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Circulation and Contaminant Fluxes in the North Sea

With 391 Figures

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Cover picture: Suspended matter distribution in the southern North Sea in May 1986, derived from satellite data.

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1 Introduction

This book presents in an integrated approach results from five years of interdisciplinary research in the project *Zirkulation und Schadstoffumsatz in der Nordsee (ZISCH)* (Circulation and Contaminant Fluxes in the North Sea). From 1984 to 1989 over 30 scientists and technicians worked in the project, which was supported by the Bundesminister für Forschung und Technologie (German Minister for Research and Technology). Together with the Universität Hamburg, which initiated ZISCH, the following institutions participated: Technische Universität Hamburg-Harburg, Rheinisch-Westfälische Technische Hochschule Aachen, Deutsches Hydrographisches Institut (now Bundesamt für Seeschiffahrt und Hydrographie), GKSS Forschungszentrum Geesthacht, Alfred-Wegener-Institut Bremerhaven, Biologische Anstalt Helgoland, Universität Paderborn. More than other national and international projects, the ZISCH project aimed at a holistic view of the marine ecosystem. For this reason, the different disciplines working together were not limited to purely marine sciences (oceanography, marine biology and chemistry), but atmospheric sciences (meteorology, atmospheric chemistry) and food chemistry also participated. Previous to ZISCH, no North Sea wide investigation of comparable complexity had ever been carried out. The area under investigation is shown in Fig. 1.1.

The ZISCH research project was established in view of the obvious threat to the North Sea environment generated by human activities. The primary causes are considered to be industrial, agricultural and municipal discharges which reach the sea over different pathways. Table 1.1 summarizes the sources and amounts of various contaminants entering the North Sea.

As the ZISCH project began, the first International North Sea Conference had just taken place (November/December 1984 in Bremen). Policy-makers from the North Sea countries had recognized that it was necessary

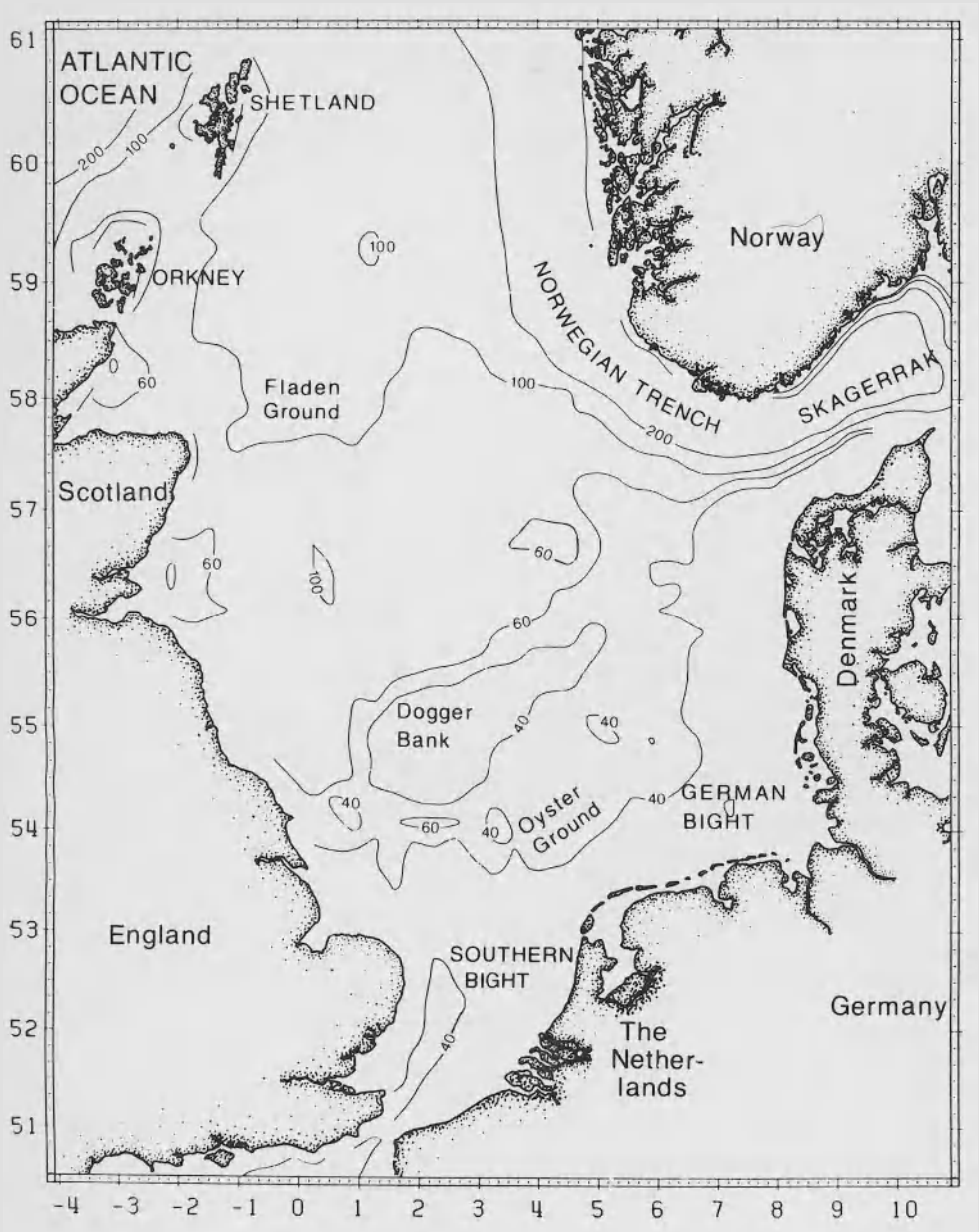

Fig. 1.1. Topography of the North Sea

Table 1.1. Estimates of inputs (tonnes) via the various pathways to the North Sea in 1990

Pathway	Cd	Hg	As	Cr	Cu	Ni	Pb	Zn	PCB*	HCH**	N	P
Riverine inputs[a]	55	25	NI	NI	1 400	NI	1 000	6 800	2.7	1.1	920 000	48 000
Direct inputs[a]	17	2.1	NI	NI	330	NI	160	1 300	0.2	0.2	120 000	7 100
Atmosphere[a,b]	74	6.9	220	[180]	740	400	1 700	5 500	NI	[8.1]	520 000	NI
Disposal at sea												
Incineration[a]	0.1	0.1	0.1	4.9	4.6	5.0	4.9	5.7	NI	NI	NI	NI
Industrial waste[c]	0.3	0.2	2.4	24	180	64	220	440	NI	NI	NI	NI
Sewage sludge	1.2	0.7	0.1	21	76	11	77	160	NI	NI	6 300	570
Dredged material[d]	71	19	720	2 800	1 300	1 200	2 700	7 900	0.6	NI	NI	NI

NI = No information; [ ] = not reliable; * = IUPAC Nos. 28, 52, 101, 118, 153, 138,180 ; ** = γ-HCH
Source: Oslo and Paris Commissions (Reports on Monitoring and Assessment & Dumping and Incineration at Sea, July 1992)

[a]Maximum estimate.
[b]Based on deposition measurements at coastal stations (calculated for an area of 525 000 km^2).
[c]Chemical waste, fly ash, rock, tailings, sediments. Dumping in internal waters is included.
[d]Dredged material from harbours, estuaries and navigation channels. Dumping in internal waters is included. Metal load is overestimated because it contains an unknown share of metals of natural origin. In addition, dumping of dredged material often means merely relocating material without any new input of constituents to the North Sea.

to act in concert to alleviate the environmental problems of this shelf sea. But what was the basis for their decision making? It turned out that despite considerable data acquisition in the North Sea over the years, making it one of the most intensively studied marine areas worldwide, no comprehensive, sufficiently representative observational material was available for assessing the ecosystem, not to mention for understanding the relationships between anthropogenic effects, climatological factors and ecological state. Previous investigations had not been carried out on a holistic, integrated basis and had only covered a small spectrum of ecological parameters (for example only heavy metals without regarding phytoplankton at the same time). Moreover, the diversity of the relevant spatial and temporal scales caused by the high degree of stochastic variability in the North Sea had not been taken adequately into consideration, so that the many data sets did not result in a representative picture. It was not possible to develop a clear protection strategy for the North Sea on this scientific basis. It was necessary to create a new, integrated and interdisciplinary concept for ecological North Sea research which would make allowance for the complex interrelationships between the physical, chemical and biological processes. ZISCH realized this approach.

The research program had the objective of quantifying fluxes of major contaminants in the North Sea. This entailed:

1. Acquisition of consistent, comprehensive data sets for the North Sea ecosystem on the whole together with the distribution of key contaminants within it.

2. Calculation of transport paths and fate of critical contaminants as well as mass budgets, considering given anthropogenic sources. Hereby, present conditions were analyzed, and predictions were attempted on the basis of various scenarios.

The conservation of mass permits formulation of the concentration of a particular substance in water according to a transport equation. Simply stated, the evolution of the concentration at a fixed location (for example, an increase in contamination of the Dogger Bank) results from the sum of local sources and sinks (for example, input from the atmosphere) and advection and diffusion in the flow field (for example, as carried by currents from the polluted plume of the River Tyne). In order to evaluate contamination, knowledge is thus necessary regarding the three-dimensional circulation and turbulent diffusion of the water masses (including suspended matter) as well as the contaminant fluxes resulting from the interactions of the hydrosphere with atmosphere, biosphere and lithosphere.

While advection and diffusion can be characterized by meteorological and hydrographical parameters, the sources and sinks of the system also include biological, chemical and sedimentological processes. A research program for investigation of contaminant fluxes must thus include physical, chemical and biological elements, closely interwoven. The individual components of the system together with the interaction mechanisms are shown in Fig. 1.2. Horizontally, it represents the transport equation, vertically, the transport media air, water, suspended matter and sediment. The arrows refer to the dominant processes.

First, in the purely hydrodynamic subsystem, the circulation of the air forces the circulation of the water. This causes dissolved substances, suspended matter and planktonic organisms to be transported, these, in turn, interacting with each other and with the sediment. Contaminants entering this system are then carried by air and water, in the latter in dissolved or particulate form. The input of contaminants occurs by means of anthropogenic "external" sources via the atmosphere, the rivers, the entrances to the North Sea and dumping. There are fluxes in both directions between the transport media air, water and sediment. Finally, the subsystem "contaminant transport" also contains "internal" sources and sinks. These include chemical transformation in the air and in the water as well as accumulation in organisms and in suspended matter and exchange processes between water and sediment. A comprehensive programme *Circulation and Contaminant Fluxes in the North Sea* must encompass all of the constituents shown in Fig. 1.2.

The ZISCH investigations represented a qualitatively and quantitatively new approach to North Sea research in several respects. Among these:

- the first simultaneous blanket coverage of all important biological, chemical and physical parameters in the entire North Sea ecosystem;
- the first simultaneous measurements of major contaminants (metals and organohaline compounds) in the different ecosystem compartments;
- simultaneous determinations of atmospheric inputs of momentum, energy and matter as important ecosystem boundary conditions;
- performance of the complex measurement program during two seasons, namely the spring plankton bloom and the subsequent winter period of minimal biological activity;
- support of data analysis and interpretation by oceanographic and meteorological numerical models on the same scales.

The present volume addresses colleagues in the marine sciences but also scientists in related fields and scientific policymakers as well as the inter-

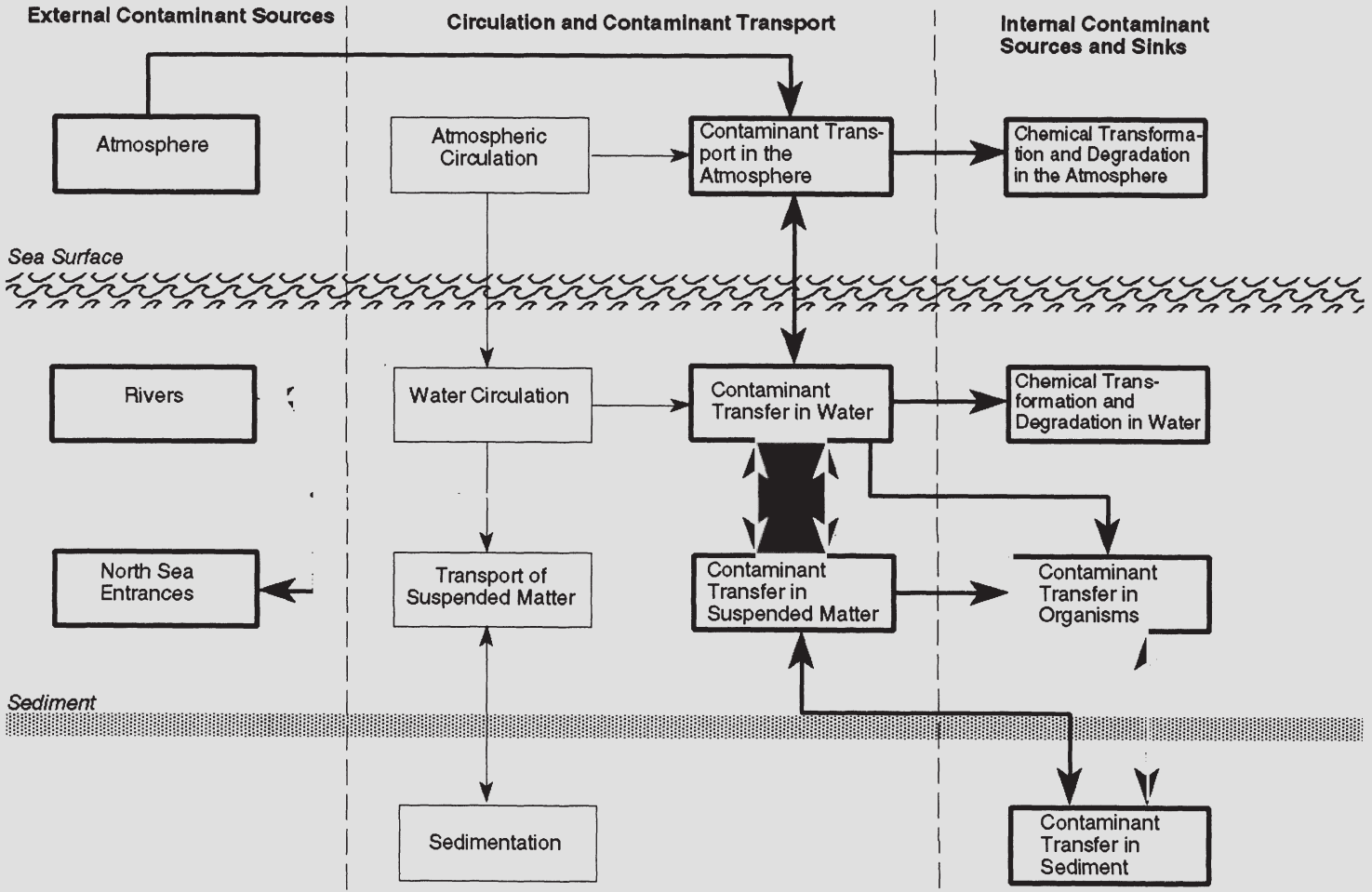

Fig. 1.2. Schematic representation of contaminant fluxes in the marine ecosystem. The thin arrows show the hydrodynamic

ested general public. Rather than presenting the results according to individual disciplines, we have tried to consolidate the diverse data in summary chapters which strive for a holistic understanding of causal relationships. A first step in this approach was taken by us previously in avery successful publication for the general public, *The North Sea - Water Exchange and Pollution* (Sündermann and Degens 1989).

For comparison, some other recently published books with reference to the North Sea ecosystem shall be mentioned:

Biogeochemistry and Distribution of Suspended Matter in the North Sea and Implications to Fisheries Biology (Kempe et al. 1988) is based on results of a German project primarily concerned with the role of suspended matter/sediment as vehicles and as long term accumulators for contaminants. In this book it is emphasized that the long term cycles of sediment fluxes (several decades) and the "ultimate rubbish dump" of contaminated sediment in the Norwegian Trench could be a threat to the ecosystem for generations, even if all inputs of contaminants were to be stopped immediately. Changes in the spectrum of species (including extraordinary algal blooms) can most probably be attributed to eutrophication and the increase in susceptibility to diseases in fish, birds and mammals to a general weakening of immunity provoked by contaminants.

Pollution of the North Sea - an Assessment (Salomons et al. 1988) attempts to take a more comprehensive, systematic approach. Authors from different countries bordering the North Sea and from different marine disciplines were invited to contribute articles describing the ecosystem, contaminant fluxes and, particularly, the effects of contaminants on organisms. These form a mosaic picture of the pollutant load and the transport mechanisms in the North Sea. The editors point out apparent ecosystem deterioration, but they only speak of indications. The inherent complexity of the system has prevented formulation of causal relationships and, thus, of prognoses. A precautionary reduction in inputs of potential pollutants is called for.

The final report *Stickstoff, Phosphor, Plankton und Sauerstoffmangel in der Deutschen Bucht und in der Kieler Bucht* (Gerlach 1990) is based on results from a German project on eutrophication of the North Sea and the Baltic. It includes a comprehensive description of the ecosystems and the influence of excessive nutrient inputs. It establishes that phytoplankton biomass has increased considerably during the past 30 years, paralleling increased concentrations of phosphorus and nitrogen compounds. Interannual fluctuations (which can coincide with extreme algal blooms and oxygen deficits) seem to be governed by atmospheric processes.

Warnsignale aus der Nordsee (Lozan et al. 1990) stresses contaminant concentrations in water, sediment and organisms as well as the changes in