Papers

The changing North Sea: knowledge, speculation and new challenges

OCEANOLOGIA, 45 (1), 2003.
pp. 247–259.

KEYWORDS
North Sea
Modelling
Instruments
Methods

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Manuscript received 19 March 2003, reviewed 31 March 2003, accepted 7 April 2003.

Abstract

Synthesis and New Conception of North Sea Research (SYCON) is the title of a German project carried out from 1998–2000 under the leadership of Hamburg University[1]. It was accompanied by an international advisory board and covered North Sea issues as well as the general challenges to shelf sea research and sustainable management under global change. Particular emphasis was placed on the interdisciplinary analysis of comprehensive areas of knowledge: the data situation, understanding of processes, model development, instruments and methods, understanding of the system. Based on this, perspectives for future North Sea research were developed. The project produced a synthesis report, eleven monodisciplinary reports and an illustrated brochure for the general public (see Annex 1, this paper, p. 258).

[1]The SYCON Project was carried out with the support of the German Federal Ministry of Education and Research under Grant No. 03F0215A. This article is based on the SYCON Synthesis Report (Sündermann et al. 2001).

The challenges to research and in research

The questions society addresses to North Sea science can be condensed to three, the Grand Challenges of North Sea research:

- Do we possess sufficient knowledge of the present state and reaction potential of the North Sea system, and what are their characteristics?
- What changes are to be expected in the future with regard to both natural variability and human impact?
- What environmental strategies support the sustainability of the North Sea system?

The societal concerns and questions about the North Sea system can often not be directly addressed by scientific research. There are basic fields of necessary knowledge which are not being sufficiently explored. Sometimes missing scientific foundations must be laid to achieve answers and progress in an applied environmental context. Bearing in mind the strong and weak aspects of our understanding of the North Sea system, the questions – research challenges for the future – to be taken up are as follows:

- How and to what extent is the North Sea controlled by external forcing?
- How and to what extent is the North Sea controlled by its internal dynamics?
- How can the real behaviour of the system be monitored, recognised and assessed in time?

Specific SYCON objectives

Evaluation of the present state of knowledge about the North Sea system in the face of the grand challenges was undertaken for four areas of interdisciplinary knowledge.

Data situation: A survey of existing data on the North Sea was carried out. *In situ*, remote sensing and model data were compiled and evaluated with regard to reliability and completeness in space and time. Since the North Sea is strongly influenced by external factors, forcing and boundary conditions also were included in the data collection.

Understanding of processes: Quantitative interpretation of data and model development requires adequate formulation of processes. These are based on small-scale field experiments or on laboratory experiments as well as on schematic calculations for test situations. SYCON surveyed the status of process parameterisations and their usefulness for making predictions about the North Sea ecosystem.

Development of models: The most important European model codes were classified and characterised according to their strengths and weaknesses. This included assessments of their completeness, their process formulations, their four-dimensional resolution, their computational complexity as well as validation, documentation and availability.

Instruments and methods: Instrumental and methodological capabilities are the basis for North Sea research. The state of their development determines how well we are able to understand the system. The potential and limits of available measuring equipment and computer generations was also surveyed.

Knowledge in each of these areas was finally compiled to yield an overall assessment of our understanding of the North Sea system.

Since the North Sea system is oblivious of national boundaries, our conclusions and recommendations are valid in a general, international sense and can thus serve as input for national or European programmes. The fact that SYCON was supported by an international advisory board also contributes to this.

The results of the SYCON synthesis form the basis for the following programmatic statements.

Understanding the North Sea system

We know that the state of the North Sea – as is the case for all natural systems – is determined by the interplay of external forcing and internal dynamics. Accordingly, the North Sea must be understood as a part of a superordinated North Atlantic/European Shelf system, and the dominant processes must be quantified. The formulation of these interactions in complex coupled models is to a certain extent the final stage of this understanding and is a scientific topic with its own priority (see Fig. 1).

Through the statistical analysis of empirical data it is largely agreed that the natural climatological variability of the Atlantic (e.g. the NAO) is transferred to the North Sea, not only to the physical but also to the biological subsystem. The actual causal chain, however, between the climatic state of the water and air in the Atlantic (circulation, distribution of kinetic and heat energy) and the shelf sea circulation and the state of the North Sea ecosystem is not clear.

- The transfer mechanisms of Atlantic variability to the North Sea must be analysed and quantified over seasonal to decadal time scales for the physical and the biological subsystems.
- A coupled four-dimensional model of the Northeast Atlantic and the North Sea/Baltic Sea must be developed which is appropriate for both

the oceanic as well as the shelf sea scales and which has a sufficiently high resolution, particularly of the transition area over the shelf edge.

- Meteorological data on net freshwater fluxes (evaporation and precipitation), solar radiation, deposition of dissolved and particulate substances (wet and dry deposition) need to be considerably more detailed and accurate than up to now. This includes new model approaches.

The internal dynamics of the North Sea system are dominated by numerous processes which characterise the interactions in and between the physical, chemical and biological subsystems.

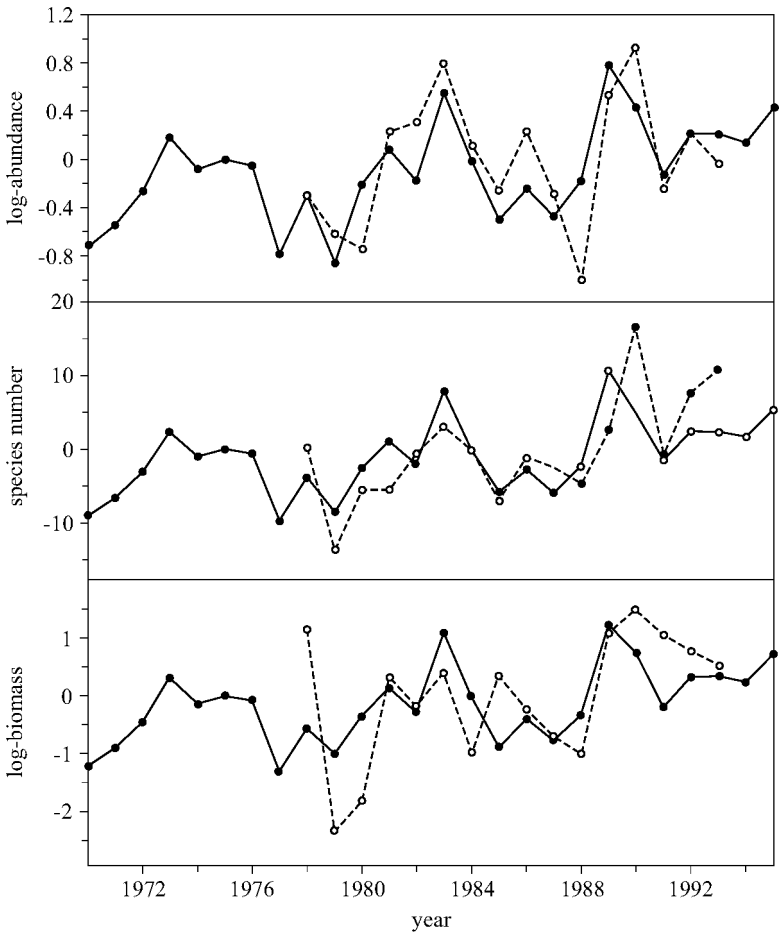

Fig. 1. Estimated (solid) and observed (dashed) anomalies of the log-abundance (top), species number (middle) and log-biomass (bottom) of macrobenthos in the 2nd quarter. The estimations were derived from the NAOI in the preceding winter (from Kröncke et al. 1998)

- New research initiatives in the area of the following key process complexes should be started: surface layer dynamics, eutrophication mechanisms, algae blooms, contaminant dynamics, trophic relationships, recruitment, morphodynamics, pelago-benthic coupling, nutrient regeneration. In each case, targeted process-oriented field investigations with laboratory experiments (including mesocosms) and model developments should be combined.

Successful understanding of the system is ultimately expressed in the development and implementation of complex coupled models which realistically and prognostically describe the functioning of the North Sea in all its compartments. In particular, three model couplings have been named which should be striven for but have not yet been sufficiently realised:

- Only just started, the model coupling between the atmosphere and the ocean for the shelf sea system North Sea/Baltic should be continued, tested and validated, and should become available as a standard tool for research and routine use.
- A coupled hydrodynamic-morphodynamic model influenced by biological feedback should be developed which can predict on the episodic to decadal scales.
- The coupling of physical, chemical and biological components to a comprehensive model of the North Sea ecosystem should be continued. It should be used to compute scenarios on the reaction potential of the North Sea in the face of natural and anthropogenic disturbances.

Natural and anthropogenic changes

One of the main tasks remains to differentiate natural variability from human disturbance of the North Sea system on different time scales, since environmental policy depends on this differentiation. Natural variation is the rule and not the exception, and it is an idle undertaking to try to combat it. Nevertheless, humans must try to use the available means to alleviate the effects of natural change such as shifts in vegetation zones. Anthropogenic disturbances are nevertheless basically controllable and should be aimed at sustainability within the framework of a wise environmental policy. Within this context, North Sea research must thus be devoted to the assessment of change and the efficacy of mitigation measures (see Figs. 2, 3, 4, 5).

With its strong fluctuations, climate is a significant factor in the external forcing of the North Sea system, particularly on the decadal time scale. The North Sea needs its own climate research programme in order to investigate the specific effects of the climate in this region.

- Existing approaches to the regionalisation of climate change for the North Sea/Baltic area must be improved and extended. Particular attention must be paid to the secular changes occurring as a result of global scenarios for the NAO, to wind statistics, to mean sea level, to surface wave statistics and to the circulation.

Anthropogenic changes in the ecological state of the North Sea/Baltic Sea are caused to a large degree by discharges of nutrients and contaminants via the rivers and the atmosphere. Although reduction measures have been successful in achieving a decrease in heavy metals, pesticides and phosphate, pollution from motor vehicles and aeroplanes (via the atmosphere) and discharges of new organic contaminants with unknown effects have for the most part increased.

- An area-wide survey of the present contamination status in the North Sea – as last carried out during ZISCH/TOSCH in 1986/87 – is essential, in particular with regard to new contaminant substances and their degradation products.
- The effects of these new contaminants and their degradation products on organisms and communities must be determined through field observations as well as laboratory and mesocosm experiments.

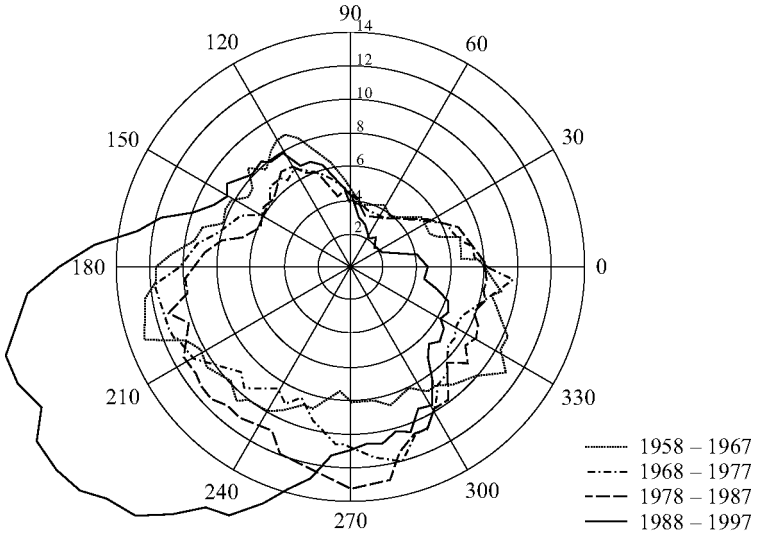

Fig. 2. Distribution of wind speed and wind direction over the North Sea for the four decades 1958–1967, 1968–1977, 1978–1987 and 1988–1997; each sector indicates the wind direction and distance from the centre of the probability of wind from that direction (adopted from Siegismund & Schrum 2001)

- Scenario calculations must be carried out to evaluate the effectiveness for the North Sea ecosystem of the measures which have been taken and which are being planned to reduce emissions.
- The combined effects of eutrophication and contamination, and the possible effects of one-sided reductions need to be studied.

In the most recent Quality Status Report for the North Sea (OSPAR Commission 2000), fisheries are accorded the rank of highest class of human impacts: '...effects occur on all levels of the ecosystem (from benthos to mammals)'. In addition to obvious measures such as fleet reduction, catch limitations or protected areas, a differentiated scientific basis for further measures is needed:

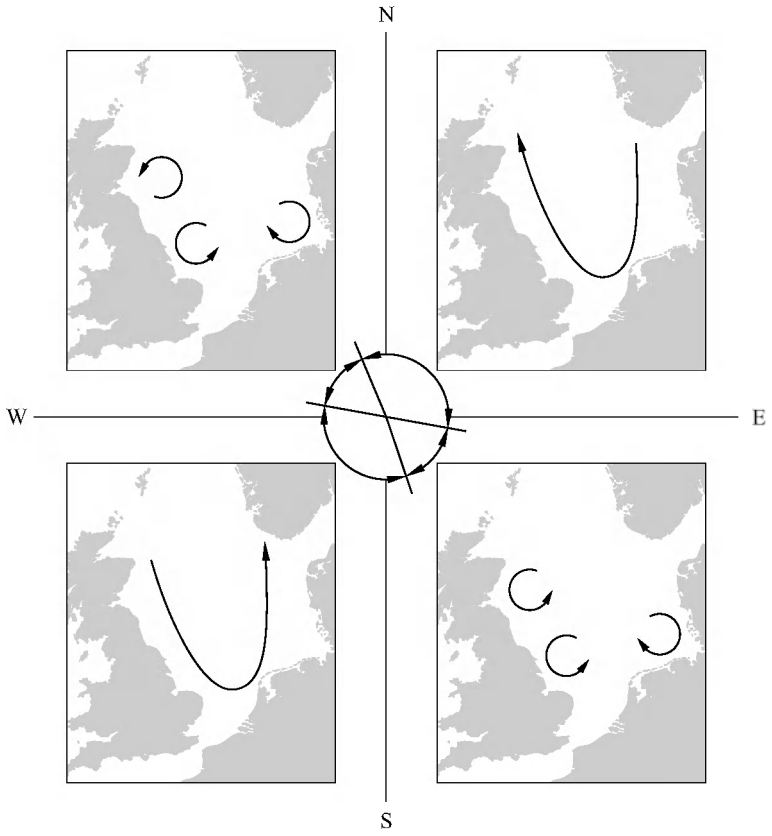

Fig. 3. The dependence of the basic circulation pattern of the North Sea on the wind direction. For the four wind sectors in the centre of the figure, which give the direction from which the prevailing winds blow, the diagrams show the corresponding general current situation. At present we have the situation at lower left with a strong cyclonic (anti-clockwise) flushing of the North Sea (schematic depiction: Jan Backhaus, unpublished)

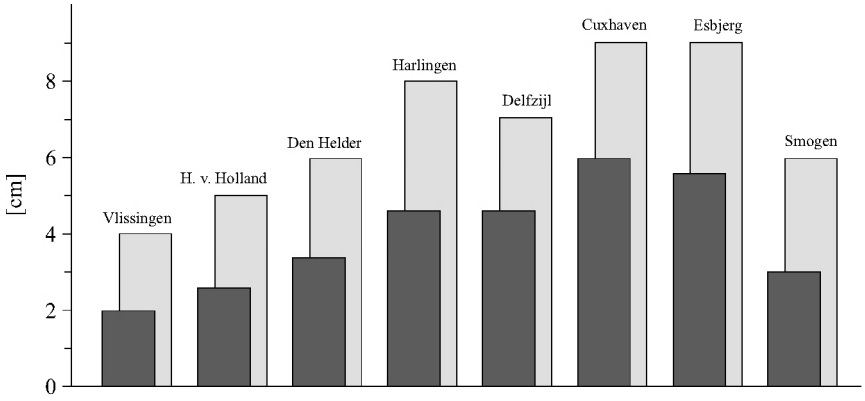

Fig. 4. Increase in maximum water level of moderate storm surges with $2xCO_2$-scenario (light grey) compared to twice the standard deviation from the years 1900–1996 (dark grey) (Langenberg et al. 1997)

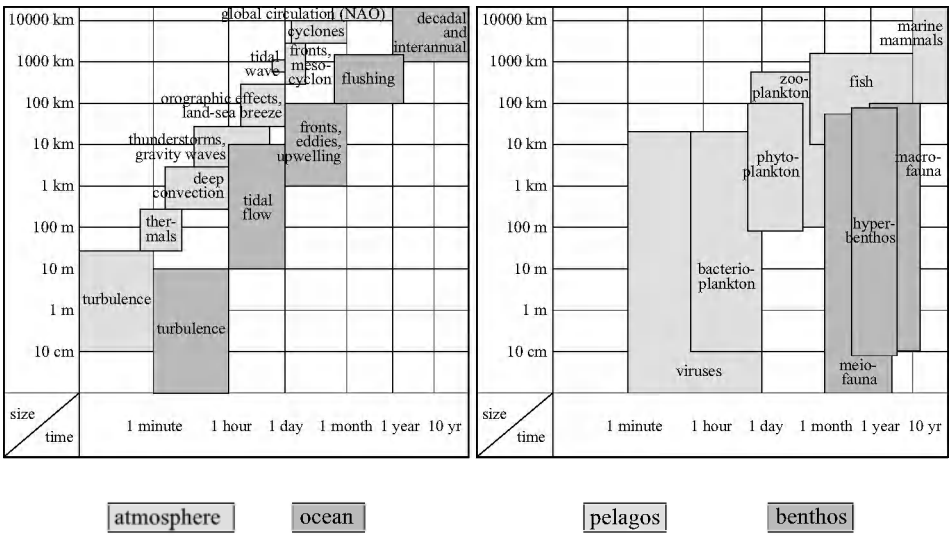

Fig. 5. Left: characteristic horizontal scales and time scales of atmospheric phenomena (after Orlanski 1975; modified for the North Sea) and hydrospheric phenomena (modified according to Pohlmann 2000; pers. communication); right: biological 'populations' in the pelagos (modified according to Floeter, Radach, Rick 2000; pers. communication) and in the benthos (modified according to Bergfeld, Radach 2000; pers. communication) of the North Sea. The horizontal scales for the biosphere characterise the area occupied by a 'population' (see above text) during a lifetime, not the total area where the specified organisms can be found or the size of the individuals. The characteristic times for the biosphere are typical lifetimes of 'populations', not maximum lifetimes

- A multi-species approach toward fisheries must be developed which considers the effects of fisheries on the entire ecosystem.
- Additional concepts need to be developed for protected areas which also include juvenile fish and benthic habitats.

An additional source of disturbance is the introduction of exotic species, e.g. through shipping and aquaculture. They can become dominant in certain situations and thus cause considerable shifts in biocenoses. Possible long-term effects on the ecosystem have hardly been investigated.

Strategies for sustainable use

The goal of using the resources of the North Sea and at the same time protecting the ecosystem requires long-term, integrated planning and management concepts. Governments, stakeholders and scientists must cooperate to develop these concepts. The object is the timely recognition of potential conflicts and the efficient use of scientific and administrative means.

Existing conceptional approaches to North Sea management need to be brought together and developed into an integrated, objective procedural package for practical implementation. Specific problems in this connection are the development of objective, commensurable assessment criteria (also for ideal values), the (monetary) appraisal of natural systems, the evaluation of decision making pathways. Model formulations will be helpful in this respect.

The conception and designation of marine nature reserves requires a strong scientific foundation. Collaboration between natural scientists, economists, sociologists and legal experts is needed for the development of targets, appropriate measures and analysis of societal implications.

Monitoring and operation

Observational data are the basis for all North Sea research. Together with targeted, usually problem-oriented experiments, there is a need for continuous representative monitoring of the North Sea system. These measurements must be complemented by the results of operational models, for these alone are capable of covering the four dimensional space-time continuum and making predictions. Finally, the entire body of experimental and numerical data needs to be stored, administered and kept available.

- We need long-term, spatially and temporally well-resolved data series for physical, chemical and biological parameters at the Atlantic entrances to the North Sea between Scotland and Norway and in the English Channel.

- Similar data series are necessary for the transition zone between the North Sea and the Baltic.

- In addition, long-term point measurements in the North Sea of the above-mentioned parameters are needed at representative locations in order to recognise changes in water quality and in the ecosystem.

- In addition to these point measurements, regular profiles provide information of high ancillary value. Thus, the Continuous Plankton Recorder (CPR) series should be carried on. Further data sets should be collected from ships of opportunity.

- There is an urgent, still unfulfilled need for a standardised North Sea-wide digital topography with a resolution of approximately 1 km to be made available to all abutting states.

- The interannual and decadal morphological changes in the North Sea must be observed, partly with the help of remote sensing methods, and employed for the correction of bathymetric data.

Monitoring must be supplemented and amplified in its effectiveness by the simultaneous employment of operational models into which the observational data can be assimilated. These then give routine information about the state of the North Sea with a high spatial and temporal resolution.

Implementation of further North Sea research

The research deficits mentioned above require new initiatives for North Sea research and for shelf seas in general. After the great progress made by large national projects (e.g. 'Circulation and Contaminant Fluxes' in Germany and the 'North Sea Programme' in the United Kingdom) and numerous European projects in the Marine Science and Technology Programme a certain stagnation has set in. This is not justified, since the impacts of global change also affect the North Sea, presenting new challenges for which there is insufficient scientific knowledge.

The 6th Framework Programme of the European Union will not explicitly support North Sea research. It will hopefully offer the opportunity to coordinate the national efforts of the riparian states (or others interested in shelf sea research) by means of Networks of Excellence. It presumes, however, that national programmes for shelf sea research are funded. Shelf sea scientists should lobby in this direction wherever possible.

References

Kröncke I., Dippner J., Heyen H., Zeiss B., 1998, *Long-term changes in macrofauna communities off Norderney (East Frisia, Germany) in relation to climate variability*, Mar. Ecol. Prog. Ser., 167, 25–36.

Langenberg H., Pfizenmayer A., von Storch H., Sündermann J., 1997, *Natural variability and anthropogenic change of storm related sea level variations along the North Sea coast*, GKSS 97/E/48, 1–26.

OSPAR Commission, 2000, Quality Status Report 2000, Region II – Greater North Sea, OSPAR Commission, London, 136 + xiii pp.

Siegismund F., Schrum C., 2001, *Decadal changes in the wind forcing over the North Sea*, Climate Res., 18, 39–45.

Sündermann J., Beddig S., Kröncke I., Radach G., Schlünzen K. H. (eds.), 2001, *The changing North Sea: Knowledge, speculation and new challenges – Synthesis and New Conception of North Sea Research (SYCON)*, Ber. ZMK, Z 3, 358 pp.

Further reading

Charnock H., Dyer K. R., Huthnance J. M., Liss P. S., Simpson J. H., Tett P. B. (eds.), 1993, *Understanding the North Sea system*, Chapman & Hall, London, 222 pp.

Sündermann J. (ed.), 1994, *Circulation and contaminant fluxes in the North Sea*, Springer-Verlag, Berlin–Heidelberg, 654 pp.

Annex 1

SYCON Products

- Twelve volumes in the series 'Berichte aus dem Zentrum für Meeres- und Klimaforschung', Hamburg, Reihe Z: Interdisziplinäre Zentrumsberichte (ISSN 0947–Z136):

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Topcu D. H., Brockmann U., 2003, Nutrients and organic compounds in the North Sea: a review, 162 pp. + Abbs.

- The general interest brochure 'The North Sea – Problems and Research Needs'.

- http://www.rrz.uni-hamburg.de/SYKON/