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The chemical pollution status of the North Sea

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Abstract
Of the many seas in the world the North Sea ranks high in several respects; the number of different countries that can potentially affect its quality and the range of activities and fisheries it supports being but two. Not surprisingly therefore there is considerable public and official interest in the quality and status of this important sector of the marine environment and the influence man's activities may be having on it. The paper will review what is known and understood about the chemical quality of the North Sea and examine the extent to which this information supports some of the claims that the North Sea is heavily polluted and in serious danger of irreversible damage. The paper will also assess the present trends, and those likely to occur in the future, of both inputs of chemical contaminants and their effects. This section will pay particular attention to what is known and what it is desirable should be known and how this might be achieved. The bulk of the material used for developing the paper will be drawn from that available to the author through his involvement in ICES and GESAMP activities. The paper will conclude with a few personal views of the author on the true present chemical status of the North Sea and the possible future changes in popular conceptions of the area in relation to man's well-being.

Introduction
This lecture is one of a series marking the 100th anniversary of the Danish Institute for Fisheries and Marine Research. I feel very honoured to have been invited to speak on such an occasion and to such an audience.

I say this because the record of the Institute's involvement in North Sea scientific research is a long and honourable one. That tradition continues and the last few years Danish scientists have played an important part in investigations of the state of the North Sea from a chemical pollution standpoint. The extent of public interest in Denmark concerning the state of the marine environment is, I know, very acute and it has clearly played a major role in actions taken by your government.

The fact that on some occasions such action has been taken without sound scientific justification, and even occasionally contrary to the scientific facts, must however be a warning sign to scientists at the Institute that they cannot rely entirely on past performance records. They, and indeed all the scientists working on North Sea problems, must endeavour firstly to have ready their answers to the public and politicians' concerns, and secondly to be able to put them across clearly. I hope that this lecture will give you an idea of what we do know about the chemical pollution status of the North Sea, what we don't know, and perhaps an idea of what are some of the important issues for the future.

Reasons for concern

The North Sea is one of the most intensively used seas in the world. It is bordered by seven of the most developed countries of the world, eight if we include the Skagerrak and your neighbour Sweden. Some 21 million people live around its shores, or very close to them, and millions more spend a substantial part of their recreation time close to the sea or on it. The North Sea also supports a highly productive fishery, yielding a record catch in 1974 of 3.44 million tonnes but regularly yielding around 2½ million tonnes or about 3.5% of the world total catch of fish. The closeness of the public's association with the sea and the fact that Denmark alone takes about 50% of the total fish catch, no doubt explains the acute interest of the Danish people in the well-being of this sea. Is there then justification for public concern?

The environmental groups would respond to such a question by pointing out that the North Sea is the scene of an extensive offshore oil and gas industry, that it is heavily used by commercial shipping (300+ ships per day through the Channel) and that both activities lead to waste inputs to the sea. In addition they would note that sewage from most coastal communities is discharged to the sea, a significant proportion of it without treatment, and that industry also discharges its effluent to the sea. They would certainly mention that at least one country dumps quantities of sewage sludge and industrial wastes in the waters off its coast and that most countries still make use of the services of incineration vessels that burn chemical wastes at sea. They may even remind us that all the countries dump dredge spoils at sea. They would argue that all of these activities are bound to affect the well-being of the sea. They might also point out that a number of large rivers discharge to the North Sea and that, as many of these are seriously polluted, this simply adds to the burden and makes matters worse. All of this sounds very reasonable but they would probably be quite hard put to list many actual effects that are clearly attributable to these terrible assaults on the environment.

The counter argument would be put that the North Sea is a very large sea and that compared to its overall volume, inputs by rivers, industrial and sewage effluents are small. This fact coupled with the fact that the North Sea as a whole has an average flushing time of only 6 months (the German Bight is longer at 36 months), must mean there is plenty of capacity to dispose of any waste man introduces. Also relevant is the fact that much of the contaminant load carried by rivers is of purely natural origin. All these points, it would be suggested mean that there can surely be little cause for concern, and the fact that the sea continues to support a productive fishery and is far from dead, proves this.

The poor scientist is in the middle. Common sense and his scientific training, plus his observations, tell him that to some extent both parties are correct but neither of them totally so. Let us then look at a few facts.

North Sea volume, inputs, their origin and effects

The North Sea certainly is quite a large sea, it has an area of approximately 525 000 km^2 and an average depth of 90 m adding up to a volume of about 47 000 km^3.

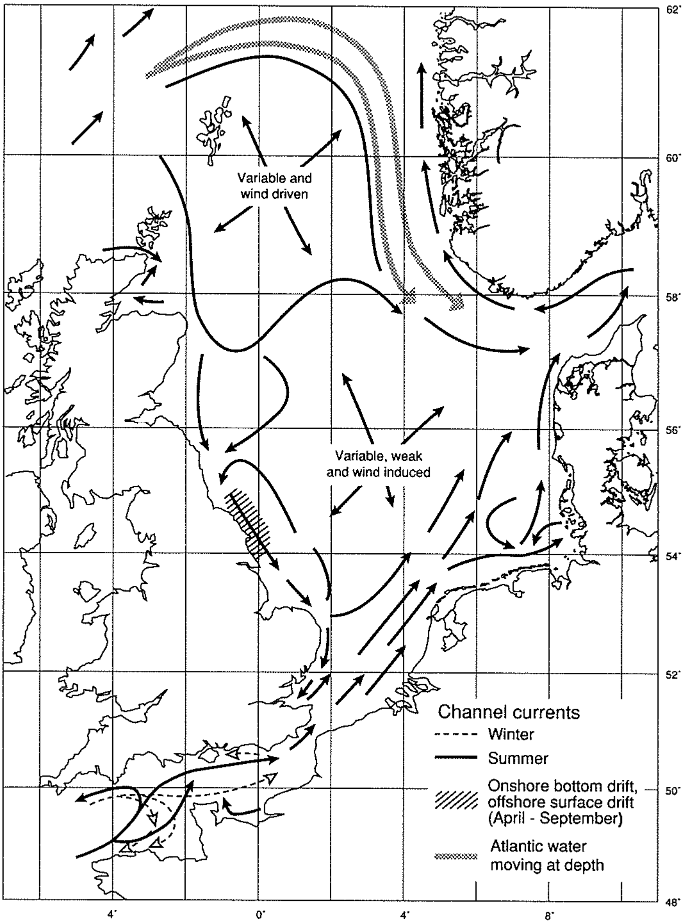

Fig. 1. Current system of the North Sea.

Compared to this the annual river input is indeed small, a mere 200 km^3 on average but the majority of this input comes from relatively few sources, the Rhine and Elbe in particular accounting for about 95 km^3 with the Thames, Scheldt, Ems, Humber, Weser, Tyne and Tees accounting for a substantial part of the rest (31 km^3). An important feature to note in this connection is the way in which these rivers discharges behave when they enter the sea (Fig. 1). They do not mix with the entire volume of the North Sea. The inputs by the major mainland rivers (Rhine, Scheldt) generally stay close to the Dutch coast and join the Elbe, Ems and Weser inputs to circulate around the German Bight before moving north up the Danish coast, through the Skagerrak and eventually out of the area via the Norwegian coastal current. The inputs from the British rivers stay close to the British coast initially and then, on being caught up with the Channel inflow water are swept along the mainland coast being diluted in the process. Because of the low salinity water from the Rhine and other rivers imposes a physical barrier they do not directly impact the European coast, although clearly some diffusion across that boundary does occur.

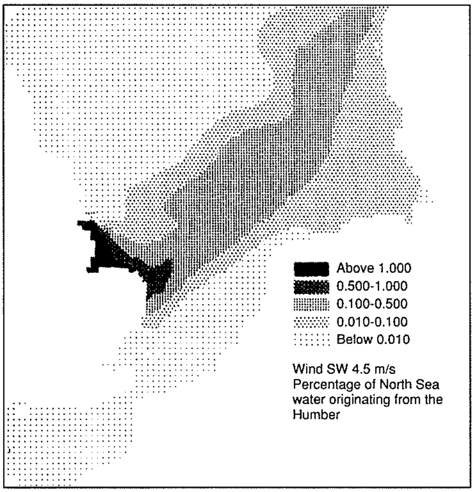

Fig. 2. Calculated spreading and dilution pattern of the river Humber.

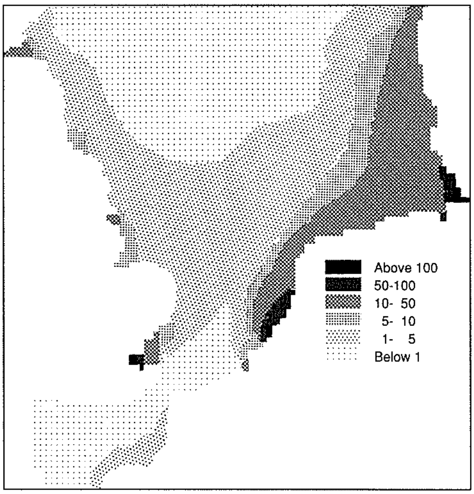

Fig. 3. Calculated distribution of concentration (arbitrary units) resulting from 10 continuous sources of passive dissolved tracer. Model characteristics: vertically integrated steady state, forcing by tides and constant wind, diffusion parameterised using eddy diffusitives.
Weighting: Rhine/Meuse 52%, Elbe 13%, Firth of Forth 6%, Tyne 6%, Weser 5%, Scheldt 5%, Thames 4%, Seine 4%, Humber 3%, Ems 2%.

This is illustrated particularly well in Figs 2 and 3. Fig. 2 shows the picture one obtains with a rather simplistic model which assumes: full conservative nature of the substance in question and only one source of input on the UK side. Fig. 3 shows a similar picture with inputs of similar concentration but different volume based on the relative size of the rivers concerned. Of course these are average conditions and as Professor Backhaus' lecture has explained these do not necessarily always apply. It is for example postulated that at certain times the formation of the Flamborough Front, a density discontinuity off the NE coast of England, can lead to the formation of the Flamborough Jet, which in effect squirts water directly away from the UK coast and this must impact the central North Sea at the very least. Equally the Rhine discharge can on occasions depart from its normally northward flow and take a trajectory due west and affect the UK coast.

The final point to note of course is that few pollutants are truly conservative most do not move entirely in dissolved form but are adsorbed to a greater or lesser extent on suspended particulate matter. In such situations it is the movement of the particulates that dictates their fate. We know little about how such distributions operate but we do know for example that sedimentary processes within an estuary can account for the removal of substantial percentages of the freshwater input load of certain metals. We are slowly learning more about the importance of such factors through field experiments, modelling and observations of concentrations of particulate pollutants in sediments. We have recently learned for example that there are higher than usual concentrations of pollutants in the sediments around the Dogger Bank and in the number of other areas of fine sediment deposition.

As Figs 2 and 3 illustrate inputs can be shown to spread over substantial areas of the North Sea, but in a far from equal way. The concentrations in these figures are for conservative substances and are given in arbitrary units, they also assume that the natural concentrations are zero. This of course is not the case and it is therefore important that we look at what actually happens to the concentrations, i.e. what measurable impact do these inputs actually have. Table 1 shows the average concentration of six metals commonly considered to be pollutants. The extent to which their concentrations are altered by coastal inputs clearly differs: mercury and cadmium show little change, at least in the central North Sea, but the concentrations of all the metals in the coastal waters both off the UK and Netherlands are clearly markedly elevated, especially those of zinc and lead. However, it has to be stated that even the highest concentrations are well below the concentrations regarded as likely to be harmful to marine species.

Table 1. Concentrations of dissolved metals in sea water (μg/1).

Metal	Average Ocean	UK Coast	Central North Sea	Netherlands Coast	German Bight
Cadmium	0.01	0.03	0.02	0.10	0.05
Mercury	0.001	0.01	0.001	0.01	0.01
Copper	0.10	0.30	0.20	0.60	0.60
Nickel	0.2	0.7	0.3	1.0	0.8
Zinc	0.1	4.0	0.6	5.0	2.0
Lead	0.003	0.05	0.03	0.05	0.05

However, even if the concentrations in seawater are, in general terms, below levels set as standards it is clear that concentrations do differ from area to area. Data on seawater are not necessarily the best means of portraying this and recourse is often taken to the use of biological indicators as a means of concentrating the metal contaminants of interest. For this we have a fairly recent set of data, because in 1985 ICES, OSPARCOM and HELCOM jointly promoted a baseline study of contaminants in fish and shellfish from the North Atlantic and Baltic Seas. The greatest level of effort was exerted around the North Sea as Fig. 4 shows. Sampling was supposed to take place according to an agreed protocol and the samples of fish and shellfish were analysed for a range of metals and selected organics. The overall aim was to

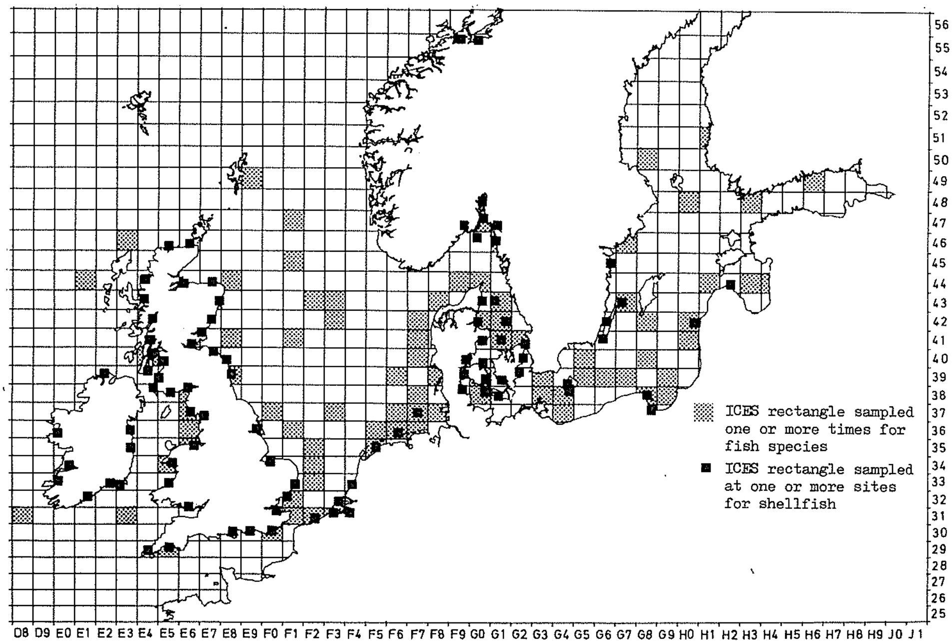

Fig.4. Areas sampled in the 1985 Baseline Study on Contaminants in Fish and Shellfish in northern European areas.

show the relative distribution of contaminants in biota and by this means to clearly identify any areas in which concentrations were unusually high. Of course the extent to which this was possible depended on the extent to which countries actually collected samples (Denmark for example collected no mussels) and the extent to which they collected them from areas likely to be contaminated. There was some suggestion that this did not always happen. Nevertheless the results do provide useful data. They broadly confirm the expectations we would have from seawater data and our knowledge of inputs, as Figs 5 and 6 show. Fig. 5 shows the levels of cadmium in mussels, the high concentrations in samples from the Rhine, Scheldt and from the Humber and Thames are not unduly surprising. Fig. 6 gives the picture for mercury in flounder and plaice and is a little different, but again the influence of coastal sources is obvious and the messages as to what to do equally apparent. That being said it should be noted that the concentrations found are not unduly high in relation to human health standards and that many of the mussel samples were collected from stocks of mussels that are not exploited for human consumption purposes.

The fact that concentrations are at present below those that might affect marine organisms or man might be reassuring, but such information on its own is no cause for complacency. Equally important is the question of what is happening in terms of trends in concentrations of these pollutants. For the metals the available data on concentrations in water clearly show that concentrations have declined over the last 20 years. However, such figures need to be treated with considerable caution. This is because in the period between the late 1960s/early 1970s and the present there

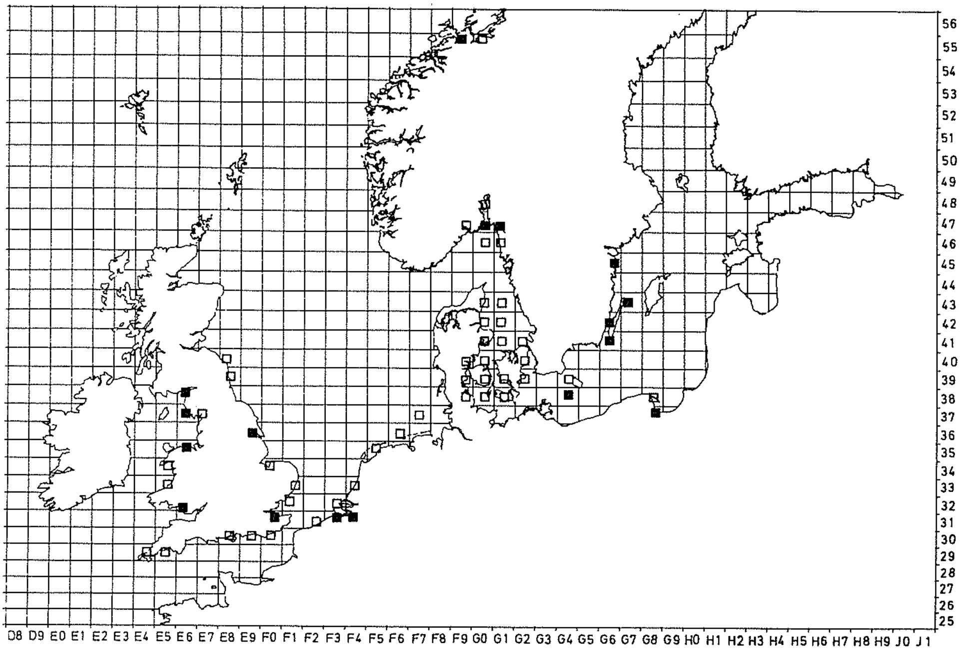

Fig. 5. Cadmium in shellfish, whole soft body (Q_{75} in mg/kg dw).

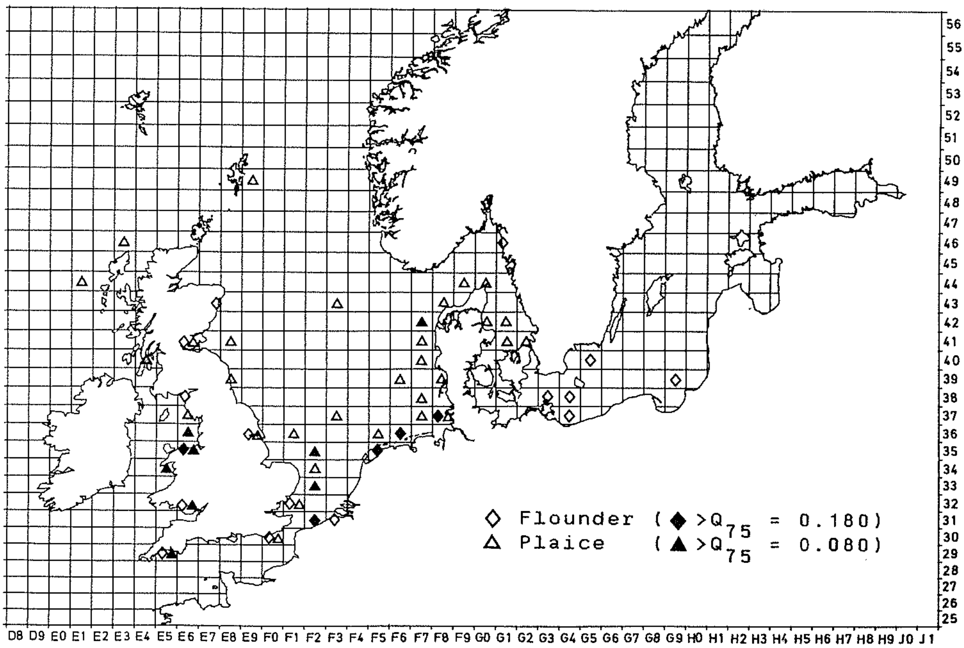

Fig. 6. Mercury in fish muscle tissue (Q_{75} in mg/kg ww).

have been considerable advances in the field of marine analytical chemistry, especially for metals. Most if not all of the earlier data, were subject to errors caused by contamination, either at the sampling stage or during analysis and it is therefore difficult to compare data directly.

Somewhat more reliable are some of the data for metal levels in fish and shellfish. Again there have been improvements in the methods used in the last 20 years and care must be taken in interpreting results. However, especially for those metals that are considered most likely to be harmful to man, i.e. mercury and cadmium, there have been genuine reductions in inputs and we can be fairly confident that the reduced levels we see in the environment do reflect the reductions in inputs that have been made. Fig. 7 relates to mercury in cod muscle from the Belgian coast and Fig. 8 relates to zinc in cod from the same area. Both figures result from recent analyses, by an ICES working group, of data sets supplied to ICES under their coordinated monitoring programme. The data sets used were not entirely consistent and this explains some of the variability but the overall downward trend is clear.

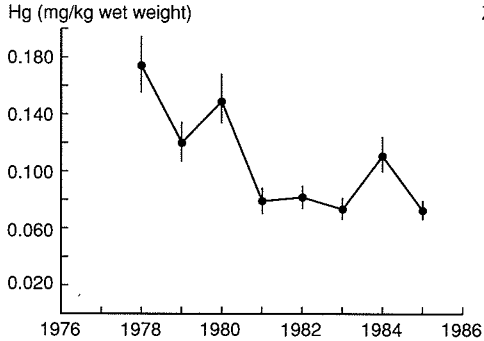

Fig. 7. (LA) Estimates of Hg in cod muscle – from area 31F2, see Fig. 4.

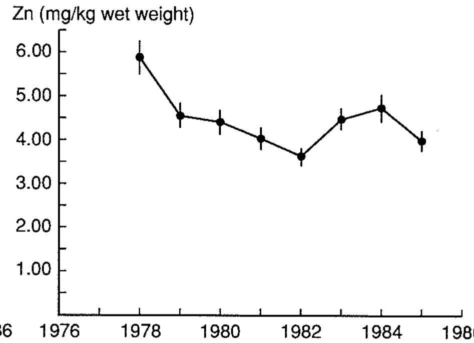

Fig. 8. (LA) Estimates of Zn in cod muscle – from area 31F2, see Fig. 4.

This then is the overall situation for metals. In summary one of probable general decline, some quite clear hot-spots but nothing, so far as we can see, that could give cause to human health problems or give rise to acute effects in marine organisms. The situation regarding organic contaminants is rather less clear but generally similarly reassuring, although there are local areas of concern. The concentrations of organics in seawater are very low and extremely difficult to measure on any sort of scale. Perhaps the only good data set exists for HCH which happens to be one of the more solubles of the organochlorine compounds. Fig. 9 is reproduced from the North Sea Quality Status report and is based on data collected by German scientists. It clearly shows the influence of mainland Europe as a source of HCH affecting much of the North Sea and it is worth noting here, if the rather crude contour lines are to be believed, that transport patterns of other purely water movements must play a part. It is interesting to speculate here that biological transport processes via fish migrations may be an important factor.

Because of the difficulty of analysing organic compounds in seawater much reliance has been placed on analysis of organics in biota and the 1985 baseline study

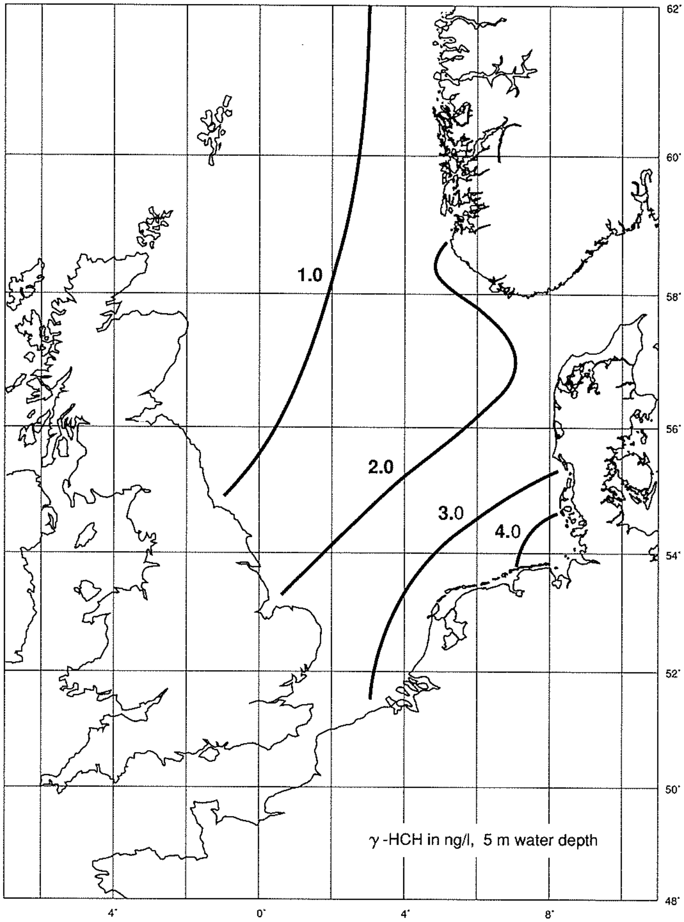

Fig. 9. Concentrations of γ-HCH in water (ng/l) in 1986.

mentioned previously, produced much valuable data in this context. Figs 10 and 11 are examples of the distributions that were observed. As with the metals no great surprises were encountered and the explanations as to sources are obvious. Again care in interpreting the data is required since it must be remembered that not all areas were sampled and, even more so than for the metals, the data were of variable quality.

The conclusions drawn from these data were that they present no risk to the human consumer. Since it is not known with certainty what levels pose a risk to fish, shellfish or other marine resources, no such clear statements can be made for marine organisms. Indeed it is apparent that in the Waddensea and Baltic seal stocks may be adversely affected by PCBs (note there were few data from this area from the baseline survey). However, the assessment of the results did lead to one slightly reassuring statement viz that it did seem concentrations in 1985 were generally lower than at the time of the previous baseline study in 1975 and that as a consequence, if marine organisms were at risk, the threat was a decreasing one relative to earlier times. This rather generalised statement is borne out by the data sets so far analysed by the ICES working group.

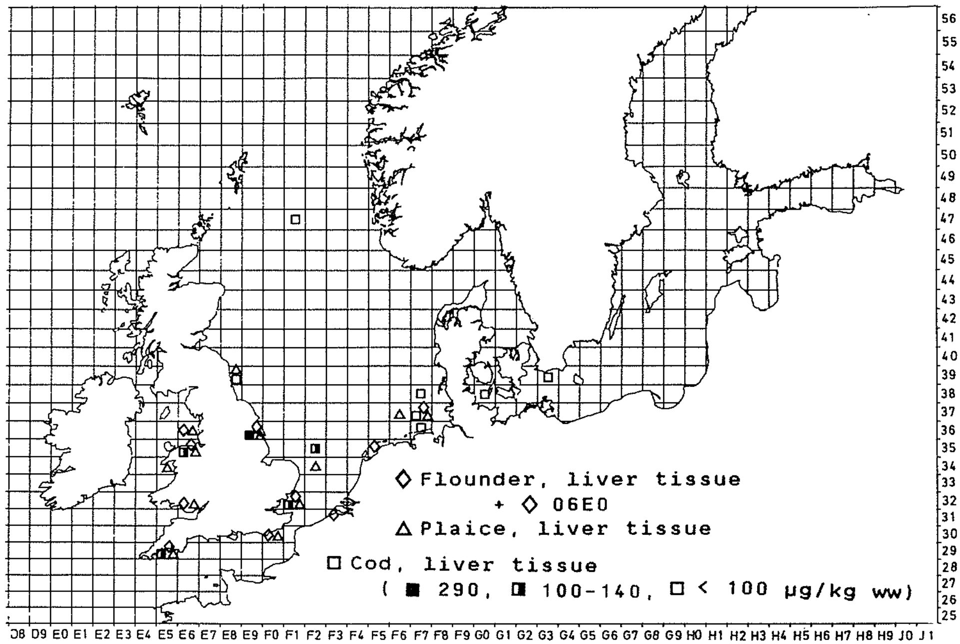

Fig. 10. Dieldrin in fish.

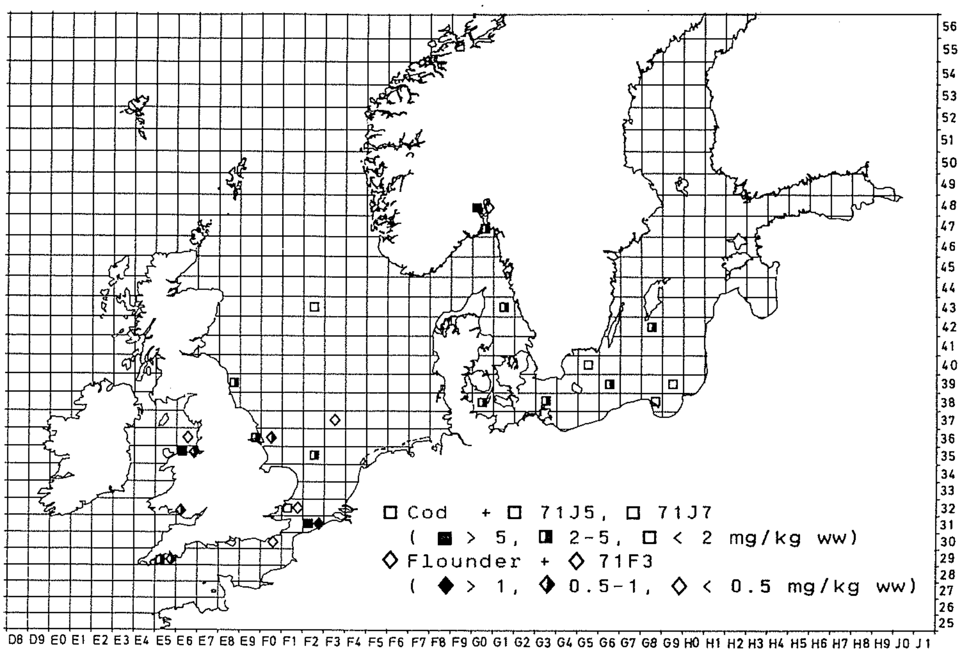

Fig. 11. PCB on a formulation basis in fish liver.

Of course the concentrations of contaminants are not all declining. As Katherine Richardson has indicated nutrients do give cause for concern and in some areas nutrient concentrations are on a rising trend or at least have risen and are staying high although this does seem to be an effect restricted to inshore areas. It must also be admitted that we do not routinely measure a wide range of organic substances and that the concentrations of some we do not measure at all may be harmful. Caution is therefore clearly indicated and it is obviously sensible to try to reduce inputs of substances wherever possible. This however calls for a knowledge of the main sources of inputs. There is clearly no point in spending vast sums of money reducing inputs of a particular substance from individual factories, if by far the greatest proportion of the input is via sewage or from the atmosphere or via land run-off.

Fortunately we do have a good idea of what the main sources of input are, at least for the majority of the main substances in which interest is commonly expressed.

Table 2. Phosphorus and nitrogen inputs to North Sea by source (percent of total).

Source	Nitrogen	Phosphorus
River input	66.4	73.2
Atmosphere	26.5	? (small)
Sewage sludge	0.8	2.7
Direct discharges	6.3	24.1

Table 2 shows the relative contributions of nitrogen and phosphorus via the main sources of input. Note that in both cases the main source is river input, but that for nitrogen, the next largest source is the atmospheric input, whereas for phosphorus the second main source is direct discharges mainly of sewage. For mercury and cadmium the available data (Table 3) suggests that the atmospheric input route accounts for about two thirds of the total input. As would be expected, direct inputs of sewage sludge, industrial waste and incineration are very small sources but river inputs and dredging inputs (much of which is recycles and not really a true input) are both significant. A similar picture is shown in Table 4 for the List 2 metals (copper, zinc, nickel, lead etc.) although for these the atmosphere only accounts for about 42% of the total input, compared to 66% for cadmium and mercury.

Table 3. List 1 metal inputs to North Sea by source.

Source	Quantity tonnes	Percent
Atmosphere	270	66
Rivers	73	17.8
Dredging	37	9.0
Direct discharges	25	6.1
Sewage sludge	3.6	0.9
Industrial waste	0.5	0.1

Table 4. List 2 metal inputs to North Sea by source.

Source	Quantity tonnes	Percent
Atmosphere	21970	42.6
Dredgings	14400	27.9
Rivers	10940	21.2
Direct inputs	2480	4.8
Industrial sources	1270	2.5
Sewage sludge	475	0.9

In relation to these data, which were taken from the 2nd North Sea Conference Quality Status report, the comments of the ICES Advisory Committee on Marine Pollution are important. These were to the effect that very considerable reliance was placed at that time on the quality of the data then available. In fact the only really reliable data were those for dumping inputs. The ACMP stressed that considerable doubt was centred around the estimates of atmospheric inputs which were based on few measurements of either concentrations or deposition volumes. They also expressed some caution over the quality of the river input data. Efforts are now in hand to improve the quality of both sets and the preliminary data from the atmospheric input programme suggest that the earlier estimates were indeed high, perhaps by as much as 2-4 fold. If this is confirmed it will shed a rather different light on the sources that we should control. It should also be remembered that the atmospheric source spreads roughly evenly over the whole North Sea and has as a consequence a lesser impact than a point source such as a river.

In addition to these data for total inputs the main individual point sources of most contaminants are known, and the extent to which they are likely to be controllable can therefore be assessed.

Uncertainties

As indicated previously with very few exceptions the data on concentration effect relationships are such that there is no cause to suspect that present rates of input of the substances recognised as potentially dangerous are actually likely to cause problems for either marine organisms or even to man.

Those words were chosen with care, they refer only to substances we recognise as potentially dangerous. As indicated previously we certainly do not look at all the substances that reach the environment. Nor do we have as complete a knowledge of concentration effect relationships as perhaps is really necessary. Certain effects and substances do catch us unawares. Two such instances can be given as examples, TBT and the effect it had on oysters and the discovery that dioxin seems to attain unusually high concentrations in species such as crabs caught close to particular forms of industrial input. You may also perhaps think of fish disease and the suggestion that this is induced by exposure to low levels of pollutants. Dr Dethlefsen will discuss this question in some detail later but there does indeed seem to be something in this allegation, although it is clear that not all diseased fish have been affected by pollution.

The conclusion one must draw from this is that caution is necessary in considering both the existing state of our knowledge and in allowing inputs of substances to the marine environment. On the other hand there is no need for panic. The evidence we have is that inputs of at least the traditional pollutants have declined and are continuing to decline. In the worst affected areas concentrations in biota are falling and, perhaps most encouraging of all, there are clear signs of recovery in the range of marine organisms one finds in such areas. We are, admittedly as a result of some of the painful lessons we have learnt, in a good position to recognise those new substances that are most likely to enter the marine environment and cause harm. We can now use Quantitative Structure Activity Relation (QSAR) approaches and other predictive tools and they are becoming increasing well tested and acceptable.

We also have available to us a growing range of biological effect techniques that detect sublethal responses of a whole variety of marine species to pollutant stress. Whilst we do not necessarily all agree that such effects actually indicate harm we can all accept they indicate a stress and as such are warning signals. A wide range of these techniques is to be put to the test next year in an ICES workshop which will examine their ability to detect one or more of three gradients in contamination levels in the North Sea. Thus whilst there remain uncertainties there is plenty of justification for optimism; the North Sea is far from dead, it remains dynamic and productive. The danger signs at a few of the coastal margins have been noted and action has been taken to prevent them getting worse. Moreover, through the general acceptance of the precautionary approach, we have good cause to expect to be able to prevent deterioration through the excessive input of new potentially damaging substances.

A look to the future

Those last few statements might be regarded as a convenient point on which to close, instead I would like to conclude my lecture by looking beyond the next few years to a rather more distant future and what I hope will be an improved understanding of our marine environment and particularly the North Sea.

There are those who either uncritically allege that the North Sea is under severe threat or equally uncritically accept all such statements. Such people argue that the precautionary principle means no waste material should enter the sea and that every possible effort should be taken to ensure this goal is met. Such aims are simply impractical nonsense, in both the short term and long term. Nobody seriously expects our modern society to volunteer to revert to the neolithic or cave man type of society (or its level of human population of this earth). We have grown not just to like, but to depend upon, much of our existing social, industrial and agricultural systems. In the latter case at least, alteration of the environment in a managed way is accepted. True with modern technology we do not need to waste resources to the extent we did in the past and both production technology and effluent treatment technologies can be devised to reduce waste arisings.

However, you do not get anything for nothing; wastes will continue to arise whether they be sewage sludge from treating sewage effluents to tertiary standard or the effluents or solid residues from full treatment of industrial waste materials. In short there will always be something to dispose of. At present the tendency is to argue that these materials may be damaging to the marine environment and must therefore be disposed of on land. Here one should pause for thought. The sea covers 4/5ths of the earth's surface and only a proportion of the remaining 1/5th is accessible to Man and an even smaller part can be utilised for waste disposal. The inevitable consequence is that if harmful effects may occur in the sea they are even more likely to occur on land. Remember the pathway to Man from the land is much shorter than that from the sea. It is surely even possible that whereas disposal to sea may have no adverse consequences at all, waste disposal on land might actually have disastrous consequences for terrestrial flora and fauna, or even for Mankind itself, e.g. through poisoning of our potable water supplies from stored waste depositories or through contamination of the land affecting long-term agricultural success, whereas disposal to sea may have no adverse consequences at all.

This should not be taken as a plea to allow free range for waste disposal at sea. I fully support a precautionary principle that says avoid excessive inputs and try to understand in advance the consequences of one's actions and monitor them thereafter. I also fully accept the sea is an international resource. What I am anxious to promote however is an acceptance of two concepts. First that at some time in the future, waste disposal will have to be looked at holistically and not on a sector exclusive basis, and second that the sea does have a role to play if we are cautious, consider the consequences before acting and check on them as a matter of course. Remember our predictive abilities are improving, as are our abilities to test for and detect danger signals, both in the laboratory and under field conditions. We should build on the knowledge and exploit it sensibly. Let us genuinely use what we know to define safe limits and protect our overall environment and not the salty water compartment to the detriment of all else.

We now know a great deal about the seas and of their quality. Unless a goal can be looked forward to within a few years that involves utilising our improved and improving understanding of the seas, most good marine scientists will be disillusioned by what they see as a lack of purpose for their work.That could be serious if the consequences are that, when the need for land or atmospheric protection becomes paramount, the sea will again suffer because we are either unable to define safe limits, or have forgotten how to recognise the danger signs, because work in these areas ceased when there seemed no use or support for it.