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International Council for the Exploration of the Sea

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Executive summary

WGINOSE is a new initiative to develop the science base for Integrated Ecosystem Assessments (IEA) in the ICES area. The group works towards this goal in cooperation with similar groups within the ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP). The meeting gathered 40 scientists from 5 countries.

This first meeting of WGINOSE had the aim to reactivate activity towards Integrated Ecosystem Assessments (IEA) for the North Sea using the groundwork of the REGNS group and WGHAME as baseline. Its focus was clearly on reviewing available (i) approaches to IEA, (ii) data for analyses on ecosystem status and trends, as well as (iii) modelling approaches to be used in a future IEA. The meeting was quite successful in terms of participation: it was attended by scientists from many different fields and hence set the baseline for its future work.

Concerning the framework for IEA to be developed for the North Sea and other ICES areas, WGINOSE considers the US approach towards IEA (Levin *et al.* 2009) to be a model for its future work. The approach is useful as it is based to a large degree on modelling approaches and data that are available for the North Sea. Still, the links between different modelling approaches need to be developed for conducting a full IEA management cycle. This development of IEA should be well coordinated between the different related groups within SSGRSP. WKBEMIA to be held in November 2011 will be a first step towards this goal. WGINOSE furthermore suggests a common meeting with the WGIAB in 2012 for coordination for IEA development and mutual methodological input. This needs to be decided during the ASC 2011 in Gdansk.

Based on the reviews of data availability and modelling approaches, WGINOSE has developed a roadmap for its future work concerning (i) ecosystem state and trend analyses, and (ii) ecosystem modelling:

i) A stronger regionalization of the ecosystem analyses is intended, i.e. conducting several separate analyses for North Sea sub-systems. WGINOSE identified potential sub-areas of the North Sea (see chapter 4.1) to be dealt with in the future. Furthermore, Wadden Sea and Skagerrak ecosystems will investigated in addition to "central" North Sea areas.

ii) Different approaches to conduct a WGINOSE modelling study have been discussed and it was concluded to initiate a multi-model study similar to the BEMA-approach developed within WGIAB (see chapter 6.10). This study will conduct projections of the North Sea foodweb and fish stock dynamics based on projections of coupled atmosphere-ocean models. It is intended to use a number of single-, multi-species and foodweb models. The design of the study will be developed intersessionally. Eventually, the output of the study can be generalized using Bayesian Belief Networks.

iii) Management-related activities in addition to the development of a full IEA management cycle is complementary to the ongoing work related to the EU-MSFD descriptors and indicators. WGINOSE intends to provide the results of their work to European and national GES working groups. This includes the further mapping of the available data and modelling outputs potentially valuable for EU-MSFD indicator and threshold development.

Overall, this first meeting of WGINOSE appeared to be a promising and successful start o f this initiative and will hopefully keep momentum in the future.

1 Opening of the meeting and adoption of the agenda

Gerd Kraus (GK) welcomed the participants in the von-Thünen Institute (vTI), Institute for Sea Fisheries and introduced the local facilities. Christian Möllmann (CM) introduced the aims and vision for WGINOSE. The group is intended to contribute to the development of the Ecosystem Approach to Marine Resource Management via delivering the science-base for Integrated Ecosystem Assessments (IEAs) for the North Sea.

CM furthermore gave a summary on the ICES structure and how the work of WGINOSE will fit into the general strategy of the SCICOM Steering Group on the Regional Seas Programme (SSGRSP) and link to other regional IEA groups. The concept of IEA is considered as a form of a management cycle and CM introduced the IEA developed by NOAA in the US (Levin *et al.* 2009, Tallis *et al.* 2010) as a model for the future work of WGINOSE. He pointed especially to the large variety of expertise, data and modelling approaches needed for conducting IEAs. Hence this first meeting of WGINOSE had the main goal to conduct extensive reviews on monitoring and modelling activities for the North Sea area.

CM furthermore gave an introduction into the Terms of Reference (ToRs) and how they relate to planned work of the meeting. The ToRs for this meeting were:

The Working Group on Holistic Assessments of Regional Marine Ecosystems (WGHAME) will be renamed Working Group on Integrated Assessments of the North Sea (WGINOSE) and chaired by Christian Möllmann, Germany; and Gerd Kraus, Germany, will meet in Hamburg, Germany, 21–25 February 2011 to:

a) Conduct a review on the various concepts of Integrated Ecosystem Assessments (IEAs), including an evaluation of their suitability to the specific North Sea needs in terms of science and advice;

b) Update the Integrated Status and Trend Assessment of the North Sea, and explore the data availability for conducting ecosystem analyses of subsystems such as the German Bight and the Wadden Sea;

c) Conduct a survey on monitoring and observation activities as well as on data availability for North Sea IEA;

d) Report on the available modelling approaches in the North Sea, evaluate their suitability for IEAs and begin to develop a modelling strategy for a North Sea IEA;

e) Review the work of other integrated assessment activities within ICES (e.g. WGNARS, WGEAWESS, WGIAB), in other international organisations (OSPAR, NAFO) as well as in on-going research projects.

In summary the intention of this first meeting was to scope data and modelling approaches as well as integrated management strategies in order to define a strategy for the practical work of WGINOSE in the next years. This strategy is outlined in chapter 7.

The agenda was adopted by the group after a short discussion (see Annex 2).

2 Review of Integrated Assessment concepts and links of WGINOSE to other activities (ToRs a & e)

A crucial future task of WGINOSE in cooperation with similar groups within ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP) is to develop Integrated Ecosystem Assessments for ICES areas. As a first step towards this goal WGINOSE has reviewed some major related activities which are described and discussed below. No review of WGEAWESS and WGNARS has been conducted, as either the groups have not met yet or reports were not available. However, the integration of the different ICES SSGRSP groups is expected to be started during the Workshop on Benchmarking Integrated Ecosystem Assessments (WKBEMIA), during a meeting at the ICES Headquarters in November 2011. The chapter below can serve as input to WKBEMIA.

2.1 Integrated ecosystem assessments: existing frameworks

Several approaches to Integrated Ecosystem Assessments (IEA) have been developed with the ultimate purpose of guiding management actions. Here we summarize the work done by OSPAR and within ICES (REGNS/WGIAB) and include examples from the United States and Canada as well as recent progress in Europe.

ICES WGECO 2007 & 2010 provided a terminology for ecosystem assessments. In the context of this chapter it is helpful to distinguish between ecosystem assessments, imaging the whole ecosystem with its major abiotic drivers, and environmental assessments, where effects of a human activity on sometimes only parts of the ecosystem are considered. In this respect, WEGECO 2007 separates between Strategic Environmental Assessments (SEA) and IEAs. WGECO 2007 synthesizes both approaches under the term "IEAs for Integrated Management of all human activities in the sea" (hereafter IEAIMHAS) comprising ecosystem dynamics and interactions, trends, cumulative effects of human activities and socio-economic analysis.

2.2 Assessment criteria and policy targets

The methodology and interpretation of assessments depends on the setting of criteria such as reference levels. In some cases, a two-step approach is followed in that operational targets and reference levels are applied. Targets are much easier to establish since they do not require an integrative assessment procedure to be carried out.

OSPAR mostly refers to natural background levels. In some cases, additional targets are set, mainly for Ecological Quality Objectives.

2.3 OSPAR approach

When referred to the "OSPAR approach", it is often overlooked that the OSPAR pilot study on holistic IEA (the Utrecht approach) is in fact only one out four different assessments carried out for the Quality Status Report 2010. Altogether, there is only little coherence between these types of assessments.

2.3.1 Sectoral assessments: Eutrophication, hazardous substances and BDC assessments

OSPARs core competence is in the field of eutrophication and hazardous substances assessments (incl. radioactive substances). For these assessments, established frameworks are available. For eutrophication, the available target is the 50% reduction on nitrogen and phosphorus input into marine waters. For hazardous substances, assessments criteria include natural background as well as concentration levels that are not harmful at the population level. A semi-spatial analysis is undertaken in that monitoring stations are counted with either acceptable or unacceptable concentration levels. OSPAR's biodiversity committee (BDC) undertakes assessments on a list of declining and threatened species and habitats based on IUCN criteria for the assessment of conservation status. BDC assessments follow the key-species principle meaning that the focus on rare and declining species as key species provides benefit to the ecosystem as a whole. Assessments are carried out in relation to pressures.

2.3.2 Holistic assessments: EcoCOs and the Utrecht pilot study

OSPAR's EcoCOs are a first step towards a holistic assessment of selected ecosystem components against human pressures. The eutrophication EcoQO is consistent with the eutrophication assessment carried out earlier. For the 10 remaining EcoQOs, new assessment avenues were chosen as compared to BDC and hazardous substances assessments, e.g. whereas in the hazardous substances assessment concentrations is sediments and bio-effects in dab (*Limand limanda*) are investigated, the respective EcoQO aims at reduction of contaminants in bird eggs.

The pilot study as a comprehensive assessment in all 5 OSPAR areas again chooses a new methodology. Opposite to the previous steps, which more refer to SEA than to IEA, the Utrecht approach is an attempt towards IEAIMHAS. Based on the Robinson *et al.* (2009) methodology it applied an expert-judgement assessment of nine broad ecosystem components across the five OSPAR Regions at a workshop held in Utrecht in February 2009. Essentially, it was a qualitative assessment of the status of a number of broad ecosystem components taking into account the degree of impact of any relevant pressures on them, and using the best available data and knowledge to guide the assessment. Geo-referenced data on the distribution of state and pressure variables was provided where available and other source materials included reports and peer-reviewed papers. Where necessary, the best available information was the collective knowledge of those experts present and a confidence assessment was used to qualify this. The methodology was based on the conceptual risk-based approach of Robinson *et al.* (2008) but was modified to meet the requirements of the OSPAR Quality Status Reporting on the ecosystem status of the OSPAR regions. This meant that the assessment of resilience and resistance within the risk-based approach was considered against two reference levels instead of the original one, and that the baseline used was pre-industrial conditions (as specified in the OSPAR guidance). The reference levels (thresholds in Robinson *et al.* (2009)) were based on the (modified) Habitat's Directive Criteria for Favourable Conservation Status for Habitats and Species. They were used to set thresholds between Good and Moderate and Moderate and Poor status, and to assess the degree of impact of any relevant pressures (those that an ecosystem component was exposed to) as High, Moderate or Low.

The assessment covered most biological aspects of the ecosystem grouped into broad categories (e.g., fish, marine mammals, deep sea habitats, seabirds), but missed other components such as the plankton, marine reptiles and jellyfish. It assessed the effects of pressures on the components, but it did not explicitly assess interactions between components, nor the effects of environmental drivers (unless they were covered by pressures resulting from themA review of the assessment using the Assessment of Assessment's (AoA) criteria is also given in ICES Advice 2009, Section 6.

2.3.2.1 Strengths

1) The framework itself was well received by the participants of the workshop, including the use of a clear audit trail and confidence assessment,

and the value of ensuring consistency across components and pressures was realised.

2) The process was successful in guiding a wide group of experts (over 60 participants from various discipline backgrounds and nationalities) to complete an assessment for large regions and multiple pressure/ component interactions in a limited time frame (5 days).

3) The process would allow the following questions to be answered:

Which key pressures of human activities are likely to be responsible for the observed trends or patterns in the ecosystem components?

Which human activities are likely to be producing the specific mix of pressures?

4) A review of the process using the AoA criteria suggested the framework scored highly in terms of relevance, and reasonably well in terms of legitimacy.

5) The framework is based on the list of ecosystem components and pressures listed in Annex III of the MSFD.

6) The use of a "worst-case" example should allow for any particularly vulnerable cases (e.g., species, habitat types) to be highlighted where they would not show up in the broad component category.

2.3.2.2 Weaknesses

1) It is not a truly an integrated ecosystem assessment because the framework does not include:
   - Socio-economic drivers;
   - Interactions between ecosystem components;
   - Environmental/abiotic drivers.

2) A review of the process using the AoA criteria suggested the framework scored poorly in terms of credibility, largely because:
   - The level of aggregation of some ecosystem components was unsuitable;
   - The thresholds used were inappropriate for some of the components and had no scientific basis.

3) The spatial scale of application did not match well to the threshold criteria for some ecosystem components.

4) The confidence in the assessment undertaken for some components in some regions was very low, and although a confidence assessment was included, there was some concern that the level of confidence would not be well conveyed in any final reporting based on such an assessment.

5) Although detailed instructions were given on the steps to follow in the assessment, there was some inconsistency of application between groups working on different ecosystem components. In particular, some groups used very different baseline conditions despite these being specified in the instructions.

6) This approach does not lead directly to management measures. This would require a further step.

7) The treatment of aggregate effects of different pressures on components was based on a score-based approach. The rationale for such an approach needs to be considered further.

8) There was not enough time allowed for the provision of data to the assessment process. Participants commented that they would have been much more confident with the results obtained had better data (where it does exist) been made available to them.

2.4 REGNS/WGIAB approach

Within ICES experts group followed an approach developed in the US and Canada (Link *et al.* 2002, Choi *et al.* 2005). This approach can be largely considered as an assessment of status and trends in many ecosystem components. It generally involved multivariate statistical analyses (e.g. Principal Component Analyses, PCA) and some discontinuity analysis to detect abrupt structural changes (i.e. regime shifts). The work in ICES was pioneered by REGNS (Regional Ecosystem Study Group for the North Sea; Kenny *et al.*, 2009). The North Sea ecosystem was defined on the basis of 114 state and pressure variables resolved as annual averages between 1983 and 2003 and at the spatial scale of ICES rectangles. The coverage of ecosystem components was limited to seabirds, plankton and fish and the assessment included a number of environmental drivers but only pressure variables related to one type of human activity – fishing. The variables were selected on the basis that they included data from a long unbroken time-series and broad spatial coverage at the scale of the North Sea. The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea applied the same approach to the Baltic Sea (Möllmann *et al.* 2009, Lindegren *et al.* 2010) with a stronger focus on regionalization, i.e. conducting analyses for several subbasins of the Baltic Sea (Diekmann & Möllmann, 2010).

2.4.1 Strengths

- The method allows for the identification of spatial and temporal trends across many different indicators or variables. Based on this some broad spatial and temporal patterns were identified for the North and Baltic Seas.
- The "shade plot" or "traffic-light plot" produced summarises patterns over many aspects of the ecosystem in one 2-dimensional picture.
- The methodology using relatedness (connectivity) between components can be used to explore the interactions of components and of the effects of environmental and human drivers on them.

2.4.2 Weaknesses

- The assessment is limited to components (ecosystem and pressure) that have available time-series over similar periods and spatial scales.
- Using this data-driven approach it would be difficult to include a full complement of pressures and ecosystem components.
- There is no inclusion of socio-economic data, and again, the inclusion of this would be limited by data resolution and coverage (spatial and temporal).
- There are a number of limitations with the analyses used:
  - The approach is essentially correlative with all known associated drawbacks: primarily, it is difficult to interpret what is cause or effect, common consequence of a hidden factor, or what are concomitant trends just by chance;
  - An unweighted principal components analysis gives equal weight to each variable and the distribution of variables amongst components

was not equal. The 'shade plot' produced from the anomalies of the PCA eigenvalues is limited by this assumption but this is not intuitively obvious to end users.

- The conclusions that can be drawn from the relatedness analyses to explore interactions between components and between components and drivers are limited in scope because of the exclusion of certain aspects of the ecosystem (ecosystem components and pressures on them).

2.5 United States approach

In the United States (US) context, an integrated ecosystem assessment (IEA) is defined as a formal synthesis and quantitative analysis of information on relevant natural and socio-economic factors, in relation to specified ecosystem management objectives (Levin *et al.*, 2009). IEAs do not necessarily supplant single-sector management; instead, they inform the management of diverse, potentially conflicting ocean-use sectors. The development of an IEA can be described as a five-stop process with a sixth step that provides monitoring feedback. These six steps are briefly described below and are linked, to the extent possible, with the steps of the MSFD (as listed above).

1) Scoping process to identify key management objectives and constraints. Starting from the entire ecosystem perspective the scoping step focuses the assessment on a sub-system of ecosystem components that are linked to the issues of management importance. The scoping process involves stake-holders with differing objectives, which cross ecological, social and political boundaries and who have unclear or open-access property rights on ecosystem services. The scoping process corresponds to elements of the MSFD initial assessment (Step 1).

2) Identify appropriate indicators and management thresholds. Indicators may track the abundance of single species, may integrate the abundance of multiple species, or serve as proxies for ecosystem attributes of interest that are less readily measured.

   Management thresholds can be derived from historical baseline data and/or models fit to the ecological data. Useful indicators should be directly observable and based on well-defined theory, be understandable to the general public, cost-effective to measure, supported by historical time-series, sensitive and responsive to changes in ecosystem state, and responsive to the properties they are intended to measure (Rice and Rochet, 2005). The step corresponds with establishing a series of environmental targets and associated indicators in the MSFD (Step 2).

3) Determine the risk that indicators will fall below management targets. The goal of the risk analysis is to qualitatively or quantitatively determine the probability that an ecosystem indicator will reach or remain in an undesirable state as specified by thresholds in Step 2. Risk analysis is used to characterize the scale, intensity, and consequences of particular pressures on the state indicators, either by qualitative ranking by expert opinion or with quantitative analyses. The MSFD does not include explicitly a risk-analysis step, but a risk-based approach has recently been suggested as an appropriate aspect of prioritising management within the MSFD assessment (Cardoso *et al.*, 2010).

4) Combine risk assessments of individual indicators into a determination of overall ecosystem status. The risk analysis quantifies the status of individual ecosystem indicators, whereas the full IEA considers the state of all indicators simultaneously. The US approach relies heavily on ecosystem models of varying degrees of complexity to provide this integration. The MSFD does not require this integrative step, or provide guidance on how to integrate multiple indicators into fewer.

5) Evaluate the ability of different management strategies to alter ecosystem status. Ecosystem modelling frameworks are used to evaluate the ability of different management strategies to influence the status of natural and human system indicators. Management strategy evaluation can be used as a filter to identify which measures are capable of meeting the stated management objectives. This step corresponds to an important aspect of the process of developing a programme of measures in the MSFD (Step 4).

6) Monitoring of ecosystem indicators and management effectiveness. Continued (and possibly enhanced) monitoring of ecosystem indicators is required to determine the extent to which management objectives are being met. A separate evaluation of management effectiveness is required to determine if management measures are having the desired effect on the pressure indicators. This step can be considered adaptive management in an ecosystem context. It corresponds to the establishment of a monitoring programme in the MSFD (Step 5).

2.5.1 Strengths

1) The IEA process and its objectives have been defined in published articles.

2) Provides an explicit vehicle to focus assessment and management actions across government agencies and state and federal jurisdictions.

3) Flexibility to make the management objectives and constraints specific to the region.

4) Management objectives can be determined as part of the scoping process, which allows for opportunity for increased stakeholder input.

5) IEAs can be performed at different spatial scales, ranging from Puget Sound (e.g., 100 km) to the California Current (e.g., 1000 km).

6) Includes risk assessment as an explicit step.

7) Combines risk assessments of individual indicators into a determination of overall ecosystem status. Integration is provided by ecosystem models, including pressure-state links.

8) Monitors ecosystem indicators and management effectiveness, allowing for adaptive learning.

2.5.2 Weaknesses

1) Lack of central guidance on the scope and core elements of an IEA (e.g., no candidate lists of state indicators and pressure indicators).

2) IEAs may become open-ended or diverted if the management objectives are not stated a priori.

3) Because of this the indicators and modelling framework may be inappropriate for answering the management questions.

4) Heavily dependent on ecosystem models (Ecopath, Ecosim, Atlantis), even in data-rich regions, to provide the integration of state indicators and to evaluate management measures (is the real ecosystem being assessed or the model of it?).

5) The IEA process does not provide guidance for setting reference points for ecosystem attributes; in the US reference points for fish stocks, marine mammals and endangered species are set by law in the corresponding acts.

6) The IEA process can help to justify existing monitoring programs but has no mandate to initiate additional monitoring to fill data gaps.

2.6 Canadian approach

The Ocean Action Plan (OAP 1; http://www.dfo-mpo.gc.ca/oceanshabitat/oceans/oap-pao/index_e.asp) developed under Canada's Oceans Act, (http://www.dfo-mpo.gc.ca/acts-loi-eng.htm) included plans to develop Integrated Management Plans for five Large Ocean Management Areas (LOMAs). The governance processes for integrated management plans was to be based on inclusive planning and consultation "tables" where multiple departments from federal, provincial and territorial, and municipal governments would all participate, along with representatives of a range of stakeholders from ocean industries, social, environmental and business organisations, academia, and communities. At these tables mixes of human activities would be discussed which would together provide the suites of social and economic benefits sought by the participants, while ensuring healthy and productive ecosystems. These consultations were to be informed by Ecosystem Assessment and Overview Reports (EOARs).

Early in the EOAR process, it was decided to take a criterion-based approach to identifying conservation priorities for each LOMA. Initially, a priori criteria would be set, on scientific grounds, for ecologically and biologically significant areas (EBSAs) (DFO, 2004), ecologically and biologically significant species and community properties (EBSSs) (DFO, 2006), depleted species, and degraded areas. Degraded areas were dropped part way through the process because of jurisdictional concerns. For depleted species, it was agreed that the assessments already being done by DFO relative to limit reference points, and assessments done by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), were sufficiently rigorous and broad in coverage to be the source of candidate Conservation Objectives associated with depleted species. The criterion-based approach to assessing ecosystem status had the advantage of making the choice of Conservation Objectives transparent and objective.

The criteria were all relative ones, such that within each class (EBSA, EBSS, Depleted species) the Conservation Objectives were ranked by ecological priority. However, as work progressed, it became clear that for the ecological importance of the Conservation Objectives to be consistent within and among LOMAs, guidelines were needed on how to merge Conservation Objectives from the three separate lists (for example, how to rank a badly depleted species of fish relative to a rare habitat type, and relative to a key foraging species). This guidance, and associated guidance on how to phrase the high priority outcomes from application of the criteria as Conservations Objectives that met the criteria above, was provided by DFO (2007; 2008).

The EOARs were completed for all five LOMAs, and in most cases within the scheduled time frame (DFO-nd). Although the governance process has gone in a different direction than envisioned at the start of OAP 1, the EOARs have been used in a number of subsequent applications where some form of integrated science knowledge was needed as a basis for action, such as the Ecosystem Status and Trends Reports required for meeting commitments for reporting of biodiversity under the CBD.

2.6.1 Strengths

1) The criteria give an objective and documentable way to select some parts of the ecosystem for focus, whether during more in-depth assessments, prioritizing conservation initiatives, planning research, or other subsequent activities. They are relative criteria so that a series of areas or species can be ranked on the criteria, rather than providing a binary in-out decision, so the selection of areas gives more flexibility to follow-up actions.

2) The criteria can be applied by a rational science-based process, where the discussion and conclusions can follow established science peer review processes for reliability, plausibility, and balanced treatment of uncertain or contradictory evidence.

3) Application of the criteria necessarily requires "integration" of information across the ecosystem components; for example identification of "forage species" or evaluating the "fitness consequences" associates with an area.

4) The criteria that led to specific places and species being ranked highly can remain associated with the places or species in the follow-up activities, so the ecological contexts and interpretations remain associated with the assessment or management uses of the higher ranking places and species.

5) Because of #4, the results of application of the criteria can give clear direction to the nature of indicators that should be used and the properties that should be reflected in the position of the reference levels on the indicators. This removes much of the arbitrariness from selection of indicators and reference levels.

6) The criteria have been shown to be usable with a variety of qualities and quantities of data, from strictly narrative traditional knowledge to fine-scale and geo-referenced datasets.

7) The science basis for the individual criteria is well-documented, and can be revised and revised as needed, as further scientific knowledge accumulates.

8) The criteria seem to be pretty stable and robust, particularly the more widely-used spatial criteria. For the place-based criteria, a literature review of 47 different publications which considered criteria for ecologically or biologically significant areas concluded that there was very little functional difference in the criteria across publications, although different publications used different phrasing for some criteria (Deardon and Topelka, 2006).

2.6.2 Weaknesses and limitations

1) Because using the criteria produces a relative ranking of areas, or species, some other process has to decide at what point down the ranking it is appropriate to stop, if the decision is "include in a follow-up activity" (whether the activity is a more in-depth assessment or prioritization for enhanced conservation measures).

2) Although the a priori criteria give structure to discussions about which parts of an ecosystem are the most important to include in follow-up measures, they do not fully protect such discussion from selective advo-

cacy. People with a special interest in a particular ecosystem component or pressure can still build partisan cases for (or against) their component of pressure, and try to push their objective to the top (or bottom) of the priority list through partisan evidence.

3) The criteria that have been used to date address only ecological importance and function. There are no provisions for criterion-based evaluations of pressures. There is no conceptual reason why criterion-based approaches to pressures could not be done, but to our knowledge it has not been attempted.

4) The approach defers consideration of the interactions of pressures and components to a step after application of the place and species criteria. It also defers consideration of social and economic aspects of decision making to steps after the application of the place, space (and, possibly in future, pressure) criteria. The approach has no specific guidance on how social and economic factors should be considered, beyond that policy and management decisions should be risk-averse relative to places and species that are ranked highly relative to the criteria.

5) When data (or other information sources) are patchily distributed, criterion-based approaches are often biased towards identifying more high priority areas or species in the places or ecosystem components that most information rich. This weakness is not unique to criterion-based assessment approaches, but these approaches also have it.

6) For comprehensive assessments, it will be necessary to apply at least separate criteria for places that are ecologically significant and for species and/or community properties that are ecologically significant. This produces at least two separate lists of priorities, and a set of meta-criteria or rules are needed for merging the independent of different types of features.

7) Although there are tested sets of criteria for ranking places and species, there are no equivalent criteria for ranking pressures. The concept makes sense, and the information needed to develop such criteria for pressures could be assembled, reviewed, and synthesised into pressure criteria. However the task has not been done.

2.7 Progress in risk based integrative SEA

In recent years, three main SEA methodologies have evolved, i.e. pressure-state-response (PSR) models aiming at indicator-based management concepts (Greenstreet *et al.*, 2009, Link *et al.*, 2010, Rochet and Rice, 2005), process-based ecological risk assessment (ERA) models able to treat uncertainty in data and processes (Fock, 2011, Landis and Wiegers, 1997, Hayes and Landis, 2004), and score-based impact or vulnerability models preferably useful for broad scale assessments due to the wide range of impacts analyzed and the many ecosystem components covered (Halpern *et al.*, 2008, Stelzenmüller *et al.*, 2010, Ban *et al.*, 2010).

Based on the OECD model for sustainability indicators (OECD, 1993), PSR models have become highly influential in developing policies. In its extended form (DPSIR) PSR is state-of-the-art for integrated marine assessments in Europe (EEA, 2009). Key concept of PSR models is the description of the environmental state evidenced by means of an indicator value. PSR rationale has tailored recent maritime legislation in Europe, i.e. MSFD and Water Framework Directive (WFD, 2000/60/EC), in that policy performance is evaluated through a set of traceable indicators each assigned to a specific ecosystem descriptor. However, the link between indicator and pressure may not be defined in all its intricacies or be even indirect, and 'decoupling' indicators may be applied if state and pressure trends do not correspond any longer (OECD, 2003). Thus, indicators are not applicable to integrating assessments for more than one pressure.

Score-based impact assessments are destined to undertake integrative large-scale assessments, given that the score-based characterization of impacts aims at delivering commensurable scales for all pressures. In turn, state of the ecosystem as independently obtained target measure is not an essential element of impact assessments, although in some cases ecosystem state is directly derived from the impact however not as independent measure (e.g. in HELCOM, 2010). Often, the link between pressure and ecosystem is established through matrices (e.g. Robinson *et al.*, 2008) based on the concept of component interaction matrices (e.g. Shopley *et al.*, 1990).

In data rich environments and where high resolution of impacts is requested, ecological risk assessments (ERA) combine the merits of large-scale analyses with the modelling of stressor-component interaction processes such as mortality. Through its conceptual working steps, it is a systematic means by which risks may be understood and their estimation may be improved (Graham *et al.*, 1992, Harwell *et al.*, 1992, Fock, 2011, US Environmental Protection Agency, 1998) and can solve complex ecological problems (Lackey, 1998). As relative ERA, cumulative impacts from different pressures can be analyzed and compared across a range of ecosystem components (Fock, 2011). The concept of risk has two sides, in that on the one hand threats ('downside risk') and on the other hand opportunities as positive consequences ('upside risk') can be imaged, both with their associated uncertainties (Chapman, 1997, Fock *et al.*, 2011). Downside risk is a measure of impact on an ecosystem component as part of the impact assessment (Fock, 2011), whereas positive risk is a further measure of effect on the state of the ecosystem component through a gain function.

For WFD purposes and thus not yet assigned to marine offshore waters, mainly indicator-based methodologies have been applied for assessments of benthic environments, either with a focus on integrating pressures (Aubry and Elliott, 2006) or on the state of the benthic environment (Borja *et al.*, 2009a, Magni *et al.*, 2005).

2.7.1 Link between PSR and risk based assessments

A link between human activity and ecosystem component can be defined as that a human activity (e.g. fisheries) exerts several pressures (e.g. abrasion, extraction of biomass,…), which affect ecosystem components in different ways. Ecosystem component and pressure are quantitatively defined by their state (quantity, extension). Ideally, a state is discrete and measurable, it is sensitive to changes in an ecosystem and its response is specific to certain pressures (Link *et al.*, 2010). For fisheries as a source of pressure, a suite of state indicators is available (e.g. measures of fishing effort Piet *et al.*, 2007). The state of ecosystem components (e.g. benthos, birds) is defined in terms of certain endpoints (biomass per unit, abundance, diversity etc).

In both the ERA and the PSR framework, the link between pressure and ecosystem component is formalized in a conceptual modelling step (Figure 3.1) (US Environmental Protection Agency, 1998), however this link is treated differently. In the PSR framework, the state of the indicator is a direct consequence of the pressure, which builds the basis for the indicator-based rationale (Figure 3.2).

This concept bears a number of caveats. First, the conciseness of the link itself depends on the adequate representation of underlying processes, the adequate selection of the indicator and the degree of resolution and aggregation the state indicators have (see hierarchy of indicators in Piet *et al.*, 2007) considering that univariate numerical state variables might not be able to reflect actual complexities in ecosystems (Rees, 2009). Indices require careful validation and selection from the suite of available methods, and generalizations for some components are yet not widely accepted (Borja *et al.*, 2009b). Second, due to delayed responses like hysteresis or resilience there may be no immediate reaction of the state to a change in the pressure. Long-term effects as known for benthic impacts of fisheries show that such instantaneous reaction is rather unlikely (Tillin *et al.*, 2006). Stochastic events may prevent the recovery of the system or attaining a predicted state. Long-term natural dynamics such as climate forcing add further variability and may lead to regime shifts, and thus weaken the established link between pressure and indicator (Mangel, 2006, Link, 2002, Frank *et al.*, 2007). This leads to the primacy of human impact management over ecosystem management (Lotze, 2004, Frid *et al.*, 2006). Practically, needing to define conservation targets for Natura 2000 sites under the European Habitats Directive the respective ICES working group recognized that it is straightforward to improve site management through the absence of human pressure if ecosystem reference conditions are unknown (ICES, 2008). Third, a lack of data or a weakly defined link between pressure and indicator may hinder to precisely define reference conditions for state indicators (Cardoso *et al.*, 2010). Reference conditions may be rather contemporary and reflect only a little of the desired background level (Rees, 2009).

Hence, the state of the indicator has limited operational properties. Consequently, the operational property to use should be fully reactive to the pressure as part of the activity, but also linked to the ecosystem indicator. Risk models solve this by means of an additional step that quantifies the potential interference between pressure and endpoint (i.e. indicator) in terms of up- and downside risk. Whereas the latter is assigned to the pressure and can be managed in terms of human impact management, the former delivers some prospect on the state of the ecosystem component itself. Opposite to state indicators, risk is probabilistic and multivariate (Fock, 2011). Risk is determined by the exposure likelihood or encounter probability taking into account quantitative state properties of both the pressure and the endpoint, and the strength of the consequence in terms of frequency, duration and impact rates. PSR models at their highest level resemble to some degree risk models (Piet *et al.*, 2007), but as mentioned above, integrative capacities remain limited. Both up- and downside risk explicitly are subject to uncertainty, i.e. uncertainty due to extrapolation and/or limited information which can be removed with more data, and uncertainty due to randomness of the system itself (Mangel, 2006, Landis, 2002). To incorporate uncertainty into ecosystem-based management advice is a key factor for future fisheries management (Frid *et al.*, 2006).

As output from the risk model approach, up- and downside risk and further derived properties, can be adopted to evaluate management options, whereas the state of the ecosystem component is not an integral part of the risk model and therefore outside the risk model framework (Figure 3.2). Down- and upside risk are defined through loss and gain functions, respectively. The relationship between gain or upside risk and the state of the indicator may be seen as a time function, i.e. the classical succession-time trajectory of an ecosystem component, which also takes into account its natural long-term sometimes irreversible dynamics.

Process-based risk models are data hungry and require extensive process studies (e.g. Piet *et al.*, 2000, Hiddink *et al.*, 2007) and knowledge on spatial distributions of involved features.

2.8 Conclusions

No single IEA approach described above fulfils all the requirements of the MSFD process (Table 3.1). Although the US approach covers all important components (ecosystem components, socio-economics, pressures (anthropogenic and natural) and interactions), the lack of guidance on how to set reference levels means that there could be poor consistency between and within assessments. The dependence on models to provide integration within the ecosystem requires a high degree of confidence that the models adequately describe the important ecosystem processes. Elements of both the OSPAR and Canadian approaches can, however, be developed and taken forward in guiding a suitable IEA approach that would meet the MSFD assessment requirements and these are described below.

In turn, risk based SEA could provide modelling of processes and uncertainty suitable for the holistic nature of the MSFD requirements. The risk model approach ensures integration across components, with explicit treatment of uncertainty for all model assumptions and data. Still, an expert-judgement type approach will be required where data are too poor to allow for risk modelling. In this sense, the overall six step process described in the U.S approach (Levin *et al.*, 2009) could be adapted to meet PSR requirements under the MSFD (Fock *et al.*, 2011).

Table 3.1. Summary of the coverage of important requirements of an Integrated Ecosystem Assessment for the MSFD by a number of existing IEA applications.

Approach	Pressure-State Links	Consistency and Comparability	Status/Trend	Missing Components
OSPAR	Approach aims at identifying significant links	Limited (no scientific basis for ref levels)	Primarily status	Socio-economics, Environmental forcing, Interactions among components
REGNS	Exploratory (correlative)	Limited (no reference level)	Trend	Those with no time-series data
US	Functional relationships assumed in assessment model	Limited (no guidance for objectives, indicators or reference levels)	Status and trend	None
Canada	Missing	Guidance from conservation objective	Status and trend	Link with socio-economics, Pressures

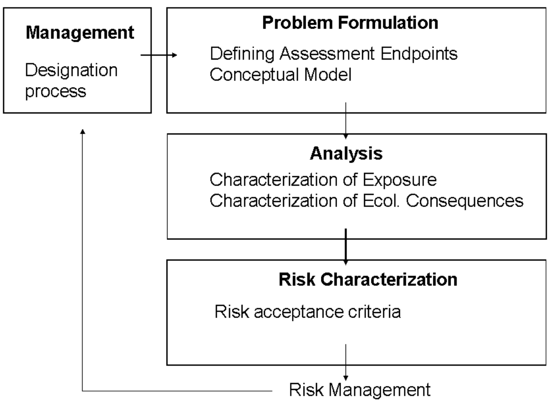

Figure 3.1. Procedural steps for ecological risk assessment (US Environmental Protection Agency, 1998).

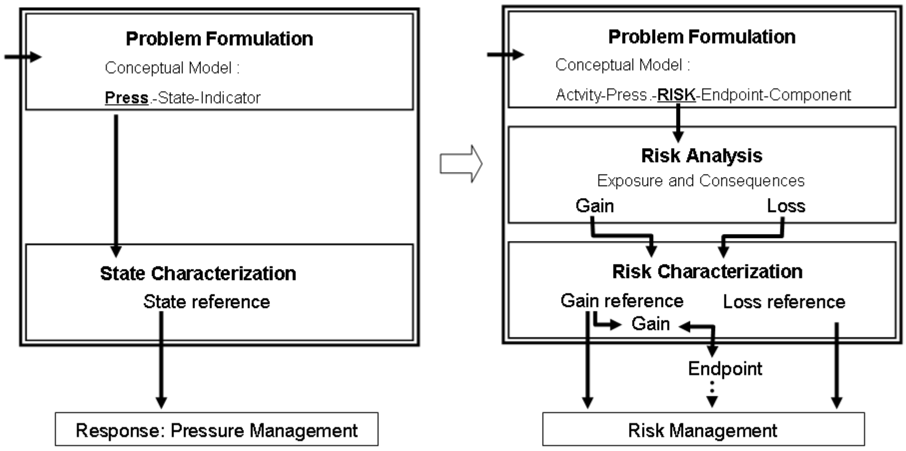

Figure 3.2. Formalizing PSR assessments (left) and the relative ecological risk assessment referring to the risk assessment steps of problem formulation, analysis and characterization. Some PSR models approach risk models, so there is a transition from left to right. Note that ecological state is not an integral part of the risk model, but for the PSR models.

2.9 Other approaches: HELCOM initial Holistic Assessment for the Baltic Sea

HELCOM has been presenting an initial holistic assessment of the Baltic Sea. Holistic assessments or ecosystem-based management are broadly considered as necessary alternatives to the status-quo of decoupled analyses and assessment of ecosystem components and services in the Baltic Sea. The major challenge of holistic assessments is to condense vast amounts of data, measurements and qualitative information on extremely complex systems into information that is useful and understandable for stakeholders and managers on the one hand, but also accounting for the critical mechanisms driving the system on the other hand.

The ability of the condensed information, be it indices, reference points, distributional charts and so further, to account for critical mechanisms driving changes in the ecosystem and services is important, because only when mechanisms are accounted for, consequences of management options or natural changes can be predicted based on the actual assessment.

HELCOM's initial holistic assessment is based on visualization of two similar indices. The Baltic Sea Impact Index (BSII), and the Baltic Sea pressure index (BSPI). The basis for both indices is that, for a given assessment area (5km x 5 km), anthropogenic pressures are translated to impacts on marine biotopes or species. It is not specified, if impacts are positive or negative, however, due to the definition of a healthy ecosystem as a system that is close to an unexploited state each impact is implicitly considered detrimental. For a given anthropogenic pressure, for example pelagic fisheries, input data (in this case of landings) are transformed to a pressure index. This is done by taking the logarithm and then normalizing the input data. The result is a pressure index ranging from 0 to 1. In the example with pelagic fisheries, this means that landings data from the Working Group on Baltic Fish stock assessment, given by ICES rectangle, are assigned to assessment areas. Each assessment area was given the same value as the whole ICES rectangle, then logarithmized and normalized.

The way the data are normalized is not specified, but usually an observation is divided by the sum of all observations. It remains unclear, though, which sum has been applied, probably the sum over ICES rectangles of total landings. In this case, each cell would represent the relative contribution of catches in the rectangle the cell is part of compared to the whole Baltic Sea.

For the BSII, subsequently the pressure is multiplied with either 1 or 0, because for the calculation of BSII, pressures are summed over the ecosystem components they act upon within a given assessment area. Thus, the index value in an assessment unit highly depends on the number of ecosystem components in that assessment unit. For the case of fishing pressure, it has to be considered problematic that fishing activities are very heterogeneously distributed within an ICES rectangle, as well as ecosystem components within an assessment area. The spatial overlap between fishing activity or other anthropogenic pressures and ecosystem components is, however, considered to be given, although this remains to be verified in order to assess the true impact of this or any other pressure.

The BSPI is calculated without summing over ecosystem units, hence, pressure are considered per assessment unit. The translation from pressure to impact is done by assigning weighting scores. The weighting scores are based on expert opinions gathered via questionnaires, asking to rank the pressures on the scale 0-4. Neither measurements nor quantitative models were used to deduct impacts from pressures. This leaves the impact assessment very subjective and dependent on the choice of experts. Finally, impacts are summed up per assessment unit, and all assessment units are plotted in a map.

Summary

1) The HELCOM approach developed for the Baltic Sea (HOLAS) is stating that human pressures are influencing the ecosystem state but without quantitatively or qualitatively linking pressures to state.

2) HOLAS is, on the other hand, a valuable spatial, mapping and visualization tool for the complex set of anthropogenic pressures throughout the entire Baltic Sea.

3) Impacts are transformed from anthropogenic pressure by weighting scores, which are based on expert opinions. There are neither process models nor measurements behind the transformation from pressure to impact.

4) Climate effects and in particular the lack of inflows since 1976 and the subsequent change (i.e. regime shift) the BS underwent is basically ignored in the definition of pressures.

5) Interactions between different types of pressures are not addressed.

6) The data time-span considered is very short in order to evaluate the state of the ecosystem, or reference conditions; recent years are not included in the analyses, for example the positive development of the cod stock is not accounted for.

7) The proposed tool for protecting the ecosystem is a system of Marine Protected Areas. These have in several cases shown not to be suited as protective measure.

8) There are some problems in the input data, for example are 13 300 tonnes cod listed as caught in surface or mid-water fisheries, which is inconsistent with the stock assessment input data.

3 Integrated Trend and Status Assessments (ToR b)

3.1 Statistical techniques and regionalization

The first WGINOSE-meeting was designed as a "scoping meeting" for the future work of the group. With regard to the integrated trend and status assessments the data analyses conducted by predecessor groups (REGNS, WGHAME) have been reviewed. Furthermore the approach of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) to conduct sub-regional analyses has been discussed.

Specifically, the Baltic example showed how ecosystems states and developments can be evaluated by means of statistical analyses. All statistical methods have their advantages and drawbacks and the suitability of the applied techniques is a permanent source of debate. Methods need to deal with time-series and multivariate data, illustrate gradual changes and/or abrupt transitions between states, identify breakpoints in the dataset, be robust and easy to use, and enable cross-comparisons between datasets and systems. To start the analysis of North Sea time-series, a suite of methods was suggested that were already used in a variety of publications as well as by WGIAB.

1) Ordination: Principal Component Analysis (PCA) based on the correlation matrix of all variables and data subsets, using the PC-scores of the first and second axis to visualise the time-trajectory of the system;

2) Discontinuity time-series analyses (identify sudden changes): (1) Chronological Clustering (Legendre *et al.*, 1985) (using all time-series) and (2) Sequential Regime-Shift Detection Method (STARS, Rodionov, 2004) (using single variables and PC-scores);

3) "Traffic light plot" (Link *et al.*, 2002) to show the status and temporal development of the system and of all variables (Quintiles of metrics are colour-coded and variables are sorted according to their subsequently derived PC1 loadings).

WGIAB so far fully analysed time-series of 7 subsystems of the Baltic Sea (The Sound, Baltic Proper (SD25, 26, 28), Gulf of Riga, Gulf of Finland, Bothnian Sea, Bothnian Bay, and Coastal site in Sweden), and the results were shown in an ICES Cooperative Research Report (CRR 302, Diekmann and Möllmann, 2010). The subsystems are spatially connected but are characterised by different environmental conditions and food web structures. Time-series of hydroclimatic variables, nutrients, phyto-, zooplankton, benthos, mammals, fish and fisheries data were used, and many variables were of the same type across systems. Nevertheless, the same species or variable types did not necessarily show similar trends over time. By using the methods mentioned above on the full suite of variables two pronounced breaks were found in nearly all systems, and these were also visible on the first factorial plane of the PCA plots: The systems showed a sudden shift in the late 1980s (mainly in 1987), when a multitude of variables across all trophic levels as well as hydroclimatic drivers were changing abruptly. A second break, although less pronounced, was found in the early to mid 1990s. Due to this congruence of state changes, a comparison of ecosystem responses, regime shifts and the importance of global and/ or regional drivers is envisaged. So far, first analyses were performed by using additive mixed models (GAMMs) and system-specific generalised additive models (GAMs) to identify the overall and local drivers. For all systems the Baltic Sea Index (BSI) as an index of climate changes in the Baltic area was found to be significant. Regionally, different factors were of importance, like temperature, salinity and nutrient loads, but also the fishing pressure on key fish species played a significant role.

A similar "regionalization" has been discussed for the North Sea as a strategy for future ecosystem analyses within WGINOSE. During this year´s meeting WGINOSE examined the available, published and presented information on species communities in zooplankton, benthic invertebrates and fish. Furthermore abiotic information as well as multivariate and survey analyses to identify potential sub-regions have been reviewed. The respective information is given in Figures 4.1 – 4.11. The aim was to determine biologically meaningful yet practical sub-divisions from a data and management perspective. From the latter it would of course be easiest to have one single area to avoid conflicting indications from different areas, however this is likely to have an associated cost in bias as this is unlikely to reflect the true dynamics of the ecosystem (process error). A highly realistic ecosystem approach, splitting the area into many divisions, will avoid the problem, but will also tend to increase the variance in estimates due to much smaller sub-sample data sets so that power will decrease significantly (type II error). Basically this is a variance-bias trade off the dynamics of which we are currently unable to quantify or assesses objectively. The arguments as to the appropriate number of sub-areas could only be resolved through expert opinion, luckily the available information on community structure made it easy to decide where these splits should occur on the basis of the available community data from the separate ecosystem components.

Figure 4.11 summarizes a potential sub-division for future ecosystem-analyses within WGNOSE. There was a very distinct line in all communities running from somewhere near the Wash (UK) to the tip of Denmark. Delineations on this trajectory are easily determined in all the available information. Subsequent divisions mostly found in the northern part of the area are more visible with increasing number of samples and at higher trophic levels. On the basis of this information in conjunction with the oceanographic information a compromise of five areas was chosen. The most obvious division separating the north from the south, with the north being split into 4 segments, three of which run parallel to the major NS axis roughly representing the origins of the water masses that make up the central NS. A final 5th division at the northern boundary is generally consistent with the area of rapid increase of water depth (bathymetry) and represents the connection with the Atlantic and the deeper water inhabitants associated with it.

The area of the NS connection with the channel indicated different degrees of influence of the channel inflow dependent on the ecosystem component investigated. Given that the degree of ingress is likely to vary over time and the relatively small scale of this effect would suggest that it would either be lost in the assessment entirely if assessed as part of one of the other divisions, or indicate continual change of the ecosystem over time. Neither of these alternatives appeared to be sensible and it would be much better to assess this area as part of the channel system with which it is much more likely to have greater commonalities.

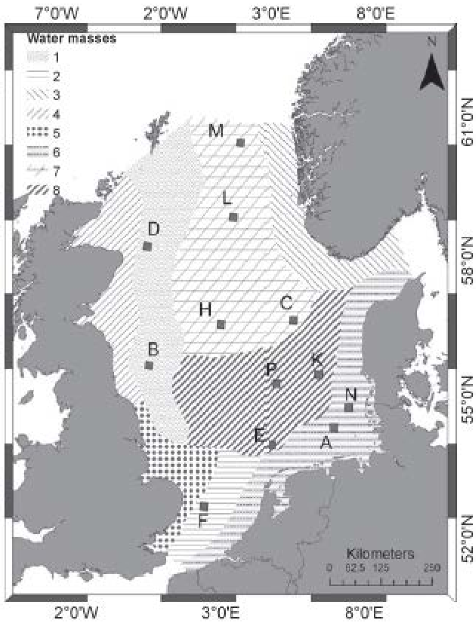

Figure 4.1. Ehrich *et al.*, 2009.

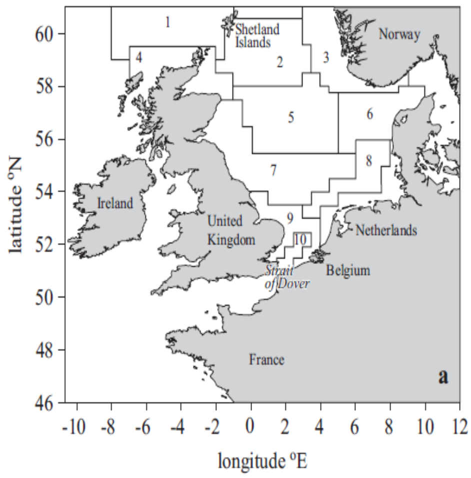

Figure 4.2. Leterme *et al.*, 2008.

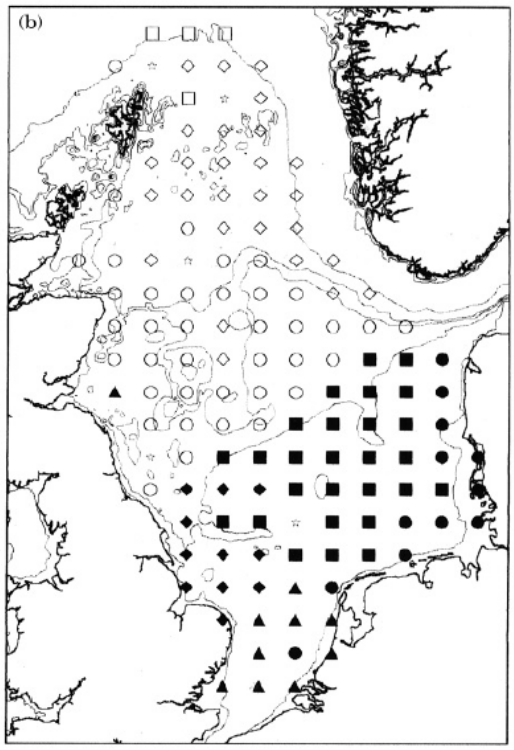

Figure 4.3. Callaway *et al.* 2002 Epibenthos.

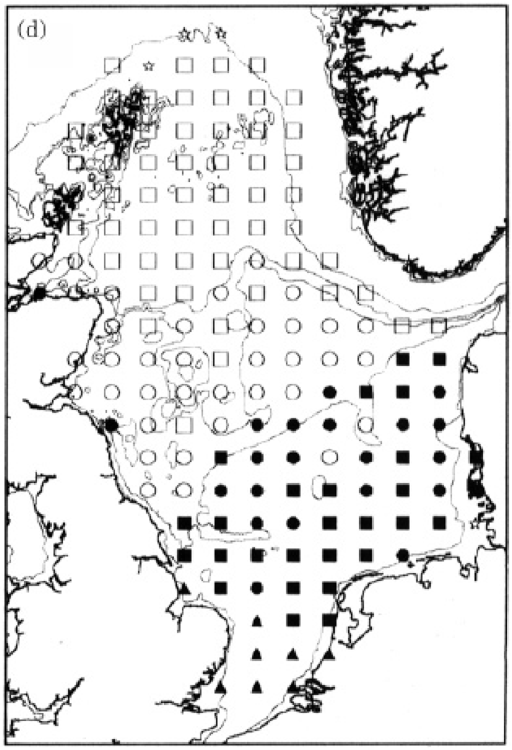

Figure 4.4. Callaway *et al*. 2002 Fish.

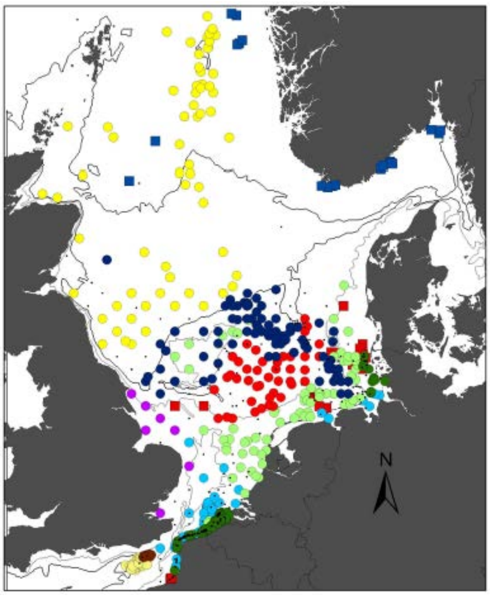

Figure 4.5. Rees *et al*., 2007. Benthic infauna.

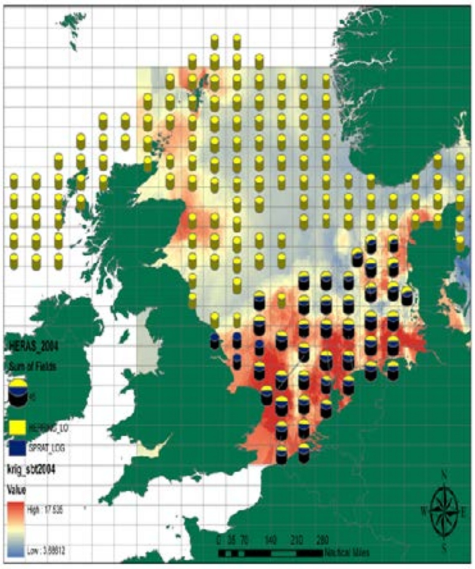

Figure 4.6. Summer distribution of sprat and herring in the North Sea from ICES pelagic survey.

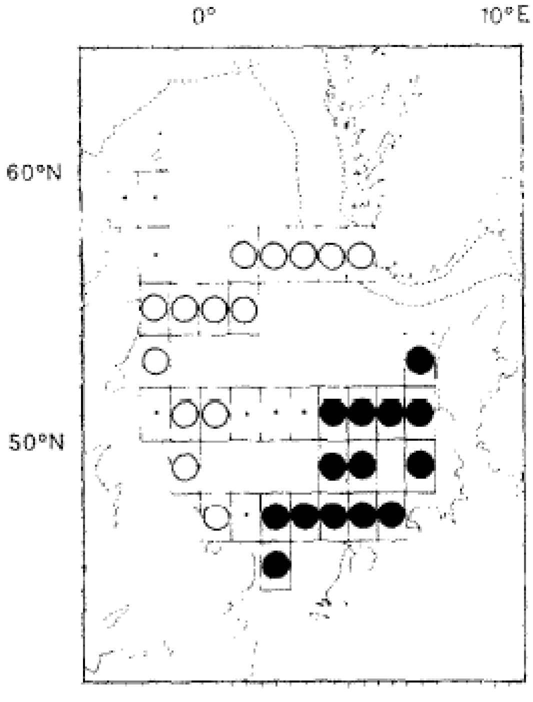

Figure 4.7. Williams *et al.* 1993. Phytoplankton.

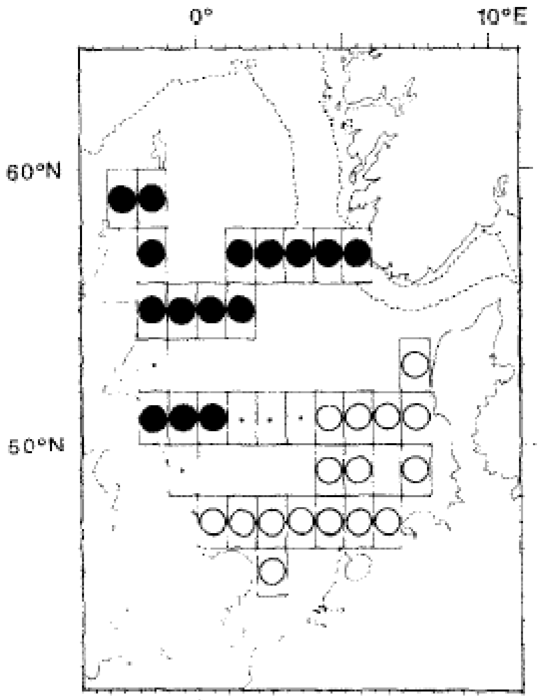

Figure 4.8. Williams *et al.* 1993. Zooplankton.

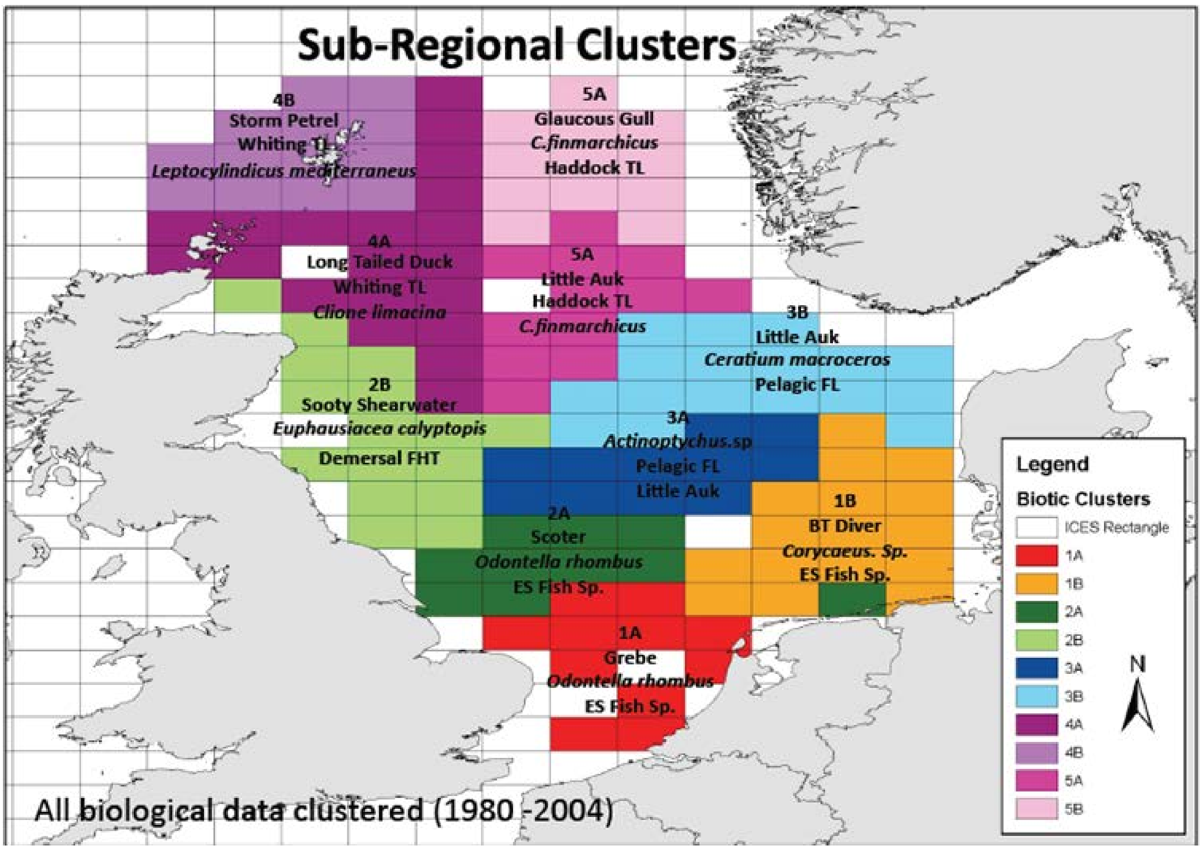

Figure 4.9. Clustering of biological data across all available ecosystem components at a level of 10 clusters (from presentation by Andy Kenny).

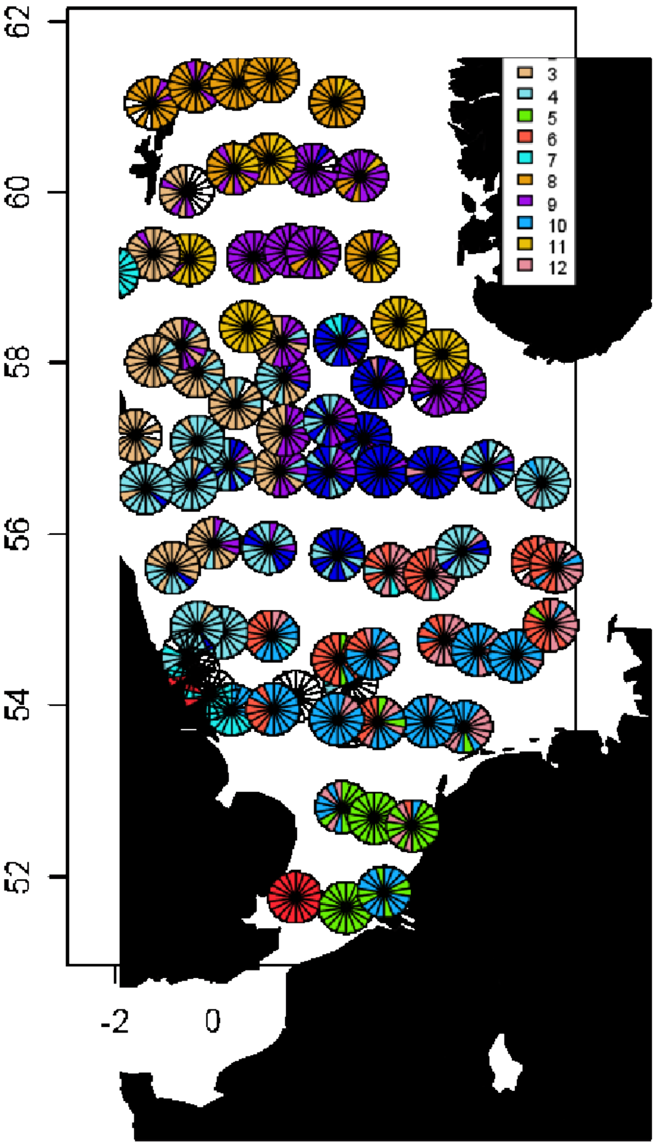

Figure 4.10. Spatio-temporal clusters of samples from the UK 3 quarter IBTS survey. Pie slices, starting at 12 o'clock with subsequent years following in a clockwise manner, indicate the allocation to cluster groupings (12 shown here) of samples taken at a each prime station over time (from presentation by Sven Kupschus).

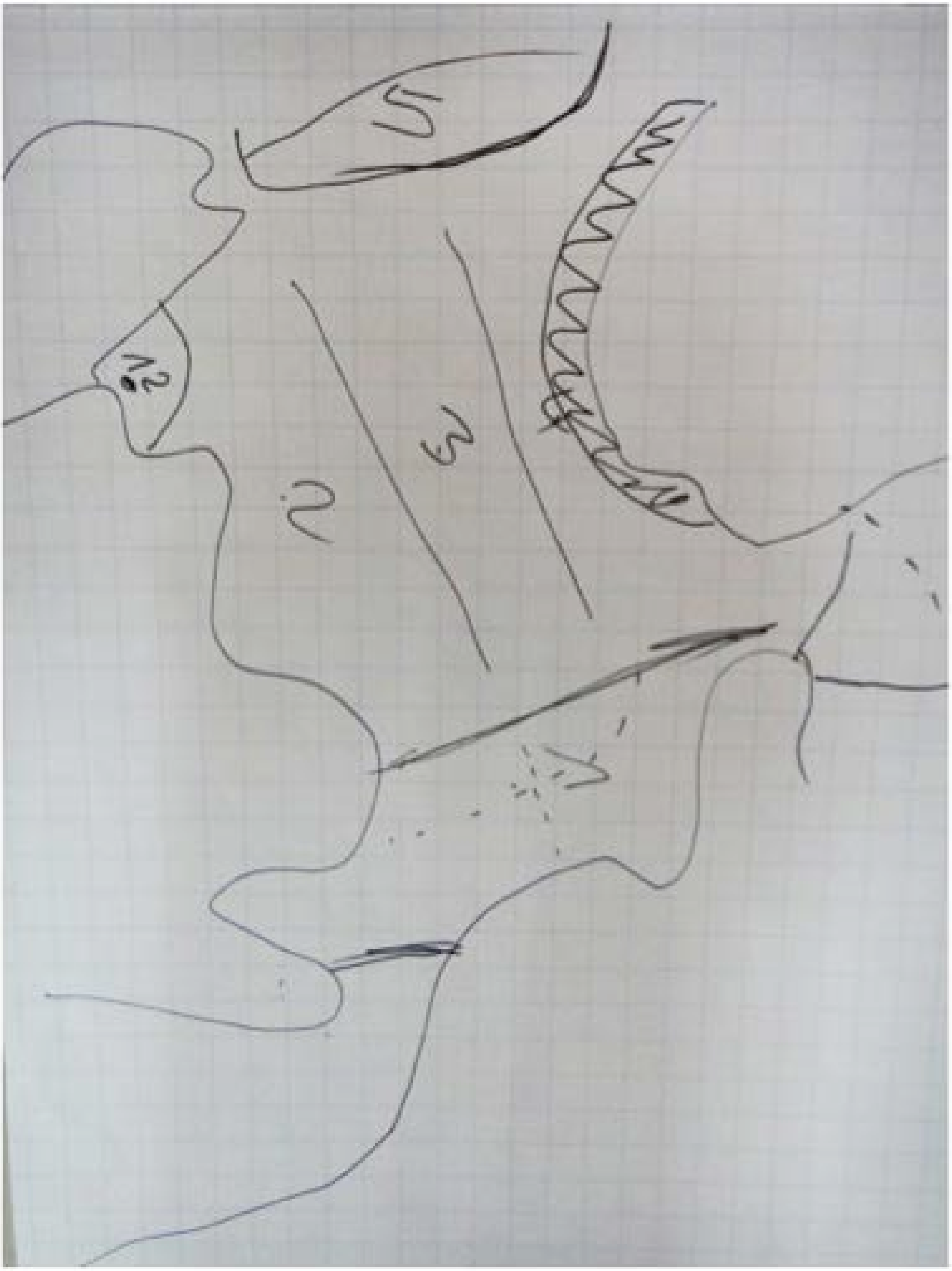

Figure 4.11. Potential sub-divisions of the North Sea for future ecosystem analyses within WGINOSE

Full legends for Figures 4.1.–4.8.

Figure 4.1. From Location of sampling areas (boxes) for the study and North Sea distribution of water masses during summer after Laevastu (1963) 1 – North Atlantic Water, 2 – Channel Water, 3 – Skagerrak Water, 4 – Scottish Coastal Water, 5 – English Coastal Water, 6 – Continental Coastal Water, 7 – Northern North Sea Water, 8 – Central North Sea Water.

Figure 4.2. Study area divided into 10 regions (a) according to hydrodynamic (i.e. stratified, mixed and frontal) and bathymetric criteria.

Figure 4.3. Epibenthic communities in the North Sea in 2000. Location of clusters identified by hierarchical classification analysis.

Figure 4.4. Fish communities in the North Sea in 2000 from otter trawl surveys. Location of fish communities indicated by analysis.

Figure 4.5. Common communities of benthic infauna from PRIMER clustering and TWINSPAN (all stations in 2000). Letters (A–D23) indicate clusters identified by PRIMER, and those in parentheses are the corresponding community clusters identified by TWINSPAN. Stations from both analyses that did not correspond are illustrated by a black dot.

Figure 4.6. Proportions of sprat and herring in the water column in summer 2004. ICES pelagic survey.

Figure 4.7. Distributions of the first component of the Principal Component Analysis of the phytoplankton.

Figure 4.8. Distributions of the first component of the Principal Component Analysis of the zooplankton.

3.2 Trial Integrated trend and status assessment for the Wadden Sea

During this year's meeting trial data analyses have been conducted for the Wadden Sea. For the preliminary analysis of Wadden Sea time-series we used 23 biological variables covering a period from 1984 to 2006. Where possible data collected in spring or annual estimates were selected. Variables comprised Chlorophyll *a* concentrations from Norderney and Sylt, seven zooplankton taxa collected near Sylt, total landings of *Crangon crangon* (regional time-series were too short or incomplete), six benthic taxa collected at a monitoring site near Norderney, and seven fish species sampled by a sole survey in the German Wadden Sea in May (see Table 4.1).

Table 4.1. Metadata: Information about time-series, data sources and variable details used for the preliminary analysis. From the macrozoobenthos and Chlorophyll *a* database, only data from the Norderney monitoring site were used. Further, the SOLES database has not yet been included.

Time-series	Source	Variables selected	Abbreviation	Unit	Season	Temporal coverage
Demersal Youngfish Survey (DYFS)	vTI, Institute of Sea Fisheries, Hamburg	Agonus cataphractus, Callionymus lyra, Eutrigla gurnardus, Merlangius merlangus, Limanda limanda, Pleuronectes platessa, Solea vulgaris	Agonus, Callionymus, Eutrigla, Limanda, Merlangius, Pleuronectes, Sol_vulgaris	N*30min-1	Fall (Q3/Q4)	1974–2009
Sole Survey (SOLES)	vTI, Institute of Sea Fisheries, Hamburg	Agonus cataphractus, Callionymus lyra, Eutrigla gurnardus, Merlangius merlangus, Limanda limanda, Pleuronectes platessa, Solea vulgaris	Agonus, Callionymus, Eutrigla, Limanda, Merlangius, Pleuronectes, Sol_vulgaris	N*30min-1	Late Spring (Q2)	1974–2010 Data gaps: 1978, ’79, ’95, 2003
Macrozoo-benthos (9 monitoring sites)	van der Graaf *et al.* 2009; Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group	Mya arenaria, Macoma baltica, Heteromastus filiformis, Arenicola marina, Nephtys hombergii, Scoloplos armiger	NN_myaare, NN_macbal, NN_hetfil, NN_aremar, NN_nephom, NN_scoarm	Abund., biomass, ash-free dry mass	Late winter/ early spring; late summer/ early autumn	1976–2006 (Norderney monitoring site)
Zooplankton	AWI, Wadden Sea Station Sylt	Acartia spp., Temora longicornis, Harpacticoidea, Bivalvia larvae, Snail larvae, Rotifera, Rathkea sp. (+ Podon sp. for summer data)	acaadult_SP, temoadult_SP, harpac_SP, bival_SP, snail_SP, rotator_SP, rathkea_SP	N*m-3	Spring (IV-V), Summer (VI-IX)	1984–2008 (spring: gap in 1988)
Chlorophyll a (5 monitoring sites)	Sylt: Wadden Sea Station Sylt, AWI, J. Beusekom Norderney: NLWKN, M. Hanslik	Chl a	Chla_Sylt, Chla_NN	mg*m-3	Summer (V-IX)	1977–2006 Norderney: 1985-2006
Crangon crangon	WGCRAN, ICES 2010	Crangon total landings	Crangon_landings	t*year-1	annual	1960–2008

Methods

Time-series were analysed by a suite of methods. First, data distributions and interrelationships were visually inspected. Then a Principal Component Analysis (PCA) based on the correlation matrix was performed (Rao, 1964; Legendre & Legendre, 1998). For this missing data were filled with the average of the four nearest data-points. All data series showed right-skewed distributions. Therefore, variables were fourth-root transformed to achieve an approximately normal distribution and linearise relationships between variables. The output of the PCA was plotted as a two-dimensional correlation biplot, with variable loadings as vectors and objects (years) as points linked consecutively with each other. Further, scores of PC1 and PC2 were plotted against time (years).

To identify sudden changes in the multivariate dataset, Chronological Clustering (Legendre *et al.*, 1985), a Clustering technique grouping sequential years, was performed. To make the results interpretable in relation to the previously performed PCA, variables were first normalised and then the Euclidean Distance Matrix was calculated. The connectedness level was set to 0.5 (for details see Legendre *et al.*, 1985) and the results were given for significance levels of 0.01 and 0.05.

Results

An overview of the temporal changes of all Wadden Sea time-series is presented in Figure 4.12, the so-called traffic light plot. Variables are sorted according to their PC1 loading of the subsequently performed PCA. This results in an order with variables that are linearly correlated to each other standing closely together. Thus, a pattern with variables at the bottom showing a decreasing trend over time (red to green), with the highest values in the first 10 years, to variables at the top demonstrating the opposite trend (green to red) with high values in recent years is generated. The first group of variables comprises *e.g.* plaice, sole, Chlorophyll *a* measures and *Rathkea* sp. (zooplankton) and *Arenicola marina* (Benthos). Increasing trends were found *e.g.* for *Crangon* landings, several zooplankton taxa (*e.g. Acartia* sp., Snail larvae, Harpacticoidea), and some benthic organisms like *Heteromastus filiformis*. Variables with less clear temporal trends are found in the centre of the plot.

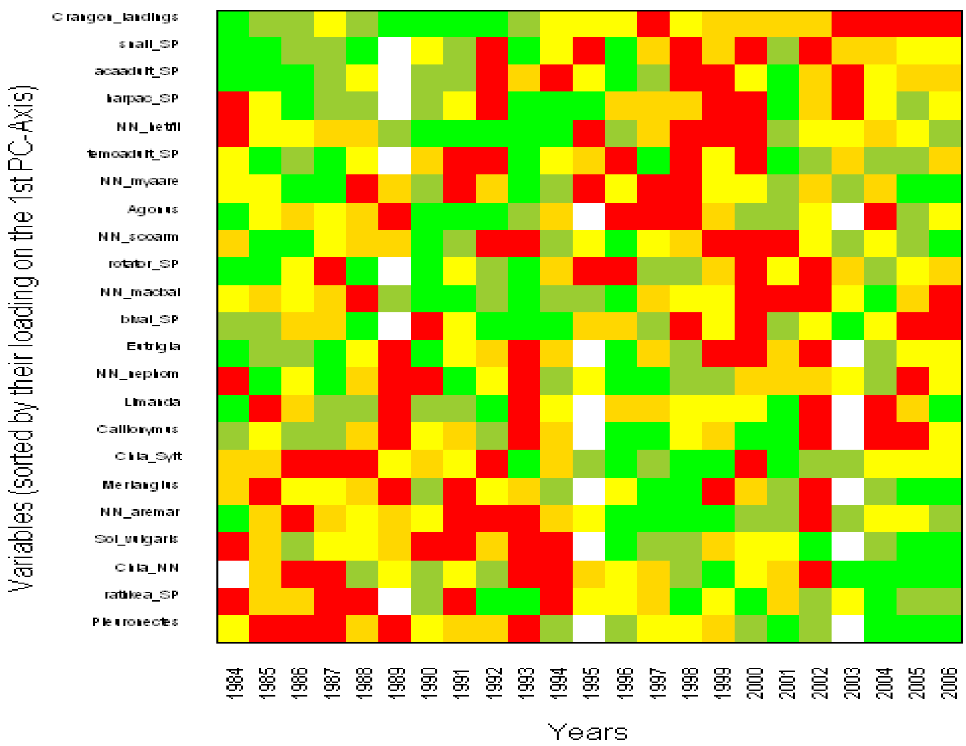

Figure 4.12. Traffic-light plot of the temporal development of 23 Wadden Sea time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table 4.1.

The standardised PCA of the 23 variables resulted in 19.6% and 13.0% explained variance on the first two Principal axes (PC1, PC2; Figure 4.13). The two-dimensional ordination plot (PC1 vs. PC2, Figure 4.13 above) represents an abstract graphical presentation of the ecosystem state. Years close to each other are more similar according to their underlying descriptors than years further apart. Linking consecutive years with a line results in a time trajectory, denoting the theoretical ecosystem development over time. It demonstrates that year-to-year changes were relatively high, meaning that years do not cluster on the first factorial plane. Nevertheless, scores show a temporal trend on PC1, with negative loadings at the beginning of the time-series and positive loadings following 1994 (Figure 4.13 below). Outstanding years, i.e. extremely high negative or positive scores were found for 1996 (PC2) and 1998 (PC1). Sudden changes in the multivariate dataset were identified for 1995/1996 (α=0.01) and 1988/1989 (α=0.05).

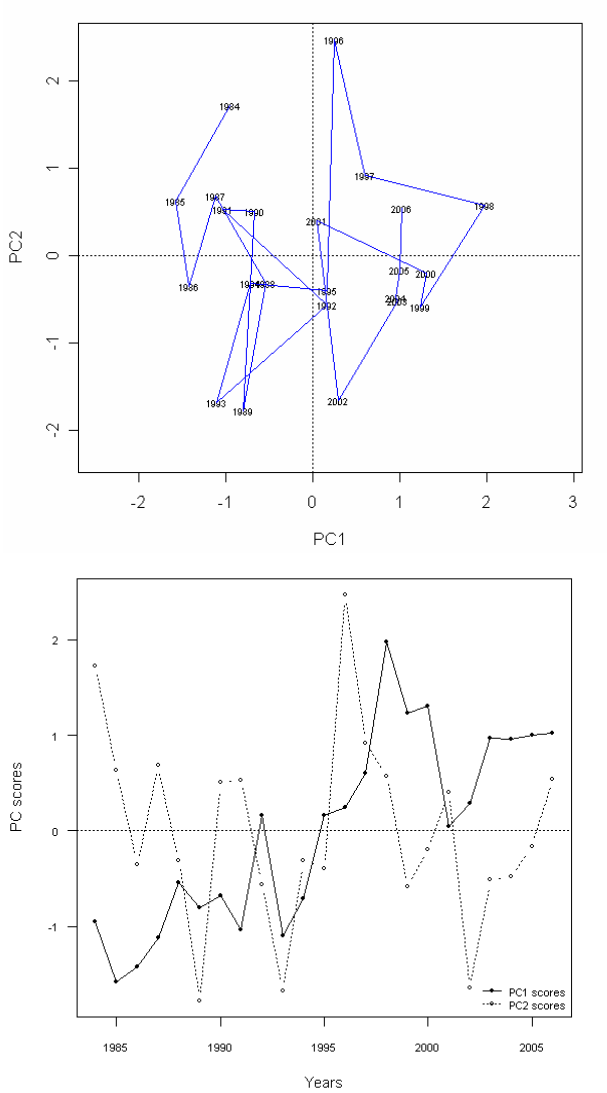

Figure 4.13. Results of the standardized principal component analysis using 23 variables (PC1 = 19.6 %, PC2 = 13.0 % explained variance). a) time trajectory on the first factorial plane; b) PC1 (black circles) and PC2 scores (white circles) against time (from left to right).

The relative changes of the variables over time and in relation to the ecosystem development can be further derived from the factor loadings on the first two principal components (Figure 4.14). Variables positively correlated with the first PC increased throughout the time period, whereas negatively correlated variables showed a decreasing trend. The latter was found e.g. for Chlorophyll *a* concentrations and the biomass of *Solea vulgaris* and *Pleuronectes platessa*. In contrast to this, *Crangon* landings were clearly increasing over time as was already shown by the corresponding traffic light plot. Fish species highly negatively correlated to the second PC were *Eutrigla gurnardus*, *Callionymus lyra* and *Limanda limanda*. According to Figures 4.12 and 4.14, their abundance was comparatively low in 1996 and the following years, but did not show a steady temporal trend.

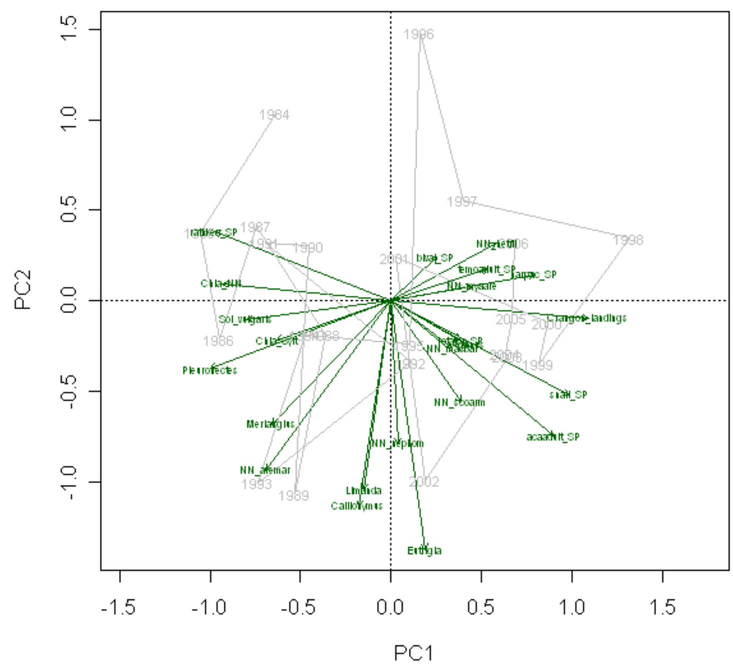

Figure 4.14. Results of the standardized principal component analysis using 23 variables, showing the variable loadings on the first factorial plane (for orientation: time trajectory from Figure 4.13 in light grey). Variable names are explained in Table 4.1.

Resumé

The analysis presented above is a preliminary attempt to describe the temporal development of the Wadden Sea ecosystem in the past 22 years. Hydroclimatic aspects and several ecosystem components were not yet included. Further, the Wadden Sea was not spatially covered but zooplankton and benthos variables were mainly taken from near the German islands Norderney and Sylt.

Nevertheless, the current results agree in principal to previous analyses of North Sea and Wadden Sea time-series. Reid *et al.* (2001) identified an ecological regime shift around 1988 based on plankton data from the entire North Sea using CPR monitoring data. Similarly, Schlüter *et al.* (2009) found a shift in 1987/1988 in the German Bight, which was probably partly driven by an increasing warming trend. An analysis of Wadden Sea data, mainly covering the Dutch coast, and time-series from the entire North Sea by Weijerman *et al.* (2005) confirmed the shift in 1988 and also identified temperature and weather conditions as the predominant driving factors. Weijerman *et al.* (2005) found another shift in 1998, which was less clear cut. In the present analysis sudden changes were not only identified in the late eighties but an even more pronounced abrupt change happened in 1995/1996. Most likely, this was caused by the severe winter with extensive ice cover. This has stronger effects in the Wadden Sea than it has in the open waters of the North Sea, which might be the reason why this later shift couldn't be explicitly found in any of the other publications.

3.3 Activities for other areas

Integrated ecosystem analyses are presently conducted and planned for various areas. An analysis was presented for the German Bight (Schlüter *et al.* 2008, Schlüter *et al.* 2010). Here connections between different ecosystem compartments was analysed by focusing on the long-term variability of key organisms and the environmental conditions in the region of the German Bight. Using principal component analysis regime shifts were identified with a diverse set of data comprising multiple trophic levels, physical and chemical long-term time-series. The results suggest a major change between 1987/88 for all components spanning the width of the German Bight and also a change in the biological data set only during this period. The shift is mainly due to hydrophysical forcing (SST and nutrients). Changes in plankton and fish could be associated to these changes. The strength of the association is widespread among the different biological species, but not of the same sign. Using Bayesian statistics it was found that the magnitude and shape of response to seasonal warming trends differs among trophic levels. Gelatinous zooplankton temporal responses are abrupt in relation to small abrupt temperature changes. No significant changes in the copepod community could be found. This has consequences to ecosystem functioning.

A future analysis for the Skagerrak is planned and research ideas are presented. The information currently available for providing a framework for an integrated ecosystem assessment for this area is under development. There is however an urgency to consider historical spatial baseline for the conservation and management of marine resources (Cardinale *et al.* 2010a, 2010b, 2009; Svedäng *et al.* 2011). At present the lack of information (e.g. stomach data) does not allow the construction of a simple food web model to untangle the complex networks of feeding relations between species (‘who eats whom’). This gap needs full attention for a better understanding of the interrelationships between community structure, stability and ecosystem processes in relation to fisheries and climate change. Ultimately there is a need to move toward a macroecological interpretation of fish stock dynamics as a component of a more holistic scientific framework for an Ecosystem-Based Management (EBM) for marine fisheries (Belgrano & Fowler 2011).

4 Monitoring activities and data availability in the North Sea (ToR c)

One major goal of this first meeting of WGINOSE was a to review monitoring activities and related data availability for future ecosystem studies for the North Sea. Below some of the reported activities (see Agenda in Annex 2) are described.

4.1 Physical data

The North Sea is one of the best sampled seas of the world. The collected temperature and salinity data are freely distributed through the international databases, such as World Ocean Database (WOD) and the International Council for the Exploration of the Sea (ICES) data centre. Both databases provide also climatologies and long-term statistics of the North Sea temperature and salinity (Antonov *et al.*, 2010; Locarnini *et al.*, 2010; Berx and Hughes, 2009). Some additional climatologies (e.g. chlorophyll, oxygen, nutrients) are available at WOD.

Most of the *insitu* data is the result of long-term observational programs, which have a very rough spatial resolution, or of short-term intensive measurement campaigns, which target only certain regions of the sea. Therefore, one has to be aware if the observational data are able to fulfil his requirements to the spatial and temporal resolutions. As an example, I showed that the available observations are sufficient or resolve interannual variability of the water properties on the spatial scale of the ICES Statistical Rectangles for some regions, but fail to resolve seasonal variability. In such cases, alternative data sources or outputs of 3D dynamic models might be used.

One of the alternative data source are gridded sea surface temperature (SST) products, which provide better temporal and special coverage in comparison with *insitu* observations. I have considered several data products here: Hadley Center SST (HadSST1), NOAA Pathfinder and NOAA Optimal Interpolation (OI) SSTs. These products differ in spatial (up to 4 km) and temporal resolution (up to 1 day), as well their time coverage (mainly from 1980s to real-time). Meyer *et al.*, 2009 showed based on the model results that SST can be used as a proxy of the water temperature down to 20 m, but is poor correlated with the water temperature below. Thus the SST data are mainly useful to study biological processes constrained in the upper water layer or in shallow regions and mainly controlled by the water temperature.

To address spatial and temporal variability of the temperature of deeper waters, salinity or water currents outputs of 3D dynamical models of the North Sea can be used. The quality and the spatial resolution of the North Sea hindcasts significantly improved during last years, but the ability to reproduce certain parameters still varies significantly between the models (Delhez *et al.*, 2004). Therefore, an appropriate model for a certain study should be chosen cautiously and validated by the available observations with the focus of the target parameter.

4.2 COSYNA

Mission: Development and test of analysis systems, consisting of observation and numerical modelling, for the operational synoptic description of the environmental status of the North Sea and of Arctic coastal waters. COSYNA aims to provide knowledge tools that can help authorities and other stakeholders to manage routine tasks, emergency situations and to evaluate trends.

COSYNA is financed and coordinated by the Helmholtz-Zentrum Geesthacht (HZG) for Materials and Coastal Research GmbH. The scientific work is carried out together with partners from the Helmholtz Association , German research institutes, universities and monitoring agencies.

General objectives: COSYNA addresses fundamental research questions of operational oceanography: which instrumentation and monitoring strategy provides relevant, cost effective and high quality information? How are observational gaps filled and model uncertainties reduced by new schemes of merging dynamic models and statistical methods (data assimilation)?

COSYNA seeks to significantly advance technological development for e.g. automated, quality controlled routine measurements or for error and data analysis. A major challenge is system integration, i.e. to build a coherent platform for sharing or retrieving data, products and infrastructure.

The COSYNA products, in particular model hind-, now- or forecasts, support information services and decision making. The generation, e.g. of maps of water elevation, harmful algal blooms, or contaminants and of scenarios support coastal management in the context of hu-man impact and climate change.

Realisation: From a capital investment for construction/development the Helmholtz-Zentrum Geesthacht received about nine million Euros form the German Federal Ministry of Education and Re-search (BMBF) to build COSYNA with focus on the

German Bight in the years 2010–2013. COSYNA will be carried out together with partner institutions in order to utilize their expertise in specialist fields. All additional money for personal, operational and maintenance purposes is taken from the basic funds of the Helmholtz-Zentrum and its partners.

Current status – Observations

Stationary in situ observations – Poles in shallow waters

Fixed platforms have been installed in the Wadden Sea which enable continuous measurements of meteorological parameters (wind speed, direction, air temperature and pressure, precipitation , irradiance, humidity) and oceanographic parameters (current velocity, wave height, water temperature, salinity, suspended matter concentration, chlorophyll concentration, pH, oxygen saturation). High resolution data are obtained which are sent onshore by telemetry.

Transectional in situ observations – FerryBox

Installation of FerryBoxes on board ships of opportunity enable continuous measurements of temperature, salinity, turbidity, chlorophyll, pH, oxygen, algal groups, dissolved inorganic macronutrients (Si, P, N), automatic water sampler for additional lab analysis. Future developments encompass pCO2, alkalinity, flow-cytometry for algal composition and gene probes. Several routes are used to cover the North Sea. Within a FerryBox consortium other regional seas are covered (Baltic, North Atlantic, Gulf of Biscay, Irish Sea).

Surveys with research vessels

To complement surface observations with the FerryBox system additional surveys are made with research vessels several times a year to detect vertical structures and areas of stratification in the German bight. A Scanfish is applied for these measurements covering temperature, salinity, SPM, chlorophyll, oxygen, local water depth and a volume scattering function as main parameters. The German Bight is covered about 4 times a year.

Radar remote sensing

Two radar types (HF and X-band) are used to obtain synoptic maps of hydrographic parameters, waves, currents and local bathymetry. To cover the German Bight three permanent stations are installed on Wangerooge, Büsum and List (Sylt). As a first product of COSYNA hourly maps of current fields in the German Bight are presented.

Ocean Colour from Satellite Remote Sensing

Satellite remote sensing is a unique technique to cover large spatial scales such as the whole North Sea. Today with the sensors available on board of the European Environmental satellite (ENVISAT) concentrations of chlorophyll, suspended matter and yellow substance (CDOM) can be measured simultaneously. Depending on cloud coverage smaller or larger parts of the North Sea can be covered on a regular scale. Monthly means and monthly maxima are delivered as a first set of products. Regular comparisons can be made with the FerryBox transects, which also can be used as ground truth for the satellite measurements.

Sediment-Water Measurements

One of the new developments in the next years will be the point measurements of sediment – water exchange by installation of a lander type platform on the sea bottom to measure near bottom currents (ADCP), turbulence, CTD, eddy correlation, particle size distribution (LISST), high resolution sonar and noise recording. In another attempt nutrient exchange between sediment and overlying water will be studied with a similar type of platform with a particle sampler, benthic flow chamber, in situ water and porewater sampler.

New technologies: in situ Zooplankton Recorder and Nucleic Acid Biosensor

With different partners new technologies to make in situ zooplankton observations are tested, whereas bio-molecular techniques are developed to detect different algal taxa and groups, based on nucleic acid biosensors.

Observation Centres – Underwater Nodes

To enable future online real-time observations of the seafloor and other instruments in the sea underwater nodes are developed and tested in the vicinity of the island of Helgoland. Plug and play methods are developed which would facilitate the connection to new sensors without bringing the network to the surface. Underwater nodes are planned in connection with the landers for sediment-water interactions.

Hydrodynamic modelling

Several existing models are used in combination with the observational data. Main challenge is to develop methods for data assimilation to improve model results but also to advice on the number of measuring points needed to cover specific areas with increased efficiency. Existing models cover currents, waves, SPM, temperature and salinity.

Biogeochemical modelling

The chemical and biological data collected will be used in biogeochemical modelling activities. This work is under development.

Data management

The data management system organizes the data streams between the observational and storage systems at HZG and partner sites. Metadata are based on German NOKIS standards. Several methods for quality control are currently developed. COSYNA follows an open data policy. All relevant information is available from the COSYNA data portal as well as instructions for data retrieval and download..

International dimension

Many of these activities are incorporated in other EU projects /activities such as EMODNET, EMECO and JERICO. A continuous exchange takes place within a FerryBox consortium, which organizes an annual workshop to inform partners about new developments and ferry routes.

4.3 The Continuous Plankton Recorder (CPR) Survey

The CPR survey is the longest running and geographically most extensive marine survey in the world, and is now in its 80th year. The Survey operates continuous plankton recorders, towed bodies that are operated monthly from ships of opportunity, in the North Atlantic, North Sea, Arctic and Pacific. Sister surveys operate CPRs in the Southern Oceans, Antarctic and the Gulf of Maine. To date, the survey has collected over 225 000 samples, and has sampled almost 6 million nautical miles. The CPRs collect both phytoplankton and zooplankton, with 250 phytoplankton and 350 zooplankton taxa routinely recorded. Samples are archived in Plymouth, and are available for retrospective analysis.

CPR methodology has remained unchanged since 1958, giving over 50 years of consistent time-series data that can be used for many different analyses. The methodology is fully documented, with standard procedures in place, giving robust QA/QC. This consistent approach has allowed CPR data to be used in not only scientific literature, but in more policy-driven work. An annual Status Report is produced for the central North Sea, where a key group of indicators are targeted, for example a simple ratio of cold water / warm water species (using the warm temperate copepod Calanus helgolandicus and the more boreal C. finmarchicus). This is used as an indicator of climate change. Other taxa can be used to show changes in phenology (seasonal timings), invasive species, harmful algal species and marine pollution. This latter topic is covered by micro-plastics, which have been routinely recorded on CPR samples for the past 6 years, and demonstrate that new approaches can be added to the routine analysis.

The CPR indicators have been developed and are now used routinely to produce reports and assist policy for the UK government, and also at the EU level. There has been a criticism of the CPR in that the whole plankton community is not sampled, and that the smaller (pico- and nano-) fraction have been missed. This is now in the process of being rectified by the addition of a Water Sampler, developed in conjunction with CEFAS and funded by DEFRA in the UK. This self-contained sampler allows the collection of discrete packages of water whilst on a routine tow, these samples can be preserved according to the planned analysis technique of the sample (i.e formalin, lugols etc.). Once returned to the lab, the sample can be ran through a flow cytometer, and used for an array of genetic analyses, giving results on the full plankton community.

4.4 Senckenberg´s North Sea benthic long-term studies

Senckenberg is running several benthic long-term studies in the North Sea:

- Infauna Dogger Bank 1980s, 1990s, 2000s (Kröncke 1992, Wieking & Kröncke 2001, Kröncke subm.)
- Infauna Jade Bay (1930s, 1970s), 2009
- Epifauna Jade since 1970
- Infauna Norderney since 1978 (Kröncke *et al.* 1998, 2001, Dippner & Kröncke 2003, Kröncke & Reiss 2010, Dippner *et al.* 2010)
- Infauna German Bight – Dogger Bank Transect since 1990 (Kröncke & Rachor 1992, Reiss *et al.* 2006)
- Epifauna greater German Bight since 1998 (Neumann *et al.* 2008, 2009b)
- Epifauna in 6 boxes from the German Bight towards the Northern North Sea since 1998 (Neumann *et al.* 2009a, Neumann & Kröncke 2010)

E.g., in the sublittoral zone off the island of Norderney macrofaunal samples were collected seasonally from 1978 to 2005.

Abundance, biomass and species numbers of single species or taxonomic groups showed different long-term variability. Temperate/eurytherm and native cold-temperate species dominate the study area. After the cold winter 1978/1979 until the mid 1980s a higher percentage of arctic-boreal species were found, while between 1988 and 2000 the percentage of native warm-temperate species increased in connection with an increasing positive North Atlantic Oscillation (NAO) Index. Since 2002 cold-temperate species increased.

Interface-feeders dominate in the area, followed by sand lickers and subsurface deposit-feeders. The latter being more abundant after cold winters utilising buried faunal organic matter.

Multivariate analyses revealed that cold winters affected the community structure briefly, but biological regime shifts in 1989/1990 and in 2001/2002 caused progressive change in the macrofauna community structure.

4.4.1 Vessel Monitoring System (VMS)

The EU Data Collection Framework (DCF), EC Regulation 199/2008, requires Member States to collect certain data under 'multi-annual national programmes', prescribes the process for collection, management and use of that data and provides for data collected in the framework of the Common Fisheries Policy (CFP), including VMS data, to be used for the purposes of such 'national programmes'. It requires Member States to provide anonymised data to 'end-users' to support scientific analysis as a basis for advice to fisheries management; in the interest of public debate and stakeholder participation in policy development, and for scientific publication (Article 18). 'End-users' are defined as bodies with a research or management interest in the scientific analysis of data in the fisheries sector. This regulation does not provide a guaranteed right of access to VMS data, which is generally considered personal information, obtained via surveillance. However, the right to withhold the data is limited, the most relevant reason being the risk of natural or legal persons being identified (Article 20). The DCF is concerned with improving the quality of information and scientific advice available for implementation of the CFP, therefore is entirely CFP-related. This obligation does not directly apply to data sharing for marine planning purposes, unless such marine planning is integral to the CFP as an environmental consideration or requirement.

Administrations of EU member states powers to share VMS data for non-CFP purposes is constrained by a combination of human rights law; data protection law; the law of confidence, and EU law - in particular the EU confidentiality obligation under Article 113 of EC Regulation 1224/2009 (the "Control Regulation"). When sharing VMS data out with the sphere of the CFP, compliance with the EU confidentiality obligation cannot be guaranteed, however, it is arguable that sharing anonymised VMS data for marine planning purposes is not contrary to human rights law, data protection law or the EU confidentiality obligation if certain safeguards are put in place to protect the commercial value of VMS data and preserve confidentiality. Such safeguards could require a clearly defined and legitimate purpose to be defined before data would be shared, either aligning with the CFP's objectives or "conservation and protection of the wider marine environment" as described in the Control Regulation, a demonstration that disclosure is necessary to fulfil that purpose and proportionate (i.e. no alternative means could achieve the same aim); the data is anonymised and aggregated to prevent the identification of any natural/legal person, and access is restricted to individuals or bodies whose functions require them to have access and that adequate safeguards are in place to prevent further unauthorized disclosure.

Commission Decision 2008/949/EC requires to analyse VMS data resolved to fisheries metier level 6. This means that logbook information is essential for VMS analysis. An

EC call for tender *MARE/2008/10; Lot 2 - Development of tools for logbook and VMS data analysis* was launched to develop such tools. The ICES study group SGVMS reviewed results from this project as far as being available (Report of the Study Group on VMS data, its storage , access and tools for analysis (SGVMS), ICES CM 2010/SSGSUE:12).

4.5 International Herring Acoustic Survey in the North Sea (HERAS)

The acoustic survey is performed annually in June and July across the entire North Sea and adjacent areas for estimations of the distribution and abundance of the pre-spawning aggregations of the North Sea Autumn Spawning Herring. Participating nations are Denmark, Germany, Ireland, Northern Ireland, Norway, Scotland and The Netherlands. The surveys are coordinated by the ICES Working Group for International Pelagic Surveys (WGIPS). Outcome of the survey is a Nautical Area Scattering Coefficient (NASC) per nautical mile for all transects. Spacing of transects is in general 15 or 30 n.mi. For the identification of the echosignal, trawl hauls are performed (2 per ICES rectangle). This sampling design enables reliable estimates of herring and sprat abundance in the ICES rectangles. Data sets are stored in the fishframe database. The standard frequency for the analysis is 38 kHz. As most research vessels are equipped with more than 2 frequencies, there is more potential use to the HERAS data. For example, a multifrequency approach for species identification could be conceivable as different fish species (e.g. with and without swimbladder) give different acoustic responses at different frequencies.

4.6 UK North Sea groundfish survey (IBTS3)

A study on the distribution, spatially and temporally, of the species compositions of fish species encountered during the IBTS survey using the GOV trawl between 1995 and 2009 was presented. The approach uses clustering analysis to examine how communities are distributed over the 75 prime stations sampled over the period.

In general, when samples are divided into up to 8 clusters most prime stations are persistently allocated to the same cluster indicating relatively stable communities. The differences in communities are coastally spatially distinct, but less so in the central NS where overlaps of areas exist. Differences in the communities are largely due to relative differences in the species composition, rather than the species which are unique to individual clusters. In fact, correspondence analysis indicates that samples are distributed across a continual gradients on the first four axes so that in many ways the classification into clusters, both with respect to the location in space and time. The number of appropriate divisions is subjective as there are now appropriate methods for determining statistical significance. However, from a monitoring perspective, in terms of defining habitats upon which one hopes to examine temporal changes, it is of course advantageous to separate spatial clusters from temporal ones. In this case the lower order divisions represent largely spatial effects (habitats) while at the level of 12 divisions temporal changes in the clustering, mainly the spatial shift of some clusters become apparent, particularly in the central NS.

Fish communities represent the central part of the food web in many ways and consequently should be representative of both the bottom up effects and the top down effects within the food web as well as the direct and indirect effects of the environmental forcing determinants considered important in the system. If one were therefore to view the spatial distribution of these communities indicative of the ecosystem as a whole, then other ecosystem components should likely vary on the same scales. A monitoring program based on the division of the NS into 10 clusters (avoiding the inclusions of temporal trends) is therefore appropriate for monitoring purposes on the basis of the IBTS3 data.

4.7 Monitoring of marine mammals

Target species of seal monitoring in the North Sea are harbour (*Phoca vitulina*) and grey seal (*Halichoerus grypus*). In German waters colonies of harbour seals can be found on sandbanks and beaches in the Wadden Sea. The grey seal started to recolonise the Wadden Sea in the last century, after several hundreds of years of absence. Today, three grey seal breeding colonies can be found in German waters: Amrum, Helgoland Dune, Isles of Juist and Norderney.

There are some whales and dolphin species that occur occasionally in German waters, like the minke whale, white-beaked and white-sided dolphin. These are most often sighted in further offshore waters, especially on the Dogger Bank. There have been some incidences of sperm whale strandings during the last decades. However, the only cetacean species occurring on a regular basis and in higher numbers is the harbour porpoise (*Phocoena phocoena*). Most of the presented monitoring programmes target this species.

Monitoring distribution and abundance

We make a division here between (1) visual (sighting) and (2) passive acoustic surveys of cetaceans.

1) Visual surveys, following the standard line transect distance sampling method, allows for absolute abundance estimation, given that the fraction missed on the transect line is estimated accurately (i.e. availability and perception bias). Platforms for visual surveys could be either boats or aircrafts. The detection of cetaceans is heavily dependent on weather conditions, particularly sea state. At the moment the systematic line transect survey is the only method available for estimating absolute abundances of harbour porpoises in the most statistically robust way. The FTZ is conducting these dedicated aerial surveys regularly. Since 2002, 69 000 km were monitored 'on effort' following pre-designed transect lines in the study area of the German North Sea. During that time 5920 sightings of porpoise groups with 7310 individuals were made.

2) Passive acoustic monitoring (PAM) is an alternative of monitoring population changes that offers a number of advantages over visual surveys. Devices can also operate at night and in all but extreme weather conditions and can be more predictable and consistent in their performance because the detection process can be automated. (a) PODs (Porpoise Detectors) are stationary acoustic self-contained data loggers that record every porpoise encounter within a radius of some hundred meters. The advantage of static PAM with PODs is that the devices are suitable for long-term deployment (months to years). It has to be noted that PODs measure acoustic activity, rather than numbers of animals. Thus, changes in the level of acoustic activity may be due to differences in behaviour, rather than true changes in density of animals. (b) Towed hydrophone arrays: a real time automated porpoise detection system has been developed that captures the full waveform of each detected click. In ship surveys it is of advantage to combine visual and acoustic surveys. However, it is not yet possible to estimate densities based on PAM; you could use it for relative densities though and you get a long-term picture on habitat use.

Monitoring of living (wild) individuals

Harbour seals are caught on sandbanks two times a year to conduct among others body size measurements, medicals, hearing tests and to take blood samples to assess the health status. In recent years satellite tagging of seals and cetaceans has been increasingly used to obtain information on seasonal movements, distribution and diving behaviour.

Monitoring of stranded and by-caught individuals

Stranding networks, including a year-round observer scheme, have been established along the German coastline in the beginning of the 1990s. In Schleswig-Holstein (North Sea coast) a total of 1861 harbour porpoise carcasses were recovered in the period 1990 to 2010 (Figure 5.1). Post-mortem examinations of animals found stranded or by-caught in fishing gear are following standard protocols and include among others various body measurements, age determination, assessment of nutritional status as well as gross and histopathological examinations. Further investigations are conducted e.g. on parasitology, morphology, histology, genetics, pathology, immunology, pollutants and diet.

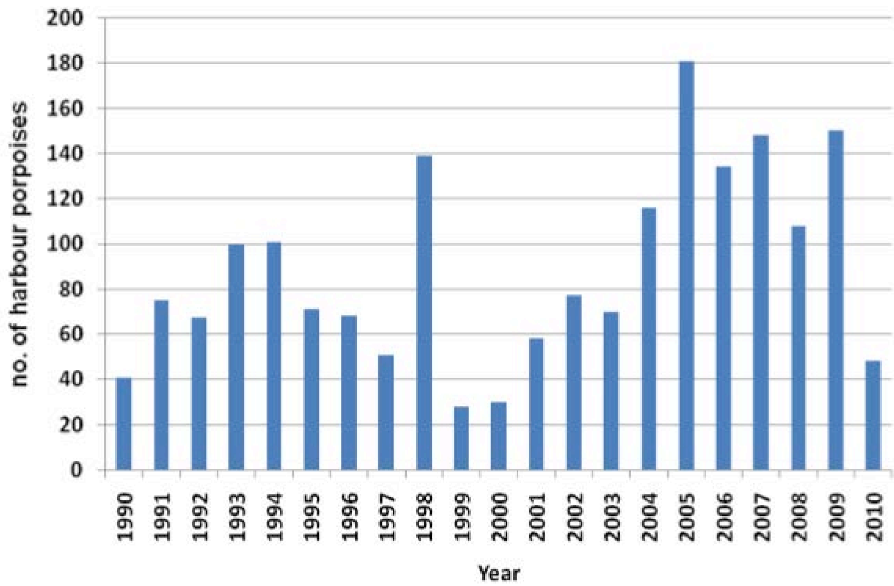

Figure 5.1. Number of stranded or by-caught harbour porpoises at the North Sea coast of Schleswig-Holstein (source: FTZ).

4.8 Seabirds: Monitoring programmes and data availability

Data on seabirds with relevance to WGINOSE may be separated into (1) Birds in the breeding colony (counts of breeding birds), and (2) Birds at sea, as well as (3) Other data.

1) Data on breeding birds have been collected in all countries bordering the North Sea since at least the 1960s while some data series reach as far back as 100 years. Counting effort differs between countries and bird species/groups but all countries have established monitoring schemes to regularly (annually) monitor species at a subset of colonies.

2) Internationally standardized bird counts are summarized in the European Seabirds at Sea (ESAS) Database and contain data from 1979 onwards. A coordinated monitoring of birds through the North Sea has not yet been

installed. Instead, the database consists of data collected due to various reasons such as vulnerability to oil programmes, discards projects, wind farm site assessments and designations and monitoring of marine protected areas. Data coverage is not good enough for an annual resolution for the overall North Sea and the subarea German Bight, but is good enough for Wadden Sea birds.

3) Other data are available for example on reproductive output (breeding success) and diet, but more comprehensive data series on these parameters exist only for few sites and species.

5 Modelling approaches available for the North Sea (ToR d)

The need for an ecosystem approach to managing human activities in the seas and oceans has been urged for decades, but operational solutions for implementation of an ecosystem approach are still under heavy discussion, and no widely accepted agreement on methodological standards has been achieved, as yet. Recently, the National Oceanic and Atmospheric Administration (NOAA) has started developing Integrated Ecosystem Assessments (IEA) in a ecosystem management context, i.e. including a full management cycle combining monitoring, data analyses and modelling (Levin *et al.* 2010). Having reviewed integrated ecosystem assessment approaches (see section 3), WGINOSE concluded that the NOAA approach outlined in Levin *et al.* (2010) and Tallis *et al.* 2010) would be a candidate for testing the applicability of the approach in the North Sea. In order to set up the full, integrated ecosystem assessment cycle a combination of monitoring, data analyses and modelling exercises is needed (Figure 6.1)

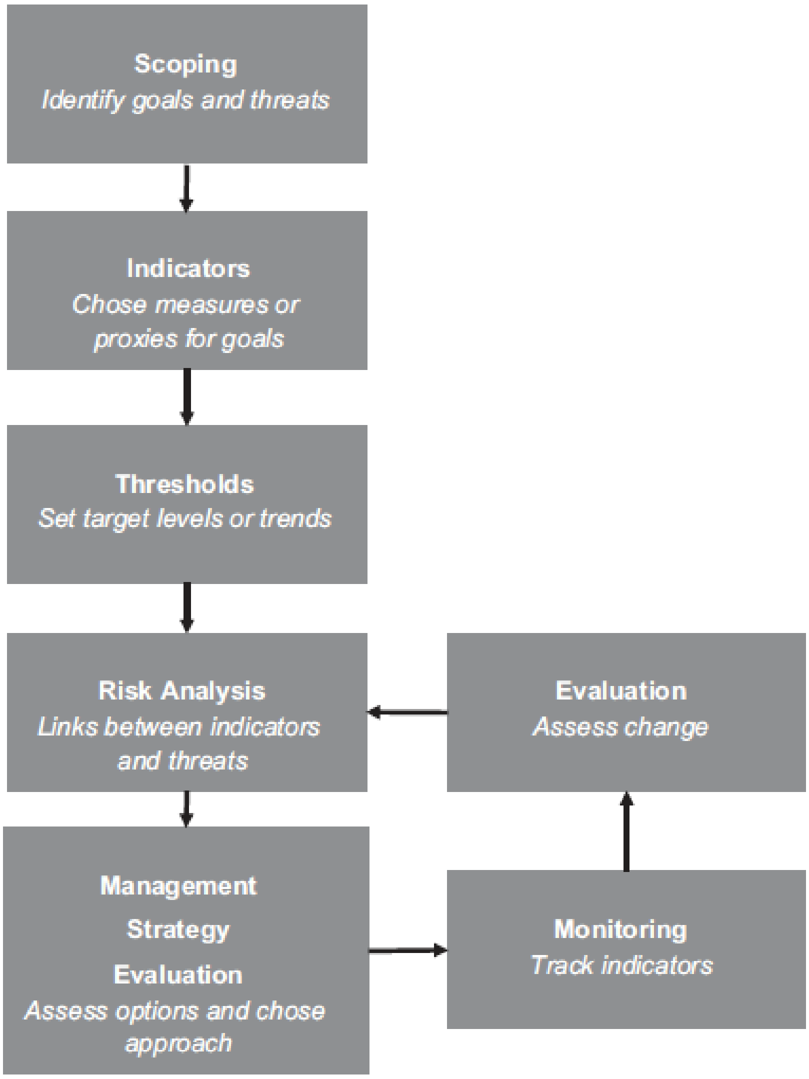

Figure 6.1. The integrated ecosystem assessment (IEA) process. From Tallis *et al.* 2010, adapted from Levin *et al.* 2010.

In this context models are needed or are beneficial for almost all steps of the assessment cycle:

- Simulation models to reveal strong connections in the system most affected by management
- Ecosystem models to identify the most responsive indicators
- Ecosystem simulation/MSE models to set thresholds for multiple objectives
- Ecosystem simulation models to describe the resilience of indicators to the full range of exposure
- Ecosystem simulation/MSE models to conduct projections of responses to management options
- Creating a „null system" using ecosystem simulation models, to show the state without management action

Therefore, a goal of WGINOSE during this first meeting was to:

- Create an inventory of models available to IEA of the North Sea
- Identify modelling gaps

- Develop a strategy for which models to use for which purposes in IEA
- Identify models and scenarios for a model comparison

Below the existing modelling activities reported during the first WGINOSE meeting are briefly described.

5.1 Multi-Decadal ecosystem variability in the North Sea - Baltic Sea system,

Both, the North Sea and the Baltic Sea experienced pronounced changes in hydroynamic-, biogeochemical and higher trophic conditions during the past decades. In the middle of the 1980s positive SST trends accelerated and a variety of pronounced and partly dramatic changes have been reported for the different levels of the marine ecosystem, which have been frequently discussed in the literature and been identified as regime shifts (e.g. Alheit *et al.*, 2005). Here we aim at investigating the multi-decadal variability of the marine ecosystems in both seas and relate it to the climatic forcing situation.

We will present results of a coupled physical-biological model for the North Sea and the Baltic Sea. The model has earlier been run for the period 1958-2004 (physics only, Schrum *et al.*, 2003) and 1980–2004 (coupled physical-biological, Schrum *et al.* 2006) and the data have been made available to the scientific community via the ICES WGOOFE web site (http://www.wgoofe.org/). Since then the model has been improved. The advection scheme has been replaced by a non-diffusive TVD scheme and the ecosystem module has been further developed to be appropriate for the Baltic Sea system. The lower trophic level module has been completed by a cyanobacteria group and two sediment pools have been introduced. Moreover oxygen dynamics, nutrient remineralisation, PAR parameterisation and the nitrogen cycle description have been improved. Compared to the earlier runs, the model results were significantly improved, e.g. with respect of frontal resolving processes. Also the conservation of the haline stratification of the Baltic was improved as well as nutrient dynamics. The improved model has been run for the period 1948–2007 (updating the simulation to 2010 is in progress) using newly created Baltic Sea runoff and load data (Baltic Hype, Donnelly *et al.* 2010) and new sea level and hydrographic boundary data. A validation exercise shows good model performance for temperature, salinity and also nutrients on interannual time scales.

The model identifies a long term multi-decadal trend and shorter periodic oscillations in primary production. The trend is likely forced by a multi-decadal oscillation of the climatic conditions in the North Sea and Baltic Sea region. We identified the most important climatic drivers, the short wave radiation and the wind speed. Higher wind speed is increasing the nutrient supply to the euphotic zone and hence increasing primary production. Increased shortwave radiation is increasing the light levels, decreasing light limitation and hence increasing production. Both drivers were highly important for production variability in the Northern North Sea and the Baltic Sea. They are less relevant for the modelled variability in the Southern North Sea, here the river loads and tidal forcing are the dominant driver.

5.2 Ecological Modelling within the OSPAR framework

After the reduction of river nutrient loads by 50% was proposed from the OSPAR commission in 1987, a number of ecosystem model simulations in different countries tried to indicate the possible consequences of such management actions on the marine environment. When confronted with the simulation results, the modellers had to struggle with the simple question “what will we consider as an improvement to the ecosystem"? This is simply related to the fact that the vision of "sustainable use" did not offer any conceptual approach towards the ecosystem one was aiming at, e.g. no definition of key indicators to allow for such a judgement.

In the meantime OSPAR installed the so-called "Comprehensive Procedure" which addressed this question and offered an conceptual approach for this problem, by defining indicators and threshold values to allow for the identification of so-called "Problem Areas" (Claussen *et al.*, 2008). Based on this assessment, OSPAR provided a frame for ecosystem modellers to compare the responsiveness of different models in relation to nutrient reduction scenarios, which led to a workshop in 2007 in Lowestoft (UK). First of all it is worth mentioning, that the provision of a set of nutrient loads for the whole North Sea, as aggregated by colleagues at Cefas (UK), was the key work on which the eutrophication study was based on. Furthermore, the use of common boundary conditions which were provided from the POLCOM-ERSEM model, for all other models with smaller domains, as well as the generalised setup of at least three years of spin-up were the key factors to derive comparable model results between the different model applications. Finally, the use of target areas for which the models calculated the parameters winter DIN and DIP, as well as summer Chlorophyll-a concentrations, allowed to compare the models results for the hindcast run for 2002 and two different reduction scenarios. The assessment of the model simulation results with the OSPAR threshold values allowed to define the improvement achieved by the different models, with the special focus which reduction was necessary to achieve an improvement for a region classified as problem area toward a non-problem area status. For further details see Lenhart *et al.* (2010).

One of the lessons learned, beyond the model comparison itself, was the fact that some of the threshold parameter used do not provide a consistent picture in relation to the model simulations. For example, two regions which have the same level on winter DIN and DIP concentration vary about a factor 3-4 in their corresponding Chlorophyll-a values. Moreover, the parameter oxygen deficiency was represented insufficiently by the comparison with bottom oxygen concentrations as mean values for the target areas used in the comparison. Here an individual time-series seemed to be more appropriate. In addition this comparison offers the potential of the model, with its consistent information in time and space, to provide important background information to the measuring community on the timing and the duration of the oxygen depletion phase.

The setup of the OSPAR workshop was able to give the decision of what can be seen as an improvement for the ecosystem by confronting reduction simulation scenarios with the Comprehensive Procedure assessment, by the simple fact that no further reduction are needed when the threshold levels are fulfilled. Or in OSPAR terms, that we are able to calculate the degree of change needed in key parameters to bring the current problem areas to non-problem area status.

Since it is possible now to define the reduction level needed to achieve the target ecosystem (non-problem area status), one can now seek for measures on land that are needed to achieve this reduction. Moreover, it is possible now to search for the most cost-effective measure to achieve the same reduction level. On this basis the next important step is to couple ecosystem models with hydrological models, where these measures can be simulated and the resulting nutrient load can be applied in ecosystem model scenarios. A number of these combined studies have already been carried out, but only on the basis of individual catchment areas, like the in the EUROCAT project for the rivers Rhine and Elbe (Hofmann *et al.*, 2005) or the studies by Lancelot *et al.* (2007), which had its focus on the Belgium rivers entering the North Sea. The next step needed is a coupled approach between a North Sea wide catchment area model and ecosystem models, which are already available for this region in a number of model application.

Finally, it should be pointed out that in order to improve the assessment potential of the ecosystem models they should be able to incorporate more key parameters which are used by OSPAR or the WFD as ecological quality indicators. In addition, also the products of presenting ecosystem model simulations should be more aggregated in their interpretation potential. Here the work from Almroth and Skogen (2010) can be used as an example, where the simulation results were presented in horizontal distributions of the final classification of problem area (red) vs. non-problem area (green), which allows for a direct comparison with the assessment by the OSPAR Comprehensive Procedure.

5.3 Simulated drifts and drift climatologies to underpin the interpretation of marine observation

The use of hydrodynamic drift simulations for supporting the interpretation of monitoring data was given by Ulrich Callies from the Helmholtz-Zentrum Geesthacht. The presentation addressed the possible integration of hydrodynamic simulations into observational programs like COSYNA but also aspects of a comprehensive analysis of long-term observations. When it comes to management decisions, however, the use and even just presentation of long-term hydrodynamic simulations may be hampered by the hugeness of numerical model output data sets. Therefore Bayesian Network technology was proposed as an efficient tool for aggregating such data sets in terms of conditional probabilities that link variables to each other. A study on chronic oil pollution in the North Sea was presented as a prototypical example, the approach of which might be transferred to other environmental problems and corresponding monitoring programs. Bayesian Networks were also proposed as an efficient tool for the representation of model uncertainty that exists in the wide spectrum of environmental models.

5.4 Individual-based modelling of fish early-life stages

Coupled biophysical individual-based models (IBMs) have been constructed for a variety of species and utilized in the North Sea to examine factors affecting the transport, survival and growth of the early life stages (eggs and larvae). A recent review of the utilization of IBMs on commercially-important species within European waters was provided by Hinrichsen *et al.* (2011). Examples of two types of approaches (transport / drift modelling and coupled lower trophic level-IBMs) were provided. A variety of modelling studies have examined habitat connectivity between adult spawning areas and juvenile nursery grounds in flatfish (sole, plaice) or backtracking of source regions (herring, cod, haddock). Coupled model approaches (NPZD-IBM) have provided spatially-explicit estimates of habitat suitability (based upon estimates of potential larval survival) for the early life stages of some species (sprat and cod). These transport and coupled-model estimates can be used to create spatial maps of suitable spawning habitats and how these would be predicted to change due to climate-driven (bottom-up) changes in physical forcing (Daewel *et al.*, 2008 & 2011). Coupled model estimates are sensitive to estimates of zooplankton biomass provided by NPZD components, the estimates of both modelling efforts are sensitive to aspects of larval behaviour that influence vertical position of particles (larvae), and aspects of predation mortality (to this point) are not well represented. In general, IBMs are being utilized to assess historical changes in the productivity of fish species and allow an exploration of how various (physical, bottom-up) processes may interact to influence recruitment variability. Although the focus of this presentation was on commercially-important fish, similar methods are being developed to examine specific zooplankton species (e.g., *Calanus finmarchicus* in northern North Sea).

This presentation emphasized that basic physiological principles (along with more complex trophodynamic relationships) govern the distribution and productivity of secondary (i.e., copepods) and tertiary (fish) levels of production (Pörtner and Peck, 2010). From a practical standpoint, models that include basic physiology (thermal windows and temperature-prey requirements supporting survival) and biophysics may allow "informed proxies" to be created that provide simple indicators estimating "good" or "bad" time periods and/or locations for specific species. If strong relationships are revealed, these informed proxies could be used to project future changes in the North Sea foodweb (based upon projections from downscaled climate models). Assessing uncertainty in these projections will be challenging but critical. Ongoing work to identify informed proxies within the German-funded "ECODRIVE" program will be available to WGINOSE.

5.5 Multi species stock assessment in the North Sea

Currently multi species stock assessment is carried out with SMS (Stochastic Multi Species model) (Lewy and Vinther, 2004), a model including biological interaction estimated from a parameterised size dependent food selection function. The model is formulated and fitted to observations of total catches, survey CPUE and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock recruitment relations and fishery mortality derived from an array of Harvest Control Rules. SMS is, in contrast to MSVPA, a stochastic model where the uncertainties on fishery, survey and stomach contents data are included. The parameters are estimated using maximum likelihood (ML) and the confidence limits of the estimated values are calculated by the inverse Hessian matrix or from the posterior distribution from Markov Chain Monte Carlo simulations. The following predator and prey stocks are included in the current SMS model for the North Sea: predators and prey (cod, whiting, haddock), prey only (herring, sprat, sandeel, Norway pout), predator only (saithe), 'external predators' (8 seabird species, starry ray, grey gurnard, Western stock mackerel, North Sea mackerel, North Sea horse mackerel, Western stock horse mackerel). The population dynamics of all species except 'external predators' is estimated within the model. Residual natural mortality (natural mortality not caused by the included predators) is set to 0.2.

In especially recruitment estimates are different when comparing standard single species assessments with multi species ones (Kempf *et al.* 2010). Medium-term forecasts simulating a recovery of cod under the current cod management plan with SMS highlight the importance of taking into account species interactions and density dependent effects as increasing cannibalism with increasing cod stock size. While in single species mode a recovery over 1 mio. tonnes SSB (never observed in the past) is expected, standard multi species forecasts predict a recovery up to around 300 thousand tones SSB what is in line with values observed during the gadoid outburst. However, also multi species assessment models suffer from structural uncertainties. Forecast results are highly sensitive towards assumptions on changes in the spatial overlap between predator and prey populations. In addition, SMS is a stock assessment model and not an ecosystem model. Therefore, in its current version SMS is not able to simulate changes in population dynamics of commercially unimportant species. A so called "Other Food" biomass pool is assumed to be constant in time ignoring potential changes in biomass over time. Consequences of such changes for the productivity, diet composition and weight at age of commercially important species cannot be taken into account so far. To solve this shortcoming could be a potential topic for WGINOSE. Information on biomass trajectories of important "Other Food" species could be included in a new SMS version.

5.6 Atlantis – the future for strategic ecosystem modelling to support fisheries management?

In contrast to SMS, Atlantis (Fulton *et al.* 2004) is an ecosystem model that considers all parts of marine ecosystems - biophysical, economic and social. Originally focused on the biophysical world and then fisheries it has grown to begin to be used for multiple use and climate questions. Therefore, it allows for the end-to end evaluation of management concepts (Figure 6.2).

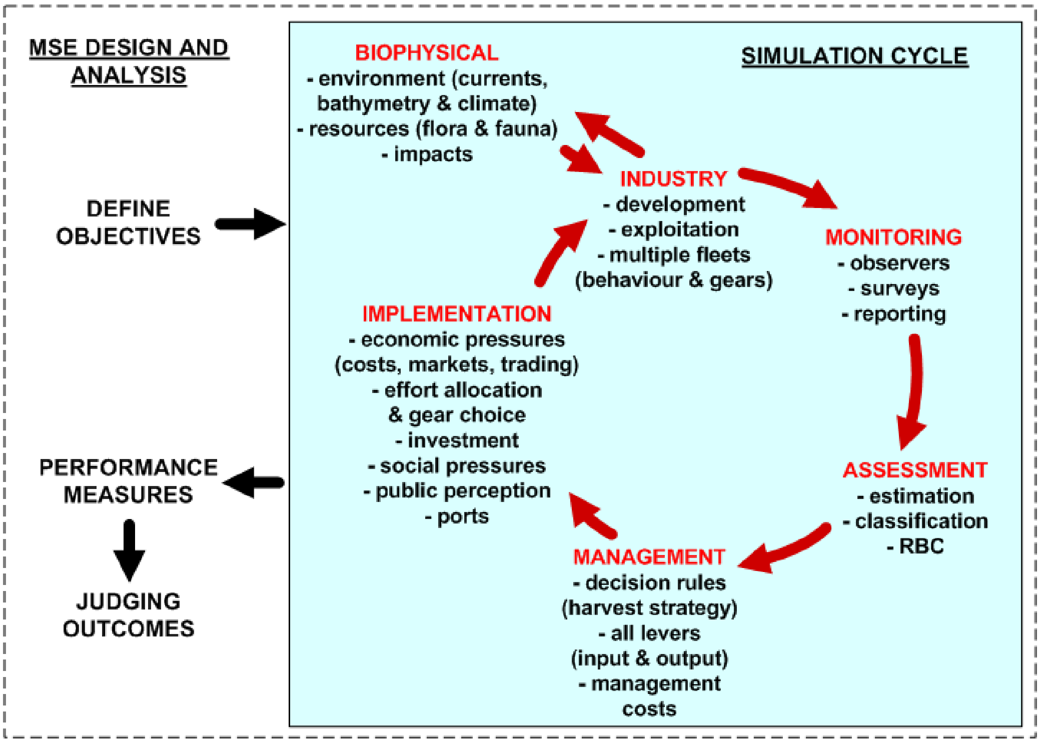

Figure 6.2. Management Strategy Evaluation loop as implemented in Atlantis.

At the core of Atlantis is a deterministic biophysical sub-model, spatially-resolved in three dimensions, which tracks nutrient (usually N and S) flows through the main biological groups in the system. The primary ecological processes modelled are consumption, production, waste production, migration, predation, recruitment, habitat dependency, and mortality. The trophic resolution is typically at the functional group level. Invertebrates are typically represented as biomass pools, while vertebrates are represented using an explicit age-structured formulation. The physical environment is also represented explicitly, via a set of polygons matched to the major geographical and bioregional features of the simulated marine system. Movement between the polygons is by advective transfer (from a 3D hydrodynamic model) or by directed movements depending on the variables in question.

Atlantis can also include a detailed industry (or exploitation) sub-model. This model can deal not only with the impact of pollution, coastal development and broad-scale environmental (e.g. climate) change, but is focused on the dynamics of fishing fleets. It allows for multiple fleets, each with its own characteristics of gear selectivity, habitat association, targeting, effort allocation and management structures. At its most complex, the model can include explicit handling of economics, compliance decisions, exploratory fishing and other complicated real world concerns such as quota trading and high grading. All forms of fishing maybe represented, including recreational fishing (which is based on the dynamically changing human population in the area).

The exploitation model interacts with the biotic part of the ecosystem, but also supplies 'simulated data' to the sampling and assessment sub-model. The sampling and assessment sub-model in Atlantis is designed to generate sector dependent and independent data with realistic levels of measurement uncertainty evaluated as bias and variance. These simulated data are based on the outputs from the biophysical and exploitation sub-models, using with a user-specified monitoring scheme. The data are then fed into the same assessment models used in the real world, and the output of these is input to a management sub-model. This last sub-model is typically a set of decision rules and management actions , which can be drawn from an extensive list of fishery management instruments, including: gear restrictions, days at sea, quotas, spatial and temporal zoning, discarding restrictions, size limits, bycatch mitigation, and biomass reference points.

5.7 Ecopath/Ecosim for the North Sea (Information collected from the EU-Project Meece)

A review of EwE representation of the North Sea ecosystem (Christensen 1995, Beattie *et al.* 2002, Mackinson 2002a) models for the North Sea highlighted a number of key topics that were considered to warrant more directed research effort before the models could be used (with any confidence) to investigate ecosystem responses to proposed management strategies. In particular, these included: (1) Improved resolution in the structure of the model and the trophic connections, with particular emphasis on the non-fish functional groups.(2). Improved detailed representation of fisheries and discards using best available data.(3) Calibration of dynamic simulations by tuning to observed time-series data.(4) Spatial representation of functional groups and fleets. (5) Testing sensitivity.

Previous research has gone some way to improving our understanding of the importance of model structure and sensitivity to predator-prey interactions (Pinnegar *et al.*, 2005; Mackinson *et al.*, 2003). This knowledge has been used to guide the development of two detailed model representations of the North Sea ecosystem (defined by ICES area IV) and its fisheries, for the years 1973 and 1991 (Mackinson and Daskalov 2007). The models' structure aims to represent an unbiased ecological perspective of the system.

The models capture and quantify the trophic structure and energy flows in 68 functional groups including marine mammals, birds, fish, benthos, primary producers and categories of detritus. They also include the landings, discards, and economic and social data for 12 appropriately defined fishing fleets. Hind caste predictions of temporal and spatial changes in the North Sea during the recent past are 'calibrated' against time-series data from assessments and scientific survey data. A critical step during the development of the models has been to ensure quality control. Accordingly, experts in their field were invited to review and contribute to the development of the model.

The models have been further developed in their application to specific problems such as evaluating the relative influence of climate and fishing on ecosystem change (Mackinson *et al.* 2008), evaluating the effects of Marine Protected Areas (MPAs) (Le-Quesne *et al.* 2008, Daskalov and Mackinson in prep), predicting fish stock recovery and evaluating harvesting strategies (Mackinson *et al.* in press).

5.8 Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM)

The Study Group emerged from a workshop meeting in 2010 in Kiel, Germany, which brought together economic and ecological researchers to explore possibilities of ecological-economic modelling in fisheries science (ICES 2010a). Fisheries are economic activities, which are dependent on and interact with the ecosystem in which they take place and management decisions are driven not only by changes in the environment but the economic activity itself. The rational of establishing such an activity within ICES was the perceived need to enhance the understanding of the effect of possible management options on the ecology and the economy and the feedback between these two. Thus the focus was on looking at examples of integrated ecological-economic models, with different level of complexity of the ecosystem and the fishery.

Within the workshop two main approaches were identified, a long-term strategic planning and advice approach, with Ecopath with Ecosim (EwE) or Atlantis as possible model frameworks, and a short to medium term management evaluation and advice approach, with FLR as one possible modelling framework.

It was realised that conceptual work is still needed to establish a model inventory, identify common modelling environments (frameworks) and to build up capacity to use these models, also within other groups or workshops. Agreement prevailed that the best way to tackle the challenge would be the use of existing models on concrete case studies. Possible case studies identified and suggested for the work of SGIMM are the North Sea mixed round fish fisheries, Central Baltic multispecies (cod, herring and sprat) and Chesapeake Bay as data rich systems and the Northern European Hake long term Management Plan as a data poor example.

One case study was developed at the meeting of the workshop on Including Socio-Economic considerations into the Climate-recruitment framework developed for clupeids in the Baltic Sea (WKSECRET, ICES 2010b). The existing modelling framework for predicting the population development of different Baltic herring stocks under climate change was extended with an economic optimisation, including age specific price and stock dependent harvest costs. The aim was to optimise profit and to investigate which F, especially in the transition of rebuilding the stock, and which SSB would be obtained in the long term. Interestingly the optimal long term F is in a range suggested by ICES (2009).

5.9 An integrated modelling approach to support an ecosystem-based management of human uses in the German EEZ of the North Sea

Marine spatial planning in the German EEZ of the North Sea was previously driven by offshore wind farm development and the designation of conservation areas. Just recently the more comprehensive marine spatial plan has been accepted and the designated sectoral preference areas are now legally binding. Although the preference areas for wind resource development have been designated, concrete wind farm constructions plans within those areas have to be approved on an individual basis. For the German EEZ and adjacent coastal waters a spatial explicit integrated modelling approach was developed accounting for the distribution patterns of the commercially important resource plaice, the activity pattern of the fishing fleet targeting plaice, the revenues generated in the areas of interest, and the spatial extent of renewable energy development such as wind farms. A Bayesian Belief Network – GIS framework was used to assess potential consequences of different spatial management scenarios which describe for instance the development of offshore wind resource and a related displacement of fishing effort. With the help of the BN-GIS framework the risks for an increased vulnerability of plaice to fishing pressure and the consequences for the fishing revenues have been explored.

Bayesian Belief Networks

Bayesian Belief Networks (BNs) are models that graphically and probabilistically represent correlative and causal relationships among variables (Marcot *et al.*, 2006). BNs have been successfully applied to natural resource management, to address environmental management problems, and to assess the impact of alternative management measures (Varis *et al.*, 1990; Varis and Kuikka, 1999; Marcot *et al.*, 2001; Borsuk *et al.*, 2004; Bromley *et al.*, 2005; Nyberg *et al.*, 2006; Barton *et al.*, 2008). One of the strengths of BNs is that probabilities in the model can be combined and quantified using empirical data, statistical associations, mathematical representations, and probabilistic quantities derived from expert knowledge (Marcot *et al.*, 2001). Ultimately the combination of BNs and Geographical Information Systems (GIS) allows a spatial representation of the model-based management scenarios. BNs have been linked to GIS to predict fisheries habitat suitability (Fulton *et al.*, 2007), or to predict species responses of coral reef macro algae (Renken and Mumby, 2009). Few studies have fully integrated BNs and GIS and explored the resulting benefits. As an example a recent study by Stelzenmüller *et al.* (2010) combined GIS analysis and BNs to support marine planning tasks by assessing what/if scenarios for different planning objectives and related management interventions.

5.10 Biological Ensemble Modelling of Climate Impacts – improving fisheries science and management by accounting for uncertainty

Predicting fish stock responses to climate change fundamentally relies on mathematical models of population dynamics. The ecosystem-based approach to fisheries management further requires that management accounts for interactions among species and other ecosystem processes. Thus, diversity and complexity of models used for predicting fish stock responses to management have increased. Yet, the structural uncertainty associated with alternative models is rarely accounted for. Here we present the biological ensemble modelling approach (BEMA) to deal with such structural uncertainty. We further illustrate how the technique can be used to disentangle structural uncertainty from the statistical uncertainty of climate predictions. Three single-species models, four multi-species models and one food-web model were used to predict the response of Eastern Baltic cod (*Gadus morhua callarias*) to five alternative fisheries management scenarios and two climate change scenarios, assuming no climate change or a warmer and less saline future Baltic Sea. Although predictions differed also qualitatively between the models, the BEMA provided a means to (i) present the full set of projected stock responses, (ii) assess whether these imply different conclusions on management, and (iii) draw general conclusions valid across all models used. Based on this example we will discuss benefits and limitations of the BEMA in furthering both fisheries management and fisheries science.

6 Management related issues

In addition to ecosystem analyses and modelling, WGINOSE started management-related activities towards the development of a full IEA management cycle. This included the mapping of the available data and modelling outputs towards the EU MSFD descriptors and indicators. A respective table has been started and will be further developed during the next meeting. WGINOSE intends to provide the results of their work to European and national GES working groups.

Furthermore a study on "Quantitative cumulative effect assessment in the Dutch coastal zone: scaling and mapping maritime pressures vs. population effects" has been reviewed. The study is based on the fact that with a foreseen increasing intensity of maritime activities and driven by several policies and conventions, spatial management at sea is of growing importance to support sustainable management of the marine environment. The management of human activities should ensure that the collective pressure of such activities is kept within acceptable levels. Cumulative effects assessment (CEA) is a valuable tool in this process. However, a transparent and widely (globally) accepted approach to CEA is still lacking and most known approaches have a highly qualitative level. CEA requires knowledge on the relation between the impact of activities and the marine environment and a good measure of sensitivity of the ecosystem to a pressure from human activities.

In respect of managing activities to a sustainable level, important aspects of an approach to assess cumulated effects on the ecosystem are: (a) transparency (b) quantitative relations between activities, pressures and ecosystem components (c) geographical presentation of pressures and effects, and (d) ability to show the (relative) contribution of each activity. The study developed a comprehensive method that meets these requirements, using the CUMULEO/RAM model to assess the relationships between pressures and ecosystem components. The study describes the general approach and demonstrates the method in a case study of the Dutch coastal zone, being part of the European Natura 2000 network. Results include maps providing information on potential population effects (based on survival and reproduction) and show relative contributions of each activity.

7 Conclusions from the meeting

WGINOSE is a new initiative to develop the science-base for Integrated Ecosystem Assessments (IEA) in the ICES area. The group works towards this goal in cooperation with similar groups within the ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP). The meeting attracted 40 scientists from 5 countries.

This first meeting of WGINOSE had the aim to re-activate activity towards Integrated Eco-system Assessments (IEA) for the North Sea using the groundwork of the REGNS group and WGHAME as baseline. Its focus was clearly on reviewing available (i) approaches to IEA, (ii) data for analyses on ecosystem status and trends, as well as (iii) modelling approaches to be used in a future IEA. The meeting was quite successful in that it attracted scientist from many different fields and hence set the baseline for its future work.

Concerning the framework for IEA to be developed for the North Sea and other ICES areas, WGINOSE considers the US approach towards IEA (Levin *et al.* 2009) to be a model for its future work. The approach is useful as it is based to a large degree on modelling approaches and data that are available for the North Sea. Still, the links between different modelling approaches need to be developed for conducting a full

IEA management cycle. This development of IEA should be well coordinated between the different related groups within SSGRSP. WKBEMIA to be held in November 2011 will be a first step towards this goal. WGINOSE furthermore suggests a common meeting with the WGIAB in 2012 for coordination for IEA development and mutual methodological input. This needs to be decided during the ASC 2011 in Gdansk.

Based on the reviews of data availability and modelling approaches, WGINOSE has developed a roadmap for its future work concerning (i) ecosystem state and trend analyses, and (ii) ecosystem modelling:

i) A stronger regionalization of the ecosystem analyses is intended, i.e. conducting several separate analyses for North Sea sub-systems. WGINOSE identified potential sub-areas of the North Sea (see chapter 4.1) to be dealt with in the future. Furthermore, Wadden Sea and Skagerrak ecosystems will investigated in addition to "central" North Sea areas.

ii) Different approaches to conduct a WGINOSE modelling study have been discussed and it was concluded to initiate a multi-model study similar to the BEMA-approach developed within WGIAB (see chapter 6.10). This study will conduct projections of the North Sea foodweb and fish stock dynamics based on projections of coupled atmosphere-ocean models. It is intended to use a number of single-, multispecies and foodweb models. The design of the study will be developed intersessionally. Eventually, the output of the study can be generalized using Bayesian Belief Networks.

iii) Management-related activities in addition to the development of a full IEA management cycle is complementary to the ongoing work related to the EU MSFD descriptors and indicators. WGINOSE intends to provide the results of their work to European and national GES working groups. This includes the further mapping of the available data and modelling outputs potentially valuable for EU MSFD indicator and threshold development.

Overall, this first meeting of WGINOSE appeared to be a promising and successful start of this initiative and will hopefully keep momentum in the future.

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Annex 2: Agenda

Monday 21/02/11 – Info day

1400 – 1430 Welcome, introduction to WGINOSE and the work of the ICES SCICOM Steering Group on the Regional Seas Programme – SSGRSP; Practical information, discussion of the agenda, planning of work and reporting (Christian Möllmann)

1430 – 1515 Integrated Ecosystem Assessments: Concepts & history in the North Sea (Andy Kenny)

1515 – 1600 Summary of the Integrated Ecosystem Analyses conducted within the ICES/HELCOM Working Group on Integrated Assessments for the Baltic Sea – WGIAB (Rabea Diekmann)

1600 – 1630 Coffee & Tea

1630 – 1715 The North Sea Region Climate Change Assessment – NOSCCA (Markus Quante)

1730 – 1800 Summary of OSPAR Assessments (Heino Fock)

Tuesday 22/03/11 – Data analysis day

0900 – 1045 Review of monitoring programmes and data availability; Presentations (15 – 30 min each)

1) Introduction into WGOOFE and potential links with/products for WGINOSE (Mark Dickey-Collas)
2) Physical data availability for the North Sea (Anna Akimova)
3) COSYNA (Franciscus Colijn)
4) The Continuous Plankton Recorder Survey (David Johns)
5) North Sea benthos data (Ingrid Kröncke)
6) Overview on North Sea fish survey data (Anne Sell)
7) A spatial cluster analysis of the North Sea fish community (Sven Kupschus)
8) VMS-fisheries data (Heino Fock)
9) Hydroacoustic fisheries data (Dominik Gloe)
10) Monitoring of marine mammals (Anita Gilles & Ursula Siebert)
11) Marine birds (Stefan Garthe)
12) The Wadden Sea analysis (Justus v. Beusekom)
14) German Bight analysis (Merja Schlüter)
15) Skagerrak under the macroscope (Andrea Belgrano)
16) Data availability from the "Deutscher Wetter Dienst" (Gudrun Schönhagen)

1045 – 1100 Coffee & Tea

1100 – 1235 Review of monitoring programmes and data availability cont.

1230 – 1400 Lunch

1400 – 1530 Review of monitoring programmes and data availability cont.

1530 – 1600 Coffee & Tea

1600 – 1800 Discussion & organisation of data analyses within WGINOSE; preparation of a data inventory and links of the data to Integrated Ecosystem Assessments

1930 – Common Dinner (Gasthof "Möhrchen")

Wednesday 23/02/11 – Management day

0900 – 1045 Management related issues; Presentations (30 min each)

1) Quantitative cumulative effect assessment in the Dutch coastal zone: scaling and mapping maritime pressures vs. population effects (Diana Slijkerman)
2) Combination of the assessment of cumulative pressures (dutch case study) and Marine strategy directive description (Diana Slijkerman)

1045 – 1100 Coffee & Tea

1100 – 1230 Breakout groups: 1) Data analysis; 2) Management

1230 – 1400 Lunch

1400 – 1530 Breakout groups: 1) Data analysis; 2) Management

1530 – 1600 Coffee & Tea

1600 – 1700 Discussion on interactions with WGOOFE

1700 – 1800 Plenary: First results and discussion of data analyses and a data analysis strategy for the next meeting; assignments for the report

Thursday 24/02/11 – Modelling Survey Day

0900 – 0930 Introduction and discussion of ideas for a WGINOSE modelling strategy (Gerd Kraus & Christian Möllmann)

0930 – 1100 Review of modelling activities for the North Sea; Presentations (15 – 30 min each)

1) Modelling multi-decadal ecosystem variability in the system North and Baltic Seas (Corinna Schrum)
2) Eutrophication modelling in the OSPAR framework (Hermann Lenhart)
3) Simulated drifts and drift climatologies to underpin the interpretation of marine observations (Ullrich Callies)
4) Individual-based modelling of fish early-life stages (Myron Peck)
5) Modelling of North Sea Brown Shrimp (Axel Temming)
6) Multi Species Stock Assessment Models & Atlantis (Alex Kempf)
7) Ecopath/Ecosim for the North Sea (Sven Kupschus)
8) Short Introduction to ICES SGIMM – Integrating ecological and economic modeling (Jörn Schmidt)
9) An integrated modelling approach to support an ecosystem-based management of human uses in the German EEZ of the North Sea (Vanessa Stelzenmüller)
10) Biological Ensemble Modelling for the Baltic Sea (Martin Lindegren)

1100 – 1130 Coffee & Tea

1100 – 1230 Modelling presentations 2

1230 – 1400 Lunch

1400 – 1530 Modelling presentations 3

1530 – 1600 Coffee & Tea

1600 – 1800 Plenary: Summary of presentations and discussion of a WGINOSE modelling strategy

Friday 23/04/10

0900 – 0930	Summary of the meeting
0930 – 1100	Report writing 1
1100 – 1130	Coffee & Tea
1100 – 1230	Report writing 2
1230 – 1300	Final plenary and closing of the meeting

Annex 3: WGINOSE terms of reference for the next meeting

The **Working Group on Integrated Assessments of the North Sea** (WGINOSE), chaired by Gerd Kraus, Germany, and Christian Möllmann, Germany, will meet in VENUE (to be confirmed), DATE April 2012 (to be confirmed) to:

a) Conduct a review on the outcome of WKBEMIA, WGIAB, WGNARS, WGEAWESS and SGIMM considering implications for the work of WGINOSE;

b) Conduct Integrated Status and Trend Assessment for different North Sea sub-systems;

c) Start using ecosystem modelling in an Integrated Ecosystem Assessment framework;

d) Promote development of Bayesian belief network modelling as decision support tools in ecosystem management and IEA's;

e) Consider to facilitate the interaction between WGINOSE and fish stock assessment as well STECF working groups.

WGINOSE will report by DATE (via SSGRSP) for the attention of SCICOM.

Supporting Information

Priority	WGINOSE aims to conduct and further develop Integrated Ecosystem Assessments for the North Sea, as a step towards implementing the ecosystem approach.
Scientific justification	Key to the implementation of an ecosystem approach to the management of marine resources and environmental quality is the development of an Integrated Ecosystem Assessment (IEA). An IEA considers the physical, chemical and biological environment, including all trophic levels and biological diversity as well as socio-economic factors and treats fish and fisheries as an integral part of the environment. The work of the group will have to goal to develop the scientific basis and the tools for implementing a full IEA. It will built on the results of REGNS and WGHAME and will to conduct (i) further analyses of ecosystem structure and function, if possible also spatially-disaggregated for different subsystems of the North Sea, (ii) implement ecosystem modelling in IEA, and (iii) coordinate its work with other groups and organisations involved in developing IEA in the North Sea and other areas. WGINOSE will contribute to the ICES Science Plan to the High Piority Research Topics "Understanding Ecosystem Functioning", specifically the research topics *Climate change processes and predictions of impacts*; *Biodiversity and the health of marine ecosystems*; *Top predators in marine ecosystems*; *Integration of surveys in support of EAM*, "Understanding Interactions of Human Activities", specifically the research topics *Impacts of fishing on marine ecosystems*, *Population and community level impacts of contaminants, eutrophicationand habitat changes in the coastal zone*, *Introduced and invasive species, their impacts on ecosystems and interactions with climate change processes*; and "Development of options for sustainable use of ecosystems", specifically the research topics *Marine living resource management tools, Operational modelling combining oceanographic, ecosystem, and population processes, Marine spatial planning, including the effectiveness of management practices and its role in the conservation of biodiversity, and Contributions to socio -economic understanding of ecosystem goods and services, and forecasting of the impact of human activities.*
Resource	Assistance of the Secretariat in maintaining and exchanging information and

requirements	data to potential participants. Assistance of especially the ICES DATA CENTER to collect and store relevant data series
Participants	The Group will be attended by 20–30 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	Relevant to the work of ACOM and SCICOM.
Linkages to other committees or groups	SSGSRP, WGNARS, WGEAWESS, WGIAB, WGOOFE, SGIMM
Linkages to other organizations	OSPAR, EU, NAFO