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Report of the Workshop on Climate related Benthos Processes in the North Sea (WKCBNS)

8–11 December 2008

Wilhelmshaven, Germany

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Executive summary

The Workshop on Climate related Benthic processes in the North Sea (WKCBNS) was initiated by the ICES Benthos Ecology Working Group (BEWG) as a follow up initiative of former North Sea Benthos Surveys (NSBS 1986; NSBP 2000) to discuss future research activities concerning the North Sea benthic ecosystem. The meeting took place in Wilhelmshaven, Germany, from 8–11 December 2008.

The present public and scientific concern with climate driven changes in marine ecosystems has stimulated much interest in how climate change might affect benthic organisms. The fact that marine benthic ecosystems are relatively complex and processes within, such as trophic and non-trophic interaction, benthic-pelagic coupling and species interaction, are only partly understood, emphasize the need for enhanced research of climate influences on benthic communities and processes.

Based on the research carried out by the NSBP 2000 this workshop was aimed to outline research strategies with the potential to address climate related processes in the benthic ecosystem of the North Sea. Therefore, the results of the NSBP were reviewed and considered. The main findings of the NSBP related to climate change were: (i) changes in the latitudinal distribution of some benthic species, (ii) changes in community composition, and (iii) the importance of large-scale hydrographic variables, such as bottom temperature, for the structuring of benthic (and fish) communities in the North Sea. Although North Sea wide surveys will be of high importance to study distribution shifts of benthic species and communities in response to climate driven changes of the ecosystem, the shortcomings of "opportunistic" synoptic survey approaches lacking standardized protocols like the NSBP 2000 hampered detailed analysis. Therefore, an integration of large-scale benthos surveys (epifauna and infauna) into international survey programs is highly recommended, especially in the light of future Ecosystem Approaches to Management. A first step forward could further be to apply the North Sea wide datasets (NSBS, NSBP) to modelling approaches, including habitat suitability and dynamic ecosystem modelling.

In order to enable a predominantly process orientated research on climate driven changes in the benthos of the North Sea, a small-scale "box" approach was proposed. In this approach integrative research should be focused on key processes in small-scale areas, which differ in relevant environmental conditions and represent the main benthic community types. Both approaches (large-scale and small-scale) were evaluated concerning their suitability to address climate linked processes in the North Sea benthos and general research strategies were outlined. The group drafted a map with proposed small-scale box areas, which has to be further developed by taking long-term series of benthic communities and other relevant data (e.g. anthropogenic pressures) into account.

The main recommendations for future benthos research in the North Sea were:

- to explore the possibilities of using existing North Sea wide datasets (NSBS, NSBP) to further the understanding (e.g. process issues) and development of tools (e.g. indicators, modelling) required to underpin an Ecosystem Approach and to initiate ecosystem and habitat suitability modelling relevant to benthos and to establish linkages with other ICES working groups on modelling.

- To implement the small-scale "model" areas to facilitate process orientated research on climate change effects on the benthic ecosystem of the North Sea and to integrate benthos surveys (epifauna and infauna) into international survey programs (e.g. IBTS) to enable monitoring of different components of the ecosystem on a regular spatial and temporal scale.

A general result of the evaluation was that modelling approaches will play an important part in most of the outlined research strategies, either as a source of necessary environmental variables or as the overarching research objective e.g. to optimize ecosystem models or for habitat suitability modelling. Thus, the linkages between benthic ecology and ecosystem modelling should be promoted.

1 Opening of the meeting

The Chair of the workshop, Henning Reiss, opened the session (8 December 2008, 13:00) at the Senckenberg Institute, Department for Marine Research (Wilhelmshaven, Germany) and welcomed the participants. 19 participants from six countries, The Netherlands, Belgium, France, UK, Norway and Germany, were present (Annex 1).

Steven Degraer, Leonie Robinson, Ingrid Kröncke and Jennifer Dannheim were appointed as rapporteurs for the meeting on a daily basis.

2 Adoption of the agenda

The group unanimously adopted the agenda (Annex 2) without any changes.

3 Review and consider the results of the North Sea Benthos Project 2000 (ToR a)

The main outcomes and recommendations of the ICES Study Group on the North Sea Benthos Project 2000 (NSBP 2000) were presented by H. Reiss.

Periodic sea-wide synoptic surveys such as the NSBP 2000 are important to underpin the interpretation of local environmental assessments, e.g. to evaluate the significance of species distributional changes (see 5.8), which may not be readily identifiable over smaller scales. Future observations in a North Sea-wide setting will also 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. However, practical lessons for the conduct of future collaborative survey and data compilation exercises included the importance of harmonized 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 (see Annex 5). Opportunistic exploitation of existing data is not a substitute for new integrated survey work. Nevertheless, 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.

Several recommendations for future North Sea wide research 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 was intended that approaches to implementing any new work will depend on the outcome of this CBNS planning workshop. The recommendations predominantly discussed and considered during the CBNS workshop were:

- Plan for the conduct of a coordinated, interdisciplinary synoptic survey of the North Sea in 2010 under ICES auspices;
- Consider the feasibility of extending synoptic surveys into other sea areas using the North Sea benthos surveys as pilot schemes;
- Conduct integrated assessments across sea areas employing the outcomes of targeted interdisciplinary effort and parallel information from other contemporary studies;

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

Considering the outcomes and recommendations of the NSBP 2000, the group highly acknowledged the importance of North Sea wide surveys. These surveys are the only way to study distribution shifts of benthic species and communities e.g. in response to climate driven changes of the ecosystem.

Nevertheless, the drawbacks of a synoptic "opportunistic" survey lacking standardized methods and sampling schemes resulted in time consuming post processing and significantly hampered the final analysis. Thus, the group considered a comparable survey already in 2010 as unrealistic. Furthermore, due to the commitment of implementing an Ecosystem Approach in Fisheries Management in European waters, efforts towards an integration of (standardized) benthos surveys into existing ICES fish monitoring surveys were highly recommended and should be further discussed. Several international projects, such as the EU projects MAFCONS and 'Monitoring biodiversity of epibenthos and demersal fish in the North Sea and Skagerrak', have demonstrated the feasibility of these integrated benthos monitoring programs (Callaway *et al*., 2002; Greenstreet *et al*., 2007).

In order to enable a more process orientated research on climate driven changes in the benthos of the North Sea, a small-scale "box" approach was discussed and considered. In this approach integrative research activities should be focused on key processes related to issues linked to climate change in small-scale model areas, which differ in relevant environmental conditions and represent the main benthic community types. The different research approaches (North Sea wide and small-scale) should be evaluated concerning their appropriateness to address climate related changes in the benthos. For this purpose the hypothesis developed and compiled during the Benthos Ecology Working Group meeting in 2008 were used as a basis (Annex 3).

The main conclusions derived from the review of the NSBP 2000 were:

- A North Sea wide synoptic survey in the same manner as the NSBP 2000 were considered as unrealistic in the first instance and effort should be channelled into an integration of standardized benthos surveys into existing demersal fish survey programs.
- Recommendation that future initiatives/study groups should take the small-scale approach with small boxes in different relevant areas of the North Sea (within the defined benthic community types) into account to focus on key processes related to issues linked to climate change.
- The different research approaches (North Sea wide and small-scale) should be evaluated concerning their appropriateness to address hypothesis of climate related changes in the benthos.

4 Evaluation and prioritisation of climate related benthic processes (ToR b)

Following the discussion about potential research approaches, it was agreed that the whole group would work on prioritising the hypotheses (Annex 3) and then break into small groups to for each selected hypothesis.

Before undertaking the prioritisation exercise, there was a plenary discussion about how some of the climate questions could be tackled using two modelling approaches: Habitat Suitability Modelling (HSM) and dynamic three-dimensional (3D) biogeochemical modelling. The combination of HSM-type approaches with biogeochemical 3D models (e.g. ERSEM, ECOHAM) was considered to be one possibility. The biogeochemical-type models can't cover the biological diversity of benthos, but they can cover the effects of changes in climate driven forcers such as stratification changes, changes in phytoplankton, eutrophication, temperature etc, on pelagic processes and the benthic-pelagic exchange. HSMs can be applied to assemblages and functional groups (as they have been in the Southern Bight of the North Sea) and thus represent the diversity of the system. Thus it would be fruitful to consider further how these approaches could be advanced together and how the data from the NSBP and from North Sea box surveys could be used in validating new approaches. The potential for using landscape template theory to underpin models of habitat suitability was pointed out and it was suggested that it would be useful to review the more recent Canadian approaches to consider their applicability (see chapter 7 and Annex 5).

Prioritisation of hypotheses to discuss

It was agreed to score each of the hypotheses given in Annex 3 against a number of set criteria that could objectively help define which were priorities. The four criteria against which the hypotheses were scored were:

1) feasibility of studying the hypothesis;
2) importance of the issue in terms of whether it is currently perceived to be a "hot topic";
3) geographic scope of the issue (local versus widespread);
4) urgency of the issue.

Table 1. Evaluation criteria for the hypotheses of Annex 3 (Feasibility: of approach on (North Sea) wide spatial scale (Feas. W) or on a small "box" scale (Feas. B); spatial scale: processes acting on a local (l) and/or a large spatial scale (w), linked hypotheses are indicated by coloured shading).

Hypothesis	Specifics	Feas. W	Feas. B	Hot topic	Urgency	Spatial scale
i	Frequency/intensity storms natural disturbance effect	1	1	1	1	l
k	Production/biomass process changes driven by climate	1	1	1	1	w
m	Community changes - habitat alteration through climate change	1	1	1	1	l/(w)
h	Altered currents - frontal positions - primary production - food	0	1	1	1	l
r	Cumulative effect of anthropogenic disturbance and climate change	0	1	1	1	w
s	Effect of interaction in anthropogenic drivers and climate change drivers	0	1	1	1	w
c	Change in timing of spawning and spatial distribution of settlement	-1	1	1	1	w

Hypothesis	Specifics	Feas. W	Feas. B	Hot topic	Urgency	Spatial scale
d	Stratification - temporal mismatch	-1	0	1	1	w
g	Changing wind directions - effect on larval transport and species distributions	-1	-1	1	1	w
j	Changes nutrient fluxes/advection	0	1	1	0	w/l
a	Poleward shifts in latitudinal distributions of species	1	0	1	0	w
b	Rising temp = >invasive species	1	0	1	0	w
p	Acidification effects	-1	-1	1	0	w
f	Reduced mixing - deoxygenation	-1	1	0	0	l
q	Parasites infection rates - consequences for survival and reproduction	-1	1	0	0	w
e	Reduced mixing - HABs effect on benthos food web	-1	-1	0	0	l
t	Climatic induced changes in macro phytobenthic plants – influence on species composition	-1	-1	0	0	l
o	Change in pollutant runoff due to climate change effecting reproduction and local extinctions	-1	-1	-1	-1	w
u	Alternative production export to deeper waters	-1	-1	-1	-1	l

For criteria 1), 2) and 4) the hypotheses were scored as either: -1, 0 or +1; where -1 equated to no (feasibility, importance or urgency), 0 to negligible (feasibility, importance or urgency), and +1 to high (feasibility, importance or urgency). For criterion 3) hypotheses were either scored as being a widespread issue (w) or a local issue (l) at the scale of the North Sea.

The hypotheses explored were those selected by BEWG at the meeting in Torregrande 2008 (see Annex 3). The plenary session split into three sub-groups to score the hypotheses using the criteria. In undertaking the exercise it was found that it was necessary to split the feasibility score into two separate assessments, one for feasibility using a widespread survey such as the NSBP, and one for feasibility using a box-type approach. Some groups also scored the feasibility cost element as a separate criterion (although the results of this are not shown in Table 1 as only a few hypotheses were scored in this way).

On completion of the exercise the individual sub-groups' results were compared in plenary. Where classifications were not the same, reasons for the differences were described and a majority decision then reached on the appropriate score for any debated criterion. The final results are shown in Table 1 and the highest priority hypotheses were selected by ordering the scores for the criteria and taking those hypotheses with the most +1 scores. Hypotheses (*l*) and (*n*) were removed from the exercise because they are only relevant to intertidal systems, and the CBNS group are tasked with considering offshore issues. A total of 12 hypotheses were selected as the highest priorities (the first 12 listed in Table 1) and these were then discussed in sub-groups. Some of the hypotheses were grouped because it was felt like they covered linked issues (e.g. *j* and *h*, *s* and *r*, *a* and *b*; linked hypotheses shown by shading in Table 1).

Research strategies that could be considered

Before breaking into sub-groups the plenary group considered any further issues that should be taken into account in thinking of suitable research strategies to tackle each hypothesis:

- For most of the boxes selected in the North Sea it would be unlikely that they would have a long-term dataset available. The box-type approach should mainly be used to consider issues with a spatial comparison. However, groups should not be limited to only describing such an approach, as it may be possible to select some long-term time series to use in future work (i.e. some of the boxes could be selected in areas where time-series data exist).
- We should not discount wide-scale surveys that could be undertaken on the back of existing surveys (e.g. ICES IBTS surveys) extension of NSBP type approach. Lessons could be learnt from the NSBP experience and certain questions may only be applicable to tackle using a widespread approach. For example, Habitat Suitability Modelling might be better undertaken at the wide-scale.
- The box-type approach is, however, preferential in tackling most questions, particularly the process issues.

The sub-groups would assess each of the priority hypotheses in terms of: (i) defining the issue (rationale); (ii) describing the key objective(s); (iii) describing potential research strategies; (iv) specifying which research strategies could be tackled in a box-type approach; (v) specifying which research strategies should be tackled with an experimental approach; and (vi) describing the recommendations/way forward.

5 Development of research approaches and recommendations for key benthic processes affected by climate change (ToRs b,c, d and e)

5.1 HYPOTHESIS (*k*): Changes (due to climate change) in the production and biomass of benthic species will have implications for food web-dynamics.

Rationale

In order to detect changes due to climate change in the production, biomass and growth of benthic species, historic data will be important in providing information on changes in these parameters. Possible climatic effects on biomass and production are mainly caused by species composition alterations and potentially increased food input by higher temperatures. At present, several countries have small 'boxes' which are sampled on a regular basis (see e.g. Ehrich *et al*. 2007). These long-term monitored boxes should continue to be used for future sampling in order to track climatic effects on benthic communities but with more co-ordinated objectives and sampling schemes. This standardised information has also to feed to the modellers to improve the benthic ecosystem box in their models.

Objectives

A standard set of measurements designed to detect changes in the production, biomass and growth of benthic species should be collected at pre-determined stations. A manual will be produced so that all measurements are standardised (to be agreed by the Benthos Ecology Working Group for example).

Research strategy

Box approach

Examine the spatial coverage of the boxes sampled by various countries. It is anticipated that there may well be few offshore boxes. If there are gaps in the spatial coverage of the boxes then new boxes need to be established, preferably at locations where there was previous sampling during the North Sea Benthos Survey (1986) so there is some previous information on species biomass at that location. These boxes have to be determined in the BEWG, based on the list of locations sampled on a long-term basis.

1) Use 'boxes' from various countries which have been sampled in a regular basis.
   - 1.1) Boxes should ideally not be located in frontal regions as conditions are too changeable
   - 1.2) Boxes should be representative of larger community types and spatially distributed over the North Sea
   - 1.3) Cross-comparisons between the different boxes

2) Data to be collected in each box;
   - 2.1) Species information – demersal fish (stomach collection for possible diet analysis), epifauna, infauna, hyperbenthos and meiofauna to cover the whole food web
   - 2.2) Individual species biomass
   - 2.3) Individual species size
   - 2.4) Condition Factors – derived from size and biomass measurements
   - 2.5) Stable isotope analysis (δ15N and δ13C)/Biological trait fuzzy coding (weighted functional groups for species)
   - 2.6) Keeping of shell matter for possible examination at a later date for analysis of growth rates, temperature information etc.
   - 2.7) Use of hard shelled molluscs (and polychaete mouth parts e.g. the work at CEFAS) sampled previously to look at growth rates of species in the past
   - 2.8) Good environmental data to be collected at each station (especially data collected close to the bottom) to calculate organic matter input (Temperature, chlorophyll, salinity, nutrients, phytoplankton, zooplankton)
   - 2.9) Information on bioturbation?

Recommendations

1) Data collected to be used in models such as ERSEM. This is very important, because modellers do not have this information. Data from boxes (e.g. on growth rates or measures of food uptake into the benthic food web) can improve models and be used to calculate biomass, production and alterations in food web dynamics for the whole North Sea.
2) Evaluation whether the models predict the observed conditions.
3) Each monitoring institute should try to collect the above information within the CBNS project and make it available for the scientific world.
4) Participating institutes should undertake this monitoring within their regular national monitoring programmes.

5.2 HYPOTHESIS (*h* & *j*): (*h*) Altered current conditions may lead to shifts in frontal areas and may change upwelling situation. This will influence primary production with consequences for the food supply to the benthos.

(*j*) Changes in nutrient fluxes due to advection, vertical diffusion and mixing, river flows and atmospheric deposition, leading to changes in primary production with consequences for the secondary production and biomass of the benthos.

Rationale

Hypotheses (*h*) and (*j*) both relate to the likely changes in primary production that will occur given alterations in the ecosystem driven by climate change (e.g. alterations in current conditions) (Behrenfeld *et al*. 2006), and how this will ultimately affect benthic biomass and production (see Figure 1). In terms of suggesting likely scenarios of alterations in properties that will influence primary production that could result from climate change, we can work with oceanographers and hydrographers who are already generating such information by model simulations (e.g. forecasting alterations in current systems, frontal positions). If we outline likely changes in weather systems on primary (and secondary) pelagic production in the North Sea we can then consider the effect of different deposition scenarios on the benthos.

In existing models of the benthic-pelagic exchange, the deposition of detritus is mainly characterised by fecal pellet production data and phytodetritus parameters that are driven by information on turnover times in primary production. Thus both 'small' and 'large' detritus falling to the seafloor are covered and based on reliable data from laboratory and field studies. If we thus know the effect of alterations in the ecosystem (driven by climate change) on primary production, we can model the amount of phytodetritus and fecal pellets falling to the seafloor. We can thus trust the pelagic production terms in the model (see Figure 1), but how well do we understand the link between this and variation in benthic biomass and production? There is certainly a body of literature on the benthic-pelagic exchange (e.g. Graf 1992; Rosenberg 1995; Boon *et al*. 1998; Dauwe *et al*. 1998, Kröncke 2006), but we need to explore further the different scenarios of pelagic food input that are likely to occur in different climate conditions (alterations in 'quality'/quantity of food) in terms of the resulting effect on benthic biomass and secondary production (e.g. Travers *et al*. 2007).

Objective

To explore the effect on benthic biomass and secondary production, of alterations in food input from the pelagic realm, driven by climate change.

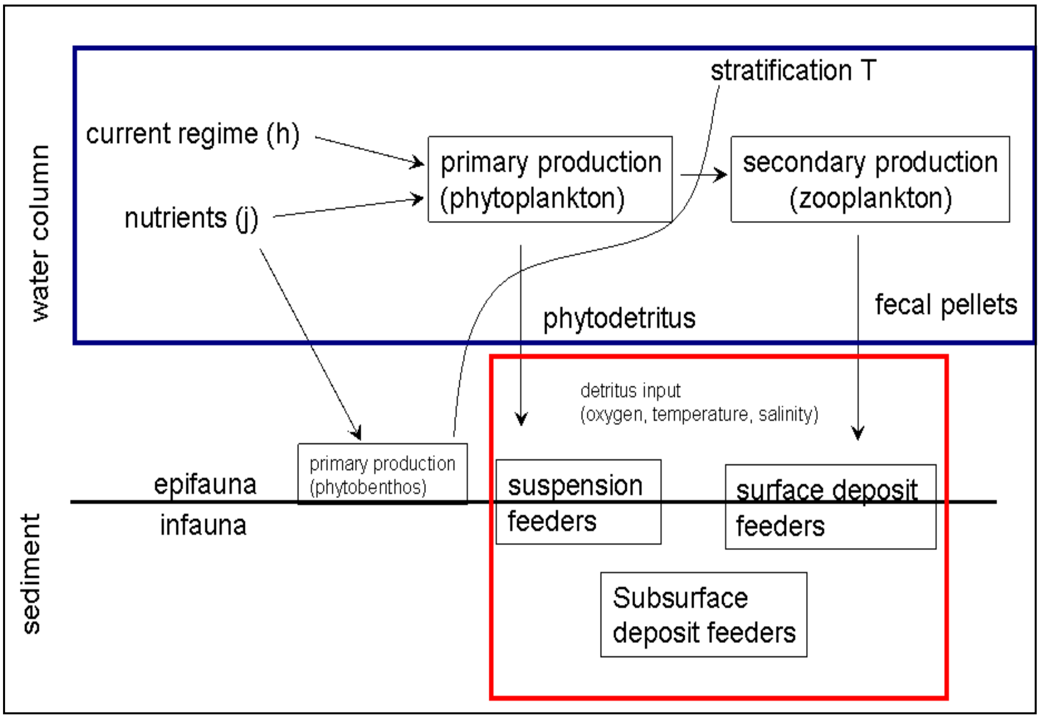

Figure 1: Schematic diagram of the exchange of organic matter between the pelagic and benthic systems in a marine ecosystem, showing how hypotheses (*h*) and (*j*) would affect the pelagic (and phytobenthic) production terms.

Research strategy

1) Collaborate with oceanographers to establish likely changes in parameters that have a direct link to primary production and the deposition of detritus from the pelagic system onto the seafloor (such as nutrient input from riverine systems, alterations in current systems, stratification etc.), with the aim of selecting a number of future climate scenarios that could be used to drive the input parameters (pelagic production and deposition to the seafloor) for a model of the pelagic-benthic exchange.

2) Review the work already undertaken on the relationship between variation in pelagic food input (quality and/or quantity or source) and benthic biomass and production. Establish if there are data available for the likely variation that would occur given future climate change scenarios (as derived from approach 1. above).

Where there are still unknowns in terms of likely effects on benthic biomass and production the following approaches could be taken:

3) Study the growth (using growth bands/rings) of model species (e.g. bivalves, sea urchins) with a lifespan of at least 5-20 years to quantify the relationship with temporal variation in primary production and secondary production (from the zooplankton) (using CPT and modelled data). Selected species would need to have clear growth bands and could be collected from a number of areas in different regions of the North Sea in terms of their stratification, depth, nutrient regime and productivity.

4) Take samples of parameters that act as a proxy for pelagic food input to the benthos (e.g. chlorophyll measurements; TOC/NOC quality; the ratio between chlorophyll and TOC; phytoplankton pigments that help to differentiate the source of food (quality and origin of organic matter)), and compare with local benthic biomass and production. Ideally we would need a number of study areas that are similar in terms of all other major benthic structuring variables (e.g. depth, temperature, substrate type) but vary in terms of pelagic food input. Alternatively if we could find time series of the same parameters in particular areas we could minimise the influence of spatial variation in other structuring factors (although there could be important interannual temporal variation in these factors e.g. winter temperature).

5) Another approach would be to check scenario variation in terms of current/ stratification/ nutrient regimes with hind cast modelled input variables and check with observational data for benthic production (meiofauna, macrofauna, bacteria) available from long-term datasets and also from the boxes covering different spatial regimes. Thus we could relate existing modelled hind casts to available observational benthic (and pelagic production (primary and secondary)) data. Ultimately we could then examine how this level of variation affects carbon budgets in the different boxes (inputs and outputs) with an aim of improving model scenarios to reflect regional variation in a regional sea such as the North Sea.

Box-type of research:

Research strategies 3-5 described above could all be undertaken using a box-type approach.

Experimental approach:

In terms of studying the processes per se that affect benthic biomass and production, experimental work is the natural home for this (e.g. mesocosm experiments). For example, mesocosm experiments could be carried out where all conditions are kept constant apart from varied treatments of pelagic detrital food input. If we could get realistic ranges in the likely variation in food 'quality' and quantity given a number of future climate scenarios (e.g. using outputs from Research Strategies 1 and 2 described above), we could study the response under controlled conditions. Tracer experiments using C13 labelled phytodetritus can be used to study and compare the transport of organic matter through the benthic system in the different areas.

Recommendations

- Set up collaborative links with oceanographers (ICES WGs and/or particular institutes) who could provide information on likely future climate scenarios and their effects on oceanographic regimes (such as nutrient flux regimes, temperature regimes, currents and stratification). Discuss feasibility of the approaches described and mechanisms for taking the work forward.
- Set up collaborative links with modellers (e.g. ECOHAM, ERSEM type box models) who could take the information on climate scenarios and produce outputs from the pelagic realm that could then be used to make predictions on the input of food to the benthos system under different future climate scenarios. Discuss feasibility of the approaches described and mechanisms for taking the work forward.

- Discuss the potential for BEWG or a future meeting of CBNS to review the work already undertaken on the relationship between variation in pelagic food input (quality and/or quantity or source) and benthic biomass and production. Establish if there are data available for the likely variation that would occur given future climate change scenarios (as derived from research strategy (1) above).
- Discuss in BEWG or at a future meeting of CBNS the feasibility of Research Strategies 3–5 in light of the outcomes from recommendations 1–3.

5.3 HYPOTHESIS (*i*): Changes in the frequency and intensity of storms will change the wave energy which will have an impact on the benthic environment.

Rationale

Changes in the frequency and intensity of storms and heavier winds will result in increased hydrodynamics. The Impact on benthos will be:

1) indirectly, due to

1.1) Changes in the sediment granulometry.

1.1.1) Increased hydrodynamics results in very shallow water results in coarser sediments. Fine sediments are deposited in specific areas (Skagerrak, German Bight). At least the coarsening has a direct impact on the benthos composition (e.g. increase of *Bathyporeia guilliamsoniana* (Kröncke *et al.* 2001)). Effects in deposit areas?

1.1.2) Impact in deeper waters (up to 40m) on sediment due to e.g. increased shearing stress. Uncertain is whether this is lasting.

1.2) Change in morphodynamics in shallow areas: effect on recruitment and species distribution (see e.g. Baptist *et al* 2006). Some species are restricted to coastal areas.

1.3) Change in food conditions: result in change in functional groups (e.g. Norderney: increase in interface feeders like *Tellina fabula* reported off the Island of Norderney; Kröncke *et al* 2001)).

1.4) Disruption of stratification, resulting in food input event (see also hypotheses *h* and *j*)

2) directly, due to

2.1) Removing animals (e.g. Armonies 2000)

2.2) Coverage by sediment (see e.g. Rachor & Gerlach 1978)

2.3) Some species are indicators for high-dynamic areas (e.g. *Donax vittatus*, Kröncke *et al* 2001).

Objectives

Long-term study of the impact of changing hydrodynamics on the benthic environment and the sessile benthic fauna.

Research strategy

Most of the effects will be local; some might act on a large part or the whole North Sea (e.g. disruption of stratification, change in percentage of functional groups). But even in that case specific studies on smaller scale (NS boxes) are needed. As effects are expected to be most relevant for sessile species, the study should focus on the endobenthic fauna.

To have enough power, monitoring program should last for at least a decade. Benthic fauna as well as the sediment characteristics should be sampled yearly. Continuous measurements of local hydrodynamics (moorings) are necessary. As a consequence the study areas have to be protected for fisheries (closed areas, wind parks, etc.) Wind parks, however, probably have their own impact and might, therefore, not be suitable for these study. The study should focus on increased hydrodynamics over several years, more than study the impact of a single storm event.

The NS boxes should be put on a gradient starting very near shore (beach barriers area) up to deeper waters. If possible, the boxes should be located in areas already studied for years; see e.g. overview in report of the BEWG 2007 and MarBef/BIOMARE Reference Sites (http://www.biomareweb.org).

Recommendations

In addition to specific studies mentioned above, additional studies in boxes:

- modelling prediction of impact,
- compare output with trends in existing long-term series,
- improve model and model 'whole' North Sea.

The BEWG should be the platform for these studies (analyses and discussions to be done on the annual meetings).

Unless linked with existing time-series, setting up new time series in boxes for a long term engagement will be difficult. EU-projects only last for 3–4 years. There seems to be no room for changes in the national monitoring programmes.

Possible links to be explored

- incorporation in climate programmes (seem to be restricted to 'existing' data)
- incorporation in sand extraction, marine landscaping projects

These programs probably will run only for a few years. But they might be a starting point for a longer time series.

5.4 HYPOTHESIS (*r*): Anthropogenic impacts caused by drivers such as fisheries and pollution may decrease the resilience of the benthic community and/or of certain benthic species to changing climatic conditions, further endangering their populations (slightly altered to include community and species level effects).

Rationale

Several studies have documented changes in benthic community structure of the North Sea over the last decades (e.g. towards more opportunistic species). Such changes are often attributed to impacts caused by anthropogenic drivers like fisheries or eutrophication/pollution, or to natural environmental drivers such as alterations in winter temperatures, or a combination of both. The resulting alteration of the community resilience to more widespread changes in climatic conditions is at present unknown. However, it is likely that if changes in community composition also result in alterations in the specific temperature tolerance of the species left, there will be implications for the influence of temperature on stability/resilience of the benthic community.

At the species level, lower population densities caused by anthropogenic impacts may reduce their resistance and resilience to changing climatic conditions. The capacity of benthic populations to withstand altered environmental conditions depends on their genetic potential and thus genetic diversity. Small populations with reduced genetic variability might thus be more vulnerable to extirpation (local extinction). Additionally, for certain types of species, Allee-effects may further endanger their viability due to reduced reproductive success associated with a decreasing likelihood of encounter of gametes.

Objective

To explore the influence of direct anthropogenic stressors on the resilience of the benthic system to climate change

Research strategies

Community effects

1) A comparison of community structure between different points in time (ideally comparing data from before the onset of intensive anthropogenic influences with those since major impacts have occurred), with specific consideration of how the distribution of species with different temperature tolerances has changed. Interpretation of what this means overall for the resilience of the community would then be based on a number of examples of future sea temperatures based on different climate change scenarios. Potential to use time series data covering periods of changes in the extent of major human pressures.

2) A comparison of community structure between different points in space, preferably using study areas with similar environmental conditions (e.g. substrate, temperature regime, depth, hydrography), but subject to different levels of anthropogenic impact, with specific consideration of how the distribution of species with different temperature tolerances varies in space. Interpretation of what this means overall for the resilience of communities subject to different levels of anthropogenic impact would then be based on a number of examples of future sea temperatures based on different climate change scenarios. Potential to use a box-type approach.

3) Habitat modelling including natural regime and additional anthropogenic stressors to produce predictions of community composition (in terms of life strategy groups), that can be tested on (existing?) observational data.

Species effects

4) A comparison of the genetic diversity of particular species between different points in time, ideally with a comparison of current individuals with those collected before the onset of intensive anthropogenic influences (unlikely to be feasible due to a lack of comparable material, but if such material could be found, this would be a favourable approach).

5) A comparison of the genetic variability and fitness of local populations under different anthropogenic impact regimes (= spatial comparison potentially using a box-type approach).

Box-type of research

Identify areas of different anthropogenic stress intensities (e.g. fishing intensities, eutrophication/pollution) and compare their benthic community structure, variability and resilience to temperature changes.

In a possible cooperation with geneticists, the genetic variability of selected target species populations at these locations, and the connectivity between local populations could be investigated. The choice of appropriate target species is essential as population exchange may wipe out spatial differences. Long lived species with low dispersal capacities seem the most promising candidates considering their lower exchange rates and prolonged periods of exposure to environmental drivers. On the other hand, short-lived species have fastest generation times and thus alterations in genetic diversity will react to anthropogenic stressors faster. The final choice of model species will need intensive considerations of autecological features (physiological temperature tolerance, life history parameters; geographical occurrence) in close cooperation with geneticists to explore the feasibility of such a study on a North Sea scale.

Experimental approach

In all the examples above, we have assumed that there is available information on the ecological tolerance range (of e.g. temperature) for benthic species. Where this is not available further experimental work is required. This could be targeted by picking species covering a range of different vulnerabilities to the major anthropogenic drivers (e.g. fishing, pollution/eutrophication). Information on the vulnerability of benthic species to different stressors is becoming more, and more readily available in the literature and through databases such as those held by MarLIN.

Recommendations

- Discuss the feasibility (research approach, suitable model species, and cost) of the genetic approach with genetics experts.
- Explore the available information on temperature tolerance of benthic species and establish cooperation with physiologists to discuss the feasibility (research approach, cost) of any further experimental work required.
- Explore the available information on vulnerability of benthic species to different anthropogenic stressors.

5.5 HYPOTHESIS (*s*): Synergistic and antagonistic effects of climatic and anthropogenic effects. (This hypothesis has been reformulated as the original formulation was ambiguous: "Changes of anthropogenic actions (e.g. fisheries, sand extraction) will have consequences for the benthic environment")

Rationale

Climate effects and anthropogenic effects may work in the same direction enforcing each other or may cancel each other out. Effects of single anthropogenic factors have been studied in many studies and climate effects also have been targeted in various investigations, but the interaction effects of multiple influences are largely unknown.

Objective

Identify cumulative effects of multiple anthropogenic pressures (like fishing, aggregate extraction, renewable energy, HABs) and climate change.

Research strategy

1) Ongoing work on cumulative effects of multiple pressures should be reviewed to identify gaps of knowledge providing the basis for field studies and experimental approaches.

2) Based on a review of existing work, identify and compare several areas of known anthropogenic influences under different climatic conditions to identify interaction effects.

Box-type of research:

The available spatial information on various anthropogenic influences is increasing steadily. Based on these data, boxes could be identified to represent various regimes of anthropogenic influence and local climate (e.g. temperature, storminess). The structure and function of the benthic communities within these boxes may allow conclusions about the interaction of these factors.

Recommendations

Postpone discussion of research approach development to future initiatives.

5.6 HYPOTHESIS (*m*): Community changes including habitat forming species will result in altered habitats.

Rationale

It is widely recognised that the presence of habitat forming species or commonly known as 'engineer species' or 'bioengineers' (Lawton, 1994; Callaway, 2006) plays a fundamental role in structuring benthic habitats. Some of their most important aspects are the reworking of sediments (i.e. bioturbation and bioirrigation activities) and providing nutrients/food to other higher tropic groups (Rosenberg, 2007). To date, current research (Van Hoey *et al*., 2008; Hendrick and Foster-Smith, 2006; Callaway, 2006; Ragnarsson and Raffaelli, 1999; Tsuchiya and Nishihira, 1986; among others) have evidenced the specific function that engineer species (i.e. *Sabellaria, Lanice, Ophiotrix, Owenia, Pectinaria, Melinna, Mytilus, Modiolus* and *Crassostrea*) provide to the overall ecosystem by creating habitats, providing shelter and food availability to other species.

Additionally, it is also important to consider these ecosystem engineers have the ability to aggregate into large patches and modify the nature and complexity of the sediment (Rabaut *et al*., 2008; Barthagaray and Carraza, 2007). Furthermore, in cases deep burrowing megafauna (e.g. *Nephrops*, Callianasidae, *Upogebia*) can also actively move and rework the sediment creating larger burrows on the seabed (Chapman and Rice, 1971; Ott *et al*., 1976; Böstrom *et al*., 2006). It is opportune to consider the distribution and role of these engineer species in areas where a man made influences occurs (i.e. dredged material disposal, fishing activities, etc.) but also in relation to natural stressors (i.e. climate). Climatic events can affect population dynamics over time and space, phenology and geography of communities (and species) (Dulvy *et al*., 2008). Furthermore, climatic events can produce habitat loss, which can affect species distribution resulting on species extinction over time, which can have severe implication on biodiversity. To date additional stressor (i.e. invasive species such as *Crepidula*, *Crassostrea*) can affect the distribution of natural communities. Invasive species are successful colonisers mainly as a result of the lack of predators and their reproduction strategies (Barnes *et al*., 1973).

Objectives

1) To assess the community structure in relation to the engineering role.

2) To investigate the patterns over time (time series assessments)

3) To disentangle the cause-effect relationships between the observed changes and climate change

Research strategy

1) Firstly to conduct a literature review on existing information on engineering species (e.g. *Lanice, Crassostrea, Mytilus, Crepidula, Melinna*).

2) To identify gaps or extrapolate from morphologically similar species in order to describe and quantify the engineering impact on the associated faunal structure and diversity indices.

3) It is also important to determine the presence and role of invasive engineer species in relation to resident fauna.

4) It is also important to assess the information in relation to time series data sets if they are available for a detailed investigation of temporal variability within North Sea boxes. The main effort should be concentrated on the species, which are included under the following criteria:

   4.1) conservation value (e.g. OSPAR, Habitats Directive e.g. Annex I habitat and species, EU Marine strategy : seabed integrity),

   4.2) invasiveness (temperature change drives the northern spread of *Crassostrea* and *Crepidula*)

   4.3) Other species

Some of the main sampling gears to conduct this type of research can be done by:

5) Acoustic techniques (side-scan sonar, multibeam)

6) Optical techniques (drop-down of sledge video (much easier), ROV (expensive, more quantitative info possible))

7) Collection of biogeochemical data/analysis

8) Target sampling strategies (i.e. grabs, trawls)

9) Temporal resolution: yearly (May-July and/or September-October) (depending on the temporal resolution needed to tackle the objectives and the resources available)

The following phases can be performed to develop this work:

1) Firstly an overall characterization of the area, using acoustic techniques (general characterization of habitat engineered habitats (footprint) and non-habitat engineered habitats (control areas)

2) Ground truthing the acoustic survey results with targeted techniques (i.e. grabs and trawls) and optical sampling (video or sediment profile camera SPI), the information collected with these tools will give us further information on species distributions and patterns. This specifically can be directed on the habitat engineers with the opportunity to differentiate between in/epifauna within and outside engineered habitat (measuring diversity levels)

Box-type of research:

This work is in relation to the wide area covered previously during the North Sea benthos survey. If there is a way to conduct a more targeted study (i.e. by only looking at certain areas of the North Sea by considering a box type approach), this can help to simplify and narrow down the necessary effort to address the following scientific questions:

1) To test the differences in associated fauna between the same habitat engineers over different climate conditions (for example northern versus southern boxes)

2) Collect environmental variables, related to climate change, such as temperature, turbidity (or SPM), NAO index, oxygen concentration, grain size distribution, primary production (satellite information)

3) Biological trait analysis of the associated fauna and the habitat engineer (e.g. non-engineered community types versus engineered community types in terms of ecosystem functioning)

Experimental approach:

1) To assess responses of habitat engineer to temperature, currents, oxygen, turbidity, turbulence burial, effects (mesocosms experiments). A series of temperature regimes can be adopted for this purpose (i.e. shock or gradual change)

2) To study competition between habitat engineers, with a view to predict future competition.

3) Experimentally to assess the response to an increased/decreased organic matter input and its effects to the habitat engineers and its associated fauna.

Recommendations

- It will be valuable to develop a standardized protocol/monitoring programme for detection of changes in species distribution;
- A detailed biological traits analysis will also provide a further understanding on possible biological interactions to enhance knowledge on process taking place at the engineering level and associated communities;
- It is necessary to possess an understanding of the causal-relationships between habitat engineers and their associated community (species);
- A suit of variables (e.g. temperature, turbidity and turbulence, changed organic matter concentration) should be considered for further testing the climate change scenario on engineering species and main associated species;
- To further investigate the engineering role of invasive species in relation to resident (engineering) fauna;
- A potential tool to assess /study the potential future distribution of habitat engineers in relation to climate change scenario can be also developed by using habitat suitability models (see Willems *et al*., 2008; Meissner *et al*. 2008).

5.7 HYPOTHESIS (c): Climate change might result in changes in the timing of reproduction. This might result in a temporal mismatch between the larval period and/or settlement and the availability of food, i.e. the plankton bloom.

Rationale

It is widely acknowledge the importance of the phytoplankton, holozooplankton and zooplankton in the production of the food resources for a wide range of marine organisms. Long-term analyses (i.e. information provided by Continuous Plankton recorder CPR) are essential to provide further understanding on the available resources and food quality available for benthic systems.

To date, research (Edwards *et al*., 2008) has indicated an increased in the presence of warm-water species of zooplankton (i.e. *Calanus helgolandicus*) in some areas of the North Sea. Some factors driving changes in distribution of species are mainly inked to the climate warming and the NAO index. Other examples have indicated changes observed in the recruitment the cumacean *Diastylis rathkei* to occur at different periods, during May in the Baltic and early in March in the North Sea (Rachor pers comm.).

Furthermore, clear examples of alterations in the timing of reproduction for planktonic organisms (i.e. echinoderm larvae) in response to an increase in sea surface temperature resulting from climate change has been observed in earlier seasonal peaks in the North Sea (Edwards *et al*., 2008; Kirby *et al*., 2007).

To develop a further understanding on mechanisms and processes influencing benthic organisms, it is important to wider our knowledge on reproduction strategies, larval stages and settlement. Furthermore, it is also important to analyse the information in relation to pelagic-benthic systems. This information will help to understand effects caused by climate change in benthic systems.

Objectives

- To assess and quantify distribution patterns (characteristic species via desk based study and literature search);
- To document what are the main factors triggering the timing of reproduction (by literature review);
- To understand the length of the larval phase (by a combination of CPR data sets and literature);
- To identify the timing of benthic larvae (e.g. holobenthic);
- Indication of settlement onto the sediment (Heye Rumohr's Benthos garden work in the Baltic; see also Bosselmann, 1991)
- To assess the availability of phytoplankton (by using CPR data sets and modelling approaches)
- To identify a suite of changing physical forces (temperature, stratification, currents, turbulence, turbidity/light, etc.), which are direct drivers of the biological systems.

Research strategy

- To conduct a literature review and gap analysis in support to the 7 objectives outlined above
- Time-series assessments to get a signal or regime shifts

- To model to assess the presence of phytoplankton and larvae, which will help to investigate the mismatch (including changing physical drivers and for developing scenarios)
- Targeted field research (i.e. selection of a box in the North Sea for in situ observation and testing scenarios), this can help to assess timing of reproduction (maturation stages of gonads)
- Small scale settlement experiments (Hall and Frid, 2000 (Tyne Estuary); see also Bosselmann, 1991); such work could be done also in boxes
- Look for larvae or young benthic stages (the latter in the boxes).

Recommendations

The sub-group outlined the following points for further consideration:

- Literature assessment including relevant taxonomic keys for identification of larvae and young stages;
- A detailed assessment of the existing CPR long-term trends data in relation to benthic time series;
- Evaluation of long-term zoobenthos studies (e.g. in the German Bight, Schröder (2005)).
- Modelling approaches especially regarding mismatch of zoobenthos pelagic larvae and food (organisms)
- Box approaches in the North and South of the North Sea
- Linkages with meiofauna colleagues for larvae or young benthic stages information.

5.8 HYPOTHESIS (*a* & *b*): (*a*) Poleward shifts in the latitudinal distributions of species, with consequent changes in species composition and species richness at any given location.

(*b*) Rising temperature could enable more human introduced species to invade and become established, replacing current native species.

Rationale

Climate change affects the distributional patterns of species or populations. The relationship between temperature and individual performance of species is reasonably well understood, and climate-related research has focused on potential shifts in distribution and abundance driven by temperature changes. Furthermore, ocean circulation, which drives larval transport, will also change, with important consequences for population dynamics. Understanding the scales over which climate will change and benthic systems will respond, is essential. Distribution shifts of marine species in the North Sea were found for several components of the ecosystem: fish (e.g. O'Brien *et al*., 2000), zooplankton (e.g. Lindley *et al*., 1995) and benthos (e.g. Eggleton *et al*. 2007). These shifts may also have consequences for food web structure, processes and functioning of the ecosystem due to e.g. cascading effects. For the investigation of distribution shifts of benthic species in response to climate change, regular large scale monitoring surveys accompanied by long-term time series are needed.

Objective

Detection of shifts in the distribution patterns of benthic species and invasion of new species in the North Sea.

Research strategy

These hypotheses should be addressed by a North Sea wide survey approach as it was done within the NSBP 2000 (but see 9. recommendations). The box-type approach will be of limited use, but long-term benthos data should be used to study the distribution shifts over time.

Recommendations

- Integration of benthos surveys (epifauna and infauna) into international survey programs (e.g. IBTS) to enable efficient monitoring of distribution shifts of benthos as a response to climate driven changes of the North Sea ecosystem.

6 Draft of small-scale "box" areas in the North Sea (ToR d)

It was agreed that future sampling approaches on climate related benthic processes should be based on box approaches. Small scale boxes within the North Sea should be selected according to the following criteria:

1) Two overarching criteria:
   - 1.1) Representation of different benthic communities (in- and epifauna) in the North Sea (see Rees *et al*. 2007)
   - 1.2) Representation of different temperature regimes

2) Criteria for the selected hypothesis (see Table 2): limited to maximum of three criteria per hypothesis.

3) Overall criteria to cover temporal scales: consideration for long-term series, previous studies, monitoring studies, anthropogenic uses.

The criterion 2) should be forwarded to the BEWG or discussed on the next BEWG meeting for a final decision of the hypothesis-criteria. During the workshop the criterion 3) was not yet considered for the selection of boxes.

According to the compiled criteria, available data during the workshop which were of sufficient or acceptable quality (depth, stratification and fish community, see Table 2; current data sets, marked in yellow) and scientific knowledge of participants in the room, boxes for future approaches have been selected. It was agreed that 10x10 nm might be a suitable box size referring to the boxes of the 'German Small-Scale Bottom Trawl Survey' (GSBTS) (Ehrich *et al*. 2007) and ICES rectangles (i.e. 1/10 of ICES rectangle size).

Table 2. Hypothesis and related criteria for the selection of boxes.

Hypothesis	Criteria	Data available		
		Current data	Existing data	Model data
i = increase in hydrodynamics/storms	Depth	1	1	
i = increase in hydrodynamics/storms	Currents/hydrodynamics	-1	0	1
i = increase in hydrodynamics/storms	Sediment transport	nd	-1	1
h/*j* = changes in primary production/biomass	Stratification	0	0	1
h/*j* = changes in primary production/biomass	Planktonic production	-1	0	0
h/*j* = changes in primary production/biomass	Euthrophication/nutrients	nd	0	0
k = production of biomass and food web dynamics	Fish community	0	0	nd
k = production of biomass and food web dynamics	Planktonic production	-1	0	0
m = habitat alteration – engineers species	Key species (invasive)	-1	0	
m = habitat alteration – engineers species	Organic matter content	-1	-1	-1
r/*s* = Anthropogenic impacts	Fishing = intensity	-1	0	nd
r/*s* = Anthropogenic impacts	Euthrophication/nutrients	nd	0	0
c = larval supply/timing of reproduction/settlement	Currents/hydrodynamics	-1	0	1
c = larval supply/timing of reproduction/settlement	Substratum	-1	0	nd
c = larval supply/timing of reproduction/settlement	Stratification	0	0	1

Footnotes (for quantity of data): 1 = sufficient; 0 = acceptable; -1 = rough/patchy/scarce; nd = no data

During the workshop the boxes (only approximate areas, see Figure 2) were selected by

1) the main benthic communities;
2) a latitudinal and longitudinal gradient in temperature and current regime (e.g. different water masses);
3) the criteria for the hypotheses.

The selected boxes only indicate areas, where it might be useful to establish study boxes for future approaches. Further criteria should be considered for the final decision of box placement (e.g. further background information on anthropogenic pressures, long-term stations).

Anthropogenic effects should not be forced into the small-scale boxes since they may impose additive or synergistic effects upon the effects of climate change. However, since it is impossible to exclude these synergistic effects the first two most important human impacts should be considered, i.e. fisheries (measuring fishing intensity) and eutrophication (measuring nutrients).

It was discussed whether hard-substrate benthic communities should be included into future approaches/concepts or generally excluded. It was agreed that future approaches should not exclude hard-substrate communities per se since they are important habitats with special focus of protection and conservation values.

Finally, 11 boxes were proposed as a starting point for further discussion.

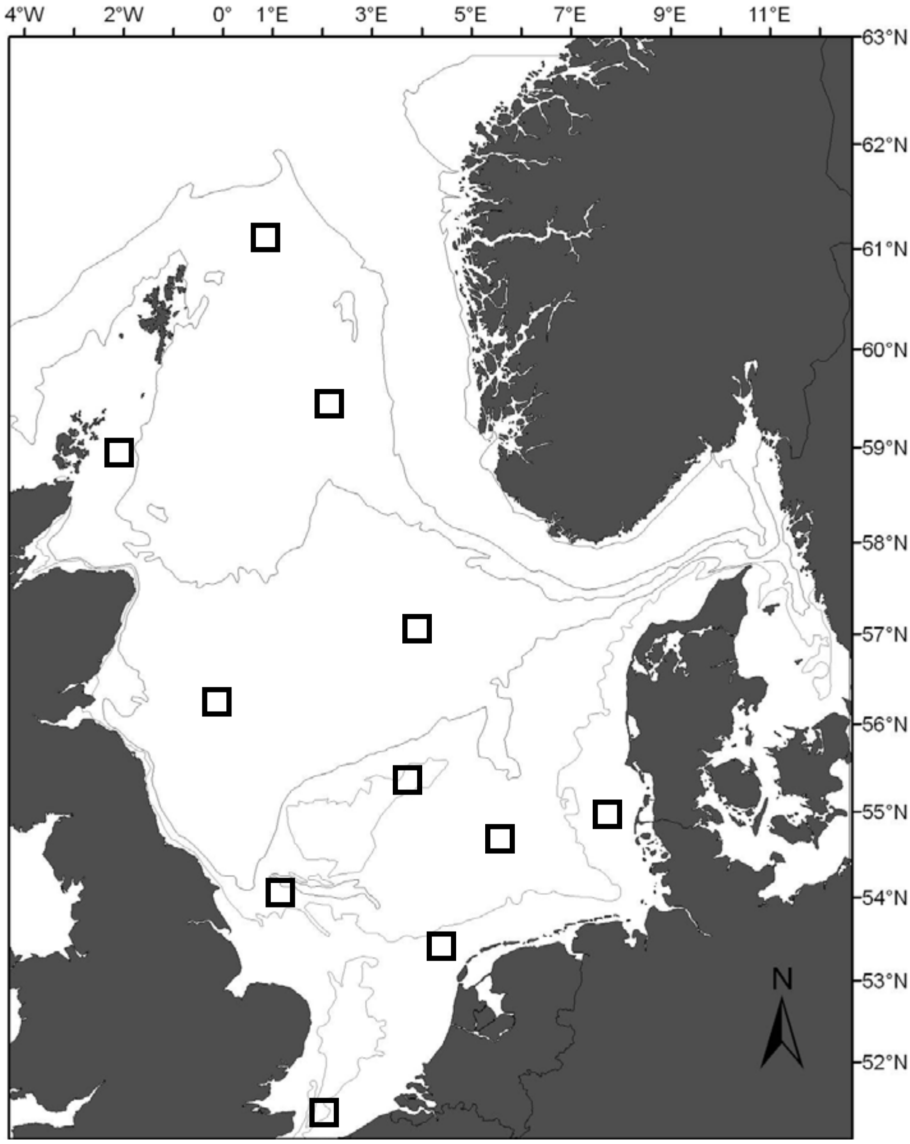

Figure 2. Map with suggested 'box' study areas. The sizes of the boxes (proposed with a square of 10 nm) are not to scale in the map.

7 Examples of modelling approaches (ToR d)

In this account two modelling approaches are discussed that can help to identifying climate related impacts on the North Sea benthos.

Introduction to habitat and dynamic modelling and their differences

To identify effects of climate change, a distinction between the variance due to the abiotic or biotic interactions resulting in annual and inter-annual variations (natural variance) and the change in the patterns due to human induced changes must be made (anthropogenic variance). As the magnitude of the changes (i.e. due to temperature rising, storm frequency increase or ocean acidification) is small, the expected change observable today is also small. Sensitive detection and modelling approaches will be needed to partition the natural variance from the human induced changes. The preference of species for temperature or other physical parameters can be modelled quite straight forward with the right data, and used for extrapolation under future climate scenarios. Some researchers (Davis *et al.*, 1998) also expect species interaction to change, due to the differential response of species. The prediction of these altered species interactions, however, is beyond the capability of the current modelling techniques.

Habitat Suitability Modelling for selected species

To model the influence of abiotic, physical habitat characteristics on the densities and distribution of benthos species, Habitat Suitability Models (HSM) (Guisan *et al*., 2000) can be used. HSM model the suitability of a habitat for the species under concern. In the most suitable habitat the species will thrive, while in unsuitable habitat the species is expected to be absent. Habitat suitability models model the species-environment relation and therefore lean on the niche theory. The assumption is that the species will thrive and produce offspring when it is in the suitable environment. The species can be observed occupying its occupied niche (Pearson, 2007), but in the absence of biotic interactions or migration barriers it would occupy its fundamental niche. Field observations of species generate data that can be used to model the occupied niche, while experiments can be used to model the fundamental niche.

Several applications of HSM can be useful for implementation in the project. A basic application of HSM for marine management is the generation of full cover species distribution maps, which are nowadays only point observations with limited cover (Pearson *et al.*, 2006). HSM can be used in more unbiased marine impact studies as they allowing separating the effect of local habitat suitability from human impacts. When the temperature preference of marine species has been modelled, the effect of climate change scenarios can be simulated and species shifts and extinctions predicted. Further, HSM can assist in the variance partitioning observed in populations, which can be separated in variance due to biological interactions and due to abiotic habitat variables.

Dynamic three-dimensional biogeochemical modelling for functional groups

The North Sea sediment and benthos is strongly coupled with the pelagic environment, mainly at the sediment-water interface and the bottom boundary layer. Particulate organic matter input to the sediment results from the three-dimensional pelagic production, lateral transports and sedimentation within the water column. Three-dimensional biogeochemical models combine the simulation of the hydrodynamic, geochemical and biological system. The state variables for the biological subsystems are not species specific but merge several species in a functional group like phytoplankton, zooplankton and the major benthos groups (epifauna, meiofauna and macrofauna). When many functional groups are included, the model became named ecosystem models.

Several ecosystem models exist for the North Sea (Moll and Radach, 2003) providing estimates of primary production and sedimentation. All models were validated showing strength and weaknesses (Radach and Moll, 2006) in simulating the annual cycle or regional differences in the nutrient and plankton distributions.

Out of the sweet of ecosystem models for the North Sea we need for a proper description of the benthic system a combination of diagenetic (Luff and Moll, 2004) and benthos (Allen *et al*., 2001; Blackford, 1997) models, while the existing pelagic models serve as forcing tools (Skogen and Moll, 2005).

Integration of the different approaches: dynamic and habitat modelling

The dynamic approach provide regional and time resolved distributions of functional group biomass and process contributions while the habitat modelling reveals species specific results. The combination of the approaches overcomes two problems, (1) the varying environmental conditions at the sediment-water interface, and (2) the multi species interactions with competition reduced to competition to the functional groups. Aim of the benthos modelling activity is to test the hypothesis depicted in Annex 3 (see also Fig. 3).

Recommendation

- Initiate a Study Group on benthos modelling based on existing data and models.

8 Evaluation of funding possibilities (ToR e)

This subject was raised among the participants during the workshop and explored as a task during sub-group discussions. Depending on the hypothesis different levels of funding would be suitable (i.e. parallel initiatives for simpler studies funded on national level or international initiatives on a wider scale funded by international (e.g. EU) proposals). Details can only be decided as soon as the specific initiatives are worked out.

9 Recommendations

- Explore the possibilities of using existing North Sea wide datasets (NSBS, NSBP) to further the understanding (e.g. process issues) and development of tools (e.g. indicators, modelling) required to underpin an Ecosystem Approach
- The BEWG to initiate ecosystem and habitat suitability modelling relevant to benthos and to establish linkages with other ICES working groups on modelling (e.g. WGPBI, WGMHM, REGNS) and establish a Study Group on benthos modelling
- Implement small-scale "model" areas to facilitate process orientated research on climate change effects on the benthic ecosystem of the North Sea
- Integration of benthos surveys (epifauna and infauna) into international survey programs (e.g. IBTS) to enable monitoring of different components of the ecosystem on a regular spatial and temporal scale. (>Transition-Group on Integrating Surveys for the Ecosystem Approach [TGISUR])
- Adoption of standardized methods and protocols (SOP) for small- and broad-scale studies and monitoring to ensure comparability
- BEWG to consider our planning

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Annex 2: Agenda

Workshop on Climate related Benthic Processes in the North Sea (CBNS)

(8 – 11 December 2008, Wilhelmshaven, Germany)

Monday, 8 December 2008

09:00 – 12:00 Arrival and set-up

13:00 – 17:00

- Opening and introduction of all participants
- Adoption of of agenda
- Appointment of rapporteur
- Review of former North Sea surveys (NSBS 1986 and NSBP 2000) ToR (a)
- Presentations: Ecosystem modelling (A. Moll), Benthos research activities, Germany (A. Schröder), Benthos research activities, The Netherlands (G. Duineveld) Database management (L. Vandepitte)
- Plenary discussion about burning issues of benthos research in the North Sea/NE Atlantic and the objectives within the CBNS project ToR (b) and outline of the CBNS concept (draft) ToR (e)

Tuesday, 09 December 2008

9:00 – 13:00

- Presentation: Habitat suitability modelling (W. Willems)
- Continue: plenary discussion about burning issues of benthos research in the North Sea/NE Atlantic and the objectives within the CBNS project ToR (b) and outline of the CBNS concept (draft) ToR (e)
- <u>Identify Sub-Groups to address</u>
    - Assessment of available and necessity for new (benthos) data ToR (c)
    - Habitat suitability modelling and other modelling approaches ToR (d)
    - Other analytical tools needed (e.g. GIS, geostatistics) ToR (d)
    - Integration of benthos monitoring into ICES surveys
    - Compilation of autecological databases

14:00 -17:00

Sub-Group activities and plenary review

Wednesday, 10 December 2008

9:00 – 13:00

- Sub-Group activities and plenary review

14:00 – 17:00

- Sub-Group activities and plenary review
- Final discussion and development of an integrated strategy for CBNS ToR (e)

Thursday, 11 December 2008

9:00-13:00

- Final plenary discussion and development of an integrated strategy for CBNS ToR (e)
- Funding possibilities ToR (f)

13:00 Close of meeting

WKCBNS terms of reference

- **ToR (a)** Review and consider the outcomes of the North Sea Benthos Survey, the North Sea Benthos Project 2000 and other relevant studies;
- **ToR (b)** Define the specific objectives for the CBPNS acknowledging the recommendations of ToR a of the BEWG report 2008, aiming at a process oriented research approach;
- **ToR (c)** Identify existing datasets to be included and evaluate the need for additional sampling;
- **ToR (d)** Identify possible additional strategies such as analytical techniques, modelling tools and GIS to address the project objectives;
- **ToR (e)** Outline of the final concept for CBPNS;
- **ToR (f)** Evaluate the possibilities for funding.

Annex 3: List of hypotheses

The following list of hypotheses related to climate change and the conceptual model illustrating climate effects on benthos is based on Annex 9 of the Benthos Ecology Working Group report 2008 (BEWG, 2008).

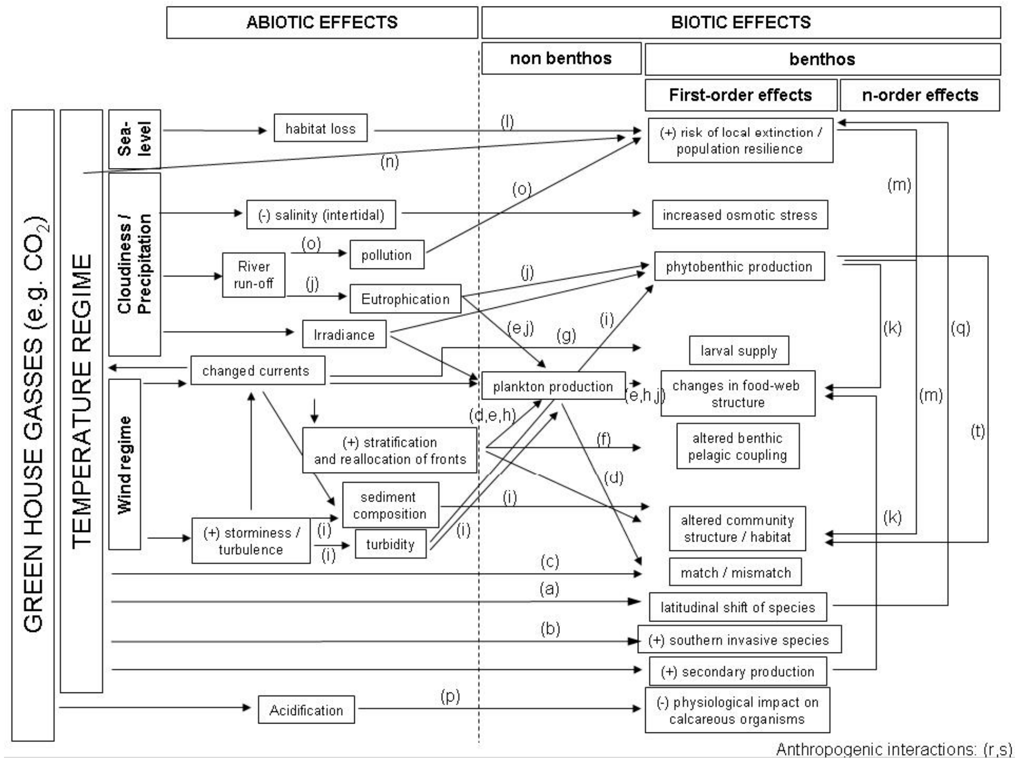

Figure 3. Conceptual model of the links between climate change and benthic communities (hypotheses indicated by letter, see text).

(*a*) Poleward shifts in the latitudinal distributions of species, with consequent changes in species composition and species richness at any given location.

(*b*) Rising temperature could enable more human introduced species to invade and become established, replacing current native species.

(*c*) Climate change might result in changes in the timing of reproduction. This might result in a temporal mismatch between the larval period and/or settlement and the availability of food, i.e. the plankton bloom.

(*d*) Stratification and spring blooms of plankton in our shelf seas will occur earlier in a warmer climate. This might result in a temporal mismatch as mentioned above.

(*e*) Reduced mixing of the water column (increased stratification) may favour many Harmful Algae Blooms-causing species. This might have effects on the benthos food web relying on phytoplankton as primary food source.

(*f*) Reduced mixing may also enhance the risk of oxygen depletion and result in altered pelagic-benthic coupling.

(*g*) Changing wind directions may lead to changing local surface currents resulting in changes in larval transport and, thus, species distribution.

(*h*) Altered current conditions may lead to shifts in frontal areas and may change upwelling situation. This will influence primary production with consequences for the food supply to the benthos.

(*i*) Changes in the frequency and intensity of storms will change the wave energy which will have an impact on the benthic environment.

(*j*) Changes in nutrient fluxes due to advection, vertical diffusion and mixing, river flows and atmospheric deposition, leading to changes in primary production with consequences for the secondary production and biomass of the benthos.

(*k*) Changes in the production and biomass of benthic species will have implications for the food web dynamics.

(*l*) Sea-level rise may accelerate the loss of intertidal habitats also because of increased coastal defences (e.g. hard structures, islands, beach nourishment).

(*m*) Community changes including habitat forming species will result in altered habitats.

(*n*) Changes in the temperature regime might lead to extreme high temperatures in the intertidal, including runnels on beaches, leading to decreased survival of some species (e.g. juvenile shrimp).

(*o*) Climate change may influence terrestrial inputs of pollutants and the release of pollutants currently locked in seabed sediments with consequences for the benthos such as effects on reproduction and local extinctions.

(*p*) Future increases in ocean acidity will have major negative impacts on some shell/skeleton-forming organisms.

(*q*) An increased distribution of parasites (such as trematodes) will lead to higher infection rates of benthic species with consequences on survival and reproduction.

(*r*) Anthropogenic impacts caused by drivers such as fisheries and pollution may decrease the resilience of the benthic community and/or of certain benthic species to changing climatic conditions, further endangering their populations (slightly altered to include community and species level effects).

(*s*) Synergistic and antagonistic effects of climatic and anthropogenic effects. (This hypothesis has been reformulated as the original formulation was ambiguous: "Changes of anthropogenic actions (e.g. fisheries, sand extraction) will have consequences for the benthic environment").

(*t*) Climatic induced changes in phytobenthic plant species composition and coverage will influence the associated faunal composition as well as animals seeking reproduction, nursery areas as well as food within the phytobenthic zone.

(*u*) Alternative production (e.g. the increase of opportunists) will increase the export of organic matter to the benthos of deeper waters, providing food, but also cause anoxia in the deeper waters.

Annex 4: Review - Modelling of the North Sea (Abstract)

Review of three-dimensional (3D) biogeochemical/ecological modelling of the North Sea shelf system: Model results, model validation and perspectives of modelling bentho-pelagic coupling

Andreas Moll

The state-of-the-art in modelling the marine ecosystem of the greater North Sea is reviewed, providing an overview especially about three-dimensional models that describe and predict how the marine ecosystem of the greater North Sea area functions and how concentrations and fluxes of biologically important elements vary in space and time, throughout the shelf and over years, in response to physical forcing. Articles with a strong concentration on modelling were selected from the available literature, and all articles around the existing "ecological modelling groups" dealing with the area of the North Sea were sorted in chronological order of their appearance in the literature. We found eleven of such groups and described their different modelling efforts (Moll and Radach, 2003). Selecting the seven three-dimensional models, we characterized the complexity of the models, by comparing the resolution in time and space, and the resolution of the trophic structure by discussing the number and kind of state variables and of the processes relating these state variables to each other.

The review of biogeochemical/ecological modelling for the greater North Sea shows that important findings by model simulations have either confirmed existing knowledge derived from field work or have given new insight into the mechanisms of the functioning of the North Sea system: the temporal and spatial development and magnitude of primary production, its spreading from the coasts to the north-west over the open North Sea, its mechanisms of limitation, the functioning of the pelagic small food web and of the benthic web, the mechanisms of nutrient regeneration, the effects of riverine and atmospheric nutrient inputs causing eutrophication of coastal waters, the extent of eutrophication in the North Sea, and the budgets for nitrogen, phosphorus, and silicon. The three-dimensional ecological models of the greater North Sea have provided consistent distributions and dynamics of the lower trophic levels on their regional, annual and decadal scales which cannot be derived to this degree of coverage by observations.

The state-of-the-art in validation for these models shows that several of the models were able to reproduce observations of the state variables correctly within an order of magnitude, but all models are not capable of reproducing every simulated state variable in the range of observations. None of the models can be called a valid model. Comparison of results from different models with datasets are evaluated according to the different spatial and temporal scales, for which data products were available, namely for regional distributions, annual cycles, long-term developments and events. The higher the trophic level the greater was the discrepancy with the data. Problems still exist in determining the necessary complexity of the model ecosystem. More complexity in the model does not necessarily improve the simulations. Special attention should be devoted to the regeneration mechanisms in the sediments. Species' groups have been simulated so far with rather limited success. The ecological model simulations did not reproduce fully the observed variability. Possible sources of lacking coincidence with observations originating from the spatial and temporal resolution of the internal dynamics, the trophic resolution, or the resolution of the forcing functions are discussed. Most of the models still need to be evaluated more inten-

sively for their predictive potential to be judged. They have not yet been tested to a degree which is possible today using the various existing datasets from the northwest European shelf seas (Radach and Moll, 2006).

One example depicts the interannual variability of the North Sea primary production as a comparison from two model studies (Skogen and Moll, 2005). To try to better understand the observed differences between two models, the two ecological models are run in an identical physical setting. With such a set-up also the interannual variability between the two models is in agreement, and it is concluded that the single most important factor for a reliable modelling of phytoplankton and nutrient distributions and transports within the North Sea is a proper physical model.

As a second example (Luff and Moll, 2004) a high-resolution early diagenetic model for the North Sea sediments has been coupled with a pelagic ecosystem model to quantify the three-dimensional processes in the coupled sediment–water system from the sea surface to a sediment depth of 11 cm focussing on the processes in the sediments of the North Sea. With the coupled model the daily benthic fluxes of POC, oxygen, nitrate, phosphate, and sulphate at the sediment–water interface for the whole North Sea area has been determined. The simulations show the seasonal and regional variations in the pelagic and the sediment system. The coupled model reproduces very well measured oxygen and nitrate penetration depths at selected validation stations. A vertical section from Fair Isle into the German Bight in summer demonstrates high spatial phosphate variability in the water column and in the sediment. Simulated annual cycle of fluxes at the sediment–water interface at a position located in the central North Sea showed a phosphate flux shifted by 1 month compared to the organic matter flux.

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Annex 5: Data Management

The Flanders Marine Institute as a data manager: an introduction and an overview of the followed methodology to create a research-oriented database

Leen Vandepitte

The Flanders Marine Institute (VLIZ) is a coordination and information platform for marine scientific research in Flanders and it serves both as a focal point for marine and coastal-related research and as an international contact point. VLIZ integrates its activities in national and international networks. One of the major activities at VLIZ is the management of the Flanders Marine Data and Information Centre (VMDC or data centre).

The data centre is responsible for the archiving of data following the latest international standards and to put this data and information at the disposal of scientists, policy makers and the public at large. The data centre is also a service centre, where it provides expertise and logistic support for the development of data and information systems, the archiving of datasets and the communication of projects. The data centre also specialises in information systems, taxonomic and biogeographic databases as well as databases that capture monitoring and survey data.

VLIZ has numerous experiences in developing research-oriented databases1 in the framework of national and international projects and collaborations (e.g. the MarBEF projects MacroBen, MANUELA and LargeNet; ICES North Sea Benthos Project) and is willing to take care of the data management and to develop a research-oriented database for the new ICES project Climate Related Benthic Processes in the North Sea (CBNS).

Data management for research-oriented databases always includes several steps:

1) Archival of received datasets, to prevent loss of data and metadata (= data on the data).

2) Description of received datasets. These metadata will be freely available on the web, making it possible for project-partners to keep track of the nature of the submitted data, to facilitate communication and to be able to identify spatial and or temporal gaps.

3) Quality control and standardisation of the received data, on different levels:

3.1) Taxonomy: taxonomic names are checked for spelling mistakes and typing errors. Subsequently, all taxon names are matched against the European Register of Marine Species (ERMS)[2] to replace (frequently used) synonyms. Doing so, confusion in the use of taxonomic names is avoided and an overestimation of the biodiversity is reduced.

3.2) Geography: all coordinates of the sampling locations are checked; are all coordinates provided and do they plot correctly on a map (N-S and E-W can accidentally be switched, as can the minus-signs)? Next, all coordinates are converted to WGS84 in decimal degrees which facilitates plotting on a map.

3.3) Units: are all the units defined? As a number of measurements can be expressed in different units, defining the unit is of the utmost importance (e.g. Secchi depth can be expressed either in decimetres or metres). Standardisation then allows researchers to talk about a measurement in a unified dimension.

4) Integration of all the data into one single database. The research-oriented or integrated database will be similar to the North Sea Benthos database. Within this integrated database, all collated datasets are available as such, but several combinations and sub-selections can be made. A number of built-in tools can also be provided (e.g. calculation of diversity indices, taxonomic distinctness), depending on the need of the researchers.

5) Support throughout the whole project. The Flanders Marine Institute guarantees a sound support with respect to content and technical functioning of the integrated database. Project partners can always address their questions to VLIZ or ask for help in extracting the desired data from the database during the whole project.

In addition, VLIZ is also willing to:

1) Develop a number of web pages: these can contain a description of the project (e.g. introduction, background, objectives), a list of the project partners, links to these partners and relevant websites or institutes, a list of the submitted data with links to their (freely available) metadata.

2) Assist in compiling a data policy. This policy should describe the agreements made among the project partners concerning data availability and data use both within the project and with third parties.

3) Provide GIS support.

4) Organise one of the project workshops. The Flanders Marine Institute has suitable facilities to organise a large workshop and can provide excellent IT-support.

5) Give the data even more visibility by making them available through EurOBIS[3], an online repository for biogeographic information on marine organisms.

[1] Research-oriented database: database that collates existing datasets from several sources making it possible for researchers to investigate possible long-term and broad-scale trends. All data in this research-oriented database are standardised and quality controlled following - where possible - European and international standards.

[2] European Register of Marine Species (ERMS): an authoritative list of taxa occurring in the European marine environment, extending from the splash zone above the high tide mark and down to a salinity of 0.5 PSU in estuaries. The taxonomic quality of this list is assured, as it is supported by the input of a large number of taxonomic experts.

[3] European node of the Ocean Biogeographic Information System (EurOBIS): an integrated database on marine organisms, with as ultimate goal is to provide the end-user with a fully searchable biogeographic database, focused on taxonomy, temporal and geographical cover. EurOBIS has been developed within the MarBEF network and acts as the European node of OBIS.