This paper not to be cited without prior reference to the author

International Council for
the Exploration of the Sea

CM 1995/Mini:9

CONTAMINANTS IN THE BARENTS SEA ECOSYSTEM

by

Kari Stange and Jarle Klungsøyr
Institute of Marine Research, P.O. Box 1870 Nordnes, 5024 Bergen, NORWAY

Abstract

A baseline study of contaminants in fish and sediments from the Barents Sea was carried out by Institute of Marine Research (IMR) as a part of the Arctic Monitoring and Assessment Programme, AMAP. Sediment samples from 140 stations covering the whole Barents Sea were analysed for selected diaromatic and polyaromatic hydrocarbons (PAH). The concentrations found were lower than typical levels found at more southern latitudes such as in deposition areas of the North Sea, but higher than expected background levels. Concentrations of benzo[a]pyrene (B*a*P), one of the PAHs of most concern due to its toxicity, ranged from <1 to 40 ng/g dry weight. Alkylated C_2-napthalenes were found in highest concentrations in sediments around Svalbard (range <1-2330 ng/g dw). Perylene concentrations ranged from <1 to 300 ng/g dw. Some of the highest levels of B*a*P were found in the ice melting zone. This may indicate that ice plays an important role in the transport and distribution of some aromatic hydrocarbons in the Arctic. Long range transport of air pollutants originating from fossil fuel burning is most likely the dominating source of unsubstituted PAH found in Barents Sea sediments.

Fish species given priority in the AMAP monitoring plan for the marine environment include cod (*Gadus morhua*), polar cod (*Boreogadus saida*) and long rough dab (*Hippoglossoides platessoides*). A total of 400 fish representing these three species were analysed for polychlorinated biphenyls (PCBs) and organochlorine pesticides (DDTs, HCHs, HCB and chlordanes). Contaminant concentrations found in the fish livers were significantly higher in cod than in polar cod and long rough dab. PCB concentrations, expressed as the sum of 13 congeners on a ng/g wet weight basis, were in the ranges 94-685, 36-114 and 8-60 for cod, polar cod and long rough dab, respectively. DDT (sum of p'p-DDD, p'p-DDE and p'p-DDT) ranges were 67-344, for cod, 8-50 for polar cod and 5-33 for long rough dab. Chlordane concentration (sum of four compounds) ranged from 39 to 207 for cod, from 21 to 54 for polar cod, and from 6 to 35 for long rough dab. HCH (sum of three compounds) concentrations found were 3-17, 7-15, and 2-8 ng/g wet weight respectively, for the three species. Feeding habits and migration patterns are likely explanations for this observed interspecies variation. There are few local sources of PCBs and pesticides within the Arctic region. Most of these compounds find their way into the Barents Sea ecosystem through long range transport from industrial and agricultural areas further south.

1. INTRODUCTION

The Institute of Marine Research (IMR) in Bergen has carried out a baseline study of contaminants in the Barents Sea as a part of the international Arctic Monitoring and Assessment Programme (AMAP). The aims of the study were to investigate the potential human impact on the Barents Sea, to contribute to the ongoing international effort to fill knowledge gaps in the environmental quality status of the Arctic, and to develop a solid base of information on which to build future monitoring efforts.

The Barents Sea is a highly productive shelf sea with an average depth of approximately 230 m. While other ocean areas within the Arctic region stay ice covered most of the year, the Barents Sea has a long ice-free period due to the inflow of warm water from the Atlantic Ocean. Capelin (*Mallotus villosus*) and Northeast Arctic cod (*Gadus morhua*) are the dominant fish stocks in the Barents Sea, and the area is of major importance for Norwegian and Russian fisheries.

Contaminants such as polychlorinated biphenyls (PCBs), chlorinated pesticides (e.g. DDT, chlordanes and lindane) and polycyclic aromatic hydrocarbons (PAH), are of special concern in the Arctic. Their persistence along with their semi-volatile character, allows long range transport to pristine areas far from industrial and agricultural sources (Barrie *et al.*, 1992). The chlorinated compounds are lipophilic, and accumulate in the fatty tissues of organisms. Slower elimination rates than uptake rates leads to increasing body burdens through the lifetime of exposed animals. Organisms high in the food chain, especially those with a lipid-rich diet and long life span, will accumulate these contaminants to high levels. Top predators in the Arctic food web are prime examples of organisms that are at risk of high exposure due to these lifestyle factors. High levels of organochlorine contaminants are found in Arctic seals and polar bears (Muir *et al.*, 1992). Indigenous Arctic people get more than the "tolerable daily intake"-limit of organochlorines defined in food advisories through consumption of traditional food with a high proportion of fat from marine animals (Kinloch *et al.*, 1992). The biological implications of this long term contaminant exposure for Arctic organisms are not known. Persistent organic contaminants have been associated with biological effects in areas with higher levels of contamination than in the Arctic. Knowledge of contaminant levels, distribution and fate in the Arctic ecosystems, is necessary to evaluate the possible threats to organisms living in this environment.

Parameters included in this baseline study were trace metals (Cr, Cu, Ni, Zn, As, Cd, Pb, Hg, Se and Li), radionuclides (^{137}Cs), and persistent organic compounds (PCBs, organochlorine pesticides and PAH). Matrixes analysed included fish and surface sediment. This paper presents some results on levels of PCBs and organochlorine pesticides in fish livers and selected aromatic hydrocarbons in surface sediments from the Barents Sea.

2. MATERIALS AND METHODS

2. 1. Sampling

Sediments were collected from a total of 206 grab stations in 1991-1993 using box corer (Jonasson and Olausson, 1966). Sub-samples (10 cm x 10 cm x 1 cm) for analysis of PAH and sediment characteristics were taken from the undisturbed sediment surface layer and packed in pre-cleaned aluminium foil. Cod (*Gadus morhua*), polar cod (*Boreogadus saida*) and long rough dab (*Hippoglossoides platessoides*) were sampled using pelagic and bottom trawls. Twenty-five fish of each species were collected at each location, with the exception of one station where only five cod were sampled. Total fresh weight, length and sex were recorded. Otoliths were collected for age determination. Sub-samples of fish livers were collected in pre-cleaned glass containers. All samples were stored at -20°C until analysed.

2. 2. Analysis

2.2.1. PAH in sediments

Two separate grab samples from a total of 140 sediment stations from the Barents Sea were analysed for PAH. Wet samples (ca. 50g) were saponified in methanolic KOH (0.5N) for 1.5 hours followed by liquid/liquid extraction with pentane. Extracts were volume reduced and cleaned on silica columns prior to injection on a Hewlett Packard 5987A GC/MS in SIM mode (Klungsøyr *et al.*, 1988). The instrument was equipped with a 50 m x 0.22 mm x 0.11 µm HP Ultra 2 fused silica capillary column. GC/MS analysis was performed using four fully deuterated internal standards added to the samples prior to extraction. Sediment particle size distribution was determined by wet sieving of the silt and clay fractions and dry sieving of the sand fraction using stainless steel sieves (Retsch GmbH & CO, Germany). Total organic carbon in the sediments was determined with a LECO SC-444 elemental analyser. The PAH components included in the analytical protocol represent both natural sources and anthropogenic sources from the use of oil and incomplete combustion of fossil fuels: Naphtalene and C_1-, C_2- and C_3-alkyl derivatives, antracene, phenanthrene and C_1- og C_2-alkyl derivatives, dibenzothiophene and C_1-, C_2- and C_3-alkyl derivatives, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzofluoranthenes, benzo[e]pyrene, benzo[a]pyrene, perylene, benzo[g,h,i]perylene, indeno[1,2,3-cd]pyrene, and dibenzo[a,h]anthracene.

2. 2. 2. PCBs and pesticides in fish

Samples were extracted using a "cold blend" method modified from Jensen *et al.* (1983). The livers were homogenised in a Waring blender. A sub-sample was used for dry weight determination. Wet liver tissue (ca. 2 g) was extracted twice in an Ultra Turrax homogeniser with acetone and acetone/hexane (1:3). The combined extracts were liquid/liquid extracted with a NaCl solution in phosphoric acid. Extractable lipids were determined gravimetrically in duplicate by evaporating a portion of the extract to constant weight before removing the fat from the remaining extract with concentrated sulphuric acid. The extracts were separated into two fractions on Florisil columns, one fraction containing the PCBs and some of the pesticides, and the other the rest of the pesticides. PCB IUPAC no. 53 was used as internal standard. Extracts were analysed for 13 PCB congeners (IUPAC Nos. 28, 31, 52, 101, 105, 118, 128, 149, 153, 156, 170 and 180) and organochlorine pesticides (p'p-DDD, p'p-DDE, p'p-DDT, α-HCH, β-HCH, γ-HCH, α-chlordane, γ-chlordane, oxychlordane, trans-nonachlor and hexachlorobenzene (HCB)) on a HP 5880 GC-ECD gas chromatograph with a 50 m x 0.25 mm x 0.25 μm CP sil 8 fused silica capillary column. Cod livers were analysed individually, while polar cod and long rough dab were analysed in pooled samples of five.

2.2.3. Method validation

IMR's chemistry laboratory has participated in a number of intercomparison exercises for validation of the methods used in this project, including the ICES/IOC/JMG intercalibration exercises on PCB in marine media. The laboratory currently participates in the Quality Assurance of Information for Marine Environmental Monitoring in Europe, QUASIMEME. IMR has regularly contributed to the European Commission's Measurement and Testing Programme for Certification of Reference Materials (BCR).

3. RESULTS AND DISCUSSION

3. 1. PAH in sediment

Concentrations of individual aromatic hydrocarbons (sum of isomers for the C_1-C_3 alkyl homologs) in surface sediments in the Barents Sea ranged from < 1 to more than 2000 ng/g dry weight. The highest concentrations were found for C_1-C_3 alkylated naphtalenes in the Svalbard area. Distribution of C_2-naphtalenes are shown in Figure 1. These compounds are most often considered derived from petroleum and can be used as indicators of oil pollution (anthropogenic) or seepage (natural). Coal particles have high contents of aromatic compounds. The Svalbard region is rich in coal, and this may also help explain the observed high levels of low molecular weight aromatics in the sediments in this region.

Perylene in the sediments ranged from <1 to 382 ng/g dry weight (Figure 2) and accounted for much of the variation in PAH concentrations between locations . This compound can have both anthropogenic and natural sources. Biosynthesis of perylene in the marine environment has been suggested as explanation for high levels of perylene found in some unpolluted areas with little influence from terrestrial runoff (LaFlamme and Hites, 1978). The levels of perylene in some of the samples from the Barents Sea are quite high in the light of this being a "remote" location. However, the observed concentrations are still well within the range of perylene concentrations reported in offshore marine sediments world wide (Venkatesan, 1988).

Some of the highest levels of unsubstituted aromatic hydrocarbons such as benzo[a]pyrene, were found in central parts of the Barents Sea (Figure 3). This corresponds to the melting zone for ice along the Polar Front in years with normal climatic conditions (Loeng, 1991). Ice may play an important role in the transport and distribution of aromatic hydrocarbons in the Barents Sea (Pfirman *et al.*, 1995).

The dynamics of organic carbon in the water column and in the sediments must also be taken into consideration. PAH components with low aqueous solubilities and high affinity for particles rich in organic carbon, will preferentially be associated with organic matter. The annual phytoplankton spring bloom reaches its maximum along the Polar Front (Rey and Loeng, 1985). Ungrazed phytoplankton will sink to the bottom and be incorporated in the bottom sediments. This is reflected in higher organic carbon content in sediments from areas with high phytoplankton production. Total organic carbon (TOC) in Barents Sea sediments is shown in Figure 4. Elvehøy and co-workers also found the highest organic carbon levels in sediments immediately south of the Polar Front in their investigation area in the Northwest Barents Sea (Elvehøy *et al.*, 1989). However, there are no simple linear relationships between TOC and sediment concentrations of the aromatic hydrocarbons discussed here, indicating that also other factors than organic carbon are of importance for sediment accumulation of these compounds.

3. 2. PCBs and pesticides in fish livers

Organochlorine contaminant concentrations in fish livers are summarised in Table 1. Of the three species investigated in this study, the highest levels of organochlorines were found in cod. The lowest levels were found in long rough dab.

3. 2. 1. Cod

Cod livers were analysed individually. Average concentrations of PCBs, DDT and chlordanes in cod livers from five locations in the Barents Sea are shown in Figure 5. Station averages ranged from 165 to 392 ng/g wet weight for PCB; from 98 to 175 ng/g for DDT; from 75 to 140 ng/g for chlordanes and from 7 to 14 ng/g for HCH. The highest levels of PCBs were found in livers of cod caught off the coast of Finnmark and the Kola Peninsula. Fish from these two stations were 2-4 years of age, younger than individuals sampled at the other three locations where lower PCB concentrations were found.

Based on the concepts of bioaccumulation and biomagnification, one would expect the older individuals to have the highest levels of PCBs. Increase in body burden of contaminants with fish length and age are commonly reported, and is one of the reasons for specifying target length intervals of fish for monitoring purposes. The relationship between liver concentration of PCB and fish age in Barents Sea cod is shown in Figure 6. Several explanations may help explain this unusual pattern.

Cod with the highest PCB levels are from an area dominated by water from the Norwegian Coastal Current. This water mass is affected by coastal influence, and can transport contaminants from areas as far south as the North Sea (Dahlgaard *et al.*, 1986). Whether this is reflected in higher contaminant concentrations in cod's prey organisms in this part of the Barents Sea compared to areas dominated by other water masses, is not known. Investigations of contaminant levels in organisms lower in the food web, residing in different water masses in the Barents Sea, would help elucidate this question.

Uptake through ingestion of contaminated food is a major route of exposure for fish (Rasmussen *et al.*, 1990). Feeding habits and migration patterns vary for cod of different size and age. The availability of prey species vary greatly with ecological fluctuations in the Barents Sea ecosystem (Skjoldal *et al.*, 1992). Detailed information on the feeding habits of the Northeast Arctic cod is collected in a database containing the results from stomach content analyses of 40.000 individual cod (Mehl *et al.* 1985). Smaller cod eat mainly copepods, krill and amphipods. Capelin is the most important fish prey for medium size cod, while larger cod prey on a variety of fish including haddock and redfish.(Mehl, 1991). Capelin is subject to predation primarily in the southern part of the Barents Sea during its spawning migration in the first part of the year. Young cod that have not yet started spawning migrations prey heavily on capelin.

The 2-4 year old cod in this study, with the higher levels of PCBs, have probably followed this feeding pattern.

From around 8-10 years of age, Northeast Arctic cod embark on an annual migration from the Barents Sea to spawning grounds along the Norwegian coast. The migration and spawning processes may influence liver accumulation of contaminants. Kjesbu and co-workers found that the amount of fat in the liver was reduced while the amount of fat in the ovaries increased in cod going through the transition from pre-spawning to spawning stage (Kjesbu *et al.*, 1991). The older Barents Sea cod may reduce their body burden of contaminants through discharge of spawning products.

Due to the high commercial value of cod, there has been a need for documentation of contaminant levels in this species from different ocean areas. The highest levels are found in cod sampled close to densely populated industrial areas such as the southern Baltic (Falandysz *et al.* 1994) and the southern North Sea (de Boer, 1989). The average level of PCBs in cod in this Barents Sea study (273 ng/g wet weight) is lower than values commonly reported in cod from the Baltic and southern North Sea by more than a factor of ten. The highest organochlorine levels measured in individual Barents Sea cod are comparable to levels in cod from the Northern North Sea (de Boer, 1989).

3. 2. 2. Polar cod

Polar cod livers were analysed in pooled samples of five. Concentration ranges of organochlorines measured in polar cod livers are listed in Table 1. Station averages are shown in Figure 7. Contaminant concentrations in polar cod were significantly lower than in cod. Station averages ranged from 47 to 91 ng/g wet weight for PCB; from 911 to 45 ng/g for DDT; from 25 to 46 ng/g for chlordanes and from 9 to 13 ng/g for HCH. Polar cod has a circumpolar distribution and is important as food for many Arctic birds and mammals. Lower contaminant levels can be expected in this species since it belongs on a lower level in the food web. Young fish feed on phytoplankton, while the diet of older fish consists of copepods and amphipods (Sameoto, 1984). Like cod, the liver of polar cod is rich in lipid (≈ 50 %). The polar cod is relatively short lived, and individuals of more than six years of age are rare. It lives near the ice edge and stays within the cold water masses. Spawning migration is limited to two separate areas within the Barents Sea, one in the south-east area and one in the western area (Gjøeæter, 1973). Whether the polar cod that migrate to the two different spawning areas are separate stocks, is not clear. Our data does not indicate that there is any difference between contaminant levels in fish from the eastern and western Barents Sea.

Little data on contaminants in polar cod is available in the literature for comparison of contaminant levels between the Barents Sea and other areas. Muir and co-workers found low levels of organochlorines in polar cod muscle in the Canadian Arctic (Muir *et al.*, 1987). Liver concentrations were not measured in their study.

3. 2. 3. Long rough dab

Long rough dab livers were analysed in pooled samples of five. Priliminary data is shown in Table 1. Organochlorine contaminant levels in long rough dab were the lowest of the three species analysed in this study. Station averages ranged from 14 to 41 ng/g wet weight for PCB; from 10-28 ng/g for DDT; from 11 to 30 ng/g for chlordanes and from 3 to 7 ng/g for HCH. Long rough dab is the most abundant flatfish in the Barents Sea, and can be found in all parts of the area (Albert *et al.* 1994). Little information is available on its feeding habits. Fish larvae and various benthic organisms such as *Ophiura* and *Pecten* are included in its diet (Pethon, 1985).

Transfer of contaminants from sediments via benthic organisms to bottom feeding fish has been documented in polluted aquatic ecosystems (Varanasi *et al.*, 1992). In the Barents Sea, where contaminant concentration in sediments is low, bottom feeders like long rough dab have no such additional source of exposure compared to pelagic feeders.

The average lipid content of the long rough dab livers analysed in this study was 9 %, approximately 40% less than average lipid content in livers of cod and polar cod. Normalised to lipid, contaminant levels in long rough dab were within the same range as polar cod, while the levels in cod were still considerably higher than in the other two species.

4. SUMMARY AND CONCLUSIONS

Concentrations of 23 aromatic hydrocarbons (including the sum of isomers for the C_1-C_3 alkyl homologs) in Barents Sea surface sediments have been investigated in this study. Analytical results for C_2-naphtalenes, B*a*P and perylene were selected to illustrate the sediment distribution pattern of 2- to 6-ring aromatic hydrocarbons representing different sources. Barents Sea sediments appear to be influenced by anthropogenic inputs of aromatic hydrocarbons. Analyses of sediment cores for historic records of PAH in Barents Sea sediments would help elucidate the extent of this influence. The information on distribution and concentration ranges of aromatic hydrocarbons generated in this baseline study is valuable for the planning of future monitoring efforts in the Arctic.

Analyses of organochlorine contaminant levels in livers of cod, polar cod and long rough dab showed considerable interspecies variation. The highest levels of contaminants were found in cod and the lowest levels in long rough dab. These differences are most likely due to these species' feeding habits and position in the food web.

Polar cod was selected as an "essential" species, and cod and long rough dab "recommended" species, in the AMAP monitoring plan for the marine environment. Opportunistic feeding habits, migration patterns and considerable variation in contaminant levels between cod of similar size caught at the same location, are factors making cod less suitable for monitoring. Low contaminant concentrations, combined with small livers that limit possible sample intake for analyses, make long rough dab an impractical species for routine monitoring. Of the three species analysed in this study, polar cod have advantages over the two others making it suitable as a monitoring species in the Barents Sea ecosystem. With a diet dominated by zooplankton and a six year life span, polar cod will better reflect the current status of contaminants than a long lived species, such as cod, with opportunistic feeding habits. Variations in contaminant levels between samples from the same location, and variation between locations, were less for polar cod than for cod. Pooling of polar cod samples accounts in part for this effect. A negative factor when using this species for monitoring is the small size of polar cod and polar cod livers. This makes analyses of individual samples difficult, and also limits the possibilities for analyses of several types of parameters on the same sample.

5. ACKNOWLEDGEMENTS

The authors would like to thank Kjell Westrheim, Merete Fonn, Guri Nesje and Grethe Tveit for sample preparation and analytical work. This study was funded by the Norwegian Ministry of Fisheries and the Norwegian Ministry of Environment, State Pollution Control Authority of Norway.

6. REFERENCES

Albert, O. T., N. Mokeeva and K. Sunnanå. 1994. Long rough dab (*Hippoglossoides platessoides*) of the Barents Sea and Svalbard area: Ecology and resource evaluation. *ICES C. M. 1994/O:8*

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

Dahlgaard, H., L. Aarkrog, L. Hallstadius, E. Holm and J. Rioseco. 1986. Radiocaesium transport from the Irish Sea via the North Sea and the Norwegian Coastal Current to East Greenland. *Rapp. P-v. Réun. Cons. int. Explor. Mer.* 186:70-79.

de Boer, J. 1989. Organochlorine compounds and bromodiphenylethers in livers of Atlantic cod (*Gadus morhua*) from the North Sea. *Chemosphere* 18:2131-2140.

Elvehøy, A., S. L. Pfirman, A. Solheim and B. B. Larssen. 1989. Glaciomarine sedimentation in epicontinental seas exemplified by the northern Barents Sea. In: R. D. Powell and A. Elvehøy (Eds.). Modern Glacimarine Environments: Glacial and Marine Controls of Modern Lithofacies and Biofacies. *Mar. Geol.*, 85: 225-250.

Falandysz, J., K. Kannan, S. Tanabe and R. Tatsukawa. 1994. Organochlorine pesticides and polychlorinated biphenyls in cod-liver oils: North Atlantic, Norwegian Sea, North Sea and Baltic Sea. *Ambio* 23:288-293.

Jensen, S., L. Reutergårdh and B. Jansson. 1983. Analytical methods for measuring organochlorines and methyl mercury by gas chromatography. *FAO Fish. Tech. Pap.* 212:21-33.

Jonasson, A. and E. Olausson. 1966. New devices for sediment sampling. *Marine Geol.* 4:365-372.

Kinloch, D., H. Kuhnlein and D. C. G. Muir. 1992. Inuit foods and diet: a preliminary assessment of benefits and risks. *Sci. Total Environ.* 122:247-278.

Kjesbu, O. S., J. Klungsøyr, H. Kryvi, P. R. Witthames and M. Greer Walker. 1991. Fecundity, atresia, and egg size of captive Atlantic cod (*Gadus morhua*) in relation to proximate body composition. *Can. J. Fish. Aquat. Sci.* 48:2333-2343.

Klungsøyr, J., S. Wilhelmsen, K. Westrheim, E. Sætvedt and K. H. Palmork. 1988. The GEEP Workshop: Organic chemical analyses. *Mar. Ecol. Progr. Series* 46:19-26.

LaFlamme, R. E. and R. A. Hites. 1978. The global distribution of polycyclic aromatic hydrocarbons in recent sediments. *Geochim. Cosmochim. Acta* 42:289-303.

Loeng, H. 1991. Features of the physical oceanographic conditions of the Barents Sea. Pp 5-18 In: E. Sakshaug, C. C. E. Hopkins and N. A. Øritsland (Eds.): Proceedings of the Pro Mare Symposium on Polar Marine Ecology, Trondheim, 12-16 May 1990. *Polar Res.* 10: 5-18

Mehl, S. 1991. The Northeast Arctic cod stock's place in the Barents Sea ecosystem in the 1980s: an overview. Pp. 525-534 In E. Sakshaug, C. C. E. Hopkins and N. A. Øritsland (Eds.): Proceedings of the Pro Mare Symposium on Polar Marine Ecology, Trondheim, 12-16 May 1990. *Polar Res.* 10(2).

Mehl, S., O. Nakken, S. Tjelmeland and Ø. Ulltang. 1985. The construction of a multispecies model for the Barents Sea with special reference to the cod-capelin interactions. Contr. Workshop comparative biology, assessment and management of gadoids from the North Pacific and Atlantic oceans. Seattle 24-28 June 1985. 1-25

Muir, D. C. G., R. Wagemann, B. T. Hargrave, D. J. Thomas, D. B. Peakall and R. J. Norstrom. 1992. Arctic marine ecosystem contamination. *Sci. Total Environ.* 122:75-134.

Muir, D. C. G., R. Wagemann, W. L. Lockhart, N. P. Grift, B. Billeck and D. Metner. 1987. Heavy metal and organic contaminants in Arctic marine fish. Environmental Studies No. 42. Indian and Northern Affairs, Ottawa. 64 pp.

Pethon, P. 1985. *Aschehougs Store Fiskebok.* Aschehough, Oslo.

Pfirman, S. L., H. Eicken, D. Bauch and W. F. Weeks. 1995. The potential transport of pollutants by Arctic sea ice. *Sci. Total Environ.* 159:129-146.

Rasmussen, J. B., D. J. Rowan, D. R. S. Lean and J. H. Carey. 1990. Food chain structure in Ontario lakes determines PCB levels in lake trout (*Salvelinus namaycush*) and other pelagic fish. *Can. J. Fish. Aquat. Sci.* 47:2030-2038.

Rey, F. and H. Loeng. 1985. The influence of ice and hydrographic conditions on the developement of phytoplankton in the Barents Sea. Pp. 49-63 in J. S. Gray and M. E. Christiansen (Eds.). *Marine Biology of Polar Regions and Effects of Stress on Marine Organisms*. John Wiley & Sons, London.

Sameoto, D. 1984. Review of Current Information on Arctic Cod (*Boreogadus saida* Lepechin) and Bibliography. Bedford Institute of Oceanography.

Skjoldal, H. R., H. Gjøsæter and H. Loeng. 1992. The Barents Sea ecosystem in the 1980s: ocean climate, plankton, and capelin growth. *ICES mar. Sci. Symp.* 195:278-290.

Varanasi, U., J. E. Stein, W. L. Reichert, K. L. Tilbury, M. M. Krahn and S.-L. Chan. 1992. Chlorinated and aromatic hydrocarbons in bottom sediments, fish and marine mammals in US coastal waters: Laboratory and field studies of metabolism and accumulation. Pp. 83-119 in Colin H. Walker and David R. Livingstone (Eds.).*Persistent Pollutants in Marine Ecosystems*. Pergamon Press.

Figure 1. C_2-napthalenes in Barents Sea surface sediment

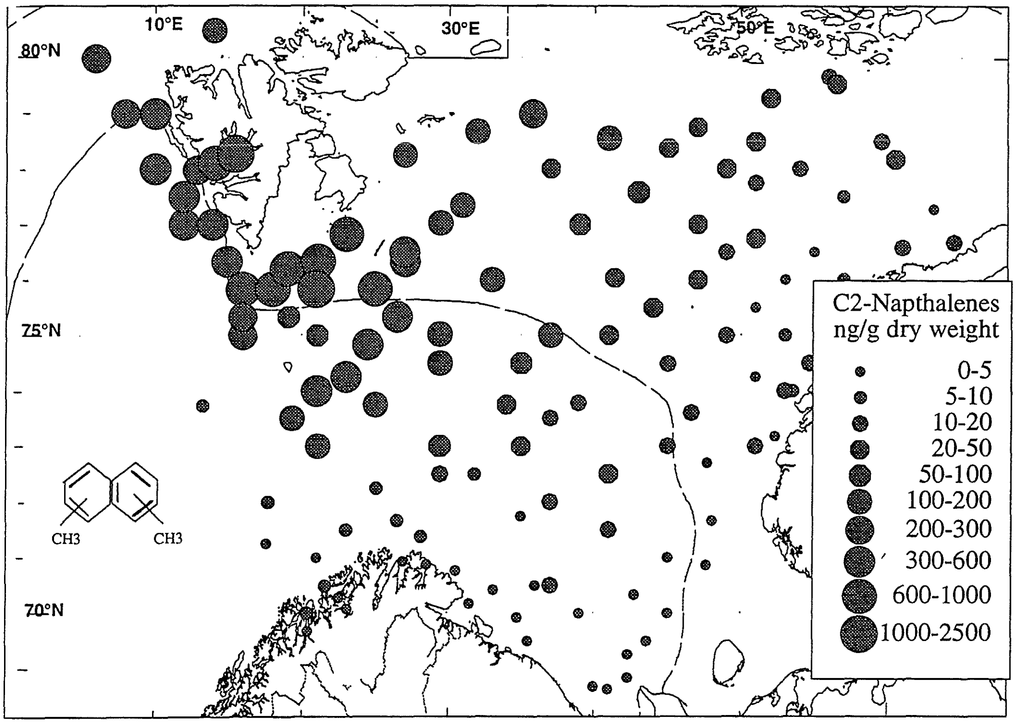

Figure 2. Perylene in Barents Sea surface sediment

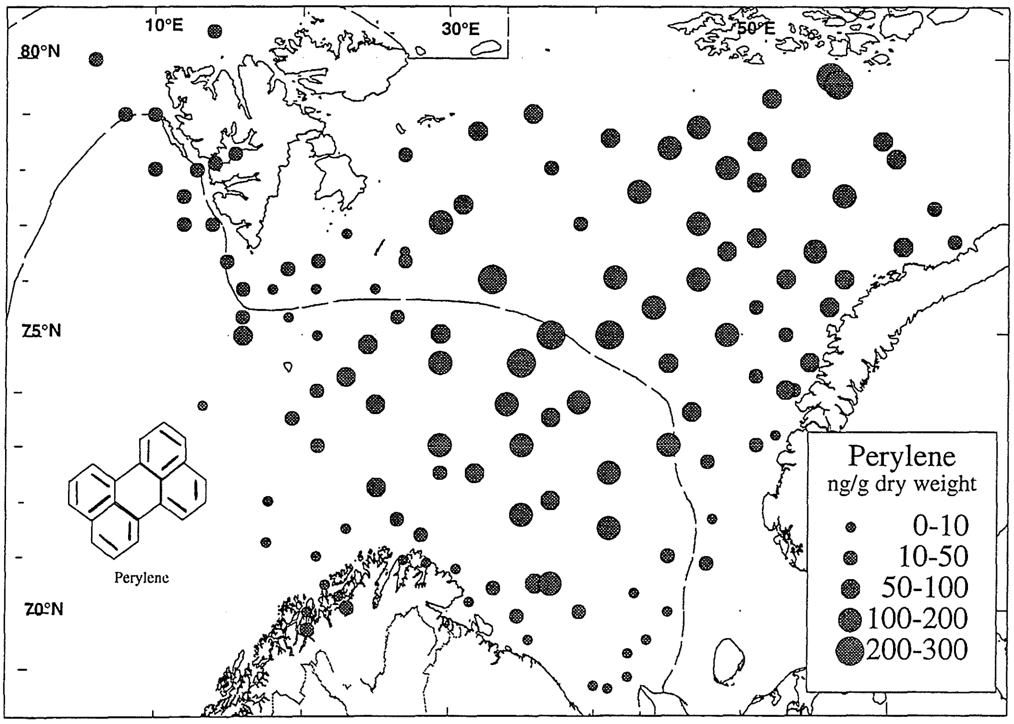

Figure 3. Benzo[a]pyrene in Barents Sea surface sediment

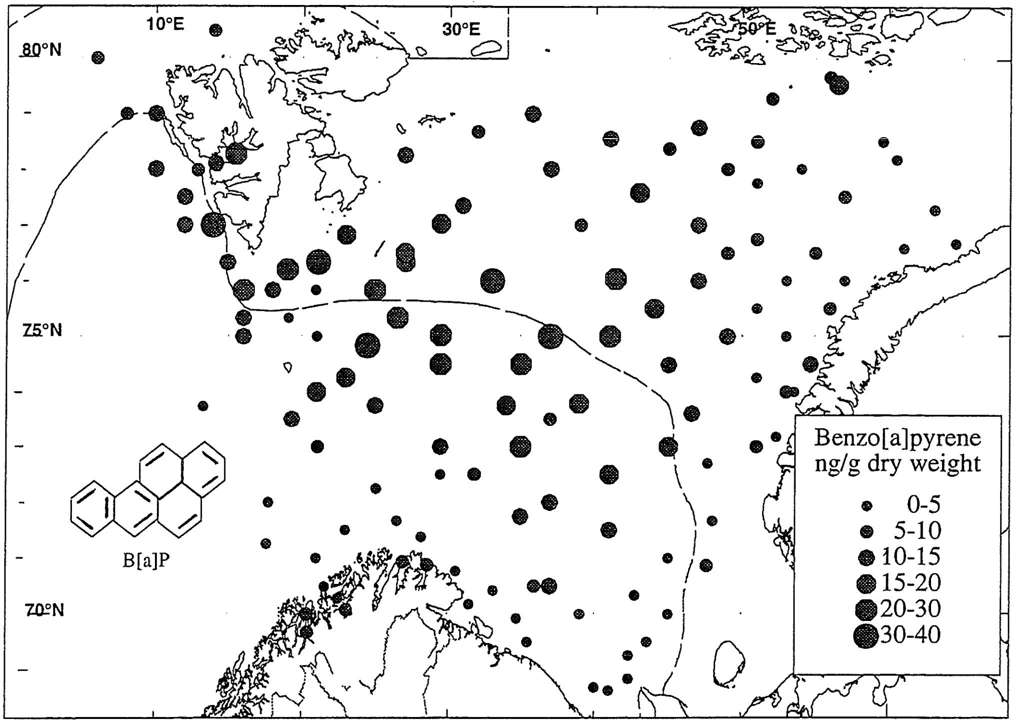

Figure 4. Total organic carbon in Barents Sea surface sediment

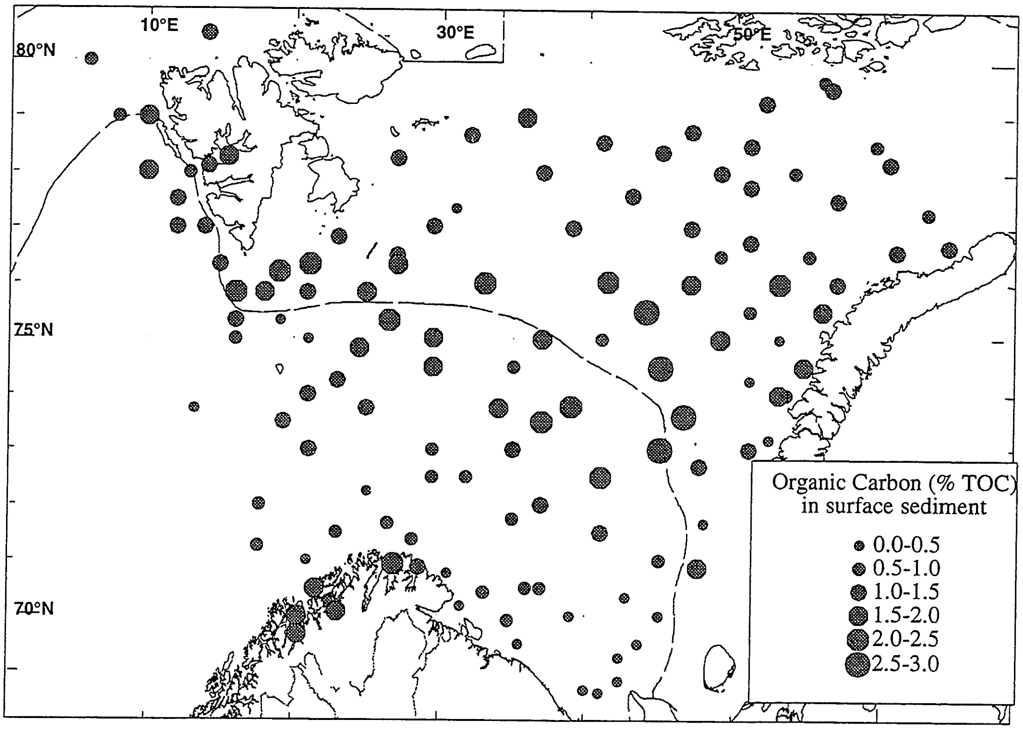

Figure 5. Concentrations (ng/g wet weight) of PCB ($\sum$ 13 congeners), DDT ($\sum$ p'p-DDD, p'p-DDE and p'p-DDT) and chlordane ($\sum$ α-chlordane, γ-chlordane, oxychlordane and trans-nonachlor) in cod livers from the Barents Sea. The bars represent the average of 25 individual measurements at each location (five cod only at the central Barents Sea station). Sample information is given in Table 1.

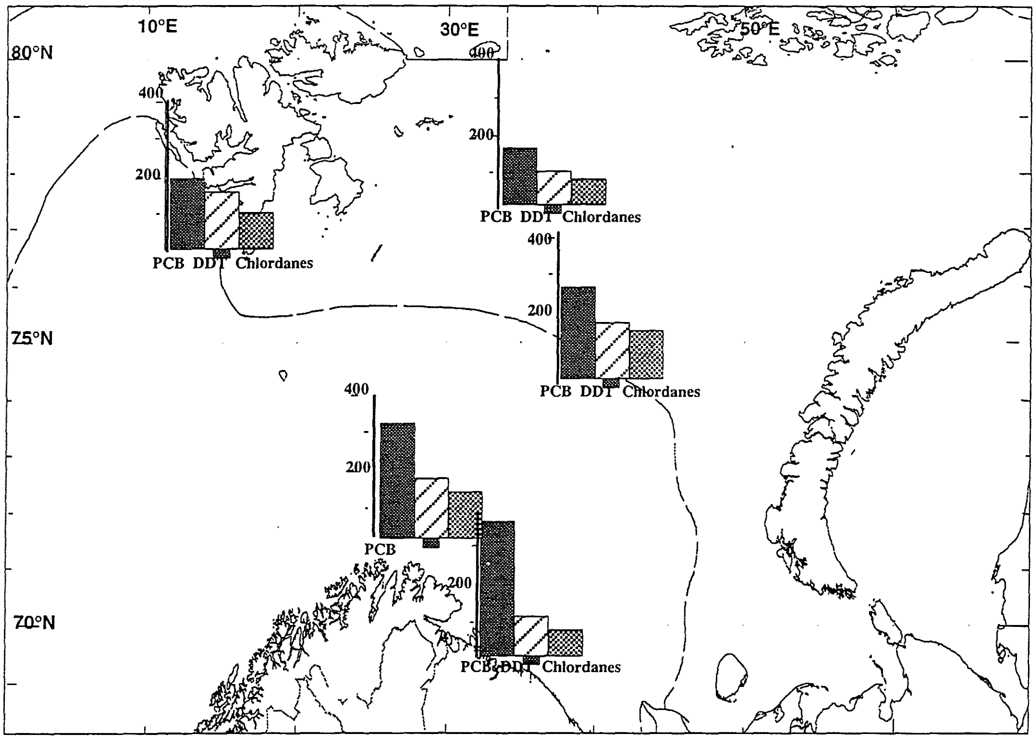

Figure 6. $\sum$ PCB in livers of cod of different age

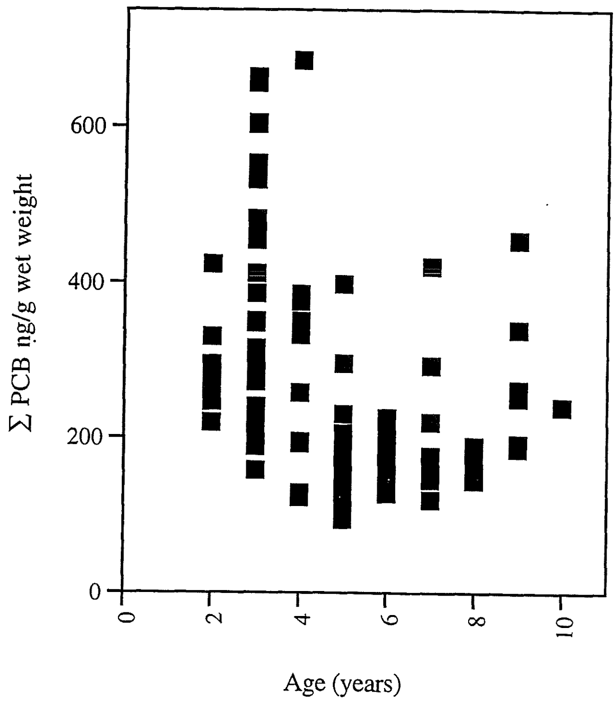

Figure 7. Concentrations (ng/g wet weight) of PCB (Σ 13 congeners), DDT (Σ p'p-DDD, p'p-DDE and p'p-DDT), chlordane (Σ α-, γ-chlordane, oxychlordane and trans-nonachlor) and HCH (α-, β- and γ-HCH) in polar cod livers from the Barents Sea. The bars represent the average of five pooled sample measurements at each location. Sample information is given in Table 1.

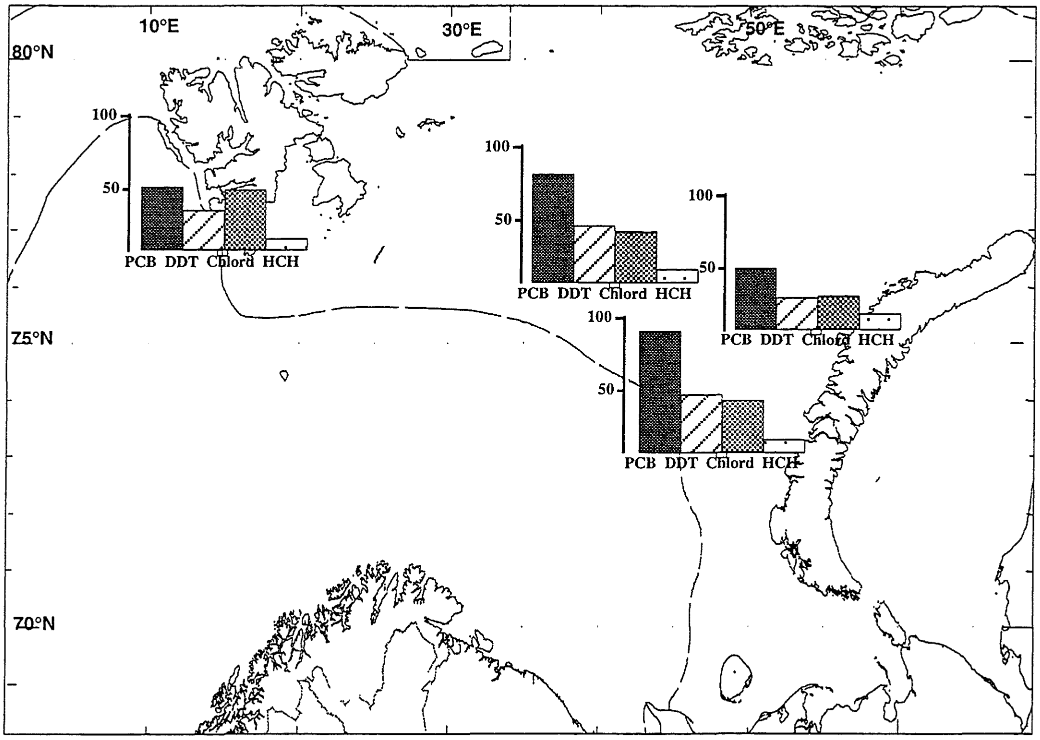

Table 1. Organochlorine concentration ranges in livers of fish from the Barents Sea.

Species	Id.	Date	Position		N	Lenght	Weight	Age	Liver lipid	Σ PCB	Σ DDT	Σ Chlordanes	HCH	HCB
			latitude	*longitude*		*(cm)*	*(g)*	*(years)*	*(%)*	*ng/g ww*	*ng/g ww*	*ng/g ww*	*ng/g ww*	*ng/g ww*
					(a)					(b)	(c)	(d)	(e)	(f)
Cod	269	31.03.93	69°28' N	35°49' E	25	39-51	600-1090	3–4	29-66	158-685	67-201	39-181	9–16	13–44
	533	21.09.92	74°22' N	41°02' E	5	71-104	3500-10700	5–10	43-53	133-456	123-261	97-207	12–16	23–32
	536	16.09.91	77°25' N	37°07' E	25	61-90	2350-7400	5–9	41-64	94-251	69-131	52-107	3–17	17–35
	593	22.08.93	76°39' N	14°52' E	25	56-94	1450-5780	4–9	19-76	115-420	93-344	60-202	4–12	7–36
	701	03.10.92	71°32' N	29°00' E	25	31-59	210-1940	2–4	5–69	192-603	116-248	91-191	3–11	9–40
Polar cod	274	03.04.93	73°04' N	48°10' E	5*5	10–17	15–50	2–5	28–41	72-114	35-50	32-45	7–11	12–16
	538	21.09.92	76°05' N	41°00' E	5*5	15–19	20–50	n.a.	38–46	65-101	14-22	30-48	9–12	7–14
	576	30.09.92	75°15' N	54°27' E	5*5	18–27	45–155	n.a.	43–55	36-62	8–12	21-27	11–15	6–8
	593	22.08.93	76°39' N	14°52' E	5*5	15–23	20–67	2–5	41–46	37-64	23-40	38-54	8–9	12–15
Long rough dab*	272	01.04.93	69°06' N	42°15' E	5*5	15–32	20–275	n.a.	3–10	25-60	7–25	6–19	3–4	1–6
	273	02.04.93	70°36' N	46°47' E	5*5	20–26	65–155	n.a.	3–11	12–44	7–20	6–18	2–5	2–6
	274	03.04.93	73°04' N	48°10' E	5*5	19–33	55–325	n.a.	3–16	12–22	5–13	6–14	2–5	1–5
	509	13.09.92	76°38' N	36°26' E	5*5	11–31	10–340	7–11	11–21	20-35	22–32	21–35	6–8	6–12
	533	21.09.92	74°22' N	41°02' E	5*5	23–29	105–275	n.a.	7–13	8–20	7–12	10–16	4–5	3–5
	593	22.08.93	76°39' N	14°52' E	5*5	25–40	178–715	6–12	12–22	12–19	14–21	17–28	5–8	6–8
	674	23.09.92	74°00' N	18°00' E	5*5	27–44	155–705	6–13	6–9	19–47	14–33	18–23	3–5	3–5

(a): polar cod and long rough dab samples analysed as pooled samples of 5
(b): IUPAC Nos. 28, 31, 52, 101, 105, 118, 128, 138, 149, 153, 156, 170 and 180.
(c): p'p-DDD, p'p-DDE and p'p-DDT
(d): trans-nonachlor, oxychlordane, α-chlordane and γ-chlordane
(e): α, β and γ– hexachlorocyclohexane
(f): hexachlorobenzene
(*): contains preliminary data
n.a.: not analysed