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Report of the Benthos Ecology Working Group (BEWG)

21–25 April

Torregrande, Sardinia, Italy

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

The Benthos Ecology Working Group (BEWG) held its 2008 meeting at the International Marine Centre (IMC) in Torregrande, Sardinia, Italy. 17 participants from ten countries attended and worked on the extensive agenda and reported on benthos research on-going in Europe.

ToR a. Starting from the work done last year, the working group completed "the assessment of changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature". The BEWG followed the lines of the SGWRECC and identified the major ways that benthic communities could be altered by the effects of climate change. All hypotheses were put into a conceptual model. The BEWG further reviewed the compilation of long-term series of benthic fauna in the OSPAR regions. Finally, the group discussed topics for future research.

ToR b. The JAMP guidelines for benthos and the Epifaunal guidelines were amended and after discussion, incorporated into the text.

ToR c. It was agreed that a workshop is appropriate as a starting point for the organisation of the new North Sea Benthos Project 2010. This workshop, to be held in November 2008, will generate a 'concept', based on the report under ToR a on climate change.

ToR d. A draft of the guidelines on phytobenthos was presented.

ToR e. There were the different reports linking benthos with fisheries and a aquaculture. ECASA is a pan-European study that focussed on the response of benthic indicators to fish and mollusc aquaculture activity; FishPact investigates spatial distribution of potential impacts of bottom trawling on characteristic species of protected habitat types in the North Sea; SUSUSE has as main objective the examination of temporal and spatial mismatch between biological processes and resource exploitation as well as management action. The project is in its final phase and will now integrate the obtained information in order to develop general approaches for sustainable ecosystem management.

Other highlights were two long-term studies of the benthos of the northern Spanish coasts; a scuba diver based monitoring project (TaMOs); and studies on habitat mapping (HABMAP) and wind farms (FINO1).

ToRs f and g were combined. When comparing climate enforced changes in the benthos in the Mediterranean to ICES waters, it appears that the increase in temperature is expected to impact more in northern than in southern seas. The impacts on ecosystems (including benthos) could be stronger for enclosed (Mediterranean, Tyrrhenian, Adriatic, Baltic) than for open seas (Atlantic).

ToR h. Benthic indicators have always been a strong point, linking the work of the group to several other interested parties. The London Symposium (*Environmental Indicators: Utility in Meeting Regulatory Needs*) stressed the importance of incorporating multiple indicators. Yet, the development and selection of the right indicators to use can be a complex process and the need for appropriate frameworks, or paradigms, for organizing and selecting the right combination of indicators must also be considered.

Finally, the results of the Workshop on Benthos Related Environmental Metrics (WKBEMET), a spin-off of the work done within the BEWG on benthic indicators, were discussed. The Workshop highlighted some recommendations for future re-

search and towards management and better development of assessments. An application has been made to the EU COST initiative which, if successful, will allow the continuation of this Group.

1 Opening of the meeting

The Chair, Heye Rumohr, opened the meeting at the IMC Labs in Torre Grande, Sardinia, Italy. He welcomed the participants, followed by safety instructions and some housekeeping information.

An ICES sharepoint site was made available before and during the meeting. This proved to be a valuable tool to speed up the work and make exchange of information more efficient.

Local host, Paolo Magni welcomed the group on behalf of IMC and gave an overview of the work he is currently involved with.

The participants then introduced themselves and gave a short review of their scientific activities. 15 participants from nine countries were present (Belgium, Faeroes, Germany, Italy, Netherlands, Norway, Spain, Sweden and the United Kingdom). Apologies were received from B. Tunberg, J. Nørrevang, I. Kröncke, G. Duineveld, K. Essink, M. Guerra, S. Birchenough, J. Van Dalfsen, J. Warzocha, A. Norkko, H. Reese, K. Gilkinson, K. Hostens and C. Smidt.

The Chair expressed his wish to have daily Rapporteurs, together with an Editing Rapporteur who would bring the daily contributions together into the final report. H. Hillewaert was appointed Editorial Rapporteur; daily Rapporteurs were A. Schröder, I. Moulaert, M. Robertson and E. Verling.

2 Adoption of the agenda

The group unanimously adopted the agenda without changes.

3 Report on ICES meetings and other meetings of interest

3.1 Annual Science Conference, Helsinki 2007

H. Rumohr reported briefly on the ASC 2007 in Helsinki. The report is on the ICES website and can be downloaded from there.

3.2 Annual Science Conference, Halifax 2008

H. Rumohr reported briefly on forthcoming the ASC 2008 in Halifax. Some concern was voiced about the low number of paper submission for the 2008 ASC in Halifax.

3.3 Marine Habitat Committee, Helsinki 2007

H. Rumohr reported briefly on the Marine Habitat Committee (MHC) in Helsinki last autumn. The report can be found on ICES website. The question whether ICES should be involved in the Water Frame Directive was answered positively as the issues concerned are an integral part of the ocean/sea system.

3.4 Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem, Burnham-on-Crouch 2008

I. Moulaert gave a brief account on the activities of the WGEXT. A summary by Kris Hostens (ILVO, Belgium) is given below.

The WGEXT meeting was hosted by CEFAS in Burnham-on-Crouch, UK. and was attended by 15 members from UK, Spain, Ireland, Belgium, Netherlands, Sweden, France, Finland and US.

For each member country, the total extracted amount of sand and gravel in 2007 was reported and the development of EIAs and marine resource and habitat mapping programs were reviewed. For the first time a map of the extraction zones and some seabed maps of France were presented, however exact data of the total amount of sand and gravel extracted in France are still not available. Also, still no extraction data are received from several other ICES-countries. If any of the BEWG members might know if these exist or who to contact in these countries (see the annual reports), this will be highly appreciated by WGEXT.

Again a lot of time was spent on finalizing the Cooperative Research Report (mainly lay-out, reference double check, recommendations added, annexes updated). It was agreed that the CRR will be sent to ICES for publication still in April. Based on this CRR, some effort was already put in the composition of a background document (in the 5 questions OSPAR-layout) that will be used for the Quality Status Report due in 2010.

Several presentations were given: (1) Michel Deprez (France) showed the results from a trophic study in Baie de Seine, where small crabs that were only found in the gravel extraction zone constituted the main diet of cod. (2) David Carlin (UK) gave an overview of different programs from ALSF and CEFAS, which aim at distinguishing the impact of different human activities. The UK is also working on a green paper to g*et al*l marine activities managed under one umbrella, the so-called Marine Bill. (3) Jan Van Dalfsen (the Netherlands) talked about the 'building with nature' concept of IMARES, where 'ecological landscaping' plays a profound role, giving the extraction industry the opportunity to positively contribution to (the protection) of the marine environment. (4) Brigitte Lauwaert (Belgium) presented some results on how black box extraction data are used in Belgium. The main problem is that the legislation in Europe is not uniform, data presented by different countries don't have the same units, and black box data are not availably for scientific purposes in some countries, which make it impossible to create a uniform extraction-intensity map for all ICES/OSPAR countries. (5) Ad Stolk (Netherlands) posed some urgent questions on the EIA-study for the Maasvlakte 2 project (the paper version of the EIA is already 1 meter long!). It was decided to have a workshop with experts on that topic. (6) Kris Hostens (Belgium) pointed out the existence of 2 Short Term Scientific Missions within the COST-MAGGNET action, which aim at reviewing the literature on the physical and biological impact of aggregate extraction on the seabed and benthic organisms (including fish) and the recovery/recolonization processes related to the cessation of extraction activities in European and other COST-countries. These STSMs will be guided from ILVO-Fisheries, while several host institutes and experts will be visited.

As fisheries have largely disappeared, Burnham-on-Crouch is promoting tourism nowadays. Through a number of large-scale projects with beneficial use of aggregates the UK plans to create a 1000 ha wetland (The Wallasea Island Wild Coast). In a first phase a 100 ha salt marsh was created with dredge mud from Felixstowe harbor. During the coming years the large agricultural area (750 ha) behind the dyke will be altered to a huge wetland and recreational area, using sand and clay from the tunnel that will be drilled under the Thames. Such projects show that the ecosystem approach, in which industrial and social profits are linked to environmental protection, are really feasible and may act as an example for other countries.

ICES WGEXT is invited by Prof. H. Bokuniewicz of the State University of New York to meet in April 2009 in New York or Manhattan.

3.5 MARBEF, Sopot 2007

H. Rumohr reported on the MARBEF General Assembly in Sopot, Poland. He also informed the meeting on a report received from M. Guerra, concerning progress in an MPA in Portugal. The report is on the BEWG SharePoint site.

3.6 Study Group on Biodiversity Science, Gent 2008

H. Reiss reported on the SGBIODIV meeting in Ghent, Belgium. The main objectives of this meeting were to i) identify ways in which ICES can capitalise on partnerships with European and international initiatives addressing marine biodiversity components, ii) to evaluate the current contributions of ICES expert groups to biodiversity science and iii) prepared an inventory of the current and future ICES science needs related to the components of biodiversity. The recommendations of the group included the need for a fundamental shift in ICES' perspective on biodiversity components, i.e. from being a cross-cutting to an over-arching theme as well as the need for the engagement with the most relevant initiative, to take full advantage of biodiversity knowledge and expertise available within Europe and internationally.

The report will soon be published by ICES. BEWG recommends raising this study group to the level of a working group, though study group members are not yet convinced themselves.

3.7 ENCORA, Copenhagen 2008

S. Degraer reported on the annual conference of the ENCORA network. A "Coastal WiKi" can be found on the web site www.encora.org.

3.8 Workshop on phytobenthos related matters in ICES history

H. Kautsky reported on the WKPHYT workshop held from 3–6 March on Askö, Sweden. The Report will be available on the ICES webpage. He also covered the subsequent EUNIS workshop on Baltic ecosystem/habitat classification held in Stockholm.

The summary can be found in Annex 6 of this report.

3.9 WGMHM, Horta 2008

Mike Robertson briefly reported on the ICES Working Group on Marine Habitat Mapping (WGMHM) which met in Horta, Azores, Portugal from the 1-4 April 2008 at the University of the Azores (Department of Oceanography and Fisheries – DOP). The meeting was chaired by David Connor (UK) and was hosted by Fernando Tempera on behalf of Dr Ricardo Santos, Director of DOP. It was attended by 20 delegates from Belgium, Denmark, France, Germany, Ireland, Norway, Portugal, Sweden and the UK. Presentations describing international (MESH, BALANCE, the OSPAR mapping programme, HERMES, CHARM, PLANOR, EUNIS) and national programmes (National Status Reports) were given by representatives from each country before the WG moved to address the topics described under the ToR's in the meeting agenda:

International access to metadata and habitat map

A broad assessment of available data and metadata portals was undertaken which indicated that they vary in quality, levels of usability and accessibility.

Mapping strategies and survey techniques

Presentations and discussions on multibeam calibration using video, bathymetric LIDAR, habitat and statistical modelling techniques were given and discussed in ple-

nary. In particular, the introduction of modelling activities to the WG highlighted the need for internet based discussion groups. A new Swedish hosted forum will be presented to the GeoHab 2008 meeting later this year.

Protocols and standards for habitat mapping

Aspects on guidance for mapping habitats were presented. For example, the MESH Guide to Habitat Mapping was considered to be a valuable tool for both technical and non-technical workers with an interest in marine habitat mapping. Discussions included presentations on the accuracy and confidence of maps both of which are extremely important when presenting mapped data to managers. Users should be informed about any limits when information is presented as a map.

Uses of habitat mapping in a management context

An outline paper was presented which sought contributions from WG members towards developing the role of marine habitat mapping in ecosystem based management (EBM). Examples from Norway, Sweden were described. True examples of EBM which have been implemented over large regions are hard to find however, there are several examples at small spatial scales. These include the management of blue mussel in the Limfjorden, Denmark, and also the CHARM project in the English Channel.

4 TOR d) Report of co-operative studies and other studies relevant to ICES

4.1 Response of benthic indicators to fish and mollusc aquaculture activity: a pan-European study (ECASA)

Authors: Ángel Borja, J. Germán Rodríguez, and Iñigo Muxika

Á. Borja gave an account.

The "Ecosystem Approach for Sustainable Aquaculture" (ECASA) is a European project which extended from 2004 to 2007. The objectives of this project were: (i) to identify indicators of the effects of aquaculture on the environment and vice-versa, and to assess their applicability; (ii) to develop operational tools, including models, to establish and describe the relationship between environmental conditions and aquaculture activities over a range of ecosystems and aquaculture production systems; and (iii) to develop effective environmental impact assessment and site selection methods for coastal area management. Among the indicators the benthic component is highly relevant, and next indicators were selected: (i) Univariate measures: density, richness, and Shannon's diversity, Pielou's evenness, Hill's diversity, Margalef's richness, Brillouin's diversity, Simpson's diversity index, AMBI (AZTI's Marine Biotic Index); ITI (Infauna Trophic Index); and (ii) Multivariate indicators: multiple regression, redundancy analysis, beta-diversity.

These indicators were tested against: redox potential, organic matter (TOM), grain size, depth, latitude, distance to cages, total farm production, years operating the farm, and current velocity. Ten sites were studied: 6 in the Mediterranean (in Greece, Italy and Spain) and 4 in the Atlantic (in France, UK and Norway), covering an ample latitudinal gradient, different water depths (from intertidal to 65 m), and culture species (tuna, salmon, cod, seabream, seabass, oyster and mussel). A total of 65 stations were sampled, using the same methodology. The samples were taken under the cages

and at increasing distances (5 m, 10 m, 25 m, etc.). The most important conclusions of the project were:

i) The pattern shown by the different analyses undertaken is quite consistent.

ii) The most important factors explaining variability in biological indicators are those related with the activity of the farms (production, years operating, distance to the cages) and the hydrographical characteristics of the area (current speed, water depth), interacting with sediment characteristics (grain size, redox, TOM).

iii) The selected biological indicators are showing the extent of the impact of aquaculture, but most structural parameters are intercorrelated

iv) Some locations do not show clear gradients of impact (good dispersion of the discharges avoiding damage to benthic communities) due to depth and dynamics

v) ITI and AMBI seem to be good indicators of benthic stress. AMBI was independent of sediment characteristics, and ITI was dependent on mud content. Both are related to the farm activity (production) or dispersal factors (current speed, depth).

vi) Some biological indicators (density, richness, diversity) show contradictory results, with increasing or decreasing values, for the same impact in different locations. Other times they show results fitting with those expected (e.g. under the cages).

vii) When cages are in shallow waters (<30 m), with low current velocity (< 7 $cm.s^{-1}$), and high production (> 500 $t.y^{-1}$), probably there will be impact on benthic communities under the cages and in the immediate vicinity (25–50 m).

4.2 Benthos studies and fisheries effects in the Faeroe Islands

J. Sørensen (Kaldbak Marine Biological Laboratory, Faeroe Islands) reported on benthic work in the Faeroe Islands. Due to a population of only 50,000 people benthic work is characterized by a small number of biologists and comparably small funding. The Kaldbak Marine Biological Laboratory (Kaldbak laboratory) in a small laboratory about 15 km outside the capitol (Tórshavn) with eight employees working on benthos in the Faeroe area.

The Kaldbak lab is funded by the Faroese government with 40–50 % and with about 50-60% from external sources like aquaculture, oil industry and other semi-governmental organizations.

By far the largest project is the BIOFAR project which mainly aimed at a complete species description of the benthic macro fauna in Faroese waters at depths from the shore to a thousand meters. More than 800 stations were sampled mainly in 1989-91. Processing of the data has been ongoing since then. Up to date about 60% of the material is identified and it is not realistic to expect this number to increase any further.

Human impacts on inshore habitats are considered limited due to a low population, no real agriculture and absence of heavy industry. Salmon farms can be found in all the major fjords and impacts on the seabed are monitored by the authorities. In offshore waters fisheries (mainly trawling) are the only human impact on the seabed. Besides the generally known impacts from trawling; trawling also is the direct cause

of destruction of large areas with cold water corals (*Lophelia pertusa*) around the Faeroe Islands. The authorities are aware of the problem and established three coral protected areas in 2004. The state of the corals is poorly known and information on the extent of coral areas is poor.

For the last decade the oil industry has contributed highly to improve knowledge about benthos and benthic communities in offshore Faroese waters, especially abundance related information and information on the deeper parts of the Faroe area.

The Kaldbak laboratory keeps database records of all available benthic information from the Faroe area. The data can be own data or data kindly provided by others.

4.3 SUSUSE

H. Reiss reported.

The main objective of the NWO project 'Sustainable use and conservation of marine living resources' (SUSUSE), which started in 1998 was the examination of temporal and spatial mismatch between biological processes and resource exploitation as well as management action. Within the final phase of the project this information is now integrated in order to develop general approaches for sustainable ecosystem management.

In this context the main objectives were (i) to test the suitability of quota management strategies for wider ecosystem management approaches and ii) to study the response of infauna community characteristics (biomass, species diversity, abundance, community structure) and ecosystem processes (secondary production) across a quantified fishing effort gradient.

A prerequisite within an ecosystem approach to fisheries management is the use of management tools directly linked to all ecological effects of fishing such as increased mortality of target and non-target species and habitat destruction. By analysing the relationship between the annual total allowable catches (TACs) and the corresponding fishing effort as a measure of overall fishing disturbance by using data of the EU project MAFCONS (2003–2006), it was found that most ecological management objectives cannot be addressed by using TACs as the main management tool since the linkage between variation in TAC and the resulting fishing effort is too weak. A significant positive relationship exists for a few main target species and some fleets only. Thus, TACs appear to be not sufficient as a general management tool within an ecosystem approach aiming to control fishing effects on all main ecosystem components. The direct regulation of fishing effort as the main management tool might be a solution.

The response of infauna communities on different effort regimes was investigated in an area in the German Bight (North Sea). This area was characterized by low variability in environmental variables and a gradient in fishing effort estimated by using Dutch VMS data. Infauna was sampled by using a 0.1 m^2 Van Veen grab at 14 stations. The results suggest that ecosystem processes such as secondary production as well as total biomass and species number of the infauna community decreased with fishing intensity. In contrast, the community structure both in terms of abundance and biomass distribution seemed to be less influenced by fishing disturbance, while sediment characteristics were the main variables affecting the community structure.

4.4 FishPact: Impact assessment of bottom trawling on benthic species in MPAs within the German EEZ of the North Sea: A modelling approach

A. Schroeder reported.

This presentation covered the methods and preliminary results of a project funded by the German Federal Agency for Nature Conservation (BfN) on spatial distribution of potential impacts of bottom trawling on characteristic species of protected habitat types in the North Sea. It is designed as a contribution to the ICES / BfN project "Environmentally Sound Fishery Management in Protected Areas [EMPAS]" aiming at fisheries management plans of the Natura 2000 sites within the German EEZ of the North Sea and Baltic Sea.

A combination of modelling the response of defined ecotypes to fishing disturbance incorporating information about the spatial distribution of fishing intensity is intended to identify areas of potential conflict with conservation targets. The proposed model is based on published data on life history parameters including age specific mortality and longevity of benthic species. It identifies differential demographic reactions of the suggested ecotypes to variations in gear type, trawling intensity and the temporal distribution of trawling events.

The Spatial distribution of potential population impacts is assessed by an estimation of trawling frequency based on Vessel Monitoring System (VMS) records. A dataset of identified "fishing" records from the German VMS-Dataset from 2006 including information on employed gear type and associated time interval was prepared and supplied by H. Fock from the Institute for Sea fisheries in the von Thünen Institute Hamburg. As the data set is only representative for German waters, subsequent analysis was restricted to this area. The effort was converted into the fished area per record by multiplying the fishing time by the average fishing speed for each gear type times the average gear width. Annual fishing frequency per hectare was then calculated using a quadratic Kernel density function.

This allows a presentation of the spatial distribution of trawling frequency for each bottom trawling gear type. For each of the designated habitat features in the MPAs, an annual trawling frequency can be estimated. The results from the population model indicated that the timing of trawling events determines population effects. Thus the temporal distribution of trawling was calculated for beam and otter trawls for each MPA separately and used as input for the population models. The models produce regression functions of population reduction for annual fishing regimes of different trawling frequencies. These functions were then used to derive the spatial distribution of predicted population reduction from local trawling frequency for each ecotype and area separately. These can be separately seen for beam or otter trawls or summed over both gear types. In this way the model is able identify potential conflicts between ongoing fishery activities and conservation strategies.

4.5 Marine Habitat Classification in the UK

E. Verling reported.

Marine Habitat Classifications are very useful as a tool for management and conservation of the marine environment, particularly for use in seabed habitat mapping. The Marine Habitat Classification for Britain and Ireland was first published in 1997 and has been updated since that time, most recently in 2004. Subsequently, it was used to provide a structure for the Marine part of the EUNIS (European Nature Information System) Classification, the aim of which is to provide a way to classify as

wide a range of European marine habitats as possible. Having a unified European system for classifying habitats would be a very useful for facilitating collaborations between countries and for broad-scale management of the marine environment.

The value of the EUNIS classification for marine habitats is currently limited however, because it is incomplete and there are many habitat types that are not described within it. If it is to be useful for projects with a wide geographic scope such as the European Commission's proposed 'Atlas of the Oceans', the gaps within the system must be addressed. The Marine Habitat Classification for Britain and Ireland (and by extension the EUNIS classification) was initially developed with a strong emphasis on inshore habitats, particularly rocky habitats. Therefore, the vast majority of the data used to derive the classification were collected from these shallow inshore areas. However, since that time the focus of marine management and conservation has shifted to include the area outside of 12 nm (the offshore area), and a considerable quantity of data have been collected in these areas in recent years. It is clear from preliminary analysis of these data that there are a great many habitats in the offshore area that are not currently accounted for within the classification.

The Joint Nature Conservation Committee, UK is planning to address this problem through a multivariate analysis of the new data from the offshore area. The analysis will focus on coarse and mixed sediment habitats, which are particularly poorly represented within the current classification. The aim is to identify a range of communities and ultimately to update the EUNIS classification.

Some further developments are also being made to the EUNIS classification by other groups and institutions. Firstly, a proposal has been put forward to include habitats in the Baltic Sea within the EUNIS structure. Secondly, the Deep Seabed (A6) section of EUNIS is being reviewed by several different groups (including the University of Plymouth, UK), with a view to coming up with a proposal to improve it. At a time when the UK and other European countries are developing a network of Special Areas of Conservation (SACs) (under the Habitats Directive) and Marine Protected Areas (under the OSPAR convention), the ability to classify habitats in a systematic way which is understandable to many different groups would be very useful.

4.6 Experimental trawling on *Lanice* reefs

C. van Colen reported on a recently published study (Rabaut *et al.* 2008).

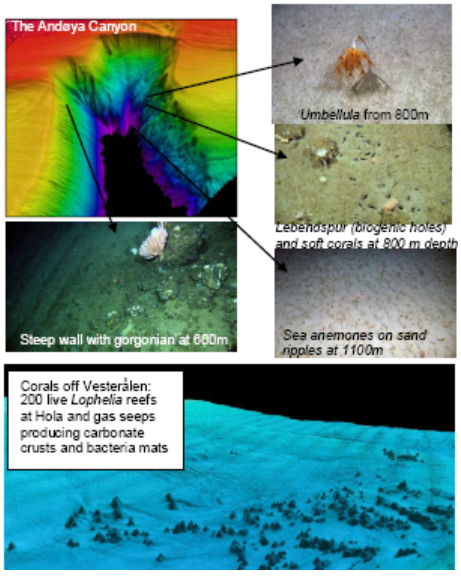
To study fisheries impact at the species level in temperate sandy bottom areas, a controlled field manipulation experiment was designed focusing on areas with high densities of the habitat-structuring, tube-dwelling polychaete *Lanice conchilega* (i.e. *L. conchilega* reefs). The hypothesis was that the impact on *L. conchilega* would be minimal, but that the fauna benefiting from the biogenically structured habitat would be impacted by beam-trawling. In this study, the impact of beam-trawl passage on intertidal *L. conchilega* reefs and its associated fauna was quantified. A treatment zone was exposed to a one-off experimental trawling. Subsequently, the impact on and recovery of the associated fauna was investigated for a period of 9 days post-impact. Community analysis showed a clear impact followed by a relatively quick recovery as apparent through MDS analysis (stress 0.06), a significant ($p < 0.001$) IMS of 0.61, through ANOSIM analysis: significant ($p = 0.001$) dissimilarities between treatment and control and through SIMPER analysis (decreasing dissimilarities over time). This impact and subsequent recovery was largely explained by two species: *Eumida sanguinea* and *Urothoe poseidonis*. Species analysis confirmed the beam-trawl passage significantly ($p = 0.001$) impacted *E. sanguinea* for the whole period of the experiment.

The experiment confirmed that closely associated species of *L. conchilega* reefs are impacted by beam-trawl fisheries. This small-scale intertidal study provides some pointers which indicate that the tightly associated species will be impacted significantly when beam-trawling *L. conchilega* reefs in subtidal areas.

4.7 MAREANO a national mapping programme documenting bottom topography, the environment and bottom fauna on the continental shelf and slope of Northern Norway

L. Buhl-Mortensen, Institute of Marine Research, Norway, reported.

What is the relationship between the physical environment, species diversity and biological resources? This is one of the questions addressed by the MAREANO program (Marine Areal Database for Norwegian Coasts and Sea Areas). The project partners, Institute of Marine Research, Geological Survey of Norway and Norwegian Hydrographic Service co-operate closely to perform the environment- and fauna-mapping. Through the MAREANO-program the Norwegian government wants to map the continental shelf and slope off Norway starting in the Barents Sea. The goal is to obtain information for the regulation of human activities such as petroleum industry and fisheries. The project was launched as an inter-ministerial financial collaboration between the ministries of the Environment, Fisheries and Coastal Affairs, Trade and Industry and the Research Council of Norway in 2005. By 2010 major parts of the Barents Sea will be mapped. The area mapped by MAREANO in 2006 and 2007 (20 000 km^2) covers: banks, troughs, ridges, canyons, large sand waves, cold seeps and coral reef areas at depths ranging from 40–2000 m (see figures).



In these areas fauna and bottom substratum has been documented with a suite of sampling gears (video, multicorer, grab, boxcorer, beam-trawl, and epibenthic-sled). The task of mapping marine substratum, biodiversity and vulnerable biota in a varied seascape is challenging and poses several questions:

What are the relevant methods for documentation of environment and fauna on all bottom-types?

How are representative sampling and observation sites selected in a varied seascape?

MAREANO will provide some answers to these questions based on the experience from the methods used by the mapping program. MAREANO will also study the relation between habitat heterogeneity at different scale and the distribution of bottom-fauna communities, biodiversity and biomass in the mapped areas.

4.8 Recolonization and succession dynamics of tidal mudflat macrobenthic communities

C. Van Colen, F. Montserrat, M. Vincx, P. M. J. Herman , T. Ysebaert, and S. Degraer.

Macrobenthic early recolonization and succession mechanisms after complete experimental defaunation were investigated in a polyhaline, intertidal soft-sediment habitat. Based on sampling of both biotic and environmental variables in replicated 16 m² experimental control and defaunated plots, with a high resolution in time during six months, the ecological interactions related to the macrobenthic assemblage succession trajectory were elucidated. Colonization was predominantly determined by juvenile recruitment. Species colonization patterns revealed positive interactions with stabilizing tube-building polychaetes and negative interactions with biodestabilizing infauna. Three succession stages were identified, each characterized by different species assemblages and distinct habitat characteristics. Tolerance, facilitation and inhibition models structured early succession. Early colonizers had either no effect (tolerance; *H. ulvae*) or a positive effect (facilitation; tube-building polychaetes) on subsequent colonizers. Later succession species negatively affected the stable conditions created by the tube-building infauna (inhibition; *H. filiformis* and *M. balthica*). Transitions between different succession stages were related to changes in environmental characteristics (oxygenation state of the sediment), direct and indirect biotic-environmental interactions (bio(de)stabilization, exploitation competition for food).

In general, our study supports 'modern' succession theories stating that succession is driven by a mixture of different kinds of interactions, all acting in a unique manner. This study indicates that there is no dominant, single succession model of macrobenthic assemblages in intertidal mudflat habitats. Succession is a dynamic process, in which natural temporal variation, life history traits of species (e.g. opportunistic behaviour) and resource availability, together with the bio-engineering characteristics of dominant species are important, structuring factors.

Some Shelduck (*Tadorna tadorna*) were found to be feeding on the diatoms. This was the only noted disturbance by scavengers/predators

There is a possible effect of the time of year in which the experiment is started, because you need the recruitment period. Probably the same succession will arise when starting the experiment in a different season, although it might take longer for the succession to start. This was confirmed by H. Rumohr, who has done a similar experiment which started in December. He found that at first colonization was chaotic, but after a few months a similar succession was found. The sampling continued for 3 years and saw a decrease in opportunist species.

4.9 Long-term changes of the infaunal subtidal communities of La Coruña Bay (NW Spain): 25-years study (1982–2007)

Santiago Parra, Eduardo López-Jamar, Oscar Francesch, Joaquín Valencia and Carmen Vázquez.

The long-term variation of benthic infauna has been studied in two stations in La Coruña Bay, NW Spain, from 1982 to the present (2007). One of the stations is located in muddy, hypoxic sediments of the harbour area, where harbour dredging was carried out in 1982. Following a relatively quick recovery after dredging operations, the infaunal community did not vary much over time, in spite of frequent sediment disturbances. The bivalve *Thyasira flexuosa* and opportunistic polychaetes are the dominant organisms. The high stability of this community is related to the dominance of

opportunists having short life-cycles, and thus well adapted to environmental disturbances. The other station is located in a relatively clean area of the bay with fine sand, and the community is dominated by species having longer life-cycles, such as *Tellina fabula* and *Paradoneis armata*. This community shows a wider temporal variation, both seasonally and interanually.

Species composition remained very stable over time in both stations, although the relative dominance of the main species was subject to change. Some major events have had an impact on the area, such as the *Aegean Sea* oil-spill (3 December 1992), which affected the communities for a few years (1993 to 1996), causing a decrease in amphipods and some bivalves and a dramatic increase in opportunistic polychaetes, such as *Pseudopolydora paucibranchiata*, mainly during the first year (1993). Long-term studies of this type are utmost importance for the detection of possible changes occurring in the infaunal communities owing to different anthropogenic alterations including accidental pollutant spills, harbour dredging and even the climate change.

The sampling was done six times/year, since 2000 two times/year, which explains the low variation in the data of the last seven years.

4.10 Long-term environmental, anthropogenic, and climatic factors affecting subtidal soft-bottom benthic communities, within the Basque coast

Authors: Ángel Borja, Maialen Garmendia, Iñigo Muxika

Á. Borja gave an overview of the project.

The dataset corresponding to the Basque Littoral Monitoring Network (northern Spain), which extends from 1995 to 2006, in a total of 19 coastal stations, placed on 25–30 m water depth, was used to study relationships between soft-bottom benthic communities and environmental variables. These variables include: sediment characteristics (grain size, organic matter, POC, PON, etc.), climatic variables (NAO, EA, precipitation, river flow, irradiance, temperature, etc.), and anthropogenic factors (metals and organic compounds). The benthic parameters include density, biomass, richness, diversity, evenness, and AMBI. The investigation was undertaken by applying both univariate analysis (Pearson correlation and Spearman rank correlation) and multivariate analysis (Canonical Correspondence Analysis (CCA) and Multidimensional Scaling ordination (MDS)). This study is part of a Basque project (*K-Egokitzen*), funded by the Basque Government, which tries to develop regional climatic scenarios for the Basque coast, taking into account IPCC global scenarios. The ultimate aim is to predict changes and try to minimise impacts in coastal waters and ecosystems.

A total of 674 taxa of benthos were recorded, being the most abundant: *Diogenes pugilator, Ampelisca brevicornis, Paradoneis armata, Spiophanes bombyx, Magelona johnstoni, Mediomastus sp., Magelona filiformis, Pisione remota, Edwarsia sp., Urothoe pulchella, Nassarius reticulatus* and *Nepthys cirrosa.* These species represent more than 25% of the total density.

CCA, with forward selection of variables and associated Monte Carlo permutation tests, suggested that the studied variables (sediment characteristics, anthropogenic parameters, and climatic variables) explained 33% of the total inertia. Climatic variables (17%) and sediment variables (11%) explain most of the differences in benthic structure and distribution; whilst anthropogenic variables explain only 5% of the variability.

Univariate analysis reveals that some structural parameters (such as AMBI and biomass) have improved significantly (<0, 05) during the last decade, probably due to

the water treatment undertaken in the Basque river basins and estuaries in recent years.

The multivariate analysis shows that the diversity was more vulnerable to changes in environmental or anthropogenic parameters than the AMBI. This is because these are coastal stations and in coastal areas the quality is good hence diversity and species richness explains more of the variability.

High NAO was found to correspond with lower precipitation (opposite direction of the river runoff). This is true for the Basque country were positive NAO does not correspond with a higher precipitation as is the case in other areas, but has more influence on the wind direction and strength.

This work is available in the *Revista de Investigación Marina,* published by AZTI-Tecnalia (www.azti.es).

4.11 TaMOs

H. Rumohr presented a new project, the 'TaMOs' project - a scuba diver based monitoring at the Baltic coast of Schleswig-Holstein. TaMOS is the attempt to make the observations of lay divers available for environmental surveillance and scientific use. This is A scientific supervised cooperation project With the National divers association (TLV-SH) and the League for environment and nature Germany (BUND-SH). The project runs a web based Documentation platform for information exchange. In special seminars Divers can learn to document geo-referenced environmental data by writing a log book after each dive. Taxonomic seminars for species identification allow the lay diver the Species identification of local fauna and flora Following the Ecosystem approach Divers become aware of ecosystem complexity and learn to survey the UW-habitats themselves

The TaMOs project is dedicated to experienced divers in Schleswig-Holstein in Germany. It is concerned with the collection, analysis and evaluation of marine biological and geological data from the Baltic Sea. The intended outcome of TaMOs is the documentation and demonstration of day to day, seasonal and annual variability in the Baltic Sea environment. Interested divers from Schleswig-Holstein will be educated in free seminars to give them the opportunity to join this project without further training. Recording the flora, fauna and sediment distribution are important parameters for the quality evaluation of the Baltic marine environment. Most of these parameters can be measured very easily by divers, if they know how to do it.

The recording of animal, plant and sediment distribution along the complete Baltic coastline of Schleswig-Holstein in Germany has not been done so far. The project is supported by the diving association of Schleswig-Holstein and one intention is to teach divers in seminars in the needed skills to achieve a complete detection of animals, plants and sediments. TaMOs aspires a close cooperation with the provincial environmental agency and for this reason it is necessary to obtain a nearly scientific standard. Such a high standard is needed to achieve comparability with scientific investigations performed by the environmental agency for evaluation of this geographically wide spread survey. The time consuming and expensive scientific studies can only be performed at certain areas at a certain time. Equal accuracy and reliability cannot be achieved by a project like TaMOs, but this may not be necessary.

This project is not only supposed to address scientific experts. A further, maybe even more important goal is to show the variability of the Baltic Sea environment right next to our location. This documentation, performed by laymen for laymen during

their spare time, is an opportunity to show the beauty of the marine environment. This can only be achieved by volunteers with their all year round support. The variability of the Baltic Sea ecosystem is part of dynamic processes that would be impossible to evaluate by a small group of people. As diving is a sport that is very closely related to nature, divers are the first to know about the changes. TaMOs provides now a platform to make these experiences public.

As part of TaMOs, the divers will be trained free of charge to identify animals and plants. This is supposed to teach the divers which animals can be determined by visual contact and which can't. All participants will be able to determine species on their own after the course and can start right after the course. To support this, TaMOs provides an underwater writing panel with species names and everything necessary to record the abundance and distribution of the most abundant species in a standardized way for each participant. The data exchange is on-line through the TaMOS web page.

Link: www.tauchmonitor.de

Members of the group mentioned similar ongoing initiatives in UK (Seasearch) and The Netherlands (Anemoon).

4.12 Dutch monitoring

Johan Craeymeersch informed the group on on-going and new monitoring programs in the Netherlands. There are two national programs covering all or most of the marine waters. A first one looks to the macrobenthic infauna on the whole Dutch continental shelf, the Wadden Sea and the Delta region in the south-west of the Netherlands. Since 2006, the surveys on the Dutch continental shelf are no longer done by NIOZ but by a consortium of Grontmij|AquaSense, Ecosub and TNO-Imares. A second national program aims at stock assessments of commercially exploited shellfish and covers the coastal area, the Wadden Sea, the Westerschelde and the Oosterschelde. The data provides the necessary information for the management of fisheries and aquaculture. Due to financial constraints, part of the surveys are presently under threat , e.g. the one in the coastal area.

Two other new programs are related to a land-reclamation, scheduled for 2008, which will extend the harbour of Rotterdam with of about 3000 ha. A first focuses on monitoring changes in a sea bed protection area (about 26000 ha), a compensation for the loss of marine habitat. In a baseline study 400 stations along the south-west coast of the Netherlands has been sampled with both a box-corer (infauna, 1mm-sieve) and a benthos dredge (triple-D look-a-like; in- and epifauna, 5 mm-sieve). A second monitoring program focuses on the effects of the sand extraction. The baseline study covers the whole Dutch coast from the Belgian border up to the Wadden Sea; 300 stations are sampled with both a box-corer and a benthos dredge.

4.13 HABMAP

M. Robertson (FRS, Aberdeen) described progress with the two year HABMAP project which ended in March 2008. During HABMAP, acoustic data were collected from transects created within a series of 3Nm by 3Nm boxes and from the vessel track between boxes from throughout the North Sea and from the Scottish west coast. However, as the time available for the high resolution surveys was severely restricted each night, the ideal situation of collecting data from fully overlapping swathes (greater than 100% seabed cover) could not be achieved. The resulting, incomplete, data grids were processed through the QTC Multiview software package while at sea to create

catalogue files containing information on the most important principal components describing all the potential sediment classes from within each area surveyed. These catalogue files were then applied to the acoustic patches recognised by Multiview within the survey box and the patch allocated to a specific class number.

Ground truth / sediment data

Ground truthing samples were collected from a number of the high resolution survey boxes in the North Sea and from the Scottish west coast. However, before the classes identified by Multiview could be allocated to specific sediment types, the ground truth sample's physical parameters had to be determined by laser granulometry in the laboratory. A total of five classes were ground truthed from the North Sea while seven were sampled from the west coast however, as seventeen classes were eventually identified from the North Sea multibeam data and twenty nine from the west coast, further extensive sediment sampling should be carried out to complete the ground truthing exercise.

Relationships between low and high resolution data

Data from twelve sites of the twenty occupied in the North Sea in 2006 were selected for analysis. However a problem with the positioning of most of the high resolution boxes within each ICES rectangle was immediately noticed where the length of the "in" and "out" leg of low resolution data was too short to allow for meaningful comparison with the high resolution data set. To overcome this, each high resolution box was treated as a centroid and low resolution data for two hours going to and coming from the survey box extracted from the cruise tracks. All data were then divided into three minute bins and attempts were made to compare these data sets using contingency table analysis. Analysis of the relationships between the high and low resolution data will also be attempted employing the methodology used to analyse single beam RoxAnn data from the Moray Firth, by analysis using the cube surface creation tools available in CARIS and by ArcGIS area analysis.

Comparisons between Multiview and RoxAnn data

During all three research cruises, both the swathe multibeam and the RoxAnn single beam acoustic systems were used to log data. However, only the cruise completed in the North Sea successfully collected data from a wide variety of sites. From these twenty stations a subset of twelve were used for comparison studies. The RoxAnn data were edited and processed using the methods described in Greenstreet *et al*, 1997 while the Multibeam data were simply plotted using SURFER and in ArcGIS. The maps resulting from these activities were in general agreement showing similar distributions of the major sediment classes within each survey box however the multibeam maps were of considerably greater complexity (up to seventeen classes but with notable edge effects on the borders of the non-overlapping swathes) than the RoxAnn maps. The multibeam data will be further processed using the tools available in the CARIS software package.

Infauna

These results have recently been received and initial analysis, using the PRIMER statistical package indicates that there are distinct differences in the infaunal communities collected from the North Sea sites at a similarity level of 40 to 45%. This low similarity is to be expected given the wide ranging nature of the sampling positions occupied however, the infaunal communities collected from the sediment classes

identified within each survey box by Multiview also exhibit differences, with similarities of around 55 to 60%. Further analysis of these results will determine whether these differences are statistically significant.

4.14 Offshore constructions' effects on Benthos: Research at the platform FINO1 in the German Bight: overview of activities & preliminary results.

A. Schroeder reported.

The effects of large underwater constructions on the benthic fauna, including invertebrates and demersal fishes, were studied at the research platform FINO1 installed 30 nm offshore in the German Bight (North Sea). Prior to the construction of actual wind farms in the German EEZ starting in 2008, this research platform was used as model structure to assess the predicted effects of the underwater structures of the Wind turbines.

The epifauna on the underwater construction quickly reached a high biomass with distinct seasonal fluctuations. However, the species composition is still developing three and a half years after installation. A distinct vertical zonation pattern developed with a differing faunal composition. The upper zone is dominated by *Mytilus edulis*, accounting for more than 50% of the total epifaunal biomass of the platform. Deeper areas are dominated by amphipods (*Jassa* spp.), Actiniaria (*Metridium senile*, *Sagartiogeton* spp.) sponges (*Halichondria panicea*) and seasonally by hydroids (*Tubularia* spp.). Numerous small invertebrates associate with the three dimensional matrix generated by these key species. Niches and crevices provide structured habitats for mobile crabs and fishes not normally found in soft bottom habitats. The fauna of the surrounding sea floor is altered by two principle processes. Typical soft sediment species are reduced by scouring induced habitat modification. Predators and scavengers are attracted by an accumulation of biogenic material falling from the construction. Acquired data were used to parameterise a model of biomass export from the construction. According to model results, the export of organic material is spread over a large area, leading to a significant organic enrichment of the sediments when extrapolated to entire wind farms.

Ongoing research will extend into the pilot wind farm *alpha-ventus* to be constructed in summer 2008 and target the effects of habitat complexity created by different types of underwater structures and integrating analyses of environmental effects from numerous wind farm studies which is intended to be extended by international collaboration.

The group members noted that cooperation between different countries on this topic is certainly advised to exchange knowledge.

Studies are also ongoing (in Belgium and Germany) to compare different materials on the kind and number of species colonizing them.

A. Schröder also mentioned that antifouling is not used on the windmill bases because it is too poisonous.

Members of the group wondered whether there would be a negative effect for the recruitment areas of fish. A positive effect for fish seems however more likely due to the increase in food and the fact that no fishing will be allowed in the area. But of course special areas (e.g. MPA's) that lie outside the no-fishing zone have to be better protected as fishing effort will shift to these areas.

4.15 Identification of Marine Ecosystems

M. Robertson (FRS, Aberdeen) briefly described the start of a new desk-based study intended to define and develop spatially distinct "ecological units" from the current understanding of Scottish marine ecosystems. Reviews of data and reports on the distribution of ecosystem components will be undertaken. This approach will maximise monitoring efficiency in reporting on the state of the ecosystem and allow the development of a classification of units consistent with known distributions of a wide range of organisms. The work is to be undertaken to allow the definition of large scale areas of the marine environment within four years as part of the EU MSD initiative as existing schemes, such as the system employing WFD water bodies, are not considered adequate for this purpose.

The objectives are therefore to:

- review existing geographical classification schemes (pelagic/benthic) as found in BGS maps, in habitat mapping projects and in EUNIS and from MESH;
- review these classification schemes in relation to major oceanographic factors;
- review geographical schemes used for Marine management. For example, the schemes used in UKMMAS / CSEMP, in the WFD, for fisheries management;
- review geographic distributions of seabed invertebrates, planktonic organisms, fish, birds and marine mammals in relation to habitat classification and using data available from FRS and REGNS;
- develop integrated geographical classification of marine ecosystems based on physical and biological factors;
- present results in GIS format.

4.16 Marine biological valuation

S. Degraer reported on the outcome of the PhD research of S. Derous (Ghent University, graduated in December 2007), focused on the development of a marine biological valuation methodology that is able to spatially-explicitly integrate all available biological information into one indicator of intrinsic value. This methodology should allow for a transparent, widely applicable and scientifically acceptable valuation of the marine biodiversity, which can be used as a baseline map for marine spatial planning. In combination with the good and services valuation, marine biological valuation should further allow for the development of comprehensive decision support systems for marine management. The five main objectives of the thesis were: (1) to develop a concept for marine biological valuation which is widely applicable and scientifically acceptable; (2) to develop a protocol around this concept which defines the different steps that need to be taken to develop marine biological valuation maps; (3) to apply the protocol to different case study areas to see how it performs under different circumstances; (4) to review the possibilities of using the protocol for the implementation of several European Directives, which relate to nature conservation in the marine environment, and as part of decision support systems for marine management in general, and spatial planning in particular; and (5) to evaluate the indicator "marine biological value" on its conceptual relevance, feasibility of implementation, response variability and utility for environmental decision-making. This presentation provided details on the development of the valuation concept

(thorough literature review and two international workshops) and protocol as well as the results of the application of the methodology to the Belgian part of the North Sea.

5 TOR a) consider the reports of the Ad Hoc Groups on; Hydrographic Attributes, Trend Analyses & Quantifying Relationships, Formulating Hypotheses and Predictions about Mechanisms, Selecting Species for More Intensive Investigations and use their recommendations concerning (1) recommended time series, (2) analytical methods and suitable software, (3) hypotheses and guidance for their use, and (4) a suggested list of species for intensive study, to complete 'the assessment of changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature.

The working group compiled a document that is attached as Annex 9.

6 TOR c) plan the next North Sea Benthos Project 2010

The group decided that in order to provide a well founded proposal, a workshop will be organized later this year. During this workshop a framework will be set up for the further organization of a project on "Climate related Benthic Processes in the North Sea" (CBPNS) as a follow up of the North Sea Benthos Project 2000. The workshop will take into account the recommendations made in Tor (a) of this report and the recommendations made by the North Sea Benthos Project 2000.

The workshop will be held in November 2008, chaired by H. Reiss and will report to ICES and the BEWG 2009.

- 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, modeling tools and GIS to address the project objectives;
- Tor (e) Outline of the final concept for CBPNS;
- Tor (f) Evaluate the possibilities for funding.

7 TOR d) discuss and report on new methods for sampling and analytical practices for benthos including electronic ones

H. Kautsky presented a draft of the guidelines on phytobenthos. This document can be found in 0to this report. A. Borja suggested the addition of the word 'coverage' to the document along with 'species composition'. On suggestion of S. Degraer, the group agreed to add a short paragraph to explain that guidelines on microphytobenthos are not included in this document; it applies only to macrophytobenthos.

A call for assistance has been received from Dr. Andreas Bick at the University of Rostock in relation to the development of new taxonomic keys for Polychaetes of the Baltic Sea (*Polydora* sp., *Spio* sp.) and Chironomidae (focus on the Baltic Sea). Speci-

mens of these Polychaetes and chironomids fixed in ethanol from the Baltic Sea and North Sea area are needed. Therefore, all colleagues who are interested and have the opportunity to take samples containing the taxa mentioned during 2008 and 2009 from the area from the Baltic Sea and North Sea are cordially invited to contribute to the project. Interested parties to contact:

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8 TOR h) report and discuss on the outcome of the workshop on Benthos Related Environmental Metrics (WKBEMET)

Benthic indicators have always been a strong point, linking the work of the group to several other interested parties. A subgroup of the BEWG has recently been doing a lot of work on this topic, resulting in a Symposium and a Workshop.

8.1 Environmental Indicators: Utility in Meeting Regulatory Needs (ICES Symposium, London, November 2007)

I. Moulaert reported.

This Symposium anticipated the translation of a number of current initiatives on indicator development into pilot or operational use within a regulatory framework. It is designed to offer a timely and strategic insight into the current status and likely future direction of the activity. While the symposium wanted to address promising new developments, emphasis was also placed on practical applications to date. Every effort was made to permit a realistic evaluation of progress, including presentations on case studies which don't appear to work, as well as those which do. The aim was to check performance and comparability both within and across disciplines and on various geographical scales, in order to allow recommendations to be made on the employment of indicators as tools to underpin effective environmental management.

A total number of 114 people from 21 countries attended the 4-day conference, collectively providing a useful insight into the utility of environmental indicators in meeting regulatory needs. The symposium was organized along 4 major themes: (1) Policy/regulatory frameworks for indicator applications, (2) Satisfying the need: case studies of the operational use of environmental indicators, (3) Promising new indicator developments and (4) Overview and forward look.

A total of 43 talks and 16 posters were presented. The importance of incorporating multiple indicators was stressed throughout the various talks of the symposium. Yet, the development and selection of the right indicators to use can be a complex process, given that the measurable characteristics of ecosystems that the indicators are tracking again are practically limitless. Thus the need for appropriate frameworks, or paradigms, for organizing and selecting the right combination of indicators must also be considered.

Very important points have been delivered throughout all of these presentations including demonstrations of the utility of indicator applications in specific areas, as well as descriptions of new indicator approaches and tools.

On Thursday afternoon a discussion forum was organized, which resulted in the highlighting of some important points: (1) Scientists should have the ability to say what the indicator really 'indicates' and thus how to act. The Cause-effect relationship is of great importance here; (2) Policy/managers want something to work with, they trust the scientists, even if a lot of variability or uncertainty is behind the indicator, something must be said. (3) Some kind of link should be made to economics as that is what makes managers react more rapid.

It was highlighted and recommended that (1) Management strategies should embrace the use of multiple indicators to offset the limitations and uncertainty of any individual measure and to provide a weight-of-evidence basis for judging condition and linking cause and effect; (2) there is also a need for effective indicator frameworks in order to guide the selection and application of an appropriate set of indicators that best addresses the stated management questions and ecosystem goals; (3) such frameworks be supplemented with long-term, time-series observations of key ecosystem components, pathways, and forcing processes, within different ecosystem types, in order to provide a basis for understanding long-term climatic trends and the separation of local perturbations from broad-scale natural patterns; (4) how to best face the fundamental conflict that emerges from the need, on the one hand, to account for the multi-faceted nature & variability of natural ecosystems in the process of measuring ecosystem health, yet the need to bring together the complex information with its associated uncertainty into easily understood conclusions for management actions? A special issue of the ICES Journal of Marine Science on the results of the Symposium will be published in 2008 under the guest-editorship of Niels Daan.

As for the benthic part some of the points highlighted were: (1) Properties of the biotic indices must be adjusted to intertidal areas and diverse perturbations. (2) Most of the currently developed biotic indices have been based on open, coastal, subtidal, benthic communities and organic matter discharges on these communities. Semi-enclosed, transitional and freshwater-influenced systems, large intertidal flats, naturally muddy environments and other (physical) disturbances should further be investigated. (3) The AMBI, BENTIX, BOPA and M-AMBI are not efficient to detect physical perturbation. (4) Looking at long term data sets from Norderney: Univariate and multivariate indices provide similar results, cold winters reduce the quality and an increase in NAOI since 1988 caused an increase in diversity and multi-metric quality. (5) Species number and species richness are good indicators of the effects of dredging disposal.

8.2 Benthic Indicators in the ICES Benthos Ecology Working Group

Over the last four years the topic of benthic indicators was raised at the BEWG. In the following text an overview is presented from the outcomes of the discussions held during our annual meetings.

BEWG 2004: Review the outcome of the 2003 Theme Session on "The Role of Benthic Communities as Indicators of Marine Environmental Quality and Ecosystem Change", and make recommendations on future developmental work

- There was a disappointing response to the call for papers for this theme session;

- ICES agreed to support a symposium in 2007 on 'Environmental indicators: utility in meeting regulatory needs';
- The BEWG recognized the importance of ongoing developments on indicators and their application and therefore recommended to ICES that it reviews the status of indicator metrics for 2005, including phytobenthic and epibenthic assemblages on hard substrata.

BEWG 2005: *Review the status of indicator metrics, for 2005 including, the development and its applications for phytobenthos and hard-substrata benthos*

- BEWG recognized the challenge of matching the need for a small suite of widely-applicable benthic biological indicators with the typically local sources of evidence for determining effectiveness;
- The members of the group considered that the best approach should be based on a combination of indicators of the ecological status of the benthos and performance indicators that can be used to link variation to specific manageable human activities;
- The group considered that further work will be required to develop performance indicators that meet criteria that have been developed by ICES (2001, 2005) and others (Rice and Rachet, 2005);
- The group described the success of available performance indicators to be used within a management context for human activities. BEWG recognizes the need to further develop this work to actually list those indicators available based on the published case studies as a meta-analysis in a future meeting. It was also emphasize that there is a need to test the applicability of different indicators at local, regional and global levels in order to aid the development of appropriate monitoring programmes.

BEWG 2006: *Relate a list of indicators to the impacts of human-induced activities and changes in ecological state. Assess the effectiveness of any potential performance indicators in identifying cause-effect relationships*

- The BEWG concluded that there is already a large amount of information available in several publications and reports. There was an agreement to progress this work further inter-sessionally during 2006 with the final aim of a working session of testing different metrics during next year's BEWG;
- To relate the performance of these indices to different types of anthropogenic impacts, case studies shall be performed with various data sets e.g.: sewage sludge disposal; dredged material disposal; aggregate extraction; offshore constructions, e.g. windfarms; pollution by various substances; bottom trawling; aquaculture and eutrophication;
- Preliminary results from these case studies will be presented and discussed during the next BEWG meeting in 2007, in order to present the final outcomes at the forthcoming indicator symposium in November 2007 in London, United Kingdom.

BEWG 2007: *Assess the effectiveness of any potential performance indicators in identifying cause-effect relationships based on a list of indicators prepared by inter-sessional work*

- No intersessional work was done;
- The group updated the list of metrics from the report of the ICES Study Group on Sensitive and Opportunistic Benthic Species (SGSOBS 2004);
- It was decided that within the scope of this working group it is difficult to come up with a full review of cause-effect relationships for each of the different indices. The ideal way of answering this question would be to organise an intersessional workshop where the majority of indices can be tested on a series of datasets from different areas with diverse anthropogenic activities. This workshop

should be open to anyone, including non BEWG members, with knowledge on benthic indices.

8.3 Workshop on Benthos Related Environmental Metrics (WKBEMET)

I. Moulaert (Chair of the workshop) reported.

The organisation of a Workshop on Benthos Related Environmental Metrics (WKBEMET) was requested by the ICES BEWG to discuss the ongoing developments in benthic indices. The meeting was a combined activity of ICES and MARBEF and took place in Ostend from 11-14 of February 2008.

A whole range of tools and benthic indices have been developed for assessing the ecological integrity or status of water bodies. The goal of all these indices is to reduce or summarize information on environmental conditions or quality to a number, which will form the basis for management decisions regarding the ecological status of ecosystems (Borja *et al*, 2007). Over the past years different initiatives have been undertaken to bring together expert scientist in the field of (benthic) indicators and a lot of work has been undertaken to expand our knowledge on the application of benthic indicators. During all these gatherings, research needs and recommendations were formulated, but clearly after all these years major gaps still exist in our knowledge. In order to avoid redundancy and duplications, the workshop participants used the 4-day meeting to gain an overview of the present status with the aim of identifying priorities for future research. All available information was grouped into different tables: Table with the different indices available, and Tables giving an overview of the general characteristics, the applicability and the habitats and stressors for which some commonly used indicators have been tested. These tables only consist of the knowledge that was present in the group and therefore are not complete. The group stressed to make these tables widely accessible in order to complete and keep them up to date and make them available for all scientists and managers.

WKBEM*Et al*so gathered with the aim of filling in gaps in the knowledge on the applicability and pressure-response of benthic indices through the use of data sets from multiple habitats and stressors. Although the group made a good start with putting all data into a common data set, no practical tests on this data were done during the working group meeting as it was decided that more efficient work could be undertaken when more data will be incorporated into the data set. In order to prepare the database for the suggested analyses some additional analytical features were built in.

The group highlighted some recommendations for future research:

- Analyze the ecological processes forming the basis of an index.
- Use large datasets with well known gradients, pressures and reference conditions in order to validate the index.
- Lack in knowledge about the use of indices in certain systems/habitats (e.g.: semi-enclosed, transitional and freshwater-influenced areas and areas with a natural salinity gradient)
- Multi-metric approach: integrated indices versus Multi-metric ss versus multivariate approach of m-AMBI. How many parameters should be included?
- Come to agreements on the sensitivity/tolerance classification of species.

The group also made some recommendations towards management and better development of assessments:

- The need for national reports to be more accessible and readable for the general public or managers. The national reports should also be available on the web and

if possible all this information should also be published in journals, reviewed and become available for the wider scientific world.

- The need to make scientific publishing part of the national programs (in terms of time/funds) so that the scientist can do this.
- The group also recommends that data should be made public as much as possible.
- The need to incorporate environmental data as an obligation into monitoring programs to be able to interpret the response of the indices/indicators correctly.
- The need to develop a world-wide accessible forum (cf. WIKI) were the applications of benthic indices can be openly discussed. This should be of great help to scientists worldwide.

Finally the group decided to submit a preliminary proposal for a EU COST Action In order to continue the collaboration, to expand the dataset and to keep up a network and platform were all information and knowledge on Benthic Indicators can be gathered.

On completion of the presentation, varied discussions on many aspects of the workshop's conclusions and report took place. Concerns were raised by L. Buhl-Mortensen (LBM) on the possibility that only the infaunal component of the benthos had been considered when applying environmental indicators to data. Was there no attempt to include the other components such as the hyperbenthos and the epifauna? It was pointed out that 99% of the indices currently used refer only to the infauna. LBM then stated that this could be a problem as marine managers generally considered changes in the epifaunal community to be good indicators of the effects of fishing disturbance and effort. I. Moulaert conceded that this was a problem and would require further work. H. Rumohr commented that the role of invasive species is very important when considering analysis of communities using these indicators.

Further discussion then ensued where LBM pointed out that as the infauna are generally dominated by polychaetes, would changes in the other faunal groups, such as in the molluscs, be detected in any analysis carried out? S. Degraer agreed with this point stating that, if 80% of changes are related only to polychaetes, it was entirely possible that subtle signals from other groups would be missed. This might explain why molluscs are absent from some impacted areas (J. Craeymeersch). Á. Borja pointed out that, if the limitations of the indices used are known, the differing group effects and faunal responses to environmental pressures can be allowed for. He also stated that WKBEMET should be a practical forum where data were provided by participants and worked on during the workshop. Many participants were not providing datasets which may cause problems with data security. However I. Moulaert pointed out that, as MARBEF data handling policies were applied during the workshop, no problems with data sharing should occur. She also asked the Group whether they felt that the work carried out by WKBEMET should be continued, possibly as a Study Group outwith BEWG. Á. Borja noted that the Study Group must have clear objectives – to list all available indices and to check whether they work. It was further noted that the BEWG supports the continuation of the work started by WKBEMET and that I. Moulaert would continue as Chair. I. Moulaert then stated that although WKBEMET was now concluded, an application had been made to the EU COST initiative which, if successful, would allow the continuation of this Group.

Discussions then continued on broadening the index list to include tests applicable to fisheries, fishery disturbance and habitats (other than soft bottom types). LBM noted that there seemed to be a "soft bottom bias" and that a broader view should be adopted. However J. Craeymeersch said that intercalibration exercises already existed for these indices as part of the Water Framework Directive and that these exercises

would continue for another two years. I. Moulaert noted that it would be possible to extend the list to include rocky shores but it would be very difficult to cover every aspect of the benthos. H. Rumohr pointed out that the inclusion of other benthic components would be manageable and that other science committees would link these together as that is their function. Discussions continued on how to expand the coverage of and the concepts considered by the working group and how to incorporate external experts.

9 TOR b) review and update the JAMP guidelines for benthos, (phytoplankton and chlorophyll) according to good current practice and/or international standards for acceptability of biological sampling and analytical practices required by monitoring programmes.

H. Rumohr led these discussions stating that H. Rees had recently provided comprehensive updates to both the document text and to the reference list. Alterations to the text, which were generally minor in nature, were then accepted from all WG members and incorporated in the final document version. The second subject of the session dealt with editing the Epifaunal Guidelines document. Again, alterations to the text were proposed by WG members, which after discussion were also incorporated into the document.

The JAMP document is at Annex 7 and the Epifaunal Guidelines are at Annex 8.

10 TOR f) and g) climate enforced changes in the benthos in the Mediterranean compared to ICES waters

10.1 Introduction

In recent times there are an increasing number of publications and reports showing climate change effects, both in the Mediterranean and ICES waters. Some of them have a global view, such as Philippart (2007), which focus on the whole of Europe; whereas others focus on regional seas: Vargas *et al.* (2008) in the Spanish Mediterranean, and the Marine Climate Change Impacts Partnership (MCCIP, 2008), in UK waters. The principal aim of the last report is to develop a long-term multidisciplinary approach to understanding and communicating the implications of climate change in UK seas. MCCIP (2008) brings together scientific understanding from a wide range of research institutes, providing an even more comprehensive assessment of UK marine climate change impacts and highlighting regional variations where possible. The following paragraphs summarise the findings of these reports and some other papers.

10.2 Some evidence

The Mediterranean is a particularly vulnerable sea to human pressures. The concentration of human population in coastal areas, fish exploitation, and pressures produced by agriculture, industry, tourism and maritime traffic are some of the examples of human activities, able to impact marine ecosystems. Together with these pressures, climate change is another threat which can alter physico-chemical conditions in the Mediterranean, and, consequently, to the marine ecosystems and resources. Vargas *et al.* (2008) have analysed atmospheric and oceanographic changes in the Spanish Mediterranean, since 1948. This study can assist in understanding changes in benthic communities around this sea.

From 1948 to mid 1970s there was a decrease in Mediterranean air and sea surface temperatures. Since this date the temperatures have experienced a dramatic increase.

The mean increase between 1948 and 2005 has ranged between 0.12°C and 0.5°C. In intermediate depths (200-600 m) the increase oscillated between 0.05 and 0.2°C, with a salinity increase of 0.03-0.09. In deep waters (1000-2000 m) the temperature increase was 0.03–0.1°C and salinity 0.05–0.06. Although these values could be seem small, they represent a huge amount of heat, whereas the salinity increase reflects the precipitation pattern decrease, the water abstraction in rivers, and the evaporation within the Mediterranean basin.

The sea level in the Mediterranean decreased between 1950s and 1990s, due to anomalous atmospheric pressures. After this date the sea level has experienced a dramatic increase, with values between 2.5 and 10 mm/yr.

Similarly, 2006 was the second-warmest year in UK coastal waters since records began in 1870; seven of the 10 warmest years have occurred in the last decade (MCCIP, 2008). Coastal erosion is expected to increase; currently, it affects 17% of the UK coastline.

As the marine ecosystem is highly interconnected through predator–prey relations, the direct impacts of ocean climate change have 'knock-on' effects through the food chain. For example, recent UK warmer conditions and associated shifts in plankton abundance and geographical distribution have led to reduced availability of prey fish for some seabirds, which has been strongly linked to recent poor breeding success and reduced survival rates (MCCIP, 2008).

Within intertidal communities, there is strong evidence from the UK MarClim (www.mba.ac.uk/marclim) project that recent rapid climate change has resulted in significant increases in abundance and extensions in the northern limits of southern, warm-water species that reach their northern biogeographical limits on rocky shores in the UK since the mid-1980s. Between 2001 and 2005 a number of these species increased their range around N. Scotland and along the English Channel (for example, the warm-water seaweed *Bifurcaria bifurcata* has established a new range boundary at Portland Headland in the last five years, 150 km east of previous records). Decreases in the abundance of northern, cold-water species have been observed, however, there is less evidence on rocky shores of northern cold-water species retreating northwards. Cold-water species (e.g. the *Balanus balanoides* and *Alaria esculentus*) have continued to decrease in abundance throughout the period 2001–2007. Some changes in Mediterranean benthic communities have been also reported between the 1960's and the 2000's (Labrune *et al.*, 2007). The most important changes observed during that period were the increase of the polychaete *Ditrupa arietina* within the *Spisula subtruncata* and *Nephtys hombergii* communities, and the decrease of the polychaetes *Scoloplos armiger* and *Notomastus latericeus* in the *S. armiger* community.

Philippart (2007) shows that a large mass-mortality event was observed in the Mediterranean in 1999, when a positive thermal anomaly during summer combined with an increase in the warm mixed layer down to a depth of 40 m resulted in an extensive mortality of 28 invertebrate species. The area impacted by this climate anomaly extended from the French to the Italian coast and, to a lesser extent, impacted the island of Corsica. Among benthic organisms, the most severely affected were sponges and gorgonians, such as *Paramuricea clavata, Eunicella singularis, Lophogorgia ceratophyta*, and *Eunicella cavolini.* It is evident that temperature anomalies, even of short duration, can dramatically change Mediterranean faunal diversity. A similar pattern has been detected in other species, such as *Posidonia oceanica* (Carlos Duarte, pers. comm.), which can reduce its abundance with high summer temperatures.

These observed shifts reflect predictions by climate models based on increased sea surface temperatures, and are occurring faster than most recorded changes in the terrestrial environment, but they are highly species-specific. This is likely to have consequences for biodiversity as the rate and extent of changes will not be synchronous, and biological interactions will be affected. Sea-level rise and storms may have an important indirect impact as sea defences create artificial habitats in areas between natural rocky shores, acting as "stepping stones" by allowing intertidal and subtidal species to extend their range.

Climatic processes influence the abundance and species composition of seabed communities, directly affecting the availability of food for bottom-feeding fish. The available data show that climatic processes, both directly, e.g. winter mortality, and indirectly, via hydrographic conditions, influence the abundance and species composition of seabed communities. These variations will directly affect the availability of food for bottom feeding fish such as cod and haddock, impact on shellfish populations (*Nephrops* and scallops/clams) and potentially alter patterns of biodiversity and ecological functioning. Similar changes are expected in the Mediterranean, and have been already published for fishes. The alteration in the seafloor communities could alter rates and timing of processes such as nutrient cycling, larval supply to the plankton and organic waste assimilation. At local (although still large) spatial scales there is also evidence of effects resulting from fishing impacts and at smaller scales habitat modification e.g. wind farms, and impacts from contaminants e.g. oil and gas exploration, waste dumping.

On the other hand, Occhipinti-Ambrogi (2007) has described the effects of climate change on invasive species. Hence, in the marine environment, both climatic change and spread of alien species have been studied extensively; and she gives a recent review on the main responses of ecosystems to climatic change, taking into account the increasing importance of biological invasions. She emphasise the importance of propagule pressure and of development stages during the time course of an invasion. Climatic change is known to affect many ecological properties; it interacts also with invasive species in many possible ways. Direct (proximate) effects on individuals and populations of altered physical–chemical conditions are distinguished from indirect effects on emergent properties (species distribution, diversity, and production). Climatically driven changes may affect both local dispersal mechanisms, due to the alteration of current patterns, and competitive interactions between invasive and native species, due to the onset of new thermal optima and/or different carbonate chemistry.

As well as latitudinal range expansions of species correlated with changing temperature conditions, and effects on species richness and the correlated extinction of native species, some invasions may provoke multiple effects which involve overall ecosystem functioning (material flow between trophic groups, primary production, relative extent of organic material decomposition, extent of benthic-pelagic coupling). Some examples worldwide are given by Occhipinti-Ambrogi (2007), including a special mention of the situation of the Mediterranean Sea.

Hence, she reports on some species (*Cyclope neritea, Ruditapes philippinarum*, etc.), but also 'ecosystem engineers', which contribute to important changes in invaded ecosystems: large scale changes in the physical structure of key habitats in a water body include spawning grounds, underwater sea grass meadows, and biogenic reefs. Among ecosystem engineers, the invasion of the green algae *Caulerpa* in the Mediterranean has profound effects both on the habitat and on ecosystem functioning. While a possible climate mediated influence has not been investigated in detail, Occhipinti-

Ambrogi (2007) suggests that it is likely that the diffusion of *C. taxifolia* has been favoured by some weakening of *Posidonia* due to pre-existing factors.

The other species introduced in the Mediterranean is *Caulerpa racemosa*, which is currently achieving dramatic and continuous expansion throughout most of the Mediterranean Sea and the Atlantic (see references in Occhipinti-Ambrogi, 2007). The growth rate of *Caulerpa spp.* is correlated with temperature and this is probably one of the reasons for the success of this species in the Mediterranean in recent years.

10.3 Conclusions

Philippart (2007) shows a summary of general trends at European seas, and the specific expectations derived from them. Hence, the increase in temperature is expected to impact more in northern than in southern seas. The impacts on ecosystems (including benthos) could be stronger for enclosed (Mediterranean, Tyrrhenian, Adriatic, Baltic) than for open seas (Atlantic). The northward movements of species are expected to be stronger in southern (Iberian coasts) than in northern seas (Norwegian), and in open (Atlantic) than in enclosed seas (Baltic, Mediterranean). The shifts in species composition could be stronger from northern to southern species (open seas, such as the Atlantic) and from endemic to congeneric species (enclosed seas, such as the Mediterranean).

10.4 References

Labrune, C., Gremare, A., Guizien, K., Amouroux, J. M. 2007. Long-term comparison of soft bottom macrobenthos in the Bay of Banyuls-sur-Mer (north-western Mediterranean Sea): A reappraisal. Journal of Sea Research, 58: 125–143.

MCCIP, 2008. Marine Climate Change Impacts Annual Report Card 2007-2008. (Eds. Baxter, J.M., Buckley, P.J., Wallace, C.J.) Summary Report, MCCIP, Lowestoft, 8 pp (www.mccip.org.uk).

Occhipinti-Ambrogi, A., 2007. Global change and marine communities: Alien species and climate change. Marine Pollution Bulletin, 55: 342–352.

Philippart, C. J. M., 2007. Impacts of Climate Change on the European Marine and Coastal Environment. Ecosystems Approach. Marine Board – European Science Foundation: 88 pp.

Vargas Yáñez, M., M. C. García Martínez, F. Moya, E. Tel, G. Parrilla, F. Plaza, A. Lavín, 2008. Cambio climático en el Mediterráneo español. Temas de Oceanografía, Instituto Español de Oceanografía, 1: 159 pp.

11 Any other business

11.1 Announcements

T. Brey announced the new location of his handbook. www.thomas-brey.de/virtualhandbook

J. Kotta is now associate editor of the new Estonian Journal of Ecology www.kirj.ee/ecology. This site offers free access to papers.

11.2 Election of new Chair

Heye Rumohr has been Chair of BEWG for six years and he is now the only remaining founding member of this group in 1981 in Texel. One of the most challenging tasks of the chair has been keeping track of the mailing list for the group, so he requested the group to please reply to emails from the chair promptly. Emails should be copied to the Secretary for the group, Vivian Piil. Heye Rumohr also said that whoever is next elected chair should be aware that the chair must be in agreement with ICES goals and procedures, and that the group is obliged to provide that which ICES requests from us (OSPAR, HELCOM, EU requests). ICES is aware that the expert groups are valuable and also recognise the value of the Chairs of the Expert Groups. Thus they are likely to use the chairs for advisory panels more than in the past.

There was only one candidate for the next chair, S. Degraer of Belgium. The members present unanimously supported SD's candidature with a show of hands. HR also mentioned many communications via email (from non-attendees) supporting SD's candidature. SD will now be announced by the Marine Habitats Committee and then reconfirmed by the delegates. S. Degraer thanked H. Rumohr on behalf of the Group, for the past six years of chairmanship.

11.3 Suggestions for future theme sessions for ICES Annual Science Conferences

The ICES Annual Science Conference 2009 will be in Berlin, but our sessions could be in the 2010 conference. The group agreed to propose one theme session on phytobenthos:

Ecosystem role of phytobenthos in ICES waters. H. Kautsky was proposed as a potential convener and possibly A. Borja.

11.4 Upcoming Conferences and Symposia

- The Iberian Symposium of Marine Biology Symposium, 9–13 September 2008 in Funchal, Madeira.
- ASLO meeting, 25–30 January 2009 in Nice, France. A special session has been proposed by A. Borja (AZTI), M. Elliott (University of Hull, UK), Danien Dauel (Old Dominian University, USA) and Charles Simestead (University of Washington) entitled Medium and long-term recovery of marine and estuarine systems – A guide to providing useful information in new scenarios to restore ecological integrity.
- 43rd European Marine Biology Symposium, September 2008 in Horta, Azores

- World Conference on Marine Biodiversity in November, 2008 in Valencia (but registration for this is now closed)

11.5 Location of next year's meeting

Next year's meeting will take place during the week of 20-24 April 2009 at Askö Field Station in Sweden (www.smf.su.se). Although it is quite remote, there is a good internet connection there and the location would is very suitable. Easter falls on the week of 10–13 April, so the week of 20–24 April was considered preferable.

12 Adoption of the report

After review and discussion the group adopted the last version of the draft report.

13 Closing of the meeting

The Chair thanked the local host for their generous hospitality and the interesting excursion to the Losa Nuraghe and the beautiful coasts of Sardinia. He also thanked the contributors for their input, especially the Rapporteurs and the editing Rapporteur and closed the meeting on Friday, 17:00 hours.

Annex 1: List of participants

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Annex 2: Agenda

ICES BENTHOS ECOLOGY WORKING GROUP

Torre Grande, Sardinia, Italy

21–25 April 2007

Agenda

Start 21 April, 09:30

Opening & Local Organisation

- Appointment of Rapporteur
- Hans, to continue updating the BEWG website, please
- Terms of Reference

Adoption of Agenda

Report on ICES meetings and other meetings of interest

- ASC 2007 (Helsinki) / ICES Annual Report for 2007
- Marine Habitat Committee, Helsinki 2007
- WGEXT
- MarBEF

TOR d) review and consider recent developments in ongoing benthos research in the ICES area;

- Cooperative studies
- Benthos and fisheries
- Benthos of soft sediments
- Benthos of rocky substrates

ToR a) consider the reports of the Ad Hoc Groups on; Hydrographic Attributes, Trend Analyses & Quantifying Relationships, Formulating Hypotheses and Predictions about Mechanisms, Selecting Species for More Intensive Investigations and use their recommendations concerning (1) recommended time series, (2) analytical methods and suitable software, (3) hypotheses and guidance for their use, and (4) a suggested list of species for intensive study, to complete 'the assessment of changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature.

ToR b) review and update the JAMP guidelines for benthos, (phytoplankton and chlorophyll) according to good current practice and/or international standards for acceptability of biological sampling and analytical practices required by monitoring programmes. (OSPAR request 10);

- review of final draft of TIMES Epifauna guidelines edited by H. Rees

TOR c) plan the next North Sea Benthos Project 2010;

ToR d) discuss and report on new methods for sampling and analytical practices for benthos including electronic ones;

- final draft for TIMES doc on Phytobenthos sampling and report on WKPHYT 2008
- publication on arctic image time series evaluation

ToR f) report and discuss possible climate enforced changes in the benthos in the Mediterranean compared to ICES waters;

ToR g) consider the Mediterranean phytobenthos in relation to Northern European environments;

ToR h)report and discuss on the outcome of the workshop on Benthos Related Environmental Metrics (WKBEMET) (Ine)

- report from ICES symposium November 2007 in London

Any other business .

- further theme sessions
- Upcoming symposia etc
- Election new BEWG chair

Recommendations and Action List

- Recommendations for next years meeting (2009)
- Recommendations for Theme Sessions/ Symposia
- Action List

Adoption of the report (due 15 May 2008)

Closing of the meeting

Morning session 9:00–13:00 coffee break 10:30–11:00

Lunch (inhouse catering) 13:00–14:00

Afternoon session 14:00–18:00 coffee break 15:30–16:00

Social events on extra announcement:

Wednesday 23.04 17:30 visit to "CONTINI" winery in Cabras (incl. tasting)

Excursion on Friday 25.04 (public holiday)

Annex 3: BEWG terms of reference for the next meeting

Please use the example below to formulate your draft resolutions for next year's meeting.

The **Benthos Ecology Working Group** BEWG] (Chair: S. Degraer*, Belgium) will meet in Askö, Sweden, in Week 17, 2009, to:

a) Consider the outcome of WKCBPNS in November 08 and plan the next North Sea Benthos Project

b) Review new developments in environmental metrics and consider future joint activities

c) Review and consider new developments in ongoing benthos research in the ICES area

d) Review recent developments in environmental quality assessment covering both phytobenthic and zoobenthic topics

e) Consider long-term observation (both phyto- and zoobenthos) with the aim of identifying effects of climate change.

BEWG will report by mid May 2009 to the attention of the Marine Habitat Committee.

Supporting Information

Priority:	The current activities of this Group will lead ICES into issues related to the ecosystem affects of fisheries, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Scientific justification and relation to action plan:	Action Plan No: 1. Term of Reference a) This project is one of the central activities throughout the existence of the group and will provide valuable data with relevance for OSPAR and EU requests Term of Reference b) The work on this topic will enable the group to answer future OSPAR and EU requests Term of Reference c) This is a prerequisite for the scientific information status of the group Term of Reference d) This is a prerequisite for the assessment of the ecosystem health in future requests for advice Term of Reference e) This ToR fits into the ongoing discussion on climatic induced changes in the marine environment and will support future requests from OSPAR.
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants:	The Group is normally attended by some 20–25 members and guests.
Secretariat facilities:	None.
Financial:	No financial implications.

Linkages to advisory committees:	There are linkages to ACME and ACE.
Linkages to other committees or groups:	There is a close working relationship with WGMHM, WGECO, WGEXT, MHC
Linkages to other organizations:	MARBEF

Annex 4: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. The group recommends a Planning Workshop for the new North Sea Benthos Project 2010 to be held in November 2008, chaired by H. Reiss, venue still to be decided.	

After submission of the report, the ICES Secretariat will follow up on the recommendations, which will also include communication of proposed terms of reference to other ICES Expert Group Chairs. The "Action" column is optional, but in some cases, it would be helpful for ICES if you would specify to whom the recommendation is addressed.

Action List:

- IM to prepare a draft for the ToR b on indicators – to make an outline of what is new etc.
- KM to report on long-term series from the Northern Baltic
- SP Possible effect of the climate change on the two long-term communities in La Coruna Bay
- AB present new research on *Gelidium* with respect to Climate Change
- LB-M will update on the MAREANO project and will report on new developments in Habitat Mapping.
- Johannes to report on the impact of mussel fisheries on biodiversity
- HK will report on long-term changes in phytobenthic communities in the Baltic
- HH to report on the WFD implementation for the Belgian coastal waters.
- HR will report on the workshop on the North Sea Benthos Project;
- Alex will present something on spatial and temporal variation of soft bottom benthos on different scales.
- EV to report on updates to EUNIS classification
- Carl to present new findings of biofilm attraction to benthic settlers

Annex 5: The Oristano Lagoon-Gulf System: Hydrological Setting and Benthic Studies

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Keywords: hydrodynamic-ecological modelling, transport, sediments, macrobenthos, fishes, food webs, ecological indicators, coastal lagoons, Mediterranean Sea

Account of the research activities carried out on the Oristano Lagoon-Gulf System by the Institute for Coastal Marine Environment of the National Research Council (CNR-IMC) and the Foundation IMC International Marine Centre of Torregrande-Oristano (Sardinia, Italy).

The Oristano lagoon-gulf system comprises the gulf of Oristano and several salt marshes and shallow eutrophic water bodies known for their nature value and economical importance. However, Oristano lagoons have recently experienced high anthropogenic pressure due to massive nutrient loading, reduction of freshwater input from upland and modifications of the inlets which have reduced the water exchange with the gulf. This has led to periodic dystrophic events with anoxia and sulphide development causing massive mortalities of benthos and fishes. Numerical models concerning physical and ecological processes were described, including a fully coupled hydrodynamic-ecological model based on the finite element method, suited for application to lagoons and coastal seas. Different scenarios characterized by modified settings of the hydraulic balance between the gulf and the Cabras lagoon were presented to predict the evolution of both hydrological and ecological variables within the system. Research on sediment characteristics (grain size composition, organics, chemical compounds), macrobenthic assemblages (in unvegetated and seagrass-dominated systems) and food webs ($\delta^{13}C$ and $\delta^{15}N$ analysis) were also described. It was demonstrated the importance of investigating and considering the cohesive (organic-C bounding) fraction of sediments within the muds in order to allow a better assessment of benthic-sediment relationships and the ecological quality of organic-enriched lagoon systems. In addition, studies on the effect of hypoxia on ecophysiology, energetics and behaviour on the various species of lagoon fishes (*Liza aurata, Mugil cephalus* and *Dicentrarchus labrax*) were briefly introduced. The main results of this multidisciplinary and integrated research were discussed in the light of their potential applicability and support to local issues and administrations, as well as their relevance to the WFD 2000/60/EC.

Annex 6: ICES WKPHYT Summary Report

Summary report on the workshop ICES-WKPHYT, Askölaboratory, Sweden, 3-6 March 2008

By Hans Kautsky

This meeting marks the first expert workshop on phytobenthos related matters in ICES history.

The natural phytobenthic communities are considered to be the most species rich areas of temperate waters. The plant communities provide a three-dimensional habitat

and secondary hard substrate to serve as habitats to a wide range of plant and animal species.

The phytobenthic communities provide the human society with a large number of goods and services (Rönnbäck *et al* 2007), e.g. functions as a gigantic filter of coastal nutrient release manifested in increased growth of filamentous and foliose algae observed in eutrophicated areas and outside point sources of nutrient release. They stabilize the shoreline. They are the source as well as harbour species for consumption and facilitate the survival of juvenile fish of commercial importance, etc. The phytobenthic plant and animal communities form a link between the land and the open and deeper oceanic ecosystems being the first ecosystem to receive the land runoff. The drifting, loose algae (and higher plants) serve as food resource for the deeper benthic communities, or when drifted ashore, were/are used as fertilizer.

The shallow phytobenthic community serves as a base for commercially important fish that spawn and breed among the algae and find food and shelter within the plant belts (e.g. Anderson, 1994; Aneer, 1985; Aneer and Nellbring 1982; Aneer, *et al*. 1985; Jansson, 1985; Pihl, *et al*. 1994; Rangeley and Kramer, 1995; Robertson, 1984). There is commercial harvest and exploitation of algal products for e.g. agar production, but also for consumption (est Ltv ref, Norway Europe). Unpolluted phytobenthic communities have recreational values. They provide living space for rare and endangered species.

Historically, the disappearance of the *Zostera marina* communities in the northern European waters in the 1920s pin-pointed to the physical importance of these plant communities as a coastal zone erosion protection (e.g. Boström and Bonsdorff, 2000, Duarte 1995), Greve, and Krause-Jensen 2005, Borum *et al*. 2004; Möller and Martin 2007). This is also documented in the Mediterranean Posidonia meadows.

The species richness of the phytobenthic community provides a battery of both plant and animal species sensitive to different pollutants and/or eutrophication. As many of the species included in a monitoring programme of the phytobenthic communities are attached and perennial they integrate the environmental load over a longer time. In combination with the relative easiness to observe the communities, they are an important indicator of the quality of the water body and are therefore included, e.g. in the WFD (Selig *et al*. 2006) and are used in several national monitoring programmes following the effects of eutrophication (e.g. Kruse-Jensen *et al*. 2008). Observations can also be done with longer time intervals to detect change which makes the study of these communities cost efficient.

To understand the change with time (mainly eutrophication and local pollution), the seasonality, natural annual variation due to population dynamics and the succession of the communities have to be known. Specific research within these topics has been performed and is ongoing. Long-term monitoring data are now interpreted not only by the correlation to different environmental impacts but also, e.g. the NAO and the large scale climatic change.

The phytobenthic communities are included in the WFD. Most countries within the European waters have developed their own phytobenthic criteria for the quality of their waters. There is an urgent need to harmonize the different approaches. For example, in Sweden a battery of species (over 20) maximum depth extension is used, in other countries the depth of a single species is used (Fucus vesiculosus and/or Zostera marina). Until the next revision of the WFD there is, e.g. an urge to develop methods that take into account the known quantitative distribution of the species

(coverage of the substrate). Also, for the quality criteria, there is a need to decrease the importance of finding the maximum depth of a species. For the classification we should be able to consider all species present at a site and not only a chosen amount. In general there seems to be an urge for field studies in eutrophicated or polluted gradients to increase our knowledge of how the species composition and coverage changes within that gradient. Thus, we may find more accurate limits for the five quality criteria in the WFD. As it is done today usually an arithmetic share or chosen depth range for each species based on historically observed maximum depth extensions of the species was used.

The topic of forming EUNIS-classes adapted to Baltic Sea conditions was briefly discussed. This topic was then discussed further in a workshop in Stockholm, in direct connection to the ICES-WKPHYT-workshop.

The EUNIS-workshop agreed to adopt a modified version of the present EUNIS system down to level 3, as presented by Dan Conley during the meeting. This will be suggested to HELCOM. We realize that for the procedure of finding operative groups for the Baltic Sea there is a need for a bottom-up approach. By e.g. using multivariate methods, species associations can be realized and environmental variable appropriate for their occurrence may be found. This analysis is ongoing today.

During the workshop we also discussed and realised the need of a database in common including operative routines for the taxonomy of the species. For the Swedish regional and national monitoring programmes such a database has been constructed.

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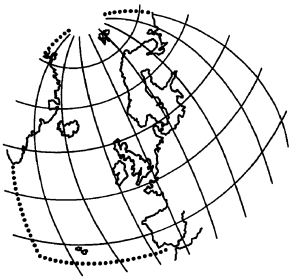
Annex 7: JAMP Eutrophication Monitoring Guidelines



JAMP Eutrophication Monitoring Guidelines:

Benthos Reviewed and amended by ICES BEWG April 2008

JAMP EUTROPHICATION MONITORING GUIDELINES: BENTHOS

1 Introduction

Benthic communities (including hard-bottom and soft-bottom macrophytobenthos and hard-bottom and soft-bottom macrozoobenthos) generally occur in recognisable states, depending on the substrate, depth, wave exposure and salinity *etc.* Macrobenthic communities are an appropriate target for monitoring since:

a) an important component of benthic communities is that formed by species which are long-lived and which therefore integrate environmental change over long periods of time;

b) they are relatively easy to sample quantitatively;

c) they are well-studied scientifically, compared with other sediment-dwelling components (*e.g.* meiofauna and microfauna) and taxonomic keys are available for most groups;

d) community structure responds in a predictable manner to a number of anthropogenic influences (thus, the results of change can be interpreted with a degree of confidence);

e) there may be direct links with commercially valued resources, *e.g.* fish (via feeding) and edible molluscs.

f) the floral part integrates long-term change of water quality (turbidity)

Nutrient enrichment/eutrophication may increase the food supply to the benthos and therefore may give rise to changes in species composition and numbers, increased biomass, a shift from k-selected to r-selected species, shifts in functional groups, changes in community structure and an impoverishment of benthic communities due to anoxia. These guidelines are intended to support the minimum monitoring requirements of the Nutrient Monitoring Programme.1

Much information exists on methodology for benthos investigations. The most relevant reports are those by Rumohr (2008), which deals largely with methodology for the collection and treatment of the soft-bottom macrofauna, and by Rees *et al*. (1991) and Rees (in prep.) which focuses on the monitoring of benthic communities around point-source discharges and epibenthic studies, respectively. These accounts also deal more generally with the role of benthos studies in investigations of human impact, including guidance on the sampling of different substrate types. The HELCOM 'COMBINE' manual for monitoring in the Baltic Sea is another important reference source (see www.helcom.fi).

A range of other documents are of value in the planning and conduct of marine benthos sampling programmes. The most useful is that by Eleftheriou and McIntyre (2005) which is a standard reference for work of this type. Gray *et al.* (1992) report on approaches to marine pollution assessment and provide practical examples of applying the PRIMER ('Plymouth Routines in Multivariate Ecological Research') package for univariate, graphical and multivariate data analyses (see Clarke and Gorley, 2001 for further details). Kramer *et al.* (1994) have produced a manual for the sampling of tidal estuaries. An account of survey methods employed by a team of scientists undertaking a review of marine nature conservation in UK inshore waters together with a rationale for such work is given by Hiscock (1996), Davies *et al*. (2001) and Connor *et al*. (2004). A monitoring programme and monitoring guidelines have been prepared

[1] The Nutrient Monitoring Programme as adopted by OSPAR 1995 (OSPAR 95/15/1, Annex 12).

for the Wadden Sea 'Trilateral Monitoring and Assessment Programme' (TMAP, 2000).

2 Purposes

The monitoring of benthic communities is carried out for, *inter alia*, the following purposes:

to monitor the spatial variability in species composition and biomass within the Maritime Area resulting from anthropogenic nutrient inputs;

to monitor temporal trends in species composition and biomass within the Maritime Area (at a timescale of years) in order to assess whether changes can be related to temporal trends in nutrient inputs;

to support the development and implementation of a common procedure for the identification of the status of the benthic communities;

to understand the relationship between nutrient concentrations and temporal trends in species/community characteristics.

3 Quantitative objectives

The patchy distribution of benthic communities together with the many taxa involved means monitoring programmes are very dependent on the design of the field programme. It is very difficult to formulate a general monitoring model suited to a wide variety of organisms, particularly for epilithic habitats. Furthermore, great care must be taken when transferring techniques developed in less complex systems (*e.g.* the Baltic Sea) to more complex systems (*e.g.* the North Sea). Taking into account these precautionary notes, the three primary objectives of benthic monitoring are as follows:

a) to test the hypothesis that eutrophication is responsible for changes in community composition and function, biomass and community structure;

b) to test the hypothesis that eutrophication is responsible for an increase in the abundance of ephemeral/annual algae such as *Cladophora*, *Enteromorpha* and *Ectocarpus* and a decrease in perennial algae such as *Laminaria* and *Fucus* and the angiosperm *Zostera marina* (eelgrass);

c) to test the hypothesis that changes in eutrophication levels are responsible for a decreased depth distribution of the macrophytes (*e.g.* due to increased turbidity).

Prior to monitoring, it is necessary to determine the number of sample replicates required to describe the species spectrum (this may be done using a species area curve or a comparable advanced technique. Alternate methods can be used when fixed frames or transects are utilized). Before sampling begins, levels of acceptable variability must be set and followed for all parameters measured. The effects of organic matter inputs on benthic communities are adequately described by the empirical "enrichment" model of Pearson and Rosenberg (1978) and examples of studies which have postulated links between changes in the benthos and eutrophication are given by ICES (1995). The model, which is equally applicable to trends in space and time, describes cyclical (*i.e.* non-linear) changes in numbers, densities and biomass of benthic species along an enrichment gradient. Multivariate analytical methods may be

used to examine between-station differences and temporal trends in the data. Univariate measures amenable to statistical testing include:

- a count of species (coverage of plants and colonial animals included);
- a coverage of plant species and colonial forms;
- measurement of densities and biomass;
- quantification of species in terms of functional groups *e.g.* feeding types;
- categorisation into r-selected and k-selected species.

The natural patchiness of benthic communities must be accounted for in the analysis. Hierarchical statistical methods may be used. Sophisticated computer packages for the statistical analyses of benthic data are now widely available. Use should be made of at least one established diversity index and one multivariate analytical technique. A consideration of trends in the "primary" variables (*i.e.* numbers of individuals, taxa and biomass) should also be undertaken in relation to physical/chemical measures derived from sediment sub-samples. The statistics for these evaluations may be undertaken using appropriate software packages

4 Sampling strategy

Sample sites should be representative of the whole monitoring area and so characteristic habitat structures and substrates must be sampled. Prior to temporal trend analysis, checks must be made to ensure that sample sites are inhabited by a homogenous benthic community rather than non-comparable, heterogeneous benthic communities. It is important to establish the baseline community structure and variability at the site under consideration. Sample points must be spread out over the extent of the habitat studied to ensure an adequate consideration of spatial variation. It cannot be assumed that one point is representative of the habitat as a whole. When measuring anthropogenically-induced change control/reference sites (preferably at least two) are required for each test site. It is critical that similar habitats are selected for comparison. There are several sources of guidance on the design and implementation of field sampling programmes, including Elliot (1971), Cohen (1977), Green (1979), Andrew and Mapstone (1987), Skalski and Robson (1992), Rees *et al*. (1991 and in prep.), Underwood (1997) and Underwood and Chapman (2005). A eutrophication-related monitoring programme would typically include a desk study and survey planning stage, followed by pilot, baseline and ongoing surveys.

The sampling strategy for macrophytobenthos and hard-bottom macrozoobenthos is described at Technical Annex 1. The sampling strategy for soft-bottom macrozoobenthos is described at Technical Annex 2.

5 Sampling equipment

The sampling equipment for macrophytobenthos and hard-bottom macrozoobenthos is described at Technical Annex 1. The sampling equipment for soft-bottom macrozoobenthos is described at Technical Annex 2.

6 Storage and pre-treatment of samples

The storage and pre-treatment of macrophytobenthos and hard-bottom macrozoobenthos samples is described at Technical Annex 1. The storage and pre-treatment of soft-bottom macrozoobenthos samples is described at Technical Annex 2.

7 Analytical procedures

Analytical procedures for macrophytobenthos and hard-bottom macrozoobenthos are described at Technical Annex 1. Analytical procedures for soft-bottom macrozoobenthos are described at Technical Annex 2.

The data generated will require storage in a database. The database should be of a type capable of storing and/or generating information of the following type:

a) the spatial distribution and size of epilithic communities, particularly concerning mats of green macroalgae, eelgrass meadows and mussel beds;

b) sketch illustrations showing the distribution of substrate types and the dominant species associated with the substrates;

c) the depth distribution of plant and animal biomass by species, functional group and any other arbitrary selection, as well as the relative quantities of the primary functional groups such as dominant, annual and perennial organisms;

d) temporal trends concerning changes in depth distribution, percentage cover, biomass, species composition and distribution *etc.*;

e) a statistical evaluation including explanatory power;

f) correlations of specific types of benthos data against supporting information (*e.g.* Secchi depth, salinity, oxygen, nutrients, pelagic primary production, other types of benthos data).

As a measure of grain size distribution for the upper 5 cm of the sediment the following sieves should be used: 63 μm, 125 μm, 250 μm, 500 μm, 1000 μm and 2000 μm together with weight loss on ignition (500°C–520°C), total organic carbon and pigments (recommended). Other more advanced methods such as Laser diffraction, sedimentation columns etc. may also be used. To measure nutrients (particulate N) in sediments samples should be dried at 60°C until constant weight (12-24h), treated with HCl, held for 24h in a desiccator, dried again at 60°C and analysed in a CHN analyser.

8 Analytical quality assurance

Effectively the quality assurance (QA) programme should ensure that the data are fit for the purpose for which they have been collected (see Rees, 2004). Appropriate QA schemes should be established before the onset of survey work. It is particularly important that adequate resources are allocated for these purposes when co-operative studies involving several institutes are to be conducted, or when the data are to be centrally archived. It is essential that the QA also includes the explanatory power and the experimental design. Thus, the QA must take into account as many steps of the analytical chain as possible in order to determine the contribution of each step to the total variation. Quality assurance methods are still under development for some activities, e.g., biomass determinations. If the abundance estimates are to be carried out

by different workers, a calibration of their cover estimates must be performed. This can be done by comparing *in situ* survey data with digital and point sampling estimates of underwater photo documentation. Underwater photography and/or video may provide an additional means of obtaining cover estimates but these techniques are more appropriate where foliose phytobenthos does not obscure underlayers. Animals that can be counted often provide a better basis for estimates of cover than subjective assessments or point sampling. The latest taxonomic literature should be used. Name changes and literature used must be recorded. Quality assurance for soft-bottom macrozoobenthos should take account of Rees (2004) and Rumohr (2008) (see also ICES 1994, 1996). Each Contracting Party which intends to deliver data to a common data pool should take part in regular intercalibration exercises and associated taxonomic workshops.

9 Reporting requirements

[Reporting formats need to be developed which will allow the exchange and evaluation both of the raw data and of all relevant ancillary information. Such formats must be readily usable by both the data centres and the originators of the data. Data for the common pool will have to be submitted via the national data centres in order for them to keep in touch with progress of the work, including the availability of data from each Contracting Party. This procedure should help to guarantee data quality, since the national data centres will be ultimately responsible for the timely submission of completed data sets to the common pool. Reporting formats will develop with the programme. As a component of the 1997 ICES Work Programme, the Oslo and Paris Commissions have formally requested ICES to establish a databank for phytobenthos and zoobenthos]

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Technical Annex 1

Hard-bottom macrophytobenthos, soft-bottom macrophytobenthos and hard-bottom macrozoobenthos

Sampling strategy

An overview of the methods available for monitoring has been given by ICES (1996), Hiscock (1996), Davies *et al.* (2001), Eleftheriou and McIntyre (2005) and Rees (in prep.). Diver operated methods in shallow water and remote underwater photography in deeper areas, are the most suitable options.

Monitoring should take place annually at a particular time within the four summer months (June–September) for the first three years of the monitoring programme. Subsequent sampling frequency then depends on the expected rate of change in species composition. In areas where large changes are expected sampling should take place on an annual basis. In areas where little change is expected sampling every 5 to 10 years would be sufficient. Three main sampling techniques are available for hard-bottom and soft-bottom macrophytobenthos and for hard-bottom macrozoobenthos: aerial surveillance (in tidal areas), diving transects (in sub-tidal areas) and quantitative sampling.

Aerial surveillance

Aerial surveillance can be used as an optional method to determine the size and distribution of epilithic communities, including mats of green macroalgae, eelgrass meadows and mussel beds. High-wing monoplanes flying at low altitude (150 m) are an appropriate platform for the relevant sensors. Positions should be located by means of satellite navigation (*i.e.* GPS). Aerial surveillance can cover large areas and results should always be calibrated by means of quantitative field inspections at selected locations (*cf.* section entitled "Quantitative sampling"). When applied, aerial surveillance of green algae should take place during May–October at four-week intervals during low tide. One flight should be carried out at the end of the winter for mapping the distribution of mussel beds.

Diving transects

Diving transects are used to provide a description of the depth distribution and abundance of the dominant plant and animal communities. The transects should extend to at least the maximum depth of the algae, but should not be deeper than 30 meters (for diver safety). Depth limits of kelp, dense foliose algae or the deeper foliose algae may be measured using digital instruments, recorded and corrected for tidal amplitude. Abundance and/or coverage should be determined at sites within the main assemblages or within sub-habitats, if these are distinct. The coverage should (Braun-Blanquet) be used for plants and animals in colonies or high abundance. Reconnaissance surveys, which may include remote sensing (see section entitled "sampling equipment") are also useful in helping to choose transect locations. Transects should be undertaken at the beginning of the monitoring programme and should be repeated regularly, for example every 5 to 10 years. As estimates of distribution and percentage cover are carried out *in situ,* a cord with meter marks should be placed along the transect. Progressing along this cord, divers should note the distribution and type of substrate as well as the degree of cover for the main plant and animal species in a strip 5-10 m wide. Divers should estimate abundance using an appropri-

ate scale (Hiscock, 1990; Kautsky, in prep. Krause-Jensen *et al*., 1994; Karlsson, 1995; Pedersen *et al*., 1995, Kautsky, 1993). This may be time consuming under water, but gives a good estimate over the whole depth zone, which is much harder to achieve using frames. An alternative approach would be to apply the abundance estimation scale at fixed sites within the main zonal biotopes. Species/categories that are not immediately obvious may warrant the use of more time-consuming techniques such as quadrat counts (see section entitled "Quantitative sampling").

The following information should be recorded in the field:

a) the exact position of the transect (using for example a map, photography, a permanent mark on the shore, GPS);

b) the distance from the shore (using a meter marked line along the transect);

c) the depth (according to a calibrated depth gauge and corrected for tidal amplitude);

d) substrate type (rock, boulders, stones, gravel, sand, mud, glacial clay, *etc.*);

e) the presence of loose sediment deposited on plants and substrate (in terms of "none", "little covered", "heavily covered");

f) an estimate of the abundance of different plant and animal species;

g) the maximum depth of dominant sub-littoral species and the lower limit of vegetation;

h) photographic and/or video documentation (video/photographic profiles of the transect, panoramic views and, at fixed marked sites if possible, stereo photographs);

i) the degree of wave exposure, Secchi disk depth (*i.e.* light transmission) and salinity (if possible).

Biological material could also be collected as reference specimens for herbaria *etc.* and for algal toxins (in conjunction with other monitoring programmes).

Quantitative sampling

Depending on the time spent on the transect, direct observations by divers may overemphasise the importance of particular eye-catching species. Quantitative sampling gives unbiased information about plant and animal communities but is extremely time-consuming. Quantitative samples, obtained via stratified random sampling, are required in order to determine species composition and biomass. At least three parallel quantitative samples of key species/communities should be collected at different pre-selected depth intervals. Sample locations at each depth are chosen by random placement of a quadrat, or by sampling at random distances along the transect from the shore. Tests should establish the number of parallel samples and the minimum sample area, and this will vary according to the type of community/species being sampled and its distributional characteristics (*cf.* Elliott, 1983). For example small but randomly distributed species may require large quadrats, whereas it may be possible to use relatively small quadrats for small but evenly distributed species. Rocky habitats are usually architecturally very complex and care is needed to specify slope, aspect and exposure. These methods follow recommendations by Anon. (1991) Dybern *et al.*, (1976), Hiscock (1987), Hiscock and Mitchell (1989), Jespersen *et al.* (1991), Kautsky (1993) and Davies *et al*. (2001).

The following data should be recorded in the field whenever possible:

a) the exact distance of the sample site from the shore;

b) water depth (according to a calibrated depth gauge and corrected for tidal amplitude);

c) a photographic image of the site;

d) the number of organisms of each species;

e) the biomass of plant species and animal species;

f) the size structure of some animals (mainly molluscs).

Biological material could also be collected as reference specimens for herbaria *etc.* and for algal toxins (in conjunction with other monitoring programmes).

Sampling equipment

Submarine video in combination with GPS is useful for choosing transects and for surveying large areas for approximate species composition and the depth distribution of the vegetation as a whole. Larger areas may be scanned using remote-sensing techniques (*e.g.* by satellite or aircraft), but only for communities close to the surface. For aerial surveillance in intertidal areas, manual mapping is sufficient. Here vertical images and video films are generally not cost-effective techniques.

Surveys estimating abundance should sample within a large area containing the same biotope in order to reduce edge-effects or effects resulting from irregular species distribution. Quadrangular frames with a side length of 0.10 m to 0.50 m are suggested for quantitative sampling (the smaller frames should be used in the littoral zone for small species such as barnacles).

Storage and pre-treatment of samples

Sampled material should be preserved by freezing (-20°C) or by using formaldehyde (2–4%). It should be emphasised that thawing may cause leakage and thus underestimate biomass, and that species may react differently depending on their morphology. The same also applies for preservation with formaldehyde. Fixation using formaldehyde should be avoided for samples which will be analysed for nutrients. Samples for biomass determination must be free of overgrowth and rinsed with freshwater before drying. Sampled animal material should be stored in alcohol (70%) after biomass (wet weight) determination.

Analytical procedures

Macrozoobenthos measurements should comprise individual length, width, volume *etc.* Macrophytobenthos determinations should normally be accompanied by the co-monitoring of relevant macrozoobenthos and vice versa.

Samples obtained using quadrangular frames (see section entitled "Quantitative sampling") may be analysed to determine plant and animal species composition and biomass. In areas where species numbers are low biomass may be expressed per species. Biomass should be expressed as either "g dry weight" samples should be dried at 60°C until constant weight (this can be up to one week depending on volume of sample) or as "g ash-free weight per m²" (samples should be dried at 500°C until con-

stant weight (at least 6h)). Biomass expressed as volume (*e.g.* using water displacement) should be measured in the field whenever possible.

The degree of accuracy required for taxonomic sorting depends on the purpose of the monitoring programme. For the present programme it should be sufficient to identify organisms, whose taxonomic specification is difficult or time-consuming, to the generic level rather than to the specific level. (*e.g. Cladophora* spp., *Enteromorpha* spp.). Rare species should be determined to higher taxonomic levels. Functional groups should be kept intact as far as possible.

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Technical Annex 2

Soft-bottom macrozoobenthos

Sampling strategy

An initial spatially extensive "baseline" survey will facilitate the selection of representative stations within and adjacent to areas perceived to be vulnerable to the effects of eutrophication. It will be necessary to repeat the baseline survey periodically to check the continued validity of representative stations and to ensure that no unexpected effects are occurring beyond the region predicted to have been affected by eutrophication. Full use should be made of historical information in the planning of surveys.

Large-scale sampling of the macrozoobenthos community in offshore subtidal soft-bottoms should comprise many stations but with few replicates per station. A large-scale sampling grid covering the whole area of investigation should be sampled at intervals of 10 years and this should be sampled by a variety of methods in order to cover the full range of the species spectrum. This large-scale sampling every 10 years is necessary to confirm the representativity of annual temporal trend monitoring stations. For temporal trend monitoring, sampling at a frequency of once per year (at the same time of year) should be adequate, although locally severe effects of nutrient enrichment (such as hypoxia) may dictate a higher sampling frequency. If the sampling frequency is twice per year, then sampling should take place in late winter/early spring to establish the stable community conditions and in late summer/autumn with a view to detecting the possible effects of nutrient enrichment (such as hypoxia) on the macrozoobenthos.

The sampling strategy for macrozoobenthos communities in coastal soft-bottom areas needs site-specific adaptations of site selection, choice of sampler and sampling frequency (see, e.g., Trilateral Monitoring and Assessment Program, 2000). For example: estuaries should be sampled from the limnic to the Marine Area, backwaters and lagoons should be sampled twice a year at representative stations (a large-scale sampling programme should be performed every 5 years) and fjords should be sampled along a transect ending at the outer edge of the sill.

The following information should be recorded in the field:

a) whether or not the ship was anchored;

b) depth and position of each replicate; a GPS track plot would be desirable;

c) the time of day;

d) the weather conditions during sampling and sea state;

e) a description of the sediment, including:

  i) surface colour and colour change with depth (as a possible indicator of redox state);

  ii) smell (H_2S);

  iii) a description of sediment type, including important notes such as the occurrence of concretions, loose algae;

f) the type and specification of the sampler;

g) mesh size of the sieve.

Near-bottom temperature, salinity and oxygen measurements are desirable. If more than one sample is taken at a station, the depth range of samples should be recorded. All samples must be treated separately, *i.e.* must not be pooled. An estimate of the volume of sediment retained should be made for all samples taken, as a measure of sampler efficiency. Criteria for rejection of samples collected by grabs are given by Rees *et al.* (1991), ICES (1994) and Rumohr (2008). Measurements of redox potential and shear-strength should be made on samples collected by a box corer rather than a grab sampler because grab samplers are likely to distort the sample.

Sampling equipment

Sampling equipment appropriate for soft-bottom macrozoobenthos is described in detail by Rumohr (2008) and Eleftheriou and McIntyre (2005). Coarse sediments which cannot be sampled using normal procedures may be sampled using either a Hamon grab or appropriate dredges (*e.g.* an anchor dredge). Sediment structure and bioturbation depth may be checked with sediment profile imagery (see below). A hand-operated corer should be used for Wadden Sea sediments (TMAP, 2000). It should be noted that more sophisticated gear, such as epibenthic sledges, might be required for sampling hyperbenthic or bentho-pelagic species. Such gear is particularly valuable for studies of species (especially crustaceans) which constitute an important component of the diet of fish. Epibenthic and hyperbenthic sledges (Rothlisberg, P. C. and Pearcy, W. C., 1977dredge; see also Brattegard and Fosså, 1991; Sorbe sledge (Sorbe, 1983)) are useful for the small mobile crustaceans and boundary fauna. If automatic closing mechanisms and dredge distance recorders are added, then these instruments can be quantitative (cf. Gage deep sea epibenthic sledge). Special attention is drawn to the Triple-D dredge which was designed for the quantitative collection of the large and rare epifauna and infauna (Bergman and van Santbrink, 1994).

(see also Rees, in prep., for guidance on epibenthic sampling)

Photographic and video records are recommended as a complement to traditional sampling methods (Rumohr, 1995). Sediment profile imaging (*cf.* Rhoads and Germano, 1982) may provide a useful means for rapid surveys and classification of soft sediment areas. Side-scan sonar images will provide information on bottom topography and substrate type, which can be useful in the planning of benthos monitoring programmes or in the interpretation of the data. These records should be 'ground-truthed' by underwater video recording and/or grab sampling of sediments.

Storage and pre-treatment of samples

Procedures for the storage and pre-treatment of soft-bottom macrozoobenthos samples are as at Sections 3.1-3.2 of Rumohr (2008).

Analytical procedures

Procedures for the sorting and biomass determination of soft-bottom macrozoobenthos samples are at sections 3.4 and 3.5 of Rumohr (2008).

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Annex 8: Guidelines for the study of the epibenthos of subtidal environments

Reviewed and finally approved by BEWG 2008

Photos to be submitted by Hubert Rees (Ed.)

DRAFT

18.4.08

EXCL. PHOTOS

GUIDELINES FOR THE STUDY OF THE EPIBENTHOS OF SUBTIDAL ENVIRONMENTS

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Contents

1 Introduction

These guidelines document a range of sampling gears and procedures for epibenthos studies to meet a variety of needs. The importance of adopting consistent sampling and analytical practices is highlighted. Emphasis is placed on ship-based techniques for surveys of coastal and offshore shelf environments, but diver-assisted surveys are also considered.

The account extends earlier work by the ICES Benthos Ecology Working Group on methods for studying the benthic communities of hard substrata (Connor, 1995: see Annex 1). It also complements the TIMES guidelines for the study of the soft-bottom macrofauna (Rumohr, 2008) and the phytobenthos (Kautsky, in prep.) and other publications dealing with benthic sampling methods, notably Eleftheriou and McIntyre (2005).

Coverage of sampling gears is not exhaustive and others may be added in future editions. The target audience includes marine scientists new to epibenthic studies, as well as established practitioners who require further detail on sampling practices to meet various objectives of contemporary interest.

1.1 Definition, role and importance of the epibenthos

The epibenthos comprises animals and plants inhabiting the sea-bed surface for most or all of their adult life-cycles. They range from sessile forms such as seaweeds, sponges and colonial hydroids, to errant forms such as crabs, shrimps and fish. The size range of epibenthic organisms is considerably greater than their endobenthic (within-sediment) counterparts, and setting ecologically plausible boundaries, *e.g.* according to sieve mesh size, can be difficult. Thus many species inhabiting rocky or coarse ground habitats are colonial, crustose or 'cushion' forming, and so it is not practically feasible to use colony size as a consistent means to distinguish between species groups, or to enumerate individuals. However, qualitative information on the larger sedentary or sessile component of the epibenthos is likely to be the most reliable. It is also essential to take account of operationally-determined factors (especially gear design, efficiency and selectivity) when interpreting ecological data at different locations or between studies, and these are further addressed in the following Sections.

Aspects of the role of the epibenthos in marine ecosystems which make them an important target for scientific study include their significant contribution to benthic production, *e.g.* foliose algae in the photic zone and subtidal mussel beds. Habitat forming algae and sessile colonial animals, *e.g. kelp forests, coral and sponge reefs*, may provide attachment points and shelter for eggs and juveniles of fish and shellfish of commercial interest, while many species are preyed upon by fish, birds, seals and cetaceans. The epibenthos can also have a significant role in the bioaccumulation and the subsequent transfer of contaminants through the food chain.

As a group, the epibenthos accounts for a significant proportion of marine biodiversity (Thorson, 1957). The vulnerability of the more conspicuous elements of coastal and offshore assemblages to human activities has attracted much recent attention in relation to the conservation of species and habitats (*e.g.* the deep-water coral *Lophelia*: Fosså *et al.*, 2002 and Jones *et al.*, 2006; European Communities, 1992; www.ospar.org). There is also much interest in the functional role of the epibenthos in marine ecosystems, *e.g.* in food web studies (Jennings *et al.*, 2002) and in evaluations of 'essential fish habitat' (Cappo *et al.*, 1998; Benaka, 1999; Rosenberg *et al.*,

2000). Other studies have addressed the longer-term effects of climatic and fishing-induced changes (*e.g.* Aronson and Blake, 2001; Hobday *et al*., 2006; Callaway *et al*., 2007), while several epibenthic species are commercially fished.

1.2 Objectives of epibenthos studies

The following objectives highlight the main areas of contemporary interest:

- assessment of the contribution of the epibenthos to marine biodiversity and ecosystem functioning
- conservation of species or assemblages
- association of biological and sea-bed features in the context of large-scale mapping of benthic 'biotopes'
- environmental quality assessment (*e.g.* through the derivation of Ecological Quality Objectives)
- responses to climatic changes
- fundamental research, including experimental, behavioural and biomedical studies of individual species

1.3 Design and conduct of epibenthos surveys

The design of epibenthos surveys will be determined by the study objectives and the nature of the habitat(s) to be sampled. It is not feasible to cover all eventualities in these guidelines, especially if there is a research focus to studies. However, the design of monitoring programmes raises a number of common issues, which are outlined in Annex 2.

A useful operational distinction may be made between low- and high-relief terrain which generally serves to differentiate between sedimentary ('level-bottom') and rocky habitats. The former opens up wider possibilities for remote sampling, including the use of towed gear, which may be more efficiently and safely deployed than over rocky areas. The results from many of these devices depend as much on their design and mode of deployment as on the natural disposition of the epibenthic assemblages. This is particularly true for trawls and dredges, and caution should therefore be exercised in interpreting the data and evaluations of gear efficiency encouraged (*e.g.* Rees *et al*., 1999; Reiss *et al*., 2006). This does not mean that operational constraints invalidate trend assessments, but it highlights the need to adopt consistent sampling practices within and between studies.

Sections 2-4 describe a range of devices for the collection or *in situ* observation of the epibenthos, and for characterisation of the associated physical habitat. These include both established practices and prototype equipment with potential for further development and/or wider application. A distinction is made between sampling practices that are destructive or non-destructive ('observational') in nature.

Under the category of destructive sampling, the two most widely used types of equipment are trawls and dredges. Descriptions are given of the design and operation of a selection of these. Although conventional grab samplers are not generally suitable for epibenthic surveys, they (along with suction samplers) may be suitable for more narrowly-defined objectives, *e.g.* quantification of the smaller sessile component, especially of coarser substrata supporting species-rich assemblages. An account is therefore provided of the Hamon grab (Oele, 1978), and of other large (prototype and operational) devices which may be effective in collecting epibenthic

organisms (see Section 2.1.3). Finally, an appraisal of the merits of all gear types against various operational criteria is given in Section 8 (Conclusions).

A number of the selected sampling devices are versatile across depths and may be used in deep-sea studies, while others are tailored to this need (see Gage and Bett, 2005). These guidelines generally cover deployment/sampling practices for shallower shelf sediments.

The use of a standard sampler design and standard deployment practices are essential if studies are to yield internally consistent results. Such details should always be included in survey reports, so that the scope for comparisons between different studies can be determined (see, *e.g.*, Rumohr, 2008).

Reviews of the developing interest in marine habitat mapping and its application to resource and impact evaluations, which commonly combine acoustic, photographic and conventional seabed sampling practices, include those of Pickrill and Todd (2003), Boyd *et al*. (2006b) and Rees *et al.* (2008).

2 Destructive sampling methods

2.1 Towed gear

Many towed gears for the remote destructive sampling of the epibenthos yield qualitative or at best 'semi-quantitative' data (see, *e.g.*, Eleftheriou and Moore, 2005, Reiss *et al*., 2006 and Rumohr, 2008 for observations on trawl sampling efficiency). They are usually deployed at the sea bed while the vessel is proceeding at a constant speed, while drifting, or in some cases using winch power while anchored. Standardisation of sampling may include towing over fixed distances or over specified time intervals, and a measure of sampler efficiency may also be obtained from an odometer wheel or transponder which reflects the distance over which actual sea bed contact is maintained (below). The more sophisticated devices, usually dredges designed to skim a known surface area of sediment to a standard depth, or to entrain a known volume of water just above the sea bed, and which may permit more accurate quantification of the epibenthos or hyperbenthos, also have mechanisms for closing the sample container before retrieval (see Section 2.1.2).

Mechanical devices for measuring tow distances such as an odometer wheel may work well over even surfaces. However, they may be less reliable over mixed substrata and may fail as a result of fouling with filamentous epigrowths (*e.g.* colonial hydroids). This risk may be reduced through the use of paired odometer wheels (*e.g.* Lavaleye *et al*., 2002; see also 'Aquareve epibenthic sled', below). A prototype of an electronic device for 'real time' evaluation of bottom contact during trawl sampling was tested during a collaborative North Sea epifauna survey (R. Callaway, pers. comm.) and is now marketed (www.remontec.com) as a microprocessor-controlled system using a sonar communication link to send and receive data. Visualisation and hence control of performance may also be achieved by attaching a video camera, *e.g.* to a trawl beam or epibenthic sledge.

For most of the more elementary designs that sample at (as well as just above) the sea bed, bottom sediments will be penetrated during deployment. An obvious consequence is that samples from such devices will combine elements of both epifauna and infauna which will require separation during processing.

Initial processing of the contents can generally be conducted at sea, and sorted material can be preserved for later laboratory attention or discarded, as necessary. For

quality control, representative specimens of all identified species should be retained (see Section 5).

The efficiency of the gear will often depend on the different tidal states and wind conditions at the time of sampling. For offshore surveys, it is rarely practicable to co-ordinate effort in such a way as to ensure close comparability on all sampling occasions. Thus sample size and quality may vary, irrespective of whether tows are conducted over fixed times or fixed distances. It is therefore essential that information on tidal state and weather conditions is recorded, as they may account for differences between stations and/or sampling times identified during data analysis.

Expert judgement on sampling efficiency will be routinely required during trawl surveys, leading to acceptance or rejection of samples.

2.1.1 Trawls

Trawl studies have traditionally taken two forms. One is an examination of the incidental 'by-catch' of epifaunal species collected by commercial-sized trawls, typically during fish stock assessment surveys. The other is the independent sampling of the epifauna using smaller-sized equipment deployed at relatively low speed and over shorter time intervals. The latter may incidentally include commercial fish species, but usually with low catch efficiency. The former have yielded useful data on the distributional properties of species over wide sea areas (*e.g.* Dyer *et al*., 1983). However, because of the large mesh sizes typically associated with commercial-sized towing gear, the epifaunal (or 'megafaunal') by-catch may bear limited resemblance to the *in situ* status of natural assemblages.

The reduced dimensions, smaller mesh sizes and shorter deployments that characterise 'experimental' trawls typically result in the more efficient sampling of the sessile and more sedentary components of the epibenthos. Trawl sampling across an even sandy seabed should provide reasonably accurate data, but less so across coarser or mixed substrata. The outcomes of trawl surveys are therefore closely linked to gear design and sampling practices, *i.e*., they are operationally-determined. As with epibenthic by-catches from commercial-sized trawls, caution must therefore be exercised in interpreting survey data.

2.1.1.1 Beam trawl

A 2 m width beam trawl is commonly used in scientific studies. For example, it has been successfully deployed in small- and large-scale studies of epifaunal biodiversity in the North Sea area (Frauenheim *et al*., 1989; Jennings *et al*., 1999; Rees *et al*., 1999, 2001; Zuhlke *et al*., 2001; Callaway *et al*., 2002b; Reiss and Kröncke, 2004; Smith *et al*., 2006). Other studies have used larger versions. For example, Serrano *et al*. (2006) sampled the epifauna of the Cantabrian Sea with a 3.5 m beam trawl, while Creutzberg *et al.* (1987) and Duineveld and van Noort (1990) used a 5.5 m beam trawl for epifaunal sampling in the southern North Sea. Further details are given at Section 6.

Riley *et al*. (1986) described a 2 m beam trawl with a wooden cross-beam that has been widely employed for young fish and epibenthic surveys. Up to three tickler chains are typically attached. More recent modifications to increase the success rate across coarser deposits and in rough weather have included the use of a steel cross-beam, the widening of the shoes and the addition of a chain mat to the underbelly to exclude boulders (Jennings *et al*., 1999 and Figure 1).

[PHOTO]

Figure 1. A heavy-duty 2 m beam trawl (Jennings *et al.*, 1999) being recovered over the stern of a research vessel. Note the metal beam between the two trawl shoes and the chain mat attached to the underside of the beam (source: Cefas, UK).

- As 2 m beam trawls have been widely used in epibenthic surveys, more detailed guidance on their use is provided below (see also Section 5 for details on sample processing):
- Trawls should generally be towed at a maximum speed of 1.5 knots over the ground for distances of ~ 500 m (usually taking 5-10 minutes). Positions at the time of first bottom contact and at the start of hauling should be recorded, allowing an approximate calculation of the area sampled. Towing over relatively short distances/time intervals should ensure that most samples are of a manageable size for processing of the entire contents, thereby minimising the need for sub-sampling.Beam trawls are towed on a pair of bridles attached to a single tow-rope or line. A weight placed in the cod-end of the trawl can be used to sink the net during deployment and hence reduce the risk of fouling across the beam. The length of the warp should be approximately 3-4 times the maximum expected water depth. Evidence that the device has maintained good bottom contact during towing should be sought from an examination of the warp under tension, which may be quantified using an attached odometer wheel or sonar device (see 2.1 above).
- The use of a 2 m beam trawl is limited to relatively uniform, low-relief terrain. In the event of serious damage to the net or frame, the possibility of trawling at nearby locations should be considered before a station is finally abandoned. On retrieval, trawls should be routinely inspected for any damage. Repairs should be conducted immediately, or the gear substituted, and the events noted in the field log. Nets should be washed down after retrieval, to ensure there is no cross-contamination of sampled material between stations.
- It is also important to recognise that the data typically generated from such surveys will, at best, be 'semi-quantitative' in nature (see, *e.g.*, Rumohr, 2008).

Further work is required in order to improve the quality and comparability of epibenthic data generated from trawl surveys. Agreement on trawl sampling procedures for recent collaborative North Sea-wide surveys (Callaway *et al.*, 2002b; Jennings *et al.*, 1999; Zuhlke *et al.*, 2001; Reiss *et al.*, 2006; see also www.mafcons.org) represents a significant advance. Specifications for gear design and sampling practices included:

- *Net*: 20 mm mesh size (stretched: 10 mm from knot to knot) for the belly and 4 mm mesh size (knotless) for the cod-end
- *Towing*: 5 minutes at 1-1.5 knots, recorded at the start and end of bottom contact, which typically gave a towing distance of 300 m
- *Sample processing*: conducted over a 5 mm mesh sieve; animals passing through this but retained on a 2 mm mesh sieve were also qualitatively assessed

2.1.1.2 Agassiz trawl

An Agassiz trawl has the advantage that it will sample with equal efficiency whichever way it lands on the seabed. In the example of Figure 2, the frame consists of square steel tubing with a net opening of 300 cm (width) x 80 cm (height) and is equipped with a chain on both sides. Eleftheriou and Moore (2005) note that the former is less efficient at catching fish. Examples of its use in offshore surveys include Basford *et al*. (1989) who deployed a 2 m width Agassiz trawl with a final mesh opening of 20 mm. Lavaleye *et al.* (2002) report on the deep-water deployment of a 3.5 m width Agassiz trawl fitted with a mechanical closing mechanism and a 1 cm mesh net. Distance travelled and seabed contact were determined using two odometer wheels, a video and cable tension gauge.

[PHOTO Note: image to use is the high-resolution jpeg version]

[PHOTO]

Figure 2. Agassiz trawl (courtesy KC-Denmark).

2.1.2 Dredges

Several designs have been produced over the years to meet a variety of scientific applications, including the sampling of very coarse substrata. They are generally used to sample smaller areas than trawls. In addition, many of the simpler designs are adaptable: light- or heavy-weight versions may be constructed for use in coastal or offshore environments and from smaller or larger vessels. Dredges are towed along the seabed under power, while drifting, or in some cases while at anchor using winch power.

For dredges that are unsuitable for attachment of a video camera or odometer wheel and have no closing mechanism, inherent uncertainties over the mode of action during deployment will result in, at best, 'semi-quantitative' data, are in nature.

In general, dredges can operate with high resolution over moderate spatial scales (~10-100 m^2) and can collect rare or large species which would not normally be sampled by grabs. Most designs are limited to softer sediments and are intrinsically disruptive to the seabed, and hence it would be counter-productive to return to precisely the same location for repetitive sampling. At some locations, heavy-duty devices may result in unacceptable damage to more delicate organisms (both those caught and those left behind). Such devices may also require skilful handling on ship to avoid safety hazards.

A selection of dredge samplers is described below. Further examples are given in Eleftheriou and Moore (2005).

2.1.2.1 Rallier du Baty dredge

The Rallier du Baty dredge (Figure 3) is designed to operate over substrata ranging from sands to cobbles, and has been widely used in the English Channel and Celtic Sea (see Cabioch, 1968; Prygiel *et al.*, 1988; Sanvicente-Añorve *et al*., 1996). It consists of a heavy-duty metal ring (55 or 39 cm diameter for large and small models), attached to a central towing arm which also serves to prevent the entry of very large stones. The finer-mesh (typically 0.5 or 1 mm) internal collecting bag is protected by a coarser-mesh outer bag which is, in turn, enclosed by a chafer. The warp is shackled to the metal ring, from which a weak link extends to the forward towing point of the central arm.

[PHOTO]

Figure 3. A Rallier du Baty dredge. The dredge consists of a robust circular metal mouth to which a collection bag is attached. The dredge is towed from the bridle attached to the outer rim of the dredge. A weak link between the towing bridle and the central towing arm is designed to break if the dredge meets an obstruction on the seabed (source: Cefas, UK).

The dredge is deployed over the stern or side of a vessel, with a warp length of three to five times the water depth. Contact with the seabed can be judged by the vibration of the warp. The speed and duration of tow will depend on the objectives of the study; for small-scale surveys, deployment might typically involve towing at not more than 1.5 knots for a period of 5–10 minutes. On retrieval, the net bags are untied and, for convenience, the dredge can then be suspended to facilitate the release of the sample contents onto the deck.

The circular leading edge of this dredge allows some lateral movement as it is towed across the seabed, which has the advantage that the device is less prone to snagging on obstructions, and it can continue to sample in all orientations. However, as with other comparable sampling devices, it may be difficult to determine whether the sample contents are evenly or erratically accumulated over the length of the tow. Samples collected by this method should be treated as, at best, 'semi-quantitative' in nature.

2.1.2.2 Anchor dredge

The Anchor dredge (Forster, 1953) was designed to be operated from a small vessel in order to sample sandy sediments, although it can produce acceptable samples when used on coarser substrata (see Eleftheriou and Moore, 2005). It consists of a rectangular metal box, open at both ends, to which fixed or hinged wishbone towing arms are attached. The latter allow collection of a sample in two orientations. A canvas or net collection bag is attached to the rear of the device to retain the sample. In a modified version (see Brown *et al*., 2002a), the collection bag is replaced by a sealed metal plate, *i.e*., the dredge consists of a metal box, the open (anterior) end of which is 0.5 m wide and 0.2 m deep.

The Anchor dredge is deployed over the side or stern of a vessel and, after sufficient warp (typically three to five times the maximum water depth) is paid out, the warp is secured. As the name suggests, the dredge is intended to collect a discrete sample from a single point as it penetrates the sediment under the weight of the drifting vessel. However, when used on larger vessels the dredge may operate (either by default or by design) as a towed body, and the mode of sample collection, *i.e*., instantaneous or gradual, may be very difficult to ascertain. Also, the gear will tend to be selective for the less motile epifauna. Therefore, the data generated should, at best, be treated as 'semi-quantitative'. The device may be particularly useful in pilot surveys of hitherto unsampled areas, or for the collection in quantity of certain target species for autecological study (*e.g.* Holme, 1966; Rees and Nicholson, 1989; Jennings *et al*., 2001a).

2.1.2.3 Newhaven scallop dredge

This dredge was designed for the catching of scallops in commercial quantities, but it may also be used to selectively sample other epibenthic species for scientific assessments (Figure 4). The dredge may be operated over very coarse terrain, but may suffer damage if towed over bedrock or through large boulder fields. There are several types of scallop dredges in use, of which the Newhaven and French dredges are described by Franklin *et al*. (1980). The leading edge of the Newhaven dredge comprises

a bolt-on metal bar to which are attached a row of spring-loaded, downwardly-directed teeth. When the dredge encounters large stones, the springs allow the tooth bar to swing back, thus avoiding snagging and reducing the quantity of stones caught. The mouth of the dredge is approximately 0.8 m wide and 11 cm deep during deployment. The lower surface of the collecting bag is made up of heavy-duty metal links (inside diameter *c*. 4 cm), while the upper surface consists of heavy-gauge nylon mesh. The minimum particle/organism diameter likely to be retained within the dredge is approximately 2 cm.

[PHOTO]

Figure 4. A Newhaven scallop dredge. Note the robust metal beam with rubber rollers on each end. Three dredges are attached to the beam, and the upper nylon mesh side of the collection bags are visible (source: Cefas, UK).

Typically, 2–3 dredges are deployed in tandem (attached to a metal beam) over the stern or side of a vessel and towed for a pre-determined time. Care must be taken to ensure that the dredges are deployed the right way up. The epibenthic component of material collected using the Newhaven (and other) scallop dredges will have undergone significant selection in response to the design features, and the eventual data should, at best, be treated as 'semi-quantitative' in nature. Rees (1987) and Kaiser *et al.* (1998) report on surveys of the epifauna in the eastern and western English Channel, respectively, using scallop dredges.

2.1.2.4 Rock dredge

The Rock dredge (Nalwark *et al*., 1962 and Figure 5) was designed for the collection of samples from deep-water rocky terrain (see also Eleftheriou and Moore, 2005). It consists of a heavy-gauge rectangular metal rim, 0.6 m wide and 0.4 m deep, to which towing arms are attached on each side. For the prevention of damage to the collecting bag during deployment, it can be constructed from interlaced metal rings of the same size as those used for the scallop dredge (above), retaining particles larger than about 2 cm diameter. A finer-mesh liner may be fitted within the chain-link bag in order to retain smaller organisms and a 'weak link' employed to reduce the risk of gear loss during deployment.

[PHOTO]

Figure 5. A Rock dredge. Note the heavy-duty rectangular metal rim and the collection bag consisting of interlaced metal rings (source: Cefas, UK).

The Rock dredge is versatile, and will even collect surface scrapings from bedrock. Deployment practices are similar to those described for other dredges. In rocky areas, towing may be achieved using the winch, while the ship remains stationary. On retrieval, the dredge is mechanically lifted by a chain attached to the rear of the collecting bag in order to release the sample contents. This device is well suited to surveys in offshore areas which are known or suspected to present significant sampling problems due to the presence of very coarse substrata. As with many other dredges, uncertainties over sampling efficiency and selectivity determine that the data generated should be treated, at best, as 'semi-quantitative'.

2.1.2.5 Naturalist's dredge

The Naturalist's – or rectangular – dredge (Figure 6) was employed as early as the nineteenth century by natural historians motivated as much by the collecting instinct as by an interest in assigning epibenthic species to the Linnaean classification system. The dredge described by Eleftheriou and Moore (2005) consists of a rectangular metal

frame with towing arms, to which a net collecting bag is attached. This dredge is still commonly used to provide a qualitative overview of the biota (*e.g.* Reise and Bartsch, 1990). Collie *et al*. (1997) employed a 1 m wide Naturalist's dredge with a 6.4 mm square mesh liner to sample the benthic fauna of Georges Bank and identified qualitative and quantitative differences between locations which were attributable to the degree of disturbance by bottom fishing gears.

[PHOTO]

Figure 6. Naturalist's dredge (source: …?).

2.1.2.6 Kieler Kinderwagen dredge

The Kieler Kinderwagen or botanical dredge (Schwenke, 1968 and Figure 7) has a 1 m-wide rectangular mouth, and functions on both sides like an Agassiz trawl. It is typically equipped with a net bag 3 m in length, with a cod-end and an inner 0.5 cm mesh net. It is used on sandy and muddy bottoms as well as in the phytal region. If required, its penetration into the sediment (typically 1–3 cm) can be enhanced by additional weights and by single tickler chains on each side of the dredge. Video images revealed efficient sampling over the ground with good sieving characteristics; irregular bottom contact occurred only in stony areas (Rumohr, pers. comm.). An account of its use in central and southern parts of the North Sea is given in Künitzer (1990).

[PHOTO]

Figure 7. Kieler Kinderwagen botanical dredge (source: …?Heye/BEQUALM).

2.1.2.7 Triangular dredge

The triangular dredge (see Schwenke, 1968) can be traced back to the work of naturalists in the 19th century. The modern version of Figure 8 is made of heavy-duty steel and the triangular frame (80 x 80 x 80 cm) supports a 30 mm mesh outer net and a knotless (10 x 10 mm) inner net for retaining biological and/or mineralogical samples. It may be used with or without a rubber plate to protect the net. When in use, a buoyancy aid is attached to the upper corner to maintain the correct position at the sea bed. Recent examples of the use of a triangular dredge on mixed/rocky terrain include the BIOFAR and BIOICE benthic sampling programmes around the Faroe Islands and Iceland, respectively (see **www.biofar.fo**; Tendal *et al*., 2005; **ftp.hafro.is/pub/bioice**; Tendal, 1998).

[PHOTO. NOTE: the image to use is the jpeg version for the 'yellow' sampler without teeth]

Figure 8. Triangular Dredge (courtesy KC-Denmark)

2.1.2.8 Ockelmann sledge

The Ockelmann sledge (Figure 9) is a light-weight instrument (10-15 kg) designed to sample the upper mm of level soft bottoms. It was developed by the Danish researcher K.W. Ockelmann (Ockelmann, 1964) to sample early life stages of macrobenthic invertebrates from the sediment surface. It is equipped with adjustable blades on both sides which determine the sampling depth. The short and fine-meshed (0.5 mm) net bag is sheltered by the broad runners that also prevent deeper penetration into the muddy sediment. It can be equipped with a light tickler chain between the towing wires to gently disturb the upper sediment layer containing the newly settled invertebrate larvae and the temporary meiofauna. This device may be considered to sample the epibenthos by default rather than by design, but nevertheless may do so efficiently in the right circumstances.

[PHOTO]

Figure 9. Ockelmann sledge (source: …?Heye/BEQUALM).

2.1.2.9 'Deep Digging Dredge' (Triple D)

The Triple-D (Figure 10) was designed to collect a large sample of the seabed in order to accurately estimate the densities of the larger and infrequently occurring infaunal and epifaunal species. The prototype (Bergman and van Santbrink, 1994) was equipped with a fixed cutting blade that sliced a strip out of the seabed over a tow length of about 150 m and a width of 0.2 m to a depth of 0.1 m. In a later modification, a hinged cutting blade is operated by compressed air, enabling a haul of a preset length, independent of vessel movement during initial deployment and eventual retrieval. Moreover, the sampling depth increased to 0.14 m. The mesh size in the dredge (0.5 x 0.5 cm) and the net (0.7 x 0.7 cm) retains all infaunal and epifaunal specimens with (outer) diameters greater than 1 cm.

2.1.3 Hyperbenthos epibenthic sledges

2.1.3.1 Aquareve Epibenthic Sled

The Aquareve III epibenthic sled was originally designed by Thouzeau and Vine (1991) and used for epifauna studies of scallop grounds on Georges Bank (*e.g.* Thouzeau *et al*., 1991). In a modified form (Rowell *et al*., 1997) it was successfully used to study the effects of otter trawling on the epifauna of a sandy bottom habitat on the Grand Banks (Prena *et al*., 1999).

The sled is towed at about 1 knot (*i.e*., about 2 m sec^{-1}). The sampling blade, 0.34 m wide, cuts to a depth of 2-3 cm and therefore can collect some infaunal species. The steel collection box has regularly spaced holes (1 cm in diameter) so most sediment can pass through. Towing distance over the seabed is measured by paired odometer wheels and displayed in the ship's laboratory. At the end of the prescribed tow length (*e.g.* 50 m), a closing door is activated electronically and the sled retrieved. Sampling performance is monitored using an illuminated colour video camera directed backward toward the sled's mouth. Underwater and deck control units communicate through a winch-mounted electro-mechanical cable and slip-ring assembly. Tows of dubious quality (*i.e*., lifting off the bottom) can be aborted and repeated. The sled is heavy (about one tonne) and, with the specialized cable, block, winch and electronics, requires a large research vessel to deploy. However, since the area of seabed sampled can be determined with a high degree of accuracy, samples are quantitative (Prena *et al*., 1999). Captured organisms are subject to damage.

2.1.3.2 Hyperbenthos sled

Sophisticated sledge-mounted designs are used for sampling the hyperbenthos – free-swimming animals inhabiting the water-column immediately above the sea bed (see, *e.g*., Brattegard and Fosså, 1991; Mees and Jones, 1997; Dauvin *et al*., 2000; Eleftheriou and Moore, 2005). They typically employ fine-mesh collecting nets (down to 0.5 mm), flowmeters and opening/closing mechanisms to facilitate quantification. Such gear is particularly valuable for studies of species (especially crustaceans) which constitute an important component of the diet of fish. Epibenthic and hyperbenthic sledges (Rothlisberg, P.C. and Pearcy, W.C., 1977dredge; see also Brattegard and Fosså, 1991; Sorbe sledge (Sorbe, 1983)) are useful for the small mobile crustaceans and boundary fauna. If automatic closing mechanisms and dredge distance recorders are added, then these instruments can be quantitative (cf. Gage deep sea epibenthic sledge).

[PHOTO]

Figure ?. Hyperbenthos sled (source …?Fosså or Buhl-Mortensen).

[PHOTO]

Figure 10. Triple D (source …?Heye/BEQUALM).

The Triple-D provides reliable density estimates of, for example, (sub)adult molluscs, echinoderms, larger polychaetes and crustaceans. Although more complex in construction than many other dredges (see above), the capacity for accurate quantification of the targeted fauna is a notable advantage (*e.g.* Duineveld *et al*., 2007).

2.1.4 Grabs

Because of the much wider size range of organisms encountered compared with the infauna, small (typically 0.1m^2) grab samplers are generally unsuitable for sampling the epibenthos. Thus larger epibenthic organisms tend to be too sparsely distributed relative to sample size, and motile species may easily evade capture. Towed gear, such as trawls and dredges, are more appropriate for sampling these species, although usually at the expense of accurate quantification. Moreover, on mixed substrata or hard ground, grab sampling devices may operate at low sampling efficiency or not at all. If grabs are to be used, then those sampling larger surface areas (*i.e.*, >0.2m^2) are to be recommended.

Details of the design and operation of standard grab-sampling devices for soft sediments may be found in Eleftheriou and Moore (2005) and Rumohr (2008). Samplers which operate with some success on coarser substrata may be useful for evaluations of the smaller sessile component, which may be relatively well developed at such locations. Of these, the Hamon grab has proved to be particularly effective, and a description of this device (after Brown *et al*., 2002a) is summarised below. By their nature, grab samplers operate on a very small spatial scale but provide high resolution, compared with many types of towed gear.

2.1.4.1 The Hamon Grab

The Hamon grab (Oele, 1978; Eleftheriou and Moore, 2005) consists of a rectangular sampling bucket attached to a pivoted arm, supported within a sturdy metal frame (Figure 11). The arm is free to pivot on contact with the sea bed. Tension in the wire at the start of inhauling then moves the pivoted arm through a rotation of 90°, driving the bucket through the sediment. At the end of its movement, the bucket locates onto an inclined rubber-covered steel plate, sealing it completely. Weights are usually attached to the supporting frame in order to minimise lateral movement during sample collection. On retrieval, the device is lowered onto a rectangular stand, under which a removable container is placed to receive the sample on release from the bucket.

[PHOTO]

Figure 11. A 0.1 m^2 Hamon grab supported on an open frame to facilitate retrieval of the sample into a moveable container following controlled release from the bucket. Note the nearside rack supporting lead weights to increase sampler efficiency; a comparable rack on the other side of the sampler is hidden from view in this photograph (source: Cefas, UK).

The Hamon grab is robust, simple to operate and has been shown to be particularly effective on coarse sediments. It has been employed in several studies of benthic

communities along the French coast (*e.g.* Desroy *et al.*, 2003) and has been used extensively to assess the biological impacts of marine aggregate extraction (*e.g.* van Moorsel and Waardenburg, 1991; Kenny and Rees, 1996; Seiderer and Newell, 1999; Boyd and Rees, 2003). The original design was for a grab which samples an area of about 0.25m²; since then, a smaller device, sampling an area of 0.1m², has been successfully employed in surveys of coarse substrata around the England and Wales coastline (see Brown *et al.*, 2002a; Boyd *et al.*, 2006a). One drawback of the Hamon grab is that the sediment sample is 'mixed' during closure of the bucket which prevents the examination or sub-sampling of an undisturbed surface layer. The attachment of a video camera to the frame has proved useful for *in situ* evaluation of surface features adjacent to the grab bucket (Brown *et al.*, 2002b).

2.1.4.2 The Videograb

The Videograb (Figure 12) is a hydraulically-actuated bucket grab equipped with video cameras. More sophisticated than a simple bolt-on camera attachment to a conventional grab, it was designed to allow precise selection of station locations, to permit remote control of bucket closure and opening, and to verify proper closure prior to recovery (Rowell *et al.*, 1997; Gordon *et al.*, 2000). Other examples of video-controlled grabs include the 'SEABed Observation and Sampling System' (SEABOSS) designed by the US Geological Survey for collecting seabed images and sediment samples in coastal regions (Valentine *et al.*, 2005).

[PHOTO]

Figure 12. Videograb (equipped with DRUMS™) being recovered (source: MFO, Canada).

An illuminated colour video camera is mounted obliquely to provide a forward-looking, wide-angle view while drifting just above the seabed. A downward-looking high-resolution video camera is mounted directly above the open bucket and provides imagery of the seabed and closure of the bucket. The bucket is closed hydraulically, and the area sampled is 0.5 m². Sampling depths range from 10-25 cm and at full penetration the sediment volume is about 100 l. The device weighs about 1100 kg and is about 2.5 m in height. In most deployments, wire angles are small and ship position (end of the crane boom) serves as a reasonable proxy for sample location. However, a transponder can be attached for more accurate positioning.

During deployment and retrieval, the winch is controlled by an operator on deck. However, when the seabed comes into sight on the monitor, control of the winch passes to a scientist in the laboratory. The usual procedure is to drift for a few minutes with the Videograb suspended just above the seabed. Once landed on features of interest, the open bucket is poised 20 cm above the bottom. By paying out slack cable, the Videograb is decoupled from the motion of the ship and high-resolution video of the seabed is recorded. Closure of the bucket simultaneously closes a retractable lid on top which reduces washout during recovery. If sampling is unsuccessful, the operator can lift the Videograb off the seabed, reopen the bucket hydraulically, and select another landing site. A video monitor is also placed on the bridge to assist in ship handling. Video imagery and navigation data are recorded on digital tape. Because of the size and complexity of the Videograb, a large research vessel is required.

The Videograb is an efficient tool for collecting quantitative samples of epi- and infauna with minimal disturbance, and has been used to study the impacts of otter trawling (Kenchington *et al.*, 2001). It works well over soft substrata, although achieving complete closure in gravelly sediments can be problematic. It has been success-

fully used for targeted sampling to ground-truth/identification of video documented organisms and to collect gorgonian corals attached to small boulders. The video provides information on the undisturbed habitat from which the sample is collected as well as on sample quality. It leaves a relatively small footprint (a few square metres) and so can be used for time series studies at a given location. The Videograb can also be adapted to provide information on small-scale structural properties of surficial sediments (Schwinghamer *et al*., 1996, Schwinghamer *et al*., 1998).

2.1.4.3 Other grabs

The Baird grab (Baird, 1958) was designed for sampling the epibenthos of coarse substrata. It collects a large surface area (0.5m^2) but remains open on retrieval and is therefore of limited utility as a fully quantitative sampler. This and a variety of other grabs sampling surface areas greater than conventional (0.1m^2) infaunal samplers are described by Eleftheriou and Moore (2005). In general, these are not widely established (or tested) tools. Another example is the Gordeev grab which was designed in the 1930s by a Russian engineer to sample the coarse sands and gravel of the Ochotsk Sea. The sampler weighed approx. 500-1000 kg, sampled 0.25-0.5 m^2 and had a maximum penetration of 50 cm into these problematic sediments. A sampler still in working condition is stored at the Zoological Museum in St. Petersburg, Russia, but published information on its performance and potential for wider use was not located at the time of publication (H. Rumohr, pers. comm.). Further investigation of the potential utility of such samplers (including industrial-scale grabs used in prospecting for seabed resources) in epibenthic studies may be merited.

2.2 Suction samplers and other diver- or remotely-operated devices

2.2.1 Suction sampling

Suction or air-lift sampling involves the release of air at the bottom of a tube which, as it rises, draws in other material due to the *venturi* effect. The sample contents are usually collected in a mesh bag. Details of a range of suction samplers along with procedures for their use in diver surveys are provided by Rostron (2001) and Munro (2005) (see also Eleftheriou and Moore, 2005). Diver- or remotely-operated suction samplers have an established role in the collection of the infauna from soft sediments and may also be a cost-effective means for quantifying components of the epibenthos, including the provision of 'ground-truth' information to accompany *in situ* photographic records. .

For coarse substrata, suction sampling may be especially useful for quantifying motile and loosely-attached sessile epibenthic species. For example, Thomasson and Tunberg (2005) employed a 'water jet' suction sampler for collecting the motile epifauna associated with vertical rock surfaces in Swedish waters. To provide quantitative data it is necessary to sample within a quadrat or other area-delimiting device, and to augment sampling effort with photographic records and/or with representative samples scraped manually from the rock, as a measure of sampling efficiency (see below). Cobbles may be sampled in a similar way and, depending on circumstances, may be moved to ensure effective sampling of micro-habitats beneath and between them.

In deeper water or other areas not accessible to divers, a Remotely Operated Vehicle (ROV) equipped with claw and suction sampler may be used. A recent example involved the collection of motile fauna associated with deep-sea corals (Buhl-Mortensen and Mortensen, 2004). The ROV was fitted with a suction pump and the

water was sieved through plankton meshes within sampling jars mounted in a carousel.

2.2.2 Scrape sampling within frames

For quantitative estimation of biomass or biodiversity, scrape samples within frames are commonly collected, the dimensions of which depend on the community type. For example, in monitoring programmes in the photic zone of Swedish waters (Kautsky, in prep.; see also www.helcom.fi), an 0.5 m square frame is used for the canopy layer formed by large plant species such as the bladder wrack (*Fucus vesiculosus*), and all specimens with holdfasts located within the frame are collected. For the other strata (the bush and field layer) a 0.2 m square frame is used. Specimens within the frame are scraped into a mesh bag attached to one side of the frame (Kautsky, 1993). A suction sampler may be used as an alternative to scrape-sampling into an attached bag (*e.g.* Gulliksen and Deras, 1975; Dybern *et al.*, 1976; Munro, 2005) and a covered frame can be used to prevent the escape of motile fauna. However, an open frame has the advantage of being easy to handle by a single diver and experience in Swedish waters shows that most organisms are recovered from within the frame.

Following removal of the canopy layer and motile or loosely attached organisms, estimates of residual presences such as encrusting bryozoans and red algae may be made *in situ*. On mixed substrata with large structural heterogeneity (*e.g.* in the presence of stones and small boulders) the use of frames may be less reliable, as it may be difficult to ensure even contact with the sea bed and there is a risk of the loss of material during sampling. Substrata consisting of pebbles, gravels and finer fractions do not present such problems.

2.2.3 Drop trap

Wennhage and Pihl (2007) provide a recent example of the use of this simple device in Swedish waters. Manually deployed, it consists of an open square metal box enclosing 0.5m^2 of sediment and the overlying water. Quoting earlier studies (*e.g.* Wennhage *et al.*, 1997) they note that it is close to 100% efficient for the dominant species of epibenthic fauna on shallow soft substrata. Motile species may be manually extracted from the box using a small net.

2.3 Sediment Profile Imagery

Sediment-profile imaging (SPI) is a standardised technique for imaging and analysis of sediment structure in profile, originally developed in the U.S. (where it is designated by the acronym REMOTS^R for 'Remote Ecological Monitoring Of The Seafloor': Rhoads and Germano 1982, 1986). Strictly, this device might be considered to be a 'locally disruptive' rather than a destructive sampler. Although it has only limited direct application to studies of the epibenthos of soft substrata, it may nevertheless provide important information on micro-habitat features which may, in turn, help to explain observations on the distribution and densities of the epibenthos sampled by other means.

Functioning like an inverted periscope, the camera consists of a wedge-shaped prism with a front face-plate and a back mirror mounted at a 45° angle to deflect the profile of the sediment-water interface up to the camera. The camera is mounted horizontally on top of the prism and provides images of the sediment column, including the surface, 15cm wide and up to 23cm deep. Estimates of a range of physical and biological variables are derived from the images using a video digitizer and an image-analysis system (Rhoads and Germano 1982, 1986; O'Connor *et al.*, 1989; Smith and

Rumohr, 2005). Proprietary software allows the measurement and storage of up to 21 variables for each image obtained.

The gear is deployed from ships, with a frame and pressure housing to sample deep-sea sediments. Diver-deployed models are also in use. A summary of its application to habitat quality assessment in Swedish waters is given by Nilsson and Rosenberg (1997) and a compilation of recent studies at various locations is given in Kennedy (ed., 2006).

3 Non-destructive sampling/sensors

3.1 Acoustics

Acoustic methodology for seabed characterisation is continually evolving and a summary of some currently-used techniques (adapted from Limpenny and Meadows, 2002; see also Smith and Rumohr, 2005 and Bale and Kenny, 2005) is appropriate, in view of their value in the planning and interpretation of epibenthic surveys. Most can be used over large areas and can provide information at high spatial resolution. For example, multibeam bathymetry can resolve features down to the scale of boulders, while accompanying backscatter data can be used to infer substratum type. RoxAnn™ and QTC™ have been used as exploratory tools in mapping benthic habitats but are yet to be proven (see below). A technique known as Synthetic Aperture Sampling also shows promise but is at a relatively early stage of development (McHugh, 2000).

Historically, the most widely used method for geophysical characterisation of the seabed habitat is sidescan sonar. Outputs from acoustic surveys can also identify bioherms such as mussel beds, and *Sabellaria* and *Lophelia* reefs (*e.g.* Magorrian *et al*., 1995; Bett, 2001; Mortensen *et al*., 2001; Hendrick and Foster-Smith, 2006; Lindenbaum *et al*., 2008). It is important to acknowledge that ground-truthing is needed because acoustic surveys are mainly indicative. This method can only indicate occurrences but ground-truth is always needed!

An evaluation of the resolution of a variety of acoustic (and other) methods relative to the area of coverage is given at Annex 3 (from Kenny *et al*., 2003).

Examples of the contribution of multibeam bathymetric surveys to the mapping of marine habitats and communities include Kostylev *et al*. (2001), James *et al*. (2007) and Lindenbaum *et al*. (2008). An example of survey output is shown in Figure 13.

[PHOTO]

Figure 13. Multibeam image of Hastings Y ALTERNATIVE IMAGE? (source: Cefas, UK).

3.1.1 Multibeam bathymetry

There are two main types of multibeam (or swathe) sonar systems: true multibeam (or focused multibeam) and interferometric (or bathymetric sidescan sonar) systems. True multibeam consists of a transmitter and receiver capable of projecting and detecting multiple beams of sound energy which ensonify the seabed in a fan-shaped swathe. Multiple soundings are thus taken at right angles to the vessel track, as opposed to a single sounding underneath the vessel with a conventional single beam echosounder. This gives a far greater density of soundings enabling quicker coverage of the survey site.

An interferometric sonar is a variant of sidescan sonar technology where electronic techniques are applied to a multiple set of sidescan sonar-like transducers arranged to give phase information in a vertical plane. This phase information is used to determine the angle of reception of reflected sound from the seabed and, given the time of flight of the return pulse, a range/angle measurement can be made of the seabed. The main difference is that soundings for a multibeam system are denser directly under the vessel, and sparser at full swathe range. The inverse is true for interferometric systems.

Both systems are prone to greater errors on the outer limits of the swathe. Both are also dependent on a very high quality motion reference unit (MRU) to determine the position and attitude. This apparatus significantly increases the cost of the system but is essential for accurate and precise depth measurement. The application of swathe bathymetry techniques demands a lengthy calibration procedure to define any systematic errors in the installation (*e.g.* heading, latency and roll).

3.1.2 Acoustic Ground Discrimination Systems (AGDS)

AGDS are designed to detect differences in the acoustic properties of varying seabed substrata. The technique uses a single beam echosounder as the host instrument. The sounder provides the acoustic pulse and the returning echo is transferred, by direct electrical connection on the transducer, to the AGDS system. There is an additional sensitivity placed on noise and quality of the seabed echoes, as there is no longer a simple detection of a significant signal defining a depth measurement as used in bathymetric survey. The shape and nature of this echo is fundamental to the technique and all other factors affecting these properties (*e.g.* pulse length and power fluctuations) must be kept constant.

Significant pitfalls can be encountered using this technique which have historically given rise to guarded acceptance of the fidelity of certain datasets. The earlier systems are based on simple analogue electronics to detect only one parameter of the first and second returns ('RoxAnn™': see, *e.g.*, Chivers *et al.*, 1990). The first return is the direct bounce off the seabed to the transducer, the second involves a continued pathway bouncing off the sea surface, off the seabed a second time and back to the transducer. The first return is sensitive to bed roughness whilst the second is sensitive to bed hardness (the harder the seabed the better the reflection). The second return is also sensitive to the sea surface.

Another more sophisticated approach is the more detailed measurement of the first return only ('QTC™ View': see, *e.g.*, Anderson *et al.*, 2002). This has advantages in a more reliable acoustic pathway, and the ability to operate in a wider range of environments. Some systems use extremely fast algorithms to extract features of the first return (some use a hundred or so features). They invariably come with bespoke software that operates on the more popular PC operating systems.

Several studies have explored the potential utility of AGDS in environmental assessment programmes (*e.g.* Magorrian *et al.*, 1995; Sotheran *et al.*, 1997; Pinn *et al.*, 1998; Pinn and Robertson, 2003; Humborstad *et al.*, 2004; Lindenbaum *et al.*, 2008). At present, it is recommended that AGDS methodology is not used in isolation to predict substratum type, but rather that it be used as an additional tool to complement established methods such as sidescan sonar, underwater TV and grab/core sampling.

3.1.3 Sidescan sonar

Sidescan sonar data are produced using towed or hull mounted transducers which ensonify a swath of the seabed to either side of the transducers (Figure 14). The reflected portion of the acoustic signal is received back by the transducers, amplified and converted into a paper or on-screen image showing levels of strength of return across the ensonified swath of seabed. Coastal sidescan sonar systems are generally designed to work in water depths of up to approximately 300m depth, and to be routinely operated at frequencies of between 100-500 kHz.

[PHOTO]

Figure 14. DatasonicsTM SIS 1500 Chirp sidescan sonar fish. This device acts as a stable platform for the transducers, and is towed behind the vessel during the survey (source: Cefas, UK).

Output from a sidescan sonar survey provides information on the texture of the substrata within the survey area, and from this it is possible to predict the particulate nature of the sediments and assign sediment descriptions to regions of the sea-bed (*e.g.* gravel, mud). Sidescan sonar will also enable sediment transport features such as sand waves and ripples, lineated gravel features and scour marks to be identified. Geological features such as outcrops of bedrock, and aggregate deposits associated with submerged river valleys may also be mapped using this technique. Examples of sidescan sonar output are shown in Figure 15.

[PHOTO]

Figure 15. Side scan sonar output (source: Cefas, UK).

As with the output from other acoustic techniques, information on the nature of the substratum may be matched with existing data on (epi)benthic communities or used to guide new biological sampling effort, depending on the study objectives (*e.g.* Service and Magorrian, 1997; Brown *et al*., 2004; Humborstad *et al*., 2004; Smith *et al*., 2007; Lindenbaum *et al*., 2008; Yeung and McConnaughey, 2008). Inferences concerning seabed sediment transport pathways and allied hydrodynamic influences may also have interpretational value in accounting for the structure of epibenthic communities.

3.2 Video and photography

Video and/or stills photography is a valuable, non-destructive method for the assessment of all types of seabed habitats (see Rumohr, 1995; Smith and Rumohr, 2005). It can be particularly useful over hard and consolidated ground where the sampling efficiency of other physical sampling methods is low.

[PHOTO]

Figure 16. … GOOD SEABED IMAGE …..

The quality of photographs and video documentation largely depends on water clarity (this can vary considerably, even at the same location, depending on the state of the tide and season of sampling), light source and quality of the video equipment. Chances of encountering good visibility can be increased by deploying the equipment at slack water periods. For towed gear, speeds of less than 1 knot over the seabed are generally required to obtain clear images. The data from such surveys can be treated at a number of levels, which will be partially determined by the quality of the images obtained. Still photographs taken at regular intervals along a transect can be treated as point quadrats, the epibenthos identified to the appropriate taxonomic level and

quantified. Data obtained by 'freezing' the video image at regular intervals can be treated in a similar manner. Further details are given in Section 5.2.1.

Unless video/photographic surveys are confined to the identification of conspicuous (usually larger) epibenthic species, it is usually essential to obtain 'groundtruth' physical and biological samples at appropriate intervals using trawl, dredge or grab, with the material being preserved for later laboratory analyses. The resulting data are used to assist in the identification or verification of many of the organisms appearing in the video/still images. Groundtruthing can also be done using a video-assisted grab (Section 2.1.3). For example, this approach proved to be effective in deep-water coral studies (Buhl-Mortensen and Mortensen, 2004).

A summary of good practice in the use of imaging methods is given at Annex 4.

3.3 Direct visual observations

In favourable conditions, divers may be used to fulfil a wide range of survey objectives, mainly in inshore waters (typically to depths of 30 m), and may be the only cost-effective option for systematic quantitative surveys of mixed or rocky terrain in the photic zone (see Annex 1). Detailed coverage of approaches, including survey design, recording techniques, quality control and safe working practices, is well documented elsewhere (*e.g.* Davies *et al*., 2001; Munro, 2005; see also Sanderson *et al*., 2008). The following example summarises methodology for visual profiling along gradients using line transects. Further information is provided by Kautsky (in prep; see also www.helcom.fi).

For a complete census, continuous observations are made within a corridor of 6-10 m width along a line marked at 1 m intervals covering the area of interest. Working from one end to the other, the divers systematically record occurrences and densities (or % cover) within the corridor on writing plates, along with information on distance from the shore, water depth, substratum type, siltation and so on. Specimens may also be collected for later identification/verification, as necessary. A widely used variation of this approach is the line intercept transect where divers only record information along the line itself, either at fixed (*e.g.* 1 m) intervals or along the entire line. This method generates sample information and must be repeated to permit population/community estimation. A third variation of the line transect is the placement of frames of standard unit area at intervals along the profile line (*e.g.* every 5 m) which again generates sample information and requires repeated effort along the transect to permit reliable community estimation. The data from frames have the advantage of being easy to evaluate statistically; the number of replicates (or frame size) required is typically relatively large (Kautsky, in prep.; see also Murray, 2001).

4 Non-destructive sampling/platforms

The most familiar and technologically 'simplest' platform for the collection of video and still images is the SCUBA diver equipped with hand-held devices (see, *e.g.*, Munro, 2005). For remotely-deployed gear, cameras have been mounted on a variety of platforms to facilitate *in situ* studies of epibenthic communities, which may be categorised as follows:

- devices which are capable of moving or being directed under their own power such as ROVs

- devices which are lowered to a point above the seabed (*e.g.* remotely-operated hoisted platforms), or are towed along the seabed, such as photographic sledges.

In recent years, the most commonly used method for epibenthic surveys of the sea bed over relatively large areas has been the camera sledge (see Section 4.1), which is robust and simple to operate. It typically includes a vertically-mounted stills camera and a forward-, or sideways-directed television camera linked by way of an electrical 'umbilical' cable to a recording unit on the survey vessel. Still photographs may be remotely triggered at locations of interest which are identified on the video camera, or taken at regular intervals. By using a fixed frame of view (determined according to distance above the seabed), the area covered by each image can be calculated and, coupled with information on the distance travelled, allows quantitative transect-type studies to be carried out.

General guidelines for the deployment of towed or piloted underwater camera systems (after Rees and Service, 1993) are as follows:

- underwater photographic systems should normally consist of at least one video camera and a high quality stills camera
- where towed sledges are used, the field of view of each camera should be known from previous calibration while immersed in water
- the distance travelled by the sledge should be known, either from the use of the ship's electronic navigator (using appropriate offsets), transponders or by the use of a meter wheel attached to the sledge
- towing should be at constant speed
- for objective quantification of assemblage structure or population sizes along transects, still photographs should be taken at fixed intervals either on a distance or on a time basis. These can be backed up by opportunistic shots of features of special interest identified on the video monitor
- when using ROVs, the distance travelled, heading, height above the seabed and field of view must be recorded

4.1 Camera sledge

The sledge design of Figure 17 is typical of a class of towed gear which has been widely used for subtidal surveys of the epibenthos and small-scale habitat features, and has proved to be robust over rough terrain, as well as being effective across soft sediments (see Shand and Priestley, 1999; Smith and Rumohr, 2005). It is generally towed at slow speeds (*c.* 0.5-1m.s^{-1}, or whilst drifting) from the stern of research vessels. In Figure 17, the sledge has a downward-pointing 35 mm stills camera at the front and a forward-looking video camera towards the rear. Service and Golding (2001) describe procedures for surveys using a towed sledge, along with a summary of methodology for generating species abundance data from video and still images (see also Section 5.2.1; Magorrian and Service, 1998; Smith and Rumohr, 2005).

[PHOTO]

Figure 17. Conventional camera sledge (source: Cefas, UK).

4.2 Drop-frame

The drop-frame and comparable devices provide photographic data over relatively small spatial scales but at high resolution (see, *e.g.*, Davies *et al.*, 2001; Smith and Rumohr, 2005). Three examples are given below.

4.2.1 Diver-operated frame-mounted cameras

Diver-operated frame-mounted cameras can provide high-resolution information on epibenthic communities and, especially when combined with fixed station locations, can provide a valuable long-term monitoring tool, as demonstrated by Lundalv (1976; 1985) for the epibenthos inhabiting rock surfaces in Swedish waters (see also Bullimore, 2001 and Munro, 2005).

4.2.2 Campod

Campod (Figure 18) is a light-weight tripod supporting video and still cameras (Milligan *et al.*, 1998; Gordon *et al.*, 2000). It was designed with an open profile and wide stance to minimise disturbance to the seabed. It is deployed while the research vessel is stationary, or slowly drifting, and collects high-resolution imagery from a relatively small area of the seabed.

[PHOTO]

Figure 18. Campod being deployed near the Hibernia oil platform on the Grand Banks (source: MFO, Canada).

An illuminated colour video camera is mounted obliquely to provide a forward-looking, wide-angle view while drifting over the seabed. A downward looking high-resolution video camera is mounted on the central axis of the frame. The still camera and two high speed flashes are also mounted on the frame. The length of the legs is adjustable and the area of the photographic image is about 0.2 m^2 when Campod is on the seabed. Because of its relatively light weight (340 kg), substantial wire angles can develop on deeper deployments so a transponder is routinely attached to provide accurate positioning on the seabed.

During deployment and retrieval, a deck operator controls the winch. However, when the seabed is sighted on the monitor, control of the winch passes to a scientist in the laboratory. The usual procedure is to drift with Campod suspended just above the seabed, and then to land on features of interest to obtain higher resolution video imagery and take still photos. In favourable conditions, it is possible to drift considerable distances (typically 500-1000 m). A video monitor is also placed on the ship's bridge to assist with ship handling. Video imagery and navigation data are recorded on digital tape. Because of the size (2 m in height) and complexity of Campod, a large research vessel is required.

Campod is an efficient tool for obtaining high-resolution video and photographic imagery of habitat type and epibenthic organisms. Applications have included studies of drilling waste impacts (Muschenheim and Milligan, 1996), impacts of hydraulic clam dredging and otter trawling (Gilkinson *et al.*, 2003), mapping of benthic communities (Kostylev *et al.*, 2001), and the study of deep-water corals (MacIsaac *et al.*, 2001). Except for the small footprint when it lands, Campod is non-destructive so that time-series observations can be made at a given location. It has also been used to carry other equipment such as optical backscatter sensors, a silhouette camera and a water sampler (Milligan *et al.*, 1998). Campod can be used over any kind of seabed regardless of relief, including steep walls of submarine canyons.

Video transects positioned to cover different habitats are useful for mapping large areas (on scales of 1–10 000 km) and large organisms (> 5 cm). Typically a transect can be 500–2000 m. It is very important to have good positioning systems to be able to quantify the video observations from large depths. Campod has proved to be very useful for this (Mortensen and Buhl-Mortensen, 2004).

4.2.3 Circular drop-camera frame

The circular drop-camera frame (Figure 19) is a robust platform for investigating locations of special interest such as may be identified from acoustic surveys of the sea bed, or for use during 'pilot' surveys of new areas, especially where there is uncertainty about the nature of bottom substrata, *e.g.* the occurrence of rock outcrops. The video and stills cameras, lights and flash unit are housed within the protective metal frame, orientated to collect images of the seabed directly below. Holt and Sanderson (2001) describe procedures for conducting video surveys of the epibiota using a comparable drop-down device.

[PHOTO]

Figure 19. A drop-camera frame. The video and stills cameras, lights and flash units are housed within the protective metal frame, orientated to collect images of the seabed directly below the frame (source: Cefas, UK).

4.3 Towed bodies

For benthic studies, towed bodies are typically deployed a few metres above the seabed, with altitude controlled by shipboard winch or by fins on the platform. Towing speed is usually about 1 $m.sec^{-1}$.

The most commonly used sensor is colour video. Cameras are generally angled to look ahead and scan a path of seabed to a width of about one metre (depending on lens and altitude). It is preferable to have the video signal transmitted to the ship by conductor cable so that the imagery can be viewed in real time. It is also possible to mount a still camera on a towed body which can take pictures at regular intervals or on command from the surface. It is also possible to mount a sidescan sonar fish for high-resolution sidescan sonar surveys.

Towed bodies can collect images over large areas in a relatively short time and therefore are appropriate tools for conducting general reconnaissance surveys. Imagery can discern major habitat features, such as substratum type and bedforms, and associated epibenthic species. No data processing is necessary in the field.

Towed bodies of this type can only be used to collect imagery information. They can not be used to collect physical samples. They also provide data of low resolution. Organisms less than about 10 cm in diameter are difficult or impossible to discern. However, they are non-destructive so the same area of seabed can be surveyed repeatedly. Their use is limited to waters with low turbidity and to seabeds of relatively low slope and relief to avoid hitting the seabed and damaging/losing the gear.

As an example, the Towcam (Figure 20) is a towed vehicle which collects low-resolution colour video imagery of the seabed over a large area (*i.e.*, transects many kilometres in length). It is towed at a constant altitude (generally about 2 m which gives a field of view about 1 m wide) above the seabed at a speed of about $1m.s^{-1}$ (Gordon *et al*., 2000).

[PHOTO]

Figure 20. Towcam fish (1999 version) being deployed off the stern (source: MFO, Canada).

The aluminum towfish is fitted with a colour video camera, a pair of halogen lights, and an acoustic altimeter. The effective maximum operating depth is about 200 m. All electrical power is supplied from the surface so there is no limit on tow duration. The towfish weighs 110 kg and is about 2 m long (including bridle). A transponder is at-

tached to determine the exact location of imagery over the seabed. Altitude above the seabed is controlled by adjusting the amount of cable paid out, and video images are displayed in the laboratory and on the bridge to assist in ship handling. Video imagery and navigation data are recorded on digital tape.

Towcam has proved to be an efficient tool for conducting general reconnaissance surveys of substratum type and bedforms, fish, and large epibenthic organisms (greater than about 10 cm). Towcam is non-destructive and has the potential to carry other sensors such as sidescan sonar and a digital still camera. It can be used over any kind of seabed as long as the relief is relatively low and the water is not turbid.

4.4 ROVs and manned submersibles

Cameras can also be mounted on Remotely Operated Vehicles (ROVs). ROVs are self-propelled vehicles controlled by commands from the surface which are relayed down an umbilical cable which also carries the video and other telemetry signals. The advantage of ROVs over towed vehicles is their greater manoeuvrability, allowing objects to be viewed from a variety of angles; the vehicle can also be stopped or moved back onto an object for further study. However, small ROVs are restricted by their limited capability to operate in current speeds in excess of 1.5 knots (*i.e.*, 0.75 $m.s^{-1}$). The area covered by ROVs is generally restricted by the length of umbilical and the water depth. They may be especially useful for examining the epibenthic communities of offshore hard substrata (*e.g.* Hardin *et al*., 1994) or for non-destructive ground-truthing of high-relief features identified from acoustic surveys (see Annex 1). Characteristics of some of the larger (and more sophisticated) ROVs for deep-sea scientific applications are summarised in Smith and Rumohr (2005).

The use of an ROV is normally an expensive alternative to systems such as drop-frames (see Section 5.2 above) and is mainly useful for video recording at smaller spatial scales (100-1000 m). ROVs are particularly useful when more detailed information on abundance, size and morphology of large organisms is needed. The ROV can be equipped with additional sampling gears (*e.g.* claw and suction samplers: see Buhl-Mortensen and Mortensen, 2004), depth sensor, compass, and two parallel laser beams. The last can provided a scale for measuring the size of seabed structures and organisms. In areas with relatively high current speeds, the effect of drag on the cable may cause problems. The ROV should have a navigation system to facilitate accurate quantification of observations. The employment of ROV (along with AUV, manned submersible, acoustic and other survey methods) has been a feature of recent studies of the mid-Atlantic ridge under the Mar-Eco project (www.mar-eco.no; see also Bergstad and Godø, 2003; Bergstad and Gebruk, 2008; Gebruk *et al*., 2008).

A 'hybrid' device in this class is the Remotely Operated Towed Vehicle (ROTV), whose depth and altitude are controlled by rotors. Such devices allow faster towing speeds and the possibility of midwater observations. However, the cost of the elaborate control systems required for these devices will tend to limit their use by smaller organisations.

Equipped with a variety of sensors and sampling capabilities, manned submersibles have found scientific applications mainly in the deep sea, with familiar and at times spectacular outcomes arising from benthic studies. By their nature and size, they generally have a limited role in epibenthic surveys in shallower waters; a brief review of the capabilities of some of the larger devices is provided by Smith and Rumohr (2005). Masuda and Stone (2003) provide a recent example of the use of a manned submersible to assess deep-water scallop populations in fished and unfished areas.

5 Sample processing and data analysis

5.1 Field processing

The following account is adapted from Cooper and Boyd (2002) and Rumohr (2008) and relates to the processing of epibenthic samples collected using towed gear.

On retrieval and transfer of the sample to a container, an estimate of the total volume of the catch should be made, along with a summary and photographic record of the contents, noting especially the presence of stones, rock, *etc*. It is essential that all organisms are removed from the net or bag and it should be thoroughly washed down on deck after every deployment. To avoid the risk of cross-contamination of samples, final reassurance may be achieved by a short tow at the sea surface with an open cod-end.

For most routine surveys employing towed gear, it is recommended that samples are processed over a frame-supported 5 mm mesh sieve, or a sieve of at least the same minimum mesh size as that of the sampling device. Any material passing through a 5 mm mesh sieve may be examined qualitatively (see Section 2.1) or discarded, depending on the objectives of the study. Callaway *et al*. (2002a) discussed the merits of 5 or 10 mm mesh sizes for processing 2 m beam trawl samples, concluding that the former was preferable for wide-scale surveys of the North Sea.

If feasible, the sample contents should be identified and counted at sea. An appropriate range of taxonomic keys should be available and waterproofed copies are strongly advised. A full census should be made of all the less common species. Densities of very abundant solitary species may be estimated from sub-samples, *e.g.* by sub-dividing the catch on the sieve mesh, or examining a known volume or weight of material, counts from which can then be related to the total sample size. Typically, the sub-sampled count should represent at least 10% of the total numbers present in a haul. It is essential that records of any sub-sampling activity are made.

Algal and colonial animal species are generally recorded on a scale of relative abundance, such as the SACFOR scale (Super-abundant, Abundant, Common, Frequent, Occasional, Rare: Hiscock, ed., 1996; see also www.jncc.gov.uk). Encrusting organisms such as barnacles and serpulids may also be evaluated in this way when present in very high numbers; alternatively, densities may be estimated from sub-samples. The presence of any infaunal organisms arising from the fouling of soft sediment should also be noted, together with the occurrences of pelagic species. However, these additional records should be excluded from data compilations prior to statistical analyses.

At least one individual of each species encountered should be retained for inclusion in a reference collection, along with other specimens that cannot be reliably identified. Samples should be fixed in 4% formaldehyde solution in seawater. For sponges, it is preferable to preserve specimens directly in alcohol in order to protect the spicules which are required for later identification. Each specimen container should be clearly labelled with the cruise and sample number, date, location and gear type. Prior to preservation, there may be advantages to recording the weight or volume of a specimen, and obtaining a photographic record in live condition, as these may aid later identification.

It is essential to compile electronic records of the results from on-board sample processing as soon as possible after completion, especially on extended sea trips. This should avoid later difficulties in interpreting hand-written notes, especially where

large numbers of taxa are encountered, where sub-sampling procedures have been adopted for certain common taxa, or when a number of scientists are communicating information on species occurrences and counts to a single data recorder.

Estimates of the biomass (as wet blotted weight) of individual species or major groups can be made using motion-compensated sea-going balances (see, *e.g.*, Jennings *et al.*, 2001b; Smith *et al.*, 2006). The same procedure as that for later laboratory analysis should be followed (see Section 5.2.2, below). Drawing from earlier experiences with infaunal AQC exercises (see Section 7), the scope for inter-operator and inter-laboratory error in biomass determinations is likely to be high. Field and laboratory intercomparison exercises are therefore strongly recommended.

5.2 Laboratory processing

5.2.1 Still/video images

5.2.1.1 Photographs

Recent (and continuing) technological advances are such that post-processing image analysis software can now achieve higher resolution than that which was initially obtained at sea. As a result, it is possible to routinely resolve epibenthic species in photographs down to the scale of several millimetres. This is invaluable when the objects of interest are small taxa or juvenile stages, and represents a more versatile and efficient technique than previous methods used to enhance resolution, including stereomicroscopy and projection of magnified images onto screen. It is difficult to be prescriptive about approaches to image analysis because of the range of options available but it is essential to work to Standard Operating Procedures, with regular updating as necessary. A summary of good practice in the use of imaging techniques is given at Annex 4. Approaches to processing still images are also summarised in Bullimore (2001), Service and Golding (2001) and Smith and Rumohr (2005).

5.2.1.2 Videos

For the purposes of identifying and enumerating the epibenthos over large spatial scales a wide variety of video camera and platform systems are available. In general, post-processing of video permits enumeration of only larger specimens of the epibenthos due to the distance and angle of the camera system off the sea bed, combined with towing speeds. Most video surveys are conducted along transects of varying distance. Often, these surveys can be viewed simultaneously with the recording of the video on a VCR (*i.e.*, in real-time). However, quantitative analyses of the videos are generally performed later by viewing the videotapes, possibly many times, in order to extract the desired information (*i.e.*, post-processing).

When larger, more dispersed taxa are being enumerated, the transects may be viewed in their entirety and total counts taken as the tape is playing. This is not possible in the case of large taxa occurring at high densities (*e.g.* sand dollars). This is particularly true when replicate transects are available. In other cases, if towing speed is relatively uniform, the transect may be divided into equidistant intervals based on time and counts made within each interval. An example of this approach is given by Mortensen and Buhl-Mortensen (2004). Sequence length will depend on habitat patchiness and community type(s). Good results have been made with sections of 10-50 m. When analysing sequences the position is noted at the beginning. Coverage of substratum, number of organisms identified, and other relevant information is recorded. The sequence is ended by again noting the position. This method makes it

possible to estimate the densities of organisms and to relate them to a particular depth and substratum type.

Regardless of the method, there are limitations to resolution of the epibenthos in images that will be a function of the actual survey parameters (*e.g.* altitude of video camera above the seabed, towing speed and variation in these two parameters), the type of video (*e.g.* digital signal for maximum quality), and the quality and types of monitors and VCRs used for display. Post-processing of videos includes counts over continuously-run segments of tape as well as at pauses (either random or targeted) in the video. In the case of the latter, static video images can be captured and imported into various PC-run image analysis systems for a variety of purposes. In all cases, the quality *(i.e.*, resolution) of paused or captured video images is less than that afforded by high quality photographs taken of the same area of seabed.

A summary of good practice in the use of imaging techniques is given at Annex 4 (see also Magorrian and Service, 1998; Smith and Rumohr, 2005).

5.2.2 Biological samples

The following account (adapted from Cooper and Boyd, 2002) covers the laboratory processing of entire epibenthic samples, as well as of sub-sets of specimens retained from field samples for later validation of identifications, or for resolution of taxonomic difficulties. In practice, most samples should be amenable to processing at sea, which has the advantage of reducing problems associated with the handling of large amounts of preserved material in the laboratory.

5.2.2.1 Sorting of epibenthic samples

The formalin fixative must be removed prior to sample processing and, since it is toxic and carcinogenic, this must be carried out under fume extraction whilst wearing disposable gloves and protective clothing. Specimens may then be transferred to labelled petri-dishes or sorting trays (depending on sample or specimen sizes) for identification and enumeration, typically with the aid of low- and high-power binocular microscopes.

If estimates of biomass are required, then it is advisable (in the short period before measurements are made) to maintain specimens in water rather than an alcohol-based preservative. After the entire sample has been processed the sieve residue can be returned to the original container, formalin or alcohol applied, and stored until satisfactory completion of quality control measures.

5.2.2.2 Identification and enumeration

All specimens of solitary taxa should be enumerated and identified down to the lowest possible taxonomic level, usually species, using standard taxonomic keys. It is essential that competent personnel are employed, in order to ensure accurate and consistent identification of specimens. The skills of personnel involved in species identification should be regularly assessed and updated through attendance at training workshops and participation in exercises designed to test proficiency (see Section 7).

Where appropriate, records should include reference to the occurrence of juveniles or adults of particular species; alternatively, measurements of specimen sizes may be made. Common species that are readily identifiable can be enumerated using digital counters. Colonial species (*e.g.* hydroids and bryozoans) may be recorded on a pres-

ence/absence basis or quantified according to the number of colonies or degree of substratum cover (see Section 5.1).

Nomenclature should conform to established inventories; for European waters, these include Howson and Picton (1997) or Costello *et al*. (2001, 2004). Both also serve as useful reference sources for taxonomic keys and all those employed during identification should be documented. In cases where specimens cannot be assigned to species level due to damage, the lowest definitive taxonomic level should be recorded. In some cases, it may be reasonable to denote uncertainty by a question mark before the second epithet for a species binomen (*e.g. Sabellaria* ?*spinulosa*), and before the generic name at the genus level (*e.g. ?Sabellaria*). In others, it may be necessary to express greater uncertainty, for example, using sp., spp. or sp.A, sp.B and so on, as designators, rather than tentative specific names. These may be further qualified: for example, 'damaged', 'indeterminate' or 'juvenile' convey information to others on the reasons for uncertainty and the likelihood (if any) of further progress being made on expert re-examination. Occasionally, due to taxonomic uncertainties in the literature, dual assignations may be necessary (*e.g. Genus sp.x/sp.y*). Identified specimens of each species should be transferred to numbered containers of appropriate size (one per species) containing preservative.

5.2.2.3 Biomass determination

For routine purposes, biomass estimates may be determined as wet blotted weight at sea (see Section 5.1). However, follow-up laboratory estimates may be necessary for a variety of reasons, including intercalibration against sea-going estimates for selected species to evaluate accuracy and precision, deriving length/flesh weight relationships for shelled organisms, and the weighing of small specimens beyond the resolving power of sea-going balances. Specimens are initially placed upon absorbent paper and, once blotted dry, should then be transferred to a weighing balance as soon as possible, and the blotted wet weight recorded once equilibrium has been attained, or after a fixed time interval.

Specimens which tend to retain fluid in the body cavity following preservation (*e.g. Echinus*) should be punctured and drained before blotting. Where possible, faunal or plant fragments should be assigned to the appropriate species and included as part of the biomass estimates for those species; otherwise they should be weighed separately and then allocated across appropriate taxonomic groups. Depending upon the degree of accuracy required, relationships may be established between whole-organism weights and measurements of the size of component parts (*e.g.* body or appendage widths), from which biomass estimates may be derived.

Ideally, estimates of biomass should be provided for each identified species and these, together with the estimated total biomass for each sample, should be reported. Procedures are in principle the same as those for the infauna, including the employment of wet/dry/ash-free dry weight conversion factors (see, *e.g.*, Rumohr, 2008) though it may be necessary (and desirable) for individual laboratories to newly-determine such relationships for several species. Full documentation both of the methods employed (*via* Standard Operating Procedures) and of the results obtained will be essential to allow inter-operator and inter-laboratory evaluations of their dependability and hence the need for any future improvements.

5.2.2.4 Preservation and storage

After completion of identification, enumeration and estimation of biomass, specimens from each sample should be transferred to a single container, and a preserva-

tive solution of 70% ethanol/Industrial Methylated Spirits (IMS) applied. Sample containers should be fully labelled in accordance with Standard Operating Procedures (see Section 7) and stored at least until all quality assurance needs have been fully addressed.

5.2.2.5 Reference collections

A separate reference collection should be catalogued and maintained in a curatorial manner for all epibenthic surveys. This involves the separate preservation of at least one individual of each species encountered. Specimens should be preserved using an alcohol-based preservative (70% ethanol/IMS) and labelled with at least the following information: species name, station number, sample number (where replicates are taken), date of sampling and name of the identifier. This collection can be used to validate identifications between samples and surveys.

5.2.2.6 Sample tracking

Collected samples constitute a valuable resource, both financially and in terms of the data they provide. Sample tracking, *i.e.*, information concerning the location and status of samples at all stages following collection, is an essential part of any Quality Assurance programme (see Section 7).

5.3 Data analysis

A typical dataset arising from a spatial survey of epibenthic communities will exceed 100 species. Numerous techniques can be employed to simplify and elucidate structure in the data and a summary of those commonly applied to benthic datasets is given at Annex 5. Each of these techniques can be used to partially fulfil the objectives of data analysis. However, it is recommended that parallel application of a range of techniques will help both to differentiate patterns and to confirm real trends in the data. For a comprehensive review of statistical methods, reference should be made to general texts such as Sokal and Rohlf (1969), Green (1979), Clarke and Warwick (1994), Underwood (1997) and Underwood and Chapman (2005).

6 Characterising the epibenthos: case studies

This Section summarises approaches to characterising the epibenthos and their habitats by reference to several case studies, and considers the effects of sampling efficiency, spatial scale, habitat complexity and study effort. Particular attention is given to level-bottom surveys using towed gears. Multivariate statistical techniques are now routinely employed as aids to classify field survey data and to identify links between biotic and environmental variability. A review of methods is given at Annex 5. Mention is made of their use in case studies but the outcomes are not described in detail.

The term assemblage (rather than community) is used to describe a group of co-occurring epibenthic species in samples from trawls or dredges, thereby avoiding assumptions about the existence of interactions among them[2].

[2]MacGinitie (1939), quoted in Thorson (1957), defined a biotic community as "*…an assemblage of animals or plants living in a common locality under similar conditions of environment and with some apparent association of activities and habits*". For the epibiota of a sheltered rock face, there is a high probability that species occurrences are a product of close association and hence constitute a community by this definition. For the epifauna of a level sandy bottom, the probability of significant interaction among sparsely-represented species may be low, and hence only the first part of the definition safely applies.

6.1 Characterising the habitat

The greater habitat complexity of high-relief (rocky) terrain accounts for the wider variety of communities found there, compared with elsewhere (see Annex 1). This is evident in the European Nature Information System (EUNIS) marine habitat classification (European Environment Agency, 2004) and also in the UK marine habitat/biotope classification of Connor *et al.* (2004). While variation in environmental influences (for example, the degree of exposure to tidal currents and wave action) and biotic interactions add further layers to the classification, one clear advantage is that the hard substratum itself is generally invariable over modest time-scales, and the biological component of interest is therefore exclusively surficial in nature.

For soft sediments, divisions used in the hierarchical classification of biotopes by Connor *et al*. (2004) are illustrated in Table 6.1. At this level, distinctions are expressed in terms of sediment types, depth zones, salinity, macrophyte dominance and biogenic structures. These parallel the descriptors used by Jones (1950), Pérès (1961) and Glémarec (1973) to discriminate between benthic community types and habitats. Descriptions of individual biotopes (*i.e.*, combining habitat and biological features: see also Olenin and Ducrotoy, 2006) within these categories are not exclusive to the epi- or endo-benthos. However, Connor *et al*. (2004) recognised that the ability to integrate such information was constrained both by the nature and quantity of currently available data. Thus, in contrast to the highly-resolved but small-scale habitat and faunal information generated from individual grab or core samples, data for the epibenthos from trawl or dredge tows are typically more poorly resolved and, in heterogeneous areas, may integrate across a range of habitat types (see below).

Table 6.1 Sublittoral sediment types for classifying biotopes (from Connor *et al.*, 2004).

SUBLITTORAL COARSE SEDIMENT	SUBLITTORAL SAND	SUBLITTORAL MUD	SUBLITTORAL MIXED SEDIMENT	SUBLITTORAL MACROPHYTE-DOMINATED SEDIMENT	SUBLITTORAL BIOGENIC REEFS
Sublittoral coarse sediment in variable salinity (estuaries)	Sublittoral sand in low or reduced salinity (lagoons)	Sublittoral mud in low or reduced salinity (lagoons)	Sublittoral mixed sediment in low or reduced salinity (lagoons)	Maerl beds	Sublittoral polychaete reefs
Infralittoral coarse sediment	Sublittoral sand in variable salinity (estuaries)	Sublittoral mud in variable salinity (estuaries)	Sublittoral mixed sediment in variable salinity (estuaries)	Kelp and seaweed communities on sublittoral sediment	Sublittoral mussel beds
Circalittoral coarse sediment	Infralittoral fine sand	Infralittoral sandy mud	Infralittoral mixed sediment	Sublittoral seagrass beds	Coral reefs
Offshore circalittoral coarse sediment	Infralittoral muddy sand	Infralittoral fine mud	Circalittoral mixed sediment	Angiosperm communities in brackish conditions	
	Circalittoral fine sand	Circalittoral sandy mud	Offshore circalittoral mixed sediment		
	Circalittoral muddy sand	Circalittoral fine mud			
	Offshore circalittoral sand	Offshore circalittoral mud			

'Coarse' or 'mixed' sediments are rarely uniform in character over larger areas, and might typically include gradients or small-scale patchiness in the proportions of different particle sizes, *e.g.* in areas supporting sand and gravel admixtures (Schneider *et al.*, 1987). The epibenthos will be responsive to such variability, but the presence of discrete assemblage types may be masked in samples collected by trawls and dredges. In energetic environments, appreciable changes in substratum type and hence faunal assemblages may also occur over time, for example, as a result of sand transport across coarse deposits or bedrock (Holme and Wilson, 1985). The difficulty of routinely accounting for variability in substratum type along trawl tows has been highlighted in several studies, and may be resolved by the parallel use of acoustic and photographic imagery (see Sections 2-4).

6.2 Characterising the epibenthos

Important considerations include:

- the diffuse boundaries that may exist between components of the benthic ecosystem. For example, Jones (1950) considered that there was no clear-cut division between the infauna and epifauna especially of coarse deposits but accepted that, in general, they were sufficiently distinct for the

terms to have descriptive validity. Thorson (1957) highlighted contrasts in the environment inhabited by the infauna and sessile epifauna in support of the ecological distinction. Both recognised that demersal fish and motile invertebrates were components of benthic communities though not necessarily bound closely to them. Biotope descriptions may combine information on the infauna and epifauna and, in principle, overcome such concerns;

- the adoption of sampling approaches which accommodate the larger size range and comparative rarity of many epibenthic species. Destructive sampling using towed gear has become established practice for many offshore level-bottom environments, but usually at the expense of resolving power (*cf*. infaunal grab/core samplers).

A review of recent publications on trawl surveys of the epibenthos conducted over relatively large geographical scales (see Annex 6) identified variability in gear design, deployment practices and methods of sample and data processing. Some involved the analysis of the epibenthic by-catch arising from established fish stock assessment surveys, and made best use of opportunities to generate data relevant to those surveys as well as having wider ecological interest. Others were conducted independently of such effort. All were 'fit for purpose' and insightful, particularly when covering newly-sampled areas, but are clearly not all suited to combined analyses of the data (at least without considerable caution). Some studies excluded occurrences of infaunal or pelagic species, while others did not.

For epibenthic by-catch surveys, there may be some scope for harmonising approaches to sample processing across studies, thereby widening the utility of the data. For separate (or parallel) epibenthic sampling, the use of a 2 m beam trawl together with standard procedures for deployment and sample-processing in collaborative North Sea programmes sets an encouraging precedent for future work in the region and perhaps more widely. All employed multivariate techniques to aid in identifying assemblage types which were then examined for any correlations with a range of potentially explanatory variables. In some cases, the apparent 'looseness' of the association with substratum type may reflect the difficulty of accurately summarising physical variability along tows.

While not overcoming sampling dependencies, adopting a consistent approach to characterising the epibenthos might facilitate comparisons with similar studies elsewhere and also those addressing other ecosystem elements. The partitioning of sampling effort for the epifauna, infauna and demersal fish is generally a practical necessity in routine studies. However, there is increasing demand for combined characterisations to meet the needs of benthic ecosystem assessments, including reports on the status of biotopes and 'essential fish habitat' (*e.g.* Kaiser *et al.*, 1999; Callaway *et al.*, 2002b; Connor *et al.*, 2004; Reiss and Rees, 2007).

Epibenthic assemblages may also be characterised using functional properties and recent work has included an examination of trophic structure and other life-history/biological traits (Jennings *et al.*, 2001b, 2002; Lavaleye *et al.*, 2002; Bremner *et al.*, 2003, 2006), in addition to conventional determinations of assemblage biomass. Again, such work has special value for assessments of ecosystem quality, trophic interactions and inputs to ecosystem models.

6.3 Discussion

On larger scales, the distribution of epibenthic assemblages identified from trawl surveys frequently matches those of the macro-infauna and demersal fish, indicating similar responses to environmental changes (*e.g.* Callaway *et al*., 2002b; Yeung and McConnaughey, 2006; Reiss and Rees, 2007). On smaller scales, patterns may diverge mainly due to contrasts in resolving power resulting from differences in the size of sampling units and hence the ground covered by, for example, a grab *versus* a trawl. For soft sediments, the relative rarity and larger size of several adult epibenthic species necessitates sampling over a considerably greater unit area than is feasible by a grab. On coarser ground characterised by the relatively common occurrence of sessile epibiota and smaller sedentary associates (in addition to larger and rarer taxa), the use of grabs, underwater photography or diver observation can reveal the existence of appreciable small-scale variability in epibenthic assemblage structure comparable with that of the infauna (*e.g.* Holme and Wilson, 1985; Rees *et al*., 2008) as well as variability on larger scales.

Describing epibenthic assemblages in terms of the main characterising taxa and their relation to substratum type, depth and/or relevant hydrographic factors seems to be generally followed. However, descriptions can be inconsistent between studies owing to differences in sampling and analytical practices. The framework for biotope descriptions in Connor *et al.* (2004) appears to be useful and, with further refinement, may be expected to lead to the addition of new biotopes as the amount of effort committed to offshore surveys and their spatial resolution increases.[3] However, difficulties associated with 'unsighted' sampling using towed gear across multiple habitats/biotopes, especially in heterogeneous areas, must be recognised.

The majority of recent published large-scale trawl surveys of the epibenthos have employed multivariate analytical techniques to identify distributional trends, and summary descriptions of assemblage types typically link the most frequently occurring taxa to influential environmental variables such as substratum type, depth and water temperature. It should therefore be relatively straightforward to agree a set of generic rules for describing epibenthic assemblage types, even though this would not overcome gear-related dependencies (beam width, towing speed, mesh size and so on). This would be an advantage in allowing new survey work to be interpreted in a wider ecological context and for ease of communication. Commonly, this would of course only be a starting point for meeting additional objectives, but could nevertheless be a helpful one.

For more accurate characterisation of poorly-studied offshore environments, the large geographical scales involved point to the benefits of high-resolution habitat-mapping linked to biological 'groundtruthing'. This should at least permit the broad dispositions of assemblage types to be predicted, and features of special interest to be identified, at manageable cost. Examples of such effort are given in Section 3.

[3]Thorson (1957) notes that an ecologist "… *may divide the material procured into smaller or greater units, but it is up to him to see that his division will help to simplify conditions for work, and not to complicate them*"; see also the cautionary remarks of Connor *et al.* (2004).

7 Quality assurance of epibenthos studies

A Quality Assurance (QA) strategy should be evolved at the outset of an investigation, and should encompass the objectives and design of programmes, as well as practical matters relating to their execution.[4] Thus the adoption of consistent and reliable practices that follow, both at the field sampling and laboratory analytical stages, will provide confidence in the validity of the output. However, they cannot make up for a sampling design which no longer serves its intended purpose. QA must therefore include regular re-evaluation of reported outcomes in relation to the original objectives of a study.

For benthic ecological studies, all-encompassing QA/AQC systems are still evolving, but the trend is towards increased involvement by individuals and institutes, especially those engaged in collaborative work requiring the synthesis of data from several sources. In the UK, an example of this trend is the establishment of a National Marine Biological AQC Scheme, which includes an epibenthic component (www.nmbaqcs.org). Although originally designed to service the needs of the UK National Marine Monitoring Programme, it has recently combined with a self-funding EU initiative (Biological Effects Quality Assurance in Monitoring Programmes: BEQUALM; www.bequalm.org) and presently offers Europe-wide participation. As part of the BEQUALM project, a training CD-ROM on benthic sampling methods was produced (accessible *via* www.asa-multimedia.de/benthos; see also Rumohr, 2008). Other European examples of QA/AQC schemes include the quality assurance panel of the German Marine Monitoring Programme of the North and Baltic Seas (GMMP). Approaches to the QA of biological measurements in the Baltic Sea are contained in the HELCOM COMBINE manual (accessible via www.helcom.fi). Finally, the Identification Qualification (IdQ) scheme involves the certification of individual competence in species identification and is operated by the UK Natural History Museum (www.nhm.ac.uk).

Guidelines for the setting up of quality systems are given in Rees (2004), with the emphasis on marine biological studies. The degree of sophistication will clearly depend upon laboratory size, and it would be inappropriate to attempt to cover the needs of all recipients in the present document. However, one of the most important practical tools in a QA system is the Standard Operating Procedure, general guidance on the structure of which is given at Annex 7.

The commitment of adequate resources to the systematic recording and management of all information relevant to the interpretation of epibenthic surveys is essential. Thus information on sampling and analytical practices and other potential error sources (*e.g.* weather conditions at the time of sampling) is required, in addition to biological records. Taxonomic naming conventions, coding systems and accompanying information should conform to standards for the construction of a permanent electronic archive. These should meet agreed local/national needs and also ensure compatibility at an international level (*e.g.* with the Integrated Taxonomic Information System [ITIS]: www.itis.gov; the European Register of Marine Species: Costello *et al.*, 2001, 2004 and the Ocean Biogeographic Information System [OBIS]: www.iobis.org), depending on the aims and scope of surveys. Vanden Berghe *et al*.

[4] Quality Assurance (QA) is the total management scheme required to ensure the consistent delivery of quality controlled information fit for a defined purpose. The scheme must take into account as many steps of the analytical chain as possible in order to determine the contribution of each step to the total variation. Analytical Quality Control (AQC) encompasses procedures which maintain the measurements within an acceptable level of accuracy and precision.

(2007) report on a recent data management initiative encompassing collaborative macrofauna surveys of the North Sea under ICES auspices.

8 Conclusions

An assessment of the performance of the gears outlined in Sections 2-4 against various operational criteria is given in Table 8.1. As expected, there is a 'trade-off' between resolution and spatial coverage, and also the costs associated with sample/data processing. The most versatile gears tend to be the non-destructive visual or acoustic methods but typically the level of resolution is lower than the conventional (destructive) towed gears or grabs. A combination of these, *i.e.*, seabed imaging techniques accompanied by more limited biological 'ground-truth' sampling, has proved to be useful in the mapping of habitats and assemblages at reasonable cost over relatively large areas (*e.g.* Kostylev *et al*., 2001; Boyd *et al*., 2006b).

Table 8.1 Qualitative assessment of gear performance/utility against various operational criteria, conducted by members of the ICES Benthos Ecology Working Group.

Device	Area covered	Resolving power (epibenthos)		Versatility		Expertise		Cost	
		Spatial pattern	Temporal trends	Habitat types	Vessel size	Deployment	Sample/data processing	Equipment	Sample/data processing
2 m beam trawl	**	**	**	*	*	*	**	**	*
5.5 m beam trawl	***	**	**	**	***	*	*	**	*
Agassiz trawl	**	**	**	*	*	*	**	**	*
Scallop dredge	**	*	*	**	**	*	*	*	*
R.-du-B. dredge	**	**	*	***	**	*	**	*	**
Anchor dredge	*	*	*	**	**	*	**	*	**
Rock dredge	**	*	*	**	**	*	**	*	**
Naturalists' dredge	**	**	*	**	*	*	**	*	**
Kiel. Kind. dredge	**	**	**	*	*	*	**	*	**
Triangular dredge	**	*	*	**	**	*	**	*	**
Ockelmann sledge	**	**	**	*	*	*	***	*	***
Aquarieve III sled	**	***	**	**	***	**	**	**	**
Triple D dredge	**	***	**	*	***	*	**	**	**
Hamon grab	*	***	***	**	**	*	***	**	***
Videograb	*	***	***	**	***	**	***	***	***
Suction sampler	*	***	***	***	*	***	***	**	***

Device	Area covered	Resolving power (epibenthos)		Versatility		Expertise		Cost	
		Spatial pattern	Temporal trends	Habitat types	Vessel size	Deployment	Sample/data processing	Equipment	Sample/data processing
Quadrat	*	***	***	**	*	*	***	*	***
SPI	*	***	**	*	**	**	***	***	*
Drop trap	*	***	***	*	*	*	***	*	***
Multibeam	***	*	*	***	**	***	***	***	**
AGDS	***	*	*	***	**	***	***	***	**
Sidescan sonar	***	*	*	***	**	***	***	***	**
Diver observation	**	**	***	**	*	***	***	**	*
Campod	**	**	**	***	***	***	**	***	*
Drop-camera	**	**	*	***	**	**	**	**	*
Towcam	***	*	*	***	***	***	**	***	*
Camera sledge	**	**	*	**	***	**	**	**	*
ROV	**	**	**	***	***	***	**	***	*

***Key*: * low/small ** medium *** high/large**

The subtidal epibenthos is of necessity a rather loosely-defined ecological entity, as a result of the variety of the habitats encountered, the variable degree of association of organisms with those habitats, and the wide range in organism size and life-history traits. Thus the epibenthos may comprise motile or attached species, colonial or individual forms, and the maximum body size is (in principle) only limited by the dimensions of the sampling gear.

Investigations into the functional and evolutionary significance of benthic body size have provided some evidence for a distinction between meio- and macro-infaunal size distributions corresponding approximately with a sieve mesh size of 0.5 mm, which is commonly used in field sampling to separate the two groups (Schwinghamer, 1981; Warwick, 1984; Warwick *et al*., 1986; Duplisea and Drgas, 1999). Observations have extended to the epibenthos and the data have considerable interpretative value, including the facility to model trophic and other ecosystem interactions (*e.g.* Edgar, 1994; Gee and Warwick, 1994; Jennings *et al*., 2002; Warwick, 2007). Further work is necessary to determine whether epibenthic body size (or mesh selection) might serve as an aid to identifying sub-groups of ecological relevance. Morphological diversity would clearly present technical challenges (see Section 1.1) but may have an additional practical benefit of helping to distinguish between reliably and not-so-reliably sampled suites of taxa (see, *e.g*., Callaway *et al*., 2002a).

As the nature of the data generated from many of the remote sampling approaches reviewed in this account is strongly gear-dependent, caution is required in ascribing ecological significance to differences in densities, size or species composition determined from different studies unless inter-calibrated (see, *e.g*., Callaway *et al*., 2007). For towed gear such as a beam trawl, sources of variability include the speed over ground relative to the escape reactions of motile organisms, the capability to dislodge sessile species, the constancy of bottom contact and changes in the habitat along and between tows. This can make accurate quantification very difficult and, for some surveys, there may be a case for identifying sub-sets of taxa with more dependable catch

efficiencies. Paradoxically, the relative inefficiency of some towed gears also explains their versatility as sampling tools for wide-scale descriptive surveys.

In favourable conditions, observations by experienced divers are likely to provide the most accurate information on the *in situ* status of epibenthic communities. However, a central requirement of all surveys is consistency in sampling and analytical practices as a means of quality control. The outcomes, even though method-dependent, can then provide a dependable way of identifying trends in response to natural and human influences (Lundalv, 1985; Maurer *et al*., 1998; Rees *et al*., 2001; Reiss and Kröncke, 2004; Smith *et al*., 2006; Yeung and McConnaughey, 2006; Callaway *et al*., 2007).

Activities to improve study practices and enhance knowledge of the epibenthos include:

- further innovations in sampler design; publication of gear efficiency studies (*e.g.* Creutzberg *et al*., 1987; Kaiser *et al*., 1994 and Reiss *et al*., 2006 for trawl sampling; see also Eleftheriou and Moore, 2005)
- more effort to standardise sampling/analytical practices for comparable environments (if not already done or if new approaches merit inclusion). International collaborative R&D and monitoring programmes have provided an important incentive (*e.g.* www.mafcons.org; www.helcom.fi; www.ospar.org) and the preparation and wider dissemination of Standard Operating Procedures, *e.g. via* ICES, should be encouraged
- more consistency in descriptions of assemblage types over larger geographical scales, as sampling methods allow
- more effort to identify and predict relationships between the epibenthos and the physical environment, especially offshore (*e.g.* Kostylev *et al*., 2001; Foster-Smith and Sotheran, 2003; Connor *et al*., 2004; Hewitt *et al*., 2004; Boyd *et al*., 2006b) which should be helped by continuing advances in seabed imaging techniques and interpretational tools
- further evaluation of size/weight relationships and benthic production, for environmental quality assessment and to explore functional interactions with other ecosystem components (*e.g.* Cohen *et al*., 2000; Jennings *et al*., 2001a, 2002; Bourget *et al*., 2003; Hinz *et al*., 2004; Smith *et al*., 2006; www.mafcons.org).
- development of indicators using information on the life-history traits and sensitivities of epibenthic species to natural and human perturbations (see MacDonald *et al*., 1996; Kaiser, 1996; Rogers *et al*., 2001; Bremner *et al*., 2003, 2006; Hiscock and Tyler-Walters, 2006; Hiddink *et al*., 2006; de Juan *et al*., 2007).

The availability of a wide range of techniques for studying the epibenthos reflects the diversity of the supporting marine habitats and the need for adaptability and innovation to meet the sampling challenge. This report has highlighted some of the more important sampling and interpretational issues, along with examples of good practice. It is hoped that it will contribute to enhancing the quality of existing survey and analytical effort, and provide a stimulus for further fundamental and applied studies.

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Annex 1: Methods for studying hard bottom substrata

(After: D. Connor, Report of the Benthos Ecology Working Group, ICES C.M. 1995/L:3, and Anon., Report of the ICES Advisory Committee on the Marine Environment 1996, ICES Cooperative Research Report, No. 217, 128–133, with minor updating).

A1.1 Introduction

This report provides a brief account of methods available to study marine benthic communities which occur on hard substrata. Hard substrata are taken to be habitats of bedrock, boulder, stable cobble and pebble, artificial substrata and biogenic reefs, such as *Mytilus edulis* and *Modiolus modiolus* beds, on which epibiota communities develop, either in the littoral or sublittoral zone. This definition excludes sediment substrata which hold infaunal communities (but may develop epibiota communities if sufficiently stable), including mobile shingle which may have little associated biota. Habitats of mixed hard and soft substrata occur which are difficult to sample for their infauna and might best be considered here.

In the history of the ICES Benthos Ecology Working Group most attention has been directed towards studies of soft bottom substrata, the predominant habitat over most offshore areas and in some coastal areas. In many countries, however, hard substrata form a major component of coastal areas and are consequently subject to many of the pressures of coastal activities, such as coastal defences, urban and industrial development, mineral extraction, coastal quarrying, fishing, chemical contamination, eutrophication, waste dumping and oil pollution. Rocky habitats often hold much intrinsic appeal both for their scenery and the wealth of marine life associated with them.

Although the ecology of littoral rocky habitats is generally well studied, that for sublittoral rock, and particularly for offshore rock, is relatively poorly understood. There remains much to be learned about the basic nature and distribution of rocky communities; also very little monitoring occurs in comparison to that done for littoral and sublittoral sediments.

A1.2 The nature of rocky habitats

The communities of rocky habitats exhibit a very high degree of heterogeneity, dependent on local conditions, particularly height up the shore (due to desiccation) or depth into the sublittoral (due to light attenuation, temperature, wave disturbance), exposure to wave action and currents, salinity, temperature, topography, geology and the effects of suspended sediment or siltation. In addition biological interactions of predation, competition and chance recruitment play their role in community structure.

The effect of this is often to yield a very high variety of communities in an area, often changing markedly over a few metres, compared with a much smaller range of sediment communities which typically cover larger expanses of shore or seabed. Such complexity in rocky habitats presents difficulties in both ecological monitoring and monitoring for man-induced change, and may in part explain why so little is undertaken.

On the shore and in the shallow kelp-dominated infralittoral zone one or several species may typically dominate community structure (numerically or by space); however

in the deeper animal-dominated circalittoral zone communities tend to comprise a wide variety of species and present a much patchier community structure; this too can make effective monitoring difficult to establish.

A1.3 Sampling rocky habitats: general principles

As with sediment studies the methods adopted need to be appropriate to the end requirements of the study. Consequently methods, equipment and resources required for mapping habitats differ considerably from those for detailed description of habitats or for monitoring studies. The scale of the study, be it local, national or international also has a marked effect on the techniques employed and the level of detail appropriate, as does the focus of the study on species distribution and dynamics, community description, productivity and so on. It has not been possible in this brief review to consider all the potential types of hard substrata sampling to suit every requirement. An attempt is made here to give general guidance of the types of method applicable to baseline resource surveys and to monitoring, as these are likely to be of most interest to ICES.

The general strategy for sampling should be similar to both littoral and sublittoral rocky habitats, although the specific methods adopted will differ according to the logistics of sampling in each zone.

Since rocky habitats by definition support epibiotic communities, they are visible by eye and sampling can typically be undertaken in a non-destructive *in situ* manner, rather than the infaunal sampling of sediments which requires removal of samples to the laboratory for analysis. For some studies removal of samples (destructive sampling) may however be appropriate.

Quantitative sampling is difficult as many species are colonial in nature (and thus cannot be counted), are difficult to count (*e.g.* stands of filamentous algae) or adhere as a crust over the rock (and so cannot be collected or counted). More effective assessment of quantity for such species is given by estimates of percentage cover. An integration of such percentage cover estimates with a $\log_{10}$-based quantitative abundance scale for species which can be counted is provided in Hiscock (1990). Fully quantitative sampling with removal of the entire sample from the rock to determine biomass is little undertaken (*e.g.* Christie, 1980, 1985).

In the sublittoral use of Scuba diving enables detailed recording and sampling to be done, particularly important in description of the community and monitoring. Use of cameras attached to remotely operated vehicles (ROV) offers advantages in the greater depth ranges that can be covered and the extended time available underwater, not requiring diving expertise and providing a permanent record of the site.

However for species identification remote video is able to pick up only the larger species at a site, amounting to only about 50% of the macrobenthic species present (R.H.F. Holt, pers. comm.). It is consequently unsuitable for detailed description of the habitat and for certain types of monitoring.

Monitoring for man-induced change requires previous knowledge of the nature of the community and its natural variability. Such basic information is lacking for the majority of rocky habitats, making the design of monitoring programmes critical to ensure they effectively answer the aims of the study. Such monitoring should therefore include sufficient study to establish natural variation at the site or parallel monitoring of a reference site which must be of a comparable nature.

A1.4 Baseline resource studies

Mapping of biotopes (i.e., habitats and their associated communities). Rapid identification of the key biological features which define each community, combined with knowledge of the extent of the physical habitat can be used to provide maps of the resource without recourse to detailed and time consuming programmes for sampling of species. Such an approach requires a pre-established biotope classification such as that developed for the British Isles (Connor *et al*., 1995; Connor *et al*., 2004). For littoral habitats Richards *et al.* (1995) have developed a technique using aerial photographs to define polygons of similar physical habitat which are then ground-truthed by field surveyors. The data are fed into a Geographical Information System (GIS) to provide maps and allow for spatial analysis of the data. In the sublittoral, a similar approach can be achieved through acoustic survey of the seabed (such as using the RoxAnn or other imaging systems) and ground-truthing with ROV cameras (*e.g.* Davies and Sotheran 1995; Sotheran *et al*., 1997; see also Davies *et al*., 2001).

Description of biotopes - main species only. In the sublittoral ROVs can be used to give a general description of the community, although only the largest conspicuous species can be identified accurately (typically those at least 10 cm in size), accounting for only up to 50% of the macrobenthic species present. ROVs can be used to great depths and have fewer time restrictions compared with divers; they are often used when diving expertise is unavailable.

Description of biotopes - all conspicuous species. *In situ* recording by experienced field ecologists to identify all conspicuous species present in a defined habitat can be achieved through search over a wide area of the habitat to ensure widely dispersed species are recorded. Diving techniques are used for the sublittoral zone. This approach was adopted for the Marine Nature Conservation Review, a major resource survey for the whole coast of Great Britain (Hiscock, ed., 1996; see also Davies *et al*., 2001). For more restricted surveys specific quadrat or transect approaches may be appropriate to provide more quantitative data for some studies.

A1.5 Monitoring studies

Monitoring requires repeat surveys of the same location at set time intervals. Marking of such sample sites is important to ensure return to the exact location, because of marked spatial variation in community structure over short distances. Epibiota communities lend themselves to photographic monitoring techniques as well as monitoring by *in situ* recording. Stereo photography techniques for sublittoral rocky monitoring have been developed by Lundalv (1971, 1976) and used for many years in Sweden. Recent advances in computer-aided image analysis allow direct comparison of photographic images with time (*e.g.* Fowler and Pilley, 1992 for monitoring growth of individual specimens of slow-growing sponges and seafans). Other publications relevant to monitoring hard-bottom communities include Crapp (1971), Lewis (1976), Jones *et al.* (1980), Hawkins and Hartnoll (1983), Christie (1985), Costelloe *et al.* (1986), Hiscock (1987), Sullivan and Chiappone (1993), Scott (1994) and Davies *et al.* (2001) .

Point source monitoring. Transects away from the source of contamination with sampling at regular intervals along one or more transects can be used but are subject to difficulties in interpretation. Heterogeneity of the rocky habitats is such that sample points along the transect are likely to be in different communities and hence not comparable; also samples within quadrats may not be representative of the wider area due to spatial variation.

Long term change (trend) monitoring - ecological or human-induced. Establishment of the baseline community structure and variability at the site under consideration is important. Sample points need to be spread out over the extent of the habitat studied to ensure adequate account of spatial variation is considered, rather than assuming one point is representative of the habitat as a whole. If measuring human-induced change then a control or reference site is required for each test site. It is critical here that like habitats are selected for comparison.

A1.6 Parallels with sediment sampling

For consistency of approach it is important to use similar strategies for sampling both rock and sediment habitats. However the differing nature of the two habitat types leads to marked differences in techniques used, as does the logistics of sampling in littoral and sublittoral environments. For rocky habitats there is generally more emphasis on *in situ* recording and photographic techniques. A broad comparison of approaches applicable to rock and sediment habitats is given in Table A1.1. It is not comprehensive as other techniques may be equally valid to use.

Table A1.1 Summary of approaches to assessing rock and sediment habitats.

Baseline resource sampling:

DETAIL	LITTORAL ROCK	LITTORAL SEDIMENT	SUBLITTORAL ROCK	SUBLITTORAL SEDIMENT
Mapping – habitat and biotope type	Aerial photography, OS maps & rapid field survey	Aerial photography, OS maps & field survey with *in situ* identification (dig over sediment)	Acoustic survey + video (ROV) ground-truthing	Acoustic survey + towed video
Describe biotopes – main species only	Rapid *in situ* recording	*In situ* identification (dig over sediment)	Rapid *in situ* recording by diver Video (ROV)	Remote sampling – identification on boat Diver observations of epibiota
Describe biotopes – all conspicuous species	*In situ* recording	Coring – samples worked up in lab.	*In situ* recording by diver	Remote sampling – samples worked up in lab.

Monitoring/surveillance:

Monitoring	Fixed transects or positions	Replicate samples on grid	Fixed transects or positions	Replicate samples on grid
	Quadrats	Regular sampling programme	Quadrats	Regular sampling programme
	Photography		Photography	

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Annex 2: Stages in the design and conduct of epibenthos surveys

This section provides guidance on the development of routine sampling programmes to assess the status of the epibenthos in relation to human activities. Descriptions of the various stages involved are adapted from Rees and Boyd (2002). Useful general sources of information concerning the evolution of sampling designs in benthic studies include Elliott (1971), Cohen (1977), Green (1979), Holme and McIntyre (1984), Andrew and Mapstone (1987), Skalski and Robson (1992), Underwood (1997) and Underwood and Chapman (2005).

A2.1 Desk study

This is an essential pre-cursor to all field sampling effort, and should allow the construction of a realistic hypothesis-testing framework to meet the overall objectives. The desk study should provide an early indication of the most suitable sampling gear(s), and of possible constraints on the amount or type of data in relation to the resources available to carry out the work (see Sections 2–4). This should lead to the drafting or adoption of Standard Operating Procedures for sampling/analytical practices, as part of an overall quality assurance plan (Rees, 2004).

Prior knowledge of the sampling area may be gained from the published literature, access to geological maps and hydrographic charts. Contacts with governmental and research agencies may reveal ongoing research and monitoring initiatives in the area of interest, including the existence of spatial data in Geographical Information Systems and archived oceanographic data. Access to the 'grey' literature, and consultations with individuals with local sampling experience may provide useful background information, which will reduce uncertainties at the planning stage, and hence increase the cost-effectiveness of sampling programmes.

A2.2 Survey planning

Information gained during the desk study will aid decisions on the range of sampling equipment needed and will, in turn, influence the size and capability of survey vessels required for field sampling. Critical issues regarding the suitability and seaworthiness of chartered vessels, along with safe working practices for scientists (including divers) at sea must be considered at this stage by competent and experienced individuals.

The choice of environmental variables for measurement alongside biological sampling will depend upon the survey objectives, and may include combinations of the following:

- substratum type (essential)
- depth below chart datum (essential)
- wind strength/direction (essential for towed gear)
- current speed
- wave action
- salinity
- temperature
- turbidity
- bottom oxygen concentrations
- water-column stratification

- sediment quality, including organic matter content and contaminant concentrations
- manifestations of other sources of human perturbations (*e.g.* the presence of trawl tracks, or dredged furrows from commercial sand and gravel extraction)

Information on variation in substratum types, scale, and depths of the area to be investigated will be especially important at the planning stage. For example, deep-water locations with hard substrata may create particular difficulties for quantitative sampling. Many deep-water species are rare and/or patchily distributed and will seldom be encountered by random photographing or other methods covering a small area.

Plans for scientific sampling may include the use of epibenthic trawls or dredges with mesh sizes below the minimum legal requirements specified for commercial fishing activity in the study area. In such cases, prior dispensation should be sought from the appropriate regulatory authorities.

In planning for surveys at locations where knowledge of the benthic habitat and the associated epibenthos is limited, but which is suspected to include very coarse or rocky substratum types, then allowance must be made for the possibility of damage or even loss of towed gear in 'pilot' surveys. To cover for such eventualities, survey planning should include the provision of duplicated sampling equipment and/or an adequate supply of spares for on-board repairs.

A2.3 'Pilot' survey

The necessity for such a survey will depend upon the availability of existing information for the area of interest. A well-studied location may provide all the information necessary for selecting suitable sampling tools, and designing a 'baseline' survey (Section A2.4, below). In its absence, preliminary sampling over a wide area encompassing the activity or feature of interest may be required, using a range of mechanical sampling devices, along with acoustic and visual methods for ground discrimination (see Sections 2–4). The ability of acoustic methods to provide topographical information on habitat types over large areas may be valuable in a number of respects. For example, it may identify biogenic structures such as *Sabellaria* or *Lophelia* reefs, aid the selection of representative biological sampling stations and determine the appropriate length and orientation of transects. Any deficiencies in local knowledge of water movements and their influence on particulate transport may be made good by the deployment of current and turbidity meters.

The adopted sampling design may be random, systematic or stratified, depending upon the extent of prior knowledge of the area. It may also be selective, *e.g.* for confirmation of the presence of a particular habitat type. The options are similar to those available for subsequent 'baseline' surveys (Section A2.4, below). Thus, in terms of design, the two may differ only in the number of stations visited, if the 'pilot' survey is successful in confirming prior inferences concerning the nature of the benthic environment.

For bottom sediments and the accompanying epibenthos, on-board or direct visual assessments of collected samples or images at a qualitative level will usually suffice at this stage. The purpose will be:

- to establish the distribution of habitat types which may influence subsequent sampling design

- to determine the most effective sampling tools to meet the aims of future monitoring
- to provide a preliminary characterisation of the nature of epibenthic assemblages

Observations on assemblage types may influence later decisions on survey approaches, including the size and number of samples to be taken. In many areas, sufficient information may already exist on a larger scale, and pilot sampling may only be necessary to confirm that local conditions conform to the wider pattern. Such an investigation may be conducted immediately prior to a 'baseline' survey, in order to refine the sampling design or sampling practices, but need not involve a separate sampling trip.

Accurate navigation is essential and, with the use of differential Global Positioning Systems (dGPS) and acoustic tracking equipment, it should be possible to determine the location of platforms (both stationary and towed) to within 15 m or less. This will require determination of offsets in order to establish the precise location and orientation of sampling gear during deployment. It is also essential to simultaneously record other data such as depth, ship speed and heading, as a function of time (GMT), along with the geodetic parameters for position-fixing such as datum and projection. Such information will allow the plotting of stations/transects over other georeferenced data sets (*e.g.* multibeam bathymetry, sidescan sonar or the output from electronic monitoring systems: see Section 3.1).

A2.4 'Baseline' survey

In an area of relative uniformity, this will typically take the form of a systematic grid of stations, although more complex and spatially extensive designs may be necessary according to local circumstances, *e.g.* to account for human activities such as waste disposal or demersal fishing, or features of conservation interest in the vicinity. A stratified random sampling design may be more appropriate where prior information (*e.g.* from desk study or 'pilot' survey) reveals well-defined spatial partitioning of habitat types. Ideally, the same sampling methodology will be employed at all stations across level-bottom terrain, but alternative methods may be necessary in some circumstances, *e.g.* in the presence of significant rock outcropping supporting distinctive epibenthic assemblages. Examples of sampling designs for trawl surveys are given at Annex 6.

As the aim is to elucidate and (as far as possible) quantify spatial patterns, a strategy involving the collection of single samples or observations over several stations is favoured over repetitive sampling at fewer stations. The latter approach is more appropriate for 'ongoing' monitoring surveys at representative stations (Section A2.5), but selective sampling at this stage in anticipation of the future need is likely to be cost-effective.

A2.5 'Ongoing' survey

The main aim of this and succeeding surveys is to monitor temporal trends. However, a spatial component is also essential. Stations may be located along a transect where effects are predicted to occur, principally along a well-defined gradient away from the human or natural influence of interest, or at representative locations within physically comparable zones. The choice of stations will be facilitated by the outcome of the 'baseline' survey, and indeed sampling to generate the first data points in an 'ongoing' monitoring series may be feasible during this survey. As part of an overall

quality assurance strategy, it will be important to check on their continued validity. This may be achieved by periodically repeating the 'baseline' survey, at intervals appropriate to local circumstances, but typically once every 3–5 years.

The number of stations will vary with the complexity of the physical habitat, the dispersive properties of the environment and the proximity of other human influences. As a minimum, an ongoing sampling design will consist of one 'treatment' station located within the predicted sphere of influence of the activity under investigation, accompanied by two 'reference' stations, one just beyond the predicted sphere of influence, and one at some distance away. This approach is comparable to the 'Control/Treatment Pairing' principle of Skalski and McKenzie (1982) and developments (by Underwood, 1992) of the 'Before/After and Control/Impact' (BACI) design of Stewart-Oaten *et al*. (1986).

The number of samples or observations to be collected at each station will reflect a balance between the statistical requirements of data analysis, the nature of the epibenthos and any resource constraints. The choice of sampler(s) combined with habitat variability will strongly influence the capability to accurately quantify epibenthic assemblages (see Sections 2–4), and decisions regarding sample number are therefore likely to be site-specific. In general, a minimum of three replicates or observations should be obtained either across a fixed point or randomly within a well-defined habitat type.

The timing and frequency of sampling will depend on many factors, including seasonality (see, *e.g*., Reiss and Kröncke, 2004) and the perceived sensitivity of the environment. However, for contributions to monitoring programmes aimed at evaluating sea-wide quality status, surveys of the epibenthos will typically be carried out at the same time each year.

A2.6 Summary

A summary of the overall strategy for the design and conduct of sampling programmes is given in Table A2.1.

Table A2.1 Summary of strategy for the planning, design and conduct of sampling programmes incorporating an epibenthic component.

DESK STUDY	SURVEY PLANNING	'PILOT' SURVEY	'BASELINE' SURVEY	'ONGOING' SURVEY
1) Determine: • testable hypotheses against study objectives • survey needs & sampling gear • QA strategy **2) Seek information on:** • wave climate • tidal/residual currents • water-column stratification • substratum type • epi- and endo-benthic communities • valued resources (e.g. fish/shellfish) • human activities/impacts	**1) Determine:** • survey timing • suitability/availability of charter vessel • availability of sampling gear **2) Attend to issues of safety at sea and other operational matters**	**1) Determine:** • local hydrography • suitable sampling gear • substratum type (qualitative) • epibenthos (qualitative) • boundaries of survey area **2) Evaluate findings**	**1) Carry out:** • quantitative spatial survey • initial sampling at representative stations • analysis/AQC of samples **2) Analyse data/report and act on findings** **3) Refine hypotheses-testing framework as necessary** **4) Repeat at intervals**	**1) Carry out:** • sampling at representative stations over time • analysis/AQC of samples • hypothesis-testing for natural or human changes **2) Report and act on findings** **3) Review sampling design / frequency**

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Annex 3: Area mapped per unit effort *v.* resolution for different seabed survey techniques

(Reproduced from: Kenny, A. J., Cato, I., Desprez, M., Fader, G., Schüttenhelm, R. T. E. and Side, J., 2003. An overview of seabed-mapping technologies in the context of marine habitat classification. ICES J. Mar. Sci., *60*: 411-418).

Key:

SSS = Side Scan Sonar

MBES = Multi Beam Echo Sounding System

AGDS = Acoustic Ground Discrimination System

		Resolution (horizontal)								
System	Area mapped ($Km^2\ h^{-1}$)	1000 m	100 m	10 m	1 m	1/10 m	1/100 m	1/1000 m	<1/1000 m	Remarks
Remote sensing, satellite	>100		•	·						Restricted to operational coverage, mainly shallow seas
Remote sensing, aircraft	>10	·	·	•	·					Generally restricted to depths <6 m
"Chirp" SSS	10		·	·	•					High-energy broad bandwidth pulse sonar
MBES	5		·	·	•	·				Allows the use of backscatter data to characterize substrata
SSS	3.5		·	·	·	•	·			Swath width depends on frequency used

Synthetic aperture sonar	3.0	· • ·	Optimal operation in range of 50–100 kHz
AGDS	1.5	· · • ·	Valid for normal (narrow) beam surface coverage only
High-resolution sub-bottom profiler	0.8	· · · • ·	Narrow-beam sub-surface coverage
Video camera	0.2	· • ·	Allows mega-epibenthos identification
Benthic grab/core sampling	0.003	· • ·	Quantitative data on macro- and meio-fauna requires laboratory analysis
Sediment profile camera	<0.001	· •	Sediment/water interface inspections
X-ray photography	<0.001	· • ·	High-resolution geochemical and physical inspections (water content, density)

Annex 4: Good practice in the use of imaging techniques

(Reproduced from: Rees, H. L. (ed.), 2004. Biological monitoring: general guidelines for quality assurance. *ICES Techniques in Marine Environmental Sciences*, No. 32, 44pp).

A4.1 General Comments

No binding procedures have so far been identified for QA/QC measures for imaging methods. Retrieval methods can be grouped as follows:

- sea-going and land-based activities;
- satellite and airborne imagery;
- evaluation and processing of images, videos and sidescan records;
- storage and retrieval of image documents.

(Important considerations in relation to diver-based retrieval include: parallel checks among several divers; photo and video documentation; double recording of profiles/transects; need for specific scientific diver training and certification; strict safety rules).

A4.2 "Best Practice" Guidelines

A4.2.1 Sea-going and land-based procedures

- Sea-going and land-based procedures should follow well-documented SOPs. In addition, a precise time log (*i.e.*, TBC or data input on screen) is a pre-requisite for proper evaluation and identification of photographic and video images. Marks on videos and photographs, and in the written log, can help in identifying and tracing back the image documents. One should note, however, that for certain purposes high quality pictures are needed for publication without the on-screen information.
- All technical details of cameras, films, tapes, camera settings, angles, distances, lightings, and parallel measurements must be recorded in writing.
- Films, tapes, and sonar records must be labelled and stored safely (in waterproof conditions).
- Underwater pressure housings should be equipped with hydrophilic drying agents (silica-gel pellets in sacks) to provide proper functioning of cameras.
- Greatest care should be given to O-ring sealings to avoid flooding of pressure housings.
- All safety instructions for diving, safety on board ships, and underwater electricity should be followed strictly.

A4.2.2 Satellite and airborne images

For satellite and airborne images the same rules apply in principle as for other imaging methods. In particular, it is important to fully document all parameters used in the registration and geo-rectification to a coordinate system.

A4.2.3. Images and recordings

- Images and recordings should be evaluated following well-documented and repeatable methods conforming to standards of the highest objectivity.

- All steps involved in processing of the original image (*e.g.* colour enhancement) must be documented and stated in documents and figure legends. Geodetic parameters must be recorded.
- Images and videos should be stored in suitable labelled magazines, to make later retrieval possible by other individuals.
- Back-ups must be stored in other buildings as video copies, CD-ROMs of photograph collections or stored on PC drives. Future storage media may include DVD drives.
- Large collections of images should be stored in image data banks in digital form, to avoid mis-identifications and losses of images. The use of key words is strongly recommended, providing information about the subject, platform, format, position depth, remarks, *etc.*
- Attention should be given to the possibility that video tapes may lose their magnetic information after > 15 years as well as CD-ROMs after > 10 years; thus back-ups are advised every 5 years.
- This also applies to old film and photographic material that is of documentary and historical value.

Annex 5: Approaches to the analysis of data from epibenthos surveys

A5.1 Objectives of data analysis

The objectives of the analysis of data arising from surveys of epibenthic communities are comparable with those for the infauna (see Schratzberger and Boyd, 2002, from which much of the following account is derived) and include:

- the identification of spatial patterns in the assemblage(s) and the relation of these to environmental information including the spatial extent of any human influences under investigation (baseline/exploratory data)
- the identification of temporal trends, and their relationship to human or natural influences (ongoing monitoring data)

Several statistical techniques described in the following account are included in the PRIMER software package (Clarke and Gorley, 2001). Details are also provided of CANOCO (including canonical correspondence analysis: Jongman *et al*., 1987) and of TWINSPAN (Hill, 1979) for multivariate analysis (see Section A5.5), and many others exist. As long as the analyses of data arising from epibenthic surveys are based on sound statistical principles and employ techniques most suited to the individual datasets, the actual software package employed is irrelevant. It should also be noted that both novel statistical approaches for the analysis of biological data and new statistical software packages are continually emerging.

In addition to biological data, analysis will generally include information on sediment type and a range of hydrographic variables. Many of the approaches described below can be applied equally to other determinands, *e.g.* biomass estimates. However, non-parametric statistical methods may be more appropriate than parametric methods when analysing count data.

A5.2 Initial data processing

Stages in initial data processing are summarised by Clarke and Green (1988). First, the data must be collated and classified using established coding systems (see Section A5.7). A species-sample matrix is then created which should include both quantitative and presence/absence data. In addition, a matrix of the biomass of individual taxa by sample (typically expressed as ash-free dry weight), and finally a matrix of the corresponding environmental data, should be prepared.

Once data are collated, any transformations (see Section A5.5) or exclusions of rare species can be made, the rationale for which must be clearly stated. Similarly, presence/absence records will be removed before analysis of quantitative data.

Statistical methods for describing assemblage structure include:

- univariate methods
- distributional techniques
- multivariate methods

For each of these classes, statistical tests have been developed to determine the significance of differences between replicated samples.

A5.3 Univariate methods

Diversity measures take into account two factors. These are species richness (number of species) and species evenness (the apportioning of individuals among the species).

Typically, indices which require no assumptions to be made about the underlying species abundance distributions are used. There are two categories of distribution-free indices (Magurran, 1988):

- information theory indices (e.g. Shannon-Wiener Index H')
- dominance indices (e.g. Pielou's evenness index J')

More information about the structure of assemblages and their change in response to human or natural events can be obtained by the use of a variety of different univariate measures including total number of individuals, total number of species, diversity (Shannon-Wiener Index H'), dominance (Simpson Index C), species richness (Margalef's d) and evenness (Pielou's J'). In general, such measures tend to be highly correlated and therefore there is limited value in calculating a large number of indices, as many will show similar trends in the data. Those indices that are less dependent on sample size (see Table A5.1) may be more appropriate for data arising from coarse substrata.

Table A5.1 Summary of the performances and characteristics of diversity statistics. The column headed "richness or evenness/dominance" shows whether an index is biased towards either species richness or evenness (modified from Magurran, 1988).

	DISCRIMINANT ABILITY	SENSITIVITY TO SAMPLE SIZE	RICHNESS OR EVENNESS/DOMINANCE
H'	moderate	moderate	richness
C	moderate	low	dominance
d	good	high	richness
J'	poor	moderate	evenness

There are indices which reflect the species richness element of diversity and measures which express the degree of evenness in the data. The number of species detected in a sample usually changes much more in relation to sample size or sampling intensity than does the distribution of relative abundances (Huston, 1996). Therefore, indices in the first category are generally better at discriminating between samples but are more affected by sample size than the evenness of diversity measures.

Taxonomic Distinctness indices (Clarke and Warwick, 1998; see also Clarke and Gorley, 2001) express the 'relatedness' of the species in each sample. They are generally less dependent on sample size than conventional diversity measures, allowing results to be compared across studies with differing and uncontrolled degrees of sampling effort. Presently, these indices are being more widely tested, and further refinements may be expected (*e.g.* Hall and Greenstreet, 1998; Clarke and Warwick, 1999; Rogers *et al*., 1999; Bates *et al.*, 2005; Ellingsen *et al*., 2005; Bhat and Magurran, 2006; Callaway *et al*., 2007).

Biotic indices are derived from the known or perceived sensitivities of species to human influences, especially the effects of contaminants and organic enrichment. Examples include Hily (1984), Majeed (1987), Dauer (1993), Grall and Glémarec (1997), Weisberg *et al*. (1997) and Borja *et al*. (2000; see also www.azti.es). Although aimed principally at evaluating infaunal benthic communities, they clearly have the potential for future adaptation to epibenthic studies, and such work is in progress (A. Borja, *pers. comm.*).

A5.3.1 Analysis of variance (ANOVA)

Testing of the significance of differences in replicated univariate measures between treatments by ANOVA relies on the following assumptions:

- that the data follow a normal distribution
- that the variance of the sample is independent of the mean, and
- that the components of the variance are additive

In general, the variance and mean tend to increase together and therefore the second condition is never fulfilled. Transformations are an essential procedure before the application of most methods associated with the normal distribution (Elliott, 1971).

Multiple comparisons tests can be performed to identify assemblages that are significantly different at $p < 0.05$.

A5.4 Distributional techniques

Diversity profiles can be visualised by plotting *k*-dominance curves (Lambshead *et al*., 1983). Species are ranked in decreasing order of dominance along the x-axis and the percentage cumulative abundance (*k*-dominance) is then plotted against the species rank *k* (Platt *et al*., 1984). The purpose of such curves is to extract information on the dominance pattern within a sample, without reducing the information to a single summary statistic, such as a diversity index. Sets of macrobenthic species counts and biomass can be jointly summarised in abundance and biomass *k*-dominance curves applying the ABC procedure (Warwick 1986). Grounded in disturbance theory, both procedures has been validated using data from soft-sediment infaunal communities but may find adaptation to account for changes in the epibenthos.

Body size (biomass) spectra have been used to examine the effects of bottom trawling and aggregate extraction on the subtidal epifauna (Jennings *et al*., 2001; Smith *et al*., 2006). Species weights were allocated to $\log_2$ size classes and normalised (class interval biomass ÷ class interval width) so that inter-site relationships could be explored.

A5.5 Multivariate methods

Multivariate techniques identify patterns in the data, which may aid in establishing causal influences. For example, analysis of variance can be used to determine which of a range of environmental variables are significantly different between station groups identified from multivariate analysis of the epibenthic data. Further insights into the causative factors may be gained through computing correlations between environmental variables and univariate measures such as the densities of selected species, diversity indices, or numbers and densities of all species at each station. More sophisticated techniques employing multivariate approaches to linking biotic and environmental data may also be used (see, *e.g*., Clarke and Warwick, 1994). One useful visual approach is to superimpose environmental data upon the output from station ordination or classification of biological data.

Field *et al*. (1982) describe a strategy for the multivariate analysis of marine biological survey data. Initial considerations include:

Data Transformation

Untransformed data may have the undesirable property of accentuating the influence of very abundant species. Transformations (*e.g.* $\log_{10}$) will have the effect of increasing equitability of the dataset. The square-root transformation has the advantage that, when similarity is assessed by the Bray-Curtis-measure (see below), the similarity coefficient is invariant to a scale change (*i.e*., it doesn't matter whether scores are expressed per cm^2 or m^2).

Similarity Measurement

The overall similarity between every pair of samples is expressed, taking all the species into consideration. Many options are available, and an example of a commonly-used index is the Bray-Curtis similarity measure (Bray and Curtis, 1957), which gives more weight to abundant species than to rare ones. Since there will frequently be a requirement for the analyses of presence/absence data from epibenthic surveys, then indices such as the Jaccard or Czekanowski coefficients will be appropriate (see Clarke and Gorley, 2001).

A5.5.1 Hierarchical classification

Hierarchical sorting strategies are used to produce a dendrogram from the similarity matrix. Again, many options are available, but one of the most commonly used methods in marine benthic studies is group-average sorting (Lance and Williams, 1967), which joins two groups of samples together at the average level of similarity between all members of one group and all members of the other.

Analysis of similarity ('ANOSIM': Clarke, 1993) can be conducted to test for statistically significant differences in assemblage structure between station groups identified from the dendrogram output. Additionally, it is important to establish which species contribute to observed differences in the data. This can be achieved by ranking species in terms of abundance or by examining the degree to which species contribute to measures of similarity/dissimilarity between individual samples or sample groups ('SIMPER': Clarke and Warwick, 1994).

TWINSPAN ('Two-Way INdicator SPecies Analysis') classifies species and samples to produce an ordered two-way table of their occurrence (Hill, 1979; a Windows version of the program is available at wintwins23.exe). The process of classification is hierarchical; samples are successively divided into categories, and species are then divided into categories on the basis of the sample classification. Species showing most difference in occurrence on the two sides (+ve and -ve) of each split are identified and termed Indicator Species. Examples of its application to benthic macrofaunal data include Künitzer *et al*. (1992) and Rachor *et al*. (2007).

A5.5.2 Non-parametric multi-dimensional-scaling ordination

In non-parametric multi-dimensional-scaling (MDS) ordination, an ordination of the n samples is produced in a specified number of dimensions. The identity of each species is retained and used integrally with, for example, abundance data to compare assemblages (Austen and Warwick, 1989). The purpose of the MDS is to construct a configuration ('map') of samples, which attempts to satisfy all the conditions imposed by the underlying similarity matrix. The distances between pairs of samples in the resulting plot reflect their relative dissimilarity in species composition.

Initially, the samples are placed in two-dimensional space at entirely arbitrary locations, and then their relative positions are gradually refined by an iterative analytical process. The intention is to move samples into positions in which the rank order of their distances from each other becomes ever closer to the rank order in the original similarity matrix. The extent to which the two disagree is reflected in the stress value (Clarke and Warwick, 1994). This coefficient indicates the degree to which the two-dimensional plot provides an acceptable summary of the multi-dimensional sample relationships. Stress values of < 0.05 indicate an excellent representation with no prospect of misinterpretation, whereas MDS plots with stress values > 0.3 should be

treated with caution as the points are close to being arbitrarily placed in the two-dimensional ordination space (Clarke and Warwick, 1994).

Analysis of similarity ('ANOSIM': Clarke, 1993) can be conducted to test for statistically significant differences in epibenthic assemblage structure between station groups identified from the MDS plots. Additionally, it is important to establish which species contribute to observed differences in the data. This can be achieved by ranking species in terms of abundance or by examining the degree to which species contribute to measures of similarity/dissimilarity between individual samples or sample groups ('SIMPER': Clarke and Warwick, 1994).

A5.5.3 Canonical correspondence analysis

Canonical correspondence analysis (CCA) is a canonical (or constrained) ordination technique using multivariate direct gradient analysis to determine relationships between biotic and environmental data (ter Braak 1986, 1987, 1994, 1996). It builds on the method of weighted averaging of indicator species and the ordination method of reciprocal averaging (Hill, 1973, 1974). Ordination axes are constrained to be linear combinations of the environmental variables used in the analysis and provide a simultaneous ordination of species, sites and environmental variables.

CCA is a reliable method of relating patterns in the biota to environmental factors, even when these are inter-correlated, by using forward selection of the environmental variables (Hill 1991, Palmer 1993). Monte Carlo permutation tests (Manly, 1990) are used to test the significance of each environmental variable. The variables can be further evaluated by examining intra-set correlations (*i.e.*, correlations between species axes and environmental variables). Detrended correspondence analysis (DCA), an unconstrained ordination technique, can be used to check whether the environmental variables are sufficient to account for the major patterns in the species variance. If the results of CCA and DCA do not correspond the environmental factors are irrelevant in explaining patterns in the biota.

CCA can be performed using the software package *CANOCO* (Canonical Community Ordination) which contains both linear and unimodal methods and integrates ordination with regression and permutation methodology (see ter Braak and Smilauer, 1998). The ordination methods include weighted averaging, reciprocal averaging/[multiple] correspondence analysis, DCA, CCA, principal components analysis (PCA) and redundancy analysis (the canonical form of PCA). Permutation methods are included for time series, line transect and rectangular grids and repeated measurement design, *e.g.* the Before-After-Control-Impact design (Stewart-Oaten *et al.*, 1986). A recent example of its application to benthic macrofaunal data from the North Sea in relation to the effects of commercial fishing activity can be found in Craeymeersch *et al*. (2007).

A5.6 Interpretation of the data

For the final stage in the interpretation of the results, knowledge of the biology of the various species (*e.g.* feeding habits, environmental preferences, functional significance) is required to assess whether variables which are empirically related to the species distributions might be causative factors. Thus, it is possible to assess which environmental factors, either natural or resulting from anthropogenic perturbations, are affecting the benthic environment and to what degree. This information may then be employed in a predictive manner to assess the likely consequences of any alterations in these factors in a given area.

A5.7 Data management

Standard procedures should be adopted for the recording and archiving of data, including all relevant information on field and laboratory practices. Species records should conform with established nomenclatural and coding systems (*e.g.* the Integrated Taxonomic Information System [ITIS]: www.itis.gov; the European Register of Marine Species: Costelloe *et al*., 2001, 2004; Howson and Picton, 1997). It is essential to ensure that adequate resources are provided for database construction and long-term management. Further information is given in Section 7.

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Annex 6: Approaches to epibenthos surveys using trawls: selected examples

A6.1 Eastern Bering Sea

Yeung and McConnaughey (2006) examined the invertebrate by-catch from otter trawls used in annual groundfish surveys across a systematic grid of stations in the eastern Bering Sea. Trawls were fitted with a 3.2 cm mesh cod-end liner and towed for 30 minutes at 3 knots, and the contents were identified, quantified and weighed. About 400 species were encountered across all surveys (1982-2002). A persistent feature was a division between inshore and offshore assemblages associated with a dynamic oceanographic front and a corresponding change in sediment type; the division was also evident in groundfish and infaunal survey data. Periodic reductions in the spatial extent of the inshore assemblage could be linked to higher-than-average mean bottom temperatures in the preceding summers, and may be explained by the effects on assemblage structure of the offshore migration of certain motile species to cooler waters. The biomass dominants were used in summary descriptions of assemblage types.

A6.2 Gulf of Carpentaria

Long *et al.* (1995) sampled the megabenthos of the Gulf of Carpentaria (Australia) using a 3 m beam trawl with a 30 mm mesh net bag, towed for 15 minutes at 6 $km.h^{-1}$. Wet weight biomass was determined for each species along with densities or colony numbers, and species were allocated to feeding types to aid interpretation. More than 840 species were identified from 107 stations located on a systematic grid. The data (including any infauna) were analysed using multivariate classification of presence/absence data, excluding species occurring at less than 2 stations. Two main communities were identified, corresponding with predominantly sandy or muddier substrata.

A6.3 Cantabrian Sea

Serrano *et al*. (2006) surveyed the epibenthos at 22 stations in the Cantabrian Sea with a 3.5 m beam trawl and a 9 mm mesh net, towed for 15 minutes (following ground contact) at 2.5 knots, giving a mean swept area of of *c*. 4,000 m^2. Sediment samples were collected with a box corer. Stations were allocated to three depth zones, spanning 30-400 m. 241 species were identified and the data were expressed as numbers per 1000 m^2. Cluster analysis of log-transformed data identified three main assemblage types. Multivariate analyses also identified gradients in depth/water temperature and sediment characteristics as significant influences on the distribution of assemblages, but correlations between univariate measures of the epibenthos and environmental factors were weak. Assemblage types were summarised according to the dominant species, depth, sediment type and organic matter content of sediments.

A6.4 North Sea

Jennings *et al*. (1999) used a heavy-duty 2 m beam trawl with a 4 mm mesh cod-end liner, towed for 5 minutes (from ground contact to the start of hauling) at 1 knot at 63 North Sea stations. (The device has since been used in two collaborative surveys of the North Sea epibenthos: see Callaway *et al*., 2002 and www.mafcons.org). Stations were randomly allocated within ICES rectangles. Samples were processed over 10 and 5 mm mesh sieves. Species were identified and counted at sea or in the laboratory; colonial species were recorded on a presence/absence basis. 334 species were

identified. Infaunal and fish species were excluded from multivariate data analysis, which was conducted separately for the attached (qualitative) and free-living (quantitative) component to identify any differences that might be attributable to the level of association with the seabed. Each identified three major groups, the dispositions of which were not identical but were consistent with a north/south division in the vicinity of the Dogger Bank. Influential environmental factors included depth, winter/summer temperature difference for both components and, for attached species only, winter temperature. Assemblages were summarised in terms of the species mainly accounting for similarities within station groups, and those accounting for most of the dissimilarity between groups.

A6.5 Northern North Sea

Basford *et al.* (1989) sampled the northern North Sea epifauna with a 2 m Agassiz trawl (final mesh opening of 20 mm), towed for 15-20 minutes at 1-2 knots. 196 taxa were identified from a systematic grid of 152 stations. From multivariate analyses of the species/abundance data with no exclusions (*i.*e., the data were not filtered for any infaunal species) they distinguished 4 major epifaunal groups and identified depth, particle size, sorting and organic content of sediments as the most important explanatory variables.

A6.6 Southern North Sea

Duineveld and van Noort (1990) sampled the epifauna of the southern North Sea with a 5.5 m beam trawl across a systematic grid of 58 stations, based on ICES rectangles. The trawl was fitted with a 10 mm stretched mesh cod-end, and towed for about 10 minutes at 3 knots. Fish were measured and weighed at sea, and the inveretebrate catch preserved for later laboratory analysis. Specimens were identified, counted and weighed (then converted to AFDW); all data were standardized to a surface area of 10,000 m^2. Infaunal taxa were excluded and the species/abundance data analysed using multivariate techniques, including and excluding demersal fish. Four main groups were identified, the most conspicuous change in species composition occurring along the northern edge of the Dogger Bank. Patterns were not closely related to sediment type or depth. Further discussion of the data appears in Duineveld *et al.* (1991).

A6.7 Southern North Sea, English Channel and western UK seas

Rees *et al*. (1999) sampled 69 UK coastal and offshore stations using a 2 beam trawl towed for 5-10 minutes (from ground contact to the start of hauling), at a speed of *c*. 0.5$m.s^{-1}$. Samples retained in a 3 mm mesh cod-end liner were sieved on a 5 mm mesh screen. The station grid combined stratified and random sampling schemes, and 414 taxa were identified at sea or during later laboratory analysis. From multivariate analyses of presence/absence data, the entire epifaunal component (*i.e*., after filtering out any infaunal or pelagic organisms) was classified into 8 assemblage types, the distributions of which were explained by sediment type, coastal influences, depth, tidal current velocity and temperature.

A6.8 Western UK seas

Ellis *et al.* (2000) examined the epibenthic by-catch from a groundfish survey of the Irish Sea, St George's Channel and Bristol Channel (UK), using a 4 beam trawl with a 40 mm stretched mesh cod-end, which was towed for 30 minutes at each of 101 stations. After removing fish and commercial shellfish, a representative sub-sample of known weight from the remaining invertebrate catch was selected for the identifica-

tion, enumeration and weighing of individual taxa; the latter two were then raised to numbers/weight per hour fished. Rocks and broken shells in the sub-sample were also weighed as an expression of the nature of the seabed sampled. Using multivariate analyses, 6 assemblages were identified and described according to the taxa mainly responsible for the differences. The distribution of epibenthic assemblages was mainly accounted for by depth, surface water temperature and substratum type. Distribution patterns were also similar to those for bottom sediments and the associated infauna determined from previous studies.

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Annex 7: Standard Operating Procedures: general guidance

Standard Operating Procedures (SOPs) are an integral part of any Quality Assurance programme and help to ensure that data collected by a laboratory are scientifically valid, comparable and adequate to meet the study objectives. An SOP is defined as "*a written procedure which describes how to perform certain routine laboratory tests or activities normally not specified in detail in study plans or test guidelines*" (Good Laboratory Practice Regulations, 1997). An absolute requirement that all laboratories carry out tasks in exactly the same way would be unrealistic, as procedures are often legitimately tailored to local circumstances (*e.g.* vessel size). However, where approaches differ between laboratories, it is essential to establish that these do not have adverse implications for the comparability of data. The following general guidance on the structure and content of an SOP is taken from Rees (2004).

A well-written SOP will help inexperienced members of staff in a laboratory to quickly develop expertise in a sampling or analytical area which is consistent with past practice at that laboratory, while being compatible with established approaches elsewhere. For those seeking laboratory accreditation, the production of SOPs will be essential as part of a wider QA package but, even for those who are not, they provide an important means to foster good practice internally. However, SOPs are clearly not, in themselves, guarantors of data quality.

SOPs should describe all steps performed in biological measurement. They should be established to cover the following areas of activity:

- station selection and location, navigational accuracy;
- handling, maintenance and calibration of field and laboratory equipment;
- handling and use of chemicals (i.e., fixatives, preservatives, reagents) used in marine environmental surveys;
- collection of biological material;
- storage of biological material including labelling and the checking of preservation status;
- distribution of biological material to external contractors/taxonomic specialists;
- analytical methods for biological material;
- identification of biological material including taxonomic expertise of the personnel;
- recording of biological and environmental data; data management;
- analysis of biological and environmental data;
- QA of report writing and documentation including signed protocols in all steps of analysis.

The preparation of SOPs to cover field and laboratory analytical activities is one of the most important practical steps that a laboratory/institute can take in seeking to improve the quality and consistency of its scientific products and is, therefore, to be strongly recommended. This having been done, interlaboratory comparisons of SOPs may then provide a useful tool in identifying any remaining inconsistencies, and hence in promoting harmonisation of methodology at a national and international level (see, for example, Cooper and Rees, 2002). Such periodic comparisons of SOPs are also to be strongly recommended. An encouraging example of international effort

to standardise approaches to sampling with a 2 m beam trawl is given in Section 2.1.1 (see also Callaway *et al*., 2002; Zuhlke *et al*., 2001). More detailed guidance on sample collection and processing is given in Sections 2-5, while advice on good practice in the use of imaging techniques is given at Annex 4. Such information provides a framework for the construction of SOPs to meet future project-specific needs.

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Annex 9: Assessment of changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature

Introduction

Request

The BEWG was requested to "complete the assessment of changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature". The assessment should look at ecologically indicative species, including the threatened and declining species identified by OSPAR, for which adequate time series exist, in order to assess to what extent there have been changes in distribution, population size and structure, and condition of species going beyond what might have been expected from natural.

Approach

In this report, we have started form the work done last year by the working group. The group further considered a draft version of the 2008 report of the Study Group on Working Hypotheses Regarding effects of Climate change (SGWRECC) and the 2008 report of the Working Group on Oceanic Hydrography.

The BEWG followed the lines of the SGWRECC and identified the major ways that benthic communities could be altered by the effects of climate change, reconsidering the SGWRECC's hypotheses. All hypotheses were put into a conceptual model. The BEWG further reviewed the compilation of long-term series of benthic fauna in the OSPAR regions. Finally, the group discussed topics for future research.

Hypotheses regarding effects of climate change

Climate change might influence fauna and flora in several ways (Figure A9.1). Temperature itself will influence the distribution of 'northern' and 'southern' species. Primary production is influenced by temperature and the direction and flow of marine currents (e.g. via the transport of nutrients). The amount of primary production reaching the benthic system strongly influences the trophic structure of the communities in question. Hydrodynamics (e.g. current velocities, stratification of water layers, wave climate) determine the transport of larvae and influence the sediment composition, which reflects food availability to the benthos. Thus, changes in both factors (temperature and hydrodynamics) will affect species composition directly or indirectly with regard to sediment preference and the trophic structure of the benthic communities.

The BEWG identified following specific hypotheses related to the effects on benthos (paragraph numbers of the hypotheses identified by the SGWRECC are given between brackets):

a) Poleward shifts in the latitudinal distributions of species, with consequent changes in species composition and species richness at any given location (SGWRECC 2.1)

b) Rising temperature could enable more human introduced species to invade and become established, replacing current native species (SGWRECC 2.2)

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 (SGWRECC 2.3). 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 (SGWRECC 2.8). 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 (SGWRECC 2.7) with consequences for the secondary production and biomass of the benthos (related to SGWRECC 2.4).

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 defenses (e.g. hard structures, islands, beach nourishment) (SGWRECC 2.6)

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 (SGWRECC 2.9) 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 (SGWRECC 2.10)

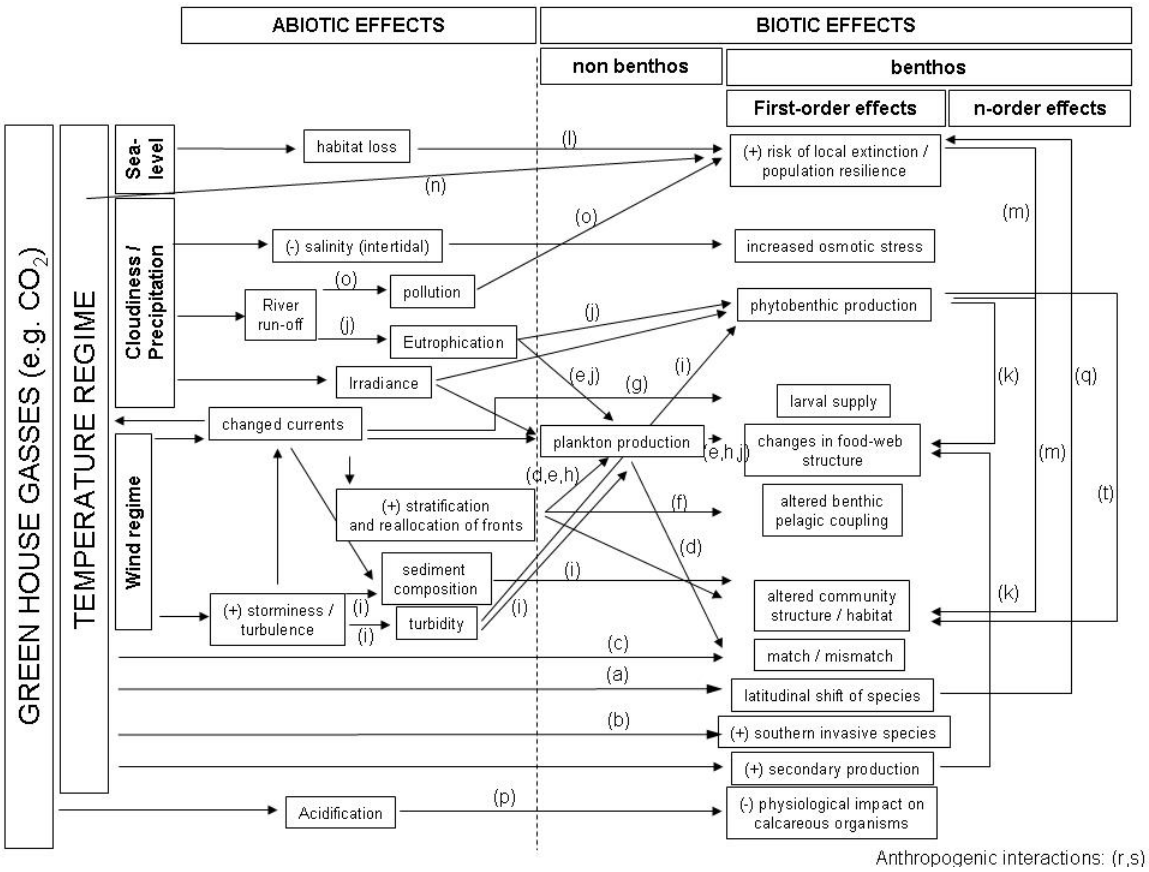
q) An increased distribution of parasites (such as trematodes) will lead to higher infection rates of benthic species with consequences on survival and reproduction.

r) Anthropogenic impacts such as fisheries and pollution may have decreased the resilience of certain benthic species to changing climatic conditions endangering their population.

s) 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.


ABIOTIC EFFECTS
BIOTIC EFFECTS
non benthos
benthos
First-order effects
n-order effects
GREEN HOUSE GASSES (e.g. CO_2)
TEMPERATURE REGIME
Sea-level
Cloudiness / Precipitation
Wind regime
habitat loss
(-) salinity (intertidal)
River run-off
pollution
Eutrophication
Irradiance
changed currents
(+) stratification and reallocation of fronts
sediment composition
(+) storminess / turbulence
turbidity
Acidification
plankton production
(+) risk of local extinction / population resilience
increased osmotic stress
phytobenthic production
larval supply
changes in food-web structure
altered benthic pelagic coupling
altered community structure / habitat
match / mismatch
latitudinal shift of species
(+) southern invasive species
(+) secondary production
(-) physiological impact on calcareous organisms
(l)
(n)
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Anthropogenic interactions: (r,s)

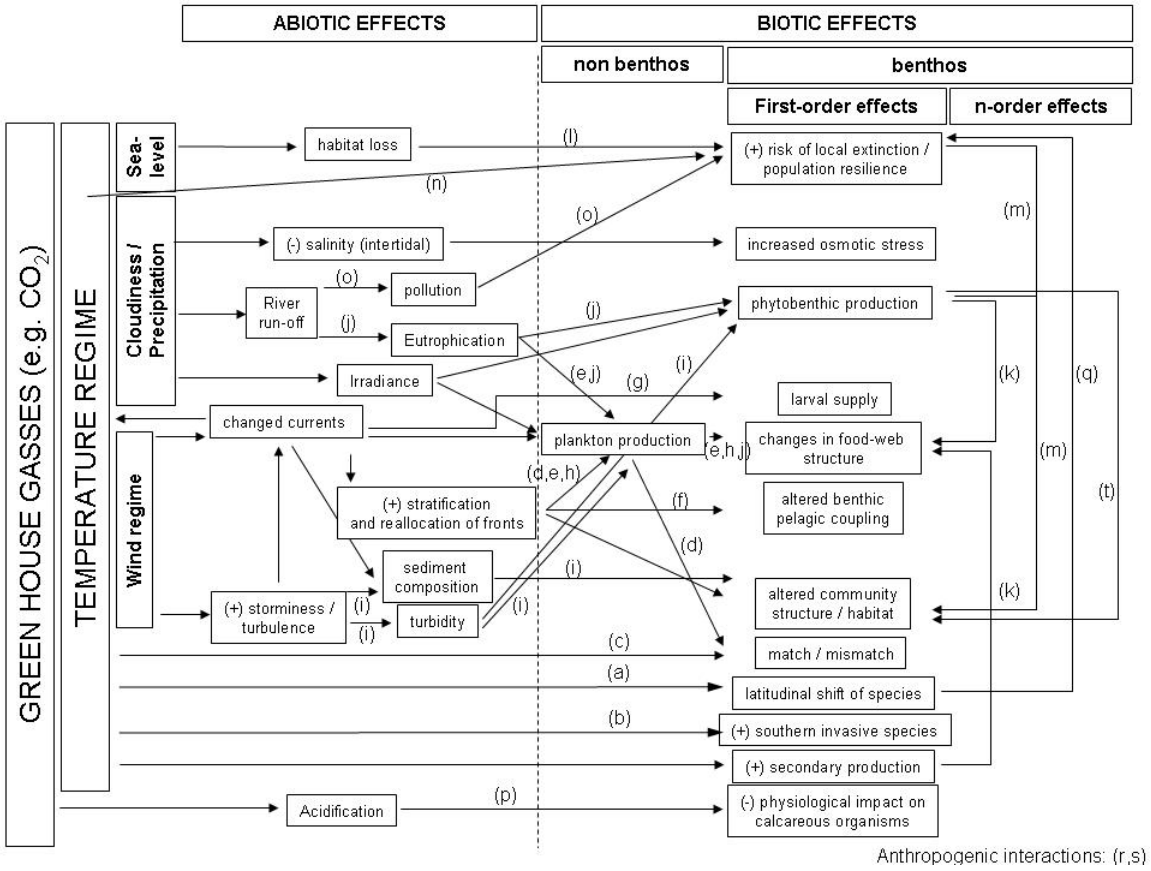

Figure 1. .Conceptual model of the links between climate change and benthic communities (hypotheses indicated by letter, see text).

Changes in benthos

Temperature

In this chapter we present a few studies available which refer directly to the influence of sea temperature on the benthos.

Well known is the structuring effect of winter temperatures on benthic communities living in relatively shallow waters. Fromentin & Ibanez (1994) showed that *Abra alba* communities in the Southern Bight responded to mild winters between 1977 and 1991 with maximum densities.

Short-term effects of cold winters on intertidal and shallow subtidal benthic communities include increased mortality among adults and increased recruitment success among e.g. bivalves (Ziegelmeier, 1970; Buchanan et al., 1978; Beukema, 1979; Schroeder, 2003; Essink et al., 2006; Reiss et al., 2006). Beukema (1990; 1992) and Bhaud et al. (1995) expected for the future a shift in species composition towards a more diverse, warmer water fauna also for the intertidal and shallow coastal waters, if the trend of increasing water temperature continues.

Also summer temperature has effects on benthic communities, through changes in species which may result in the creation of new habitats. In the Wadden Sea, the Pacific oyster (*Crassostrea gigas*) increased considerably in abundance after 2000, causing the partial disappearance of intertidal beds of *Mytilus edulis*, at the same time creating new oyster reefs with an approximately equally biodiverse accompanying fauna. This increase of the Pacific oyster correlates strongly with the occurrence of higher

than average water temperatures during July-August in these years, causing an increased settlement success of spat (Nehls and Büttger, 2007).

For the macrofauna off the Eastfrisian island of Norderney, Kröncke et al. (1998) found that abundance, species number and biomass in the 2nd quarter of the year are correlated with sea surface temperature (SST). The SST is the mediator between the benthos and the NAO in late winter and early spring. The results indicate that macrofaunal communities were severely influenced by cold winters, whereas storms and hot summers have no impact to the communities. It appears that mild meteorological conditions, probably acting in conjunction with eutrophication, resulted in an increase, especially of the total biomass, since 1989.

On a North Sea wide scale some shifts in the distribution patterns of species have been described (NSBP, chapters 5.2 and 5.3). In the German Bight, examples are shifts in the distribution of the brittle star *Amphiura brachiata* and of the bivalve *Nucula nucleus*, as well as shifts in community boundaries especially of the mud-inhabiting *Nucula nitidosa* community. In the Dutch coastal waters such change in distribution have been reported for e.g. dog whelks (Craeymeersch and Rietveld, 2005). These shifts can be understood as consequences of warming and of changes in circulation and eutrophication patterns (e.g. Rehm and Rachor, 2007). A general increase of warm-temperate species in the southern North Sea is evident, e.g. the amphipod *Megaluropus agilis* and *Amphiura brachiata* on the Dogger Bank, whereas cold-temperate species decreased in abundance such as the polychaete *Ophelia borealis* (Wieking and Kröncke, 2001).

A shift in the climate of the North Sea towards more oceanic conditions is regarded an important factor explaining long-term trends and drastic changes in the macrofauna of hard-bottom areas around Helgoland (Franke and Gutow, 2004). Many of the recent records of new warm-temperate species of southern origin indicate a continued warming since the 1980s.

Alcock (2003) studied the distribution of many benthic species, including macroalgae, molluscs and arthropods, along the Bay of Biscay, between the end of 19th century and 2000-2001. He determined some northward and southward shifts, depending on the occurrence of warm and cool periods during the 20th century. Taking into account this development and the IPCC scenarios of temperature increase for next 50 years, Alcock (2003) modelled the future shift of some benthic species in the Bay of Biscay, North Sea, and Norwegian Sea. These scenarios should be taken into account in future monitoring programmes in order to check the northward shift of the geographic range of benthic species due to climate change.

In temperate marine environments the recruitment success of higher trophic levels is highly dependent on synchronization with pulsed planktonic production (Stenseth et al. 2002, Edwards & Richardson 2004). If climate change results in an advancement in the timing of reproduction, this might lead to a mismatch between spawning and phytoplankton bloom. Philippart et al (2003) hypothesized that the decrease of the stock of *M. balthica* was very likely at least partly governed by a mismatch between the spawning and the phytoplankton spring bloom. In addition, mild winters advance the onset of the crustacean reproduction resulting arrowing the time gap between spawning of *Macoma* and predation by newborn shrimps.

This mismatch in the timing between different levels in the food might become true for much more species. One of the consequences is a mismatch in the timing between different levels in the food web because many key processes in ecosystems depend on a tight temporal and spatial coupling (Adrian et al. 2005).

Looking beyond the OSPAR regions, Oviatt (2004) also described a variety of temperature-mediated changes in coastal biota of NW Atlantic waters associated with the occurrence of persistently positive values of the NAO Index in the 1980s and 1990s.

Wind and currents

Large-scale hydrodynamic changes were found for the North Sea. Oceanographic models by Siegismund (2001) and Siegismund and Schrum (2001) showed differences in the water current regimes of the North Sea between the 1980s and 1990s caused by increasing inflow of Atlantic water masses mainly through the Fair Isle Current as a result of stronger south-westerly winds. Hydrographic changes in the Baltic are to a large extent related to variability of inflow of North Sea water masses through the Danish Straits (e.g. Hänninen et al., 2000).

The variable inflow of Atlantic water into the North Sea influenced plankton and fish (Ehrich and Stransky, 2001; Reid and Edwards, 2001; Reid et al., 2003). For the benthos however, only little information is available. This information consists mainly of an inferred causal relationship between the benthos and NAO driven hydrodynamics.

Witbaard (1996) assumed that the variations in the ESAI (East Shetland Atlantic Inflow) and the Dooley Current influenced the strength of the eddy system over the Fladen Ground and consequently the accumulation of food material causing growth variations in the bivalve *Arctica islandica*.

Hagberg et al. (2004) suggests a possible relationship between the NAO and the benthos off Northumberland due to the strong connections between the inflow of North Atlantic water to the North Sea and the NAO.

Wieking & Kröncke (2001) found that the benthic communities along the northern slope of the Dogger Bank were strongly influenced by increasing wind stress and stronger currents at the northern slope of the Dogger Bank in the 1990s as compared to the 1980s. During the 1990s, these wind and current conditions were caused the positive NAO index prevailing in that period (Siegismund, 2001; Siegismund and Schrum, 2001). Changes in larval supply, food availability and sediment composition caused by resuspension of fine material lead to a decrease in species occurring on fine sand (e.g. *Ophelia borealis*) as compared to the 1980s, whereas abundances and total number of species preferring coarser sediment (e.g. *Echinocyamus pusillus*) increased in the 1990s.

In the Bay of Biscay, Borja et al. (2006) found strong relationships between wave energy and biomass, abundance and cover of *Pollicipes pollicipes* in hard-bottom communities Consequently, increasing NAOI values (as predicted by Cook et al. (2005) for the next 50 years), could lead to an increase of northwesterly wind circulation over the area, and to an increase of wave energy (as predicted by several models for the area). This can lead to an increase of *Pollicipes* biomass.

Laine et al. (1997), like many others, describe effects on the benthos in the Baltic Sea. Here variations in North Sea water inflow influence the oxygen concentration in deep waters of the basins and thus the benthos.

Sea-level rice

The construction of coastal defenses will result in changes in the coastal habitat and in the hydrodynamics of the inshore waters. The direct and indirect effect on the benthic communities of such large-scale works have been studied in the past by e.g..

Nienhuis and Smaal (1994), describing the impacts of these works in de south-west Netherlands.

Precipitation

Changes in the precipitation might have effects on the benthos in different ways: differences in the distribution of suspended particulate matter (van Raaphorst et al, 1998), changes in the salinity variability (Heyen and Dippner, 1998), changes in nutrient run-off (Prena et al, 1997). Less saline, warmer and thicker surface layer of low-density water inside and outside estuaries/fjords can hamper density driven renewal of bottom water. This will increase the risk of hypoxia events in estuaries rich in organic matter and thus threaten benthos. Observed effects on the benthos are scarce. Prena et al (1997) describe the possible impact of enhanced nitrogen discharge and water stratification on teh recruitment of the benthos in the Baltic Schroeder (2003) found a significant negative correlation between the number of species present with the annual and winter NAO index of the previous year and the Elbe-river run-off with a two-year time lag.

Acidification

The most common cold water reef forming coral *Lophelia pertusa* is known to occur in water with temperatures between mainly between 4 and 12 degrees (Frederiksen et al, 1992). Changing climate will likely also affect the deep sea with changed temperatures and alkalinity. Temperature changes may be caused by warming of water masses or changes in currents systems, but the effect will still the same. If the changes occur at a slow pace, at the scale of centuries, the coral may be able to move its distribution boundaries, but with faster changes the distances needed for larval transport may exceed its dispersal abilities. However, the larval transport range is only known indirectly from interpretation of distribution patterns.

The effect of ocean acidification has been documented in lab experiments for warm water corals (Kleypas, open ref). With increased pH of the sea water carbonate precipitation will be severely hampered. As a result of transport of CO2-enhanced sea water to greater depths, the deep sea will be influenced by anthropogenic emissions. Reduced carbonate precipitation will first lead to weakened skeletons in marine organisms such as cold water corals, later probably to a large-scale population collapse. According to models (ref to come) the Northeast Atlantic is especially susceptible to the acidification of the sea.

NAO Index

Many recent studies on changes in the benthic system in the North East Atlantic describe large scale climatic variability by means of the NAO Index (Drinkwater et al., 2003). The North Atlantic Oscillation (NAO) strongly influences the weather in northern Europe especially in winter. Positive values of the winter-NAOI are associated with westerly weather and thus a stronger oceanic influence and mild winters (Hurrell 1995) and an increasing frequency of strong winds observed in the German Bight (Schroeder 2003). Negative NAOI values are associated with easterly weather, which results in a continental influence on northern Europe and, consequently, often cold winters (Hurrell 1995).

Significant correlations between NAO Index and changes in abundance and biomass were found in the western North Sea (Rees et al. 2006), in the Skagerrak (Tunberg & Nelson 1998), the western Baltic (Gröger and Rumohr, 2006), at the Dogger Bank

(Wieking and Kröncke, 2001), and in the German Bight (Kröncke et al., 1998; Schroeder, 2003), in all cases with a time lag from months to years.

From these studies we know that in general a negative NAO Index is associated with lower than average abundance and biomass, while a positive NAO Index is often associated with higher than average values. According to recent insights the NAO Index shows a long-term increasing trend, however, with internal oscillations. This increasing trend would therefore mean increasing trends in abundance, species number and biomass of benthos. In specific areas deviations from general "rule" may occur due to specific local forcing (e.g. Tunberg and Nelson, 1998).

For example, in the south of the Bay of Biscay, high values of the NAO Index coincide with lower benthic diversity, and negative values coincide with high diversity values (Borja, pers. communication).

Indirect effects: changed interactions with other anthropogenic actions (e.g. fisheries). .. changing vulnerability of species to anthropogenic effects e.g. *Ostrea edulis*. Populations too low …. Higher risk for extinction.

Long-term time series of benthic fauna

A compilation (not necessarily complete) of long-term studies in the OSPAR regions made by the BEWG during their 2007 meeting is presented in Table 1. As can be seen from this table there is a focus of relevant studies on region II (North Sea). Therefore, our main discussion will refer to studies of this region. For further details see NSBP (Rees et al 2007).

Table 1. Compilation of metadata of long-term series and long-term comparisons of benthic fauna in the OSPAR regions.

SOFT-BOTTOM INFAUNA			
SEA AREA	OSPAR REGION	TIME SCALE	REFERENCES
Van Mijenfjord (Svalbard)	I	1980, 2000–present	--
Svalbard fjords	I	1990s–present	--
western Barents Sea	I	1980, 1992, 2005	--
German Bight (Ziegelmeier)	II	1950s–1970	(Ziegelmeier, 1978)
Dogger Bank	II	1951–52, 1985–87, 1996–98	(Wieking and Kröncke, 2001)
German Bight (AWI)	II	1965–present	(Schroeder, 2003)
Skaggerak	II	1970–1998	--
NOR oil platform monitoring	II	1973–present	--
off Northumberland	II	1971–present	(e.g. Frid et al., 1996)
UK oil platform monitoring	II	1977–1998	--
off Norderney (Senckenberg)	II	1978–present	(Kröncke et al., 2001)
Norderney (Niedersachsen)	II	1976–1999	--
Northern North Sea	II	1981–1986	--
Dutch oil platform monitoring	II	1985–1993	(Daan and Mulder, 1995)
German inshore monitoring	II	1987–present	--
North Sea (NSBS, NSBP)	II	1986, 2000	(e.g. Rees et al., 2007)
Danish monitoring program	II	1989–1999	--
Dutch monitoring North Sea (BIOMON)	II	1991–present	(e.g. Daan and Mulder, 2001)
Dutch Continental Shelf (MILZON)	II	1988–1993	(Holtmann & Groenewold, 1994)
Shellfish monitoring North Sea	II	1995–present	(Craeymeersch and Perdon, 2004)
Shellfish monitoring Waddensea	II	1991–present	(Craeymeersch and van Stralen, 2004)
Gullmarsfjord	II	1983– ?	--
Dutch monitoring Waddensea	II	1980s–present	(e.g. Dekker and de Bruin, 2001)
Danish monitoring Skagerrak	II	? –2004	(Ærtebjerg et al., 1998)
German Bight Transect	II	1990–present	(Kröncke and Rachor, 1992)
Creutzberg Dutch North Sea sampling (NIOZ)	II	>1970	(Creutzberg et al., 1984)
German Bight (GB), surveys	II	1923, 1965, 1975, 2000	(Rachor and Nehmer, 2003)
GB Borkum Riffgrund	II	1967–72, 1996, 1999	(Rachor and Nehmer, 2003)
Belgian Continental Shelf	II	1979–present	--
Disposal Sites, Northumberland (UK)	II	1984–present	(Rees et al., 2003)
Disposal Sites, Thames (UK)	II	1985–present	--

Table 1. continued.

SOFT-BOTTOM EPIFAUNA			
SEA AREA	**OSPAR REGION**	**TIME SCALE**	**REFERENCES**
UK National Marine Monitoring Programme	II	1995–present	(Anonymous, 2004)
La Coruna Bay, NW Spain	IV	1982–present	(López-Jamar et al., 1995)
Bay of Biscay (Basque coast, Nervion estuary)	IV	1989–present	(Borja et al., 2006)
Bay of Biscay (Basque coast and estuaries)	IV	1995–present	(Borja et al., 2004)
van Mijenfjord	I	1980, 2000–present	-
Svalbard fjords	I	1990s–present	-
western Barents Sea	I	1980, 1992, 2005	-
Shellfish monitoring North Sea	II	1995–present	(Craeymeersch and Perdon, 2004)
Shellfish montoring Waddensea	II	1991–present	(Craeymeersch and van Stralen, 2004)
MAFF	II	1980–1986	--
NSBS	II	1986	(Duineveld et al., 1991)
ZISCH	II	1987–1988	--
EU (Biodiversity, MAFCONS)	II	1986–present	(Zühlke et al., 2001)
Epibenthos (GSBTS)	II	1998–present	(Ehrich et al., 2007)
Creutzberg's trawl surveys North Sea	II	1970s–1980	(Creutzberg, 1979)
German Bight, Epi AWI, incl. Stones	II	1999–present	(Rachor and Nehmer, 2003)
Belgian Continental Shelf	II	1979–present	--
Hard-bottom epifauna			
Svalbard fjords	I	1980s–2006	--
South-West Netherlands	II	1985–2004	--
Helgoland	II	1987–1991, 2000 - 2004	--
Danish monitoring on stone reefs	II	1990–2004	--
Helgoland (BAH-AWI)	II	last 150 years	(Franke and Gutow, 2004)

Recommended topics for future research

The BEWG acknowledge the fact that all the hypotheses above are relevant, though not all hypotheses are equally feasible to tackle and of equal relevance within an ecosystem approach framework. A prioritization of the hypotheses is thus considered necessary. Given the expertise available at the 2008 meeting, the group suggest to give high priority to the following hypotheses:

- Poleward shifts in the latitudinal distributions of species, with consequent changes in species composition and species richness at any given location (SGWRECC 2.1)
- 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.
- Changing wind directions may lead to changing local surface currents resulting in changes in larval transport and, thus, species distribution.
- Changes in the production and biomass of benthic species will have implications for the food web dynamics.
- Community changes including habitat forming species, both phyto- and zoobenthic, will result in altered habitats.
- Anthropogenic impacts such as fisheries and pollution may have decreased the resilience of certain benthic species to changing climatic conditions endangering their population.

A strategy forward to address the hypotheses is to select model entities (species, functional groups,….) to be studied. The choice should be based on:

- life-history traits;
- autecological characteristics;
- biogeographical spread;
- physiological tolerances;
- ecological function;
- vulnerability to other anthropogenic impacts.

The BEWG considered it worthwhile taking into account the benthos species in the OSPAR 2004 Initial List of Threatened and/or Declining Species and Habitats as a starting point. Following remarks can be made:

- *Arctica islandica* – This is a northern-temperate species. A further decrease of this species is to be expected in the North Sea as the trend of increasing sea temperature continues;
- *Ostrea edulis* – There are no clear indications that the poor status of this bivalve species along the eastern coast of the North Sea has been caused by changes in temperature;
- *Nucella lapillus* – The condition of populations of this gastropod is influenced by certain polluting substances rather than by hydrodynamics or temperature. In the Basque coast, however, the species has disappeared since 1982, due to increasing temperatures;
- *Modiolus modiolus* beds – These habitats represent a poor status since long. No causal relationships with changes in hydrodynamics or temperature are known,

- Intertidal *Mytilus edulis* beds – Data from the Wadden Sea show that part of these beds may be taken over by the invasive Pacific oyster *Crassostrea gigas*. On the other hand, however, beds of the Pacific oyster also provide adequate substrate for settlement of new *Mytilus edulis* (Nehls and Büttger, 2007);
- Sea-pen and burrowing fauna communities – as sea-pens are cold-temperate species, a future decrease of his species and accompanying change in this community can be foreseen when sea temperature continues to increase.

Other aspects that could be taken into account to increase feasibility to tackle the hypotheses are e.g. data availability and the possibility to collect the necessary data:

- baseline data such as long-term series (listed in table 1),
- phenological database (to our knowledge presently not existing for the marine environment),
- relevant hydrographic data (see e.g. report of ICES Working Group on Oceanic Hydrography)
- data on co-variates such as fishery effort and nutrient concentrations to enable disentangling anthropogenic and climate effects.

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Annex 10: Draft guidelines on phytobenthos

Draft ver.8/5 2008

DRAFT

The importance of the phytobenthic plant and animal communities to marine ecosystems and their scientific study

Contents

- Background
- Definition
  - Importance of phytobenthic system as a boundary land - sea
  - Environmental hazards

Coupling to ICES Habitat group, UK SAC, water frame work, EUNIS, etc.

General aspects - Methods

- -- Divers investigations
- -- Photographic frames
- -- Video transects
- -- remote methods
  - video hangers, sledges
  - ROV
  - areal photography, satellite

Recommendation of methods

- description in detail of few, possible approaches for monitoring and habitat mappimg

Appendix

1) EUNIS classification definitions
2) Methods presently used in the
   - Baltic Sea region
   - North Atlantic and North Sea
   - Mediterranean Sea
   - other areas
3) Swedish method of transect estimates along corridors

The immediate future work on the guideline will be to compile and review the literature on methods used to describe the plant and animal communities. The literature list will be distribution among the members of the subgroup to add relevant references.

Background

The prime target audience will be those who want to start a monitoring programme and are working in connection with e.g. the Water Frame Work Directive. Depending of the objective, suggestions will be given of appropriate techniques and what should be included.

The guidelines will deal with diving techniques and visual methods investigating the (macroscopic) plant and animal communities of the tidal and subtidal zone on hard to soft substrates down to 30 m depth. The lower limit is not fixed but should be within the limits of safe diving and to some extent coincide with the lower limit of macroscopic, non-crustose plants.

In this paper the emphasis will be on divers methods to survey and monitor the phytobenthic plant and animal communities. Depending on the scope of the investigation, different methods will be appropriate. Therefore, the methods used in different countries will briefly be reviewed, where their advantage and shortcuts are discussed. A recommendation of a method in common for the ICES-waters will be given. It is mainly based on the Swedish monitoring programme running since 1993, is in accordance with HELCOM recommendations and included in the new ISO-19493:2007 -standards and OSPAR-JAMP guidelines. This method, and variations of it, is used by several countries in the area. The report will also discuss the use of video technique as replacement of divers when, e.g. large areas are to be covered and/or the distribution of few, conspicuous species is investigated. Other methods performed in different parts of the world and relevant for the survey and monitoring of the phytobenthos will briefly be mentioned and literature will be cited where also more detailed descriptions are given.

We are aware of each question has its relevant approach but here we will emphasise the importance of the key features of species depth distribution and coverage. Most of the methods used in the world today have these features in common.

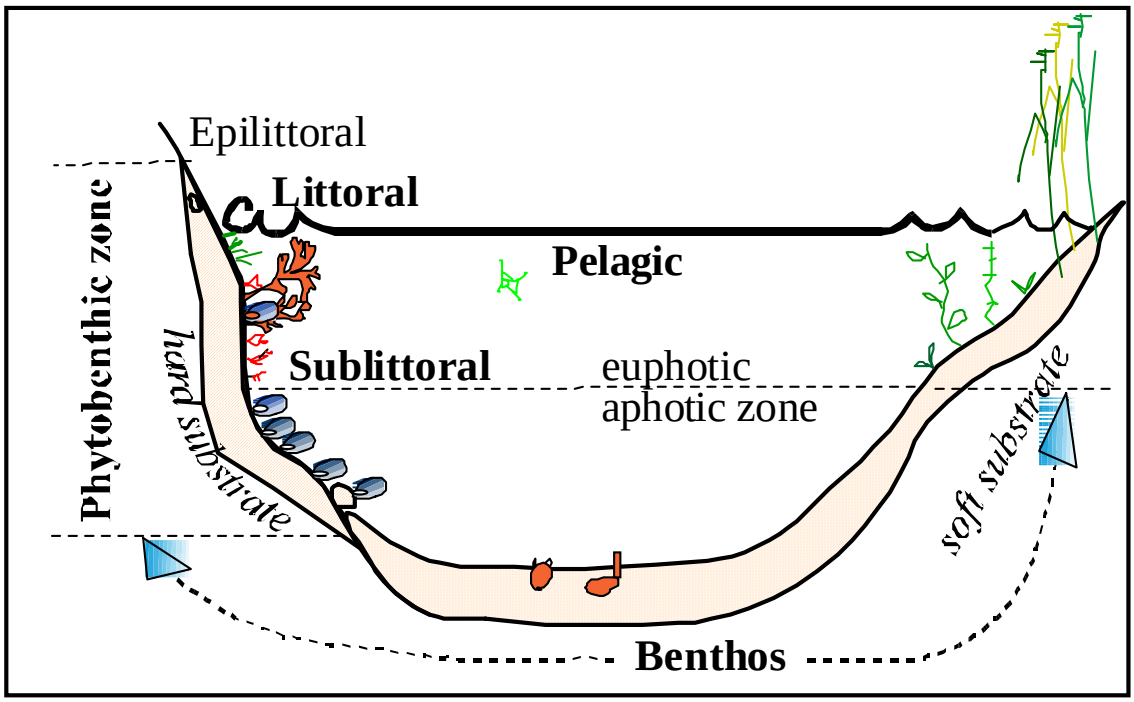
The purpose with the methods described will be to give describe species composition, their depth distribution, coverage of the substrate and biomass.

In the context of the Water Framework Directive, the attached phytobenthic plants are included. Mainly, the depth distribution of plants is used, but also species composition along a horizontal or vertical gradient.

Definition

Definition of the area of work

In this paper we have defined the phytobenthic communities as the vegetation covered substrates of the euphotic zone. It includes all types of substrates from hard, over sand and mixed, to soft. In the Baltic Sea we also include the hard substrates below the euphotic zone which usually have extensive growth of *Mytilus edulis*. The lower limit is set to 30 m depth. Thereafter, usually only few plants remain but also the divers method is not operative below this depth without practicing more extensive safety precautions.



EUNIS Habitat classification

In classical literature the phytobenthic zone has obtained different names of the different, for the author relevant subdivisions (see, e.g. the classical works of Lewis 1961, 1964,, Stephensson and Stephenson 1972, Lüning 1985, Schwenke 1974 etc.) The definition of the relevant zones is somewhat different and some are given in the **appendix 1**. The simplest and perhaps the most relevant subdivision is the separation of intertidal and subtidal zone as used in most American literature. The EUNIS classification system ((mrw.wallonie.be/dgrne/sibw/EUNIS/home.html) defines the phytobenthic communities to be included in the littoral including the supra- and eulittoral and sublittoral including the infra-and circalittoral zone. However, in our case the maximum depth is restricted to 30 m due to SCUBA-divers security reasons. A EUNIS classification system relevant for the Baltic Sea area is under development.

The importance of the phytobenthic communities

The coastal phytobenthic systems are key areas for several ecological functions and for goods and services. They belong to the most species rich marine habitats found on earth, they form, a buffer between ocean and land, the seascape, providing food and shelter as well as serving as a giant filter for the land runoff binding nutrients and pollutants in the biota body tissues.

The natural phytobenthic communities are considered to be the most species rich areas of temperate waters. The plant communities provide a three-dimensional habitat and secondary hard substrate to serve as habitats to a wide range of plant and animal species.

The phytobenthic communities provide the human society with a large number of goods and services (Rönnbäck *et al*., 2007), e.g. functions as a gigantic filter of coastal nutrient release manifested in increased growth of filamentous and foliouse algae observed in eutrophicated areas and outside point sources of nutrient release. They stabilize the shoreline. They are the source as well as harbour species for consump-

tion and facilitate the survival of juvenile fish of commercial importance, etc. The phytobenthic plant and animal communities form a link between the land and the open and deeper oceanic ecosystems being the first ecosystem to receive the land runoff. The drifting, loose algae (and higher plants) serve as food resource for the deeper benthic communities, or when drifted ashore, were/are used as fertilizer.

The shallow phytobenthic community serves as a base for commercially important fish that spawn and breed among the algae and find food and shelter within the plant belts (e.g.Anderson, 1994, Aneer, 1985, Aneer and Nellbring 1982, Aneer, et al. 1985, Jansson, 1985, Pihl, et al. 1994, Rangeley and Kramer, 1995, Robertson, 1984). There is commercial harvest and exploitation of algal products for e.g. agar production, but also for consumption (est Ltv ref, Norway Europe). Unpolluted phytobenthic communities have recreational values. They provide living space for rare and endangered species.

Historically, the disappearance of the *Zostera marina* communities in the northern European waters in the 1920s pin-pointed to the physical importance of these plant communities as a coastal zone erosion protection (e.g. Boström, and Bonsdorff 2000; Duarte, 1995; Greve, and Krause-Jensen, 2005; Borum *et al*., 2004; Möller and Martin 2007). This is also documented in the Mediterranean Posidonia meadows.

The species richness of the phytobenthic community provides a battery of both plant and animal species sensitive to different pollutants and/or eutrophication. As many of the species included in a monitoring programme of the phytobenthic communities are attached and perennial they integrate the environmental load over a longer time. In combination with the relative easiness to observe the communities, they are an important indicator of the quality of the water body and are therefore included, e.g. in the WFD (Selig *et al*. 2006) and are used in several national monitoring programmes following the effects of eutrophication (e.g. Kruse-Jensen *et al*. 2008). Observations can also be done with longer time intervals to detect change which makes the study of these communities cost efficient.

The microphytobenthos

The microphytobenthos can be of major importance for the phytobenhtic ecosystem production, especially on shallow, sandy substrates and intertidal watt areas and, e.g. the impoverished Bothnian Bay. The techniques for sampling these communities is however not included here.

The sensitivity

The large number of species provide a battery of more or less sensitive species (indicating species) to eutrophication, pollutants physical disturbance etc., which help to understand the ecosystem response in e.g. monitoring programmes and provide criteria for water body classifications, as done in the WFD.

Environmental hazards

The most common chronic stress factor along our coasts is the eutrophication caused by sewage outlets, leakage from agriculture and forestry via rivers etc... Locally, also aquaculture may contribute substantial amounts of nutrients to the environment, depending of the species cultured. Also the areal deposits caused by e.g. traffic are substantial. On a local basis, various industries are the main cause for change of the phytobenthic communities, where usually both eutrophication and pollution have a negative effect on the composition of the species and/or for the especially sensitive

species. A spectacular, and in the media well described pollution comes from major oil spills and other single events. Usually, those have only a local and short time effect on the natural communities,. However, the chronic pollutants and eutrophication usually are higher per year and may permanently alter the species composition and community function. Many monitoring programmes follow the change of eutrophication. Some map the effect of local pollutants. The effect of spectacular events is often investigated during a short time after the exposure to follow the recovery.

Standards

There are a few recommendations and standards of what a phytobenthic survey should include. For the Baltic Sea area HELCOM Guidelines for monitoring of phytobenthic plant and animal communities in the Baltic Sea Annex for HELCOM COMBINE programme 26 March 1999 compiled by Sara Bäck http://www.helcom.fi/stc/files/CombineManual/PartC/AnnexC9.pdf), the new ISO-standard ISO-19493:2007 Water quality –Guidance on marine biological surveys on hard-substrate communities and e.g. OSPAR documents on quality assurance.

Method descriptions

Several good summaries of methods relevant for the phytobenthic communities are found in e.g. Eleftheriou and McIntyre (eds) 2005. Methods for Marine Benthos (3d ed.), UK, JNCC Marine SACs project Marine Monitoring Handbook, march 2001. http://www.jncc.gov.uk/page-2430 and Hiscock 1998 Biological monitoring of marine Special Areas of Conservation: a review of methods for detecting change. (JNCC Report No. 284) http://www.jncc.gov.uk/page-3817, **JAMP Eutrophication Monitoring Guidelines** www.ospar.org/documents/dbase/decrecs/agreements/97-02e.doc , **Borum**, J., CM **Duarte**, D Krause-Jensen and TM Greve. 2004. European **seagrasses**: an introduction to **monitoring** and management. The M&MS project, Copenhagenhttp www.seagrasses.org/ (EU-seagrass project http://www.seagrasses.org/handbook/european_seagrasses_high.pdf

General

General descriprions and "cook books" are found under the web-references listed below, where the JNCC handbook s are the most comprehensive.

http://www.ospar.org/,

http://www.jncc.gov.uk/marine/mmh/Contents.htm

(http://www.jncc.gov.uk/marine/default.htm)

http://www.biomareweb.org/

A matter of scale

Depending on the question asked, the collection of data is a matter of scale. It goes from remote over direct observations to sample collection and analysis. All methods have their advantage and disadvantage and may be appropriate within a given context. There is a trade-off between the large-scale picture and detailed descriptions, between cost and benefit. Some methods are good compromises and are applicable in various concepts within the dynamics of the phytobenthic plant and animal communities. The more generally usable methods will be discussed in more detail below.

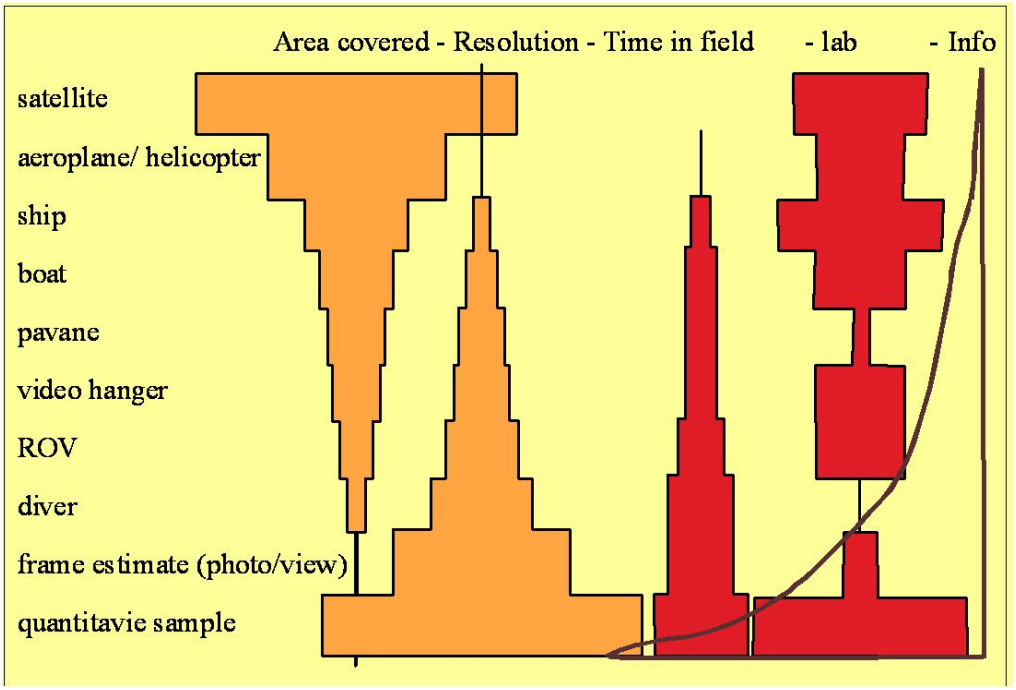


Figure 2.

If we look at the scale there is a trade-off between the area covered and the information gained usually also coupled to the time spent in field and laboratory. Satellite data cover the broadest area but usually with little information and low resolution (pixel sizes of 50x50 m and in special cases down to 20x20 m) which is necessary to be able to handle and process the data information. Usually, all time is spent interpreting the data signal and no time in field. Areal photography can only cover limited regions – usually a picture covers more or less 500 x500 m area. However, the resolution is much higher than the satellite picture and objects down to few dm can be observed. It is a visual method where the shape of the studied objects is seen and therefore less time is spent for the interpretation of data in lab. A new technique is under development using air born laser techniques for the bathymetry, e.g. down to approximately 20 m depth in the Baltic Sea region (is dependent on the turbidity of the water). It can thus be used to produce charts of high resolution which is necessary for efficient planning of surveys etc. and modelling of results. The next step in laser technology will be to identify species and thus be able to map the different belts areal and depth extension. Every species has a unique reflection of the laser light, which today is used in mapping of land living plant populations. The identification of species is limited by the turbidity of the water (can be applied down to ca 1.5 times the Secchi depth). Ship born registration tools usually are not limited by depth (e.g. echo

sounder and sonar) or may operate within the phytobenthic zone without problems (video hanger and ROV). Depending on the method used there will be a trade off between resolution (information obtained) and the area covered. The non-visual methods require longer time in lab for the interpretation of data signals. There is an increase in information gained on the cost of area covered when going from video hanger to ROV and end with divers observations. The highest resolution and information is gained by quantitative sampling either by frame pictures or destructive sampling. Destructive sampling is by far the most costly method as it requires tedious sorting in lab.

Table 1

Relevant methods for the study of phytobenthic communities

- Satellite
- Areal photograph (true colour, filtered etc)
- From ship
  - Echo-sounder, side scan sonar
  - Videohanger
  - ROV
- From boat
  - Aquascope
  - (videohanger)
  - pavane
- Walking (intertidal, shallow water)
- Diver
  - transects
  - frames
  - destructive sampling

Satellite

Satellite is mostly used to monitor pelagic production. The technique may have a potential in phytobenthic communities but development of methods (signal - interpretation) are needed. Also, routines have to be developed to handle the immense amounts of data with reasonably high resolution (1x1m to 10x10m grids). Another major drawback is that the obtained pictures cannot see deeper down than few m into the water column (in temperate waters). Also, atmospheric disturbances (clouds etc) limits the number of usable images to a few per year in many regions. Data from satellites can show the water turbidity, major outflows from land and thus provide with essential data for the interpretation of results from phytobenthic studies especially when large scale models are used. All satellite data needs ground proofing.

Areal photography

Relatively large areas can be covered by areal photography. The pictures often allow observations down to about 3 m depth in Nordic waters, but in clear water areas (e.g. Mediterranean, tropical areas) it can be used to map vast areas down to several m depth the resolution is in general high (>0.1 m) at least close to the surface under ideal conditions. However, the method is weather dependent (cannot fly when cloudy, and/or windy) as it should not be cloudy, the sun has to be in the right angle not throwing reflections from the water surface into the camera and no waves should blur the picture. The method is limited in depth usually does not give information of communities deeper than 3 m depth. The images need ground proofing for the interpretation of the observed structures.

Areal photograph has successfully been applied in mapping reed belts (Finland), shallow bays , shallow e.g. *Zostera*- and *Fucus*- communities (Swedish West coast, locally on the east coast), in mapping *Posidonia* meadows, the intertidal Watt area Northern Germany and mapping coral reef extension etc.

A relatively new, potentially highly interesting method using laser techniques for the bathymetry and identification of species is under development

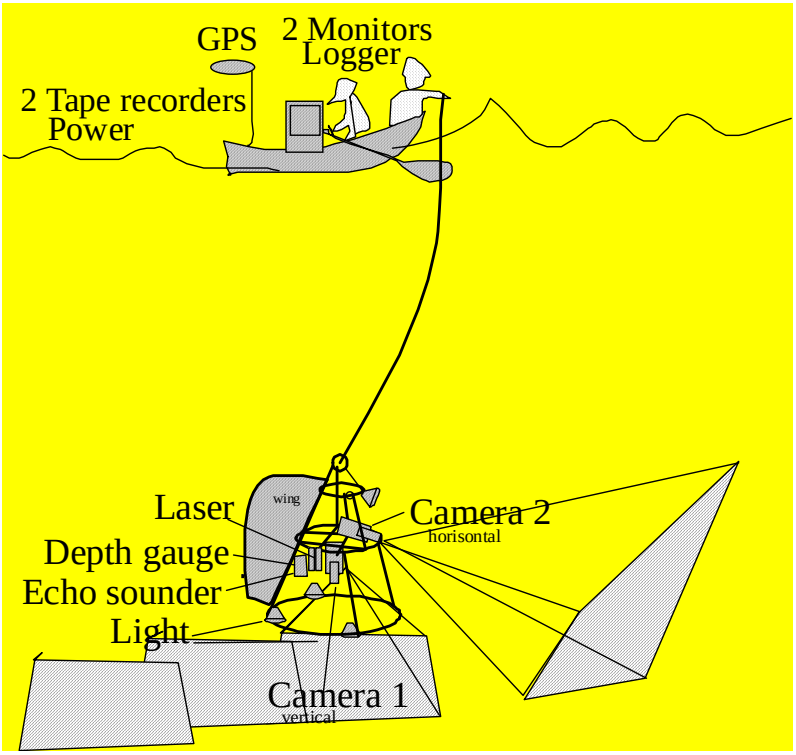
Echo-sounding, side-scan sonar

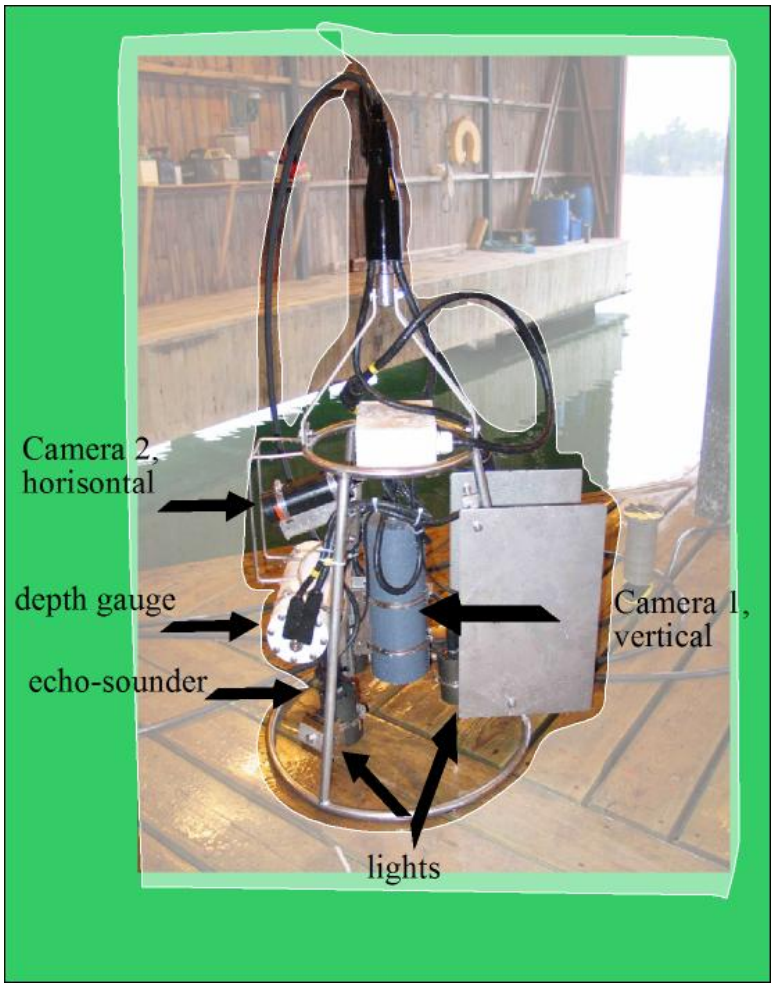
The echo sounding and side scan sonar techniques can cover large areas, with a relatively high resolution (> 0.1 m). The techniques have no depth limit and give good to excellent depth information. Especially the sonar technique gives good estimates of the substrate type, and they can detect plant cover. The drawback is that all data signals need interpretation and calibration through ground proofing. The signals are dependent on the layers in the water column and may generate different pictures of the sea floor just due to change in water temperature and/or salinity etc. There is still the need for interpreting the data signals, what they actually say and which are the best (which frequency to chose for a given purpose).

The methods have successfully been used in producing marine geological maps (side-scan-broader view) in the mapping of e.g. Posidonia meadows in the Mediterranean and seagrass beds in the USA. There are ongoing projects to improve the signal interpretation using echo sounding (e.g. NIVA-Simrad, etc.).

Video hanger

When using a video hanger the data obtained are visual and no signal interpretation is needed. The camera can be towed over a relative large distance and thus cover the depth range of the photic zone within one video session or km-long, horizontal distance. The resolution is high (<0.01 m). The data from the video profile can be documented and interpreted the same way as free estimates along transects linesin to a known gradient, as described later. Also, during large scale habitat mapping (e.g. the Finish coast) a grid based system of making observations within a proportion of statistically chosen squares may be used to choose the observation points. Each video picture should always be accompanied by the exact positioning (GPS) and depth information. Also, temperature should be included when e.g. observing fish. The equipment can be inexpensive (ca € 1000 well functioning systems are found on the web). The documentation on tapes gives excellent opportunity to go back to the material for verification or for looking at it from new perspectives. However, the instability of the picture caused by the camera movement and wave induced ship movement makes it sometimes hard to exactly see what is on the picture and some ground proofing is needed. The method has successfully been used in e.g. habitat mapping of offshore shallow reefs in the Baltic Sea. It may serve as a survey tool for finding suitable stations for diving transects in e.g. the start up of monitoring programmes. The major drawback is the unstable picture fully depending on the ship movement in combination with the usually low wide angle view of the camera lens. These problems may to a part be solved by technical improvement of the gear, but then cost increases. A vertical picture gives a limited view of the surrounding and therefore it is recommended that another camera is added which has a more horizontal view.


GPS
2 Monitors
Logger
2 Tape recorders
Power
wing
Laser
Camera 2
horisontal
Depth gauge
Echo sounder
Light
Camera 1
vertical


Camera 2,
horisontal
depth gauge
echo-sounder
Camera 1,
vertical
lights

ROV

Remotely operated vessel (ROV) is a more sophisticated version of a video hanger. It is independent of the movement of the mother ship, therefore it usually has a more stable picture and is easy to stop at an object of interest. The more advanced ROVs have manipulateurs and can collect samples. The major drawback is a relative high cost, a smaller operation range (depending on the length of the navel cord) and the demand of a skilled pilot navigating the ROV into position.

Manta taw

The manta taw is a tool developed for military purpose for search of objects. It can cover relatively large areas and gives a rough estimate of the habitats. It is quick. The major drawbacks is that it needs a Scuba diver making the observations, there is no time to stop and rest, and few opportunities to document the observations (always something new coming). In many cases it can also be dangerous for the diver and needs full concentration to keep on track. The method has successfully been used for the survey of the distribution of single, conspicuous species e.g. when mapping *Furcellaria lumbricalis* communities outside the Lithuanian coast and in tropical regions mapping the extension of coral reefs, etc...

Scuba diving

Scuba diving is usually applied by doing transects. There are a few ways of placing the transects and how the information is gathered along them. In the simplest form, the intercept method, the transects are placed parallel to the shore line at defined or randomly determined depths, where every transect represents a replicate. The observations are made just under the transect line at given intervals (usually every 1 m length). A more sophisticated method is to place frames along the transect line and make observations within the frame usually having a 0.5 or 1 m side length. The frames can be placed at random or within given intervals along the transect line. A special case is when frames are placed as a ladder side by side and thus observations are made continuously along the transect line. In the extreme case the frames are abandoned all together and observations are made in a corridor either defined by parallel lines at a given distance from the transect line or imagined. The transects as such can be placed horizontally but also if the scope is to see the depth extension of the plant species the transects should be placed perpendicular to the depth curve. This last approach, with a vertical transect and observations made in a imagined corridor of approximately 6–10 m width is the standard method in the national monitoring of the vegetation covered substrates along the Swedish coast in the Baltic Sea. It is quick and accurate and gives the depth extension and coverage (7-grade scale) of the substrate of the conspicuous species. The transects can also easily be documented by over-view photos during the dive. As a standard, two divers make independent observations in parallel along the transect line. Notes are done directly on site. When compared the two observations obtain the same results only with minor deviations. This clearly shows that the method is independent of observer and the results can be repeated. The major drawback is the dependency on SCUBA divers, limiting the time and depth of observation.

As each transect has to be considered as one observation describing the actual world along the transect line and not based on samples (fractioned observations in frames along the transect line from which the true world is estimated, giving a measure of statistical uncertainty and thus a statistical, but not always accurate view of the real-

ity) several transects have to be placed in an area to be able to draw more general conclusion of its status.

Estimates done in squares

Estimates based on observations within frames are widely used by ecologists. Adding replicates to the investigation (unfortunately not always done) an estimate of the species present with an attached uncertainty can be made. The major drawback is that frames used seldom are larger than 1 m^2, most commonly only 0.25 m^2 (05x05 m frame). The alternative would be to look at a sufficient large area to diminish unwanted, spatial variation (e.g. the Danish monitoring programme of the phytobenthos uses 25 m^2 fixed frames, the size obtained after evaluation (Dorte Krause-Jensen et al. 2000) and the Swedish programme making estimates within a "free" 6–10 m wide corridor (at least 10 m^2 per observation – the method is described as an recommended method in this report). A nice evaluation of the free estimates contra observations within small frames is found in Dethier et al. (1993) They came to the conclusion that around 10-14 small frames are needed to obtain the same precision as the free estimates of the studied area.

The species abundance or/and coverage is estimated in several ways. Besides presence and absence, either a percentage scale is used (classically, the Braun-Banquet 6 grade-scale) or the occurrence under the internodes (obtained by a grid subdividing the frame in e.g. 10 by 10 lines) is counted. The true coverage can be obtained by photo-grametric methods. The method gives accurate measurements of a small area. By repeating the frames an estimate of the community is obtained with an estimated statistical uncertainty attached. Classical statistics are generally easy to apply as each frame is a replicate. The major drawbacks are the need of usually a large amount of samples to encompass the natural spatial variation of the phytobenthic communities. This is especially the case when the frames are relatively small (e.g. the standard of 0.5 or 1 m side length). Evaluations in Denmark came to the conclusion that at least 5 by 5 m frames should be used to cope with spatial variation (Krause-Jensen *et al*., 2000,
http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/fr323.pdf

When used in the subtidal zone, SCUBA- divers have to be used with all drawbacks of time limitation and cost.

Collection of samples

Quantitative samples can be obtained by either photo frames (stereo -photo frames) (Lundälv, Karlsson) or destructive sampling. The methods give results that can easily be treated by traditional statistical methods. When destructive sampling is applied all species are included. A major drawback is the high cost to process the samples on lab. If photo frames are used, the canopy layer shading the understory species may be a problem and in general, this method needs a fairly steep sloping substrate.

Conclusion methods review

Satellite, echo-sounder, side-scan sonar give background data and indirect indications of the species distribution. The other methods give directly spp. geographical distribution and/or detailed occurrence on sites

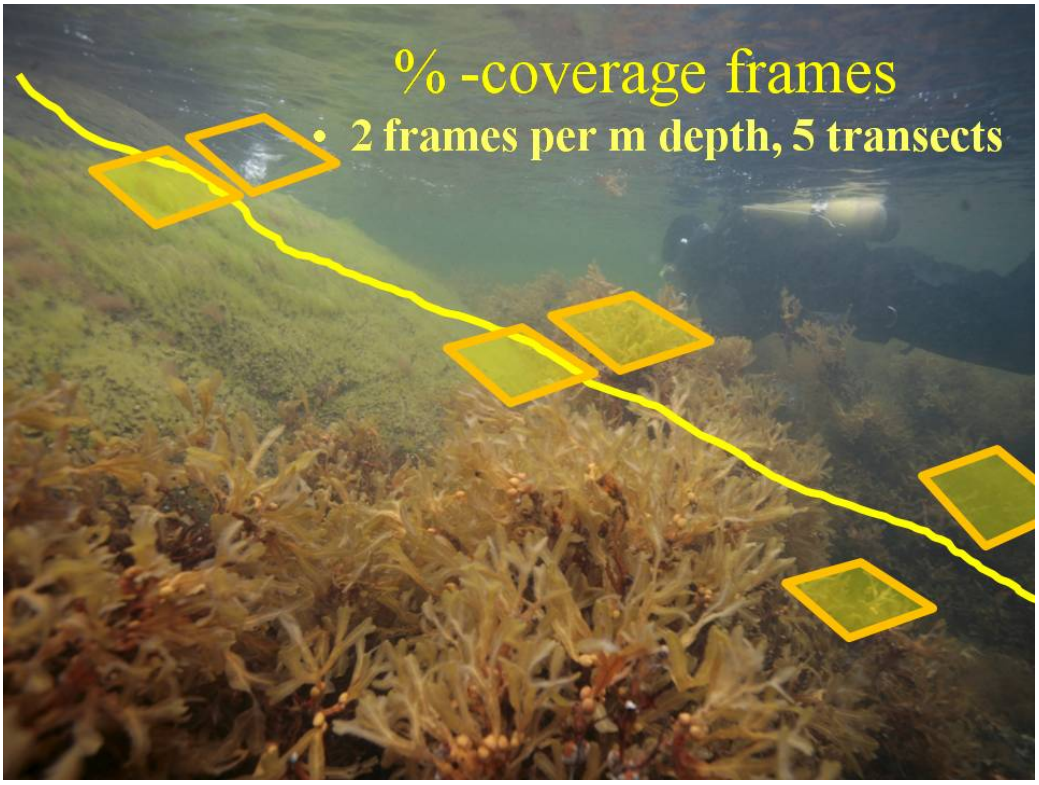
Discussion of the transect line method

The use of horizontally placed transect lines has mostly been used in tropical waters. The scope was to describe the community composition. In the context of monitoring

ecological status and as data for WFD vertical transect are used to obtain data of species depth distribution. The observations along the vertical transect line are done in several ways either in frames placed along the line using either replicates or just single frames at regular distances. For monitoring purpose the frames usually are placed at fixed depth intervals. Fixed frames have been used to follow long term change of the communities, this is a standard procedure in the intertidal zone but has also been applied by Lundälv xxxx and Gulliksen xxxx in the subtidal zone. Several investigations use fixed depths where the. frames are placed (e.g. Karlsson xxx) or at regular distance along the transect line. In a number of programmes the frames have been abandoned all together and the observations are either done continuously making a note whenever a change in substrate, species occurrence or species coverage is seen. A variation of this method is to make free observations at given depth intervals.

In the following some argument for one or the other approach will be discussed.

When the scope is to follow species depth distribution and their change with time, vertical profiles are used. Along the transect line observations may be done in frames at given depths (Figure xx). To obtain a good estimate of the population at a given depth (or region) a number of replicates have to be taken. This results in good estimates of the species distribution at discrete depths along the transect line. However, to obtain the maximum depth of a single species additional observations must be performed in between the depths of sampling – if not, the method will only record species depth distribution at discrete intervals (with 1 to 2 m depth resolution depending on the placement of the frames).

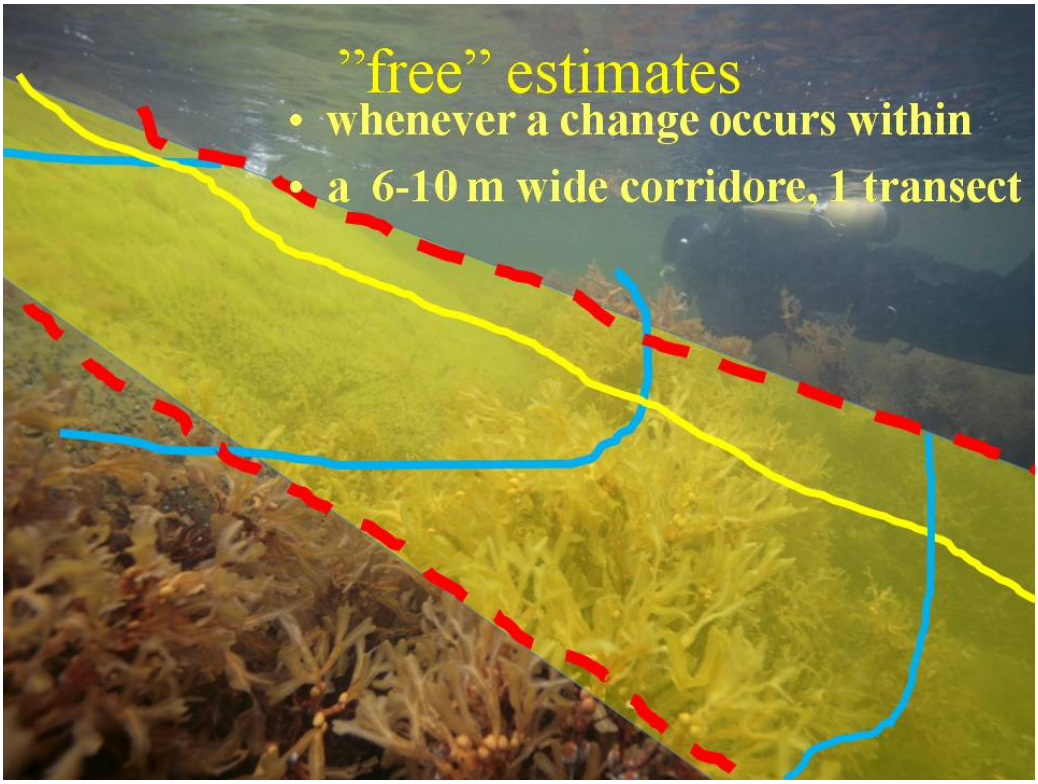


When making observations along the transect line without using frames, the entire area within the corridor is scanned by the divers for species (Figure xx). A record is

done whenever a change in the type and/or composition of the substrate, species occurrence and coverage is observed. For each observation the distance from shore and the depth is noted. Thus, we obtain a continuous description of the plant and animal communities within that corridor and can easily depict any species depth distribution by different criteria, e.g. the deepest individual, when the species covers more than 5 % of the substrate etc.. The method gives a true observation of the communities within the corridor which in the case of using frames had to be estimated with a given uncertainty.

As always, the description holds only for the described transect, and to give areal estimates the transects have to be accordingly replicated in the given area. In this case each transect is treated as one replicate.

The method is fast and as mentioned earlier is observer independent. As with all methods the observer has to have a certain skill usually obtained by training and inter-calibration. A workshop on Helgoland 2006 (ref.) arranged by the German BUND and participants from Nordic and Baltic countries, France, and Germany, the frame-approach as well as free estimates of species distribution was practiced along a ca 50 m long transect in the intertidal. The free estimate group (French taxonomic expert, Norwegian and Swedish monitoring experts) had achieved a detailed description of species distribution and cover within ca 1 hour, whereas the frame-group (Danish and German taxonomic experts and researchers working in the Helgoland area) completed about 3 frames (1x1 m) during the same time (ref....)



The free form of observing the communities along corridors usually cover 100-fold larger areas as the placement of frames along the transect line. In a Norwegian monitoring programme initially replicate frames were placed at given depths but after some years this was abandoned in favour of free estimates. The frame- observations tool too long time (Frithjof Moy, pers. com). A standard Swedish method for shallow

bays subscribes that observations are done in 0.5x.5 m frames each 10 m –and if the transect is long, each 20 m .. A to the scale comparison of the area covered by this method and the free estimates within 6 to 10 m wide corridors is illustrated in Figure Xx. Along a 50 m long transect the frame method would give observations from at total of 1.5 m² where the resolution of change is at best 10 m. The corridor method covers 300–500 m² area, including exact position of change in either substrate, species occurrence and their cover..

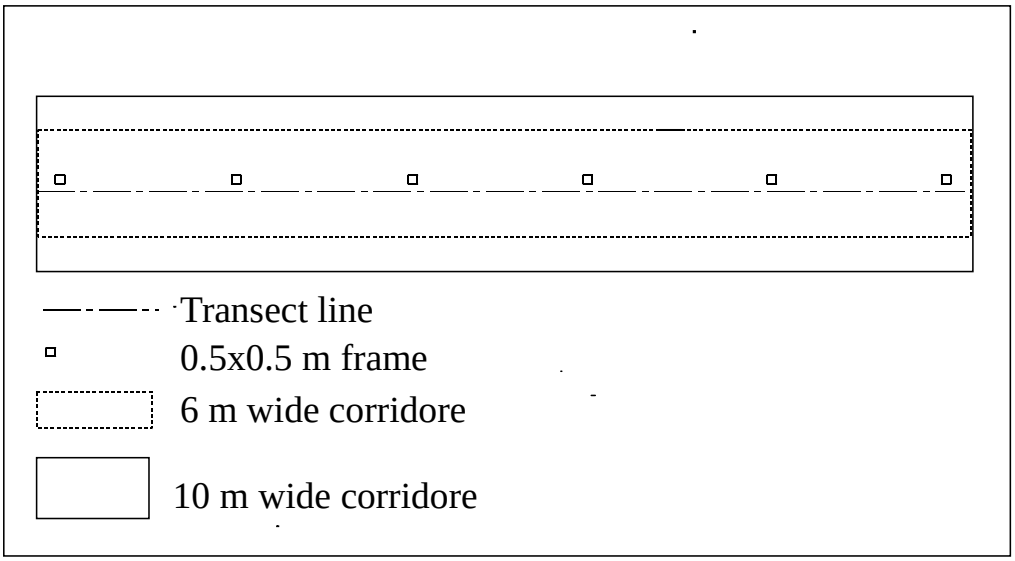


Fig xx: To the scale comparison of area covered by placing a 0.5x0.5 m frame at every 10 m distance or performing free estimates of the distribution and cover within a 6 and a 10 m wide corridor along a 50 m long transect line.

Photo frames

Instead of estimating species occurrence and cover within frames in field, the framed can be photographed and processed later on in the laboratory. A first, more systematic use of photo frames for the determination of species occurrence and coverage was done both in Sweden and Norway (see e.g. Lundälv and Christie, 1986). Both used fixed sites marked under water, which where revisited at given time intervals to follow the temporal change. A version of this approach is the monitoring programme of the Swedish west coast but where statistical aspects have guided the setup. Along a fixed 30 m long horizontal line five vertical transects are randomly placed at m distances. Along each transect 2 parallel pictures are taken at each m depth. At the surface down to x m each 0.5 m and below xx m depth each 2 m. Thus, within each station, 2.5 m² are observed at discrete depths along the depth gradient. In addition the most conspicuous species depth distribution along the transect line are noted, t o obtain the true, maximum depth distribution of the species.

Remote methods

Here Rees is cited

A review of methods was done by {Bäck, 1998 #783; Bäck, 1996 #652}. Several overview methods are suggested, either based on satellite, areal photography, ecosounding and side scan, video transects or ROV.

Conclusion as so far

Taken into account several approaches discussed above and national methods referred to in the annex, there are two main philosophies to approach the problem of describing and using the phytobenthic communities for e.g. monitoring purpose. In the first case, the classical approach, is to estimate the structure by collecting samples (frames), derive a mean value and give an estimate of the statistical error. The other approach is to observe the structure in a more extensive area or along corridors following, e.g. a transect line (may also be areal photography, video transects etc.). The second approach gives no estimate of the variation (statistical error) unless a number of transects are placed in the area of interest and where then each transect is seen as one replicate. However, this areal approach gives the true value of how it looks like along the transect line at the time of observation – it is not an estimate that approximates the truth (with a given statistical error).

If the goal is to establish species distribution along a gradient (e.g. depth) and monitor change, a cost efficient approach will be to follow change over fixed transects where observations are made continuously in corridors This approach has been practiced in Sweden since the year 1974 and is standard monitoring method, also recommended in HELCOM, OSPAR, (JAMP), is included in the new ISO-standard and is practised by several countries.

The method described in some detail in appendix x in one example of how it can be performed. There are a but a few parameters that should be incorporated in all investigations dealing with monitoring of the phytobenthic communities (besides the exact positioning, time, wave exposure etc.) along a depth gradient should be the type of substrate (including siltation), species depth distribution and species coverage

The following text will be altered in the near future

- What should be measured?
  - **Divers investigations**
  - **Photographic frames**
  - **Video transects**
  - **Remote methods**
    - **video hangers, sledges**
    - **ROV**
    - **areal photography, satellite**

Description of recommended method

A first draft of one, suggested set of SCUBA diver methods was presented in detail. The methods are presently used in the Baltic Sea, and are relevant for surveys and monitoring of the plant and animal communities found there, but has been practiced in more marine and tropical regions. The main purpose of the methods is to give species depth distribution and coverage and describe their environmental conditions (e.g. substrate, wave exposure, salinity) and to collect quantitative samples. The maximum depth of plants will reflect the water quality. For quantitative description and biodiversity studies, destructive, quantitative samples are collected by randomly tossing frames of relevant size - in the Baltic Sea quadrangular frames with the side length of 0.2 and 0.5 m are used.

History of method recommended

The method described has been in use in the Baltic Sea since the year 1974 (e.g. [Jansson, 1977 #200; Kautsky, 1989 #238; Kautsky, 1995 #590; Kautsky, 1992 #250; Kautsky, 1988 #235]). The main principles have been adopted by HELCOM (Annex C-9 HELCOM COMBINE Manual).

Similar line transect methods have been suggested elsewhere (e.g. line intercept method in Australia (c.f. for description and ref's in [English, 1994 #589] ,[Kingsford, 1998 #939]). Also, in Europe various methods are described (e.g. [Hiscock, 1998 #941] , [Hiscock, 1999 #940]). US Canada

In comparison to other, the main difference of this method is the "openness" as it gives an actual description of the communities found within the limits of the corridor along the transect line, based on the **observations** of divers. Most other methods give a number of replicate samples along the transect line, either from line intercept or from a given meter or from placed frames of defined sizes (usually .5x.5 or 1x1 m) in regular or random order along the transect line. The samples then have to be interpreted and statistically evaluated for their generality. In the method described here an accurate description is directly obtained for the entire transect. Depending on the purpose of the investigation then repeated transects describes the variation within the geographic region.

The observations along the transect line are traditionally done by divers. Later years also the use of video transects are evaluated to see if these more cost efficient methods can replace much of the divers work.

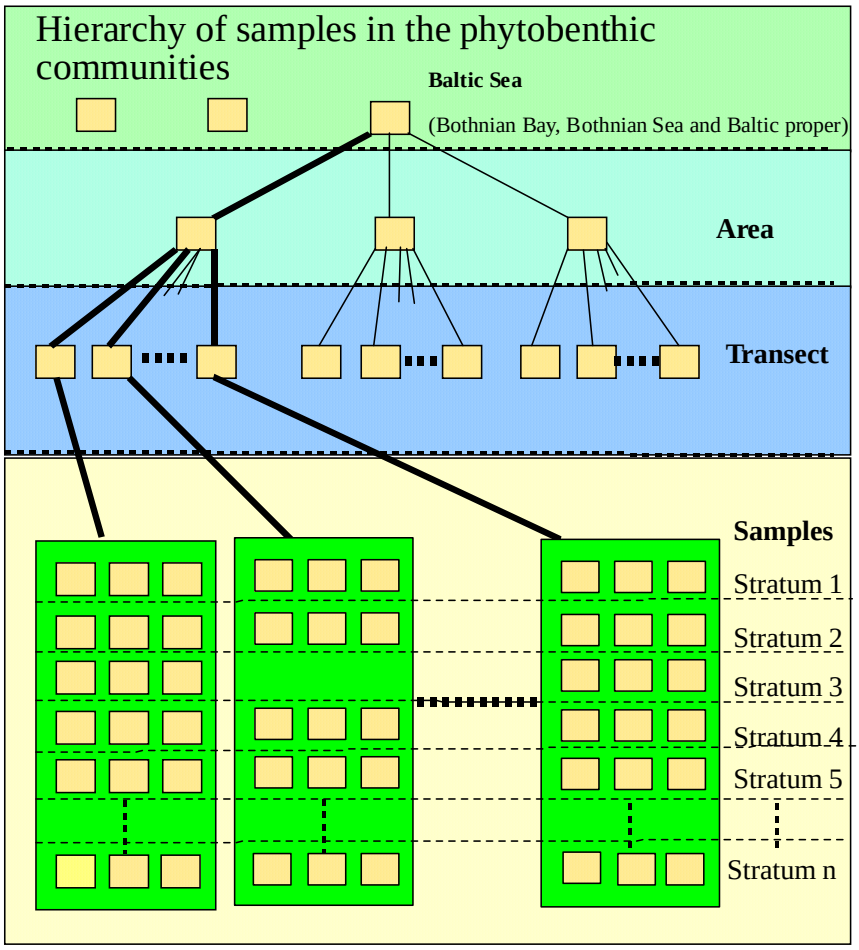
The main goal is to give the depth distribution of the plant and animal species, or chosen species, in a given area.

Planning of investigation

Overall hierarchy of the sampling strategy

Monitoring

In monitoring the goal is to find temporal variation that can be attributed to environmental change, e.g. increase or decrease of eutrophicating substances. Therefore, all other environmental parameters not relevant for this purpose should be kept at a minimum. We know from start that the phytobenthic communities are heterogeneous and just a relocation of the transect of 30 to 40 m along the shoreline may result in completely new communities as the wave exposure and type of substrate has changed. Also there is a steep gradient from the surface to the depth where almost every meter deeper down can give a new community. The shallow, intertidal communities will look entirely different from those found deeper down. If the purpose is not to mirror the geographic heterogeneity of the area and the depth gradient the location of the transects and where to collect samples may be determined strictly. The interpretation of data must take this into account. The comparisons in a given area or with time should follow a hierarchy where samples/observations from the same depth are compared within a given area with similar environmental conditions (same/similar wave exposure, salinity, …..



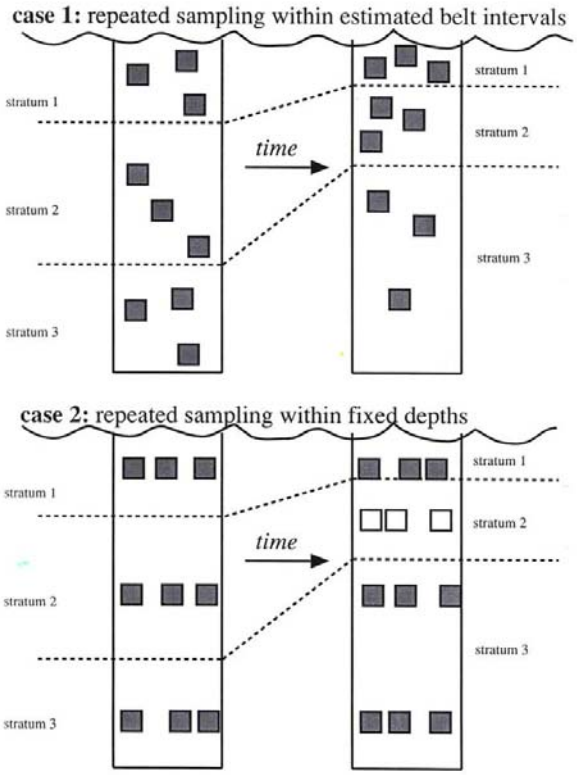
Samples from one depth will be different from the samples from an other depth. This we know as the environmental conditions for the biota is entirely different. Therefore, these comparisons are less fruitful.

With the sampling we want to achieve the possibility to see any change. The change may be either depth dependent, e.g. the deepest finding of a given species, or it may be dependent on the subarea, e.g. in the inner part of an archipelago or close to the source of waste, or it may be a change in the whole area. The final hierarchy is the entire region e.g. Baltic proper, North Sea, etc.

The strategy should be: samples from the same stratum are compared with each other. Then they are compared with samples take in same type of sub-area (e.g. inner part of the archipelago). Then transects from the same area are compared. To make general statements of an area the number of transects has to be at least three and will be better for each new transect added.

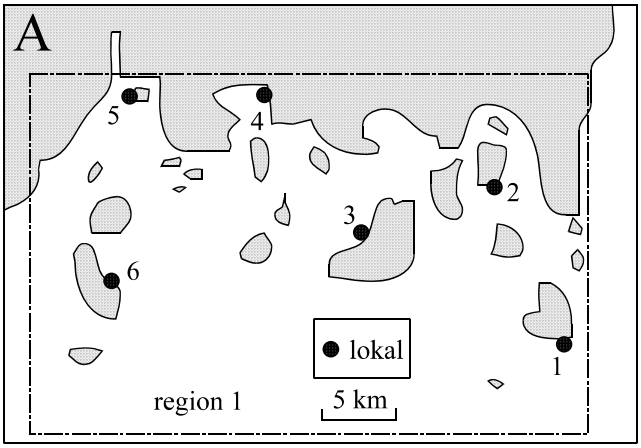
Quantitative samples

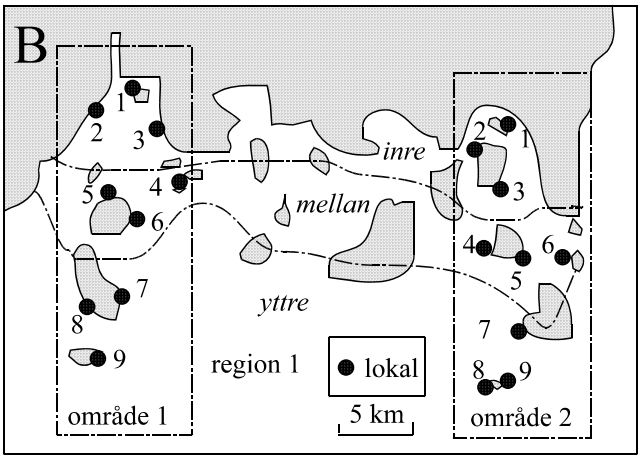
When quantitative samples are taken, the statistical prerequisites as for all sampling techniques are relevant. The number of replicates have to be enough to make any statistical evaluation, i.e. at least three samples per stratum (depth interval) must be taken. To minimize the effort, it is advisable to apply a hierarchic sampling design.



Choice of station

Depending on the aim and the finances of the survey the starting point is either chosen or randomly placed in the environment. With any knowledge of the geographic area it is preferred to use a stratified sampling to obtain at least three replicates within the same type of area. In e.g. an archipelago area is present it is not recommended that samples are evenly placed in the area (Fig xA). If so, when comparing the different stations (transects) with each other they are bound to be from different types of environmental conditions and just for that reason will be different. A transect from e.g. the inner part of an archipelago or from the leeside of an island is different from the wave exposed site. The same species will have e.g. different max depth distribution, we know that and it has nothing to do with any change in environmental conditions we study as pollution or eutrophication. Instead, the transects should be placed in such a way that a given amount will come in the inner part, as many in the middle and outer part of the archipelago (Fig x, B). The exact choice of the number of stations in each subarea should consider the homogeneity of the area, e.g. in an archipelago it is more likely that the stations differ from each other in the inner and middle part whereas the outer archipelago area is fairly similar. Therefore , less effort should be put in the most wave exposed area. As an example then 4 stations are put in the inner and middle archipelago respectively and 3 in the outer. Then the stations from the subareas can be compared and any general trend in change of the plant and animal communities in the area may be detected.





When limited resources. Only one transect per station should be placed. There is no need to put several transects within a station unless they are in shallow areas and would be extremely long to cover the entire depth range of the photic zone (see later). We know from start that transects close to each other are bound to be different just because the environmental conditions have changed. It is a better strategy to place the same amount of transects more spread out in the subarea to be able to find out if the changes are general for the area studied.

When applied in the right way the hierarchy of sampling makes it possible to separate the changes from the different subareas as well as the changes at the different depths. If we work in a pollution or eutrophication gradient higher response is expected in the inner parts of the study area. Whereas the outer, more exposed and flushed areas show little or no response. If the areas investigated are repeated also regional changes may be detected, such as a general decline of depth distribution of a given plant species in the coastal area.

(To see temporal changes)The results are analysed hierarchically, change within a given depth, within a transect, within a subarea, within the area, within the region. If there is a congruent change within one stratum it is valid for the next step in the hierarchy.

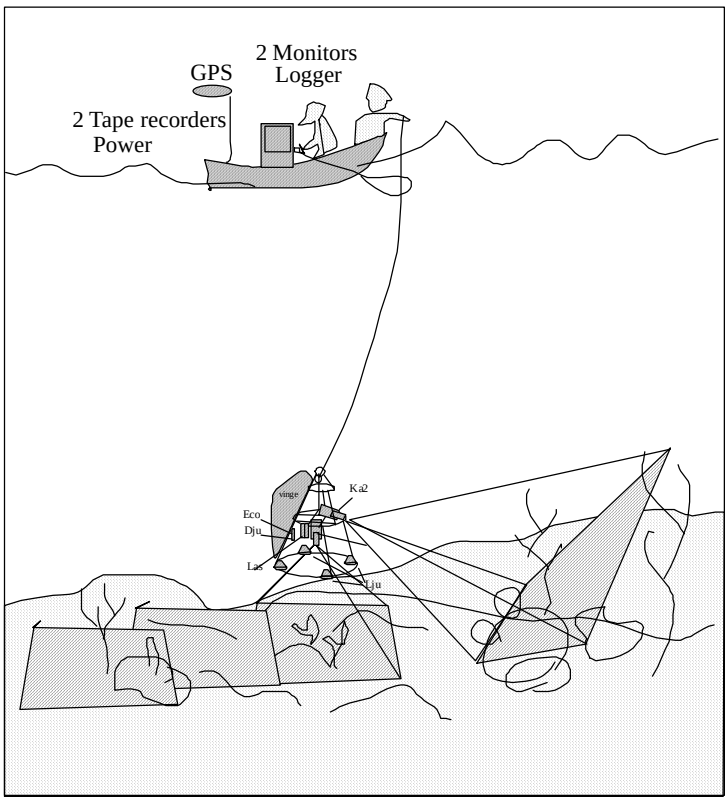
For monitoring purpose, we are only interested in the temporal change. It is therefore recommended that the transect is fixed with a permanent strating point and fixed compass direction. In other cases we will never know if the observed changes are due to spatial differences or if they actually come from temporal change. Thus, to be able to make general statements of the change within an area is fully dependent on enough replicates of transects in the area. If we have only one transect per area we can only see changes on that transect - and even only changes within a given depth - and nothing else. But if a number of transects within a subarea or area show congruent development we may predict general statements of the change in that area.

Data analysis.

Video transect

Video transect method is used as a complement to divers transects. The principle is the same. Instead of divers, the video camera records the substrate and its contents. Afterwards, a protocol is written based on the video record and the environmental data collected simultaneously (e.g GIS- position, depth, type of substrate etc.).

In Sweden a light weight system has been developed suitable for small boats e.g. 5 m, outboard motor suits as working platform and few operators (2-3 persons), one making the observations one holding the video rack, one steering the boat (could also being the one observing).

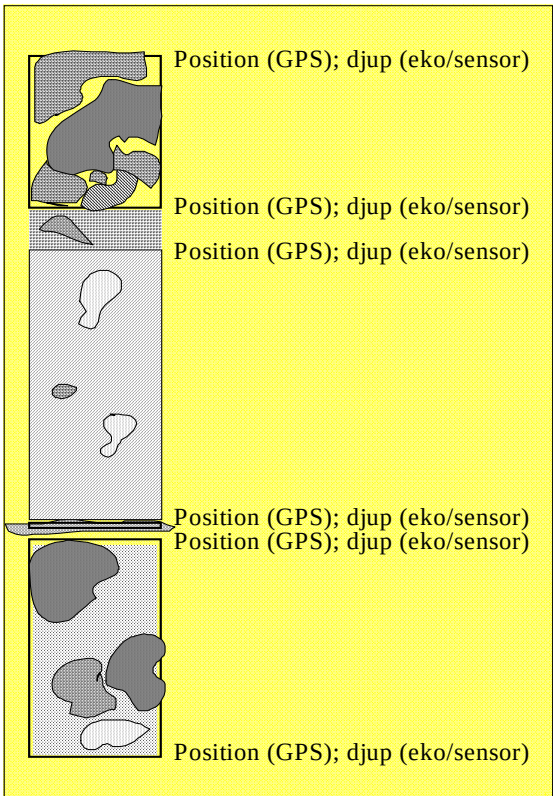


The hanger is composed of two cameras, one high resolution camera (3 CCD) gives a vertical picture, one high resolution (1 CCD) camera is more horizontally placed, which helps the observer to see where the camera gear is heading, but also gives a better overview of the area. Additional light, parallel laser beams, eco-sounder and a depth gauge are placed on the underwater gear. The picture of both cameras is seen on two monitors at the surface, and is recorded separately on two tape recorders together with the GIS position and all environmental parameters measured. The environmental parameters are recorded directly on the audio strip of the video tape. Of choice any measured information can be seen on the monitor. All video equipment is held in two Pelican-boxes, easily transported and mounted on any ship. The system is designed to work from small boats in shallow waters, but can be operated from ships. The equipment has a 75 m long cable (25+50).

Below, the principle of the equipment is shown.

Output from the video

The result of the video is a 100 to 1000 m long transect of one to a few m wide depending of the distance over the substrate of the video camera. The observations are then classified accordingly as described for the divers transects. For each new observation the GIS position, depth and other parameters measured are registered in a protocol. New observations are made when either a new species is seen , the coverage of the species changes and/or the type of substrate and its composition changes. Thus, along the transect several subareas are recorded with various length. For each starting point the Position (GPS) is recorded, together with depth, type of substrate and its coverage, the species and their coverage. In addition, in the Swedish hanger the distance of the video camera to the substrate and to the surface is measured by an eco sounder (0.1 m accuracy) and a depth gauge, respectively, the declination of the gear and time are recorded. The equipment allows additional 3 to 5 sensors to be added.



Exempel på hur datamatris kan se ut Utsjöinventeringar för framställning av GIS-karta					
Lokal nr	1	1	1	1	2
Datum	2004-08-14				
Profil nr	1	1	3	4	1
Obs nr	1	2	3	4	
Pos long (GPS)	xx xx.xxx				
Pos lati (GPS)	xx xx.xxx				
Djup	0.1				
Djup ekolod	0.1				
Avstånd kamera (laser)	0.1				
nn (t.ex. vågexponering)					
nn					
nn					
bottentyp:	% täckning				
häll	100				
block	75, 50				
sten	25				
grus	10				
sand	5				
mjuk	+				
art 1	% täckning				
art 2	100				
art 3	75				
art 4	50				
art 5	25				
art 6	10				
art 7	5				
art 8	+				
art 9					
art 10					
art 11					
art 12					
art 13					
art 14					
art 15					
art 16					
art 17					
art 18					
art 19					
art 20					

Appendix 2

Short review of methods used today for monitoring in countries of ICES-waters

BALTIC SEA REGION

FINLAND

A proposal for long-term monitoring in Finland was described by Bäck et al.

{Bäck, 2002 #953}. Their proposal is based on the Swedish monitoring programme and according to the recommendations of HELCOM monitoring programme (COMBINE) and Nordic Council of Ministers (see below, {Bäck, 1998 #783; Bäck, 1996 #652}).

Jocke pock gör monitoring in finlanf d(kola Moy-wporkshop

Saara Bäck[1] , Jan Ekebom[1] and Pentti Kangas[1]

A Proposal for a Long-Term Baseline Phytobenthos Monitoring Programme for the Finnish Baltic Coastal Waters: Monitoring Submerged Rocky Shore Vegetation

JOURNAL	Environmental Monitoring and Assessment
PUBLISHER	Springer Netherlands
ISSN	0167-6369 (Print) 1573-2959 (Online)
ISSUE	Volume 79, Number 1 / October, 2002
DOI	10.1023/A:1020095220957
PAGES	13–27
(1)	Finnish Environment Institute, Helsinki, Finland

Abstract Several local surveys on the submerged vegetation have been conducted in past decades along the Finnish Baltic coastal areas. Surveys have been carried out by using various methods,which make the temporal comparisons of the results difficult.The need of a joint programme for coastal phytobenthic monitoringis emphasised by the Nordic Council of Ministers and HELCOM. TheFinnish coastal phytobenthic monitoring programme complements theBaltic HELCOM monitoring programme (COMBINE). It is primarily designed to reveal the effects of eutrophication. The programmeincludes general principles for selection of monitoring areas aswell as a proposal for monitored habitats, communities and species. The need of evaluated and tested field methods, datacollecting, interpretation and data storage are addressed in theQuality Assurance part. The cost-efficiency is secured by integrating the phytobenthos programme with the coastal water monitoring for obtaining the supporting data such like salinity,temperature and nutrients. In the design of the monitoring programme a special interest is paid on areas with high protection values such as Natura 2000 or HELCOM's BSPA (Baltic Sea Protected Areas) or on aspects that would support the implementation of the EU Water Framework Directive.

Baltic Sea - macroalgae - monitoring programme - phytobenthos

DENMARK

Total and opportunistic algal cover in relation to environmental variables

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[c]European Commission, Directorate General Joint Research Centre, Institute for Environment and Sustainability, Inland and Marine Waters Unit, TP 280, I-21020 Ispra (VA), Italy

Available online 25 September 2006.

Abstract

Based on a large data set from the national Danish monitoring program, spatial and temporal variability in total algal cover and in the fraction of opportunistic macroalgae was analysed in relation to environmental variables. Variations in water clarity and salinity combined with information on geographical location of sampling areas were found to explain almost 80% of the large-scale variation in algal cover between areas. As water clarity was largely regulated by concentrations of total-nitrogen (TN), and TN-concentrations by TN-input from land, total algal cover at given water depths was partly related to TN-input from land. The fraction of opportunistic algae responded predominantly to differences in salinity, the highest fractions being found in the most brackish areas. Temporal variability in algal cover and fraction of opportunists over the 14-year investigation period was much smaller than the variability between areas and could not be predicted from variations in environmental variables. In order for macroalgal cover to become a more sensitive indicator of water quality it would be necessary to either increase the sensitivity of the method or identify and include supplementary regulating factors in the model.

Keywords: Macroalgae; Opportunistic algae; Cover; Eutrophication; Salinity; Denmark

Monitoring nutrient release from fish farms with macroalgal and phytoplankton bioassays

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Received 11 May 2005; revised 16 January 2006; accepted 16 February 2006. Available online 28 February 2006.

Aquaculture 256: 302-310.

Abstract

The release of nutrients from fish farms may cause environmental problems and is traditionally monitored by analysis of nutrient concentrations in the surrounding waters. As concentrations vary strongly over the day this requires intense and expensive sampling. The aim of this study was to demonstrate the use of bioassays as an alternative low cost monitoring strategy that may document the distance from the farms where pelagic primary production is affected. We used a macroalgal and a phyto-

plankton bioassay to monitor the release of nutrients from four fish farms located in Cyprus, Greece, Italy and Spain. The macroalgal assay consisted of *Ulva* sp. contained in net cages and the phytoplankton assay was surface water, filtered through a 50 μm filter to remove grazers and then incubated in dialysis bags. Growth in both types of bioassay was highest closest to the fish cages as a result of nutrient release from the cages. The 2 types of assays agreed in most cases and growth exceeding background levels in both types was only found less than 150 m from the fish cages. This indicates that pelagic primary production was stimulated by nutrient release from these 4 fish farms up to a distance of 150 m downstream in the dominant current direction. The content of N, but not of P, in *Ulva* tissue was highest closest to the cages. This indicates transfer of N to the primary producers. The N : P ratio of *Ulva* tissue was > 40 in all cases, indicating a severe phosphorous limitation in agreement with the general notion of the Mediterranean being P limited. The content of N and P in *Ulva* tissue was at or below literature values of the minimum nutrient content necessary for growth. However, *Ulva* did grow and subsistence quota from the literature may not hold for Mediterranean *Ulva*. It is thus recommended that the variation in threshold concentrations for a given *Ulva* population is investigated, before a firm translation of internal nutrient concentrations to growth conditions is made.

Keywords: Aquaculture; Nutrient release; Bioassay; Eutrophication; Mediterranean

Present and past depth distribution of bladderwrack (*Fucus vesiculosus*) in the Baltic Sea

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Received 23 October 2004; revised 10 June 2005; accepted 5 July 2005. Available online 19 October 2005.

Aquatic Botany
Volume 84, Issue 1, January 2006, Pages 53-62

Abstract

This study aimed to (1) assess the present depth distribution of *Fucus vesiculosus* in the Baltic Sea and evaluate differences between districts and (2) assess long-term and recent changes in depth distribution and evaluate reasons for such changes. This was done through compilation and analysis of existing data (3356 obs.). Depth limits were shallowest in the Kattegat, the Danish Belts and the Øresund (~1.5 m on average), located at the entrance of the Baltic Sea and markedly deeper in the central and inner parts of the Baltic (up to ~4.5 m on average). This increase in depth limits to some extent matched the decline in salinity and may in part be explained by reduced competition when species diversity decreases successively along the Baltic salinity gradient. In the central and inner Baltic Sea, Secchi depths explained part of the variation (16%) in depth limits and the majority (85%) of the variation in maximum attainable depth limits whereas at the entrance of the Baltic Secchi depths explained a negligible part of the variation (~1%). In most districts, depth limits moved upwards during the 20th century. In many cases this happened during or shortly after the 1960s/1970s, and was most likely due to eutrophication.

Keywords: Baltic Sea; *Fucus vesiculosus*; Depth distribution; Salinity; Water clarity; Long-term change
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ESTONIA

Follows HELCOM Guidelines (e.g. Kautsky)

LATVIA

POLAND,

GERMANY

North Atlantic and North Sea

A suggested Norwegian Standard for littoral and sublittoral hardbottom communities is presently under developement ({ISO, 2003 #945}). The standards only includes any type of hard substrates in the littoral zone and sublittoral zone down to 30 m depth, i.e. rock, to loose pebbles-stones (what is called mixed in this report) but also pipelines and other hard underwater constructions. The general method described up to now is the use of gridlines, i.e. a low number (4) of fixed or randomly placed frames of appropriate size and the counting of species within the frame. Overview survey: a simple documentation of bottom conditions and hard-bottom fauna (why not also flora?) mapping using divers video and/or ROV 2 description of environmental conditions, 3 trend monitoring

On the more marine Swedish west coast the national monitoring programme is based on stereo-photography in fixed stations with randomly placed transects every year (Karlsson 199x, www.environ.se).

GREAT BRITAN

http://www.ukmarinesac.org.uk

http://www.marlin.ac.uk

http://www.jncc.gov.uk/csm/guidance/PDFs/CSM_marine_rock.pdf

FRANCE

parameters **:** species density, optical density, bathymetry, temperature, reflectance

*****instruments*** **:** dredges, submarine cameras and video cameras (benthos), airborne and satellite cameras, sonar

*****data-themes*** **:** ALGUES, BENTHOS, BIOLOGIE MARINE, ROCHES SEDIMENTS EAUX INTERS., IMAGERIE SONAR, PHANEROGAMES MARINES, PHOTOGRAPHIE ET VIDEO, MESURES DISTANTES,

*****summary*** **:** Phytobenthos in French coastal waters and other coastal areas in Mediterranean, and Pacific and Indian Oceans

The data set consists of sea measurements and remote sensing. Phytobenthos samples are collected between 0 and 50 m depths from seashore and from boats, by dredge or by scuba diving. The samples are analysed for biometry and species identification; these data are used as 'ground truth' for the remote sensing. Remote sensing of phytobenthos species densities are recorded on submarine and surface photos and videos and on sonar imagery. The analogue photos are calibrated by using ground reference marks. The reflectance on visible and infrared digital images is calibrated with standard marks. Samples are in LER/LR laboratory of IFREMER Brest.

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SPAIN

Mediterranean Sea

In Greece [Panayotidis, 2004 #954] suggested a low-budget monitoring of macroalgae in the upper infralittoral down to 1 m depth. The main goal was to implement the European Water Frame Work and thus the ability to class the communities under study in the five ecological status classes of high, good, moderate, low and bad (see e.g. http://forum.europa.eu.int/Public/irc/env/wfd/library?1=/framework_directive/guidance documents&vm=detailed&sb=Title) <--check site and COASTS (2002) in connection with Natura 2000. They used 5 permanent site squares of 5 x5 m which were photodocumented and in addition within the large square one ramdomly placed quantitative frame of the size 0.2x0.2 m was used for destructive sampling. The sampling was repeated 6 times. The cover value of each taxa vas measured (in the photoframes) and the structure of the vegetation was described. They used various indicies (Shannon- Weaver, Pielou-eveness, Multi-dimensional scaling plot by Bray-Curtis similarity and ecological-evaluation-index). MDS and EEI were the better to describe differences.

Comment: the method is a simplification of the suggested method with according loss in prediction power.

PORTUGAL

To increase the knowledge of marine habitats and of populations of the Park. - Awareness of the public opinion for the importance of preservation of diversity and for necessity of implementation of management measures

- Harmonizing preservation of marine sensible habitats with the activities that cause its disturbance, through the installation of fixed points of knotting in the places more visited.

CIMAR is studying the distribution, use and conservation of the botanical heritage of the Northern coast of Portugal. There has an ongoing study on the effects of trampling in intertidal communities. This study is measuring the real impact of the use of these areas by local people and fisherman.

- CIMAR does research on the impacts of dredging for beach nourishment on the marine communities off the central Algarve.
- CIMAR is currently monitoring seagrass beds, as part of integrated in European management programmes Complete list of projects can be provided under request

Management plans for important components of marine and coastal ecosystems

- Recovery plans in place for Southern hake and Norway lobster stocks and other critical ecosystem components in Western Portuguese mainland coast, under Council Regulation nº 2166/05, of 20 December aiming at rebuilding the stocks to safe biological limits.
- Land Plans within Natural Parks and Reserves Network and National Submarine Ecological Reserve
- On the scope of fisheries, commercially explored key species are subject to exploration status evaluation and management plans are being developed.
- In Azores on the scope of Natura 2000 sectoral plan, management plans for all MPA were developed, and gradually being implemented through classification process in Regional network of protected areas.
- Portugal is gathering data of the species that occur in the coastal area and is producing a Management Plan to protect those species.

ITALY

Monitoring Posidonia oceanica meadows in a Mediterranean coastal lagoon (Stagnone, Italy) by means of neural network and ISODATA classification methods

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DOI: 10.1080/0143116031000066882

Publication Frequency: 24 issues per year

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Abstract

ISODATA (Iterative Self-Organizing Data Technique of Analysis) and neural network classification methods were carried out to map shallow Posidonia oceanica meadows in coastal areas of the Mediterranean Sea, using Coastal Zone Colour Scanner (CZCS) airborne sensor data obtained at different altitudes and an aerophotogrammetric image. Reference test points of P. oceanica have been checked against aerial photographs. The neural-based classification method gives the best performance (92-95%) for all the images of the set, except for the highest altitude flight (1000 m, accuracy 74%). ISODATA classification of CZCS images was generally more accurate (81-85%) than applied to the aerophotogrammetric image (79%). The study also indicated that 4 m represents the 'critical' resolution useful for the extraction of reliable information within the study analysed area. Where P. oceanica forms dense and continuous meadows, a lower resolution (such as those obtainable from satellite sensors) could be successfully applied.

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The use of bio-indicators for quality assessments of the marine environment: Examples from the Mediterranean Sea

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The aim of this paper is to give an overview of the use of indicators and indices for the evaluation of the status of the marine environment. This procedure represents a new integrated approach, where the coastal marine environment is considered as a complex ecosystem, to be studied in all its components. Recent national and international legislation introduces this new concept of environmental quality, while requiring data and information on parameters which were not evaluated in the past. Until now, monitoring and control programmes for the marine environment focused mainly on the chemical status of coastal waters. However, aspects of the biological quality are fundamental for the description of the ecological status; the need for the development of biological indicators and indices provides a challenge for the scientific and technical community managing the marine environment. Living organisms represent the most appropriate indicators for the environmental quality of a water body, as they integrate biotic and abiotic components through their adaptive response. The available information on the current use of biological indicators and in-

dices are illustrated and suggestions and examples on the Mediterranean sea environment are discussed.

Abbreviations

- MCSD = Mediterranean Commission on Sustainable Development
- OECD = Organization for Economic Cooperation and Development
- UNEP-MAP = United Nation Environmental Programme – Mediterranean Action Plan.

Keywords: Benthic community, Biocenosis, Cartography, Coastal environment, Ecological state, Environmental quality, Index, Indicator, Water legislation, Water monitoring

OTHER AREAS

The sampling of biodiversity and monitoring was addressed by Canadian authorities (http://www.eman-rese.ca/eman/ecotools/protocols/marine/ or http://naturewatch.ca/english/monitoring/protocols/marine/). Several documents give monitoring protocol for marine benthos, for seaweeds, site specific protocols and others.

THE US GOVERNMENT

AUSTRALIA

EQUADOR

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Appendix 1

Definition of zones within the phytobenthic zone.

The following is a glossary copied from the web, for references and links see the homepage http://mrw.wallonie.be/dgrne/sibw/EUNIS/eunis.gloss.html . The list of definitions below neatly describes the somewhat un-precise or alternative defined terminology used in literature, and we have not yet included American, German and French definitions of the same.

circalittoral *Definition:* 1. Sub-tidal or non-tidal water, with insufficient light penetration to allow algae to dominate. May have some wave action and tidal currents may exert a strong influence. (see also littoral, infralittoral, supralittoral) 2. The area of the continental shelf seabed that lies below the zone of periodic tidal exposure. (1. EUNIS based on BioMar v. 97.06; 2. Allaby 1994)

circalittoral *Definition:* Of, relating to or inhabiting the part of the depth gradient along the shore of a sea or ocean extending from the lower limit of occupation by marine phanerogams to the lower limit of occupation by pluricellular algae (IRSNB 1995)

hydrolittoral *Definition:* The shores of non-tidal waters which are regularly or occasionally exposed by the action of wind, and which lie below the mean water level. (EUNIS)

infralittoral *Definition:* Shallow sub-tidal or non-tidal water, wave disturbed or algal-dominated or within the euphotic zone. (See also littoral, circalittoral, supralittoral). (EUNIS based on BioMar v. 97.06)

infralittoral *Definition:* Of, relating to or inhabiting the part of the depth gradient along the shore of a sea or ocean extending from the upper limit of constant immersion to the lower limit of occupation by marine phanerogams.(IRSNB 1995)

littoral *Definition:*The intertidal zone of the seashore. (GEMET v.1.0, LBC)

littoral zone *Definition:* 1. The area in and adjacent to shallow, fresh water, where light penetration extends to the bottom sediments, giving a zone colonised by rooted plants (helophytes). 2. In marine ecosystems the shore area or intertidal zone, where periodic exposure and submersion by tides is normal. Since the precise physical limits of tidal range vary constantly, a biological definition of this zone, which essentially reflects typical physical conditions rather than more rarely experienced events, is generally more useful. Thus in Britain, for example, the littoral zone is defined as the region between the upper limit of species of the seaweed [Laminaria] and the upper limit of [Littorina] (periwinkles) or of the lichen [Verrucaria]. (See also infralittoral, circalittoral, supralittoral) (Allaby 1994)

mediolittoral *Definition:* Of, relating to or inhabiting the part of the depth gradient along the shore of a sea or ocean in which there is an alternance of immersion and emergence due to tides and waves. (IRSNB 1995)

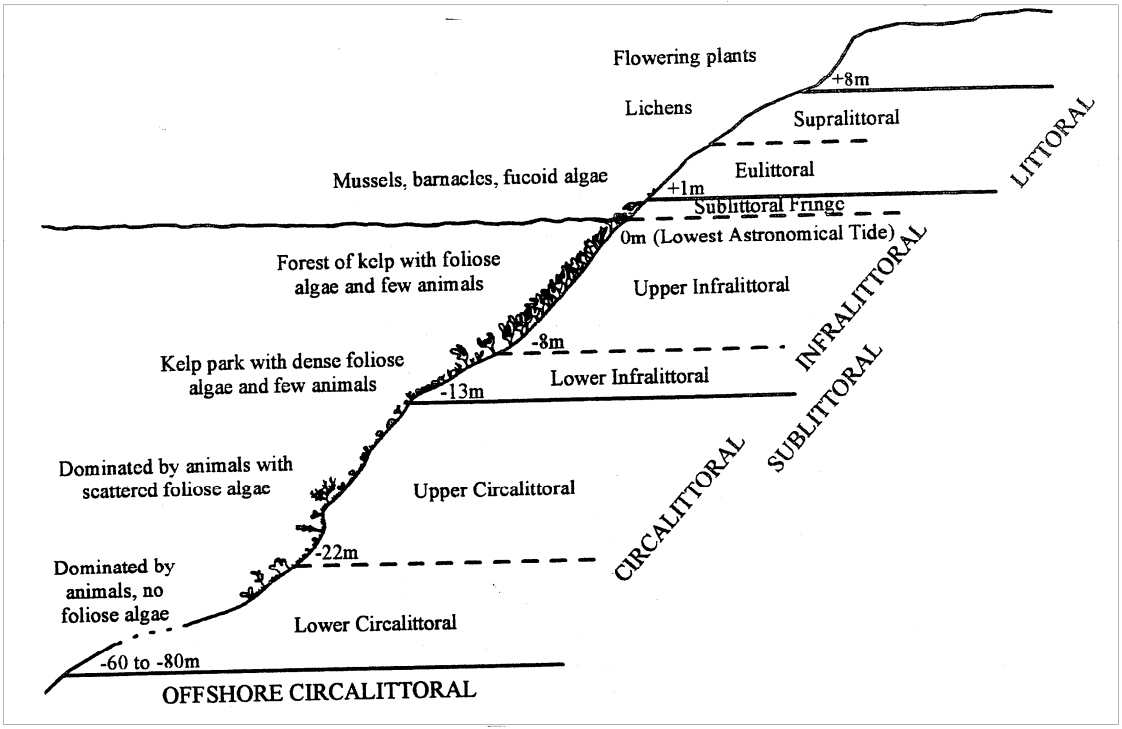
sublittoral *Definition:* (Marine habitats) The sea-shore zone lying immediately below the littoral (inter-tidal) zone and extending to a depth of about 200 metres or the edge of the continental shelf. Red and brown algae are characteristic of this area.

Typical animals include sea anemones and corals on rocky shores, and shrimps, crabs and flounders on sandy shores. (Allaby & Allaby 1999)

supralittoral *Definition:* The seashore zone immediately above the littoral fringe and beyond the reach of tidal submergence, though affected by sea spray. (See also littoral, infralittoral, circalittoral) (EUNIS based on Allaby 1994)

supralittoral *Definition:* Of, relating to or inhabiting the part of the vertical gradient along the shore of a sea or ocean which is normally emerged, only wetted by spray and very high waves. (IRSNB 1995)

Profile of rocky shore and seabed to show the biological zones; depths are typical values for south-west Britain (after Connor et al., 1997, modified from Hiscock *ed*. 1996).

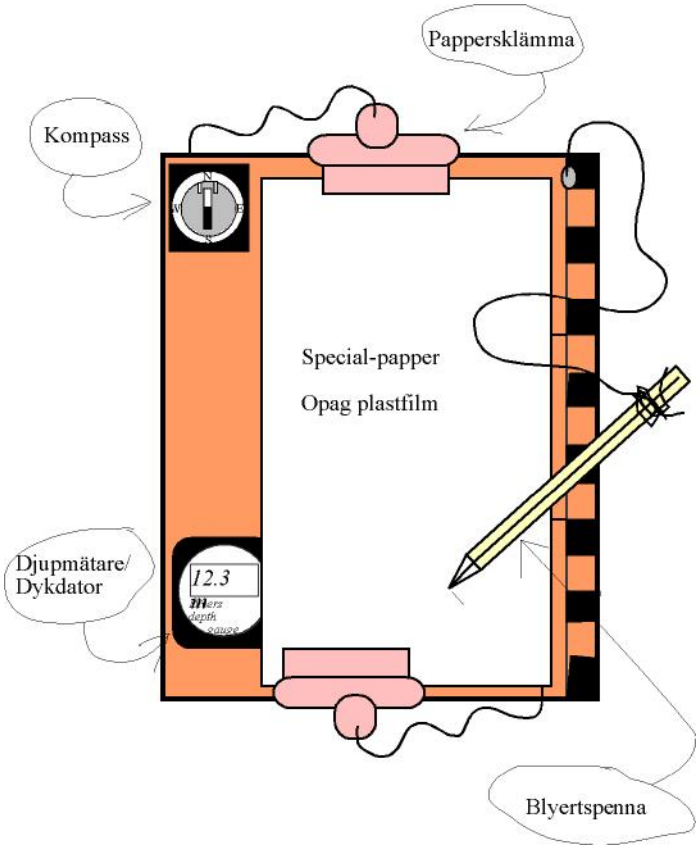


Appendix 3

Field sampling

SCUBA divers transects

For practical reasons it is essential that all the parameters investigated during a SCUBA divers transect can be done by the divers in a replicable way. To keep costs at a limited level all the work has to be done within the limited time a diver can be exposed to depth without more sophisticated diver routines (no forced deco- stop etc.).



Scuba divers swim in a given compass direction, perpendicular to the depth curve, putting out a meter marked line (standard measuring tape) until the end of the photic zone is reached. Then they turn and swim towards the shore and note *in situ* on a writing plate the distance from shore, depth, type of substrate and its coverage, siltation and the species present and their coverage. The observations are made in a corridor of 3- to 5 m width on either side of the meter marked transect line. The width is dependent on the site in the water. The divers make a new note whenever there is a change in the substrate, a new species occurs and/or the coverage of the species changes.

Every set of observation must start with the distance and depth. Then it is followed by the composition of the substrate and estimate of its coverage, then an estimate of silt and thereafter the species and their coverage. As a routine, if any of the parameters have not changed, no new notation must be done. However, it is recommended that everything is written down anew when a new observation is done (see example of field protocol, Fig xx).

Salinity

If the area of investigation covers a large geographical area or is placed in, or in the vicinity of an estuary the salinity may be important for the distribution of plant and animal species and has to be measured. The salinity should always be measured in areas where we can expect a gradient, e.g. in the Baltic Sea area where a mixture of fresh water and marine species occurs.

Temperature

Temperature is essential in a broad biogeographical context but on the local scale in a given region it has no or little effect on the phytobenthic communities. However, temperature is important if fish studies are included in the investigation.

Wave exposure

The wave exposure is an essential environmental factor which together with the geological prerequisites of the site rules the composition of the substrate. It also directly influences the species composition and biomass. The wave exposure of a site should always be measured or estimated. ICES gives some direction of how it can be done in an easy way by using the longest fetch distance. More sophisticated methods using GIS applications are under development ({Isaeus, 2004 #944}). Actual, reliable measurements of the wave exposure giving an integrated value over a longer time have to be developed, the attempts are numerous in literature, from classical plaster balls over springs to taw instruments.

In monitoring, if there is a large difference in wave exposure between two stations they can not be compared as many essential environmental factors dependent on wave exposure will be entirely different and result in totally different plant and animal communities. A common mistake in surveys of polluted areas is to pick the reference station as far away from the source as possible without taking into account the different natural, environmental factors that have changed just due to the wave exposure. The change in species composition due to pollution can then not be separated from the natural change. This most often leads to an overestimate of the differences between polluted and unpolluted areas.

Position

The starting point of the transect on a station is always documented with the GPS-position. The WGP84-system should be chosen as standard. If the transect starts from shore it should be photo documented and if the transect is used for monitoring purpose, it should be marked permanently in an appropriate way (e.g. hole in the rock). In the case of shallow areas the transects may be very long. In this case they can be subdivided in such way that the entire depth range is covered, e.g. a part of the transect for instance 30 -50 m long covers 1 to 2 m depth, the next covers 3 to 6 m depth, and so on depending on the topography of the area. In this case it is essential to mark each starting point. The endpoint should in general be possible to calculate by the length of the sub-transect and its compass direction.

Distance and compass direction

Usually only the starting point can be established with a high accuracy if there is a hole in the rock, or with a DGPS-position when the transect starts in mid water. To revisit the exact spot one has to know the distance from that starting point and the compass direction. It is fairly easy to swim in a given compass direction under water. During ten years experience from the monitoring programme in the Baltic Sea the

endpoint at 50 to 100 m and sometimes 200 m distance from the shore is reached within a 5 m deviation. Brick stones placed under the transect line at 2 m and 5 m depth are usually within 1 m from the transect line. As the transect corridor is 10 m wide we will swim over the same substrate as the year before. The changing currents may however force the diver to deviate from the right direction. This can be minimized by being alert during the dive, or better, as indicated above, by placing permanent marks along the transect or note conspicuous landmarks under water, e.g. a large boulder, crevices etc.. In less wave exposed sites usually brick stones or there like may be placed out along the transect. Also, "bergkil eller herring" may be bolted into the cliff at regular distances.

The distance from shore is essential when repeating the sampling in, e.g. a monitoring programme. The distance is always the same from a given staring point. The depth may change both downwards and upwards with the distance from shore depending on the topography of the area. When repeated quantitative sampling is done, for instance by photogrammetric methods of a fixed area or when using a destructive sampling technique, the distance is the only way to come back to the exact same spot as visited before. It is the only inexpensive operative method under water for scuba divers today to position themselves. The distance also gives the spatial range (width) of the species found along the transect.

Depth

Depth is an essential environmental parameter, easily measured with calibrated divers depth gauges, giving a 0.2 m accuracy. The phytobenthic communities as such are in general not directly dependent on the water column pressure increasing with depth. However, the directly structuring environmental parameters light and water movements will decrease with increased depth.

The depth noted during the dive has to be calibrated to mean depth (chart depth??) when put into the database. Therefore, the water level must always be noted (if no "pegel" in the vicinity then by noting the clock time for the dive and by consulting tidal tables.

When the depth distribution of species is the aim of the study, a good strategy is to pick or stratify the area that several stations reach deeper than the expected deepest finding of the species investigated.

Light

All plants are dependent on the light climate. In clear water the light decreases exponentially with depth. The depth distribution of plants is dependent on the quality of the water. The change of water quality change is reflected in the depth distribution of the plants. There is a strong correlation between the max depth of plants and the secchi depth reflecting the light climate of the area (Dannish text K3W etc.).

As a routine, when possible (it requires a boat), the easily established secchi depth should be measured at every station. The secchi depth is bound to change quickly depending on the weather conditions at the moment of measuring. For monitoring purpose the average change of the secchi depth over the years is of major interest. Therefore, the changes in secchi depth should be measured at least by other programmes in the area. The measure done during the dives may be used to compare the different sub-areas visited.

Substrate

The type of substrate along the transect has to be known as different plant and animal communities have different ability to stay on and occur on the different types of substrate. The share of mixed and soft substrates id bound to increase deeper down. In many cases e.g. when going deeper down the type of substrate sets the limit of species distribution not the light. To describe the biodiversity of an area as many of the different substrates should be incorporated. The algal communities usually dominate on hard and mixed substrates while seaweeds may dominate mixed and soft substrates.

The substrate noted *in situ* is divided into rock, boulders, stones, gravel, sand and soft. Each type of substrate is given e coverage, e.g. rock (100 %) has on it scattered boulders (10 %) and stones (25 %). Afterwards then, the substrate can be classified in the database as hard, mixed or soft substrates.

Table xx. The types of substrates and their codes used in databases. The ICES codes also contain SH = shells, CM=common mussels and OT= other, which are not used in the Baltic Sea, Sweden.

description	substrate code local SE	ICES	rock RK	boulders BD	stones ST	gravel GR	sand SD	soft SS	
hard	1	RK							
	2	BD							
	3	BD							
	4	ST							
mixed	5	MX							
	6	ST					(including, if only stones)		
	7	MX							
	8	GR						(including if only gravel)	
	9	MX							
sand	10	SD							
soft	11	SD							
	12	SS							
others	13	MX/OT						(alternative also soft - SS)	
hard	14	MX						(alternative also soft - SS)	

Percent coverage

The percentage cover of the different substrates is essential in the case where e.g. a vast area along the transect is covered by seemingly depleted sand or soft substrate, on the scattered boulders a luxuriant growth of plants is described which may cover the boulder completely but as boulders only have a given low occurrence (percent cover) the total coverage of the plants will be low in the area.

The percent coverage is estimated by the divers "directly" by looking around in the corridor of the transect and making a general description of the depth interval. The method makes an observation of the conditions, and not a sample of the area, which then has to be statistically interpreted. The seemingly subjective way is fully replicable by any skilled diver and thus quite objective (for discussion see e.g. [Dethier, 1993 #759] and below).

The percent cover scale for both the substrate and the biota is derived from the classical Bran-Banquet six-point scale. A seventh category, 75 %, has been introduced. The divers can not census more detailed coverage estimates without using any kind of device as e.g. grid frames or photogrammety of areas with fixed size. But it has proven that this percentage scale if fully accurate for the purpose to detect change

within the phytobenthic communities (ref.). The percent coverage are interpreted as follows: + is for presence, if a species was observed once, 5 % is when the species occurs in low numbers and covers a minor part of the substrate, 10 % is when the species covers clearly less than 25 % and more common than only on 5 % of the substrate. The percentage of 25 % means clearly less than half the substrate is covered but clearly more than 10 %. At 25 % coverage and higher the species is considered as belt forming. Half of the substrate means 50 % and the entire substrate covered means 100 %. In cases where clearly more than half of the substrate is covered but not the entire substrate 75 % is noted. In practice, there are no problems to give right, repeatable results replicable among different divers of coverage above 25 %. In the Swedish monitoring programme in the Baltic Sea usually two divers make the coverage estimates and they have exactly the same estimates from 25 % and higher. The lower estimates may differ with one step (25 % instead of 10 or 5 instead of 10 %). To improve the estimate a simple trick is to see how much of the substrate is not covered by the species in question. This "negative" estimate (well known from art classes) of how much is not covered will give a better estimate in general. Divers tend to overestimate conspicuous species and underestimate discrete and cryptic species, as well as species they are uncertain of their name.

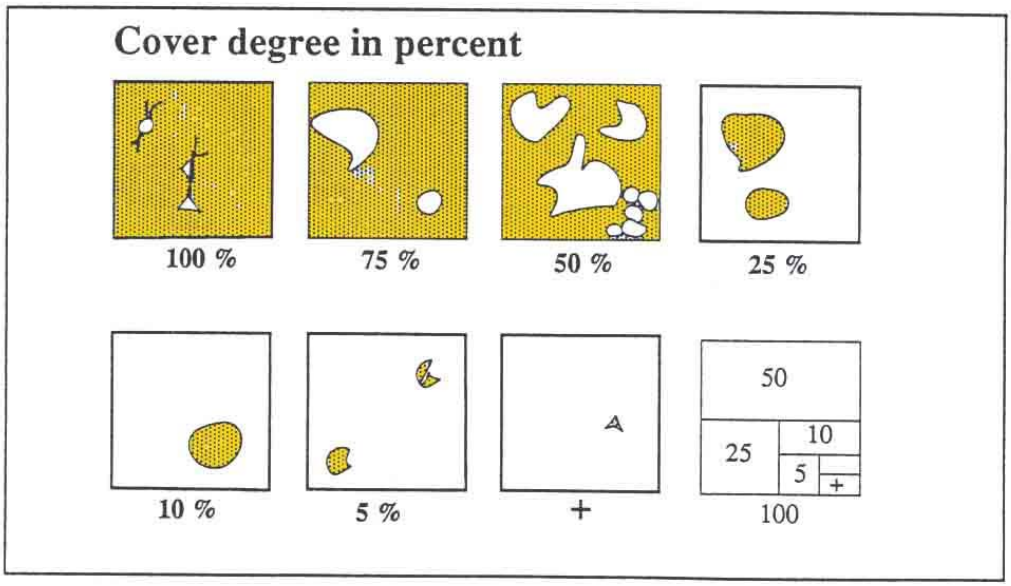


Figure xx The percent coverage used. In the lower right corner the classical subdivision used by Braun-Banquet is shown (slightly modified, as every lower percent scale should be half of the former).

Siltation

The amount of silt on the substrate will tell of the wave exposure of the site and the water currents over the substrate. In monitoring a change in the silt content may theoretically alter the substrate from hard to soft.

The silt on the substrate is estimated by using an induced water current by the divers hand to stir up the silt. A simple four grade scale is used where 1 is no siltation, 2 is moderate siltation, i.e. the induced water movement will stir up silt but that will settle directly, 3 is when the silt stays for a while in the water column but settles within a few moments within one or two minutes) and 4 is when the silt permanently destroys

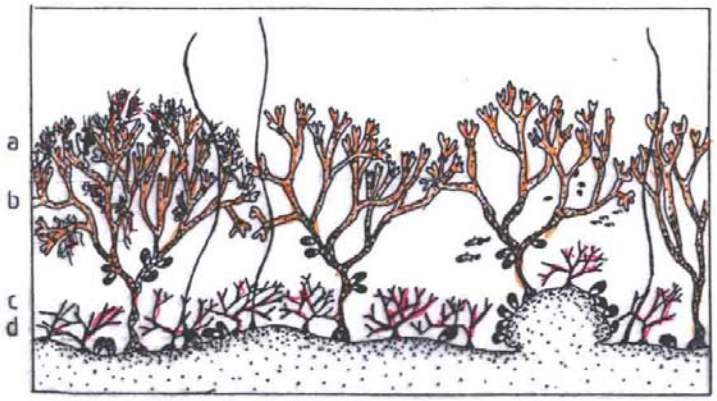
the site for the diver for a long period (several minutes to hours). The silt is noted on the plate immediately after the estimate of the substrate. as silt1, silt2, silt3 and silt4.

The depth distribution and coverage of biota

The purpose of the method is to establish the depth distribution of the plant and animal communities in the phytobenthic zone. Depending on the budget and/or skill of the operator, parts of the biota may be studied, e.g. seaweeds, *Fucus*- or *Laminaria* communities. Any conspicuous species that is relevant for the purpose, e.g. especially sensitive species to a given pollutant under investigation, may be chosen.

The species are noted immediately as they are observed under water. The distance and depth is noted followed by the species name and an estimate of coverage using the seven-point scale described above. For every species observed the coverage is estimated. Thereafter the divers continue and swim in the corridor along the meter marked transect line. A new note of distance, depth substrate silt and species and their coverage is done when there is a change (new species or coverage). It is essential that the observations are noted directly under water, because the memory seems to fail and nothing is remembered after a while under pressure.

The estimates are done for all species, including the epiphytes. As the communities have different strata: a bottom layer, shrub layer and canopy with epiphytes, the total coverage will often be far over 100 % Figure xx).



Figur 6: Blåstångbältet kan delas upp (som på land) i ett trädskikt som består av blåstången själv (a) vars övre del i allmänhet är lite bevuxen (a) och den nedre delen är kraftigt bevuxen med växter och djur (b), ett buskskikt (c) bestående av t.ex. rödslick och gaffeltång samt ett grässkikt (d) bestående av röd- och brunhinna och en del fastsittande djur. Tångruskan till vänster är i dålig kondition och därför helt övervuxen.

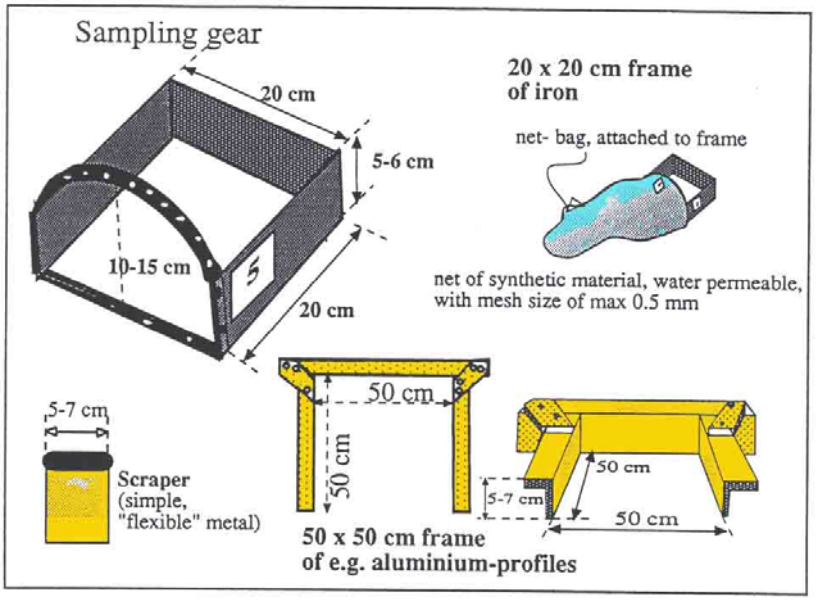
Special observations as e.g. grazing marks on the thallus of plants, frequency of gametes etc. should be marked.

The loose plants should be included. In recent years problems caused by loose and decaying filamentous algal mats on shallow substrates have been discussed (ref…). the loose plants are treated as the attached - when possible they should be determined to species and given a percentage cover of the substrate. In several areas loose plant may form natural, living communities. However, the deepest finding of a species should be based on observations of attached specimen.

Quantitative samples

As the ability of recognizing species under water are limited, samples have to be collected. In some cases it will be enough to collect species for the later determination on land or in lab. Preferably, the divers always carry a number of in beforehand uniquely numbered mesh bags in a pocket of their buoyancy west or whatever appropriate. The samples are then collected into any of mesh bags just picked from inside his pocket and the number of the bag is noted on the plate together with distance and depth of collection.

For biodiversity studies quantitative samples have to be collected. An easy, well proven way is to use frames. The frames should have the frame size appropriate for the communities collected. In the Baltic Sea as standard frames of 0.5 x 0.5 m side length are used to collect samples from the *Fucus* communities and some seaweed communities. If *Fucus* is collected only the *Fucus* plants attached within the frame are picked. For the remaining community a frame with the side length of 0.2 x 0.2 m is used. The frame is placed on the substrate and everything within the frame is scraped into a mesh bag attached to one side of the frame (Figure xx).



Thus, the sample reflects a unit area of the substrate. The samples are then transformed to appropriately marked plastic bags and frozen for later sorting on lab. On lab, the samples are sorted to species or nearest higher taxon or to the level decided by the goal of the investigation. The animal species are counted, and each species is dried separately in 60 °C to constant weight, i.e. at least two weeks. In the Swedish monitoring programme the biomass is given in g dry weight per m^2, including shells when present.

Photo 5. Four different designs of "Kautsky" frame used in different Baltic laboratories (use of this type of frame is suggested by HELCOM COMBINE Guidelines).

The size of the frame has to be appropriate for the purpose of the investigation and for the species collected. It is strongly recommended to keep the use of different frame sizes at a minimum. The frame size may be one cause for an observed difference in the results. The problem is of course resolved by using just one frame size. However, a simple cost - benefit analysis will show that this is not always practical. It takes to long time to process a 0.5 x 0.5 quantitative frame if the entire community was sampled.

The data are stored in a database (Sweden uses Access) www.ices....., example of the contents in the database is given in a spreadsheet below:

Annex 11: Draft Resolution for ICES BEWG phytobenthos TIMES

The report on the **The importance of the phytobenthic plant and animal communities to marine ecosystems and their scientific study,** edited by **Hans Kautsky** as reviewed and approved by the Chair of the Marine Habitat Committee, will be published in the *ICES Techniques in Marine Environmental Sciences (TIMES)* series. The estimated number of pages is 50.

The Benthos Ecology Working Group (BEWG) agrees to submit the final draft of the proposed publication by December 2008.

Supporting Information

PRIORITY:	High
SCIENTIFIC JUSTIFICATION	This text ist the first approach of ICES into the field of phytobenthos research although the advisory routine has already covered this field. In order to provide reliable and comparable data on phytobenthos biomass, diversity and the phytobenthic community it is of utmost importance that generally agreed method recommendations are published that help the individual to approach this goal.
RESOURCE REQUIREMENTS:	Cost of production and publication of a 50-page TIMES. The material in the reports is fairly straightforward, and therefore no specific additional costs are necessary.
PARTICIPANTS:	Approximately one month's work is required by the editor to finalise this draft.
SECRETARIAT FACILITIES:	About one month of the services of Secretariat Professional and General Staff will be required.
FINANCIAL:	Secretariat support with document preparation, publication and final editing..
LINKAGES TO ADVISORY COMMITTEES:	ACOM
LINKAGES TO OTHER COMMITTEES OR GROUPS:	MHC, BEWG, SGEH, WGMHM, SGBIODIV, SGQAB
LINKAGES TO OTHER ORGANIZATIONS:	HELCOM, OSPAR

Annex 12: Technical Minutes from the WGECO Review Subgroup

- WGECO
- The review took place during the WGECO meeting (6–13 May).
- Reviewers: Jake Rice (Chair)
  Catherine L. Scott
  Ellen L. Kenchington
  Gerjan Piet
  Keith Brander
  Stuart I. Rogers
  Øystein Skagseth
  Secretariat: Cristina Morgado
- The reviewers provided written comments to Section 4 and Annex 9 of BEWG report.

General comments

Section 4 and Annex 9 of the 2008 BEWG report had a fair number of short presentations of useful information for illustrating how different benthic species or communities can be affected by environmental conditions. All such information was clearly presented and well documented. This information was very important for the case histories used by WGECO. However the BEWG do not provided quantitative information that allows WGECO to use in any integrative analyses. The cases presented were a positively biased subset of a much larger group of species - much larger but of unknown size, that were examined before those cases were studied.

In Section 4 and Annex 9 of BEWG report there is no time-series information available that allows WGECO to separate the "normal variation" from the directional climate signal in the hydrographic information. BEWG misses the point that the central focus of the ToR a) was to try to determine how much, if any, of the changes in the benthic populations (species or communities) were behind what of was expected from the "normal variation".

The material provided by BEWG on Section 4 and Annex 9 on possible hypotheses for how benthic populations, species and communities could be affected by climate change were very interesting. However, the RG considered that this output is too late at this stage. RG was expecting the best information available for testing some of those hypotheses - or even better - the results of their own efforts at testing them with the best information that they could pull together.

It is fairly clear that future requests of this kind will require more detailed dialogue between the WG and the group carrying out the overview and analysis in order to ensure that there is a common basis and methodology and that the WG is clear about what information is required. A common source of data and products on changes in ocean climate is an essential part of this.