THE ICES NORTH SEA BENTHOS PROJECT 2000: AIMS, OUTCOMES AND RECOMMENDATIONS

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ABSTRACT

The ICES Study Group on the North Sea Benthos Project 2000 undertook to integrate recent (1999–2002) macrobenthic infaunal and environmental data from various national sources. The main aim was to compare the outcome with that of the ICES North Sea Benthos Survey conducted in 1986, to identify any significant changes and their likely causes. In the process, the exercise yielded valuable lessons for the conduct of international collaborative programmes, as well as insights into the utility of a range of interpretational tools. These are timely in view of increasing requirements for periodic sea-wide assessments of quality status to meet international obligations, such as those under OSPAR, ICES, HELCOM, and EU auspices for European waters. This paper provides an overview of the work which, in contrast to the 1986 survey, was more reliant on the opportunistic gathering of existing data from various sources. This presented special challenges for locating willing contributors, and then for combining and managing the sources effectively, a task which was greatly facilitated by dedicated data management support. The range of interpretational approaches aimed at evaluating spatial patterns and changes over time are summarised and the overall conclusions are presented. North Sea benthic communities appear to exhibit traits both of resilience and adaptability over different scales but continue to be structured by predominantly natural forces. Finally, lessons learnt from the ICES NSBP 2000 initiative are reviewed, and recommendations are made for the conduct of future surveys on comparable scales in the North Sea and elsewhere.

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INTRODUCTION

The Greater North Sea is defined (OSPAR Commission, 2000) by coordinates at 48° to 62°N, and 5°W to 12°E (Figure 1). To the south, it embraces the entire English Channel bordered by England, France, and Belgium, and to the east the waters of the Skagerrak and Kattegat, bounded by Denmark, Norway, and Sweden. Exchange occurs principally through the influx of Atlantic water to the north and to a lesser extent *via* the Channel, and from the Baltic to the east, along with northward efflux, mainly along the Norwegian coast. An overall estimate of about one year for the flushing time of the entire North Sea disguises significant regional and temporal variations associated, *inter alia*, with prevailing depth, wave and tidal current regimes, and thermal stability of the water column. The North Sea is relatively shallow, with depths generally not exceeding 100 m, except in the northern North Sea and in the Norwegian Trench.
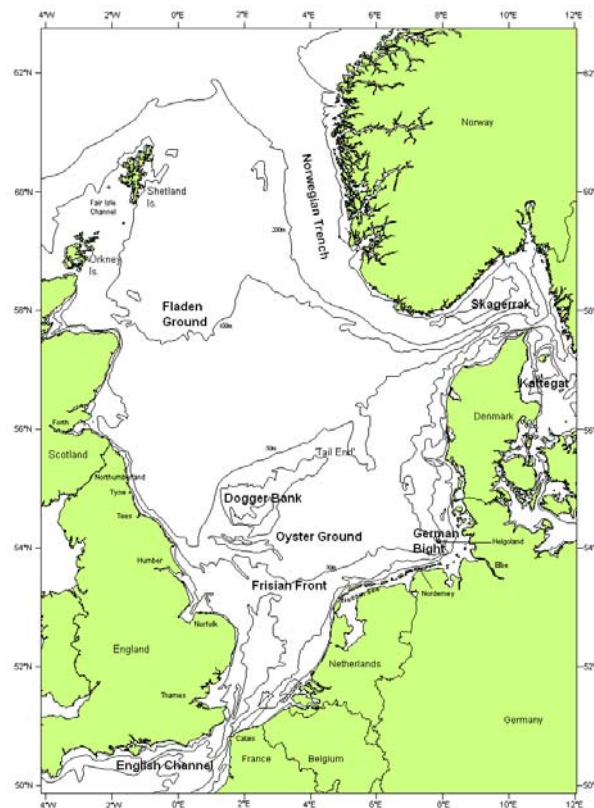

Figure 1. The North Sea with depth contours (courtesy M. Curtis, Cefas).

Macroinfaunal communities are especially suited to comparative investigations of the status of benthic ecosystems, because many of the constituent species are of low mobility, relatively long-lived, and integrate effects of environmental changes over time. Sampling and analytical methodologies, and accompanying frameworks for the interpretation of patterns or trends, are now well established. The macrobenthos of the North Sea has been studied on localised scales for many years and, because it is relatively easy to sample quantitatively and consistently over time, it is the mainstay of many biological trend monitoring programmes. However, the initiative to conduct a synoptic sampling exercise for the entire North Sea was only taken in 1986, under ICES auspices (*e.g*., Heip and Craeymeersch, 1995; Heip *et al.*, 1992; Künitzer *et al.*, 1992; Craeymeersch *et al.*, 1997). Five countries (Belgium, the Netherlands, Germany, France, and the UK) collaborated in the sampling of the southern North Sea in April 1986. The data were supplemented by an earlier extensive grid survey of the northern part conducted by Scotland (see *e.g*., Eleftheriou and Basford, 1989). In addition to analysis of the benthic macrofauna from corers and grabs, data were also generated on the physico-chemical status of sediments (Basford *et al.*, 1993; Irion and Müller, 1987), on the meiofauna (principally copepods: see Huys *et al.*, 1992), and on the epifauna from small trawls or dredges (*e.g*., Duineveld *et al.*, 1991).

Following the success of this work, the ICES Benthos Ecology Working Group recommended that a survey be repeated to identify any changes to the status of communities identified in 1986 and their relationship with natural or human influences. A decision was made to promote national re-sampling of stations from the 1986 North Sea Benthos Survey or, alternatively, to seek contributions from ongoing national research and monitoring efforts that, collectively, might allow a holistic assessment comparable with that achieved in 1986. This paper summarises the outcome of a collaborative exercise to reappraise the status of the North Sea macrofauna, involving seven countries and 14 data contributors. The work was conducted under the auspices of the ICES Study Group on the North Sea Benthos Project (NSBP) 2000. A full account is given in Rees *et al*. (eds., 2007) and further insights may be expected in follow-up peer-reviewed publications.

AIMS

The main task of the ICES NSBP 2000 Study Group was to conduct a re-appraisal of the status of the North Sea benthic communities following the earlier (1986) ICES North Sea Benthos Survey. Specific aims were to:

- revisit as many stations as possible sampled during the 1986 ICES North Sea Benthos Survey
- augment new sampling effort with existing information from other sources collected during the period 1999–2002 in order to maximise coverage of the North Sea area
- establish a dedicated NSBP 2000 database at the Flanders Marine Institute
- work through annual ICES study group meetings, intersessional workshops, and *via* the ICES Benthos Ecology Working Group to resolve problems affecting the compatibility of datasets from different sources

- determine patterns in contemporary North Sea benthic communities and causal influences by reference to supporting environmental data from NSBP 2000 and other sources
- compare the outcome of NSBP 2000 with that of the 1986 ICES North Sea Benthos Survey and postulate causes for any observed differences
- report findings to ICES and produce peer-reviewed papers
- provide a strategic evaluation of the utility of the collaborative exercise for sea-wide quality assessments and make recommendations for the timing and coordination of any future work

OUTCOMES

NSBP 2000 data management (Vanden Berghe *et al*., 2007)

A combination of new sampling effort at a proportion of the 1986 ICES North Sea Benthos Survey stations, along with contributions of existing data from several other sources, provided good coverage of the North Sea, especially of the southern part (Figure 2). Data from inshore environments and the eastern English Channel extended the scope of the earlier survey. Much effort was committed to the harmonisation of datasets on the macrobenthic infauna and associated environmental variables from different sources, which included desk-based evaluation of combined species lists and some laboratory work to resolve identification problems. A database dedicated to the outputs from the ICES North Sea Benthos Project (NSBP) 2000 was constructed at the Flanders Marine Institute, underpinned by a national resource commitment. This was indispensable in serving the needs of the present collaborative assessment and will continue to act as an international repository for relevant biological and environmental data.
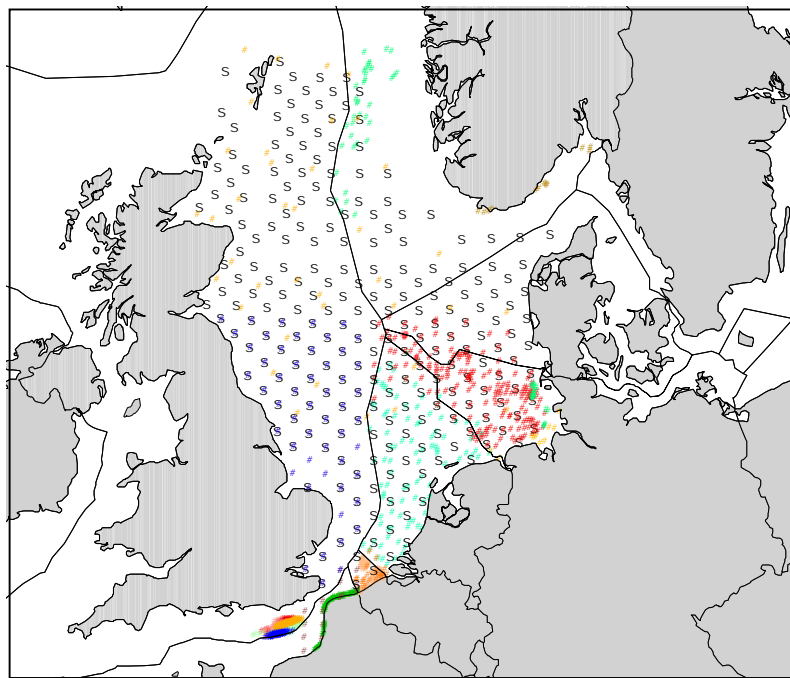

Figure 2. Location of sampling stations (1986 and 2000 surveys). The different datasets contributing to NSBP 2000 are colour-coded. The NSBS 1986 stations are indicated by the letter S (from Vanden Berghe *et al*., 2007).

Sediment particle size (Hillewaert, 2007)

Sediment types in 2000 matched the expected pattern, with coarser sediments to the south and east of the study area, and finer sediments to the north. The pattern can be broadly linked to changes in bathymetry and tidal current velocities. Despite differences in methodologies for particle size analyses both between (1986 and 2000) and within (2000) surveys, principally relating to the use of conventional sieving or laser sizing, the derived statistics suggested that the two datasets were very similar between years, and no major changes were evident (Figure 3).
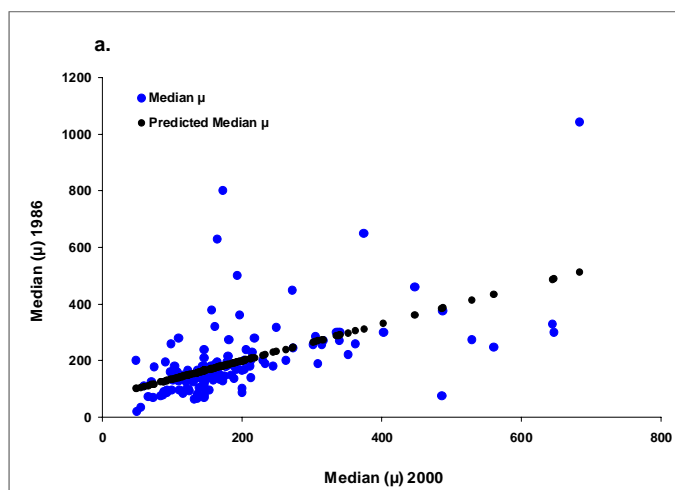

Figure 3. Relation between median grain sizes for 146 station pairs (1986 and 2000 data); Pearson correlation = 0.567, P <0.001 (from Hillewaert, 2007).

Trace metal concentrations in sediments (Kershaw *et al.*, 2007)

This assessment was limited to the southern North Sea in 2000, and was further constrained by methodological differences between surveys (Figure 4). However, useful insights could also be gained from other surveys in the intervening period between 1986 and 2000. Evaluations against OSPAR criteria revealed a widespread legacy of contamination of fine sediments as a result of two centuries of industrialisation. Regional differences may also reflect the erosion of geological strata which vary naturally in trace metal content. For some areas, it may therefore be more realistic to determine the degree of contamination by reference to regionally- rather than globally-defined norms. Multivariate analysis of the relationships between trace metal concentrations of sediments and the benthic macrofauna in the SW North Sea provided no evidence of any adverse consequences at the levels encountered in 2000. The limited geographical coverage and methodological constraints reflected the opportunistic nature of data gathering for NSBP 2000 and it is recommended that adequate resources are targeted at the resolution of these issues in future North Sea-wide collaborative surveys.
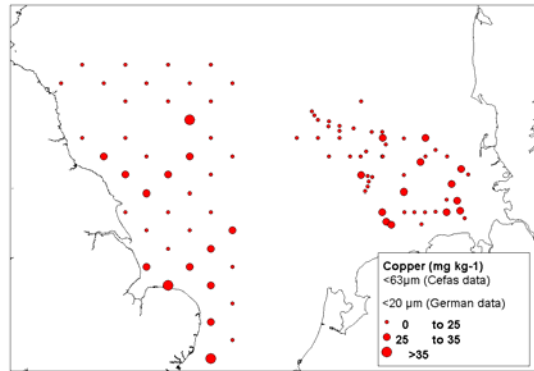
Figure 4. Distribution of copper (mg kg−1) in the <20 μm fraction of surface sediments from the German Bight, and the <63 μm fraction of surface sediments from English waters (from Kershaw *et al*., 2007).

Structure, distribution and characterising species of North Sea macro-zoobenthos communities in 2000 (Rachor *et al*., 2007)

The major divisions in benthic communities in 2000 were especially associated with the 30 m (Frisian Front) and 50 m (Dogger Bank) contours (Figure 5). Water depths generally increase from south to north, while soft sediments generally become finer and, as in 1986, these are matched by increased community diversity to the north. Coarser substrata in the southwestern North Sea and the eastern English Channel sampled in 2000 generally supported species-rich communities and hence contrasted with the trend of increasing diversity of the fauna of finer sediments to the north. A combination of increased hydroclimatic variability, reduced salinity and human-induced perturbations may account for the reduced diversity of soft sediments in the shallowest parts of the southern North Sea. These factors, along with distance from the richer Atlantic species pool, may also explain a west-to-east decline in diversity.
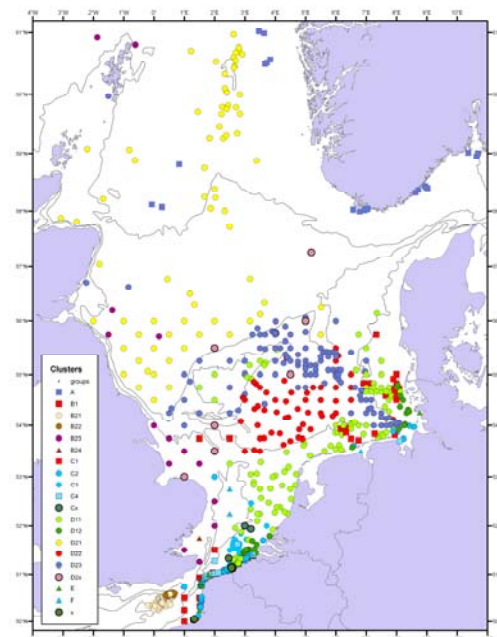

Figure 5. Distribution of assemblages in the North Sea in 2000 according to group-average cluster analysis (from Rachor *et al*., 2007).

Changes in community structure (1986-2000) and causal influences (Kröncke and Reiss, 2007)

Comparisons between the 1986 and 2000 surveys employing a reduced dataset of 'matched' stations indicated broad similarities in the disposition of communities and hence relative stability at the scale of the whole North Sea (Figure 6). The major divisions between community types occurred at the 50 and 100 m depth contours. At the assemblage level, there were significant differences between clusters at some locations, especially in the eastern North Sea and off the northern UK coast. The boundaries of these assemblages were not identical between years, and appreciable differences occurred at the stations comprising each cluster. Changes in species occurrences or densities could be accounted for, in part, by sampling or analytical differences especially in the northern North Sea, where sampling effort was also much reduced in 2000. Changes may also be accounted for by hydroclimatic influences on sediment structure, *e.g.*, in the vicinity of the Dogger Bank (see also Wieking and Kröncke, 2001). NAO-influenced increases in SST and associated food availability could also account for species compositional changes, *e.g.*, in the German Bight and the SW North Sea approaching the English Channel.
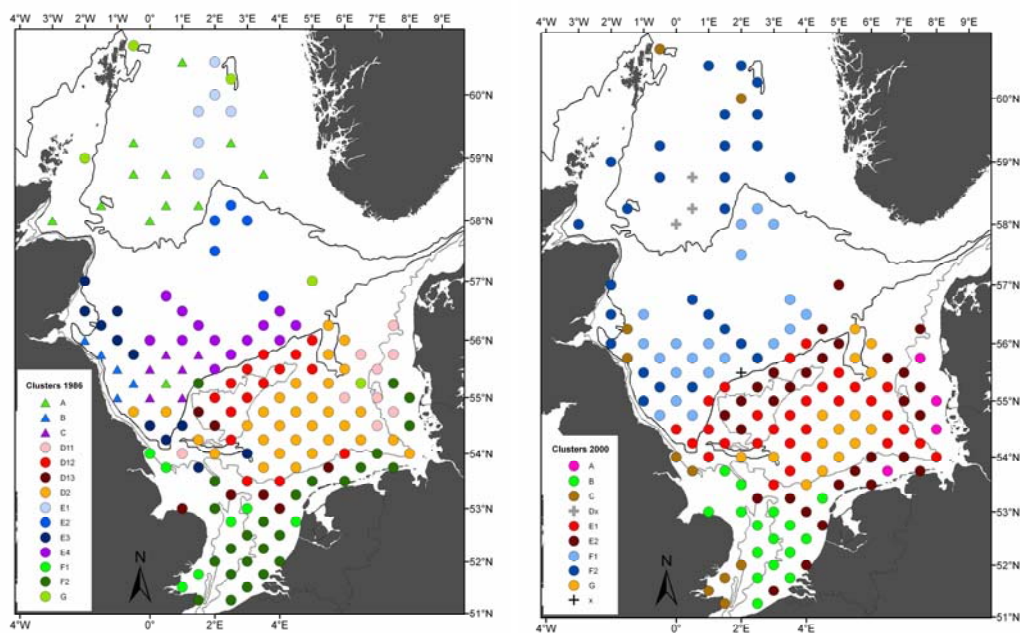

Figure 6. Spatial distribution of infaunal communities in 1986 (left) and 2000 (right), based on fourth-root transformed abundance data (from Kröncke and Reiss, 2007).

Relations and interactions between environmental factors and biotic properties (Willems *et al.*, 2007)

Patterns in the North Sea benthos can be explained largely by the measured or modelled environmental variables and multivariate (PCA) analyses helped to characterise assemblage types in terms of their 'realised' niches. Single-variable plots are useful to visualise the major trends, though caution is required due to the potential for co-variability. The inclusion in 2000 of biodiverse samples from coarser deposits in the English Channel altered a number of conventional perceptions of macro-scale

relationships for the predominantly finer deposits to the north. Additional insights included a negative correlation between densities and tidal bed stress, and a positive correlation between diversity and stratification (which, however, could also be linked with latitudinal variation in temperature and depth regimes).

Spatial trends in 1986 and 2000 were very similar, indicating stability in benthic ecosystem responses to environmental variability at the level of the North Sea. In both years biomass and, more strikingly, mean individual weights decreased with increasing latitude. Opportunistic exploitation of the more energetic shallower southern North Sea might have been expected to show the reverse, but might be explained by greater dependability and quantity of food inputs to the seabed in southern waters. Heip *et al.* (1992) identified a positive relation between sediment chlorophyll *a* and benthic biomass in 1986 but no data were available in 2000 and no link could be established between surface chlorophyll *a* and biomass.

Finally, the occurrence of increasing diversity with latitude for finer sediments in the North Sea (Figure 7) is contrary to the global expectation (but see Gray, 2002), indicating that regional circumstances may confound hypothesised relationships over larger scales. The interruption to the pattern for finer sediments resulting from the inclusion of species-rich coarser (principally Channel) stations in 2000 is a further reminder that certain relationships when viewed at the scale of the North Sea may be correlative or at, best, locally rather than globally causative.
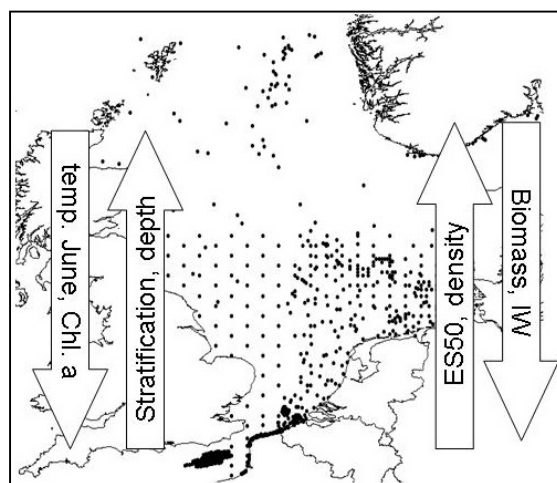

Figure 7. Schematic overview of the abiotic and biotic gradients. The arrows point in the direction of the highest values for the variables (from Willems *et al.*, 2007).

Species distributions and changes (1986-2000) (Eggleton *et al.*, 2007)

Naturally-occurring species in the North Sea are generally categorised as northern, southern or cosmopolitan. In the first two cases, distributional limits have frequently been identified in the vicinity of the Dogger Bank (*e.g.*, Wieking and Kroncke, 2001). An examination of the occurrences and densities of a wide range of species revealed a generally close association with habitat type, upon which biogeographical influences may be super-imposed. Between 1986 and 2000, there was evidence of appreciable flux over a variety of spatial scales, which may be accounted for by natural seasonal and year-to-year changes in recruitment and survivorship, coupled with the relatively

short-lived nature of the majority of species encountered (*i.e.*, considerably less than the 15-year interval between the two synoptic surveys). Overall, changes in the distributions or densities of the selected species appeared to reflect a dynamic equilibrium, with no evidence of a consistent directional trend. Individual species that might be linked to any net warming trend included the brittle-star *Acrocnida brachiata* which showed an increasing presence in the eastern North Sea, especially the German Bight, and on the Dogger Bank (Figure 8).
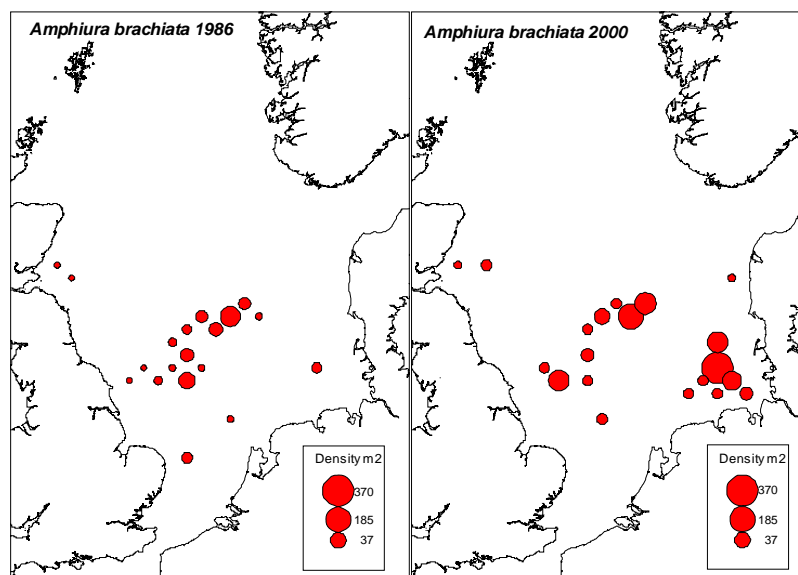

Figure 8. Distribution and densities of *Acrocnida brachiata* at 1986 (left) and 2000 (right) North Sea benthos survey stations (from Eggleton *et al.*, 2007).

Functional diversity (Lavaleye *et al.*, 2007)

An evaluation of North Sea-wide patterns in the proportional numerical contribution of feeding types identified interface feeders as the most important component across most stations, while suspension feeders predominated on the Oyster Ground (Figure 9). The same pattern was evident in 1986 and 2000, both when mapped and expressed graphically for each feeding type against the latitudinal gradient. However, when the data were grouped according to the three main assemblage types identified (from the 1986 NSBS) by Künitzer *et al.* (1992), significant differences in the proportional contribution of feeding types between 1986 and 2000 were found. The direction of change appeared to differ between assemblages, and the causes remain speculative. On the Oyster Ground, further insights are available from the recent work of van Nes *et al.* (2007), who ascribed changes in dominant species in the mid-1990s to an ecological 'regime shift', the timing of which was inconsistent with earlier climate-mediated events such as a shift in the 1980s to warmer water temperatures.
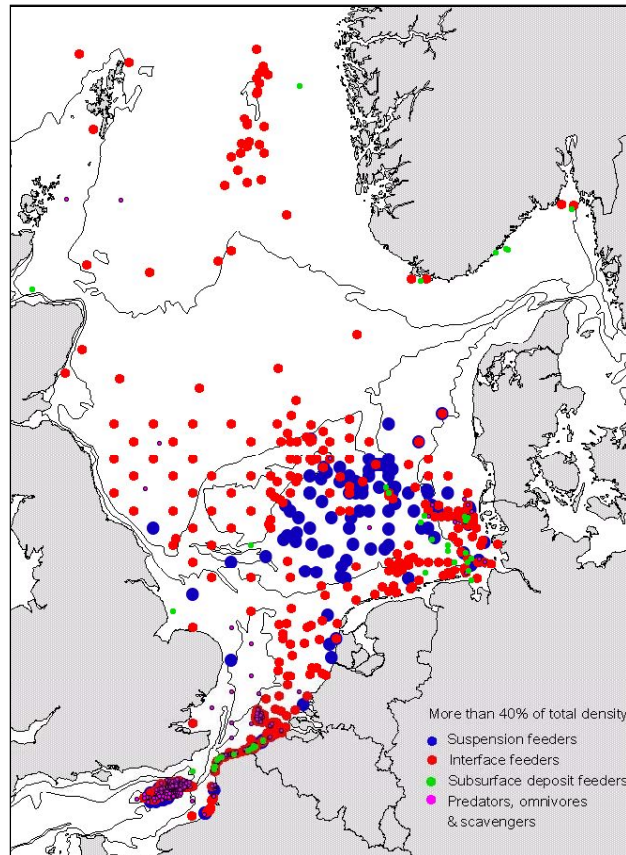
Figure 9. Distribution of the feeding types for NSBP 2000. The feeding types per station are shown only if larger than 40%. The symbols have different colours as well as different sizes to make a possible overlap visible in the case of two feeding types having more than 40% of the total density at the same station (from Lavaleye *et al.*, 2007).

A comparison of indicators reflecting the status of the North Sea benthos (Van Hoey *et al.*, 2007)

Overall, there was evidence of marginally increased densities (N) and decreased diversity (ES[50]) between 1986 and 2000 (Figure 10), though some caution was necessary in the interpretation of findings, in view of sampling inconsistencies both within and between these surveys. Other univariate indices, including multimetric compilations, showed no significant differences. At the assemblage level, differences included enhanced diversity in the northern North Sea which may be an artefact of improved taxonomic sufficiency. Most univariate measures showed declines between years, although in many cases these were not statistically significant. Multimetric indices generally performed consistently, despite their different formulations, and there was some evidence of a significant decline in values for assemblages at the Dogger Bank and in the Southern Bight. However, according to these indices, the status of all assemblages could be classified as 'good' to 'high'.
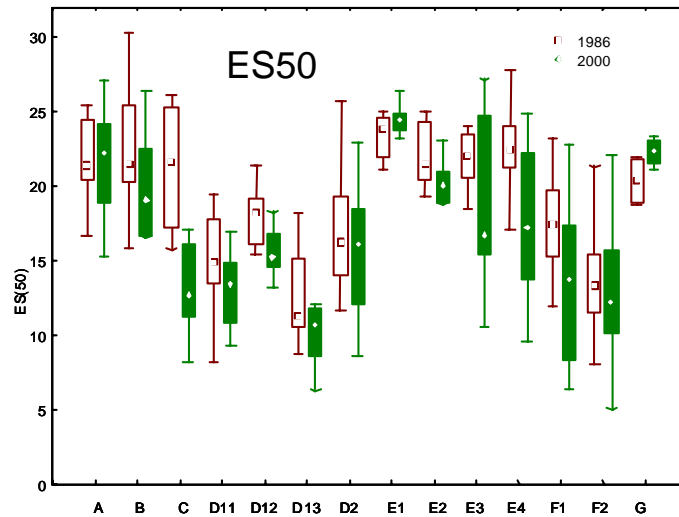
Figure 10. Box plots comparing ES(50) for 1986 (brown) and 2000 (green) across assemblage types identified by Kröncke and Reiss (2007) (from Van Hoey et al., 2007).

Benthic community studies over relevant time-scales (Rees et al., 2007)

There was no evidence from the available literature of a consistent directional trend over time in the densities or diversity of the benthic macrofauna at various North Sea locations (Figure 11). However, a number of studies identified responses to climatic changes, exemplified by correlations with the NAO Index, the nature and timing of which varied with locality.
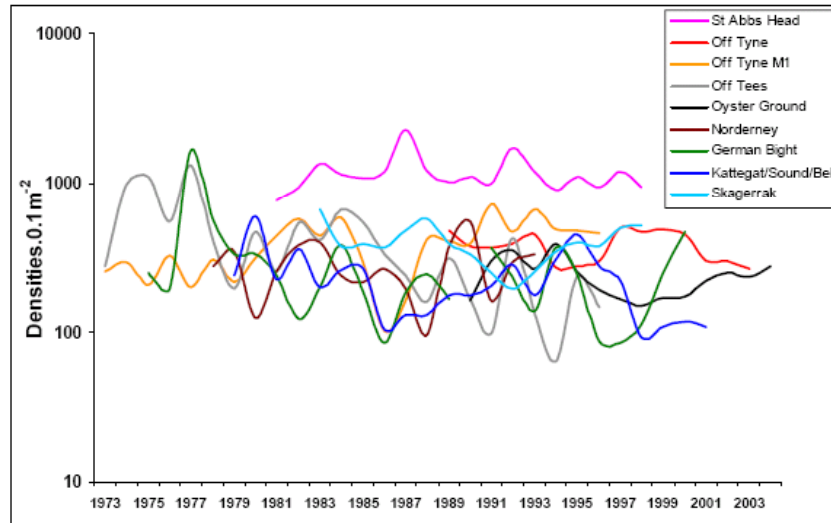

Figure 11. Annual trends in total densities of the macrofauna from various published studies (from Rees et al., 2007).

Links between infauna, epifauna and demersal fish distributions (Reiss and Rees, 2007)

In order to provide a broader ecosystem context for the interpretation of NSBP 2000 outputs, the data were analysed in conjunction with epifaunal and fish assemblage data collected under other (EU and ICES) auspices. Patterns in univariate derivations

from the latter two datasets were similar in some respects, *e.g.*, species numbers were in both cases positively correlated with latitude, but different in others, *e.g.*, epifaunal densities in the northern North Sea were highest to the east, while fish densities were highest to the west. Patterns in the distribution of epifaunal and fish assemblage types determined from cluster analyses were very similar (Figure 12), with major distinctions between the southern (<50 m), central (50-100 m) and northern (100-200 m) North Sea.

The degree of similarity with the infaunal (NSBP 2000) data was quantitatively assessed for a subset of matching stations. No significant correlations were found between univariate measures of the infauna and fish. However, the multivariate similarity matrices of all three components were significantly correlated. This supports visual assessments of the disposition of assemblage types across the North Sea, and leads to the important conclusion that there appears to be a broad level of consistency in the responses of the infauna, epifauna and fish to widely-operating environmental forces. This was further re-inforced by the outcome of an analysis of inter-relationships with a range of environmental variables, with hydrographic influences being especially important. However, their influence on smaller spatial scales appeared to more variable across the faunal components. For future assessments, it is recommended that there is co-ordinated sampling across all components to satisfy the needs of an ecosystem approach to environmental management.
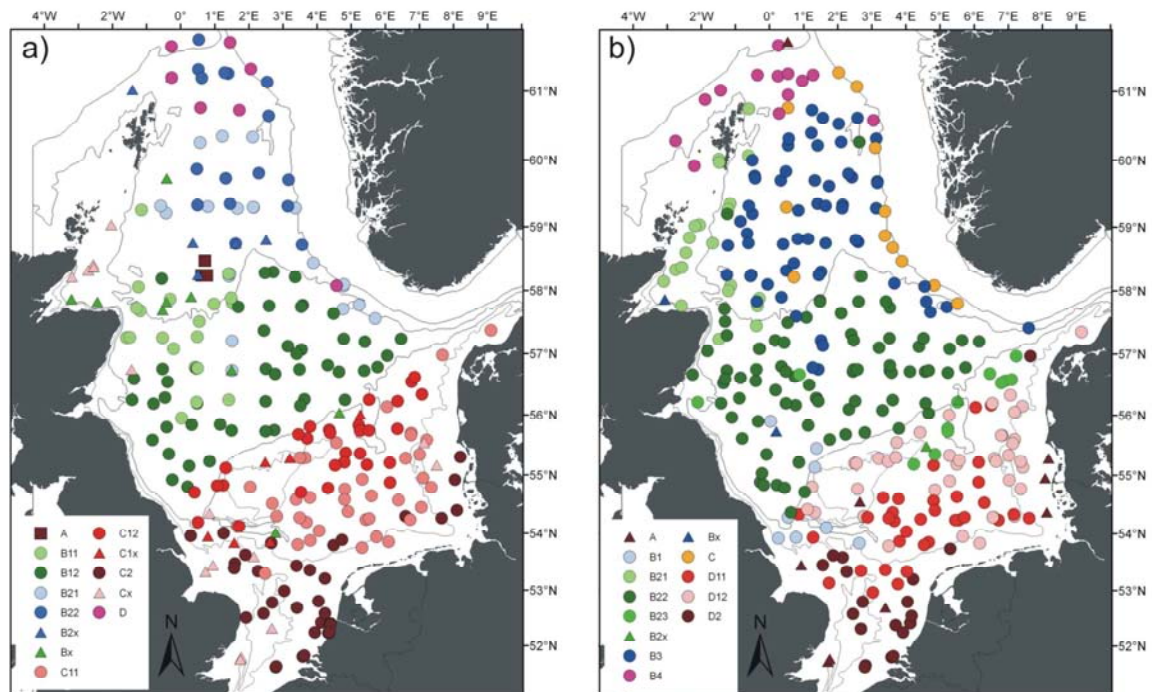

Figure 12. Distribution of (a) epifauna and (b) fish assemblages in the North Sea according to the outputs from cluster analyses of fourth-root transformed abundance data (from Reiss and Rees, 2007).

Benthic foodweb studies (Duineveld, 2007)

Further investigation of trophic interactions among the major ecosystem components was beyond the scope of the NSBP 2000 initiative. However, a review of recent studies in the North Sea indicated that, while the effects of commercial fishing may (through gear impacts or predator removal) induce structural changes in benthic assemblages, there was as yet no evidence of adverse consequences for the overall process of energy transfer through the benthic ecosystem.

Fishing practices (Craeymeersch *et al*., 2007)

This assessment greatly benefited from recently-compiled data on the distribution of fishing effort under the EU MAFCONS project (www.mafcons.org and Greenstreet *et al*., 2007a,b). Analyses of the relationships between these data, other NSBP 2000 environmental variables and the benthic macrofauna identified small but significant differences in species composition between areas experiencing different fisheries. For example, at some locations elevated densities of certain opportunistic polychaete and bivalve species could be linked with fishing pressure. However, the apparent effect of seine gears and industrial otter trawling was surprising as these are not normally considered to be as influential as (for example) beam trawling. As a result, the relationship between fishing activities and benthic communities was considered to be largely correlative rather than causative. Many studies have identified a broad association between the distribution of benthic communities, commercial fish distributions and hence fishing effort and this encapsulates one of the main difficulties of separating fishing effects from natural variability (known or unkown) based on field observations. For example, comparisons of heavily- and lightly-fished areas may be confounded by environmental distinctions which themselves account for the presence or absence of commercially-exploitable stocks.

There was no evidence that changes in the benthos between the two sampling occasions (1986 and 2000) were attributable to changes in fishing effort. The largest changes were encountered in the northern North Sea and in coastal waters (Figure 13). The former may be an artefact of taxonomic sufficiency, while the latter appear to be largely natural in origin as a result of greater inter-annual variability in response to the more dynamic environment of shallower waters. The findings accord with those of the EU MAFCONS project (Greenstreet *et al*., 2007a,b), namely the absence of a classical response of the benthos to fishing-induced perturbations in space or over time, exemplified by the 'Intermediate Disturbance' hypothesis of Huston (1996).

NSBP 2000 data are unsuitable for evaluating the effects of fishing activities on larger (and rarer) infaunal species which are not sampled adequately by conventional grabs or corers. Other work has identified the potential for effects to be expressed through changes in the distribution of body sizes and further analyses of NSBP data employing such information is to be recommended, as is the integration of findings with parallel epifaunal studies, and the gathering of more precise information on fishing effort from satellite data.
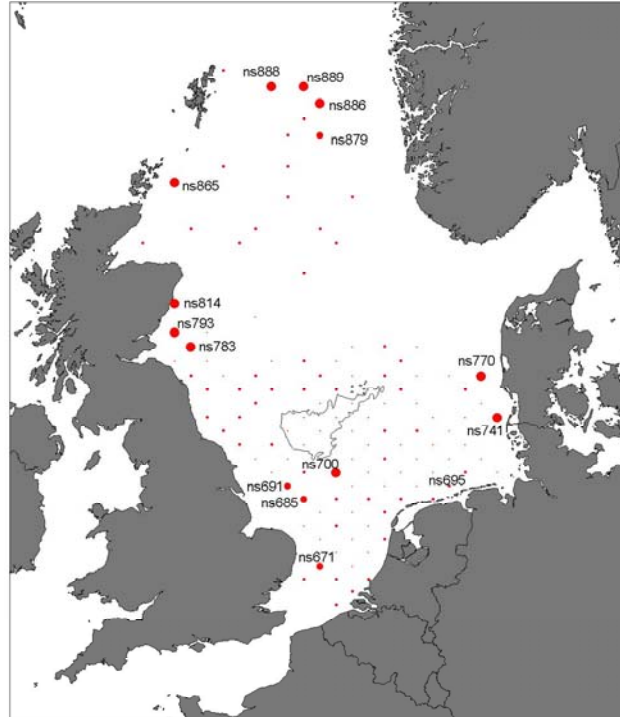
Figure 13. Position of the stations sampled in both 1986 and 2000 used for the partial correspondence analysis. The superimposed symbols represent the change in species composition: the larger the radius of the circles, the larger the change of the position on the first ordination plane (from Craeymeersch *et al*., 2007).

Meiofaunal and microbial communities (Schratzberger, 2007a,b)

Meiofaunal nematodes were studied at NSBP 2000 stations in the SW North Sea and compared with parallel data for the macro-infauna, epifauna and fish. Nematode communities were similar to those encountered in comparable environments world-wide, and varied locally in response to changes in depth and sediment type. In agreement with the wider assessment of Reiss and Rees (2007), similar distributional patterns were observed for all faunal groups over the station grid, reflecting broad comparability in the responses to environmental influences, especially habitat type and the hydrodynamic regime. Acute effects on the nematode fauna of trace metal contaminants in sediments at the levels encountered are unlikely (see Kershaw *et al*., 2007), though the effects of bottom trawling cannot be ruled out.

Research into the structure of benthic microbial communities in the western North Sea also demonstrated a close dependence on substratum type. Recent technological advances accentuate the potential utility of microbial ecological studies in evaluating structural and functional responses to human influences over various spatial scales.

Habitat suitability modelling (Willems, 2007)

The development of 'habitat suitability' models for predicting species occurrences provided a good example of the potential for wider application of the NSBP 2000 data. Employing a combination of distributional records and a sub-set of influential environmental variables from PCA output, Neural Network Analysis was performed

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to predict occurrences which could then be tested against field observations and iteratively adjusted for plausibility. The outcome may be used to erect hypotheses for testing against the outcome of future surveys, as well as to extend existing observational data, *e.g.*, in support of habitat-mapping initiatives.

The effect of the presence of *Lanice conchilega* on the soft-bottom benthic ecosystem of the North Sea (Van Hoey, 2007)

A further example of the value of the NSBP 2000 data was provided by a parallel study of the ecological role of the sand-mason worm *Lanice conchilega*. This successfully demonstrated a link between the development in patches of species-rich assemblages and the presence of adult *Lanice* in appreciable densities, especially in shallow-water sandy substrata. Here, the stabilising effect of the tubes, together with the creation of a structurally more complex, benign and food-rich micro-environment, promoted benthic biodiversity and productivity in circumstances which (in their absence) typically limited assemblage development to an early successional stage, due to disturbance by strong tidal currents and wave action.

OVERALL CONCLUSIONS

Through the co-operation of a variety of existing data holders, and the conduct of additional sampling, the ICES NSBP 2000 initiative sought to evaluate the status of benthic communities on an international (North Sea-wide) scale and their relationship with other biotic and abiotic ecosystem elements. In addition to providing a contemporary description to update the findings of the ICES NSBS 1986, the exercise provided important lessons for the future coordination and resourcing of effort to facilitate such international assessments, including means to better exploit existing data from national sources. Elements of this collaborative initiative may also contribute usefully to the wider aim of developing an ecosystem approach to the assessment and management of the North Sea (*e.g.*, Anon., 1998, 2001; OSPAR Commission, 2000; Commission of the European Communities, 2002).

Similarities in the broader divisions between community types across the North Sea in 1986 and 2000 may be linked to well-established dependencies, such as depth and sediment type. As might be expected on this scale, the latter showed no significant compositional change. However, underlying these similarities, significant differences in structural and functional properties within communities were identified, *i.e.*, there was evidence of local adaptation to environmental changes. This may also be deduced from comparisons of the distributions of individual species but these did not, in combination, indicate a consistent directional trend. Although caution is necessary in drawing from the evidence of only two surveys, a number of the above studies hint at why a uniform response to natural environmental changes is unlikely on the scale of the North Sea. For example, significant correlations between population fluctuations in the benthos and the NAO Index have been reported (see Rees *et al.*, 2007), but these may be either positive or negative, and lagged in time to varying degrees depending on locality.

Boesch and Rosenberg (1981) define resilience as "the ability to recover to some more or less persistent state". This appears to have some merit in accounting for the

recurrence of major patterns in North Sea benthic communities, as episodic events (as well as longer term trends) with the potential to induce significant changes in the benthos have occurred over the 15-year interval between surveys. Thus, the evidence supports relative constancy, *i.e.*, resilience, at the level of the North Sea, rather than the emergence of dramatically altered states and the breakdown of pattern. Of course, this is not to say that all North Sea communities are equally resilient (see *e.g.* van Nes et al., 2007). We conclude that North Sea benthic communities remain in equilibrium with natural environmental forces, which account for most of the observed variability in space and time. Traits of resilience and adaptability help to explain patterns and changes in the benthic communities at the level of the entire North Sea and more locally, respectively. This conclusion can be applied to the responses both to natural and human influences.

The outcomes of analyses of the NSBP 2000 data generally corroborate the findings from the earlier (1986) ICES survey, rather than reveal hitherto unsuspected influences. The inclusion of a wider array of abiotic variables than in 1986 *via* modelled outputs aided data interpretation. For example, NSBP 2000 analyses highlighted the dynamic nature of the interaction between sediments and water movements and their role in structuring benthic communities. Combinations of variables that best explain patterns at a locality may change in their relative importance or differ at another, and additional variables may assume importance as the scale is enlarged to encompass the North Sea as a whole. Although interpretational problems associated with autocorrelation and non-linearity in responses are likely to increase with the numbers employed, including more rate variables, which may be cost-effectively sourced from validated ecosystem models, could enhance confidence in cause–effect deductions. At the same time, "stand-alone" biological assessments using appropriate interpretational tools continue to have utility (*e.g.*, indicator applications).

Periodic sea-wide synoptic surveys are important to underpin the interpretation of local environmental assessments, *e.g.*, to evaluate the significance of species distributional changes, which may not be readily identifiable over smaller scales. It is likely that the major divisions between community types in the North Sea will still be evident in a future synoptic survey conducted after an interval of 10–15 years, but predicting the path of population changes within communities is more difficult. For example, adaptations may be expected to accompany any directional climatic changes because there are known sensitivities, but these are not expected to follow the same trajectory throughout the North Sea. Future observations in a North Sea-wide setting will therefore be important to identify the range of ecological consequences of any directional climatic changes.

The NSBP 2000 initiative provided an excellent example of the willingness of many data providers to cooperate under ICES auspices and reflects the changing attitude towards the sharing of data with others. The often underestimated resource need in relation to data management was overcome, in this case, by the support of the Flemish Government for its conduct at the Flanders Marine Institute (VLIZ). Practical lessons for future collaborative survey and data compilation exercises included the importance of harmonised survey and sampling methodologies, the wider conduct of ring-testing and certification of taxonomic identification skills, the better documentation of individual datasets, and improved incentives for the submission of

data to repositories to avoid data loss. Although opportunistic exploitation of existing data is not a substitute for new survey work, it has the potential to increase the frequency of periodic assessments on large scales that are increasingly required to address issues such as the consequences of global warming or ocean acidification.

The exercise also profited from the involvement of a number of experts engaged in parallel international initiatives, *e.g.*, the EU MarBEF (www.marbef.org) and MAFCONS (www.mafcons.org) projects. Though reporting through separate channels and to different deadlines, interactions were facilitated by the longer time-frame of the ICES undertaking: a positive, if unintended, consequence of the absence of coordinated international funding for a synoptic survey. It resulted in improved integration with other North Sea-wide information sources, thereby contributing to a wider goal of promoting an ecosystem approach to environmental management.

The facility to report on wider spatial patterns and on changes occurring over long (10–20 year) timescales allows generic policy and scientific interests to be addressed, without substituting for the more detailed assessments that are also required. Thus, the insights gained from sea-wide synoptic surveys provide a valuable underpinning to more targeted R&D and monitoring programmes. The benefits for the latter, typically conducted at national or more localised levels, include the opportunity for individual countries to:

- better understand large-scale changes that may be "hidden" in local datasets, *e.g.*, in relation to the distribution of rare or endangered species
- evaluate the effectiveness of national monitoring designs (this applies particularly to checks on the continued validity of reference stations), and hence adapt programmes as necessary
- identify stations to facilitate routine cross-referencing against the outcome of other national programmes, to place survey outcomes into a wider geographical perspective
- use the results to assess the quality and comparability of sampling and analytical work
- improve the targeting of influential environmental variables, *e.g.*, hydrodynamic properties, to underpin interpretations of biological data

RECOMMENDATIONS

Several recommendations for future work were drafted by the ICES Study Group on the North Sea Benthos Project 2000, foremost among them being a proposal for a third synoptic survey. It is intended that, initially, these would be further developed by the ICES Benthos Ecology Working Group and approaches to implementing any new work will depend on the outcome of the planning phase.

1. Plan for the conduct of a coordinated, interdisciplinary synoptic survey of the North Sea in 2010 under ICES auspices. In doing so, the following lines of inquiry should be pursued:

- identify the circumstances which might in future attract international

funding for periodic sampling and analytical effort on the scale of whole sea areas

- review the feasibility and costs, at a national level, of a periodic uplift in sampling effort to effect a sea-wide synoptic survey consistent with the needs of ongoing national assessments
- alternatively, seek the support of national agencies for a comparable ICES-sponsored international assessment using data from national monitoring programmes and other sources on an opportunistic basis
- appraise the advantages and limitations attached to widening the time interval (*e.g.*, 2–3 years) for completion of a synoptic survey
- identify the scope for exploiting existing ship time for North Sea sampling

2. Consider the feasibility of extending synoptic surveys into other sea areas using the North Sea benthos surveys as pilot schemes.

3. Conduct integrated assessments across sea areas employing the outcomes of targeted interdisciplinary effort and parallel information from other contemporary studies.

4. Ensure long-term support for the North Sea Benthos database and establish links with the ICES and EurOBIS* databases to facilitate access by the wider scientific community, subject to the requirements of data contributors as outlined in Vanden Berghe *et al.* (2007). (*European node of the Ocean Biogeographic Information System).

5. Provide wider access to the NSBP 2000 database through initiatives such as the EU MarBEF network, subject to the requirements of data contributors as outlined in Vanden Berghe *et al.* (2007).

6. Further promote the benefits of annual monitoring at representative national locations, to facilitate the interpretation of infrequent, larger scale assessments.

We also gratefully acknowledge the large numbers of scientists and support staff who were originally responsible for the collection and analyses of the samples.

The following additional individuals contributed to the initiative through attendance(s) at ICES NSBP 2000 Study Group meetings:

R. Bönsch (AWI), R. Daan (NIOZ), K. Deneudt (VLIZ), K. Essink (RIKZ), J. Heuers (AWI), M. de Kluijver (Amsterdam University), R. Knust (AWI), M. Latuhihin (RIKZ), J. Mees (VLIZ), P. Nehmer (AWI), A. Schröder (AWI), I. Suck (AWI), J. Wittoek (Ghent University).

The support over several years of members of the ICES Benthos Ecology Working Group was essential to sustaining an interest in the North Sea benthos project and special thanks are due to the chairs of this Group since the 1986 survey, namely C. Heip, P. Kingston, K. Essink and H. Rumohr. We thank VLIZ (Belgium) and the Flemish Government for vital data management support, and the ICES Secretariat for the efficient administration of all Study Group and publication needs. Finally, we are very grateful for the constructive inputs from three reviewers (K. Essink, J. Vitaliano and T. Noji) of Co-operative Research Report No. 288, from which this synopsis is derived.

REFERENCES

Anon. 1998. Workshop on the ecosystem approach to the management and protection of the North Sea, Oslo, 15-17 June, 1998. TemaNord, 1998: 579, 100 pp.

Anon. 2001. Towards a North Sea ecosystem monitoring component as a contribution to assessment and management. Statement of conclusions from a strategic workshop in Bergen, Norway, 5-7 September 2001, co-sponsored by IOC, ICES, OSPAR, the North Sea Conferences and EuroGOOS. Volume 6, 1-36.

Basford, D. J., Eleftheriou, A., Davies, I. M., Irion, G., and Soltwedel, T. 1993. The ICES North Sea benthos survey: the sedimentary environment. ICES Journal of Marine Science, 50: 71–80.

Boesch, D. F. and Rosenberg, R. 1981. Response to stress in marine benthic communities. In: Barrett, G. W and Rosenberg, R. (eds.), Stress effects on natural ecosystems. Chichester: John Wiley and Sons, 179-200.

Commission of the European Communities 2002. Towards a strategy to protect and conserve the marine environment. COM (2002) 539 final, Brussels, 64 pp. (See also ec.europa.eu/environment/water/marine.htm).

Craeymeersch, J. A., Bergman, M. J. N., Duineveld, G. C. A., Kröncke, I. and Reiss, H. 2007. Fishing practices. ICES Cooperative Research Report No. 288, 156-171.

Craeymeersch, J. A., Heip, C. H. R., and Buijs, J. 1997. Atlas of North Sea benthic infauna. (Based on the 1986 North Sea Benthos Survey). ICES Cooperative Research Report, No. 218, 86pp.

Duineveld, G. C. A. 2007. Benthic foodweb studies. ICES Cooperative Research Report No. 288, 153-155.

Duineveld, G. C. A., Künitzer, A., Niermann, U., De Wilde, P. A. W. J., and Gray, J. S. 1991. The macrobenthos of the North Sea. Netherlands Journal of Sea Research, 28: 53-65.

Eggleton, J. D., Smith, R., Reiss, H., Rachor, E., Vanden Berghe, E. and Rees, H. L.

2007. Species distributions and changes (1986-2000). ICES Cooperative Research Report No. 288, 91-108.

Eleftheriou, A., and Basford, D. J. 1989. The macrobenthic infauna of the offshore northern North Sea. Journal of the Marine Biological Association of the UK, 69: 123-143.

Gray, J. S. 2002. Species richness of marine soft sediments. Mar. Ecol. Prog. Ser., 244: 285-297.

Greenstreet, S., Robinson, L., Callaway, R., Reiss, H., Ehrich, S., Piet, G., Kröncke, I., Craeymeersch, J., Lancaster, J., Jorgensen, L., Degraer, S. and Goffin, A. 2007a. Managing fisheries to conserve North Sea groundfish and benthic invertebrate species diversity. Fisheries Research Services, Aberdeen, U.K. Collaborative Report No 05/07, 136 pp.

Greenstreet, S., Robinson, L., Piet, G., Craeymeersch, J., Callaway, R., Reiss, H., Ehrich, S., Kröncke, I., Fraser, H., Lancaster, J., Jorgensen, L. and Goffin, A. 2007b. The ecological disturbance caused by fishing in the North Sea. Fisheries Research Services, Aberdeen, U.K. Collaborative Report No 04/07, 169 pp.

Heip, C., Basford, D., Craeymeersch, J. A., Dewarumez, J. M., Dörjes, J., DeWilde, P., Duineveld, G., Eleftheriou, A., Herman, P. M. J., Niermann, U., Kingston, P., Künitzer, A., Rachor, E., Rumohr, H., Soetaert, K., and Soltwedel, T. 1992. Trends in biomass, density and diversity of North Sea macrofauna. ICES Journal of Marine Science, 49:13-22.

Heip, C., and Craeymeersch, J. A. 1995. Benthic community structures in the North Sea. In: The Challenge to Marine Biology in a Changing World: Future Perspectives, Responsibility, Ethics, pp. 313-328. Ed. by H. D. Franke, and K. Luening. Helgoländer Meeresuntersuchungen, 49: 930 pp.

Hillewaert, H. 2007. Sediment particle size. ICES Cooperative Research Report No. 288, 28-32.

Huys, R., Herman, P. M. J., Heip, C. H. R., and Soetaert, K. 1992. The meiobenthos of the North Sea: density, biomass trends, and distribution of copepod communities. ICES Journal of Marine Science, 49: 23-44.

Irion, G., and Müller, G. 1987. Heavy metals in surficial sediments of the North Sea. In: Heavy Metals in the Environment, Vol. 2, 38-41. Ed. by S. E. Lindberg, and T. C. Hutchinson. CEP consultants Ltd, Edinburgh.

Kershaw, P. J., Mason, C., Irion, G., Bolam, T. and Smith, R. 2007. Trace metal concentrations in sediments. ICES Cooperative Research Report No. 288, 33-45.

Kröncke, I. and Reiss, H. 2007. Changes in community structure (1986-2000) and causal influences. ICES Cooperative Research Report No. 288, 60-68.

Künitzer, A., Basford, D., Craeymeersch, J. A., Dewarumez, J. M., Dörjes, J., Duineveld, G. C. A., Eleftheriou, A., Heip, C., Herman, P., Kingston, P., Niermann, U., Rachor, E., Rumohr, H., and de Wilde, P. A. J. 1992. The benthic infauna of the North Sea: species distribution and assemblages. ICES Journal of Marine Science, 49: 127-143.

Lavaleye, M., Craeymeersch, J. A. and Duineveld, G. C. A. 2007. Functional diversity. ICES Cooperative Research Report No. 288, 109-115.

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

Rachor, E., Reiss, H., Degraer, S., Duineveld, G. C. A., Van Hoey, G., Lavaleye, M., Willems, W. and Rees, H. L. 2007. Structure, distribution and characterizing species of North Sea macro-zoobenthos communities in 2000. ICES Cooperative Research Report No. 288, 46-59.

Rees, H. L., Eggleton, J. D., Rachor, E. and Vanden Berghe, E. (Eds.) 2007. Structure and dynamics of the North Sea benthos. ICES Cooperative Research Report No. 288, 258pp.

Rees, H. L., Rachor, E., Craeymeersch, J. A., Kröncke, I., Duineveld, G. C. A., Reiss, H. and Rumohr, H. 2007. Benthic community studies over relevant time-scales. ICES Cooperative Research Report No. 288, 128-140.

Reiss, H. and Rees, H. L. 2007. Links between infauna, epifauna and demersal fish distributions. ICES Cooperative Research Report No. 288, 141-152.

Schratzberger, M. 2007a. Patterns of nematode populations in the southwestern North Sea and their link to other components of the benthic fauna. ICES Cooperative Research Report No. 288, 172-176.

Schratzberger, M. 2007b. Spatial and temporal variation of microbial communities at selected sites in the North Sea. ICES Cooperative Research Report No. 288, 177-178.

Vanden Berghe, E., Rees, H. L. and Eggleton, J. D. 2007. NSBP 2000 data management. ICES Cooperative Research Report No. 288, 7-20.

Van Hoey, G. 2007. The effect of the presence of *Lanice conchilega* on the soft-bottom benthic ecosystem of the North Sea. ICES Cooperative Research Report No. 288, 188-199.

Van Hoey, G., Rees, H. L. and Vanden Berghe, E. 2007. A comparison of indicators reflecting the status of the North Sea benthos. ICES Cooperative Research Report No. 288, 116-127.

van Nes, E. H., Amaro, T., Scheffer, M. and Duineveld, G. C. A. 2007. Possible mechanisms for a marine benthic regime shift in the North Sea. Mar. Ecol. Prog. Ser., 330: 39-47.

Willems, W. 2007. Habitat suitability modelling. ICES Cooperative Research Report No. 288, 179-187.

Wieking, G. & Kröncke, I. 2001. Decadal changes in macrofauna communities on the Dogger Bank caused by large-scale climate variability. Senckenbergiana maritima, 31: 125–141.

Willems, W., Rees, H. L., Vincx, M., Goethals, P. and Degraer, S. 2007. Relations and interactions between environmental factors and biotic properties. ICES Cooperative Research Report No. 288, 69-90.