change will affect humans and the environment in both the rich and the poor parts of the world. Taking climate change seriously has become a prerequisite for achieving sustainable development.

The Danish government takes global climate change seriously, within the framework of the Kyoto Protocol, under the auspices of the EU, Denmark is committed to reducing its emissions of greenhouse gases by 21% in 2008-12 compared to the level in 1990, taking into account the unusually high import of electricity in 1990 (Anon, 2003a). This is one of the hardest reduction targets in the world.

Since Denmark issued its First (1994) and Second (1997) National Communication under the UN Climate Convention, the Kyoto Protocol has been adopted, and the Conference of the Parties has taken the decisions necessary on realisation of the Protocol. Denmark ratified the Kyoto Protocol together with the other EU countries on 31 May 2002. The Danish government hopes that the Protocol will enter into force in 2003, policies and measures, including national action plans are described in Anon. (2003a).

As part of the national action plans for Greenland the GIWA-Greenland task team experts recommended that Greenland participate actively in the International Polar Year 2007. The year 2007-2008 will mark the 125th anniversary of the First International Polar Year (1882-1883), the 75th anniversary of the Second Polar Year (1932-1933), and the 50th anniversary of the International Geophysical Year (1957-1958). It will obviously be a good idea for Greenland to actively participate in the planning of the International Polar Year 2007 (http://ipy.gsfc.nasa.gov). The IPY-2007 will be a good opportunity for Greenland to inform the world of the severe changes for Arctic life caused by the predicted global warming.

Conclusions

Many of the root causes for overexploitation of Greenland's marine resources are to be solved within Greenland. However, climate change and chemical pollution from outside Greenland influence and have severe impact on the dynamics of natural resources and human health in Greenland. Both climate change and chemical pollution are caused by the industrialised world and they are global international problems to be solved in international cooperation. It is important for Greenland to inform the UN and the world about the impact of climate change and chemical pollution and to take active part in solving the root causes to the problems. Through its memberships and active participation in international organisations e.g. Arctic Council, AMAP, ICES, NAFO, NEAFC, JCCM, NAMMCO, IWC, etc., Greenland is very aware of the threats to the habitats, biota, and human health of overexploitation, climate change and chemical pollution, and want to actively participate in the international discussions to address the external impacts on the marine ecosystems of Greenland.

References

AMAP, 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii+859 pp

AMAP, 2002. Arctic Pollution 2002. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Vii + 112 pp. www.amap.no.

AMAP, 2003. AMAP 2002: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xiv + 137 pp.

Anonymous, 1996. Handlingsplan for den fremtidige affaldshåndtering i byerne i Grønland. Report from Carl Bro as. 68 pp.

Anon., 2003a. Denmark´s third national communication on climate change. Under the United Nations Framework Convection on climate change. Danish Environmental Protection Agency, Danish ministry of the Environment. 212 pp.

Anon., 2003b. GREENLAND 2001-2002, Statistical Yearbook, 6th of March 2003 (www.greenstat.gl).

Anon., 2003c. North-Western Working Group.NWWG, Report for 2003.(www.ices.dk).

Bjerregaard, P., 2003. Chapter 2. Sociocultural environment, lifestyle, and health in Greenland. In: Deutch B. and J.C. Hansen (Editors), 2003. AMAP Greenland and the Faroe Island 1997-2001. Vol. 1: Human Health. DANCEA. Ministry of Environment, Denmark: 15-19.

Bjerregaard, P. and Young, T. K., 1998. The Circumpolar Inuit - health of a population in transition. Munksgaard, Copenhagen.

Bjerregaard, P., Senderovitz, F., Ramlau-Hansen, L., 1995. Kalaallit Nunaanni inuit peqqinnerlu - Mennesker og sundhed i Grønland. Dansk Institut for Klinisk Epidemiologi. Sektion for Grønlandsforskning. Peqqinnissamut, Avatangiisinut Illisimatusarnermullu Naalakkersouisoqarfik. In Greenlandic and Danish.

Boertmann, D., P. Lyngs, F.R. Merkel, and A. Mosbech, 2004. The significance of Southwest Greenland as winter quarters for seabirds. - Bird Conservation international, 14: 87-112.

Born E.W. and J. Bøcher (Editors), 2001. The Ecology of Greenland. Ministry of Environment and Natural Resources, Ilinniusiorfik, Nuuk 2001.ISBN: 87-558-1514-6, 429p.

Born, E.W, Heide-Jørgensen, M. P. and Davis, R.A. 1994. The Atlantic walrus (Odobenus rosmarus) in West Greenland. Meddr. Grønland, Biosci, 40: 1-33.

Born, E.W., S. Rysgaard, G. Ehlmé, M. Sejr, M. Acquarone, and N. Levermann. 2003. Underwater observations of foraging free-living Atlantic walruses (Odobenus rosmarus rosmarus) and estimates of their food consumption. Polar Biology 26: 348-357.

Buch, E. (1990). A Monograph on the Physical Oceanography of the Greenland Waters. Greenland Fisheries Resource Institute. 405 pp.

Buch, E., Horsted, S. Aa. and Hovgård, H. 1994. Fluctuations in the occurrence of cod in Greenland waters and their possible causes. ICES Mar. Sci. Symp. 198: 158 - 174.

Buch, E., T. G. Nielsen, C. Lundsgaard, and J. Bendtsen 2001. Deep Water Convection and Biogeochemical Cycling of Carbon in the Northern North Atlantic. In: Climate Change Research - Danish Contributions. Danish Meteorological Instititute.DMI Ministry of Transport. Gads Forlag. 53-76.

Buch, E., Pedersen, S.A. and Ribergaard, M.H., 2004. Ecosystem variability in West Greenland waters. Journal of Northwest Atlantic Fishery Science Vol. 34: 13-28.

Caulfield, R., 1997. Greenlanders, Whales and Whaling: Self-determination and Sustainability in the Arctic. Hanover NH and London, University Press of New England.

Chisholm, S. and Parfit M. 2002. For National Geographic Today, October 24, 2002. (http://news.nationalgeographic.com/news/2002/10/1024_021024_TVGreenland.html)

Christensen, J. H., M. Goodsite, N. Z. Heidam, H. Skov and P. Wåhlin, 2003. Chapter 1. Atmospheric Environment. In: Riget, F., J. Christensen and P. Johansen (Editors). AMAP Greenland and the Faroe Islands 1997-2001 Vol. 2: The Environment of Greenland. DANCEA, Ministry of Environment, Denmark: 11-46

Dahl, J., 1989. The Integrative and Cultural Role of Hunting and Subsistence in Greenland. In Études/Inuit/Studies, 13(1): 23-42

Det Rådgivende Udvalg Vedrørende Grønlands Økonomi. 2002. Den økonomiske udvikling i Grønland. Danish State Ministry, Copenhagen. 113 p.

Deutch B. and J.C. Hansen (Editors). 2003. AMAP Greenland and the Faroe Island 1997-2001. Vol. 1: Human Health. DANCEA. Ministry of Environment, Denmark. 234pp.

Dickson, R. R., Osborn, T. J., Hurrell, J. W., Meincke, J., Blindheim, J., Adlandsvik, B., Vinje, T., Alekseev, G. and Maslowski, W. 2000. The Arctic Ocean Response to the North Atlantic Oscillation. Journal of Climate, Aug. 2000.

Egevang, C. and Boertmann, D. 2001. The Greenland Ramsar sites, a status report. – National Environmental Research Institute, Denmark, NERI Technical Report No. 346, 96pp.

Egevang, C. and K. Falk. 2001. Chick diet of dovekies Alle alle in Northwest Greenland. Polar Biol. 24: 53-58.

Egevang & Boertmann 2003. Havternen i Grønland. Status og undersøgelser 2002. Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 438 (elektronisk): 72 s.

Egevang, C., D. Boertmann, A. Mosbech, and M. P. Tamstorf, 2003. Estimating colony area and population size of little auks Alle alle at Northumberland Island using aerial images. Polar Biol. 26: 8-13.

Engelstoft, J. J, Isaksen, B., Larsen, R. B., Rosing, M., Zachariassen, K 2001. Studies of technical methods for secure shrimp fishery in the Redfish Box, East Greenland. Project Report for the Nordic Strategy for the Environment and Fisheries. Greenland Institute of Natural Resources. Report.

Falk, K. and K. Kampp. 2001. Lomvien i Grønland: mulige effekter af forskellige faktorer, praktiske grænser for ressourceudnyttelse. Teknisk rapport nr. 38, marts 2001. Grønlands Naturinstitut. In Danish. 54 pp.

Falk, K. and J. Durinck, 1991. The by-catch of Thick-billed Murres in salmon drift nets off West Greenland in 1998. In Gaston, A.J. and Elliot, R.D. eds. Studies of high-latitude seabirds. 2. Conservation biology of Thick-billed Murres in the Northwest Atlantic. - Canadian Wildlife Service, Occasional Papers 69.

Falk K. and F. Merkel (unpublished). Embedded lead shots in Common and King Eiders wintering in West Greenland. - Greenland Institute of Natural Resources.

FAO, 2001. What is the code of conduct for responsible fisheries? FAO Rome, 2003. 13pp.

FAO, 2003. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2. FAO Rome, 2003. 112p.

Fox, A.D. and Madsen J. 1997. behavioral and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. - Journal of Applied Ecology 34: 1-13.

Frich, A. S. 1997. Ederfuglefangst i Grønland 1993. Teknisk rapport nr. 9. December 1997. In Danish. 33pp.

Friis, P. and Rasmussen, R. O. 1989. The Development of Greenland's main industry - the fishing industry. NORS Papers no.6, Publications from the Institute of Geography, Socio-economic Analysis and Computer Science. Research report no. 67. Roskilde, Roskilde University

Gilliland, S., Gilchrist, H. G., Rockwell, R., Robertsen, G. J., Savard, J.-P., Merkel, F. R., & Mosbech, A. 2003. Evaluating the sustainability of fixed-number harvest of northern common eiders in Greenland and Canada.manuscript submitted

Glahder, C. M., Asmund, G., Mayer, P., Lassen, P., Strand, J. and Riget, F. 2003: Marin recipientundersøgelse ved Thule Air Base 2002. Danmarks Miljøundersøgelser. 126 s. -Faglig rapport fra DMU nr. 449. http://faglige-rapporter.dmu.dk

Grandjean, P., Weihe, P., White, R.F., and Debes, F., 1998. Cognitive performance of children prenatally exposed to "safe" levels of methylmercury. Env. Res. Sec A. 77, 165-172.

Greenland Institute of Natural Resources (ed.). 2000. Status 2000 – a biological status of the living resources of Greenland. Internal Report, Greenland Institute of Natural Resources, Nuuk. 36 pp. (In Greenlandic and Danish).

Greenland Institute of Natural Resources. 2002. ECOGREEN: an integrated research programme into the structure and function of the marine ecosystem off West Greenland. Internal Report, Greenland Institute of Natural Resources, Nuuk, July 2002.

Hamilton, L., P. Lyster, and O. Otterstad. 2000. Social change, ecology and climate in 20th-century Greenland. Climate Change, 47: 193–211.

Hansen, A.S., Nielsen, T.G., Levinsen, H., Madsen, S.D., Thingstad, T.F., and Hansen B.W. 2003. Impact of changing ice cover on pelagic productivity and food web structure in Disko Bay, West Greenland: a dynamic model approach. Deep-Sea Research I, 50: 171-187.

Hansen, J.C. 1998. Pollution and Human Health. In: AMAP Assessment Report: Arctic Pollution Issues. AMAP, Oslo Norway, pp. 775-844.

Hansen, P.M. 1949. Studies on the biology of the cod in Greenland waters. Conseil Permanent International pour l´Exploration de la Mer: Rapports et Procés-verbaux des Réunions volume 123:1-77.

Heide-Jørgensen, H.S. and Johnsen, I., 1998: Ecosystem Vulnerability to Climate Change in Greenland and the Faroe Islands. Miljønyt no. 33, Danish Environmental Protection Agency, 266 pp.

Heide-Jørgensen, M. P. 2001. Modern Hunting – and research. In Born E. W. and J. Bøcher (Editors), 2001. The Ecology of Greenland. Ministry of Environment and Natural Resources, Ilinniusiorfik, Nuuk 2001.ISBN: 87-558-1514-6, page:365-379.

Heide-Jørgensen, M.P. and Acquarone, M. 2002. Size and trends of the bowhead whale, beluga and narwhal stocks wintering off West Greenland. NAMMCO Scientific Publications 4, 191- 210.

Heide-Jørgensen, M.P. and K.L. Laidre, 2004. Declining open-water refugia for top predators in Baffin Bay and adjacent waters. Ambio, in press.

Heilman, P. 1998. Optakt til den anden dag, p. 60-65 In Grønlands Naturinstitut (Ed.) Seminar om de levende ressourcer, Nuuk, 9-11 October 1998. Teknisk Rapport No. 20.

Horsted, S.A., 2000. A Review of the Cod Fisheries at Greenland, 1910-1995. J. Northw. Atl. Fish. Sci. Vol. 28, 1 - 109.

Hurrell, J. W., 1995. Decadal Trends in the North Atlantic Oscillation Regional Temperatures and Precipitation. Science 269, 676–679

Hvingel, C., 2002a. Assessment, Prediction and Risk Analysis of Stock Development: Shrimp off West Greenland, 2002. Northwest Atlantic Fishery organization, Serial No. N4786, NAFO SCR Doc. 02/157. 10p.

Hvingel, C., 2002b. The Fishery for Northern Shrimp (Pandalus borealis) off West Greenland, 1970-2002. Northwest Atlantic Fishery organization, Serial No. N4780 NAFO SCR Doc. 02/151. 20p.

ICES, 2003. Advisory Committee on Fisheries Management (ACFM), Report on Northwest Atlantic Fish Stocks, 2003 (www.ices.dk).

Jacobsen, C.S., M. Bender, and G. Felding. Global forurening af den Grønlandske indlandsis med miljøfremmede stoffer og tilstedeværelse af levedygtige mikrobielle kim. GEUS rapport 2003/64. 35pp. (In Danish).

Jarre, A. (ed.). 2002. Workshop "Ecosystem West Greenland". A stepping stone towards an integrated marine research programme. INUSSUK, Arctic Research Journal No. 2002-1:1-99.

Jensen, A.S. 1939. Concerning a change of climate during recent decades in the Arctic and subarctic regions, from Greenland in west to Eurasia in the east, and contemporary biological and geophysical changes. Det Kgl. Danske Videnskabernes Selskab. Biologiske Meddelelser XIV,8. København. (Munksgaard. 75pp. with 2 charts.)(in English).

Jensen, D.B. (Editor), 1999. Greenland Biodiversity – a natinal study. Teknisk rapport nr. 27, maj 1999. Pinngortitalriffik, Grønlands Naturinstitut. 220s.(in Danish).

Johannesen, O. and eleven co-authors, 2002. Arctic climate change – observed and modeled temperature and sea ice variability. Nansen Environmental and Remote Sensing Center. Technical report No. 218, Bergen. 22p.

Johansen, P. and Asmund, G. 1999. Pollution from mining in Greenland - monitoring and mitigation of environmental impacts. In: Azcue, J.M. (ed.) Environmental Impacts of Mining Activities - Emphasis on Mitigation and Remedial Measures. Springer-Verlag, pp. 245-262.

Johansen, P., G. Asmund and F. Riget, 2001. Lead contamination of seabirds harvested with lead shot – implications to human diet in Greenland. Environ. Pollut. 112: 501-504

Johansen, P. & Asmund, G. 2003. Tungmetaller i tang og musling ved Ivittuut 2001. Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 444 (elektronisk): 34 s.

Johansen, P., G. Asmund and F. Riget, 2004. High human exposure to lead through consumption of birds hunted with lead shot. Environ. Pollut. 127: 125-129.

Jørgensen, A.M.K., J. Fenger, and K. Halsnæs. 2001. The Scope of Human Induced Climate Change. In: Climate Change Research - Danish Contributions. Danish Meteorological Instititute.DMI Ministry of Transport. Gads Forlag. 1-22. (available online version: www.dmi.dk).

Kaae, B. C. 2003. Udredningsprojekt om turisme, naturforvaltning og lokalsamfund i Grønland. DANCEA and Center for skov, landskab og planlægning. 139p. (In Danish). http://www.fsl.dk/pub/

Kampp, K., 1988. Migration and winter ranges of Brünnich's Guillemots Uria lomvia breeding or occurring in Greenland. - Dansk Ornithologisk Forenings Tidsskrift 83: 117–130.

Kampp, K., Nettleship, D. N. and G.H. Evans, 1994. Thick-billed murres of Greenland: status and prospects. In Nettleship, D. N., Burger, J. and Gochfeld, M. eds. Seabirds on Islands, Threats, case-studies and action plans. - BirdLife International, Conservation series No. 1.

Kingsley, M. C. S., Kanneworff, P. and Carlsson, D. M., 1999. By-catches of Fish in the West Greenland Shrimp Survey: an Initial Analysis. NAFO SCR Document no. 111, serial No. N4191, 7p.

Koeller, P.A., 2000. Relative Importance of Abiotic and Biotic Factors to the Management of the Northern Shrimp (Pandalus borealis) Fishery on the Scotian Shelf. Journal of Northwest Atlantic Fishery Science, Volume 27: 21-33.

Lage, S., and R. O. Rasmussen, 1993. Ressourceforvaltning og kontrol indenfor fiskeriet. Nationalt notat Grønland. Nordisk Ministerråd. Nordisk Seminar- og Arbejdsrapporter 1993:583.

Lilly, G. R., Parsons, D. G., Kulka, D.W., 2000. Was the Increase in Shrimp Biomass on the Northeast Newfoundland Shelf a Consequence of a Release in Predation Pressure from Cod? Journal of Northwest Atlantic Fishery Science, Volume: 45–61.

Lyngs, P. 2003. Migration and winter ranges of birds in Greenland. - Dansk Ornitologisk Forenings Tidsskrift 97: 1-167.

Ludwig, D., Hilborn, R., Walters, C., 1993. Uncertainty, resource exploitation and conservation. Science 260, 17–26.

Lunn, N. J., Schliebe, S., and Born, E.W. (comps. And eds.), 2002. Polar Bears: Proceedings of the 13th Working Meeting of the IUCN/ SSC Polar Bear Specialist Group, Nuuk, Greenland. IUCN, Gland, Switzerland and Cambridge, UK.vii+ 153pp.

Macdonald, R.W., T. Harner, J. Fyfe, H. Loeng and T. Weingartner, 2003. AMAP Assessment 2002: The Influence of Global Change on Contaminant Pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+65 pp.

Madsen, J., 1998. Experimental refuges for migratory waterfowl in Danish wetlands. II. Tests of hunting disturbance effects. - Journal of Applied Ecology 35: 398-417.

Maguire, J-J. 2001. Fisheries Science and Management in the North Atlantic. Pages 36-48 in Pitcher, T.J., Sumaila, U.R. and Pauly, D. (eds) (2001) Fisheries Impacts on North Atlantic Ecosystems: Evaluations and Policy Exploration. Fisheries Centre Research Reports 9 (5): 94 pp.

Marquardt, O. and Caulfield, R. A., 1995. Development of West Greenlandic Markets for Country Foods Since the 18th Century. Arctic 49(2): 107-119.

Mattox, W.G., 1973. Fishing in West Greenland 1910-1966. The Development of a new native industry. Meddelelser om Grønland bind 197, nr 1, København: C.A. Reitzels Forlag

Meltofte, H. 2001. Unsustainable take of murres in Greenland. In CAFF (Conservation of Arctic Flora and Fauna) Arctic flora and fauna: Status and conservation. - Helsinki: Edita.

Meltofte H., Rysgaard, S. and Pedersen, S.A., 2003. Climate change in Greenland. In: Denmark´s third national communication on climate change. Under the United Nations Framework Convection on climate change. Danish Environmental Protection Agency, Danish ministry of the Environment. 212 pp.

Merkel, F.R., 2002a. The impact of fishing and hunting on the Marine Ecosystem. In, Jarre, A. (ed.). 2002. Workshop "Ecosystem West Greenland". A stepping stone towards an integrated marine research programme. INUSSUK, Arctic Research Journal 1:1-99.

Merkel, F.R., 2002b. Ederfugleoptællinger i Ilulissat, Ummannaq og Upernavik Kommuner, 1998–2001. - Pinngortitaleriffik, Grønlands Naturinstitut, teknisk rapport nr. 43.

Merkel, F.R. and S.S. Nielsen, 2002. Langsigtet overvågningsprogram for ederfuglen i Ilulissat, uummannaq and Upernavik Kommuner - vejledning og baggrund. - Pinngortitaleriffik, Grønlands Naturinstitut, teknisk rapport nr. 44.

Merkel, F.R., Mosbech, A., Boertmann, D. and L. Grøndahl, 2002. Winter seabird distribution and abundance off West Greenland, 1999. Polar Research 21: 17–36.

Mikkelsen, N. and Ingerslev, T.(eds) 2002: Nomination of the Ilulissat Icefjord for inclusion in the World Heritage List. Geological Survey of Denmark and Greenland. Copenhagen: Schultz Forlag, 136 pp.

Mosbech, A. (ed.), 2002: Potential Environmental impacts of oil spills in Greenland. An assessment of informations status and research needs. National Environmental Research Institute, Denmark. 118 pp. – NERI Technical Report No. 415. http://technical-reports.dmu.dk

Mosbech, A. and Boertmann, D. 1999. Distribution, abundance and reaction to aerial surveys of post-breeding king eiders (Somateria spectabilis) in western Greenland. Arctic 52(2), 188-203.

Mosbech, A., Boertmann, D., Nymand, J., Riget, F. and Acquarone, M. 1998: The Marine Environment in Southwest Greenland. Biological resources, resource use and sensitivity to oil spill. National Environmental Research Institute, NERI Technical Report nr. 236. 205 pp.

Mosbech, A., Dietz, R., Boertmann, D. and Johansen, P. 1996: Oil Exploration in the Fylla Area, An Initial Assessment of Potential Environmental Impacts. National Environmental Research Institute, 92pp. - NERI Technical Report no. 156.

Møller, P., Glahder, C. and Boertmann, D. 2003: Foreløbig miljøvurdering af land- og havområder i Nordgrønland. Status i forbindelse med afgrænsning af kontinentalsoklen. Danmarks Miljøundersøgelser. 68 s. - Faglig rapport fra DMU nr. 431, http://faglige-rapporter.dmu.dk

NAFO, 2003. Northwest Atlantic Fisheries Organisation (NAFO), Scientific Council Reports – 2002 "Redbook 2002", www.nafo.ca.

Namminersornerullutik Oqartussat, 2002. Piniarneq 2003. Nuuk: Namminersornerullutik Oqartussat/Atuakkiorfik.

Olsen, A. 2001. Co-operative societies in Greenland – what went wrong? p. 261-270. In G. Winther (ed.) Participatory ownership and management in Greenland and other Arctic regions. Inussuk, Arctic Research Journal No. 2001-1.

OSPAR Commission, 2000. Quality Status Report 2000, Region I – Arctic Waters. OSPAR Commission, London. 102 + xiv pp. (www.ospar.org)

Pauly, D., Palomares, M. L., Froese, R., et al., 2001. Fishing down Canadian aquatic food webs. Canadian Journal of Fisheries and Aquatic Sciences, January 1, 2001, Vol. 58, No. 1, 51–62.

Pécseli, M., F. Riget, K. Vorkamp, M. Glasies, and G. Asmund, 2003. Chapter 5. Other Contaminants. In: Riget, F., J. Christensen and P. Johansen (Editors). AMAP Greenland and the Faroe Islands1997-2001. Vol. 2: The Environment of Greenland. DANCEA. Ministry of Environment, Denmark: 115-154.

Pedersen, H., (ed.), 2002. Greenland – a modern society. Ministry of the Environment, Environmental Assistance to the Arctic. (www.mst.dk). 95 pp.

Pedersen, H. 2003. Det ukendte Grønland – de 10.000 arters land. Direktoratet for Miljø og Natur, Grønland. 95.pp. (In Danish).

Pedersen, S.A. 1994a. Mortality on Northern shrimp (Pandalus borealis) and species interactions on the offshore West Greenland shrimp grounds. Ph. D. thesis, University of Copenhagen - Five papers in English and a summery in Danish of 19p.

Pedersen, S.A. 1994b. Multispecies interactions on the offshore West Greenland shrimp grounds. ICES C.M. 1994/P:2.

Pedersen, S.A. 1995. Feeding habits of starry ray (Raja radiata) in West Greenland waters. ICES J. Mar. Sci. 52:43-54.

Pedersen, S. A. and Smidt, E. L. B., 2000. Zooplankton distribution and abundance in West Greenland waters, 1950–1984. Journal of Northwest Atlantic Fishery Science vol. 26, 45–102.

Pedersen, S.A. and Zeller, D., 2001. A mass balance model for the West Greenland marine ecosystem. In: Guenette, S., Christensen, V. and Pauly, D. (eds). Fisheries impacts on North Atlantic Ecosystems: Models and Analyses. Fisheries Centre Research Reports 9(4)., 111–127.

Pedersen, S.A., and Rice, J. 2002. Dynamics of fish larvae, zooplankton, and hydrographical characteristics in the West Greenland Large Marine Ecosystem 1950-1984. In: Large Marine Ecosystems of the North Atlantic. Changing States and Sustainability. K.S. Shermann, H.-R. and Skjoldal (eds). Chapter 5. Elsevier Science. p.151-193.

Pedersen, S.A. and B. Bergström (Editors). 2003. Proceedings of the Workshop on "Coupling biological models to ocean circulation models of the seas of Greenland, Iceland, and Norway with special emphasis on northern shrimp (Pandalus borealis) recruitment", Held 7-9 October 2002 at the Danish Meteorological Institute, Copenhagen, Denmark. 52p. (Nordic Council of Ministers in 2003).

Pedersen, S.A., Storm, L., and Simonsen, C.S. 2002. Northern shrimp (Pandalus borealis) recruitment in West Greenland waters. Part I. Distribution of Pandalus shrimp larvae in relation to hydrography and plankton. Journal of Northwest Atlantic Fishery Science, 30: 19-46.

Pedersen, S.A, M.H. Ribergaard & C.S. Simonsen 2003. Micro- and mesozooplankton in Southwest Greenland waters - Juni 1999, May and July 2000. Greenland Institute of Natural resources, Technical Report no.53. 59 pp (downloaded from: www.natur.gl).

Perry, R. and R. Ommer 2003. Scale issues in marine ecosystems and human interactions. Fish. Oceanogr. 12:4/5, 513–522.

Petersen, H., H. Meltofte, S. Rysgaard, M. Rasch, S. Jonasson, T.R. Christensen, T. Friborg, H. Søgaard, and S.A. Pedersen. 2001. The Arctic. In: Climate Change Research - Danish Contributions. Danish Meteorological Instititute.DMI Ministry of Transport. Gads Forlag. 303-330. Online version: http://www.dmi.dk/f+u/publikation/dkc-publ/klimabog/CCR-chap-20.pdf

Poole, G., 1995. The Development of Greenland's Shrimp Fishing and Processing Industry since 1979: A Study in Applied Economics. Institut for Nationaløkonomi, Handelshøjskolen i København

Rasmussen, E. and M. Aarø-Hansen (Editors), 2003. Denmark's Third National Communication on Climate Change. Under the United Nations Framework Convention on Climate Change. Ministry of the Environment, Danish Environmental Protection Agency (www.mst.dk). 212 pp.

Rasmussen, R. O. 1994. Types of social importance of fisheries. Improving the links between Fisheries Science and Management. ICES C.M. 1994/T:33.

Rasmussen, R. O., 1998a. "Settlement structure, resource management, and sustainable development: Megaprojects vs. Local participation in Greenland". in: Duhaime, G., Rasmussen, R.O., Comtois, R. : Sustainable Development in the North - Local Initiatives vs. Megaprojects. Circumpolar Arctic Social Sciences Ph.D. Network. Proceedings of the Second Conference. Quebec.

Rasmussen, R. O., 1998c. Settlement development and the formal, informal and subsistence sector in the Arctic. Geografisk Tidsskrift, Danish Journal of Geography, Special Issue 1.

Rasmussen, R. O., 1998e. Managing resources in the Arctic - problems in the development of fisheries. Working paper #135. Publications from Geography, Department of Geography and Development Studies, Roskilde University, Denmark.

Rasmussen, R. O., 2000a. "Formal economy, renewable resources and structural change in West Greenland." Études/Inuit/Studies 24(1): 41–78.

Rasmussen, R. O., 2000b. Langtidskonsekvenser af Greenex minen ved Maarmorilik Uummanaq kommune - del 1: Historik, Beskæftigelse og Mobilitet. Arbejdspapirer nr. 163, NORS-skrifter nr. 50, Publikationer fra Geografi, Institut for Geografi og Internationale Udviklingsstudier: Roskilde Universitetscenter.

Rasmussen, R. O. 2002. Food Consumption Patterns and Local Markets in the Arctic. In Gérard Duhaime (ed): Sustainable Food Security in the Arctic: State of Knowledge. CCI Press and GÉTIC, Occasional Publication Series No. 52. (pp 117-144)

Rasmussen, R. O. og Jensen, K. 2000. Konsekvenser af storskala råstof og energiprojekter i Arktis. Arbejdspapirer nr. 161, NORS-skrifter nr. 48, Publikationer fra Geografi, Institut for Geografi og Internationale Udviklingsstudier: Roskilde Universitetscenter.

Rasmussen, R. O., and L. C. Hamilton, 2001. The Development of Fisheries in Greenland, with Special Focus on Paamiut/Frederikshab and Sisimiut/Holsteinsborg. Roskilde, Denmark: North Atlantic Regional Studies.

Rasmussen, R. O. og K. G. Hansen, 2002. Aspekter af bæredygtig udvikling i Grønland. Begreber, borgerdeltagelse og økonomi. Naturforvaltning og kultur. Sisimiut Museum. Nors forskningsrapport nr. 54. 168s.

Rasmussen, R. O., Danielsen, M., Andersen, Th., Knudsen, Th., Nielsen, O., 1998. "Fiskeri/Fangst". In: Danielsen, M., Andersen, Th., Knudsen, Th., Nielsen, O.: Mål og strategier i den grønlandske erhvervsudvikling. Nuuk, Sulisa.

Ribergaard, M.H., S.A. Pedersen, B. Ådlandsvik, and N. Kliem. 2004. Modelling the ocean circulation on the West Greenland shelf with special emphasis on northern shrimp recruitment. Continental Shelf Research, Vol 24/13-14: 1505-1519.

Riget, F. and J. Boje. 1989. Fishery and some biological aspects of Greenland halibut (Reinhardtius hippoglossoides) in West Greenland waters. Sci. Council Studies, 13: 41-52.

Riget, F., P. Johansen, H. Dahlgaard, A. Mosbech, R. Dietz, and G. Asmund, 2000. Chapter 1: The Seas Around Greenland. In C. Sheppard (Editor). Seas at The Millennium: An Environmental Evaluation. Elsevier Science Ltd.:5-16.

Riget, F., J. Christensen and P. Johansen (Editors), 2003. AMAP Greenland and the Faroe Islands1997- 2001. Vol. 2: The Environment of Greenland. DANCEA. Ministry of Environment., Denmark. 193pp.

Riget, F., H. Dahlgaard and D. Muir, 2003a. Chapter 3. Fresh Water Environment. . In: Riget, F., J. Christensen and P. Johansen (Editors). AMAP Greenland and the Faroe Islands1997- 2001. Vol. 2: The Environment of Greenland. DANCEA. Ministry of Environment, Denmark: 59-66.

Riget, F., P. Johansen, M. Glasius, K. Vorkamp, H. Dahlgaard, D., Muir, G. Asmund1 and E.W. Born, 2003b.: Chapter 4. Marine Environment. In: Riget, F., J. Christensen and P. Johansen (Editors). AMAP Greenland and the Faroe Islands1997- 2001. Vol. 2: The Environment of Greenland. DANCEA. Ministry of Environment, Denmark: 67-114.

Roth, E. 1988. Belysning af de økonomiske konsekvenser ved valg mellem produktion of pillede, søkogte og japanrejer. Syddansk Univeristet, Fiskeriøkonomisk Institut Rapport No. 6/88, 49 p.

Roth, E. 1989. Mål og midler i Grønlands fiskeripolitik. Syddansk Univeristet, Fiskeriøkonomisk Institut Rapport No. 8/89, 80 p.

Rudels, B., E. Fahrbach, J. Meincke J, G. Budéus, and P. Eriksson, 2002. The East Greenland Current and its contribution to the Denmark Strait overflow. ICES Journal of Marine Science, 59: 1133-1154.

Rysgaard S, Nielsen TG, Hansen B., 1999. Seasonal variation in nutrients, pelagic primary production and grazing in a high-Arctic coastal marine ecosystem, Young Sound, Northeast Greenland. Mar. Ecol. Prog. Ser. 179:13-25

Rysgaard S., Vang T., Stjernholm M., Rasmussen B., Windelin A.. Kiilsholm,S. 2003. Physical conditions, carbon transport and climate change impacts in a NE Greenland fjord. Arctic, Antarctic and Alpine Research 35:301-312

Rätz, H.-J. 1999. Structures and changes of the demersal fish assemblage off Greenland, 1982-96. NAFO Sci. Coun. Studies, 32: 1-15.

Rätz, H.-J., Stein, M. and Lloret, J., 1999. Variation in growth and recruitment of Atlantic cod (Gadus morhua) off Greenland during the second half of the twentieth century. Journal of Northwest Atlantic Fishery Science, Volume 25, 161 – 170.

Sejersen, F. 2003. Grønlands Naturforvaltning – ressourcer og fangstrettigheder. Akademisk Forlag. 191p. (In Danish).

Siegstad, H., Rätz, H.-J. and Stransky C. 2003a. Assessment of Demersal Redfish in NAFO Subarea 1. Northwest Atlantic Fishery Organization. Serial No. N4853, NAFO SCR Doc. 03/35. 8p.

Siegstad, H., Rätz, H.-J. and Stransky C. 2003b. Assessment of Other Finfish in NAFO Subarea 1. Northwest Atlantic Fishery Organization. Serial No. N4851, NAFO SCR Doc. 03/34. 6p.

Smidt, E.L.B. 1989. Min tid i Grønland – Grønland i min tid. Fiskeri-Biologi-Samfund 1948-1985. Nyt Nordisk Forlag Arnold Busck, København. 214 p. (In Danish).

Sonne-Hansen, C. , R. Dietz, F. Riget, E. Born, L. Hyldstrup and P. S. Leifsson, 2003. Chapter 6. Effects. In: Riget, F., J. Christensen and P. Johansen (Editors). AMAP Greenland and the Faroe Islands1997- 2001. Vol. 2: The Environment of Greenland. DANCEA. Ministry of Environment, Denmark: 155-164.

Soto, C.G. 2002. The potential impacts of global climate change on marine protected areas. Reviews in Fish Biology and Fisheries 11: 181-195.

Steele, J. and P. Hoagland, 2003. Are fisheries "sustainable"?. Fisheries Research 64 (2003) 1–3

Stein, M., Wieland, K., Nielsen, M.H., Jonsson, S., Brander, K. and Harms, I., 2002. Stocks at Iceland and Greenland. Chap. 4 in: Report of the Workshop on the Transport of Cod Larvae. ICES CM 2002/C:13.

Stern, H.L. and M.P. Heide-Jørgensen 2003. Trends and variability of sea ice in Baffin Bay and Davis Strait, 1953-2001. Polar Research 22(1), 11-18.

Svelle, M., H. Aarefjord, H.T. Heir, and S. Øverland. 1997. Assessment Report on Fisheries related Species and Habitats Issues. Fifth International Conference on the Protection of the North Sea. Intermediate Ministerial Meeting 1997. 127 pp.

Takahashi, T., S. C. Sutherland, C. Sweeney, A. Poisson, N. Metzl, B. Tilbrook, N. Bates, R. Wanninkhof, R. A. Feely, C. Sabine, J. Olafsson, Y. Nojiri. 2002. Global sea-air CO2 flux based on climatological surface ocean pCO2 and seasonal biological and temperature effects. Deep-Sea Research, II, 49:1601-1622.

United Nations 1994. Convention related to the Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. URL http://www.un.org/Depts/los/convention_agreements/convention_agreements.htm. Accessed on 24 November 2003.

Valeur, H.H., Hansen, C., Hansen, K.Q., Rasmussen, L. and Thingvad, N. (1996). Weather, sea and ice conditions in eastern Baffin Bay, offshore Northwest Greenland., A review. Danish Meteorological Institute. Technical Report No. 96-12. 36 pp.

Vestergaard, N. and S. Christensen. 1993. Analyse af det grønlandske fiskerierhverv, Del 1. Syddansk Univeristet, Fiskeriøkonomisk Institut Rapport No. 13/93 (1/2).

Vestergaard, N., C.L. Jensen and H. Frost. 1993. Analyse af det grønlandske fiskerierhverv, Del 2. Fiskeriøkonomisk Institut Rapport No. 13/93 (2/2).

Wieland, K. and Hovgaard, H. 2002. Distribution and Drift of Atlantic Cod (Gadus morhua) Eggs and Larvae in Greenland Offshore Waters. J. Northw. Atl. Fish. Sci. 30: 61–76.

Wiese, F.K. and Ryan P.C. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984-1999. - MARINE POLLUTION BULLETIN 46 (9): 1090-1101.

Wiig, Ø., E.W. Born, and L.T. Pedersen. 2003. Movements of female polar bears (Ursus maritimus) in the East Greenland pack ice. Polar Biology 26: 509-516.

Winther, G. 1988. Erhvervsudvikling i Grønland: en selvforvaltet fiskeindustri? Ålborg Universitet, Rapport Serie om Nordatlantiske Forhold No. 11.

Winther, G. 2000. Ejerformer og økonomiske systemer i Grønland, p. 117-164. In M. Holm and R.O. Rasmussen (eds.) Udviklingsforskning, udviklingspolitik of udvikklingsenterprise: 3 faktorer i det grønlandske samfunds forandring og udvikling. Inussuk, Arktisk Forskningsjournal No. 2000-1.

Winther, G. 2001. Participation and self-management in Greenland revisited, p. 233-252. In G. Winther (ed.) Participatory ownership and management in Greenland and other Arctic regions. Inussuk, Arctic Research Journal No. 2001-1.

WGFS, 2003. Working Group on fishery systems. Resource Management Committee. ICES CM 2003/D:06. Ref. ACFM, ACE. 32p. (www.ices.dk)

World Commission on Environment and Development. 1987 - Our common future. Oxford, UK; Oxford University Press: 398 pp.

Annexes

Annex I
List of contributing authors and organisations involved

Name	Institutional affiliation	Country	Field of work
Stage 1: Scaling and Scoping" meeting held 15. August 2003 at the National Environmental Research Institute (NERI)			
Frank Riget	Senior Research Scientist, NERI	Denmark	Chemical pollution/Environmental assessment/Exploitation
Anders Mosbech	Senior Research Scientist, NERI	Denmark	Environmental assessment/Exploitation
Poul Johansen*	Senior Research Scientist, NERI	Denmark	Chemical pollution/Environmental assessment/Exploitation
Jesper Madsen	Chief Research Scientist, NERI	Denmark	Chemical pollution/Environmental assessment/Exploitation
Torkel G. Nielsen*	Research Professor, NERI	Denmark	Environmental assessment
Ole Jørgensen	Senior Research Scientist, Danish Institute for Fisheries Research	Denmark	Exploitation
Jesper Boje*	Senior Research Scientist, Danish Institute for Fisheries Research	Denmark	Exploitation
Søren A. Pedersen	Senior Research Scientist, GINR/DIFRES	Denmark	Environmental assessment/Exploitation
Erik Buch*	Chief Research Scientist, Danish Meteorological Institute	Denmark	Global change
Rasmus Ole Rasmussen*	Associated Professor, NORS, Roskilde University	Denmark	Socio-economic development
Søren Rysgård*	Senior Research Scientist, NERI	Denmark	Environmental assessment
Jørgen Bendtsen*	Research Scientist, NERI	Denmark	Global change
The "Stage 1: Scaling and Scoping" meeting held 3. September 2003 at the Greenland Institute of Natural Resources (GINR)			
Astrid Jarre	Senior Research Scientist, GINR	Greenland	Environmental assessment/Exploitation/Economy
Per Kanneworff	Senior Adviser, GINR	Greenland	Exploitation
Marie Storr-Paulsen	Research Scientist, GINR	Greenland	Exploitation
Mads-Peter Heide-Jørensen	Senior Research Scientist, GINR	Greenland	Exploitation
Carsten Egevang	Research Scientist, GINR	Greenland	Exploitation
Karen Motzfeldt	Head of Section, Greenland Home Rule, Direktoratet for Fiskeri, Fangst og Landbrug	Greenland	Exploitation
Mette-Astrid Jessen	Head of Section, Greenland Home Rule, Direktoratet for Miljø og Natur	Greenland	Exploitation
Andreas Vedel	Head of Section, Greenland Home Rule, Direktoratet for Miljø og Natur	Greenland	Freshwater storage/Pollution

** Not present at the scaling and scoping meetings*

The Global International Waters Assessment

This report presents the results of the Global International Waters Assessment (GIWA) of the transboundary waters of the Arctic Greenland region, East- and West Greenland Shelf regions. This and the subsequent chapter offer a background that describes the impetus behind the establishment of GIWA, its objectives and how the GIWA was implemented.

The need for a global international waters assessment

Globally, people are becoming increasingly aware of the degradation of the world's water bodies. Disasters from floods and droughts, frequently reported in the media, are considered to be linked with ongoing global climate change (IPCC 2001), accidents involving large ships pollute public beaches and threaten marine life and almost every commercial fish stock is exploited beyond sustainable limits - it is estimated that the global stocks of large predatory fish have declined to less that 10% of pre-industrial fishing levels (Myers & Worm 2003). Further, more than 1 billion people worldwide lack access to safe drinking water and 2 billion people lack proper sanitation which causes approximately 4 billion cases of diarrhoea each year and results in the death of 2.2 million people, mostly children younger than five (WHO-UNICEF 2002). Moreover, freshwater and marine habitats are destroyed by infrastructure developments, dams, roads, ports and human settlements (Brinson & Malvárez 2002, Kennish 2002). As a consequence, there is growing public concern regarding the declining quality and quantity of the world's aquatic resources because of human activities, which has resulted in mounting pressure on governments and decision makers to institute new and innovative policies to manage those resources in a sustainable way ensuring their availability for future generations.

Adequately managing the world's aquatic resources for the benefit of all is, for a variety of reasons, a very complex task. The liquid state of the most of the world's water means that, without the construction of reservoirs, dams and canals it is free to flow wherever the laws of nature dictate. Water is, therefore, a vector transporting not only a wide variety of valuable resources but also problems from one area to another. The effluents emanating from environmentally destructive activities in upstream drainage areas are propagated downstream and can affect other areas considerable distances away. In the case of transboundary river basins, such as the Nile, Amazon and Niger, the impacts are transported across national borders and can be observed in the numerous countries situated within their catchments. In the case of large oceanic currents, the impacts can even be propagated between continents (AMAP 1998). Therefore, the inextricable linkages within and between both freshwater and marine environments dictates that management of aquatic resources ought to be implemented through a drainage basin approach.

In addition, there is growing appreciation of the incongruence between the transboundary nature of many aquatic resources and the traditional introspective nationally focused approaches to managing those resources. Water, unlike laws and management plans, does not respect national borders and, as a consequence, if future management of water and aquatic resources is to be successful, then a shift in focus towards international cooperation and intergovernmental agreements is required (UN 1972). Furthermore, the complexity of managing the world's water resources is exacerbated by the dependence of a great variety of domestic and industrial activities on those resources. As a consequence, cross-sectoral multidisciplinary approaches that integrate environmental, socio-economic and development aspects into management must be adopted. Unfortunately however, the scientific information or capacity within each discipline is often not available or is inadequately translated for use by managers, decision makers and policy developers. These inadequacies constitute a serious impediment to the implementation of urgently needed innovative policies.

Continual assessment of the prevailing and future threats to aquatic ecosystems and their implications for human populations is essential if governments and decision makers are going to be able to make strategic policy and management decisions that promote the sustainable use of those resources and respond to the growing concerns of the general public. Although many assessments of aquatic resources are being conducted by local, national, regional and international bodies, past assessments have often concentrated on specific themes, such as biodiversity or persistent toxic substances, or have focused only on marine or freshwaters. A globally coherent, drainage basin based assessment that embraces the inextricable links between transboundary freshwater and marine systems, and between environmental and societal issues, has never been conducted previously.

International call for action

The need for a holistic assessment of transboundary waters in order to respond to growing public concerns and provide advice to governments and decision makers regarding the management of aquatic resources was recognised by several international bodies focusing on the global environment. In particular, the Global Environment Facility (GEF) observed that the International Waters (IW) component of the GEF suffered from the lack of a global assessment which made it difficult to prioritise international water projects, particularly considering the inadequate understanding of the nature and root causes of environmental problems. In 1996, at its fourth meeting in Nairobi, the GEF Scientific and Technical Advisory Panel (STAP), noted that: *"Lack of an International Waters Assessment comparable with that of the IPCC, the Global Biodiversity Assessment, and the Stratospheric Ozone Assessment, was a unique and serious impediment to the implementation of the International Waters Component of the GEF"*.

The urgent need for an assessment of the causes of environmental degradation was also highlighted at the UN Special Session on the Environment (UNGASS) in 1997, where commitments were made regarding the work of the UN Commission on Sustainable Development (UNCSD) on freshwater in 1998 and seas in 1999. Also in 1997, two international Declarations, the Potomac Declaration: Towards enhanced ocean security into the third millennium, and the Stockholm Statement on interaction of land activities, freshwater and enclosed seas, specifically emphasised the need for an investigation of the root causes of degradation of the transboundary aquatic environment and options for addressing them. These processes led to the development of the Global International Waters Assessment (GIWA) that would be implemented by the United Nations Environment Programme (UNEP) in conjunction with the University of Kalmar, Sweden, on behalf of the GEF. The GIWA was inaugurated in Kalmar in October 1999 by the Executive Director of UNEP, Dr. Klaus Töpfer, and the late Swedish Minister of the Environment, Kjell Larsson. On this occasion Dr. Töpfer stated: *"GIWA is the framework of UNEP´s global water assessment strategy and will enable us to record and report on critical water resources for the planet for consideration of sustainable development management practices as part of our responsibilities under Agenda 21 agreements of the Rio conference"*.

The importance of the GIWA has been further underpinned by the UN Millennium Development Goals adopted by the UN General Assembly in 2000 and the Declaration from the World Summit on Sustainable

The Global Environment Facility (GEF)

The Global Environment Facility forges international co-operation and finances actions to address six critical threats to the global environment: biodiversity loss, climate change, degradation of international waters, ozone depletion, land degradation, and persistent organic pollutants (POPs).

The overall strategic thrust of GEF-funded international waters activities is to meet the incremental costs of: (a) assisting groups of countries to better understand the environmental concerns of their international waters and work collaboratively to address them; (b) building the capacity of existing institutions to utilise a more comprehensive approach for addressing transboundary water-related environmental concerns; and (c) implementing measures that address the priority transboundary environmental concerns. The goal is to assist countries to utilise the full range of technical, economic, financial, regulatory, and institutional measures needed to operationalise sustainable development strategies for international waters.

United Nations Environment Programme (UNEP)

United Nations Environment Programme, established in 1972, is the voice for the environment within the United Nations system. The mission of UNEP is to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations.

UNEP work encompasses:

- Assessing global, regional and national environmental conditions and trends;
- Developing international and national environmental instruments;
- Strengthening institutions for the wise management of the environment;
- Facilitating the transfer of knowledge and technology for sustainable development;
- Encouraging new partnerships and mind-sets within civil society and the private sector.

University of Kalmar

University of Kalmar hosts the GIWA Co-ordination Office and provides scientific advice and administrative and technical assistance to GIWA. University of Kalmar is situated on the coast of the Baltic Sea. The city has a long tradition of higher education; teachers and marine officers have been educated in Kalmar since the middle of the 19th century. Today, natural science is a priority area which gives Kalmar a unique educational and research profile compared with other smaller universities in Sweden. Of particular relevance for GIWA is the established research in aquatic and environmental science. Issues linked to the concept of sustainable development are implemented by the research programme Natural Resources Management and Agenda 21 Research School.

Since its establishment GIWA has grown to become an integral part of University activities. The GIWA Co-ordination office and GIWA Core team are located at the Kalmarsund Laboratory, the university centre for water-related research. Senior scientists appointed by the University are actively involved in the GIWA peer-review and steering groups. As a result of the cooperation the University can offer courses and seminars related to GIWA objectives and international water issues.

Development in 2002. The development goals aimed to halve the proportion of people without access to safe drinking water and basic sanitation by the year 2015 (United Nations Millennium Declaration 2000). The WSSD also calls for integrated management of land, water and living resources (WSSD 2002) and, by 2010, the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem should be implemented by all countries that are party to the declaration (FAO 2001).

The conceptual framework and objectives

Considering the general decline in the condition of the world's aquatic resources and the internationally recognised need for a globally coherent assessment of transboundary waters, the primary objectives of the GIWA are:

- To provide a prioritising mechanism that allows the GEF to focus their resources so that they are used in the most cost effective manner to achieve significant environmental benefits, at national, regional and global levels; and
- To highlight areas in which governments can develop and implement strategic policies to reduce environmental degradation and improve the management of aquatic resources.

In order to meet these objectives and address some of the current inadequacies in international aquatic resources management, the GIWA has incorporated four essential elements into its design:

- A broad transboundary approach that generates a truly regional perspective through the incorporation of expertise and existing information from all nations in the region and the assessment of all factors that influence the aquatic resources of the region;
- A drainage basin approach integrating freshwater and marine systems;
- A multidisciplinary approach integrating environmental and socio-economic information and expertise; and
- A coherent assessment that enables global comparison of the results.

The GIWA builds on previous assessments implemented within the GEF International Waters portfolio but has developed and adopted a broader definition of transboundary waters to include factors that influence the quality and quantity of global aquatic resources. For example, due to globalisation and international trade, the market for penaeid shrimps has widened and the prices soared. This, in turn, has encouraged entrepreneurs in South East Asia to expand aquaculture resulting in the large-scale deforestation of mangroves for ponds (Primavera 1997). Within the GIWA, these "non-hydrological" factors constitute as large a transboundary influence as more traditionally recognised problems, such as the construction of dams that regulate the flow of water into a neighbouring country, and are considered equally important. In addition, the GIWA recognises the importance of hydrological units that would not normally be considered transboundary but exert a significant influence on transboundary waters, such as the Yangtze River in China which discharges into the East China Sea (Daoji & Daler 2004) and the Volga River in Russia which is largely responsible for the condition of the Caspian Sea (Barannik et al. 2004). Furthermore, the GIWA is a truly regional assessment that has incorporated data from a wide range of sources and included expert knowledge and information from a wide range of sectors and from each country in the region. Therefore, the transboundary concept adopted by the GIWA extends to include impacts caused by globalisation, international trade, demographic changes and technological advances and recognises the need for international cooperation to address them.

International waters and transboundary issues

The term "international waters", as used for the purposes of the GEF Operational Strategy, includes the oceans, large marine ecosystems, enclosed or semi-enclosed seas and estuaries, as well as rivers, lakes, groundwater systems, and wetlands with transboundary drainage basins or common borders. The water-related ecosystems associated with these waters are considered integral parts of the systems.

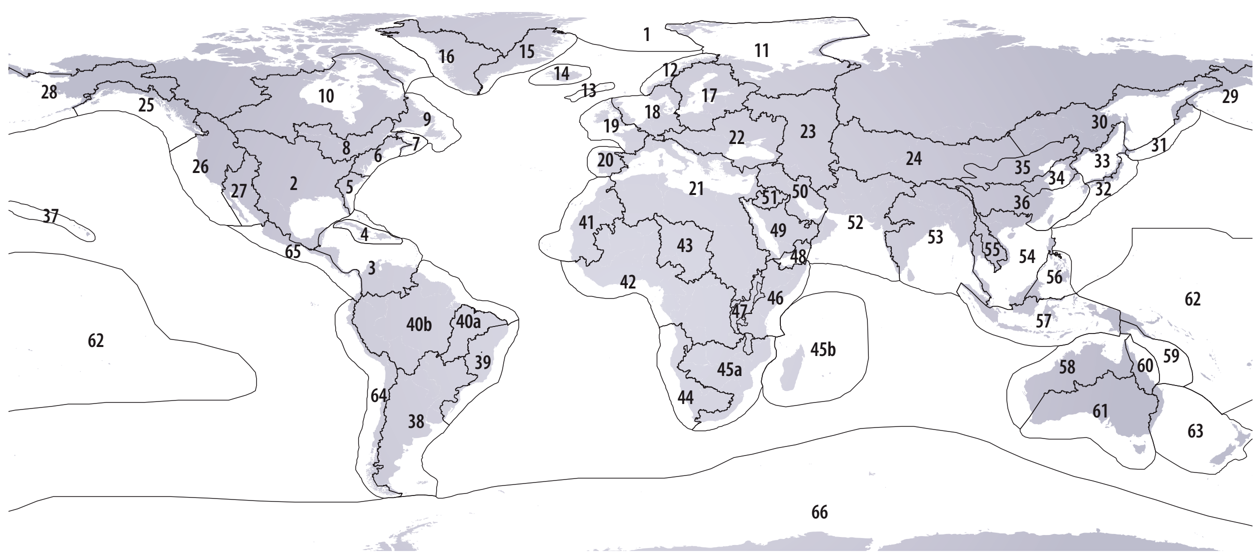
The term "transboundary issues" is used to describe the threats to the aquatic environment linked to globalisation, international trade, demographic changes and technological advancement, threats that are additional to those created through transboundary movement of water. Single country policies and actions are inadequate in order to cope with these challenges and this makes them transboundary in nature.

The international waters area includes numerous international conventions, treaties, and agreements. The architecture of marine agreements is especially complex, and a large number of bilateral and multilateral agreements exist for transboundary freshwater basins. Related conventions and agreements in other areas increase the complexity. These initiatives provide a new opportunity for cooperating nations to link many different programmes and instruments into regional comprehensive approaches to address international waters.

The organisational structure and implementation of the GIWA

The scale of the assessment

Initially, the scope of the GIWA was confined to transboundary waters in areas that included countries eligible to receive funds from the GEF. However, it was recognised that a truly global perspective would only be achieved if industrialised, GEF-ineligible regions of the world were also assessed. Financial resources to assess the GEF-eligible countries were obtained primarily from the GEF (68%), the Swedish International Development Cooperation Agency (Sida) (18%), and the Finnish Department for International Development Cooperation (FINNIDA)



1 Arctic
2 Gulf of Mexico (LME)
3 Caribbean Sea (LME)
4 Caribbean Islands
5 Southeast Shelf (LME)
6 Northeast Shelf (LME)
7 Scotian Shelf (LME)
8 Gulf of St Lawrence
9 Newfoundland Shelf (LME)
10 Baffin Bay, Labrador Sea, Canadian Archipelago
11 Barents Sea (LME)
12 Norwegian Sea (LME)
13 Faroe plateau
14 Iceland Shelf (LME)
15 East Greenland Shelf (LME)
16 West Greenland Shelf (LME)
17 Baltic Sea (LME)
18 North Sea (LME)
19 Celtic-Biscay Shelf (LME)
20 Iberian Coastal (LME)
21 Mediterranean Sea (LME)
22 Black Sea (LME)
23 Caspian Sea
24 Aral Sea
25 Gulf of Alaska (LME)
26 California Current (LME)
27 Gulf of California (LME)
28 East Bering Sea (LME)
29 West Bering Sea (LME)
30 Sea of Okhotsk (LME)
31 Oyashio Current (LME)
32 Kuroshio Current (LME)
33 Sea of Japan/East Sea (LME)
34 Yellow Sea (LME)
35 Bohai Sea
36 East-China Sea (LME)
37 Hawaiian Archipelago (LME)
38 Patagonian Shelf (LME)
39 Brazil Current (LME)
40a Brazilian Northeast (LME)
40b Amazon
41 Canary Current (LME)
42 Guinea Current (LME)
43 Lake Chad
44 Benguela Current (LME)
45a Agulhas Current (LME)
45b Indian Ocean Islands
46 Somali Coastal Current (LME)
47 East African Rift Valley Lakes
48 Gulf of Aden
49 Red Sea (LME)
50 The Gulf
51 Jordan
52 Arabian Sea (LME)
53 Bay of Bengal S.E.
54 South China Sea (LME)
55 Mekong River
56 Sulu-Celebes Sea (LME)
57 Indonesian Seas (LME)
58 North Australian Shelf (LME)
59 Coral Sea Basin
60 Great Barrier Reef (LME)
61 Great Australian Bight
62 Small Island States
63 Tasman Sea
64 Humboldt Current (LME)
65 Eastern Equatorial Pacific
66 Antarctic (LME)

Figure 1 The 66 transboundary regions assessed within the GIWA project.

(10%). Other contributions were made by Kalmar Municipality, the University of Kalmar and the Norwegian Government. The assessment of regions ineligible for GEF funds was conducted by various international and national organisations as in-kind contributions to the GIWA.

In order to be consistent with the transboundary nature of many of the world's aquatic resources and the focus of the GIWA, the geographical units being assessed have been designed according to the watersheds of discrete hydrographic systems rather than political borders (Figure 1). The geographic units of the assessment were determined during the preparatory phase of the project and resulted in the division of the world into 66 regions defined by the entire area of one or more catchments areas that drains into a single designated marine system. These marine systems often correspond to Large Marine Ecosystems (LMEs) (Sherman 1994, IOC 2002).

Large Marine Ecocsystems (LMEs)

Large Marine Ecosystems (LMEs) are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margin of the major current systems. They are relatively large regions on the order of 200 000 km^2 or greater, characterised by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations.

The Large Marine Ecosystems strategy is a global effort for the assessment and management of international coastal waters. It developed in direct response to a declaration at the 1992 Rio Summit. As part of the strategy, the World Conservation Union (IUCN) and National Oceanic and Atmospheric Administration (NOAA) have joined in an action program to assist developing countries in planning and implementing an ecosystem-based strategy that is focused on LMEs as the principal assessment and management units for coastal ocean resources. The LME concept is also adopted by GEF that recommends the use of LMEs and their contributing freshwater basins as the geographic area for integrating changes in sectoral economic activities.

Considering the objectives of the GIWA and the elements incorporated into its design, a new methodology for the implementation of the assessment was developed during the initial phase of the project. The methodology focuses on five major environmental concerns which constitute the foundation of the GIWA assessment; Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, and Global change. The GIWA methodology is outlined in the following chapter.

The global network

In each of the 66 regions, the assessment is conducted by a team of local experts that is headed by a Focal Point (Figure 2). The Focal Point can be an individual, institution or organisation that has been selected on the basis of their scientific reputation and experience implementing international assessment projects. The Focal Point is responsible for assembling members of the team and ensuring that it has the necessary expertise and experience in a variety of environmental and socio-economic disciplines to successfully conduct the regional assessment. The selection of team members is one of the most critical elements for the success of GIWA and, in order to ensure that the most relevant information is incorporated into the assessment, team members were selected from a wide variety of institutions such as universities, research institutes, government agencies, and the private sector. In addition, in order to ensure that the assessment produces a truly regional perspective, the teams should include representatives from each country that shares the region.

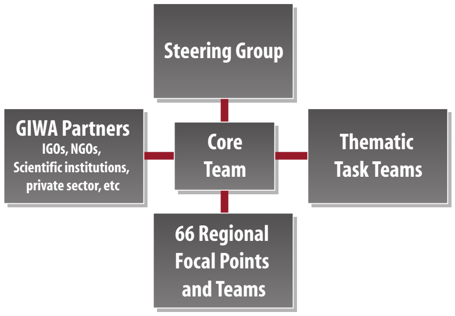


Figure 2 The organisation of the GIWA project.

In total, more than 1 000 experts have contributed to the implementation of the GIWA illustrating that the GIWA is a participatory exercise that relies on regional expertise. This participatory approach is essential because it instils a sense of local ownership of the project, which ensures the credibility of the findings and moreover, it has created a global network of experts and institutions that can collaborate and exchange experiences and expertise to help mitigate the continued degradation of the world's aquatic resources.

GIWA Regional reports

The GIWA was established in response to growing concern among the general public regarding the quality of the world's aquatic resources and the recognition of governments and the international community concerning the absence of a globally coherent international waters assessment. However, because a holistic, region-by-region, assessment of the condition of the world's transboundary water resources had never been undertaken, a methodology guiding the implementation of such an assessment did not exist. Therefore, in order to implement the GIWA, a new methodology that adopted a multidisciplinary, multi-sectoral, multi-national approach was developed and is now available for the implementation of future international assessments of aquatic resources.

UNEP Water Policy and Strategy

The primary goals of the UNEP water policy and strategy are:

(a) Achieving greater global understanding of freshwater, coastal and marine environments by conducting environmental assessments in priority areas;

(b) Raising awareness of the importance and consequences of unsustainable water use;

(c) Supporting the efforts of Governments in the preparation and implementation of integrated management of freshwater systems and their related coastal and marine environments;

(d) Providing support for the preparation of integrated management plans and programmes for aquatic environmental hot spots, based on the assessment results;

(e) Promoting the application by stakeholders of precautionary, preventive and anticipatory approaches.

The GIWA is comprised of a logical sequence of four integrated components. The first stage of the GIWA is called Scaling and is a process by which the geographic area examined in the assessment is defined and all the transboundary waters within that area are identified. Once the geographic scale of the assessment has been defined, the assessment teams conduct a process known as Scoping in which the magnitude of environmental and associated socio-economic impacts of Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources, and Global change is assessed in order to identify and prioritise the concerns that require the most urgent intervention. The assessment of these predefined concerns incorporates the best available information and the knowledge and experience of the multidisciplinary, multi-national assessment teams formed in each region. Once the priority concerns have been identified, the root causes of these concerns are identified during the third component of the GIWA, Causal chain analysis. The root causes are determined through a sequential process that identifies, in turn, the most significant immediate causes followed by the economic sectors that are primarily responsible for the immediate causes and finally, the societal root causes. At each stage in the Causal chain analysis, the most significant contributors are identified through an analysis of the best available information which is augmented by the expertise of the assessment team. The final component of the GIWA is the development of Policy options that focus on mitigating the impacts of the root causes identified by the Causal chain analysis.

The results of the GIWA assessment in each region are reported in regional reports that are published by UNEP. These reports are designed to provide a brief physical and socio-economic description of the most important features of the region against which the results of the assessment can be cast. The remaining sections of the report present the results of each stage of the assessment in an easily digestible form. Each regional report is reviewed by at least two independent external reviewers in order to ensure the scientific validity and applicability of each report. The 66 regional assessments of the GIWA will serve UNEP as an essential complement to the UNEP Water Policy and Strategy and UNEP's activities in the hydrosphere.

Global International Waters Assessment

References:

AMAP (1998). Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Barannik, V., Borysova, O. and Stolberg, F. (2004). The Caspian Sea Region: Environmental Change. Ambio, 33:45-51.

Brinson, M.M. and Malvárez, A.I. (2002). Temperate freshwater wetlands: types, status, and threats. Environmental Conservation, 29:115-133.

Daoji, L. and Daler, D. (2004). Ocean Pollution from Land-based Sources: East China Sea, China. Ambio, 33:98-106.

FAO (2001). Reykjavik conference on responsible fisheries in the marine ecosystem. Iceland, 1-4 October 2001.

IOC (2002). IOC-IUCN-NOAA Consultative Meeting on Large Marine Ecosystems (LMEs). Fourth Session, 8-9 January 2002, Paris, France.

IPCC (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kennish, M.J. (2002). Environmental threats and environmental future of estuaries. Environmental Conservation, 29:78-107.

Myers, R.A. and Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. Nature, 423:280-283.

Primavera, J.H. (1997) Socio-economic impacts of shrimp culture. Aquaculture Research, 28:815-827.

Sherman, K. (1994). Sustainability, biomass yields, and health of coastal ecosystems: an ecological perspective. Marine Ecology Progress Series, 112:277-301.

United Nations conference on the human environment (1972). Report available on-line at http://www.unep.org

United Nations Millennium Declaration (2000). The Millennium Assembly of the United Nations, New York.

WHO-UNICEF (2002). Global Water Supply and Sanitation Assessment: 2000 Report.

WSSD (2002). World Summit on Sustainable Development. Johannesburg Summit 2002. Key Outcomes of the Summit, UN Department of Public Information, New York.

The GIWA methodology

The specific objectives of the GIWA were to conduct a holistic and globally comparable assessment of the world's transboundary aquatic resources that incorporated both environmental and socio-economic factors and recognised the inextricable links between freshwater and marine environments, in order to enable the GEF to focus their resources and to provide guidance and advice to governments and decision makers. The coalition of all these elements into a single coherent methodology that produces an assessment that achieves each of these objectives had not previously been done and posed a significant challenge.

The integration of each of these elements into the GIWA methodology was achieved through an iterative process guided by a specially convened Methods task team that was comprised of a number of international assessment and water experts. Before the final version of the methodology was adopted, preliminary versions underwent an extensive external peer review and were subjected to preliminary testing in selected regions. Advice obtained from the Methods task team and other international experts and the lessons learnt from preliminary testing were incorporated into the final version that was used to conduct each of the GIWA regional assessments.

Considering the enormous differences between regions in terms of the quality, quantity and availability of data, socio-economic setting and environmental conditions, the achievement of global comparability required an innovative approach. This was facilitated by focusing the assessment on the impacts of five pre-defined concerns namely; Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources and Global change, in transboundary waters. Considering the diverse range of elements encompassed by each concern, assessing the magnitude of the impacts caused by these concerns was facilitated by evaluating the impacts of 22 specific issues that were grouped within these concerns (see Table 1).

The assessment integrates environmental and socio-economic data from each country in the region to determine the severity of the impacts of each of the five concerns and their constituent issues on the entire region. The integration of this information was facilitated by implementing the assessment during two participatory workshops that typically involved 10 to 15 environmental and socio-economic experts from each country in the region. During these workshops, the regional teams performed preliminary analyses based on the collective knowledge and experience of these local experts. The results of these analyses were substantiated with the best available information to be presented in a regional report.

Table 1 Pre-defined GIWA concerns and their constituent issues addressed within the assessment.

Environmental issues	Major concerns
1. Modification of stream flow 2. Pollution of existing supplies 3. Changes in the water table	**I Freshwater shortage**
4. Microbiological 5. Eutrophication 6. Chemical 7. Suspended solids 8. Solid wastes 9. Thermal 10. Radionuclide 11. Spills	**II Pollution**
12. Loss of ecosystems 13. Modification of ecosystems or ecotones, including community structure and/or species composition	**III Habitat and community modification**
14. Overexploitation 15. Excessive by-catch and discards 16. Destructive fishing practices 17. Decreased viability of stock through pollution and disease 18. Impact on biological and genetic diversity	**IV Unsustainable exploitation of fish and other living resources**
19. Changes in hydrological cycle 20. Sea level change 21. Increased uv-b radiation as a result of ozone depletion 22. Changes in ocean CO_2 source/sink function	**V Global change**

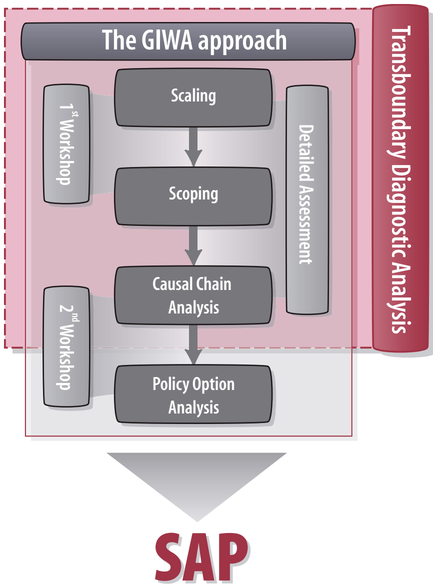


Figure 1 Illustration of the relationship between the GIWA approach and other projects implemented within the GEF International Waters (IW) portfolio.

The GIWA is a logical contiguous process that defines the geographic region to be assessed, identifies and prioritises particularly problems based on the magnitude of their impacts on the environment and human societies in the region, determines the root causes of those problems and, finally, assesses various policy options that addresses those root causes in order to reverse negative trends in the condition of the aquatic environment. These four steps, referred to as Scaling, Scoping, Causal chain analysis and Policy options analysis, are summarised below and are described in their entirety in two volumes: *GIWA Methodology Stage 1: Scaling and Scoping*; and *GIWA Methodology: Detailed Assessment, Causal Chain Analysis and Policy Options Analysis*. Generally, the components of the GIWA methodology are aligned with the framework adopted by the GEF for Transboundary Diagnostic Analyses (TDAs) and Strategic Action Programmes (SAPs) (Figure 1) and assume a broad spectrum of transboundary influences in addition to those associated with the physical movement of water across national borders.

Scaling – Defining the geographic extent of the region

Scaling is the first stage of the assessment and is the process by which the geographic scale of the assessment is defined. In order to facilitate the implementation of the GIWA, the globe was divided during the design phase of the project into 66 contiguous regions. Considering the transboundary nature of many aquatic resources and the transboundary focus of the GIWA, the boundaries of the regions did not comply with political boundaries but were instead, generally defined by a large but discrete drainage basin that also included the coastal marine waters into which the basin discharges. In many cases, the marine areas examined during the assessment coincided with the Large Marine Ecosystems (LMEs) defined by the US National Atmospheric and Oceanographic Administration (NOAA). As a consequence, scaling should be a relatively straight-forward task that involves the inspection of the boundaries that were proposed for the region during the preparatory phase of GIWA to ensure that they are appropriate and that there are no important overlaps or gaps with neighbouring regions. When the proposed boundaries were found to be inadequate, the boundaries of the region were revised according to the recommendations of experts from both within the region and from adjacent regions so as to ensure that any changes did not result in the exclusion of areas from the GIWA. Once the regional boundary was defined, regional teams identified all the transboundary elements of the aquatic environment within the region and determined if these elements could be assessed as a single coherent aquatic system or if there were two or more independent systems that should be assessed separately.

Scoping – Assessing the GIWA concerns

Scoping is an assessment of the severity of environmental and socio-economic impacts caused by each of the five pre-defined GIWA concerns and their constituent issues (Table 1). It is not designed to provide an exhaustive review of water-related problems that exist within each region, but rather it is a mechanism to identify the most urgent problems in the region and prioritise those for remedial actions. The priorities determined by Scoping are therefore one of the main outputs of the GIWA project.

Focusing the assessment on pre-defined concerns and issues ensured the comparability of the results between different regions. In addition, to ensure the long-term applicability of the options that are developed to mitigate these problems, Scoping not only assesses the current impacts of these concerns and issues but also the probable future impacts according to the "most likely scenario" which considered demographic, economic, technological and other relevant changes that will potentially influence the aquatic environment within the region by 2020.

The magnitude of the impacts caused by each issue on the environment and socio-economic indicators was assessed over the entire region using the best available information from a wide range of sources and the knowledge and experience of the each of the experts comprising the regional team. In order to enhance the comparability of the assessment between different regions and remove biases in the assessment caused by different perceptions of and ways to communicate the severity of impacts caused by particular issues, the results were distilled and reported as standardised scores according to the following four point scale:

- 0 = no known impact
- 1 = slight impact
- 2 = moderate impact
- 3 = severe impact

The attributes of each score for each issue were described by a detailed set of pre-defined criteria that were used to guide experts in reporting the results of the assessment. For example, the criterion for assigning a score of 3 to the issue Loss of ecosystems or ecotones is: "*Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades.*" The full list of criteria is presented at the end of the chapter, Table 5a-e. Although the scoring inevitably includes an arbitrary component, the use of predefined criteria facilitates comparison of impacts on a global scale and also encouraged consensus of opinion among experts.

The trade-off associated with assessing the impacts of each concern and their constituent issues at the scale of the entire region is that spatial resolution was sometimes low. Although the assessment provides a score indicating the severity of impacts of a particular issue or concern on the entire region, it does not mean that the entire region suffers the impacts of that problem. For example, eutrophication could be identified as a severe problem in a region, but this does not imply that all waters in the region suffer from severe eutrophication. It simply means that when the degree of eutrophication, the size of the area affected, the socio-economic impacts and the number of people affected is considered, the magnitude of the overall impacts meets the criteria defining a severe problem and that a regional action should be initiated in order to mitigate the impacts of the problem.

When each issue has been scored, it was weighted according to the relative contribution it made to the overall environmental impacts of the concern and a weighted average score for each of the five concerns was calculated (Table 2). Of course, if each issue was deemed to make equal contributions, then the score describing the overall impacts of the concern was simply the arithmetic mean of the scores allocated to each issue within the concern. In addition, the socio-economic impacts of each of the five major concerns were assessed for the entire region. The socio-economic impacts were grouped into three categories; Economic impacts, Health impacts and Other social and community impacts (Table 3). For each category, an evaluation of the size, degree and frequency of the impact was performed and, once completed, a weighted average score describing the overall socio-economic impacts of each concern was calculated in the same manner as the overall environmental score.

Table 2 Example of environmental impact assessment of Freshwater shortage.

Environmental issues	Score	Weight %	Environmental concerns	Weight averaged score
1. Modification of stream flow	1	20	Freshwater shortage	1.50
2. Pollution of existing supplies	2	50		
3. Changes in the water table	1	30		

Table 3 Example of Health impacts assessment linked to one of the GIWA concerns.

Criteria for Health impacts	Raw score	Score	Weight %
Number of people affected	Very small – Very large 0 1 2 3	2	50
Degree of severity	Minimum – Severe 0 1 2 3	2	30
Frequency/Duration	Occasion/Short – Continuous 0 1 2 3	2	20
Weight average score for Health impacts		**2**	

After all 22 issues and associated socio-economic impacts have been scored, weighted and averaged, the magnitude of likely future changes in the environmental and socio-economic impacts of each of the five concerns on the entire region is assessed according to the most likely scenario which describes the demographic, economic, technological and other relevant changes that might influence the aquatic environment within the region by 2020.

In order to prioritise among GIWA concerns within the region and identify those that will be subjected to causal chain and policy options analysis in the subsequent stages of the GIWA, the present and future scores of the environmental and socio-economic impacts of each concern are tabulated and an overall score calculated. In the example presented in Table 4, the scoping assessment indicated that concern III, Habitat and community modification, was the priority concern in this region. The outcome of this mathematic process was reconciled against the knowledge of experts and the best available information in order to ensure the validity of the conclusion.

In some cases however, this process and the subsequent participatory discussion did not yield consensus among the regional experts regarding the ranking of priorities. As a consequence, further analysis was required. In such cases, expert teams continued by assessing the relative importance of present and potential future impacts and assign weights to each. Afterwards, the teams assign weights indicating the relative contribution made by environmental and socio-economic factors to the overall impacts of the concern. The weighted average score for each concern is then recalculated taking into account

Table 4 Example of comparative environmental and socio-economic impacts of each major concern, presently and likely in year 2020.

Concern	Types of impacts								Overall score
	Environmental score		Economic score		Human health score		Social and community score		
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.3	2.3	2.7	2.8	2.6	3.0	1.8	2.2	**2.3**
Pollution	1.5	2.0	2.0	2.3	1.8	2.3	2.0	2.3	**2.0**
Habitat and community modification	2.0	3.0	2.4	3.0	2.4	2.8	2.3	2.7	**2.6**
Unsustainable exploitation of fish and other living resources	1.8	2.2	2.0	2.1	2.0	2.1	2.4	2.5	**2.1**
Global change	0.8	1.0	1.5	1.7	1.5	1.5	1.0	1.0	**1.2**

the relative contributions of both present and future impacts and environmental and socio-economic factors. The outcome of these additional analyses was subjected to further discussion to identify overall priorities for the region.

Finally, the assessment recognises that each of the five GIWA concerns are not discrete but often interact. For example, pollution can destroy aquatic habitats that are essential for fish reproduction which, in turn, can cause declines in fish stocks and subsequent overexploitation. Once teams have ranked each of the concerns and determined the priorities for the region, the links between the concerns are highlighted in order to identify places where strategic interventions could be applied to yield the greatest benefits for the environment and human societies in the region.

Causal chain analysis

Causal Chain Analysis (CCA) traces the cause-effect pathways from the socio-economic and environmental impacts back to their root causes. The GIWA CCA aims to identify the most important causes of each concern prioritised during the scoping assessment in order to direct policy measures at the most appropriate target in order to prevent further degradation of the regional aquatic environment.

Root causes are not always easy to identify because they are often spatially or temporally separated from the actual problems they cause. The GIWA CCA was developed to help identify and understand the root causes of environmental and socio-economic problems in international waters and is conducted by identifying the human activities that cause the problem and then the factors that determine the ways in which these activities are undertaken. However, because there is no universal theory describing how root causes interact to create natural resource management problems and due to the great variation of local circumstances under which the methodology will be applied, the GIWA CCA is not a rigidly structured assessment but should be regarded as a framework to guide the analysis, rather than as a set of detailed instructions. Secondly, in an ideal setting, a causal chain would be produced by a multidisciplinary group of specialists that would statistically examine each successive cause and study its links to the problem and to other causes. However, this approach (even if feasible) would use far more resources and time than those available to GIWA[1]. For this reason, it has been necessary to develop a relatively simple and practical analytical model for gathering information to assemble meaningful causal chains.

Conceptual model

A causal chain is a series of statements that link the causes of a problem with its effects. Recognising the great diversity of local settings and the resulting difficulty in developing broadly applicable policy strategies, the GIWA CCA focuses on a particular system and then only on those issues that were prioritised during the scoping assessment. The starting point of a particular causal chain is one of the issues selected during the Scaling and Scoping stages and its related environmental and socio-economic impacts. The next element in the GIWA chain is the immediate cause; defined as the physical, biological or chemical variable that produces the GIWA issue. For example, for the issue of eutrophication the immediate causes may be, inter alia:

- Enhanced nutrient inputs;
- Increased recycling/mobilisation;
- Trapping of nutrients (e.g. in river impoundments);
- Run-off and stormwaters

Once the relevant immediate cause(s) for the particular system has (have) been identified, the sectors of human activity that contribute most significantly to the immediate cause have to be determined. Assuming that the most important immediate cause in our example had been increased nutrient concentrations, then it is logical that the most likely sources of those nutrients would be the agricultural, urban or industrial sectors. After identifying the sectors that are primarily

[1] This does not mean that the methodology ignores statistical or quantitative studies; as has already been pointed out, the available evidence that justifies the assumption of causal links should be provided in the assessment.

responsible for the immediate causes, the root causes acting on those sectors must be determined. For example, if agriculture was found to be primarily responsible for the increased nutrient concentrations, the root causes could potentially be:

- Economic (e.g. subsidies to fertilisers and agricultural products);
- Legal (e.g. inadequate regulation);
- Failures in governance (e.g. poor enforcement); or
- Technology or knowledge related (e.g. lack of affordable substitutes for fertilisers or lack of knowledge as to their application).

Once the most relevant root causes have been identified, an explanation, which includes available data and information, of how they are responsible for the primary environmental and socio-economic problems in the region should be provided.

Policy option analysis

Despite considerable effort of many Governments and other organisations to address transboundary water problems, the evidence indicates that there is still much to be done in this endeavour. An important characteristic of GIWA's Policy Option Analysis (POA) is that its recommendations are firmly based on a better understanding of the root causes of the problems. Freshwater scarcity, water pollution, overexploitation of living resources and habitat destruction are very complex phenomena. Policy options that are grounded on a better understanding of these phenomena will contribute to create more effective societal responses to the extremely complex water related transboundary problems. The core of POA in the assessment consists of two tasks:

Construct policy options

Policy options are simply different courses of action, which are not always mutually exclusive, to solve or mitigate environmental and socio-economic problems in the region. Although a multitude of different policy options could be constructed to address each root cause identified in the CCA, only those few policy options that have the greatest likelihood of success were analysed in the GIWA.

Select and apply the criteria on which the policy options will be evaluated

Although there are many criteria that could be used to evaluate any policy option, GIWA focuses on:

- Effectiveness (certainty of result)
- Efficiency (maximisation of net benefits)
- Equity (fairness of distributional impacts)
- Practical criteria (political acceptability, implementation feasibility).

The policy options recommended by the GIWA are only contributions to the larger policy process and, as such, the GIWA methodology developed to test the performance of various options under the different circumstances has been kept simple and broadly applicable.

Global International Waters Assessment

Table 5a: Scoring criteria for environmental impacts of Freshwater shortage

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 1: Modification of stream flow "An increase or decrease in the discharge of streams and rivers as a result of human interventions on a local/ regional scale (see Issue 19 for flow alterations resulting from global change) over the last 3-4 decades."	■ No evidence of modification of stream flow.	■ There is a measurably changing trend in annual river discharge at gauging stations in a major river or tributary (basin > 40 000 km²); or ■ There is a measurable decrease in the area of wetlands (other than as a consequence of conversion or embankment construction); or ■ There is a measurable change in the interannual mean salinity of estuaries or coastal lagoons and/or change in the mean position of estuarine salt wedge or mixing zone; or ■ Change in the occurrence of exceptional discharges (e.g. due to upstream damming.	■ Significant downward or upward trend (more than 20% of the long term mean) in annual discharges in a major river or tributary draining a basin of >250 000 km²; or ■ Loss of >20% of flood plain or deltaic wetlands through causes other than conversion or artificial embankments; or ■ Significant loss of riparian vegetation (e.g. trees, flood plain vegetation); or ■ Significant saline intrusion into previously freshwater rivers or lagoons.	■ Annual discharge of a river altered by more than 50% of long term mean; or ■ Loss of >50% of riparian or deltaic wetlands over a period of not less than 40 years (through causes other than conversion or artificial embankment); or ■ Significant increased siltation or erosion due to changing in flow regime (other than normal fluctuations in flood plain rivers); or ■ Loss of one or more anadromous or catadromous fish species for reasons other than physical barriers to migration, pollution or overfishing.
Issue 2: Pollution of existing supplies "Pollution of surface and ground fresh waters supplies as a result of point or diffuse sources"	■ No evidence of pollution of surface and ground waters.	■ Any monitored water in the region does not meet WHO or national drinking water criteria, other than for natural reasons; or ■ There have been reports of one or more fish kills in the system due to pollution within the past five years.	■ Water supplies does not meet WHO or national drinking water standards in more than 30% of the region; or ■ There are one or more reports of fish kills due to pollution in any river draining a basin of >250 000 km².	■ River draining more than 10% of the basin have suffered polysaprobic conditions, no longer support fish, or have suffered severe oxygen depletion ■ Severe pollution of other sources of freshwater (e.g. groundwater)
Issue 3: Changes in the water table "Changes in aquifers as a direct or indirect consequence of human activity"	■ No evidence that abstraction of water from aquifers exceeds natural replenishment.	■ Several wells have been deepened because of excessive aquifer draw-down; or ■ Several springs have dried up; or ■ Several wells show some salinisation.	■ Clear evidence of declining base flow in rivers in semi-arid areas; or ■ Loss of plant species in the past decade, that depend on the presence of ground water; or ■ Wells have been deepened over areas of hundreds of km²;or ■ Salinisation over significant areas of the region.	■ Aquifers are suffering salinisation over regional scale; or ■ Perennial springs have dried up over regionally significant areas; or ■ Some aquifers have become exhausted

Table 5b: Scoring criteria for environmental impacts of Pollution

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 4: Microbiological pollution "The adverse effects of microbial constituents of human sewage released to water bodies."	■ Normal incidence of bacterial related gastroenteric disorders in fisheries product consumers and no fisheries closures or advisories.	■ There is minor increase in incidence of bacterial related gastroenteric disorders in fisheries product consumers but no fisheries closures or advisories.	■ Public health authorities aware of marked increase in the incidence of bacterial related gastroenteric disorders in fisheries product consumers; or ■ There are limited area closures or advisories reducing the exploitation or marketability of fisheries products.	■ There are large closure areas or very restrictive advisories affecting the marketability of fisheries products; or ■ There exists widespread public or tourist awareness of hazards resulting in major reductions in the exploitation or marketability of fisheries products.
Issue 5: Eutrophication "Artificially enhanced primary productivity in receiving water basins related to the increased availability or supply of nutrients, including cultural eutrophication in lakes."	■ No visible effects on the abundance and distributions of natural living resource distributions in the area; and ■ No increased frequency of hypoxia[1] or fish mortality events or harmful algal blooms associated with enhanced primary production; and ■ No evidence of periodically reduced dissolved oxygen or fish and zoobenthos mortality; and ■ No evident abnormality in the frequency of algal blooms.	■ Increased abundance of epiphytic algae; or ■ A statistically significant trend in decreased water transparency associated with algal production as compared with long-term (>20 year) data sets; or ■ Measurable shallowing of the depth range of macrophytes.	■ Increased filamentous algal production resulting in algal mats; or ■ Medium frequency (up to once per year) of large-scale hypoxia and/or fish and zoobenthos mortality events and/or harmful algal blooms.	■ High frequency (>1 event per year), or intensity, or large areas of periodic hypoxic conditions, or high frequencies of fish and zoobenthos mortality events or harmful algal blooms; or ■ Significant changes in the littoral community; or ■ Presence of hydrogen sulphide in historically well oxygenated areas.

Issue 6: Chemical pollution "The adverse effects of chemical contaminants released to standing or marine water bodies as a result of human activities. Chemical contaminants are here defined as compounds that are toxic or persistent or bioaccumulating."	■ No known or historical levels of chemical contaminants except background levels of naturally occurring substances; and ■ No fisheries closures or advisories due to chemical pollution; and ■ No incidence of fisheries product tainting; and ■ No unusual fish mortality events. If there is no available data use the following criteria: ■ No use of pesticides; and ■ No sources of dioxins and furans; and ■ No regional use of PCBs; and ■ No bleached kraft pulp mills using chlorine bleaching; and ■ No use or sources of other contaminants.	■ Some chemical contaminants are detectable but below threshold limits defined for the country or region; or ■ Restricted area advisories regarding chemical contamination of fisheries products. If there is no available data use the following criteria: ■ Some use of pesticides in small areas; or ■ Presence of small sources of dioxins or furans (e.g., small incineration plants or bleached kraft/pulp mills using chlorine); or ■ Some previous and existing use of PCBs and limited amounts of PCB-containing wastes but not in amounts invoking local concerns; or ■ Presence of other contaminants.	■ Some chemical contaminants are above threshold limits defined for the country or region; or ■ Large area advisories by public health authorities concerning fisheries product contamination but without associated catch restrictions or closures; or ■ High mortalities of aquatic species near outfalls. If there is no available data use the following criteria: ■ Large-scale use of pesticides in agriculture and forestry; or ■ Presence of major sources of dioxins or furans such as large municipal or industrial incinerators or large bleached kraft pulp mills; or ■ Considerable quantities of waste PCBs in the area with inadequate regulation or has invoked some public concerns; or ■ Presence of considerable quantities of other contaminants.	■ Chemical contaminants are above threshold limits defined for the country or region; and ■ Public health and public awareness of fisheries contamination problems with associated reductions in the marketability of such products either through the imposition of limited advisories or by area closures of fisheries; or ■ Large-scale mortalities of aquatic species. If there is no available data use the following criteria: ■ Indications of health effects resulting from use of pesticides; or ■ Known emissions of dioxins or furans from incinerators or chlorine bleaching of pulp; or ■ Known contamination of the environment or foodstuffs by PCBs; or ■ Known contamination of the environment or foodstuffs by other contaminants.
Issue 7: Suspended solids "The adverse effects of modified rates of release of suspended particulate matter to water bodies resulting from human activities"	■ No visible reduction in water transparency; and ■ No evidence of turbidity plumes or increased siltation; and ■ No evidence of progressive riverbank, beach, other coastal or deltaic erosion.	■ Evidently increased or reduced turbidity in streams and/or receiving riverine and marine environments but without major changes in associated sedimentation or erosion rates, mortality or diversity of flora and fauna; or ■ Some evidence of changes in benthic or pelagic biodiversity in some areas due to sediment blanketing or increased turbidity.	■ Markedly increased or reduced turbidity in small areas of streams and/or receiving riverine and marine environments; or ■ Extensive evidence of changes in sedimentation or erosion rates; or ■ Changes in benthic or pelagic biodiversity in areas due to sediment blanketing or increased turbidity.	■ Major changes in turbidity over wide or ecologically significant areas resulting in markedly changed biodiversity or mortality in benthic species due to excessive sedimentation with or without concomitant changes in the nature of deposited sediments (i.e., grain-size composition/redox); or ■ Major change in pelagic biodiversity or mortality due to excessive turbidity.
Issue 8: Solid wastes "Adverse effects associated with the introduction of solid waste materials into water bodies or their environs."	■ No noticeable interference with trawling activities; and ■ No noticeable interference with the recreational use of beaches due to litter; and ■ No reported entanglement of aquatic organisms with debris.	■ Some evidence of marine-derived litter on beaches; or ■ Occasional recovery of solid wastes through trawling activities; but ■ Without noticeable interference with trawling and recreational activities in coastal areas.	■ Widespread litter on beaches giving rise to public concerns regarding the recreational use of beaches; or ■ High frequencies of benthic litter recovery and interference with trawling activities; or ■ Frequent reports of entanglement/ suffocation of species by litter.	■ Incidence of litter on beaches sufficient to deter the public from recreational activities; or ■ Trawling activities untenable because of benthic litter and gear entanglement; or ■ Widespread entanglement and/or suffocation of aquatic species by litter.
Issue 9: Thermal "The adverse effects of the release of aqueous effluents at temperatures exceeding ambient temperature in the receiving water body."	■ No thermal discharges or evidence of thermal effluent effects.	■ Presence of thermal discharges but without noticeable effects beyond the mixing zone and no significant interference with migration of species.	■ Presence of thermal discharges with large mixing zones having reduced productivity or altered biodiversity; or ■ Evidence of reduced migration of species due to thermal plume.	■ Presence of thermal discharges with large mixing zones with associated mortalities, substantially reduced productivity or noticeable changes in biodiversity; or ■ Marked reduction in the migration of species due to thermal plumes.
Issue 10: Radionuclide "The adverse effects of the release of radioactive contaminants and wastes into the aquatic environment from human activities."	■ No radionuclide discharges or nuclear activities in the region.	■ Minor releases or fallout of radionuclides but with well regulated or well-managed conditions complying with the Basic Safety Standards.	■ Minor releases or fallout of radionuclides under poorly regulated conditions that do not provide an adequate basis for public health assurance or the protection of aquatic organisms but without situations or levels likely to warrant large scale intervention by a national or international authority.	■ Substantial releases or fallout of radionuclides resulting in excessive exposures to humans or animals in relation to those recommended under the Basic Safety Standards; or ■ Some indication of situations or exposures warranting intervention by a national or international authority.
Issue 11: Spills "The adverse effects of accidental episodic releases of contaminants and materials to the aquatic environment as a result of human activities."	■ No evidence of present or previous spills of hazardous material; or ■ No evidence of increased aquatic or avian species mortality due to spills.	■ Some evidence of minor spills of hazardous materials in small areas with insignificant small-scale adverse effects one aquatic or avian species.	■ Evidence of widespread contamination by hazardous or aesthetically displeasing materials assumed to be from spillage (e.g. oil slicks) but with limited evidence of widespread adverse effects on resources or amenities; or ■ Some evidence of aquatic or avian species mortality through increased presence of contaminated or poisoned carcasses on beaches.	■ Widespread contamination by hazardous or aesthetically displeasing materials from frequent spills resulting in major interference with aquatic resource exploitation or coastal recreational amenities; or ■ Significant mortality of aquatic or avian species as evidenced by large numbers of contaminated carcasses on beaches.

Table 5c: Scoring criteria for environmental impacts of Habitat and community modification

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 12: Loss of ecosystems or ecotones "The complete destruction of aquatic habitats. For the purpose of GIWA methodology, recent loss will be measured as a loss of pre-defined habitats over the last 2-3 decades."	■ There is no evidence of loss of ecosystems or habitats.	■ There are indications of fragmentation of at least one of the habitats.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by up to 30 % during the last 2-3 decades.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades.
Issue 13: Modification of ecosystems or ecotones, including community structure and/or species composition "Modification of pre-defined habitats in terms of extinction of native species, occurrence of introduced species and changing in ecosystem function and services over the last 2-3 decades."	■ No evidence of change in species complement due to species extinction or introduction; and ■ No changing in ecosystem function and services.	■ Evidence of change in species complement due to species extinction or introduction	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure; and ■ Evidence of change in ecosystem services[2].

[2] Constanza, R. et al. (1997). The value of the world ecosystem services and natural capital, Nature 387:253-260.

Table 5d: Scoring criteria for environmental impacts of Unsustainable exploitation of fish and other living resources

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 14: Overexploitation "The capture of fish, shellfish or marine invertebrates at a level that exceeds the maximum sustainable yield of the stock."	■ No harvesting exists catching fish (with commercial gear for sale or subsistence).	■ Commercial harvesting exists but there is no evidence of over-exploitation.	■ One stock is exploited beyond MSY (maximum sustainable yield) or is outside safe biological limits.	■ More than one stock is exploited beyond MSY or is outside safe biological limits.
Issue 15: Excessive by-catch and discards "By-catch refers to the incidental capture of fish or other animals that are not the target of the fisheries. Discards refers to dead fish or other animals that are returned to the sea."	■ Current harvesting practices show no evidence of excessive by-catch and/or discards.	■ Up to 30% of the fisheries yield (by weight) consists of by-catch and/or discards.	■ 30-60% of the fisheries yield consists of by-catch and/or discards.	■ Over 60% of the fisheries yield is by-catch and/or discards; or ■ Noticeable incidence of capture of endangered species.
Issue 16: Destructive fishing practices "Fishing practices that are deemed to produce significant harm to marine, lacustrine or coastal habitats and communities."	■ No evidence of habitat destruction due to fisheries practices.	■ Habitat destruction resulting in changes in distribution of fish or shellfish stocks; or ■ Trawling of any one area of the seabed is occurring less than once per year.	■ Habitat destruction resulting in moderate reduction of stocks or moderate changes of the environment; or ■ Trawling of any one area of the seabed is occurring 1-10 times per year; or ■ Incidental use of explosives or poisons for fishing.	■ Habitat destruction resulting in complete collapse of a stock or far reaching changes in the environment; or ■ Trawling of any one area of the seabed is occurring more than 10 times per year; or ■ Widespread use of explosives or poisons for fishing.
Issue 17: Decreased viability of stocks through contamination and disease "Contamination or diseases of feral (wild) stocks of fish or invertebrates that are a direct or indirect consequence of human action."	■ No evidence of increased incidence of fish or shellfish diseases.	■ Increased reports of diseases without major impacts on the stock.	■ Declining populations of one or more species as a result of diseases or contamination.	■ Collapse of stocks as a result of diseases or contamination.
Issue 18: Impact on biological and genetic diversity "Changes in genetic and species diversity of aquatic environments resulting from the introduction of alien or genetically modified species as an intentional or unintentional result of human activities including aquaculture and restocking."	■ No evidence of deliberate or accidental introductions of alien species; and ■ No evidence of deliberate or accidental introductions of alien stocks; and ■ No evidence of deliberate or accidental introductions of genetically modified species.	■ Alien species introduced intentionally or accidentally without major changes in the community structure; or ■ Alien stocks introduced intentionally or accidentally without major changes in the community structure; or ■ Genetically modified species introduced intentionally or accidentally without major changes in the community structure.	■ Measurable decline in the population of native species or local stocks as a result of introductions (intentional or accidental); or ■ Some changes in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).	■ Extinction of native species or local stocks as a result of introductions (intentional or accidental); or ■ Major changes (>20%) in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).

Table 5e: Scoring criteria for environmental impacts of Global change

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 19: Changes in hydrological cycle and ocean circulation "Changes in the local/regional water balance and changes in ocean and coastal circulation or current regime over the last 2-3 decades arising from the wider problem of global change including ENSO."	■ No evidence of changes in hydrological cycle and ocean/coastal current due to global change.	■ Change in hydrological cycles due to global change causing changes in the distribution and density of riparian terrestrial or aquatic plants without influencing overall levels of productivity; or ■ Some evidence of changes in ocean or coastal currents due to global change but without a strong effect on ecosystem diversity or productivity.	■ Significant trend in changing terrestrial or sea ice cover (by comparison with a long-term time series) without major downstream effects on river/ocean circulation or biological diversity; or ■ Extreme events such as flood and drought are increasing; or ■ Aquatic productivity has been altered as a result of global phenomena such as ENSO events.	■ Loss of an entire habitat through desiccation or submergence as a result of global change; or ■ Change in the tree or lichen lines; or ■ Major impacts on habitats or biodiversity as the result of increasing frequency of extreme events; or ■ Changing in ocean or coastal currents or upwelling regimes such that plant or animal populations are unable to recover to their historical or stable levels; or ■ Significant changes in thermohaline circulation.
Issue 20: Sea level change "Changes in the last 2-3 decades in the annual/seasonal mean sea level as a result of global change."	■ No evidence of sea level change.	■ Some evidences of sea level change without major loss of populations of organisms.	■ Changed pattern of coastal erosion due to sea level rise has became evident; or ■ Increase in coastal flooding events partly attributed to sea-level rise or changing prevailing atmospheric forcing such as atmospheric pressure or wind field (other than storm surges).	■ Major loss of coastal land areas due to sea-level change or sea-level induced erosion; or ■ Major loss of coastal or intertidal populations due to sea-level change or sea level induced erosion.
Issue 21: Increased UV-B radiation as a result of ozone depletion "Increased UV-B flux as a result polar ozone depletion over the last 2-3 decades."	■ No evidence of increasing effects of UV/B radiation on marine or freshwater organisms.	■ Some measurable effects of UV/B radiation on behavior or appearance of some aquatic species without affecting the viability of the population.	■ Aquatic community structure is measurably altered as a consequence of UV/B radiation; or ■ One or more aquatic populations are declining.	■ Measured/assessed effects of UV/B irradiation are leading to massive loss of aquatic communities or a significant change in biological diversity.
Issue 22: Changes in ocean CO_2 source/sink function "Changes in the capacity of aquatic systems, ocean as well as freshwater, to generate or absorb atmospheric CO_2 as a direct or indirect consequence of global change over the last 2-3 decades."	■ No measurable or assessed changes in CO_2 source/sink function of aquatic system.	■ Some reasonable suspicions that current global change is impacting the aquatic system sufficiently to alter its source/sink function for CO_2.	■ Some evidences that the impacts of global change have altered the source/sink function for CO_2 of aquatic systems in the region by at least 10%.	■ Evidences that the changes in source/sink function of the aquatic systems in the region are sufficient to cause measurable change in global CO_2 balance.

The Global International Waters Assessment (GIWA) is a holistic, globally comparable assessment of all the world's transboundary waters that recognises the inextricable links between freshwater and coastal marine environment and integrates environmental and socio-economic information to determine the impacts of a broad suite of influences on the world's aquatic environment.

Broad Transboundary Approach

The GIWA not only assesses the problems caused by human activities manifested by the physical movement of transboundary waters, but also the impacts of other non-hydrological influences that determine how humans use transboundary waters.

Regional Assessment - Global Perspective

The GIWA provides a global perspective of the world's transboundary waters by assessing 66 regions that encompass all major drainage basins and adjacent large marine ecosystems. The GIWA Assessment of each region incorporates information and expertise from all countries sharing the transboundary water resources.

Global Comparability

In each region, the assessment focuses on 5 broad concerns that are comprised of 22 specific water related issues.

Integration of Information and Ecosystems

The GIWA recognises the inextricable links between freshwater and coastal marine environment and assesses them together as one integrated unit.

The GIWA recognises that the integration of socio-economic and environmental information and expertise is essential to obtain a holistic picture of the interactions between the environmental and societal aspects of transboundary waters.

Priorities, Root Causes and Options for the Future

The GIWA indicates priority concerns in each region, determines their societal root causes and develops options to mitigate the impacts of those concerns in the future.

This Report

This Report presents the results of the GIWA assessment of the marine waters around Greenland – comprising unique and globally significant ecosystems. Major concerns are due to overexploitation of fish, seabirds and marine mammals and toxic contamination of the marine resources due to long-range transport from chemical emissions to water and air in industrial areas in northern Asia, Europe and America. In the Northern part, severe impacts on the arctic habitats can be expected, if global warming continues unabated.

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