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Fish in the polluted North Sea

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Abstract

During the last two centuries aquatic environments in Europe experienced a progressing state of pollution. With the beginning of the industrial revolution severe impact of pollutants on the stocks of fishes and benthic organisms were demonstrated in all major North Sea estuaries. Open North Sea areas including coastal zones were generally thought to be not influenced until the end of 1970. Reports indicated low dissolved oxygen concentrations in German and Danish coastal waters impacting fish abundance and distribution and reports on high prevalences of diseases of fishes, especially the flatfish dab (*Limanda limanda*).

Between the time of the first detection and today intensive epidemiological studies of fish diseases have been carried out in the North Sea. The major results were: high prevalences of externally detectable diseases and liver abnormalities in flounder and dab. Increased infection rates were not restricted to onshore waters. Present studies indicate increased disease levels in the whole of the North Sea.

In the North Sea certain hot spots of exceptionally high disease prevalences were encountered; the German Bight, the Dogger Bank, and Dutch, Danish and English coastal waters. Also in areas far offshore increased disease prevalences were found. High contamination levels were found in dab in areas of high disease prevalences, although no simple relationships seemed to exist. The disease prevalences are interpreted to be a deviation from normal. The interpretation whether they are anthropogenically caused or not is at present disputed and will be a matter for discussion in the future. This is due to the fact that causes for diseases are multifactorial and can exclusively be natural. On the other hand many of the known anthropogenically introduced contaminants occurring in elevated levels in the biota of the North Sea have the potential to trigger the diseases mentioned.

A number of studies have been conducted to investigate the impairment of pollutants of the reproductive capability of North Sea fish species. Two approaches have been followed:

1. The correlation between the contamination of gonads in certain fish species and the quality of their offspring has been studied. It has been found, especially for whiting (*Merlangius merlangus*) and other species, that the contamination with certain organochlorines including congeners of PCBs and DDE were correlated with a reduced quality of the offspring. It could be shown that a certain percentage of the population of the fishes studied were contaminated beyond a level where an impairment of reproduction was detectable.

2. Malformation rates of free living pelagic fish embryos were investigated in Dutch, Danish, and German coastal waters. It was found, that in the centre of the German Bight and off the Dutch coast high malformation rates of fish embryos were detectable. These malformations were found to be fatal for the individuals. The studies have also been performed in areas outside the North Sea with similar results. It is therefore concluded that an impact of pollutants on the reproductive capability of fishes is demonstrable, but its impact of stock size is unknown. Since many of the biological deviations regionally and in time coincide with what is known on contaminant levels it is the expressed will of the governments of many North Sea states to reduce concentrations of contaminants.

Introduction

Generally pollution of the environment is thought to be a result of recent human activities. Sediment cores, however, prove that significant contaminant loading of the environment occurred after the onset of the industrial revolution, beginning in the middle of the last century. Then concentrations of lead, mercury, cadmium, and zinc surpassed biochemical background by factors of ten, eight, seven and four. In the upper layers of sediments further recent drastic increases of the contamination could be detected (Förstner & Reineck, 1974). The organochlorine contamination of sediments started to show elevated levels at the beginning of the 1940s, when concentrations of PCBs and DDTs reached a rapid plateau which did not change significantly shortly after 1940 (Müller *et al.*, 1980).

First man made impact on aquatic ecosystem occurred in rivers and lakes. Already at the end of the 18th century fishermen complained that the living conditions for fish in the river Elbe were progressively destroyed (Riedel-Lorjé & Gaumert, 1982). In the middle of the past century first indications of biological dysfunctions were to be recognized in major estuaries at the North Sea coast (for example Rees, 1984). Progressing from estuaries, enclosed or semi-enclosed marine areas like the Mediterranean and the Baltic were found to exhibit signs for deterioration. The chemical status of North Sea contamination is described beginning in the 1970s. Based on the wrong assumption, that contamination is a recent problem, and that, for example, biological deviations from normal, described around the turn of the century, are therefore to be considered to be natural phenomena. It was not prior to the early eighties that major biological dysfunctions, i.e. high prevalences of fish diseases, were reported to occur in the North Sea and discussed in relation to contamination (Dethlefsen, 1980).

In the following paper the information available on fish diseases in relation to pollution in the North Sea and on the impact of contaminants on the reproduction of fishes in the area is reviewed. The findings are discussed in the context of further ecological malfunctions, as expressed in plankton and benthic communities, and information on contamination of biota is provided as far as it is necessary to discuss biological effects.

Reactions of organisms to contaminant exposure

Organisms response to exposure to contaminant is unspecific. The physiological reaction triggered by contamination does not differ from that resulting from non-optimum environmental factors (Sindermann, 1984). Stressors are impacting hyperpthalamus reaction which either result in a breakdown of steroids or the production of adrenalin. Steroids play a role in reproduction of organisms and are important for the immune system. In a contaminated aquatic ecosystem it is therefore advisable to look for these two general dysfunctions: a) suppression of the immune system and b) impact on reproduction.

If these impairments are found in a natural environment, a certain plausibility for these influences to be caused by contamination is given but not in the sense of a cause effect relationship. Due to the unspecificity of these responses non contamination factors including biological and abiotic have to be included in the analysis.

Shifts of tolerance of organisms and populations

A general reaction of populations to stress including contamination is that the sensitive components of an ecosystem are eliminated. After a certain pollution history we are confronted with an adapted population able to cope with the actual pollution loads. The search for biological deviations from normal in such populations is unsuccessful, leading to the conclusion that pollution is significant. After the elimination of sensitive organisms due to contaminant exposure, the resulting population community is less sensitive towards pollution (Blanck *et al.*, 1988). This adaptation mechanism allows biological systems to survive in stressed environments. Even in some of the most contaminated European rivers stocks of fish maintain a relatively high biomass (Möller, 1988). Most of the organisms used for ecotoxicological investigations are taken from contaminated areas. This means from adapted populations with an increased tolerance towards pollution. Recent results of biological and biochemical investigations also in fishes revealed the presence of detoxification mechanisms, especially mixed function oxidases, which enable organisms to detoxify xenobiotics (Sindermann, 1984). The presence of these phenomena certainly leads to an underestimation of the degree of stress present in todays North Sea populations.

In the following part of the paper some of the information available on fish diseases and impact on reproduction of fishes will be reviewed. Both topics have been subject of a number of papers and were reviewed for example by Dethlefsen (1988a; 1988b; 1988c; 1989).

Fish diseases

Despite the recent upsurge of interest in the subject of fish diseases in the North Sea most of the phenomena described in recent papers are not new. In general, it can be stated that diseases are a concomittant of life and certain prevalences of diseased organisms belong to populations without representing a distress signal. Most of the disease phenomena presently encountered especially on dab (*Limanda limanda*) in the North Sea have already been described at the turn of the century by Johnstone (United Kingdom). In his reports he provides information on the histology of diseases of a number of different fish species (Johnstone 1912; 1924; 1925). Heron *et al.* (1988) re-appraised the Johnstone collection and confirmed his diagnosis in most cases. Unfortunately no quantitative data are available so that no conclusion is possible on prevalences of the disease phenoma around the turn of the century.

Systematic fish disease studies in the North Sea were initiated after 1977 in the German Bight, when high prevalences of externally visible diseases of dab (*Limanda limanda*) were detected to occur in the dumping area for wastes from titanium dioxide production (Dethlefsen, 1978; 1984). First studies of fish diseases in the open North Sea were done by Möller (1979), and in the German Bight and Danish coastal waters by Möller (1981). Dethlefsen (1984) and Dethlefsen *et al.* (1987) provided information on high rates of externally visible diseases of dab (*Limanda limanda*). The diseases described were lymphocystis, ulcerations, epidermal papilloma and hyperplasia, and others. They were described to occur in relatively high frequencies and it was the statement of Dethlefsen & Watermann (1980) that high disease rates within the centre of the German Bight might be related to pollution, especially to wastes from titanium dioxide production.

After these initial papers interest in fish diseases rose and studies were carried out in Thames estuary in the 1980s by Bucke *et al.* (1983), Scottish (Wootten *et al.*, 1982), and Irish waters (McArdle *et al.*, 1982). Authors of these papers considered their material to preliminary to come to a conclusion whether pollution plays a role in the outbreak of diseases. McVicar *et al.* (1987) studied fish diseases in the North Sea in relation to sewage sludge dumping. He positioned his control areas as close as half a mile next to a dumping area, and found indications for higher disease prevalences of dab in the control area. He therefore recommends to be extremely careful with the interpretation of the results. In none of these studies the contamination of the organisms, sediments etc. has been analyzed. The conclusions of the authors are therefore more or less based on assumptions on the degree of contamination of their areas and fishes studied. The same holds for the investigations carried out by Möller (1979; 1981).

To the disease phenomena not described by Johnstone belong pseudobranchial tumours of cod (*Gadus morhua*) (Watermann & Dethlefsen, 1982), hyperplasia in gadoid species (Watermann & Dethlefsen, 1985), x-cells in gills of dab (*Limanda limanda*) (Knust & Dethlefsen, 1986), and fin rot in various species including flatfish and gadoids in the German Bight (Dethlefsen, 1980). The diseases lymphocystis, ulcerations, hyperplasia, skeletal deformities, and fin rot have been found in more than one species (Dethlefsen, 1980). The species most frequently afflicted with externally visible diseases were dab (*Limanda limanda*) and cod (*Gadus morhua*). The diseases most frequently found on dab were lymphocystis, ulcerations, epidermal papilloma plus hyperlasia, and those most frequently encountered in cod were pseudobranchial tumours, ulcerations, skeletal deformities, and fin rot. Dab (*Limanda limanda*) was the species that most workers in the North Sea concentrated on during their studies. Frequencies of affliction of dab (*Limanda limanda*) with the most frequently occurring externally visible diseases from January 1987 to May 1989 are given in Table 1. The dominating disease during these studies was lymphocystis, followed by healed ulcerations and epidermal papilloma. An example for the regional distribution of these major diseases is given in Figs 1, 2 and 3. Highest prevalences of dab (*Limanda limanda*) afflicted with lymphocystis of various degrees of intensity were to be found in Scottish onshore waters, in areas 6 and 7; fur-

Table 1. Dab (*Limanda limanda*). Percentage of afflicted fish (Dethlefsen and Lang, unpublished).

			Epidermal	Ulcerations		
		Lymphocystis	papilloma	acute	healing	healed
1987	January	7.4	2.2	0.4	0.4	4.3
	May	13.4	3.4	3.5		6.1
1988	January	10.2	2.4	1.3		5.6
	May	19.8	3.8	2.8		7.0
1989	January	16.7	4.8	1.2		6.1
	May	20.3	4.6	2.5		6.2

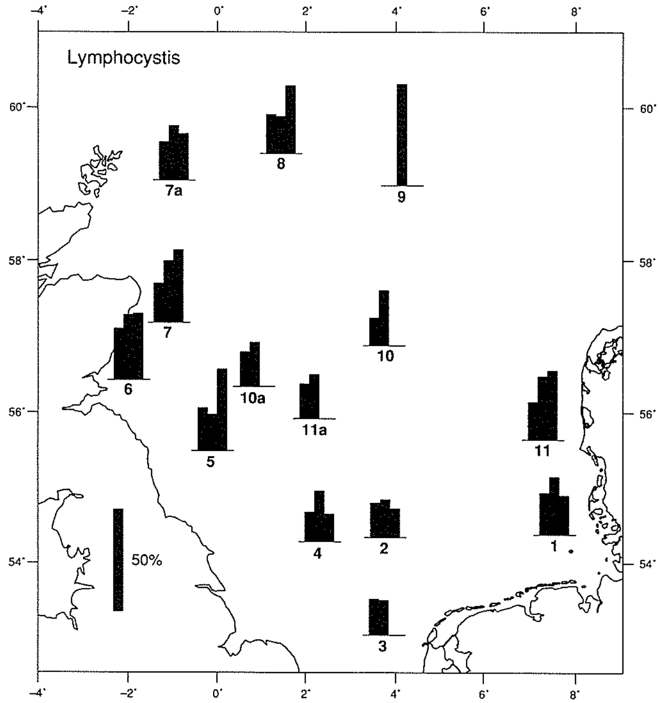

Fig. 1. Dab (*Limanda limanda*) May/June 1989. Percentage of affliction with lymphocystis. Bars from left to right: length groups 10-14 cm, 15-19 cm, 20-24 cm (Dethlefsen & Lang, unpublished).

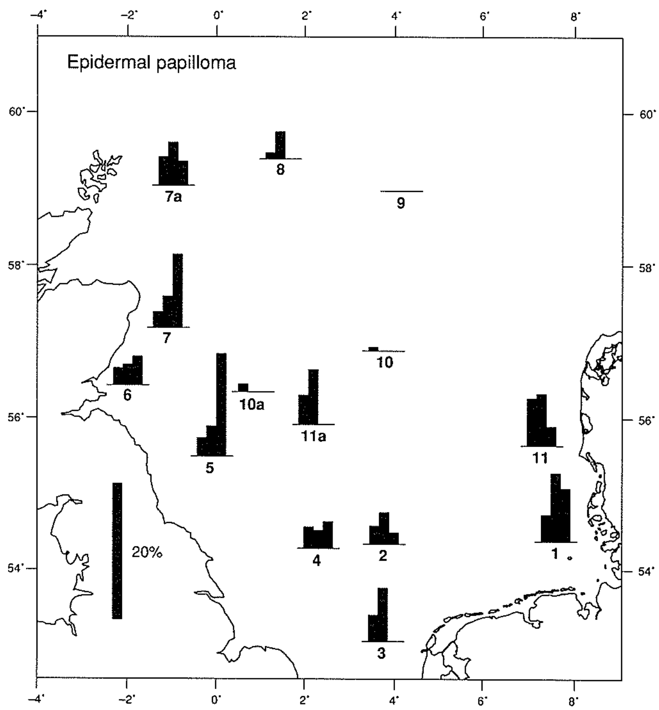

Fig. 2. Dab (*Limanda limanda*) May/June 1989. Percentage of affliction with epidermal papilloma. Bars from left to right: length groups 10-14 cm, 15-19 cm, 20-24 cm (Dethlefsen & Lang, unpublished).

thermore in the German Bight, area 1, and Danish coastal waters. The overall impression is, and this is consistent with the information in the published literature, that the prevalences of lymphocystis of dab (*Limanda limanda*) are quite evenly distributed throughout the areas studied. Furthermore from the figures it can be taken that in general disease prevalences increase with increasing length of fish, this is a widely known phenomenon. Exceptions were results for stations in the German Bight and on the Dogger Bank (Fig. 1). Prevalences of epidermal papilloma of dab are much lower during the time of this study, an average affliction rate of 4.6% of dab (*Limanda limanda*) investigated were found. Highest rates of affliction were encountered in fish from the German Bight and Danish coastal waters. While the rate of affliction was less on central stations of the area studied (Fig. 2). Scottish onshore areas, the German Bight, and the Dogger Bank are characterized by high prevalences of acute and healing ulcerations on dab, and the rate of affliction with healed ulcerations was exceptionally high on dab (*Limanda limanda*) of the Dogger Bank and Scottish onshore waters (area 6) (Fig. 3). The variability of the rates of affliction over time is given by Dethlefsen (1988b). It is shown that the development of disease prevalences differs in different areas, for example on the Dogger Bank for epidermal papilloma a steep increase of disease prevalences was detected beginning in summer 1982, ending in summer 1986 with a decrease thereafter. The increase from 1982 to 1986 was from less than 1.0% to more than 13.0% for fish from the Dogger Bank and from less than 2.0% to less than 10.0% for fish from the titanium dioxide dumping area (summer data). No increase was detectable for winter data obtained in January. In May 1984 the highest prevalences of lymphocystis have been found on dab in the dumping area for wastes from titanium dioxide production, being around 19.0% and for the Dogger Bank being around 20.0%. During a sampling in May 1989 the average of all dab investigated in the North Sea afflicted with lymphocystis was 20.3%. These data indicate an increase of the prevalences of lymphocystis on dab during the period studied (1979-1989).

During the early days of the fish disease investigations it was assumed that the contamination of fish and water should be high onshore and decrease further offshore. The fact, that he found high disease prevalences, for example on the Dogger Bank, led Möller (1979) to the conclusion that effects of anthropogenic pollution if any on fish diseases in the open North Sea are masked by more significant natural conditions.

Results obtained by Claussen (1988) on concentrations of cadmium, lead and mercury in livers of dab of the North Sea were surprising in so far that fish from the Dogger Bank displayed highest contamination for the two metals cadmium and lead. Also the contamination of fish from the British coast was higher as compared to that from the German Bight (Figs 4 and 5). The picture obtained for the contamination of livers of dab with organochlorines was different. For example the highest contamination of livers of dab with PCBs was found in fish from the German Bight and Danish waters, while the contamination of fish from the Dogger Bank and the British coast with DDT was higher than in fish from other areas. These coincidences between areas of high disease prevalences and high contamination of fish support the hypothesis that amongst the factors contributing to the outbreak of diseases of dab in the southern North Sea might be contamination.

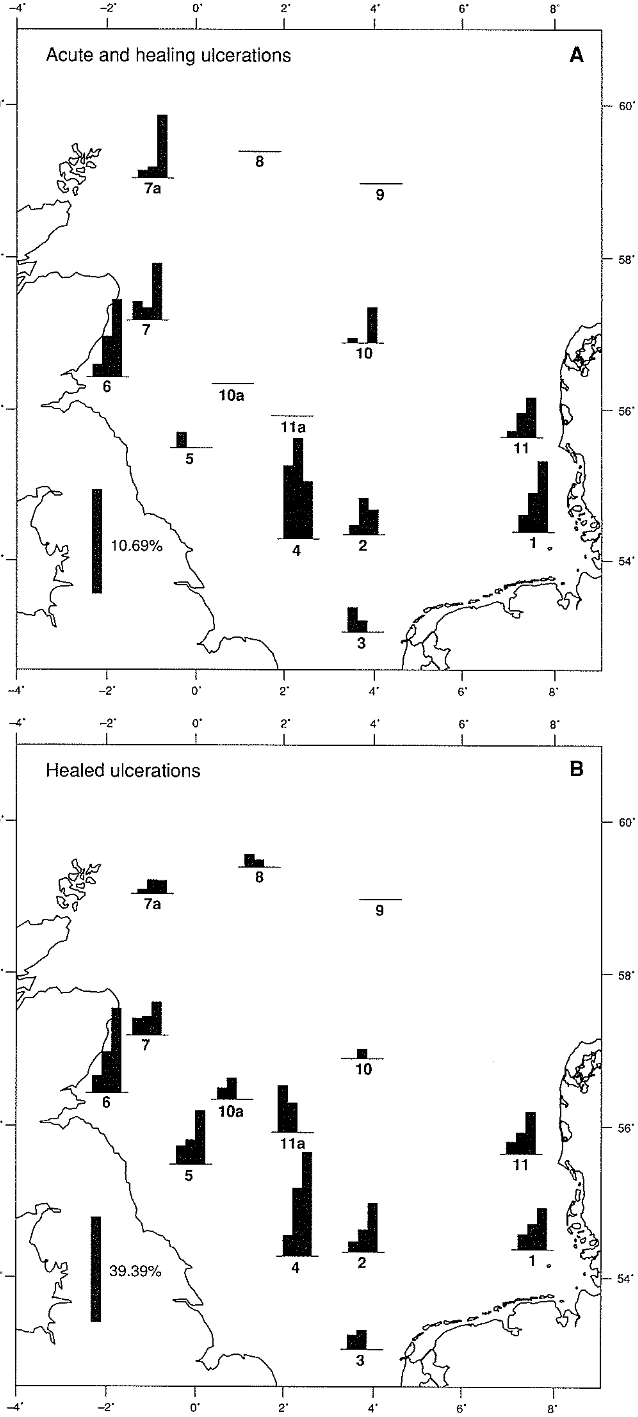

Fig. 3A, B. Dab (*Limanda limanda*) May/June 1989. Percentage of affliction with acute and healing (A) and healed (B) ulcerations. Bars from left to right: length groups 10-14 cm, 15-19 cm, 20-24 cm (Dethlefsen & Lang, unpublished).

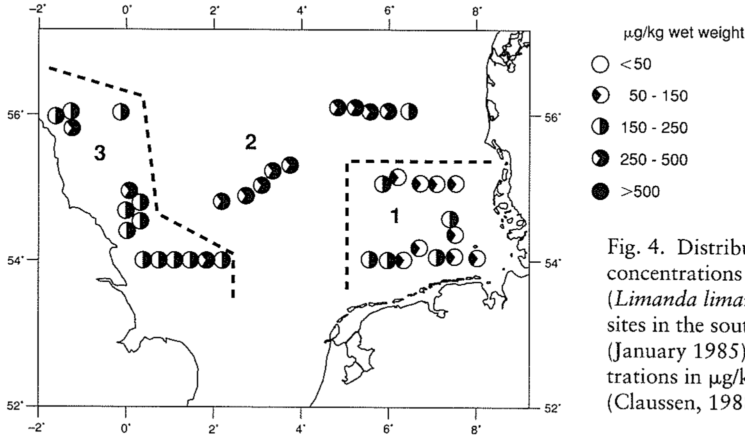

Fig. 4. Distribution of cadmium concentrations in livers of dab (*Limanda limanda*) from sampling sites in the southern North Sea (January 1985). Ranges of concentrations in µg/kg (wet weight) (Claussen, 1988).

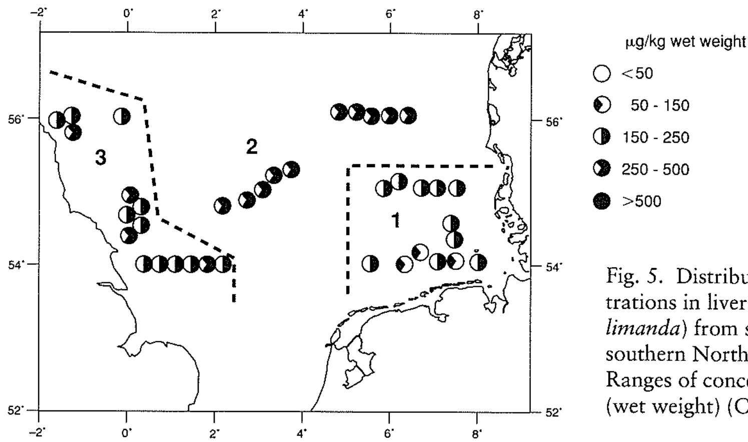

Fig. 5. Distribution of lead concentrations in livers of dab (*Limanda limanda*) from sampling sites in the southern North Sea (January 1985). Ranges of concentrations in µg/kg (wet weight) (Claussen, 1988).

Fish diseases in the dumping area for wastes from titanium dioxide production

During all fish disease cruises carried out in the German Bight increased disease prevalences, especially of dab (*Limanda limanda*) afflicted with epidermal papilloma, were found in the centre of the region which is the dumping area for wastes from titanium dioxide production. The area is in operation since 1969, for location and quantities see Dethlefsen (1986). Statistical tests revealed that during the majority of the cruises disease prevalences of dab in this area were significantly higher as compared with the vicinity, also when different lengths and sexes of fishes were taken into account. Furthermore increased heavy metal concentrations were found to occur in the water column, in sediments, and in certain tissues of the dab (*Limanda limanda*). There was a positive correlation, though not significant, between chromium contamination of dab livers and the size of epidermal papilloma. The findings were interpreted to be circumstantial evidence for a correlation between disease and wastes in the dumping area (Dethlefsen, 1986). Recent findings in the Dutch dumping area for wastes from titanium dioxide production (Bos, 1989) confirmed the German findings. Prevalences of dab (*Limanda limanda*) afflicted with epidermal papilloma was twice as high as compared to reference areas. The contamination of sediments with heavy metals and gills of dab with chromium was higher in the dumping area and contamination of benthic organisms (hermit crab) with heavy metals in the dumping area was elevated as compared to reference stations. Further indications for effects of wastes from titanium dioxide production in the German Bight, are in the next chapter dealing with impact of pollutants on reproduction of fish. In the course of these studies it could be shown that increased malformation rates of fish embryos were to be found in the German Bight and slightly north of the Dutch dumping area (Dethlefsen *et al.*, 1987).

Due to the political brisance the results obtained in the German dumping area for wastes of titanium dioxide production were widely discussed and there was a considerable reluctance to accept the conclusion that the biological deviations from normal in this area could be linked to the dumping. After the presentation of the results of the Dutch studies a new situation is emerging. As a classical case in epidemiology similar effects are to be found in two areas which differ significantly in a number of properties.

1. Currents – very high in Dutch and low in German waters.
2. Sediment structure – rough in Dutch and fine grained in German waters.
3. Fishing intensity – low in Dutch and high in German dumping area.
4. Population density – lower in the Dutch than in the German dumping area.

This means that amongst the factors to be found in both areas are diseased dab (*Limanda limanda*) and wastes from titanium dioxide dumping. The dumping in both areas will be terminated at the end of 1989. More than 1 mio tons of wastes will be recirculated on land from then on.

Oxygen and diseases in the eastern North Sea

Mellergaard & Nielsen (1987) reported on correlations between low dissolved oxygen in certain areas in the eastern North Sea and increased disease prevalences. Also in our data it could be shown that after periods of low dissolved oxygen concentrations in northern stretches of the German Bight high disease prevalences were found. This was especially marked for the affliction of dab (*Limanda limanda*) with epidermal papilloma (Dethlefsen, 1988b). After the summers of 1982 and 1983 no further drastically low dissolved oxygen concentrations were found in these areas and consequently the disease prevalences decreased.

Impairment of reproduction of fish by contamination

Two approaches were followed by German investigators:

1. Correlations between residues in gonads and viability of hatch.
2. Malformations of embryos, including gross deformities and chromosomal abnormalities during the spawning season.

The studies to disclose correlations between residues and hatch combined the advantages of *in situ* long-term exposure under natural conditions and controlled experiments. The methodology is described by von Westernhagen *et al.* (1981; 1989). Mature fish of the respective species were caught in their natural habitat. After stripping spawning products of males and females and artificial fertilization the embryonic development is followed on aliquotes of the spawning material in small glass containers. Aliquotes of the gonads of individuals used for these experiments were taken for residue analysis, heavy metals and organochlorine were analyzed by von Westernhagen *et al.* (1981) and organochlorines by Hansen *et al.* (1985), and von Westernhagen *et al.* (1989). For the metals cadmium, zinc, and mercury no correlations existed between the viability of the hatch and residues in flounder from the Baltic (von Westernhagen *et al.*, 1981). Correlations existed between the contamination with PCBs and the loss of reproductive capacity of marine teleosts (von Westernhagen *et al.*, 1987). Viable hatch was significantly correlated with ovaries PCBs content: flounder (*Platichthys flesus*), herring (*Clupea harengus*), whiting (*Merlangius merlangus*), DDE: herring (*Clupea harengus*), whiting (*Merlangius merlangus*), and dieldrin. Von Westernhagen *et al.* (1989) came to the conclusion that for the major contaminants, ΣDDT, dieldrin and, ΣPCBs, threshold values higher than 20 μg/kg and 200 g/kg wet weight respectively impeded reproduction considerably.

An example for the correlation between viable hatch and three contaminants mentioned is given in Fig. 6. It can be taken from this figure that also in the lower

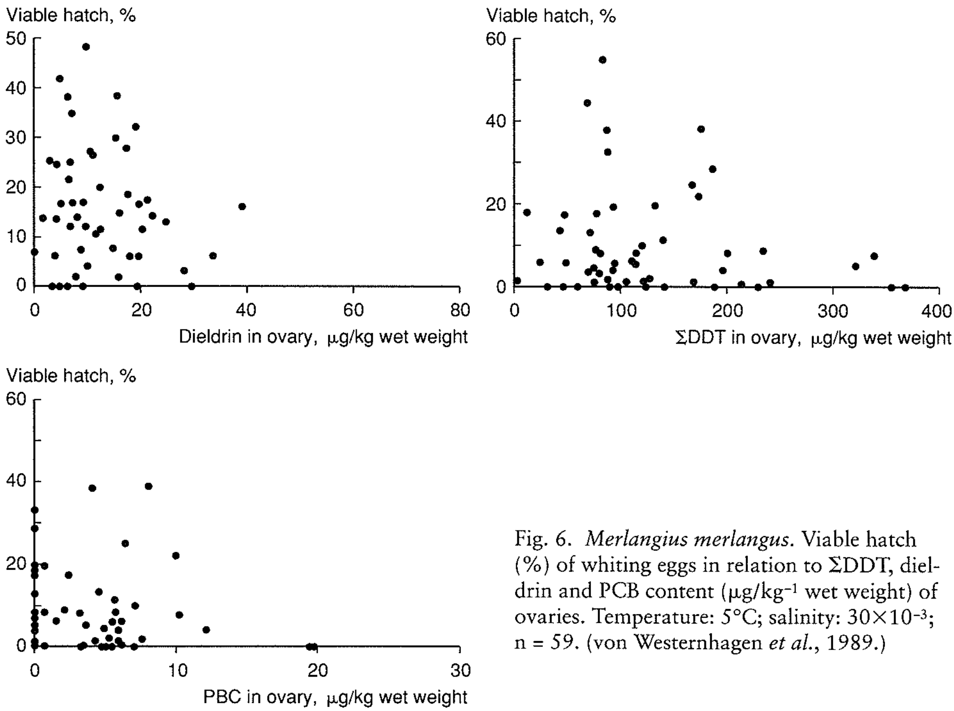

Fig. 6. *Merlangius merlangus.* Viable hatch (%) of whiting eggs in relation to ΣDDT, dieldrin and PCB content (μg/kg^{-1} wet weight) of ovaries. Temperature: 5°C; salinity: 30×10^{-3}; n = 59. (von Westernhagen *et al.*, 1989.)

ranges of the contaminants low percentages of viable hatch were registered indicating that only part of the variability encountered in hatching success was associated with these contaminants. Viable hatch for North Sea whiting (*Merlangius merlangus*) was generally well below values registered for other marine species (von Westernhagen *et al.*, 1981; Hansen *et al.*, 1985). The highest value recorded was just about 50%. The contamination of whiting liver was consistently higher than that of flounder (*Platichthys flesus*) and herring (*Clupea harengus*) (von Westernhagen *et al.*, 1989). The methods mentioned were also applied by American investigators. Spies & Rice (1988) found a negative correlation between concentrations of PCBs and embryological success of starry flounder (*Platichthys stellatus*) from San Francisco Bay. Cross & Hose (1988) found that ovarian DDT concentrations beyond 4 ppm impaired reproduction of white croaker while PCB concentrations in the range of 1.5 to 1.7 ppm were ineffective. Johnson *et al.* (1988) studied reproductive success of English sole (*Parophrys vetulus*) from Puget Sound, Washington (USA) in relation to pollution and animals from sites with high levels of PCBs in sediments had a lower hatching success. Thus the data published so far indicate that certain coastal fish accumulate organochlorines beyond levels which suppressed hatching success. For the German studies it was found that between 3.0% and 5.0% of the individuals tested of the respective species show a contamination level beyond which this impairment was registered.

Malformations of pelagic fish embryos

Following a study by Graumann & Sukhorukova (1982) who found a mass occurrence of abnormal cod and sprat embryos in the Baltic from 1979 to 1981, malformation rates of pelagic fish embryos in the Baltic and the North Sea were investigated. Results are to be found in von Westernhagen *et al.* (1988) for Baltic, and Dethlefsen *et al.* (1987) for the North Sea. In the western Baltic for example in 1983 18% of cod- (*Gadus morhua*), 22% of flounder- (*Platichthys flesus*), 24% of plaice- (*Pleuronectes platessa*) embryos were defective. In 1984 28% of plaice-, 32% of cod-, 44% of flounder embryos were abnormally developed. The predominating North Sea pelagic fish embryos in German, Dutch and Danish coastal waters in the early spring were of dab, flounder, whiting, cod, and plaice (Dethlefsen *et al.*, 1987). Depending on species composition 300 to 1 000 embryos per station were investigated. The deviations in early developmental stages were mainly characterized by irregular cell division, in later embryos by circular enclosures and irregular development. For subsequent years, beginning in 1984, similar distribution patterns of prevalences of malformed pelagic fish embryos were encountered. Fig. 7 contains information on malformations of early stages of dab and flounder in March 1987. In the centre of the German Bight off the Eastfrisian Islands and in an area off the Dutch coast increased prevalences of malformed dab embryos were to be found, while increased malformation rates of early embryos of flounders were to be detected in the German Bight and off the Dutch coast. Frequencies of malformed embryos for the sampling in March 1985 (Dethlefsen *et al.*, 1987) in the North Sea where 82 stations have been covered and altogether 53 000 embryos were investigated can be taken from Table 2. For the sampling in March 1987 malformation rates for the

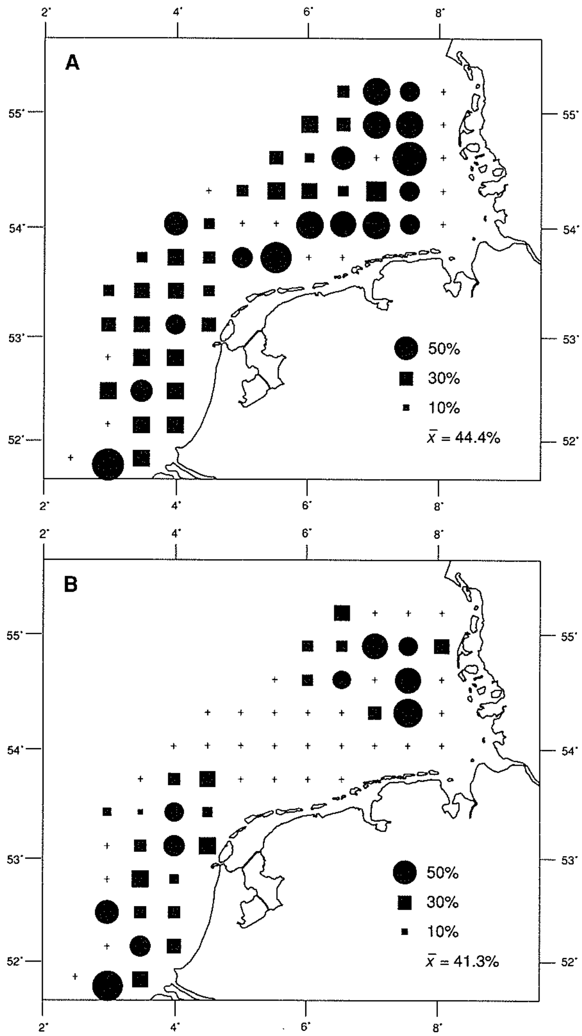

Fig. 7. Prevalences of malformed embryos, early developmental stages, March 1987.
A: Dab (*Limanda limanda*).
B: Flounder (*Platichthys flesus*).
(Cameron, Berg, Dethlefsen, unpublished).

five major fish species investigated are given in Table 3. Embryos of whiting were most frequently found to be malformed, followed by those of dab, flounder, and plaice. In subsequent years this ranking of malformation rates in species changed slightly but embryos of dab and flounder were always to be found in the medium prevalence ranges, those of plaice in the lowest and whiting in the highest ranges. The same ranking is reflected in the levels of PCB contamination of adult fish of the respective species in the German Bight area (Büther, 1988; Dethlefsen *et al.*, 1987). This means, that embryos of species less contaminated also showed low medium malformation rates. This interesting finding has to be substantiated by further studies.

Table 2. Percentage of defective development 1985 (82 stations), n = investigated, (Dethlefsen *et al.*, unpublished).

	Developmental stage					
	Ia	n	Ib	n	II	n
Limanda limanda	27.5	6416	20.7	2476	17.1	6739
Platichthys flesus	29.9	2608	24.9	1178	13.5	1999
Merlangius merlangus	38.4	825	45.2	197	53.4	915
Gadus morhua	27.7	2102	25.8	832	21.1	1497
Pleuronectes platessa	18.0	1075	14.3	470	11.0	1377
Sum	27.9	13026	22.8	5153	19.0	12527
	Developmental stage					
	III	n	IVb	n	Sum	n
Limanda limanda	7.0	9030	3.8	2679	15.2	27340
Platichthys flesus	7.1	2627	1.9	688	16.9	9100
Merlangius merlangus	44.5	1384	17.6	989	39.1	4310
Gadus morhua	12.0	1891	3.2	943	18.9	7265
Pleuronectes platessa	4.6	1392	0.6	1406	8.5	5720
Sum	10.6	16324	4.9	6705	17.2	53735

Table 3. Malformation rates of fish embryos of the southern North Sea and German Bight (March 1987), stages and species. For species weighted medium rates per species are given and for stages weighted medium rates per developmental stages are given (Dethlefsen *et al.*, unpublished).

	Dab	Flounder	Whiting	Cod	Plaice	Stage
Ia	44.4 %	41.3	64.5	27.1	26.0	43.5
Ib	21.0 %	22.3	–	10.5	11.6	19.9
II	31.9 %	28.9	62.6	22.3	24.8	31.5
III	12.7 %	12.3	51.7	13.8	9.5	13.5
IV	4.9 %	6.8	21.0	3.6	1.7	4.8

Summarizing the finding on reproduction studies it can be stated that present data indicate the existence of an impairment of reproductive capabilities of fish by two factors:

1. Accumulation of organochlorine in gonads of coastal fish.
2. Acute effects in the water column.

Malformation rates of fish embryos cannot be compared with earlier data because in former studies the sampling has been done with high speed sampling gear. By this procedure most of the sensitive fish embryos are mechanically damaged. Furthermore the fixation of fish embryos after catching does not allow the detection of slight deviations from normal development due to the fact that the yolk has turned opaque. Therefore no comparisons can be made with earlier results on malformed or dead fish embryos from marine areas.

Further ecological deviations from normal

It is self-evident that fish cannot be regarded isolated from its biotic and abiotic environment. Therefore it is necessary to briefly list further examples for ecological dysfunctions or changes that have recently been discovered in the North Sea.

Plankton, nutrients, oxygen

In the period between 1962 and 1984 in an area in the vicinity of the island of Helgoland surface temperatures increased, salinities decreased, concentrations of phosphate and nitrate and nitrite increased, while that of silicate and ammonia decreased (Radach & Berg, 1986). At present nitrogen loads in the southern North Sea are four times and phosphate loads seven times higher than natural background (Gerlach, 1988). As compared to data from 1936 nutrient concentrations in the German Bight have in 1978 increased by a factor of two to three (Weichart, 1986). The phytoplankton biomass close to Helgoland has increased significantly, especially flagellates increased by a factor of 16. Bätje & Michaelis (1986) report on increasing intensities of blooms of *Phaeocystis pouchetii* in the past decade. In the summers of 1981 to 1983 extensive areas in the German Bight and off the Danish coast were found with low dissolved oxygen concentrations in bottom near waters (Rachor & Albrecht, 1983; Dethlefsen & von Westernhagen, 1983). The latter authors found mortalities of fish and benthic organisms in areas with lowest oxygen concentrations. Subsequent studies also revealed impact on benthic communities with recovery in summers with normal oxygen concentrations (Hickel *et al.*, 1989). These authors describe low dissolved oxygen situations to occur as a combination of hydrological and meteorological conditions which lead to stable water stratification and high biological oxygen demand in the areas studied. Low dissolved oxygen concentrations amongst other effects aggravates the toxicity of substances as well as their accumulation. Low dissolved oxygen represents a general stress with subsequent consequences for the immune system.

Benthic changes

A number of macrobenthic organisms formerly abundant in the Helgoland area and at the German coasts were shown to have disappeared (Dörjes, 1986). Other species show some population decreases and further groups are characterized by marked fluctuations in their population density. Kröncke (1988a) showed significant changes of the macrobenthos composition of the Dogger Bank as compared to that of the 1950s. Especially molluscs have decreased in abundance while certain polychaetes known to be opportunistic species have increased in population density. There are numerous examples for local changes of macrobenthos populations over time (Michaelis, 1987) for Jade-Busen, Reise (1986) and Riesen & Reise (1982) for Wadden Sea, Mühlenhardt-Siegel (1981; 1985) and Rachor (1982) for a sewage sludge dumping area in the German Bight. Reasons for these changes are largely unknown and the authors discuss whether pollution might have played a role.

Changes in fish populations

In a study from 1954 to 1981 bycatch data of German shrimpers (*Crangon crangon*) were analyzed for the occurrence of fish and crustacean species (Tiews, 1983). Seven inhabitants of the Wadden Sea area have decreased in abundance: shore crab, butterfish, sea snails, gobies, eel, little sole, and gurnard, while three of the facultative inhabitant, dab, sprat and cod have increased in numbers to equal the former total biomass. 15 further species remained constant. For two of the decreased species correlations existed between population levels and meteorological factors (temperature). Since fishing intensity and strategy in the Wadden Sea have remained unchanged over the period of the survey, the author discusses whether contamination might be amongst the causative factors. To the circumstantial evidence listed belongs that contamination of water and sediments was higher in areas of clearest population decreases. In a continuation of his study Tiews (1989) found that two of the seven species declining until 1981, shore crab (*Carcinus maenas*) and butter fish (*Pholis gunellus*) have reversed their downward trend and increased in abundance. The other five species are still declining. The data base analyzed is the longest available for the German coast. The author points at the necessity to include contamination data in future monitoring.

Mortality of seals

In the period between May and December 1988 5800 seals (*Phoca vitulina*) were found dead on the Schleswig-Holstein coast of the Wadden Sea. In the North Sea and the Baltic more than 17000 individuals were killed (Heidemann & Schwarz, 1989). After the introduction of an array of protection measures seal stocks had recovered in the 1980s, reaching a population level of 4200 in 1988 as compared to 1540 in 1974 at Schleswig-Holstein coast. But no indications for overpopulation were detected, i.e. condition and size of blubber of dead animals were good.

Residue analysis in tissues of killed seals did not reveal any dramatic recent increases of contaminant levels (Heidemann & Schwarz, 1989). The most likely primary cause is presently seen to be a canine distemper virus (Osterhaus & Vedder, 1988).

Since seals are known to carry high contaminant loads of especially organochlorines it is not excluded that this contamination is responsible for the suppression of the immune system via impact on the hormone system (Reijnders, 1986; 1988). PCBs were shown to cause enhanced break down of steroids. Gonadal steroids regulate the immune system.

Trends in contaminants

Investigations on environmental radioactivity started as early as 1960 (for example Aarkrog *et al.*, 1984). For heavy metals the pollution history of the German Bight is documented using sediment profiles (for example Förstner & Reineck, 1974) and for organochlorine sediment cores from the Baltic it could be shown that PCBs and DDTs did not appear prior to 1940 (Müller *et al.*, 1980). Trends for heavy metals and total extractable organochlorine substances for the river Rhine for the period between 1973 and 1980 show a clear downward tendency (Sloof, 1982). For the rivers Elbe and Weser, major contributors of contaminants to the German Bight, no downward trends of concentrations of heavy metals were detected over the last decade. In the period between 1980 and 1988 concentrations of alpha-HCH and HCB decreased in the estuary of the Elbe while levels of gamma-HCH fluctuated but did not decrease (Deutsches Hydrographisches Institut, 1988).

For the sum of DDT in cod fillets between 1974 and 1979 a decrease of residues was detected (Barke *et al.*, 1983, cited after Schreiber, 1986). For PCBs in the period between 1977 and 1983 levels in fish tissues of the German Bight remained more or less constant (Huschenbeth, 1986). Residues of heavy metals in *Mytilus edulis* from various places of the German coast have been analyzed since 1973/74. The decrease thereafter was followed by a new increase in 1979/80. The starting niveau was not reached. It was only for mercury in mussels from the river Ems that a statistically significant downward trend could be found (Borchardt, 1986). In another study of heavy metals and pesticide residues in mussels from Eastfrisian Wadden Sea areas it could be shown that the concentrations of lead have decreased in the period between 1979 and 1984, while concentrations of cadmium vary without any detectable trend. No trends were detectable for HCB, gamma-HCH, dieldrin, DDE, DDD and DDT for the period between 1979 and 1984 (Sperveslage, 1986).

Comparison German Bight versus North Sea

It is generally assumed that the contamination of abiotic and biotic compartments of the sea is high onshore and decreases offshore being lowest in the central North Sea. Recent studies demonstrate that there are numerous exceptions from this pattern. Results for heavy metals in seawater are provided by Schmidt & Dicke (1988), in sediments and suspended solids by Förstner *et al.* (1988), in benthic organisms by Kröncke (1988b), in hermit crabs (*Pagurus pagurus*) by Karbe & Borchardt (1988), and bottom fish, dab (*Limanda limanda*) by Claussen (1988). Organochlorine contamination of sea water was analyzed by Deutsches Hydrographisches Institut (1988), of sediments by Lohse (1988), of phyto- and zooplankton by Steinhart & Knickmeyer (1988), of hermit crab (*Pagurus* spec.) by Knickmeyer & Steinhart (1988), and of fish, dab (*Limanda limanda*) by Büther (1988).

Despite the considerable variability of the data for various biota, strata and species the results of these studies show that contamination is often higher in offshore areas, especially on the Dogger, the Fisher Bank etc. Heavy metal concentrations in hermit crabs were highest in east Scottish offshore areas, PCBs in these organisms were high east of Orkneys and Shetlands, the central northern North Sea etc.

Conclusions

Ecological changes are to be found in all organisational levels, individual and populational and in all groups of organisms of the North Sea. Changes in ecology as such are nothing to cause special concern, it is a trueism that species compositions change with time. It might therefore be disputed whether the observed changes constitute abnormal deviations or represent results of natural variability. Since the changes discussed are general responses of populations or individuals to deviating living conditions, question arises whether they are natural or man made.

The discussion of the plausibility for the effects to be caused by contamination should be based on the following considerations.

1. An increase in nutrient loads causes eu- or hypertrophication. Hypertrophication causes changes in plankton communities, similar to those observed. Hypertrophication causes low dissolved oxygen in bottom near waters, similar to those observed.

2. The presence of PCBs in biota influences gonadal steroids leading to a reduction of reproductive capability and to influences on the immuno capabilities of organisms. Reduced reproductive capabilities have been observed in fishes and high fish disease rates indicate an impact on the immune system.

There is ample experimental evidence that heavy metals and organochlorines play a role in triggering diseases in fish (Meyers & Hendriks, 1982).

Thus there seems to be a high plausibility for the observed changes to be caused by contamination. On the other hand a number of natural and non pollutional anthropogenic factors are known to cause similar changes. To these belong the long-term increase in temperature which might intensify benthic growth, the spreading of contagious diseases etc.

Impact through fisheries certainly constitutes a major influence on marine ecosystems by

a. changing structure and size of population communities,

b. injuring an enormous number of fish which can escape fishing gear, and

c. by impacting benthic organisms through heavy fishing gear.

In the discussion of causes of biological deviations from normal in marine ecosystems it more or less depended on personal preferences which factors were given the highest weight. The preferences are not based on scientific criteria. Both groups, one interpreting the deviations as being expressions of natural variability and second claiming that contamination is the major cause, have good reasons for their position. Both ignore the complexity of cause effect relationships.

Again it is a trueism to state that biological deviations from normal are multifactorial and caused by an interplay of natural and anthropogenic influences. But this statement does not lead us anywhere. The important question which has to be answered is: Do we need a reduction in contaminant levels in the marine areas under survey?

This question cannot be answered based on the present knowledge due to the absence of proven cause effect relationships and the question arises whether this situation can be improved by better scientific knowledge as a result of long-term monitoring programmes. The monitoring of biological variables as such over long time periods without factors being monitored which might be causatively linked to the observed variability will not allow a future analysis of causality. On the other hand the example given by Tiews (1989) reporting on 35 years of monitoring of fish populations in the German Wadden Sea shows that it is unrealistic to expect clearly interpretable trends from long-term monitoring of biological variables. The sudden reversal of trends as described by Tiews (1989) for fishes in the Wadden Sea casts doubt on our ability to explain reasons for these reversals.

At present marine science is charged with the task to prove effects of contaminants *in situ* after these substances have been released into the environment. The examples given above show that this cannot be achieved. Epidemiological techniques are applied which allow to detect coincidences in regions and time, but these coincidences are correlations and nothing more.

In the future a reversal of the situation has to be postulated. Substances with teratogenic, mutagenic and bioaccumulative potential should under no circumstances be released into the environment. This requires the ecotoxicological testing of all substances which are going to be produced. To this end science has to provide ecotoxicological methods sensitive enough to detect the properties mentioned above.

Furthermore industry has to install technical facilities which prevent toxic materials from being released into the environment. This is an extension of the precautionary approach which so far was only understood to include the reduction of concentrations of known contaminants in the marine environment despite the absence of proof of cause effect relationships.

The history of aquatic pollution goes back to the time of intensified industrial processes. In Europe this occurred in the period between 1850 and 1890. In the time since we have observed pollution problems to progress from rivers and lakes down to estuaries, from here to enclosed marine areas, like the Mediterranean and the Baltic, and now it seems that semi-enclosed marine areas, like the Japanese Sea, the New York Bight, and the North Sea, are amongst others the next in line. Let us prevent open oceans from becoming future victims.

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