XIX-58 West Greenland Shelf: LME #18

M.C. Aquarone and S. Adams, D. Mikkelson and T.J. Pedersen

The West Greenland Shelf LME extends along Greenland's west coast in the Atlantic Ocean, and encompasses a number of banks, including the Fyllas Bank. It has an area of 375,000 km^2, of which 1.37% is protected, and contains one major estuary, the Tasersuaq (Sea Around Us 2007). It is characterised by its subarctic climate, as well as by ice cover for parts of the year. For a map of sea currents and geography, see Pedersen & Rice (2002). Climate is the primary force driving this LME, with intensive fishing as the secondary driving force. Nutrient enrichment and mixing depend on changes in sea and air temperature. Book chapters and articles pertaining to this LME include Hovgård & Buch (1990), Blindheim & Skjoldal (1993), Pedersen & Rice (2002) and UNEP (2004).

I. Productivity

The West Greenland Shelf LME is a Class III, low productivity (<150 gCm^{-2}yr^{-1}) ecosystem. The waters of the West Greenland Current come from Greenland's south coast, the Labrador Sea and from East Greenland's strong Irminger Current. For a map of surface currents in the northern part of the Atlantic Ocean, see Hovgård & Buch (1990, p. 39). Hydrographical conditions seem to be changing in the Irminger Sea to the east. For more information on variations in climate, see Hovgard & Buch (1990). There is a relatively long time series of plankton and hydrographic samples allowing an exploration of the links between climate, physical oceanography and abundance of major zooplankton and ichthyoplankton species (see Pedersen & Rice 2002). Investigations on selected fish larvae and zooplankton in relation to hydrographic features are currently undertaken as part of the monitoring programme NuukBasic. The marine component of the monitoring program was initiated in 2005, and is managed by the Center of Marine Ecology and Climate Effects at Greenland Institute of Natural Resources. Results from the monitoring programme are published in annual reports, as well as in peer-reviewed scientific papers when appropriate. Currents carry cod eggs and larvae in a clockwise direction around the southern part of Greenland, but there is a need to learn more about the patterns of occurrence of selected fish larvae and zooplankton over time and space and how those patterns relate to hydrographic features. For more information on the variable inflow of cod larvae from Iceland, see Hovgard & Buch (1990). Studies showed a decreasing trend in zooplankton abundance. Information on current velocity is scarce. For a study of factors affecting the distribution of Atlantic cod, Greenland halibut, redfish, long rough dab, wolf fish, sandeel and northern shrimp, see Pedersen & Rice (2002). The decline of cod, redfish and long rough dab stocks can be seen mostly as consequences of changes in climate, temperature and salinity. NORWESTLAND has conducted surveys along 3 transects in the West Greenland coast, Store Hellefiske bank, Sukkertop bank and Fyllas bank, where sea temperatures and salinities have been measured.

Oceanic fronts (Belkin et al. 2009) (Figure XIX-58.1): The West Greenland Current Front (WGCF) closely follows the shelf break and the steep upper slope until 52°W, where the slope becomes notably less steep and therefore no longer stabilises the WGCF. The front instability results in eddy generation that enhances cross-frontal exchange of heat, salt and nutrients as well as larvae and juvenile fish. The WGCF waters originate partly in the cold, fresh East Greenland Current and partly in the warm and salty Irminger Current. The Mid-Shelf Front (MSF) runs over mid-shelf roughly parallel to the coast and carries very cold, low-salinity polar water originated in the East Greenland Current augmented by melt water from the Greenland Ice Sheet.

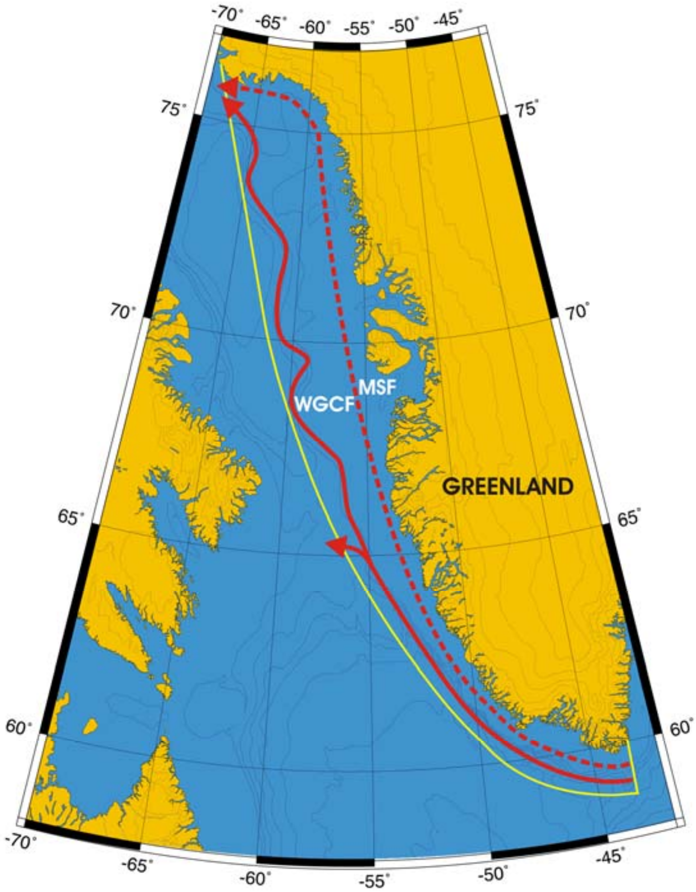

Figure XIX-58.1. Fronts of the West Greenland Shelf LME. MSF, Mid-Shelf Front (most probable location); WGCF, West Greenland Current Front. Yellow line, LME boundary. After Belkin *et al.* (2009).

West Greenland Shelf SST (Belkin 2009) (Figure XIX-58.2):

Linear SST trend since 1957: 0.42°C.
Linear SST trend since 1982: 0.73°C.

The long-term 50-year warming of the West Greenland Shelf was interrupted by cold events peaked in 1970, 1983-84, and 1996. These cold anomalies were associated with low-sali high-sea-ice cover anomalies dubbed "Great Salinity Anomalies" or GSAs since they are detected in the salinity time series (Dickson et al., 1988; Belkin et al., 1998; Belkin, 2004). GSAs form in the Arctic and are transported by oceanic currents into the northern North Atla either through Fram Strait between Greenland and Svalbard or through the straits of Canadian Arctic Archipelago; some GSAs could also form locally in the Labrador Sea. The W Greenland Shelf is one of a few LMEs where the GSAs are conspicuous in temperature reco as well as in salinity time series. As the GSAs travel along the Subarctic Gyre, they a spawning and fishing grounds; generally, their impact is detrimental to fish stocks. The anomaly (GSA'70s) led to a collapse of cod stock in this area, ultimately replaced by shrimp. ensuing cod-to-shrimp transition of local fisheries has had profound societal ramifications at regional level (Hamilton et al., 2003). The cold episodes of the early 1980s and early-to- 1990s have been caused by the harshest climatic conditions ever recorded in this area since

beginning of meteorological observations at Godthab (now Nuuk) in the mid-19th century. Du
these events, enhanced export of cold and fresh Arctic waters to the Baffin Bay and Labra
Sea (through Canadian straits and also through Fram Strait) likely contributed to the formatio
the GSA'80s and GSA'90s. The all-time maximum SST of >1.4°C in 2003-2004 may have b
advected from the upstream-located East Greenland Shelf LME where SST peaked at >2.6°
2003.

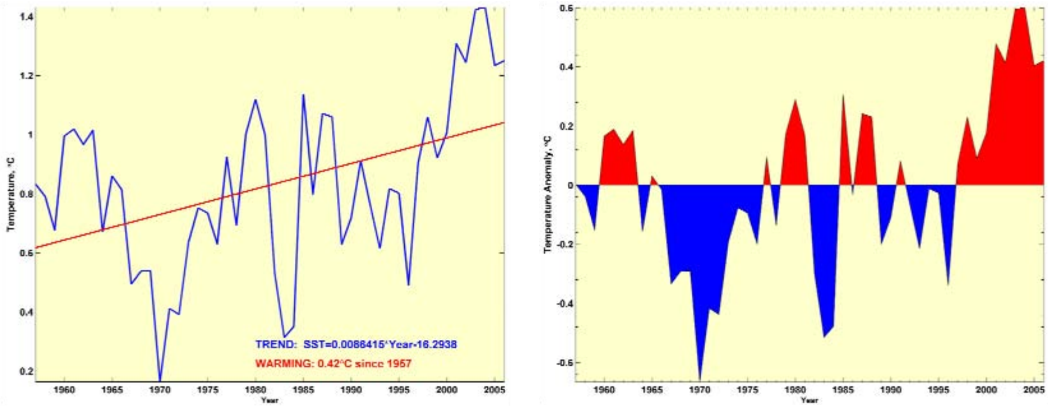

Figure XIX-58.2. West Greenland Shelf LME annual mean SST (left) and SST anomalies, 1957-2006, based on Hadley climatology. After Belkin (2009).

West Greenland Shelf LME Chlorophyll and Primary Productivity
This LME is a Class III, low productivity (<150 $gCm^{-2}yr^{-1}$) ecosystem (Figure XIX-58.3).

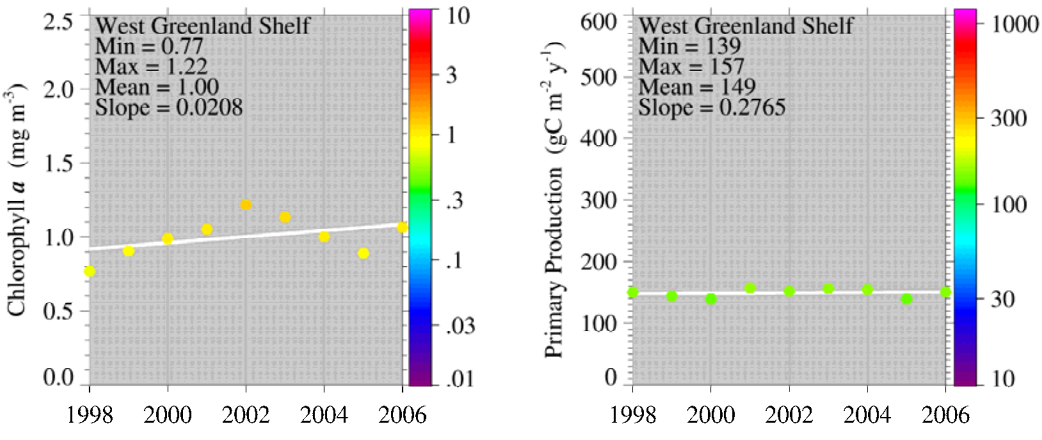

Figure XIX-58.3. West Greenland Shelf LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The most important species group in terms of shelf catches for recent years is the northern prawn (*Pandalus borealis*), representing more than two-thirds of the total catch. Another important species group is flatfish. For a study of changes in the West Greenland fisheries, see Pedersen & Rice (2002). Reported landings of commercial fish species show major changes over the past century, from a system dominated by Atlantic cod landings to one defined by prawn landings Reported landings were at a historical peak of over 350,000 tonnes in the 1960s (Figure XIX-58.4). They subsequently showed significant declines to under 100,000 tonnes, with the decline in cod landings, but have shown an increasing trend over the last few years (Figure XIX-58.4). As northern prawn now contributes the majority of the reported landings, a potentially large amount of fish bycatch can be assumed to remain unreported. The value of the reported landings reached US$400 million (in 2000 US dollars) in the 1950s and 1960s, but has since reduced to US$163 million in 2004 (Figure XIX-58.5).

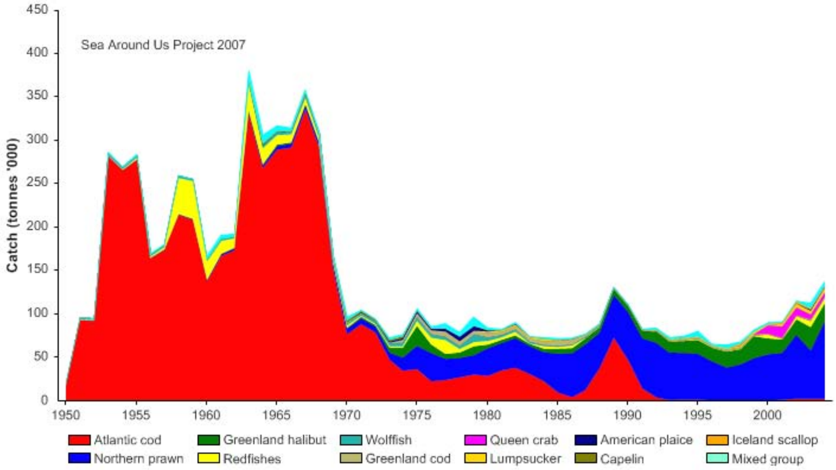

Figure XIX-58.4. Total reported landings in the West Greenland Shelf LME by species (Sea Around Us 2007).

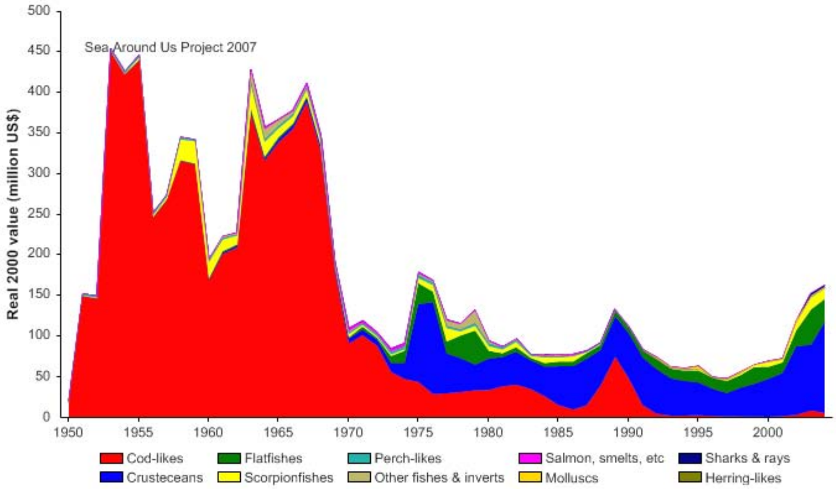

Figure XIX-58.5. Value of reported landings in the West Greenland Shelf LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME was over 70% of the observed primary production in the 1960s before declining to less than 2% over the last three decades. The extremely high PPR recorded in the 1960s is likely a result of the high level of accumulated biomass of cod stocks being exploited, not due to the exploitation of annual surplus production.

Greenland accounts for the largest share of the ecological footprint in this LME, although European countries accounted for the majority of the footprint in the 1950s and 1960s.

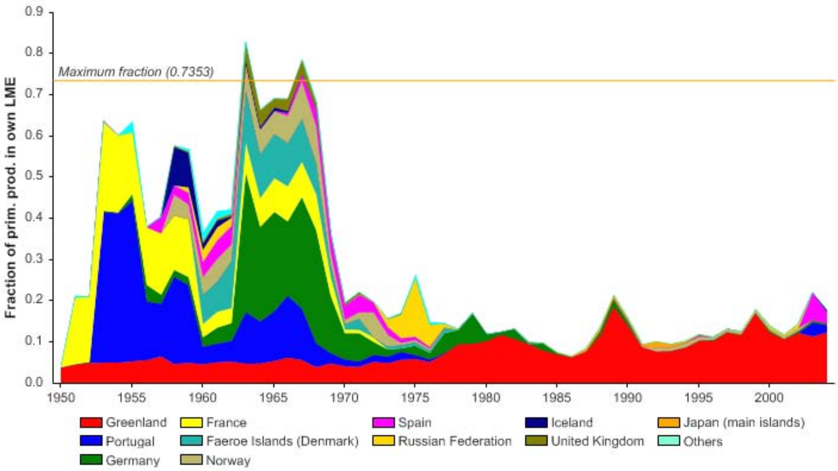

Figure XIX-58.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the West Greenland Shelf LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

From 1950 to 1970, cod was dominant in the reported landings in this LME and as a result, the mean trohic level (i.e., the MTT, Pauly & Watson 2005) remained high. It then showed a decline with the change from cod to prawn dominance in the ecosystem (Figure XIX-58.7, top).

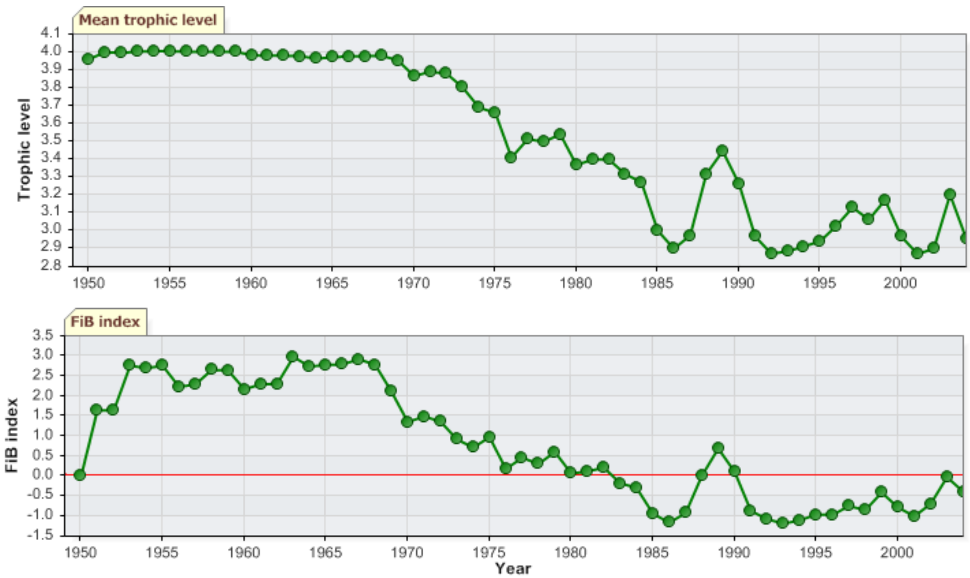

Figure XIX-58.7 Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the West Greenland Shelf LME (Sea Around Us 2007).

This trend, by its definition, implies a 'fishing down' of the food web (Pauly *et al*. 1998). The FiB index showed a similar trend (Figure XIX-58.7, bottom), suggesting that the reported landings did not compensate for the decline in trophic levels during that period. However, it must be noted that inclusion of bycatch may alter the trends in the indices observed here. Furthermore, it is known that the system shift from cod to prawn was to a large extent driven by environmental changes (see, e.g., Pedersen & Zeller 2001).

The Stock-Catch Status Plots indicate that more than 70% of commercially exploited stocks in this LME have collapsed (Figure XIX-58.8, top), however, with 90% of the landings still from fully exploited stocks, more specifically from the northern prawn (Figure XIX-58.8, bottom). Considering the decrease in the reported landings over the past three decades (Figure XIX-58.4), the observed trends in these plots present a stark reminder that they must be examined as a pair, not in isolation from each other.

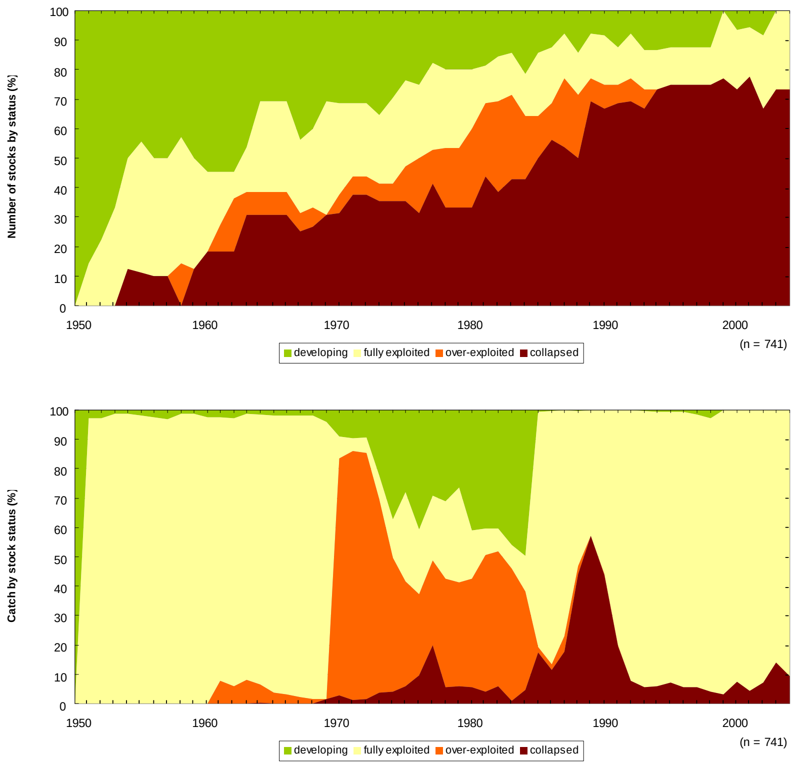

Figure XIX-58. 8. Stock-Catch Status Plots for the West Greenland Shelf LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

Landings of cod, redfish and long rough dab have declined. Low recruitment played an important role in the collapse of the cod fishery. The periodic fluctuations of cod stocks have been linked to changes in sea and air temperature (see Hovgård & Buch 1990). These authors also examine the southern displacement of the cod fishery, and provide information on the development of the cod stock since 1956. For more information on the biological effects of the temperature and salinity anomaly on the West Greenland cod, see Blindheim & Skjoldal (1993). In the same period, catches of Greenland halibut and northern shrimp increased. For nominal catches of Atlantic cod, redfish, Greenland halibut and northern shrimp, see Pedersen & Rice (2002, p. 153). The present abundance of shrimp in this LME may partly be the result of a lower abundance of cod and redfish (see Horsted 2000). Large numbers of redfish, Greenland halibut, polar cod, cod and others are caught and discarded in the West Greenland shrimp fishery (see Pedersen & Kanneworff 1995). It is important to also consider the added influence of changes in fishery technology and effort on cod stocks. The International Cod and Climate Change Programme (ICCC) studies the response of different cod populations to climate changes in various regions of the cod's North Atlantic range. Pedersen, Madsen and Dyhr-Nielsen (2004) report that 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 (GIWA 2004).

III. Pollution and Ecosystem Health

The waters of the West Greenland Shelf LME are little polluted. Information about pollutants and their transport vectors in the Arctic region including Greenland is available from the Arctic Marine Assessment Program (AMAP) (www.amap.no). Larsen et al. (2001) reported in Environmental Pollution (2001) that elevated levels of lead and zinc have been found in sediments and biota in the fjord at Maarmorilik, West Greenland—a legacy from the mining once done in the area. Bindler et al. (2001) concluded that the lead in Søndre Strøfjord (W. Greenland) sediments dated since WW II bears isotopic signatures suggesting W European sources as well as Russian sources. Larsen et al. (2001) conclude that this has important implications for future depositions of eco-toxicologically important pollutants such as Hg and POPs. Pedersen et al.(2004) cite studies showing that the cold Arctic climate creates a sink for Hg and POPs, and that the already high levels of mercury in the Arctic are not declining despite significant emissions reductions in Europe and North America.

IV. Socioeconomic Conditions

Greenland made the transition from a nation of hunters to a nation of fishers, primarily for cod, over the course of the last century. A rich Atlantic cod fishery started in the 1920s after a general warming of the Arctic. It developed from a local, small-boat fishery to an international offshore fishery of primarily trawlers. Today the fishery is dominated by shrimp, crab and halibut. The industries of West Greenland include fish processing, gold, uranium, iron and diamond mining, handicrafts, hides and skins, and small shipyards. Pedersen et al. (2004) suggest that economic diversification is not yet sufficient to offer alternative income possibilities to professional fishermen and hunters.

V. Governance

Both Canada and Greenland share jurisdiction over this LME. After 1945 Canadian fisheries were regulated under the International Commission for the Northwest Atlantic Fisheries (ICNAF), consisting of all the industrialised fishing nations of the world operating in that area (see www.nafo.ca/about/icnaf.htm). ICNAF's effectiveness, however, was limited by the voluntary nature of compliance to its rules. With the increase in foreign fishing fleets after World War II, the cod fishery expanded greatly. The limited development of Canada's domestic fleet prompted Canada to establish a 200-mile EEZ in 1977. The Greenland Institute of Natural Resources is responsible for providing scientifically sound management advice to the Government of Greenland. Pedersen et al. (2004) point out that chemical contamination of the waters and ecosystems of Greenland come there from Europe, Asia and North America. Concerted international effort should be focused on control of these emissions and to enforce existing agreements.

References

Belkin, I.M. (2004) Propagation of the "Great Salinity Anomaly" of the 1990s around the northern North Atlantic, *Geophysical Research Letters*, **31**(8), L08306, doi:10.1029/2003GL019334.

Belkin, I.M. (2009) Rapid warming of Large Marine Ecosystems, Progress in Oceanography, in press.

Belkin, I.M., Cornillon, P.C., and Sherman, K. (2009). Fronts in Large Marine Ecosystems. Progress in Oceanography, in press.

Belkin, I.M., Levitus, S., Antonov, J. and Malmberg, S.-A. (1998) "Great Salinity Anomalies" in the North Atlantic, *Progress in Oceanography*, **41**(1), 1-68.

Bindler, R., Anderson, N.J., Renberg, I. & Malmquist. C. (2001). Palaeolimnological investigation of atmospheric pollution in the Søndre Strømfjord region, southern West Greenland: accumulation rates and spatial patterns. Geology of Greenland Survey Bulletin 189:48-53.

Blindheim, J. and Skjoldal, H.R. (1993). Effects of climatic changes on the biomass yield of the Barents Sea, Norwegian Sea, and West Greenland Large Marine Ecosystems, p 185-198 in: Sherman, K., Alexander, L.M. and Gold, B.D. (eds), Large Marine Ecosystems: Stress, Mitigation and Sustainability. AAAS Press, Washington, D.C., U.S.

Buch, E., Pedersen, S.A. and Ribergaard, M.H. (2003). Ecosystem variability and regime shift in West Greenland waters. Journal of Northwest Atlantic Fishery Science 34:13-28.

Dickson, R.R., Meincke, J., Malmberg, S.-A., and Lee, A.J. (1988) The "Great Salinity Anomaly" in the North Atlantic, 1968–1982, *Progress in Oceanography* **20**(1), 103–151.

GIWA (2004) Regional Assessment 18, 15, 16—Arctic Greenland, East Greenland Shelf, West Greenland Shelf available at www.giwa.net/publications/r1b_15_16.phtml.

Hamilton, L.C., Brown, B.C. and Rasmussen, R.O. (2003) West Greenland's cod-to-shrimp transition: Local dimensions of climate change, *Arctic,* **56**(3), 271-282.

Horsted, S.A. (2000). A review of the cod fisheries at Greenland, 1910-1995. Journal of Northwest Atlantic Fishery Science 28:1-109.

Hovgård, H. and Buch, E. (1990). Fluctuation in the cod biomass of the West Greenland Sea ecosystem in relation to climate, p 36-43 in: Sherman, K., Alexander, L.M. and Gold, L.M. (eds), Large Marine Ecosystems: Patterns, Processes and Yields. AAAS, Washington, D.C. U.S.

Larsen, T.S., Kristensen, J.A., Asmund, G. and Bjerregaard, P. (2001) Lead and zinc in sediments and biota from maarmorilik, West Greenland: An assessment of the environmental impact of mining wastes on an Arctic fjord system. Environmental Pollution 114(2): 275-283.

Pauly, D. and Christensen, V. (1995). Primary production required to sustain global fisheries. Nature 374: 255-257.

Pauly, D. and Watson, R. (2005). Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. Philosophical Transactions of the Royal Society: Biological Sciences 360: 415-423.

Pauly, D., Christensen, V., Dalsgaard, J., Froese R. and Torres, F.C. Jr. (1998). Fishing down marine food webs. Science 279: 860-863.

Pedersen, S.A. and Kanneworff, P. (1995). Fishes on the West Greenland shrimp grounds, 1988-1992. ICES Journal of Marine Science 53:165-182.

Pedersen, S.A., Madsen, J. And Dyhr-Nielsen, M. (2004) Arctic Greenland, East Greenland Shelf, West Greenland Shelf—GIWA Regional assessment 1b, 15, 16. Available electronically at www.giwa.net/publications/r1b_15_16.phtml.

Pedersen, S.A. and Rice, J.C. (2002). Dynamics of fish larvae, zooplankton, and hydrographical characteristics in the West Greenland Large Marine Ecosystem 1950-1984, p 151-194 in: Sherman, K. and Skjoldal, H.R. (eds), Large Marine Ecosystems of the North Atlantic: Changing States and Sustainability. Elsevier, Amsterdam, The Netherlands.

Pedersen, S.A. and Zeller, D. (2001). Multispecies interactions in the West Greenland marine ecosystem: importance of the shrimp fisheries. p 111-127 in: Guenette, S., Christensen, V. and Pauly, D. (eds), Fisheries Impacts on North Atlantic Ecosystems: Models and Analyses. University of British Columbia Fisheries Centre Research Reports 9(4).

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 26:45-102.

Pedersen, S.A., Simonsen, C.S and Storm, L. (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.

Petersen, H., Meltofte, H., Rysgaard, S., Rasch, M., Jonasson, S., Christensen, T.R., Friborg, T., Søgaard, H. and Pedersen, S.A. (2001). The Arctic, p 303-330 in: Climate Change Research -

Danish Contributions. Danish Meteorological Instititute, Ministry of Transport. Gads Forlag, Copenhagen, Denmark.
Sea Around Us (2007). A Global Database on Marine Fisheries and Ecosystems. Fisheries Centre, University British Columbia, Vancouver, Canada. http://www.seaaroundus.org/lme/SummaryInfo.aspx?LME=18
UNEP (2004). Pedersen, S.A., Madsen, J. and Dyhr-Nielsen, M. Arctic Greenland, East Greenland Shelf, West Greenland Shelf, GIWA Regional Assessment 1b, 15, 16. University of Kalmar, Kalmar, Sweden. http://www.giwa.net/publications/r1b_15_16.phtml