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Man's Impact on the Barents Sea

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ABSTRACT. The Barents Sea ecosystem is a polar system with high biological production. Production takes place during a short season, mainly along the ice margin. As biological production is very limited in both space and time, the ecosystem is vulnerable to the influence of human activity.

Fishing activity represents the most significant environmental load by man on the Barents Sea. In recent years offshore oil and gas exploration activity has increased, resulting in environmental problems as well as conflicts with fishing operations.

Heavy metals and organic contaminants of man-made origin have been observed in both sediments and organisms at different trophic levels. Both long-range atmospheric transport and transport by ocean currents are important. Organic contaminants accumulate mainly in the body fat of the organisms; northern ecosystems are therefore especially vulnerable because fat has much greater ecological importance in such systems than in more southerly ecosystems.

In recent years there has been public concern in both Norway and Russia over the possibility of radioactive pollution. Nuclear power plants, nuclear vessels and weapons are present in the area and produce radioactive wastes. Reports of wastes have influenced public opinion in many countries.

The Barents Sea is strongly influenced by ocean climate variations. Global climate models forecast that the most elevated ocean temperatures due to possible greenhouse effects will probably occur in polar regions.

Key words: Barents Sea, fishing, offshore oil activity, organic contaminants, radioactivity

RÉSUMÉ. L'écosystème de la mer de Barents est un système polaire ayant une haute productivité biologique. La production a lieu au cours d'une brève saison, principalement le long de la marge glaciaire. Étant donné que la production biologique est très limitée à la fois dans le temps et dans l'espace, l'écosystème est très sensible à l'activité humaine.

La pêche constitue le plus gros fardeau environnemental que fait peser l'être humain sur la mer de Barents. Au cours des dernières années, l'exploration pétrolière et gazière au large a augmenté, donnant lieu à des problèmes écologiques ainsi qu'à des conflits avec l'industrie de la pêche.

On a trouvé des métaux lourds et des contaminants organiques anthropiques dans les sédiments comme dans les organismes, et ce, à différents niveaux trophiques. Le transport atmosphérique de longue portée et le transport par les courants océaniques sont importants. Les contaminants organiques s'accumulent surtout dans le tissu adipeux des organismes; les écosystèmes nordiques sont donc particulièrement vulnérables car le gras a beaucoup plus d'importance écologique dans ces systèmes que dans des écosystèmes localisés plus au sud.

Durant les dernières années, en Norvège comme en Russie, le public s'est dit concerné par une éventuelle pollution radioactive. Centrales, vaisseaux et armes nucléaires sont présents dans la région et produisent des déchets radioactifs. Des rapports sur ces déchets ont influencé l'opinion publique dans de nombreux pays.

La mer de Barents est fortement influencée par les variations du climat océanique. Des modèles climatiques planétaires prédisent que c'est probablement dans les régions polaires que se produiront les plus fortes hausses de températures océaniques dues à l'effet de serre éventuel.

Mots clés: mer de Barents, pêche, activité pétrolière au large, contaminants organiques, radioactivité

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INTRODUCTION

The Barents Sea is a shallow-water ecosystem with high biological production of fish and mammals (Sakshaug et al., 1994a). It contains some of the world's largest seabird populations. The biological resources in the area have been exploited for generations by fishermen and hunters from several nations. Research activities, mostly related to biological resources, have been carried out mainly by Russian and Norwegian institutions.

During the period 1984–89, research was intensified and broadened by the Norwegian Research Programme on Marine Arctic Ecology (PRO MARE). The aim of this programme was to increase understanding of how pelagic ecosystems function in Arctic regions, thereby improving the basis for government decision-making as well as improving

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the scientific base for fish stock management and the evaluation of pollutive effects. The main results from this programme are summarized in the proceedings from the PRO MARE symposium in May 1990 (Sakshaug et al., 1991).

Some years ago the Barents Sea was considered to be a relatively unpolluted ocean because of its long distance from densely populated and industrialized areas (State Pollution Control Authority, 1983). More recent studies, however, have demonstrated that the Barents Sea is affected by chemical pollution (Muir et al., 1992; Matishov, 1993). Biological production in the Barents Sea is limited in space and time and the ecosystem is therefore especially vulnerable to pollution. In addition to pollutants from local sources, chemicals are transported into the Barents Sea by both ocean currents and long-range atmospheric transport.

Here we review the current knowledge of man's impact on the Barents Sea ecosystem, based on our own research as well as the available literature. Regrettably, a significant part of the Russian investigations has not been included because we lack translations and because some methodological discrepancies made it difficult to compare Russian and Norwegian observations.

CHARACTERISTICS OF THE BARENTS SEA ECOSYSTEM

Physical Conditions

The area of the Barents Sea is approximately 1.4×10^6 km^2. It is a relatively shallow continental shelf sea with an average depth of 230 m (Fig. 1). The maximum depth of 500 m is found in the west between Norway and Bear Island. The shallowest areas are on the Svalbard Bank and the southeastern part, where depths are less than 50 m. The bottom topography strongly influences the current conditions. Over the banks there are anticyclonic eddies, while there is cyclonic circulation above some deeper areas. In the eddies the watermasses have a relatively long residence time, a fact of considerable biological importance.

There are three main current systems linked to three different water masses (Fig. 2). The Norwegian Coastal Current flows along the Norwegian coast, transporting water to the Barents Sea from the Baltic, the North Sea and the Norwegian fjords. This watermass is characterized by low salinity and relatively high temperature. The Atlantic Current transports water with high salinity ($S > 35.0$) and a temperature that varies between 3.5° and 6.5°C at the inflow between Norway and Bear Island. The Atlantic water arrives in two main branches: one that flows north along the western coast of Spitsbergen, and another that spreads into the Barents Sea (Fig. 2). The influx of Arctic water to the Barents Sea also occurs along two main routes: between Spitsbergen and Franz Josef Land and, more importantly, between Franz Josef Land and Novaya Zemlya (Dickson et al., 1970). A small inflow of cold water from the Kara Sea takes place south of Novaya Zemlya. The Arctic water has salinities of 34.3 to 34.8 and temperatures below 0°C. The core of the Arctic water, however, has temperatures below -1.5°C. The Arctic and Atlantic water meet and mix in the Polar front, which is an important area for biological production.

Rather little is known about the volume of water transported by the different currents. Blindheim (1989) calculated the inflow and outflow between Norway and Bear Island on the basis of current measurements. He indicated a mean transport of 3 Sverdrup (SV) (10^6 m^3·s^{-1}) in and about 2 SV out through this section. An outflowing current with the same transport volume is located in the strait between Novaya Zemlya and Franz Josef Land. The fluxes vary from 1 SV during summer to 3.5 SV during winter time (Loeng et al., 1993). A numerical wind-driven model indicates fluctuations of about the same magnitude as the mean transport (3 SV) between Norway and Bear Island (Ådlandsvik and Loeng, 1991). Variability in the Atlantic current due to remote forcing is of about the same order (McClimans and Nilsen, 1990).

Ecosystem Characteristics

The Barents Sea can roughly be divided into four ecological regimes (Skjoldal and Rey, 1989): 1) the western and central area dominated by Atlantic water, 2) the northern central area with Arctic water, 3) the Svalbard Bank area in the northwest with Arctic water, and 4) the eastern Barents Sea with mixed Atlantic and Arctic water (Figs. 1, 2).

The Barents Sea is characterized by large fluctuations in the inflow as well as large seasonal and interannual variability in the ice cover. A rapidly developing phytoplankton bloom occurs at the ice edge. This bloom forms a sweeping band of high production that follows the ice front as it retreats northwards during the summer (Sakshaug and Skjoldal, 1989).

Zooplankton can graze the major part of a slowly developing spring bloom if their initial stock size is sufficiently high. Of the short-lived and intense blooms in the ice-edge region, much will sink ungrazed. The herbivore grazing pressure may influence the development and the duration, as well as the phytoplankton species composition, of the spring bloom (Skjoldal and Rey, 1989).

The predominant herbivore in the Atlantic water is the copepod *Calanus finmarchicus*, which has a one-year life cycle. In the Arctic water *Calanus glacialis*, with a two-year life cycle, is the main species. Advective production of zooplankton is an important ecological factor in the southern and central Barents Sea. *Calanus finmarchicus* is transported into the Barents Sea from the Norwegian Sea during spring and summer (Skjoldal and Rey, 1989). During autumn and winter, it migrates to layers deeper than 500 m in the Norwegian Sea and is therefore mostly unavailable for transport into the Barents Sea during this period.

The Barents Sea ecosystem contains some of the world's largest fish stocks, such as capelin *(Mallotus villotus)*, cod *(Gadus morhua)* and herring *(Clupea harengus)*. The plankton production is mainly harvested by capelin and juvenile herring (Hamre, 1991). There is little overlap between the feeding areas of juvenile herring and adult capelin in the

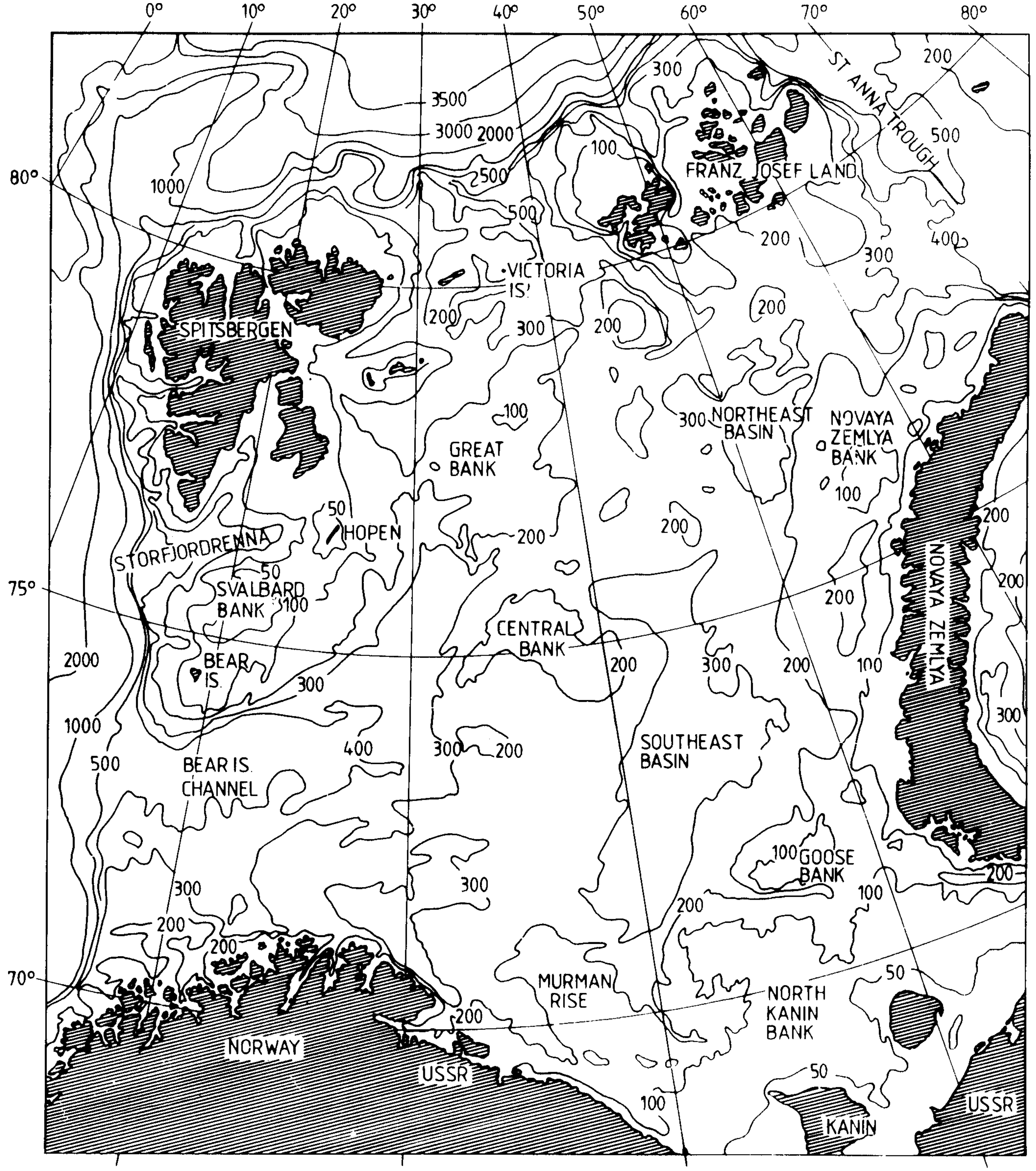

FIG. 1. Bathymetric map of the Barents Sea.

Barents Sea; the capelin mainly utilize the region north of 72°N, while the herring are confined to the more southern region (Gjøsæter, 1995). There are strong interactions between the main fish stocks, with variations in year-class sizes having marked influence on other components of the ecosystem (Hamre, 1991).

Capelin play an important role in the ecosystem of the Barents Sea where they are a major food source for minke whales *(Balaenoptera acutorostrata),* harp seals *(Phoca groenlandica)* and predatory fish such as cod (Sakshaug and Skjoldal, 1989). The larvae and juveniles of both herring and capelin are heavily predated by seabirds.

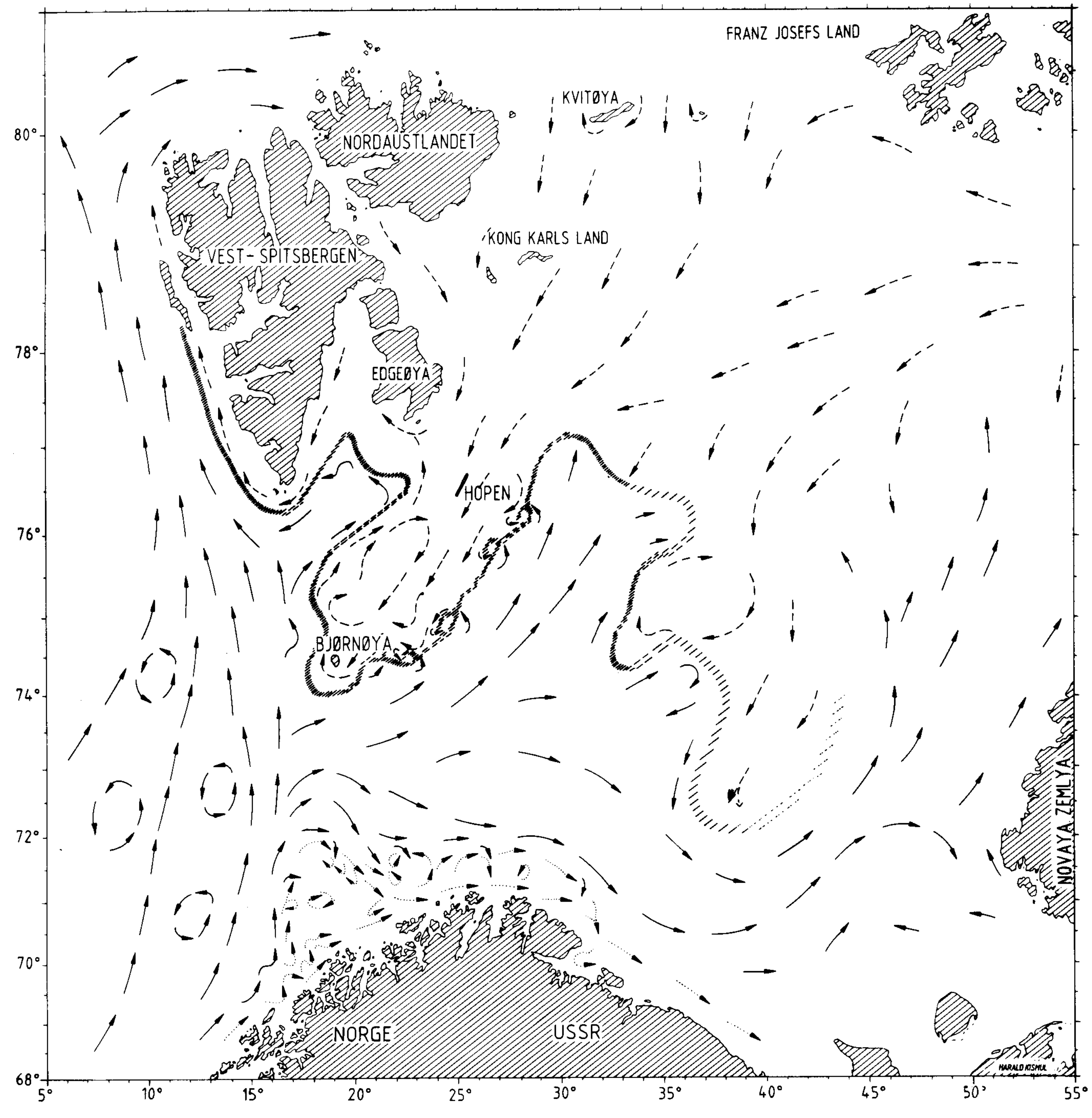

FIG. 2. The dominant surface current system of the Barents Sea. ——▶ Atlantic current; ------▶ Arctic current; ········▶ Coastal current. The polar front is indicated by a hatched line.

IMPACT OF MAN

Fishing Activity

Fishing operations have the most significant anthropogenic impact on the marine environment. The direct effects are as follows:

- Fisheries cause mortality on the target fish and incidentally on other biota.
- Fisheries make food available to other species in the ecosystem by i) discarding unwanted catch of fish and benthos, ii) discarding wastes, and/or iii) by killing or damaging animals in the path of the gear during its deployment.
- Fisheries disturb the seabed by the action of towed fishing gears.
- Fisheries generate litter composed of lost or dumped gear.

(ICES, 1992:2)

During the last forty years, the total fish harvest from the

Barents Sea has been in the order of 2.0 to 3.5 million tonnes per year, which is approximately the same as for the North Sea. The proportion of gadoids in the total catches has decreased from about 50% in the 1950s to about 30% in the 1980s. During the same period, the proportion of pelagic species like capelin and herring has increased to about 60% of the total catches (Hamre, 1991; Gjøsæter, 1995).

During recent decades the development of cod, capelin and herring stocks has shown strong biological interaction and dependence on climatic variability. Dramatic ecological events took place in the Barents Sea ecosystem during the 1980s (e.g., Blindheim and Skjoldal, 1993). In 1983 strong year-classes of cod and herring were formed. Heavy predation on capelin from both these species and commercial fishing (Hamre, 1991) caused the capelin stock to collapse in 1986. This decline had drastic effects on other components of the Barents Sea ecosystem, resulting in food shortage and poor growth of cod, migration of seals to and along the Norwegian coast and heavy mortality among seabirds (Blindheim and Skjoldal, 1993).

The Barents Sea ecosystem fluctuates between two extremes: periods of strong recruitment to cod and herring stocks and reduced size of capelin stock, and periods of absence of herring, moderate recruitment to the cod stock, and a large capelin stock (Gjøsæter, 1995). The fisheries for pelagic stocks may play a major role in the ecosystem by intensifying these fluctuations. The fisheries most likely contributed to the collapse of the herring stock in the 1960s, and may also have played a minor role in the collapse of the capelin stock two decades later (Hamre, 1991).

The impact of fishing on bottom sediments and thus also on the benthic fauna is mainly caused by dragged gear like beam trawls and demersal trawls. The use of bottom trawls in the fishery for demersal fish, shellfish and shrimps can cause destruction at the seabed and in the benthic epi- and infauna communities. The main effect of bottom trawls is the resuspension of sediments and animals living in the upper sediment layers. Only a minor percentage of animals directly collides with the trawl doors. Opportunistic species can rapidly recolonize the disturbed areas (Rauck, 1989; Noji and Noji, 1991). The subsequent benthic fauna will have a low species diversity and high abundances of a few dominant species (Bergmann et al., 1990). The establishment of the original benthic equilibrium community will take several years. Matishov (1991, 1993) mapped vast areas exploited by bottom trawling in the Barents Sea, which he regards as having devastated benthic communities, although his documentation for this appears weak.

Bycatch of nontarget species and undersized fish takes place. Most of this bycatch is discarded at sea and enters the food chain via sea birds, fish and benthic organisms. Netbursts of purse seines as well as trawls and seines can cause accumulation of large quantities of dead fish on the bottom in a restricted area. The same is known to happen when larger amounts of a catch are discarded at sea. Unfortunately, there is not enough information to estimate the full significance of these effects on the Barents Sea.

During shooting of longlines, seabirds are often caught and thus killed. Fishing nets can cause bird mortality (Strann et al., 1991). Gill nets that are lost will continue to catch fish for a long time (“ghost-fishing”). Trawls or other gear parts might be lost during fishing operations, mainly while fishing in areas with rough ground or other obstacles, such as shipwrecks and debris from offshore oil exploitation. The effects of lost trawl gear on the biological environment are unknown. Most likely this will create new habitats and thus increase production of epifauna and aggregate fish.

Offshore Oil Activity

A very limited part of the Barents Sea close to the Norwegian coast was opened for exploratory oil activity in 1980. According to the Norwegian Petroleum Act, an environmental impact assessment must be performed before a new area is opened for exploration. Such impact analysis for part of the Barents Sea south of 74°30′N and west of 32°E was completed in 1988 (Børresen et al., 1988), and the area was opened for exploratory drilling. The environmental impact assessment of the northern Barents Sea within the Norwegian Exclusive Economic Zone (EEZ) is now being carried out. Engelhardt (1985) has extensively reviewed the effects of petroleum on the arctic environment.

During the period 1980–92, 54 exploratory wells were drilled in the Norwegian sector of the Barents Sea. The positions of these drilling sites are shown in Figure 3. There have been 4611 days of drilling which is, on average, 85 days per well. The Russian drillings up to 1989 are from Matishov (1991).

The impact of the offshore oil activity on the marine environment is related to seismic activity, pollution and area conflicts. Seismic surveying takes place before exploratory drilling is performed, using air guns as energy sources. The air guns reportedly cause the death of larval fish in relatively close proximity (2–3 m) to the emission source (Dalen and Knutsen, 1987). Recent Norwegian experiments confirm that the youngest larval stages are the most vulnerable (J. Dalen, pers. comm. 1993) In these studies there was an immediate mortality of larval fish at a distance of 1.5–2.0 m from the energy source. Apparently sublethal effects which resulted eventually in death were observed at greater distances. Matishov (1993) claimed that the Barents Sea was subject to intensive anthropogenic destruction during the last thirty years. Among the most important causal factors he named geophysical surveying, although the significance of seismic activity for the fishery resources is still a matter of debate. At present, research projects to study the biological effects of geophysical surveying are in progress. While waiting for these results, the Norwegian authorities have chosen to use the precautionary principle and have imposed strict regulations on seismic activity within the Norwegian EEZ.

Seismic activity has, in addition to causing a possible increase in mortality of larval fish, been blamed for frightening adult fish away from the fishing grounds. Recent Norwegian studies in the Barents Sea (Engås et al., 1993) found that the catch rates for trawl and long-line as well as total biomass

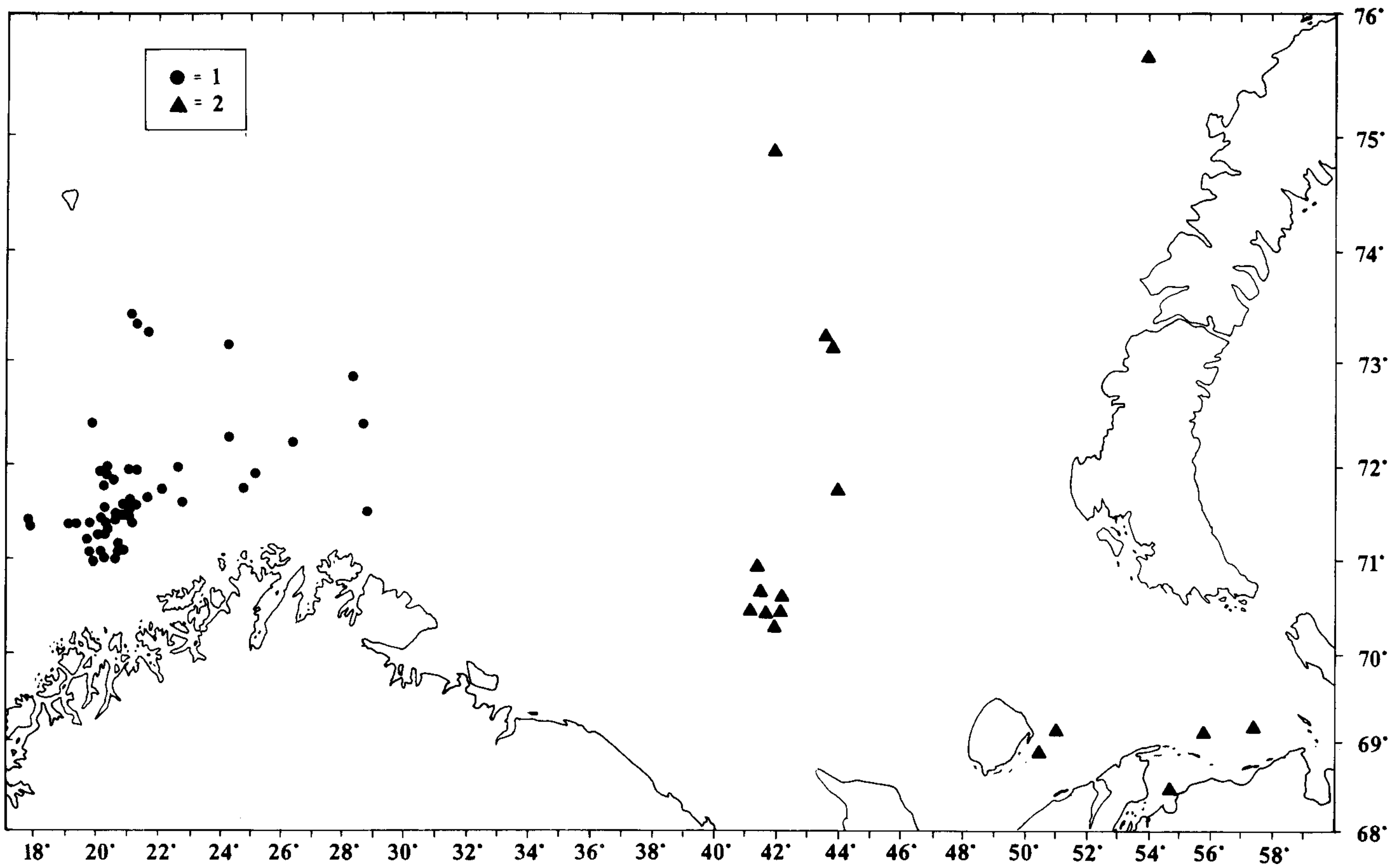

FIG. 3. Exploratory drillings for oil and gas in the Barents Sea. 1) 54 Norwegian drillings during the period 1980–92 (Norwegian Petroleum Directorate); 2) Russian drillings up to 1989 (Matishov, 1991).

of cod were clearly influenced by seismic activity. The frightening effect depended on the size of the fish. Large cod (over 60 cm) more than 20 nautical miles away from the seismic activity were scared away. Five days after the seismic activity had stopped, the large fish had still not returned to the test site.

Pollution from offshore oil activity in the Barents Sea is related to accidental oil spills and to operational discharges of oil and chemicals from drilling operations and test production. A large-scale blowout would probably be the most dramatic event, with the furthest-reaching consequences to the biological resources in the area (Børresen et al., 1988). The Norwegian State Pollution Control Authority has calculated the probability of an oil spill in the Barents Sea. Statistically, one must be prepared for one oil blowout for every 1800 exploration wells. The probability of a blowout during production is somewhat higher, because of the longer lifetime of such wells. Gas blowouts are also more frequent, but they are not expected to cause the same harmful effects.

Even if the probability of an oil blowout is relatively low, it may occur. It is well known that oil on the surface can be lethal to seabirds if they get oil on their feathers, and that even small spills can wipe out a large number of birds (Barret, 1979). The area is very important for seabirds and it has been estimated that ca. 14 million seabirds use the Norwegian part of the Barents Sea for breeding and/or feeding (Sakshaug et al., 1994b). There are also important bird colonies in the Russian part of the area. The birds most vulnerable to oil are those spending a great time of their life at sea, such as fulmar and guillemot. The areas close to breeding colonies or those used as migration routes in the moulting period, are those where an oil spill can cause most damage. Marine mammals like seals and polar bears could also be affected by surface oil. There are estimated to be about 1.3 million seals in the Barents Sea (Sakshaug et al., 1994b).

Oil at the surface may be mixed into the water by wind and wave motions. This may affect fish and other resources in the water column, particularly in the upper few meters. Adult fish will probably swim away from oil-infected water, but fish eggs and larvae can be very vulnerable to oil. Experiments on cod, commercially the most important fish stock in the Barents Sea, have shown that the first three to four weeks after hatching represent the most vulnerable stage (Føyn and Serigstad, 1987). Cod larvae drift into the Barents Sea from the southwest. If a big oil spill in the Barents Sea were to coincide in time and space with the highest densities of cod eggs and larvae, it has been estimated as a worst case that a maximum of 10% to 15% of the total larval production could be killed (Børresen et al., 1988). The chance for such an event is very small, however.

The exploratory drilling and test production in the Barents Sea result in operational discharges. More than 50 wells have been drilled using water- and oil-based muds; this has released drilling muds and cuttings to the water column and the seabed. In addition, contaminants from discharges of production water, smaller spills and flaring operations enter the marine environment. The total amount released by these operations is not known. A major component of these sources is oil, but other substances are also involved. Chemicals are used in both drilling and production operations, and some of these enter the sea. Using data from the North Sea (OSPARCOM, 1993), the amount discharged via cuttings is by far the largest source of oil. Since there has not been any permanent production of oil in the Barents Sea, the contribution of contaminants from production water and flaring operations is probably low. The most notable effect of discharges of cuttings and drilling muds is the physical smothering and contamination of the seabed close to the drilling sites, which negatively affects the benthic community (OSPARCOM, 1993).

Conflicts between the oil industry and fishermen are mainly caused by the reduction of areas available for fishing owing to the presence of platforms and subsea installations such as pipelines and temporarily abandoned wells.

Organic Contaminants and Trace Metals

Atmosphere: Organic contaminants and trace metals reach the Barents Sea through long-range transport. Although the importance and magnitude of different sources are not well known, it is recognized that the atmospheric poleward transport from more urbanized and industrialized areas plays an important role (Bidleman et al., 1981; Iversen, 1984; Oehme and Ottar, 1984; Barrie, 1986; Hargrave et al., 1988; Pacyna and Oehme, 1988; Bidleman et al., 1989; Patton et al., 1989; Oehme, 1991). Observations of organic contaminants and trace metals in the air over the Barents Sea region have been carried out from land-based stations. Ambient air concentrations of selected chlorinated compounds were determined at Ny-Ålesund (Spitsbergen), Hopen, Bear Island and Jan Mayen from 1982 to 1984 (Oehme and Semb, 1989). Increased concentrations of hexachloro-cyclohexanes (alpha-, gamma-HCH) and polychlorinated biphenyls (PCBs) were observed several times simultaneously at most measuring stations, which indicates episodic, long-range transport to the Arctic. During such periods, concentrations were comparable to those at lower latitudes in central Europe. Other groups of organic contaminants like hexachlorobenzene (HCB), chlordanes, and fluoranthene were also present.

The concentration of alpha-HCH in the air at Spitsbergen (1982–84) varied from 0.16 to 1.3 ng/m^3; this is comparable to but slightly higher than Canadian measurements (Oehme and Mano, 1984). HCB has been detected at concentrations around 0.1 ng/m^3, but DDT and its degradation products were below detectability (Pacyna and Oehme, 1988; Oehme and Mano, 1984).

Anthropogenic trace metals are an important component of particulate pollution in the arctic environment (e.g., Pacyna and Ottar, 1985). Unfortunately, the literature contains little data on the levels and sources of heavy metals in air in the Barents Sea region. Most of the information has been collected from measurements at Ny Ålesund, Spitsbergen and a few stations in northern Norway. The most extensive measurements were carried out in the period from 1982 through 1984 (Pacyna et al., 1985). Atmospheric concentrations were lower in summer than in winter. At the above-mentioned stations, different sources of air pollution were identified, with signatures from eastern North America, Eurasia and Europe (Maenhaut et al., 1989). The results indicated that less than 10% of the mass of trace elements came from eastern North America. Elevated levels of trace metals in the air occur in coastal areas of the Barents Sea owing to emissions from local industry, most notably from metallurgical plants at the Kola Peninsula (Matishov, 1993). Akeredolu et al. (1994) calculated the flux of anthropogenic trace metals into the Arctic from the mid-latitudes in 1979 and 1980. The total annual flux of cadmium and lead into the Arctic from Eurasia was 47 and 2400 tonnes respectively, representing 4.2% and 3.0% of the source emissions.

Seawater: In seawater, persistent organics like PCBs and polycyclic aromatic hydrocarbons (PAH) occur at low concentration because of low water solubility and high lipophilicity. Most persistent organics are associated with dissolved organic matter and suspended particulate matter in seawater. Methodological problems still exist for the quantitative determination of trace organics in seawater, and such compounds have been included in monitoring programmes only to a very limited extent. Slightly contaminated Norwegian coastal water originating from the North Sea enters the Barents Sea. Gaul (1992) observed a gradient of decreasing HCH concentration between the North Sea and the Barents Sea, which reflected the importance of European sources of HCH-isomers. The HCH (alpha + gamma) levels in 1985 ranged from 4.8 to 6.2 ng/l in the North Sea, from 2.3 to 3.8 ng/l along the coast of Norway, and from 1.2 to 1.8 ng/l in the Barents Sea (Gaul, 1992). Mean concentrations in the Norwegian Sea during that study were 0.2 and 1.0 ng/l for gamma-HCH and alpha-HCH respectively. Other chlorinated organic contaminants were present in seawater from the Barents Sea, but usually at much lower concentrations than the HCH-isomers.

Vlasov and Melnikov (1990) analysed HCH concentrations in surface seawater collected during 1986–89 from the Kara, Laptev, East Siberian and Chukchi Seas that were similar to those observed in the Barents Sea (Gaul, 1992). The highest concentrations of HCH measured by Vlasov and Melnikov (1990) in Russian waters were in samples from the Ob and Gydan River mouths (4.0–4.5 ng/l). These river inputs probably do not significantly influence the general concentrations of HCH in the Barents Sea.

No recent information is available on the levels of trace metals in water from the Barents Sea. Concentrations of trace metals in sea water are in general very low; in addition, measurements may be unreliable because secondary contamination during sampling and analysis is difficult to avoid. The levels of trace metals in seawater from offshore areas of the Barents Sea will likely be similar to levels found in the Norwegian Sea. Mart and Nurnberg (1984) reported lead concentrations in the surface water of the North Atlantic and the Norwegian Sea ranging from 29 to 41 ng/l, which is close to the background concentration for oceanic water (Fowler, 1990). Danielsson et al. (1985) reported a cadmium concentration of 22 ng/l in surface water in the Norwegian Sea, which is somewhat higher than levels (5 to 10 ng/l) reported for oceanic water by Fowler (1990). Little information is available on baseline values for mercury in the Norwegian and Barents Seas. Olafsson (1983) reported mercury concentrations in the North Atlantic varying from < 1 to 3 ng/l.

Sediments: Published information on contaminants in sediments from the Barents Sea is scarce. The accumulation of trace metals and organic contaminants in sediments from the Barents Sea is therefore being examined now in a baseline study by the Institute of Marine Research in Bergen. From the sampling programme in 1991, sediments from eleven sites in the Barents Sea were analysed for polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) and compared with five locations in the North Sea (Oehme et al., 1993). The levels found over a wide area in the Barents Sea were quite uniform and of the order of 0.5 pg/g d.w. expressed as 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (Nordic model). The levels found in the North Sea were at least an order of magnitude higher. Combustion processes were the most probable origin of the PCDD/PCDF. Octochloro congeners dominated in the North Sea, while tetra-and pentachlorodibenzofurans were the most abundant congeners in the Barents Sea. Differences in the wet and dry deposition rates might be the reason why the more volatile congeners are found in regions far from the sources (Oehme et al., 1993).

PCBs have been analysed in sediments from nine sampling sites in the Barents Sea (Klungsøyr, unpubl. data). The concentrations of 13 PCB congeners (IUPAC Nos 28, 31, 52, 101, 105, 118, 128, 138, 149, 153, 156, 170, 180) varied from < 0.05 to 0.7 ng/g d.w. The mean concentration of PCBs in sediments from the Barents Sea was 0.5 ng/g d.w., and this is nearly an order of magnitude lower than in the Skagerrak, a major deposition area for the North Sea (Green and Klungsøyr, 1994). Normalizing the data to the fine fraction of the sediments (GS < 63 μm) leads to smaller differences, but still the data show a higher level of PCBs in the North Sea than in the Barents Sea.

As part of the same baseline study, sediments from the Barents Sea were analysed for aromatic hydrocarbons with two to six aromatic rings (Klungsøyr, unpubl. data). Figure 4 presents some preliminary results on the distribution of Benzo(a)pyrene in total sediment (< 2 mm). The major source is believed to be incomplete combustion of fossil fuels. The concentrations in the sediments varied from approximately 1 to 40 ng/g d.w. (Green and Klungsøyr, 1994). The results indicate that Barents Sea sediments are influenced by anthropogenic inputs of aromatic hydrocarbons.

Biota: Information on the levels of PCBs and DDT (plus derivatives) in biota from the Barents Sea are summarized in Table 1. From this table it is clear that fish, seabirds, marine and terrestrial mammals in the Arctic accumulate persistent organics from different sources. For PCBs it is difficult to make direct comparisons between concentrations because different PCB congeners have been analysed in different studies. Relatively few measurements on persistent organics in fish have been reported. The concentrations of PCBs (as the sum of IUPAC Nos. 28, 52, 101, 118, 138, 153, 180) in cod livers from the Barents Sea sampled in 1983 were approximately the same as in cod from the northern North Sea (de Boer, 1988). Cod sampled in 1992 in the central Barents Sea show concentrations slightly lower than those found in 1983. DDTs (pp-DDT, pp-DDE and pp-DDD) were found at relatively low concentrations (Table 1). Plaice *(Pleuronectes platessa)* and sea trout *(Salmo trutta)* from northern Norway and the White Sea contained low concentrations of PCBs.

Levels of PCB in the blubber of ringed seals *(Phoca hispida)* from Svalbard vary from 0.39 to 9 μg/g w.w. (Table 1). These concentrations seem to be slightly higher than those in ringed seals from the Canadian Arctic (Muir et al., 1992). The same has been found for DDTs. Except for one high value (9 μg/g w.w.), the PCB levels in arctic ringed seals are 10 times lower than those reported for land-locked ringed seals in Finland (Helle et al., 1983). Andersson et al. (1988) reported that concentrations of PCBs and DDT in ringed seal and Brünnich's guillemot (*Uria lomvia)* from Spitsbergen were much lower than in the Baltic, while the levels of Toxaphene (PCCs) differed less. Only one ringed seal was analysed, and this had a PCC concentration of 4.4 μg/g in the blubber.

Concentrations of 2.3.7.8-TCDD (tetrachlorodibenzo-dioxin) in the blubber of ringed seals from Svalbard ranged from ≤ 2 to 8.2 pg/g (Oehme et al., 1988, 1990). Daelemans et al. (1993) analysed non-ortho and mono-ortho PCBs in the blubber of ringed seals from the same area and found that the toxic equivalent factor, TEQ (nordic model), for the planar PCBs was 11 times higher than the TEQ factor for the PCDDs/PCDFs reported by Oehme et al. (1988). Bignert et al. (1989) found that seals from the Baltic contained from six to ten times higher concentrations of polychlorinated dibenzodioxins (PCDD) and dibenzofurans (PCDF) than ringed seals from the Arctic.

Espeland et al. (1994) analysed PCBs, DDTs, chlordanes, HCH-isomers and HCB in blubber samples from 97 harp seals (*Phoca groenlandica*) from the Barents Sea region. The seals were collected during 1989–93 at different times of the year. Seasonal differences in the organochlorine concentrations between adult animals of both sexes were found. Animals with a thick blubber layer caught in September or October contained less than 1 μg/g PCB and DDT (average), while the leanest animals caught during April and May contained between 2 and 4 μg/g. Chlordanes, HCH-isomers and HCB were also found in the animals, but at lower concentrations than the PCBs and DDTs.

Polar bears *(Ursus maritimus)* sampled from Svalbard during the period 1978–89 have been analysed for HCB, DDTs, PCBs, HCHs, oxychlordane, drins and several other contaminants (Norheim et al., 1992). The concentration ranges of HCB, DDE and PCBs in fat were < 0.05–1.5, < 0.1–3.4,

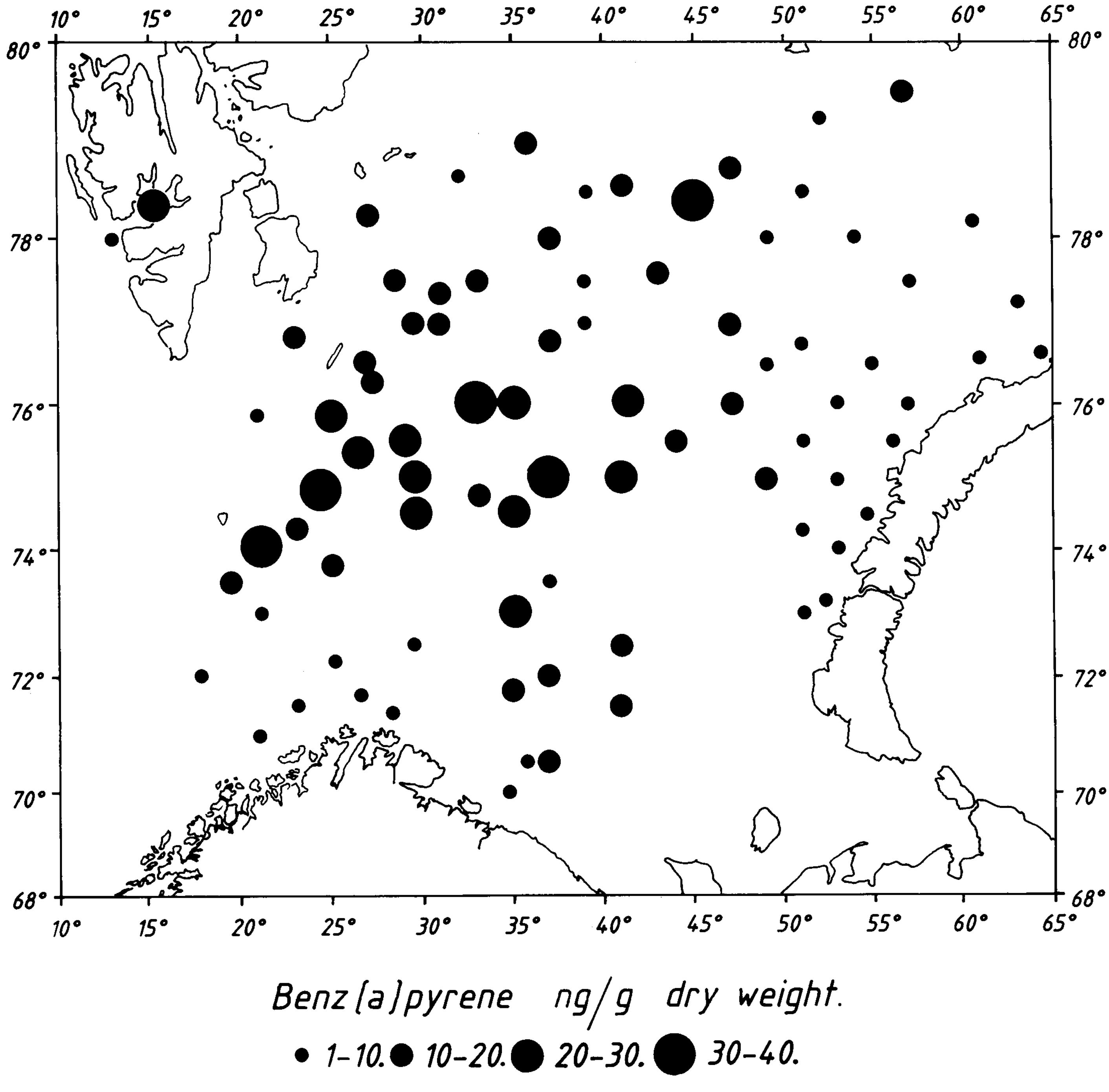

FIG. 4. The distribution of Benzo[a]pyrene in sediments expressed in ng/g dry weight.

and 2.9–90 μg/g, respectively. The corresponding results for liver were < 0.01–0.11, < 0.1–0.5, and 0.1–78 μg/g, respectively. PCB levels in polar bears from Svalbard seem to be higher than in bears of the Canadian Arctic (Norstrom et al., 1988). The range of hepatic concentrations of oxychlordane was 5–19 μg/g. The levels of PCB were particularly high, and possible biological effects—especially on reproduction—cannot be excluded. Ringed seal and, to some extent, bearded seal (*Erignathus barbatus*) are the main food source of the polar bear. It is therefore likely that the exposure to environmental pollutants occurs via the consumption of these two species.

Levels of PCBs have been determined in subcutaneous fat and liver from 27 arctic foxes *(Alopex lagopus)* caught at Svalbard (Wang-Andersen et al., 1993). The study revealed that the PCB levels in arctic foxes were high and essentially unchanged over the period from 1973–74 to 1983–84 (Table 1). In the case of the most highly contaminated foxes, effects on vital functions from the observed levels of PCBs cannot be excluded (Wang-Andersen et al., 1993).

With a few exceptions, birds from the Barents Sea region contain relatively low levels of chlorinated hydrocarbons, similar to those found in corresponding samples from Green-

TABLE 1. Mean concentration of ∑PCB and ∑DDT in biota from the Barents Sea (μg/g wet weight).

Species Site and Year	Tissue[1]	N	∑DDT[2]	∑PCB[3]	Source[4]
Cod (*Gadus morhua*)					
Barents Sea, 1982	L	28	0.08	0.45	1
Barents Sea, 1991	L	25	–	0.18	1
Sea Trout (*Salmo trutta*)					
Ranafjord, 1989	M	20	–	0.007	1
Plaice (*Pleuronectes platessa*)					
White Sea, 1991	L	4	–	0.09	1
Ringed Seal (*Phoca hispida*)					
Svalbard, 1980	B		4.5	9	2
Svalbard, 1984	B	5	0.64	0.48	3
Svalbard, 1986	B	7	1.6	0.84	4
Svalbard, 1990	B	13	1.3[a]	1.4	5
Finnmark, 1990	B	12	3.0	2.5	6
Bearded Seal (*Erignathus barbatus*)					
Svalbard, 1984	B	2	0.95	1.1	3
Grey Seal (*Halichoerus grypus*)					
Finnmark, 1989–90	B	24	2.0	5.8	6
Harp Seal (*Phoca groenlandica*)					
Finnmark, 1990	B	38	3.1	3.0	6
Barents Sea region, 1989-93	B	97	0.27–4.7[c]	0.45–4.1[c]	7
Harbour seal (*Phoca vitulina*)					
Finnmark, 1990	B	7	5.3	2.5	6
Harbor Porpoise (*Phocoena phocoena*)					
Finnmark, 1988–89	B		13	21	6
Minke whale (*Balaenoptera acutorostrata*)					
Barents Sea, 1989–93	B	173	2.0	3.0	6
Sperm Whale (*Physeter catodon*)					
Troms, 1989	M	1	0.55	0.45	1
White Beaked Dolphin (*Lagenorhynchues albirostries*)					
Troms, 1989	B	1	3.3	2.4	1
Arctic Fox (*Alopex lagopus*)					
Svalbard, 1974	F	44	–	10	8
Svalbard, 1974	L	44	–	0.94	8
Svalbard, 1984	F	17	0.20	8.3	9
Svalbard, 1984	L	27	–	0.40	9
Polar Bear (*Ursus maritimus*)					
Svalbard, 1978–89	F	7	0.75[a]	31	10
Svalbard, 1978–89	L	16	0.18[a]	13	10
Svalbard, 1992–93	F	73	0.25	25	6
Kittiwake (*Rissa tridactyla*)					
Bear Island, 1972	L	1	0.08[a]	1.6[b]	11
Murmansk, 1979	M	10	0.83	0.99	12
Murmansk, 1979	L	10	1.0	1.1	12
Kittiwake (*Rissa tridactyla*) – continued:					
Murmansk, 1979	Br	10	0.23	0.35	12
Svalbard, 1984	L	2	0.06	0.55	3
Svalbard, 1984	E	5	0.17	0.17	3
Brunnich's Guillemot (*Uria lomvia*)					
Bear Island, 1972	L	2	0.1[a]	0.2[b]	11
Svalbard, 1980	M	4	0.12	0.26	2
Svalbard, 1980	L	9	0.16	0.4	13
Svalbard, 1984	L	4	0.07	0.18	3
Hopen, 1984	E	6	0.08	0.08	3
Svalbard, 1990	L	8	–	0.08	14
Common Guillemot (*Uria aalge*)					
Bear Island, 1972	L	1	0.2[a]	0.8[b]	11
Herring Gull (*Larus argentatus*)					
Finnmark, 1969	E	9	1.6[a]	4.6[b]	15
Finnmark, 1969–72	E	10	1.7[a]	2.2	16
Finnmark, 1972	E	10	1.9[a]	9.7	17
Finnmark, 1979–81	E	25	1.5[a]	3.8[b]	15
Murman coast, 1979	L	6	3.4	3.8	12
Puffin (*Fratercula arctica*)					
Spitsbergen, 1972	L	2	0.09[a]	0.4[b]	11
Svalbard, 1984	L	2	0.22	0.61	3
Little Auk (*Alle alle*)					
Bear Island, 1972	L	1	0.23[a]	0.7[b]	11
Svalbard, 1984	L	2	<0.05	<0.1	3
Black Guillemot (*Cepphus grylle*)					
Svalbard, 1984	L	2	<0.05	<0.1	3
Svalbard, 1990	L	10	–	0.13	18
Svalbard, 1990	L	10	–	0.16	14
Fulmar (*Fulmar glacialis*)					
Bear Island, 1972	L	1	0.3[a]	1.6[b]	11
Svalbard, 1980	L	10	0.63	1.6	13
Svalbard, 1984	L	2	<0.05	<0.1	3
Glaucous Gull (*Larus hyperboreus*)					
Bear Island, 1972	L	6	23.3[a]	72.0[b]	11
Svalbard, 1980	L	11	1.9[a]	6.1	13
Svalbard, 1984	L	2	1.5	7.5	3
Svalbard, 1990	L	13	–	20.9	18
Svalbard, 1990	L	9	–	8.9	14
Eider (*Somateria mollissima*)					
Svalbard, 1980	M	5	0.03	0.07	2
Svalbard, 1984	L	2	<0.05	<0.1	3
Svalbard, 1990	L	9	–	0.04	14

[1] L = Liver; M = Muscle; B = Blubber; F = Fat; Br = Brain, E = Egg

[2] ∑DDT (dichlorodiphenyltrichloroethane): Sum of p,p-DDT, p,p-DDE and p,p-DDD; [a] only p,p-DDE

[3] ∑PCB - Polychlorinated biphenyls quantified as sum of individual congeners; see original literature for information on congeners used for quantification; [b] Quantified in technical PCB equivalents; [c] Range of mean given, see original paper for further explanation

[4] 1. Institute of Marine Research, Bergen, Norway, unpubl. results; 2. Andersson et al. (1988); 3. Carlberg and Bøler (1985); 4. Oehme et al. (1988); 5. Daelemans et al. (1993); 6. Utne Skaare et al. (1994a); 7. Espeland et al. (1994); 8. Norheim (1978); 9. Wang-Andersen et al. (1993); 10. Norheim et al. (1992); 11. Bourne and Bogan (1972), Bourne (1976); 12. Savinova (1991); 13. Norheim and Kjos-Hansen (1984); 14. Mehlum and Daelemans (1994); 15. Moksnes and Norheim (1986); 16. Holt et al. (1979); 17. Fimreite et al. (1977); 18. Daelemans et al. (1992).

land (Carlberg and Bøler, 1985; Savinova et al., 1995). Most arctic seabirds are less contaminated than similar species located farther south. Data from Svalbard and Bear Island indicate relatively high levels of organochlorines in fulmars (*Fulmar glacialis)* and glaucous gulls (*Larus hyperboreus*) (Table 1). The levels of PCBs recorded in glaucous gulls may be high enough to reduce survival (Mehlum and Bakken, 1994). The glaucous gull is a predatory species, feeding on little auks, seabirds' eggs, fish, offal, garbage, and carrion.

Recent data on trace metals in fish from the Barents Sea are few. Data from the Directorate of Fisheries in Bergen show that the levels of lead, cadmium and mercury in cod are at natural background concentrations (Table 2). Significant differences were found in mercury concentrations between grey seals (*Halichoerus grypus*), harbour seals (*Phoca vitulina*), harp seal and ringed seals caught in the same coastal area in Finnmark, close to the Russian border (Utne Skaare et al., 1994b). Very low hepatic mercury concentrations were found

TABLE 2. Mean concentrations (µg/g w.w.) of lead (Pb), cadmium (Cd) and mercury (Hg) in biota from the Barents Sea region.

Species Site and year	Tissue	N	Pb	Cd	Hg	Source[1]
Cod (*Gadus morhua*)						
Finnmark	M	36	–	–	0.07	1
Barents Sea West, 1993	M	25	0.003	<0.001	0.03	2
Barents Sea East, 1993	M	25	0.005	0.001	0.04	2
Polar Cod (*Boreogadus saida*)						
Svalbard, 1984	M	1	0.02	0.01	0.03	3
Svalbard, 1984	L	1	<0.02	0.09	0.01	3
Plaice (*Pleuronectes platessa*)						
Svalbard, 1984	M	1	0.02	<0.005	0.03	3
Svalbard, 1984	L	1	0.03	0.08		3
Ringed Seal (*Phoca hispida*)						
Svalbard, 1984	L	5	0.05	0.55	0.38	3
Svalbard, 1984	B	5	0.05	<0.02	<0.01	3
Finnmark, 1989–90	L	7F	–	–	0.45	4
Bearded Seal (*Erignathus barbatus*)						
Svalbard, 1984	L	2	0.01	8.0	6.3	3
Svalbard, 1984	B	2	0.05	<0.02	<0.01	3
Grey Seal (*Halichoerus grypus*)						
Finnmark, 1989–90	L	18F	–	–	22.4	4
Harbour Seals (*Phoca vitulina*)						
Finnmark, 1989–90	L	2F	–	–	0.83	4
Harp Seal (*Phoca groenlandica*)						
Finnmark, 1989–90	L	8F	–	–	0.33	4
Harbor Porpoise (*Phocoena phocoena*)						
Finnmark, 1989–90	L	11M	–	–	5.42	5
Polar Bear (*Ursus maritimus*)						
Svalbard, 1978–89	L	16	0.5	0.6	2.6	6
Brunnich's Guillemot (*Uria lomvia*)						
Svalbard, 1980	L	9	–	3.9	0.6	7
Svalbard, 1984	L	4	<0.05	3.0	0.20	3
Glaucous Gull (*Larus hyperboreus*)						
Svalbard, 1980	L	11	–	3.6	1.6	7
Svalbard, 1984	L	2	<0.5	2.1	0.21	3
Puffin (*Fratercula arctica*)						
Svalbard, 1984	L	2	<0.5	3.0	0.29	3
Little Auk (*Alle alle*)						
Svalbard, 1980	L	9	–	4.3	0.5	7
Svalbard, 1984	L	2	<0.5	0.7	0.04	3
Black Guillemot (*Cepphus grylle*)						
Svalbard, 1984	L	2	<0.05	0.03	0.08	3
Svalbard, 1984	L	2	<0.05	0.5	0.09	3
Kittiwake (*Rissa tridactyla*)						
Svalbard, 1984	L	2	<0.05	5.5	0.07	3
Eider (*Somateria mollissima*)						
Svalbard, 1984	L	2	<0.5	2.1	0.07	3
Fulmar (*Fulmar glacialis*)						
Svalbard, 1980	L	10	–	17	2.1	7

[1] 1. Directorate of Fisheries (1983); 2. Måge (1994); 3. Carlberg and Bøler (1985); 4. Utne Skaare et al. (1994b); 5. Teigen et al. (1993); 6. Norheim et al. (1992); 7. Norheim (1987).

in arctic species like the ringed and harp seals, a factor 10 to 40 times lower than in the harbour and grey seals which are considered more coastal species. In the harbour seals caught along the coast of Norway, mercury concentrations were decreasing from south to north.

Concentrations of mercury and selenium were determined in the liver and kidney of 92 harbour porpoises *(Phocoena phocoena)* caught along the Norwegian coast (Teigen et al., 1993). The hepatic and renal mercury concentrations ranged from 0.26 to 9.9 and 0.15 to 3.5 µg/g, respectively, while the corresponding selenium concentrations ranged from 0.74 to 14.2 and 0.60 to 8.6 µg/g, respectively. The results revealed a decreasing mercury concentration gradient from south to north along the Norwegian coast.

Trace metals were determined in polar bear from Svalbard (Norheim et al., 1992). The hepatic concentration ranges of mercury, cadmium and lead in animals of all ages were from 0.4 to 6.0, < 0.1 to 1.2, and < 0.5 to 1.6 µg/g, respectively. This indicates moderate exposure. The levels of copper and zinc represented normal physiological concentrations. Seabirds from Svalbard (Table 2) contained approximately the same levels of trace metals found in seabirds in Greenland (Overgaard Nielsen and Dietz, 1989).

Radioactivity

Radioactive contamination in the Barents Sea has been received from the following sources: atmospheric nuclear weapon tests in the 1950s and 1960s; discharges from the nuclear industry, particulary Sellafield, U.K.; possible runoff from Siberian rivers; discharge of low-level liquid waste; and the Chernobyl accident. Additionally, there are several potential sources, such as the dumped solid nuclear waste in the vicinity of Novaya Zemlya, possible leakage from the underground nuclear weapon tests on Novaya Zemlya, and the wrecked nuclear submarine "Komsomolets" in the Norwegian Sea. While the contributions from the nuclear weapon tests, the discharges from Sellafield and the Chernobyl accident are fairly well documented (Joseph et al., 1971; Gunnerød et al., 1990; Matishov, 1993), the extent of contamination from the other sources mentioned is uncertain.

The most pronounced contamination of the Barents Sea was detected during the previous Soviet atmospheric nuclear weapon tests. According to Joseph et al. (1971), 79 nuclear detonations took place in the Arctic up to 1968, and most of these were carried out prior to the cessation of widespread atmospheric bomb testing in 1963. Measurements of radioactivity in cod and haddock caught in the Barents Sea during and after the test period are presented in Figure 5 (Føyn, 1991). The measurements were made on commercial landed fish, and the mean values therefore represent fish caught in all commercial fishing grounds in the Barents Sea. The data demonstrate a fairly rapid decrease in the radioactive contamination of marine fish after 1963, the year with the highest reported values of up to 80 Bq·kg^{-1} w.w. In 1968, when the monitoring of commercial fish landings was terminated, the measured radioactive contamination was found to be below 10 Bq·kg^{-1} w.w. (Fig. 5).

When the monitoring programme was terminated in 1968, it was believed that the problem of radioactive contamination of fish resources in the Barents Sea belonged to the past. The Chernobyl accident and more recent events, such as the sinking of the Soviet nuclear submarine *Komsomolets* in 1989 and documentation released by the Russian government (OPRF, 1993) concerning radioactive materials dumped on the east coast of Novaya Zemlya, have brought the issue of radioactive contamination in the Nordic Seas back on the agenda.

After the Chernobyl accident, the health authorities advocated restrictions on daily intake of food containing more than 600 Bq ^{137}Cs·kg^{-1} w.w. This figure may be compared to the maximum reported mean values of less than 80 Bq·kg^{-1} in marine fish during the peak period of the nuclear bomb tests. Recent measurements in fish from the Barents Sea show values well below 10 Bq·kg^{-1} w.w. (P. Strand, pers. comm. 1993).

Evidence from the time of nuclear bomb testing and the situation following the Chernobyl accident indicate that the marine environment is less vulnerable to radioactive contamination than freshwater and terrestrial environments. As an example, following the Chernobyl accident, Gunnerød et al. (1990) reported average radiocesium values (^{134}Cs and ^{137}Cs) above 1500 Bq·kg^{-1} w.w. in brown trout *(Salmo trutta)* and arctic char *(Salvelinus alpinus)* caught in several high-altitude lakes, while radiocesium values in wild reindeer muscles ranged from less than 10 000 to more than 50 000 Bq·kg^{-1} w.w. These figures may be contrasted with those of less than 80 Bq·kg^{-1} w.w. for marine fish during nuclear bomb testing and those following the Chernobyl accident, when marine fish scarcely registered any contamination.

Measurements of Barents Sea sediments (Sværen and Føyn, 1992) are presented in Figure 6. We have included in the figure supposed areas for discharges of liquid radioactive waste and supposed dumping sites for solid radioactive waste. (OPRF, 1993). The areas and points for the alleged dumping are indicated according to unofficial sources. The amount of dumped waste is even more unclear, but there seem to have been dumpings every year from the 1960s until at least 1990 (OPRF, 1993). At some locations, the radiocesium values are reported to be above 100 Bq·m^{-2}. Figure 6 indicates that the area northwest of Novaya Zemlya is more contaminated than the rest of the Barents Sea. The very low values reported from points close to stations showing high values is due to differences in the texture of the bottom sediments, i.e., coarse sediments and little sedimentation give low values (Sværen and Føyn, 1992). The greater level of contamination found northwest of Novaya Zemlya is probably the result of the bomb tests near the sea surface in the 1950s and 1960s. However, the fairly low level of contamination in sediments at most locations indicates a rather modest radioactive contamination of the Barents Sea.

Unverified information on the possible dumping of huge amounts of radioactive waste from the former Soviet Union in the Barents and Kara Seas resulted in public concern. A joint Norwegian-Russian expedition to the Kara Sea was carried out both in 1992 and in 1993. The main results from the 1992 expedition are as follows (Føyn and Semenov, 1992; Ministry of Environment, 1993): 1) the radioactive contamination in the southeastern Barents Sea and the Kara Sea is mainly due to atmospheric fallout, including that from the Chernobyl accident, discharge from Sellafield, and runoff from the rivers Ob and Yenisey; 2) contamination levels in water were 3–22 Bq·m^{-3} for ^{137}Cs, 3–12 Bq·m^{-3} for ^{90}Sr, and 2–21 Bq·m^{-3} for $^{239/240}$Pu; 3) in sediment samples from the Kara Sea, the ^{137}Cs level in the upper 10 cm was 120–150 Bq·m^{-2}, and for $^{239/240}$Pu, the level was 2–24 Bq·m^{-2}; and 4) the level of radioactive contamination in the Kara Sea is clearly lower than in the Baltic Sea, the Black Sea and the North Sea. There were no indications of any influence from the dumped radioactive waste.

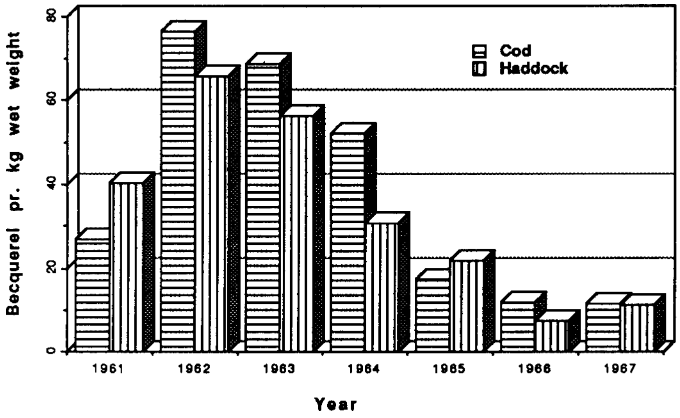

FIG. 5. Mean value of radioactivity in cod and haddock from the Barents Sea 1961–67, expressed as total beta-activity minus the potassium -40 activity.

During the 1993 expedition, two of the actual dumping sites were investigated. These were the fjords Stepovogo and Tsivolki on the eastern coast of Novaya Zemlya (Føyn and Nikitin, 1993). The preliminary results based on ^{137}Cs measurements indicate that the level of radioactive contamination is low. Even samples taken close to the dumped reactors from the icebreaker *Lenin* and several nuclear submarines gave no indications of any elevated levels.

On 7 April 1989, the nuclear submarine *Komsomolets* sank in the Norwegian Sea approximately 185 km southwest of Bear Island. The geographical position of the wreck site is 73°43′16″N, 13°15′52″E where the bottom depth is 1658 m (Fig. 6). The submarine had nuclear propulsion, and its armament included two missile torpedoes with nuclear warheads (OPRF, 1993). From information on the power generated by the power plant of the *Komsomolets*, experts estimate that the reactor core contains approximately 1.55·10^{15} Bq of ^{90}Sr and 2.03·10^{15} Bq of ^{137}Cs. The radioactivity of its warheads from their ^{239}Pu content is approximately 1.6·10^{13} Bq. While ^{239}Pu is mostly insoluble in water, the two other isotopes, ^{137}Cs and ^{90}Sr, dissolve and will be dispersed in the oceanic water masses if they are exposed to seawater. So far, however, there are no indications of any radioactive influence from the submarine (Blindheim et al., 1994).

Insoluble ^{239}Pu will settle in the sediments and remain in the vicinity of the wreck. Recently, a Norwegian study was carried out on the most likely pattern of the distribution of radioactive elements if a leakage from the wreck occurs. On the basis of hydrographic observations, current measurements and numerical models (Blindheim et al., 1994), the study concluded that the distribution of possible radioactivity will be along isopycnic surfaces. The radioactive components will be spread by the pulsating current in the area, but they will remain in the deep waters and gradually be diluted as they are dispersed from the source. It is not likely that watermasses to any measurable extent will rise from the depth of about 2000 m to the surface. If they do, the radioac-

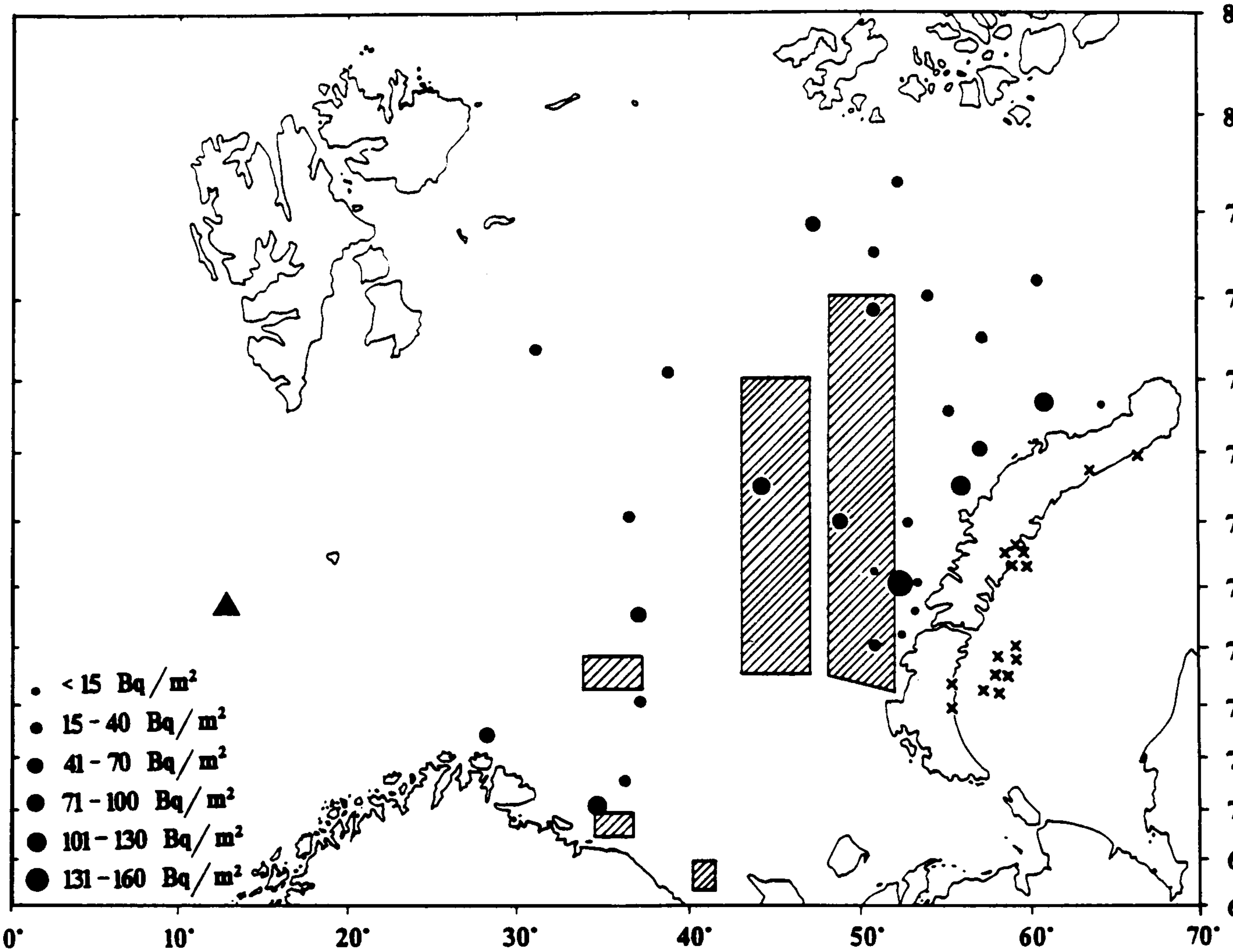

FIG. 6. Caesium-137 values in sediment samples from the Barents Sea and areas and sites of supposed discharges and dumpings of radioactive waste. × = supposed areas for dumped solid radioactive waste; ▨ = supposed areas for dumping of liquid radioactive waste; ● = sediment samples collected October 1991 (Sværen and Føyn, 1992); and ▲ = wrecked nuclear submarine *Komsomolets*.

tivity concentration will be only a small and insignificant fraction of the concentration near the wreck. The radioactive components will therefore gradually be dispersed in the deep water masses of the Nordic Seas and the Polar Ocean, and will not enter into the Barents Sea.

Climate Change

In recent years, a possible change in the global climate due to the increase in the atmospheric CO_2 has been of great concern. The climatic response to this increase is unclear in climate prediction models. This is especially so in the Arctic because of uncertainty about the different feedback mechanisms between ocean, ice and atmosphere. A scenario applied by the Norwegian authorities for studies of possible consequences of climatic changes is the following (Øiestad, 1990):

During the next 40 years, the contents of atmospheric CO_2 will be doubled. This increase will result in an increase in air temperature in Norway of 3° to 4°C during winter and about 2°C during summer. For the Arctic the uncertainty depends on the degree of melting of the polar ice. The knowledge and insight needed to predict probable developments in the Barents Sea are emerging from studies of the biological response to previous climatic variability.

Climatic variation in the Barents Sea depends mainly on the flux of water and heat in the inflowing Atlantic water. Figure 7 shows a three-year running mean of the temperature conditions observed in Kola-section (along 33°30′E) by the Russians. Cyclic variations of 3 to 5 years have been proposed by several authors (e.g., Kissler, 1934; Lunde, 1965). Loeng et al. (1992) analysed several time series from the Barents Sea and found periods varying from 2.8 to 17.5 years.

The large temperature variations influence biological conditions. The timing of major inflow events in relation to the seasonal vertical migration of *Calanus finmarchicus* in the Norwegian sea determines whether the inflowing water is poor or rich in zooplankton. Variability in the Atlantic inflow is therefore important in explaining the large inter-annual variations in the zooplankton biomass in the southern Barents Sea (Skjoldal and Rey, 1989).

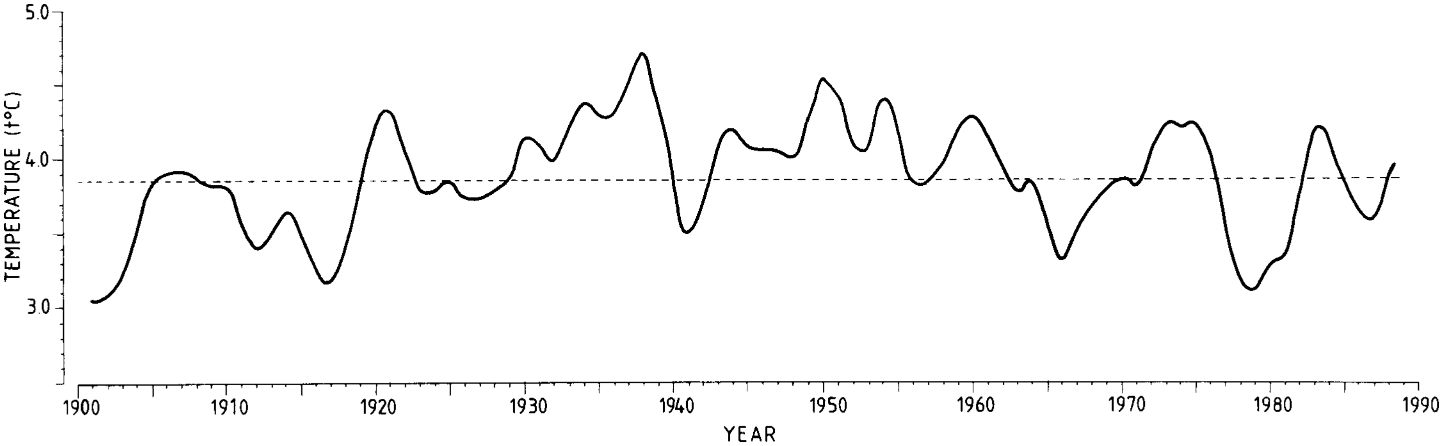

FIG. 7. Three years average of yearly temperature in the Kola section (along 33°30′E) during the period 1900–90 (Loeng, 1991).

The Barents Sea is a marginal area for several fish species. It is therefore likely that changes in the climatic conditions strongly influence the distribution of the fish, as well as recruitment and growth (Loeng, 1989). Immature cod make seasonal migrations in the Barents Sea (Maslov, 1968). In addition there are temperature-related changes in abundance on both small and large time and space scales. All the studies so far demonstrate a clear westward shift in the distribution of young cod year-classes in periods with decreasing temperature (Eggvin, 1938; Hylen et al., 1961; Midttun et al., 1981; Boytsov et al., 1987; Shevelev et al., 1987). Large-scale changes of water temperature also seem to generate a significant displacement of the capelin distribution. During warm periods, capelin are found to reach the northern extremity of their distribution area whereas in cold years, capelin are distributed more to the southwest.

The recruitment of commercially important species also seems to vary with temperature changes. Sætersdal and Loeng (1987) concluded that Barents Sea cod year-classes of high and medium abundance are directly associated with positive temperature anomalies in the early part of a warm period when the feeding areas are expanding. As an example, the mean yearly production during the warm period 1970–76 was three to four times higher than in the cold period 1977–82. Herring and haddock also seem to have their best recruitment in warm years (Sætersdal and Loeng, 1987).

Nakken and Raknes (1987) clearly demonstrated that young cod had higher growth rates with an increase in temperature. Loeng (1989) showed that the length of 3-year-old cod decreases from west to east parallel with the temperature decrease. Also capelin seem to have the best growth in the areas where temperature is highest (Gjøsæter and Loeng, 1987).

Øiestad (1990) used this insight into the variability of the Barents Sea ecosystem to evaluate the consequences for fisheries and aquaculture of a steady increase in temperature over the next 40 years. His evaluation is based on two suggested scenarios: one giving an increase of the annual mean sea temperature of 1°C and one giving an increase of 2°C. With either scenario, Øiestad speculated that, in the Barents Sea, larger areas will be free of ice and consequently total biological production will increase. Species such as cod, herring and capelin will increase their populations to a level comparable with historic maximum values. The total fish biomass may be three times that of today. The pattern of fish distribution will change also. For example, the spawning area of capelin may shift from the coast of northern Norway and Kola to the coast of Novaya Zemlya.

The great uncertainty of these prognoses, however, should be stressed. Increased melting of the polar ice and thereby a fresher surface layer may reduce the formation of deep- and bottomwater in the Nordic seas. Such a development could reduce the Atlantic inflow to the Nordic Seas and thereby decrease the sea temperature in the northeast Atlantic Ocean. This could cause unexpected collapses in the fish populations.

THE NECESSITY OF RESEARCH AND MONITORING

Since arctic ecosystems are specially vulnerable to anthropogenic influence, they need a higher degree of protection and surveillance. At a Ministerial Conference of the eight arctic countries in Rovaniemi, Finland in June 1991, “A Strategy for Arctic Environmental Protection” was adopted. Among its general principles and objectives, the strategy promoted the development of an Arctic Monitoring and Assessment Programme (AMAP). An AMAP Working Group was set up at the first meeting of the member countries in Tromsø, Norway in December 1991.

The major aim in AMAP is to monitor the levels of anthropogenic contaminants in the arctic environment and assess the environmental conditions of the area (State Pollution Control Authority, 1993). This work includes studies on the biological effects of contaminants on arctic ecosystems and human health. To monitor the levels of pollutants, high quality measurements will be essential. The components to be measured will include radionucleides, heavy metals, persistent organic contaminants, various atmospheric gases and areosols, and various biological and physical parameters. Models will be used to complete the knowledge gained from measurements. In addition, studies on climate will be included in the program. The data obtained will be used as a major source of information for the preparation of an environmental assessment of the Arctic to be ready in 1997.

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