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Report of the Working Group on Holistic Assessments of Regional Marine Ecosystems (WGHAME)

12-16 October 2009

ICES Headquarters, Copenhagen

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Executive Summary

WGHAME had held its first meeting at ICES HQ in Copenhagen from 12–16 October, 2009. The meeting was co-chaired by Andrew Kenny (Cefas, UK) and Hein Rune Skjoldal (IMR, Norway). There were a total of 17 participants representing seven countries from 11 different institutes (see Annex 1).

The primary purpose of the meeting was to **i**. update the 2006 North Sea Integrated Assessment by including new data from 2003 to 2007, **ii**. perform the same analysis at a sub-regional scale in the North Sea, **iii**. initiate a comparative analysis of regional marine ecosystem dynamics, **iv**. review the OSPAR methodology and approach to IEA in Chapter 11 of the draft QSR 2010.

The approach taken was first to familiarise the group with the expertise available in the group through a series of short presentations on relevant work. This was followed by agreeing and assigning subgroups of experts to address specific sets of ToR then to report back in plenary their discussions and conclusions. Drafting activities of the subgroups and by individuals then continued through the remainder of the meeting with periodic plenary discussions to share information on progress and findings (see Annex 2).

The report structure follows the ToR as set out in 2008/2/RMC11 – which are in agreement with the principal aims and purpose of the meeting described above.

The group delivered an updated integrated assessment of the North Sea which shows a continuing decline in some of the principal components of the system as described in the previous analysis (up to and including 2003). However in recent years (from 2003–2007) there has been a significant weakening of the relationship between plankton and the environment, suggesting a relative reduction in bottom-up forcing compared to fishing pressures. We also observed a corresponding decline in herring (with an almost 100% correlation with the decline in bottom-up forcing) over the same period.

An examination of the same bottom-up/top-down processes on a smaller sub-regional scale suggests some spatially dependant differences in ecosystem resilience, with the smaller assessment area demonstrating less resilience.

A comparative analysis of atmospheric indicators of ocean climate forcing with a review of studies describing LME regime shifts serves to highlight the importance of such drivers in predicting large-scale events such as those witnessed in the late 1980s. Further analysis of such time-series should help to predict the occurrence of similar events in future and would therefore allow managers to mitigate and adapt to change rather than try to maintain the *status-quo* through excessive regulatory controls.

Finally the group considered in some detail the request from OSPAR to review the draft QSR 2010 text (Chapter 11) on IEA. A possible 7 step pragmatic approach to IEA was proposed by WGHAME then applied to the OSPAR assessment in an objective way. From this evaluation WGHAME identified a number of important gaps in the OSPAR assessment (as presented) which gives rise to some uncertainty in its findings.

WGHAME recommends that a workshop be held in collaboration with other expert groups in the ICES Regional Seas Programme to develop protocols and guidelines for the conduct of IEAs, this would help define the scope and type of ecosystem benchmark assessments and the scope and content for future periodic IEAs.

1 Opening of the meeting

The meeting was officially opened by Andrew Kenny and Hein Rune Skjoldal (Co-Chairs) who welcomed the participants to the first meeting of WGHAME. Some background information was provided on the ToR for the Group and on how WGHAME fits into the new ICES Science structure and more specifically the 5 year plan for the Regional Seas Programme.

2 Adoption of the agenda

The agenda for the first two days was discussed and adopted without change. Subsequent discussions at the start of Day 3 resulted in specific work activities being assigned to subgroups and individuals to address our ToR. The formal agenda for days 1 and 2 is presented in Annex 2.

3 Up-date of the North Sea Integrated Assessment including an examination of scale dependent differences (items a and d)

3.1 Background

WGHAME aim is to develop and continue the work undertaken by the ICES Regional Ecosystem Group for the North Sea (REGNS). A review paper describing the results of REGNS was published in 2009 (Kenny, *et al.*, 2009) and following on from this it was concluded that the methods developed to integrate different types of data for the purpose of holistic ecosystem assessments should be further applied and evaluated against new sets of data, in particular to include more recent years into the original analysis.

Furthermore, as a result of evolving marine management policies the demand for integrated assessments of regional marine ecosystems is growing rapidly. The scientific community is being seriously challenged to put forward credible new methods and approaches to assess the status and health of marine ecosystems at a range of scales in time and space. This challenge is recognized by ICES in the new Science Plan (2009–2013). WGHAME will work in collaboration with other Expert Groups so as to achieve the goals set out in the ICES Science and Strategic Plans.

3.2 Trends in North Sea state (1983–2007)

In order to update the integrated analysis conducted in 2006 (for the period 1983 to 2003); we reconstructed a new dataset covering the period 1983–2007. This presented some challenges, notably the methods for the original data extraction were not sufficiently well documented so as to be 100% certain that the same methods of extraction could simply be applied to the additional new years of data. We therefore reconstructed a new dataset covering the period 1983–2007 to ensure we achieved internal consistency in the data. Table 1 summarizes the data used in the updated integrated analysis. A total of 108 variables were selected, comprising 13 abiotic, 8 plankton, 29 demersal fish stock, 31 demersal fishery, 16 pelagic fish stock and 11 pelagic fishery. The spatial extent of the dataset is shown in Figure 1 which relates to ICES Area IV, however, in future assessments we may wish to examine data defined by ICES ecoregion II.

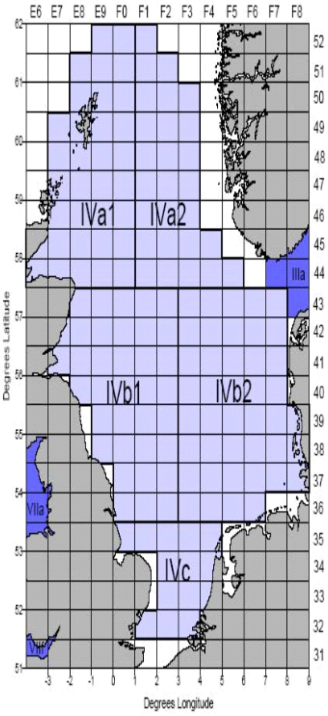


Figure 1. Area covered in the North Sea integrated assessment based upon ICES Area IV.

The first step in analysing these data was to generate a matrix of sample years consisting of variable annual averages. A PCA was then performed having first log (x+1) transformed and normalized the data (reduced to the same scale of measurement – see Kenny *et al.,* 2009). The result of this analysis is shown in Figure 2.

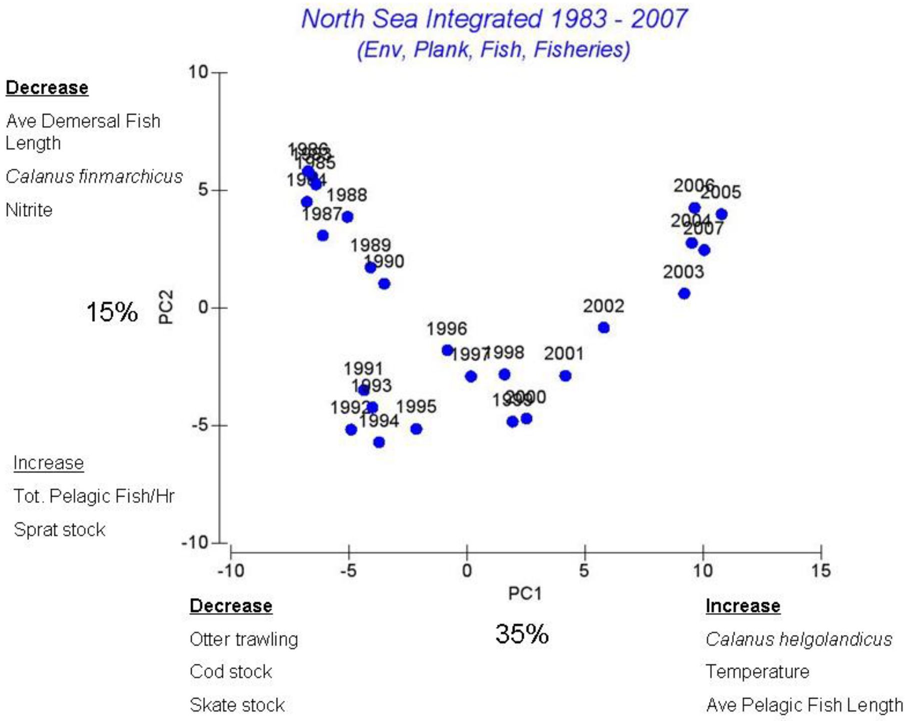


Figure 2. Principal Components Analysis ordination of sample years using all 106 pressure/state variables for the North Sea.

It is noteworthy, that PC1 accounts for 35% of the variation in the total data and there is a clear gradient in sample years which relates predominantly to a decline in the status of the cod and skate stocks, and a decline in Otter trawling effort over this period. By contrast, over the same period (1983 to 2007), there is an increase in the abundance of *Calanus helgolandicus,* seawater temperature and average pelagic fish length. Trends in these principal variables of the North Sea ecosystem are graphically presented in Figure 3.

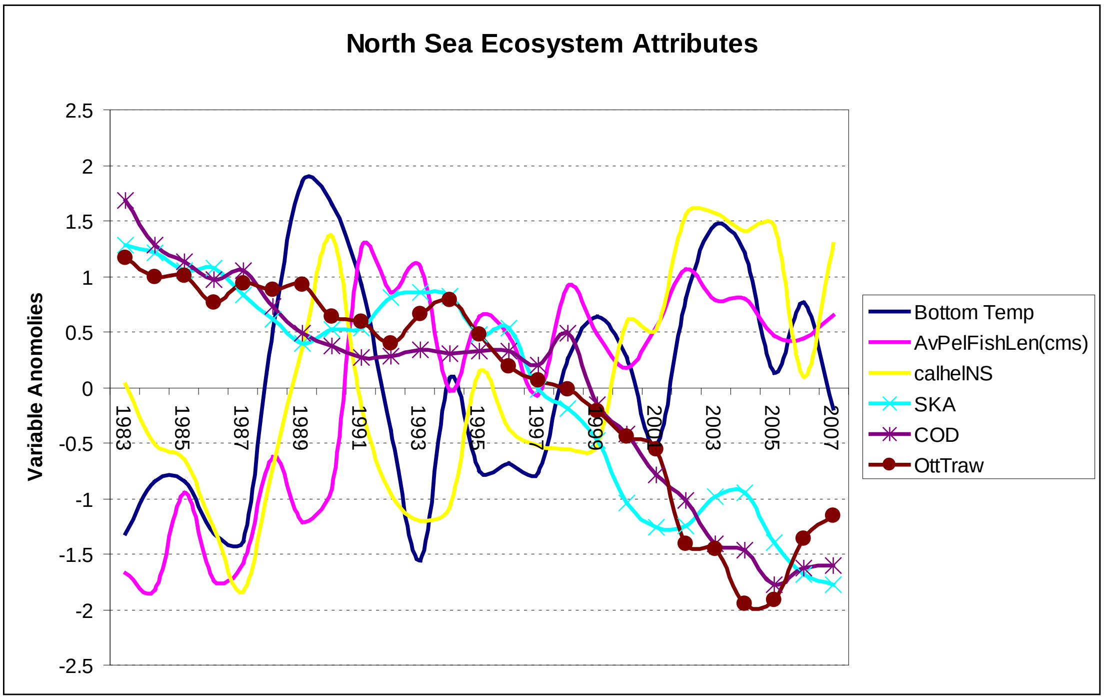


Figure 3. Trends in the anomalies of the principal variables describing the patterns of variation in Figure 2.

The updated integrated analysis shows a continued and intensified decline in the status of some of the same variables described in the previous analysis, namely declines in the status of the cod and skate stocks (see Figure 3 for the period 2003 to 2007). However, the trends in variables exhibiting an increase in dominance (e.g. certain pelagic fish stocks, bottom temperature and *Calanus helgolandicus*) have not intensified to the same extent over the same period (2003 to 2007 – see Figure 3). The contrast between an increase in the intensification of variables with negative trends compared to variables with positive trends is further highlighted by comparing the shade plots of the North Sea ecosystem for the periods 1983–2003 and 1983 2007, respectively (Figure 4). The shade plots clearly show the intensification of negative trends (more blue) for a wider number of variables in recent years compared to the previous analysis covering the period 1983 to 2003. This result highlights the need for a continued cautious approach in managing human pressures (notably fisheries) since more biotic state variables are at lower levels in 2007 compared to their levels 2003.

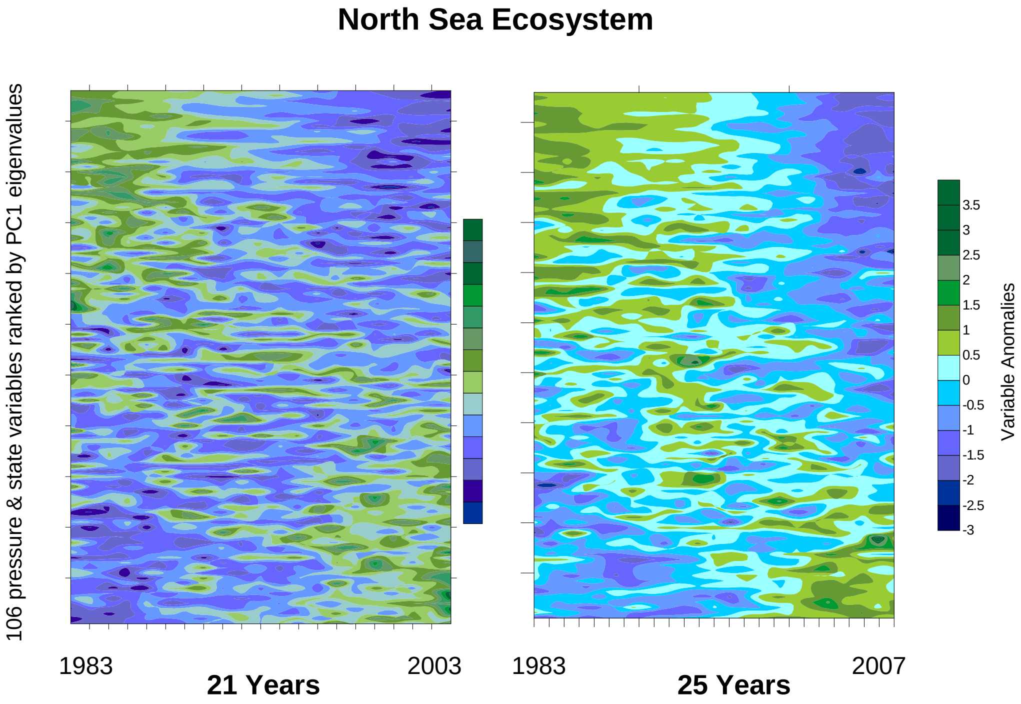
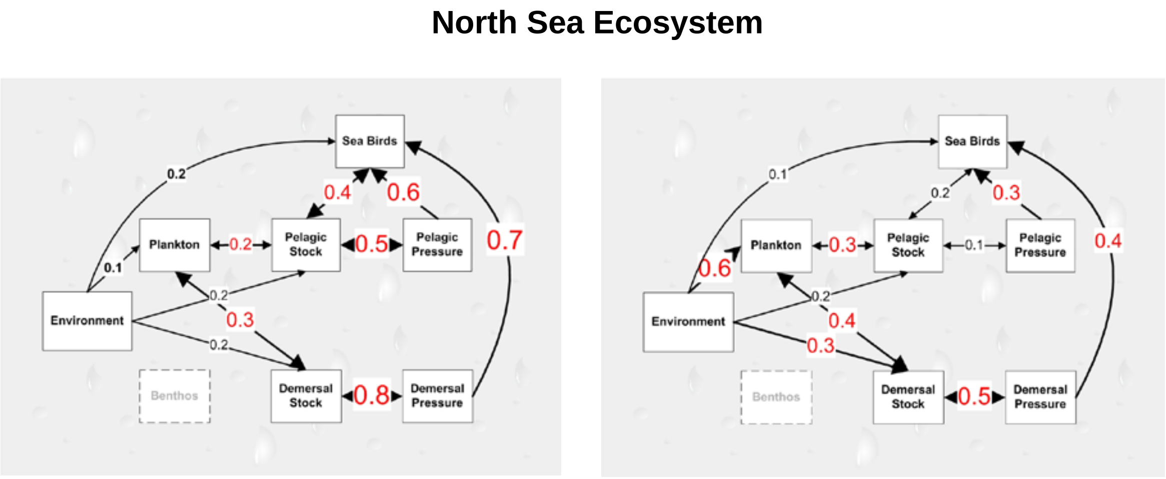


Figure 4. Shade plots showing the status (as variable anomalies) of the North Sea for the periods, i. 1983 to 2003 and ii. 1983 to 2007. Note the relative increase in negative anomalies between 2003 and 2007. Categories of anomalies are the same for both plots, as are the number and types of variables used.

3.3 Trends in North Sea function (1983–2007)

Although the above analysis describes the overall state of the North Sea such that we see an overall decline in the North Sea state measured as a ratio of negative to positive variable anomalies over time, it does not, however, allow for the interactions or dependencies between sets of variables at defined trophic levels in the system. By grouping the ecosystem variables into specific (trophic) groups or ecosystem components, namely; environment, plankton, fish stocks and fisheries; then examining the level of correlation between each of the components the relative effects of top-down (fisheries) and bottom-up (ocean climate) forcing can be estimated and assessed. For example, although the overall status of a stock (or some other indicator of the system state) may be low or high there is a need to identify which pressure has the most influence on its state at any given time, e.g. is it a manageable (fisheries) or unmanageable (climate) pressure mainly determining the state? Such forces clearly do not work in isolation of each other, therefore an analytical approach which can assess the relative contribution of all pressures (in this case both fishery and climate pressures) on the system at any one time is needed. A possible method to achieve this was presented in Kenny *et al.* (2009) which described the degree of relatedness between the main components of the North Sea ecosystem for two separate periods, namely 1983 – 1993 and 1993 – 2003 (see Figure 5). A logical development of this approach and one applied to the updated dataset is to produce comparable sets of Rho values (or plots of relatedness) between ecosystem components for groups of 10 years moving forward the 10 year window by one year at a time, thereby creating 16 separate plots of relatedness values.



(1983 – 1993)

(1993 – 2003)

Figure 5. Relatedness between principal ecosystem components in the North Sea for two separate periods, i. 1983 – 1993 and ii. 1993 – 2003 (from Kenny *et al.*, 2009)

For example, the correlation coefficient (Rho) was calculated between all of the variable groups (ecosystem components) in the first step corresponding to the years 1983 to 1992, this was then repeated a second time (2nd step) corresponding to the years 1984 to 1993 (e.g. the 10 year time window had been moved forward a single year) etc. to the end of the time-series, thereby generating 16 separate ten year time-series with a corresponding 16 sets of Rho values for each of the component interactions. The trends in the component interactions (Rho values) representing the bottom-up (environment and plankton) and top-down (fishery and fish stock) pressures can then be shown as a continuous time-series as shown in Figure 6.

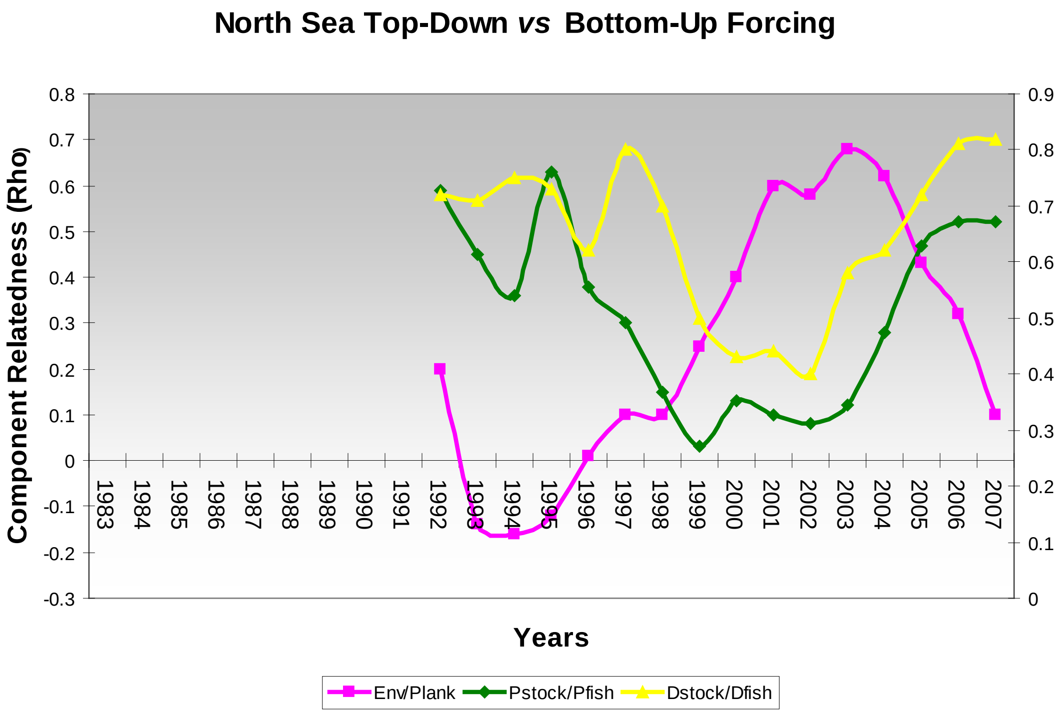


Figure 6. Trends in bottom-up (environment-plankton relatedness) and top-down (fisheries-fish stock relatedness) for the North Sea. Rho values are based upon ecosystem component correlations for any given 10 year period. For example the first values are shown for 1992 based upon examining the degree of ecosystem component relatedness over the period 1983 to 1992. In other words the value shown in 1992 is based upon using preceding data between 1983 to 1992.

The first thing to note is that the trends in the Rho values are not stochastic – they exhibit smooth directional responses over time which is indicative of a robust method. Specifically, it can be seen that between 1992 and 1997 the North Sea ecosystem was dominated by relatively high fishery-fish stock (top-down) pressure compared to the environment-plankton (bottom-up) pressure over the same period. However, by 2002 the situation had reversed such that the most dominant pressure in the North Sea at this time appears to be related to bottom-up forcing. Such a response is in agreement with the witnessed reductions in fishing effort and fish landings at this time together with step-change increases seen in some of the environment-plankton (bottom-up) variables such as seawater bottom temperatures. However, more recent data in Figure 6 (2003–2007) shows a reversal in the system properties such that top-down fishery pressures are now relatively more dominant than bottom-up forcing. It is important to understand that the relationships described in Figure 6 are relative and not absolute, for example if bottom-up forcing conditions remain stable (or constant from one year to the next) then any small changes in fishing pressures are likely to have a much greater influence on the status of the fish stocks than the corresponding bottom-up processes and hence give rise to higher fishery-fish stock Rho values. Conversely, if fishing pressure remains stable and high from one year to the next then any small change in climate forcing (such as an increase in temperature) is more likely to have a greater influence on the status of the plankton community than the corresponding top-down fishing pressure and hence it will give rise to relatively high bottom-up environment-plankton Rho values. Nevertheless, we believe that there is practical utility in this method in using to help predict future changes in the status of fish stocks. For example, Figure 7 shows some of the same data, but it also includes the spawning-stock biomass of North Sea Herring. It can be seen that there is a very close relationship between the status of the Herring SSB and the environment-plankton component relatedness with an almost 1 to 1 match in trend allowing for a 1 year time-lag difference.

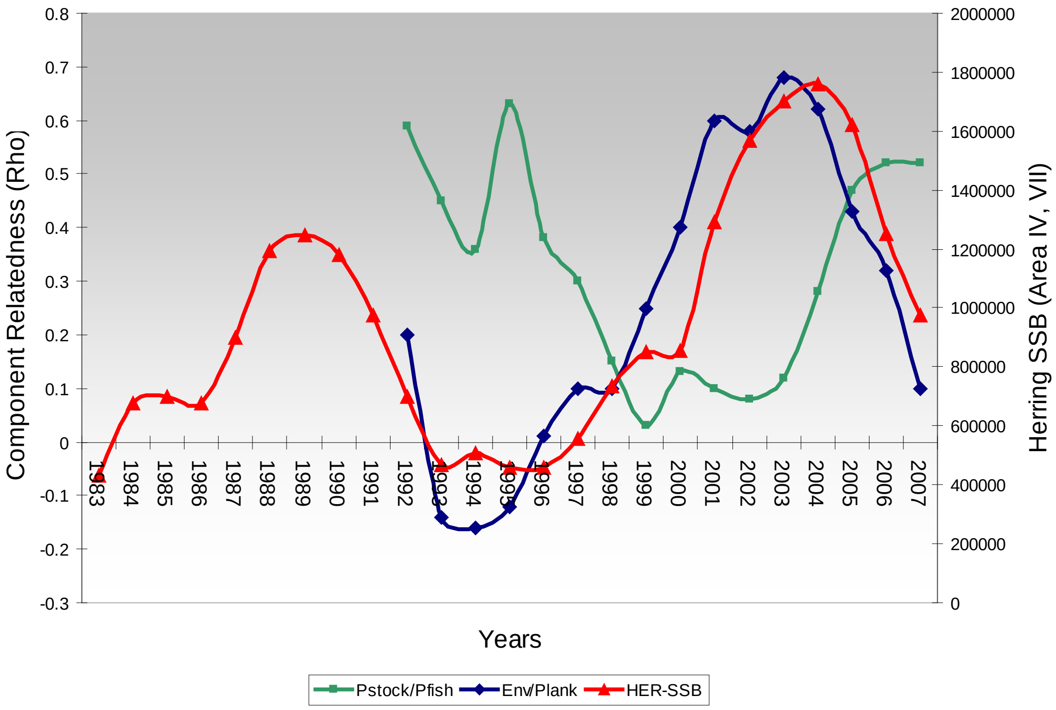


Figure 7. Trends in bottom-up (environment-plankton relatedness) and top-down (fisheries-fish stock relatedness) for the pelagic part of the North Sea ecosystem including trends in the spawning-stock biomass of North Sea Herring (HER-SSB).

Based upon the trends described in Figure 7 (and all things being equal) it is likely that a low point in the status of Herring SSB along will be witnessed sometime between 2008 and 2010.

In considering some overall measure or approach to describe the 'health' or 'stress' of the North Sea ecosystem it is necessary to integrate an assessment of both its state and function, that is to combine the results shown in Figures 3 and 4 (which describe attributes of state) with the results shown in Figure 6 (which describe aspects of function). This is something we have yet to develop and validate, but the fact that using the same number and type of variables for the two periods of analyses, e.g. i) 1983 to 2003 and ii) 1983 to 2007 shows a change in state such that there are now more variables exhibiting negative anomalies (see Figure 4) compared to those exhibiting positive anomalies. We also see a return to a system dominated by top down pressures (both pelagic and demersal parts) a situation comparable to that observed in the early 1990s, albeit at a much reduced absolute level of fishing effort. Taking these two state and function measures together we may conclude that the present (2007) health of the North Sea is probably worse than it was in 2003.

Table 1. Variables used in the updated integrated assessment of the North Sea. Variables shaded are those included in the sub-regional analysis described in Section 5.

Abiotic	Plankton	Demersal Stock	Pelagic Stock	Demersal Fishery	Pelagic Fishery
Bottom AMON (umol/l)	calfinNS	*Anarhichas Lupus*	SCOPHTHALMUS MAXIMUS	L-cod-347d	L-her-47d3
Bottom CPHL (mg/m^3)	calhelNS	*Gadus Morhua*	SCOPHTHALMUS RHOMBUS	L-had-34	L-nop-nsea
Bottom DOXY (umol/l)	euphNS	*Hippoglossus Hippoglossus*	AMMODYTES MARINUS	L-ple-nsea	Herring
Bottom NTOT (umol/l)	cladNS	*Lophius Piscatorius*	CLUPEA HARENGUS	L-sai-3a46	Mackerel
Bottom NTRA (umol/l)	meroNS	*Melanogrammus Aeglefinus*	SCOMBER SCOMBRUS	L-sol-nsea	Norway pout
Bottom NTRI (umol/l)	copsNS	*Merlangius Merlangus*	SPRATTUS SPRATTUS	Cod (TAC)	Sprat
Bottom PHOS (umol/l)	dinoNS	*Merluccius Merluccius*	TRACHURUS TRACHURUS	Haddock (TAC)	HER
Bottom PHPH	diaNS	*Pleuronectes Platessa*	TotPelFishHrTow	Plaice (TAC)	HOM
Bottom PSAL		*Pollachius Virens*	AvPelFishLen(cms)	Saithe (TAC)	MAC
Bottom SLCA (umol/l)		*Rajidae*	SSB-her-47d3	Sole (TAC)	MidTraw
Bottom Temp		*Solea Solea*	SSB-nop-nsea	Whiting (TAC)	PairTraw
Bottom TPHS (umol/l)		*Trisopterus Esmarki*	R-her-47d3	ANF	
NAO		TotDemFishHrTow	R-nop-nsea	BLL	
		AvDemFishLen(cms)	B-her-47d3	BeaTra	

Abiotic	Plankton	Demersal Stock	Pelagic Stock	Demersal Fishery	Pelagic Fishery
		SSB-cod-347d	B-nop-nsea	CAA	
		SSB-had-34		COD	
		SSB-ple-nsea		DemSie	
		SSB-sai-3a46		HAD	
		SSB-sol-nsea		HAL	
		R-cod-347d		HKE	
		R-had-34		JOD	
		R-ple-nsea		MUR	
		R-sai-3a46		NEP	
		R-sol-nsea		OttTraw	
		B-cod-347d		PLE	
		B-had-34		POK	
		B-ple-nsea		SKA	
		B-sai-3a46		SOL	
		B-sol-nsea		TUR	
				WHG	

4 Management of data and links to new data sources (items b and c)

4.1 Background

Prior to the establishment of WGHAME, work was undertaken by the Regional Ecosystem Study Group for the North Sea (REGNS). The resulting dataset which REGNS created had a number of data feeds from the ICES Data Centre, however it proved difficult for other working groups to find these dataset and there were a number of issues regarding updating the dataset and how best to manage it for future use by WGHAME and other expert groups.

4.2 Lessons learned

Following the REGNS experience and more recently in initiating an update of the REGNS data for WGHAME, lessons have been learned and shared with others, notably the ICES Data Centre, as to what works best. The key message is that all data to be used for integrated assessment purposes should be coordinated officially through recognized Data Management Centres which can ensure data policies, quality and access rights are in place for its use. REGNS collated datasets not held at that time by officially recognized Data Centres (e.g. Seabirds and Plankton data) and this proved to be a problem in enabling further access rights to the REGNS data. Furthermore, the REGNS database consisted of a combination of raw and summarized data as data products – this caused confusion for users not part of the REGNS process, but it was an inevitable consequence of having to deal with data originally collected for very different purposes and at very different scales in time and space. The Data Centres therefore hold the key to ensuring consistency in quality and data format over time when assessments have to be repeated periodically, often by different groups not originally involved in the collation of the raw data.

A common problem encountered by WGHAME for example, was how to repeat the exact methods and queries used to extract and summarize the raw data during the first assessment. For example, the raw ICES CTD data which was the main source for environmental data in the original analysis, is complex consisting of different determinands analysed from water samples taken at different depths, from different stations and at different times of the year. In order to construct an internally consistent abiotic dataset, this meant extracting data from the start of the time-series because the precise methods used originally to extract the data were not fully documented. It was therefore more simple (and quicker) to re-create a new dataset from scratch.

Strategically, the ICES Data Centre would like to ensure the smooth transmission of data into Expert groups, such as WGHAME and also to ensure the resulting products and datasets follow ICES or International data management standards as closely as possible. This will maximize the effectiveness of the group and ensure the longevity of the datasets.

4.3 Links to other sources of data

WGHAME and the ICES Data Centre should work together to define criteria for the data feeds needed from ICES Data holdings to address a broad range of holistic assessment activities within this groups remit. This should build on ICES existing work with web services and other OGC services. In addition, the products and services arising from EMECO, EMODNET and ICES EcoSystemData should be examined to identify products and information suitable for sharing across the systems, for example shape files of OSPAR areas, ICES EcoRegions etc. This task will be progressed ahead of the next meeting by the ICES Data Centre and WGHAME so that an update on other types of data and their availability can be thoroughly evaluated. Such efforts should focus (in the first instance) on acquiring data on shipping activities.

4.4 Suggested data record for Regional Integrated Assessments

It is important to achieve consistency in the types of data used in repeat assessments and especially in comparative assessments of regional marine ecosystems. WGHAME therefore recommends that a systematic documentation of data types be undertaken as a matter of course when compiling data for regional integrated ecosystem assessments. A suggested example of a record template is given in table 2, but members of the group also recognize that standard XML meta-data formats already exist such as those defined by the European Directory of Marine Environmental Data (EDMED) – part of the SeaDataNet project (and now largely part of EMODNET too). Clearly an alignment of the suggested data fields and descriptors with this established system would ensure a smooth transfer at some later date from the WGHAME meta-data source into the EDMED database – or anywhere else for that matter.

Example XML data record:

https://www.bodc.ac.uk/data/information_and_inventories/edmed/report/?session=RMRWU9F6KH18PGEG2GEHZULBW1QQEQ7X&v1=10&v2=1

Table 2. Suggested template for an "Overview of dataseries used in Regional Integrated Assessments"

CATEGORY	SUB-CATEGORY	SUITABLE ENTRIES	EXAMPLE
Variable	Term	Short description	Surface Salinity in Summer
	Abbreviation	Abbreviation of the Variable	Sal_Surf_Summer
	Definition	Longer description	Direct output parameters from TS instruments such as thermosalinograph or CTD. Representative for the upper water layer (approx. 1-5 m)
Data Type	Model / Observation	Model, Observation	Observation
	Unit	Unit of the measurement	psu
	Source	Sampling platform	Measurements are taken during the 3rd quarter International Bottom Trawl Survey (IBTS)
Coverage	Space	Short description	ICES Sub Area IV (North Sea)
	Time	Short description	1991-2009
Resolution	Space	Short description	ICES Statistical Rectangle ('30 min lat, 1° lon. approx. 30 nautical miles square), between 1 and 3 measurements per year, quarter, rectangle
	Time	Short description	3rd Quarter of the year
Suitability	Quality	Expert judgement according: 1 = high confidence, 2 = low confidence	High confidence

CATEGORY	SUB-CATEGORY	SUITABLE ENTRIES	EXAMPLE
	Bias	Expert description of any known bias in space or time or methods	none
	Special Value	Optional expert comment on the key value of this time-series, despite its short-comings in e.g. coverage / bias.	-
	Usage in Core IA	To be included in the Core IA (yes / no)	yes
	Reason for (non) usage in Core IA	Rationale for including (or not) it in the Core IA	High confidence and key physical driver
Contact	Institute	Institute Name and Address	ICES Data Centre, H. C. Andersens Boulevard 44-46 DK-1553 Copenhagen V Denmark
	Person	Contact person	Neil Holdsworth
	Reference	http://www.ices.dk/datacentreWeb link or publication	http://www.ices.dk/datacentre

5 Integrated assessments and the issue of scale (item d)

5.1 Background

The view of any system depends on the scale of investigation. Thus the choice of scale can fundamentally affect the perspective and interpretation of the system's properties, not least because the variability of virtually all ecosystem descriptors are critically dependent upon the scale on which the measurements are made (Figure 8). It therefore follows that the scale of the area to be assessed for management and policy purposes will have a great influence on the type and mode of descriptor to be measured. For example, measuring molecular processes which operate at small spatial scales (e.g.. nm – µm) would add little to understanding the variation in ecosystem dynamics if the area to be assessed is at a broad scale (100 km or more), here monitoring the status of ocean currents, fronts and seabed type would be more useful.

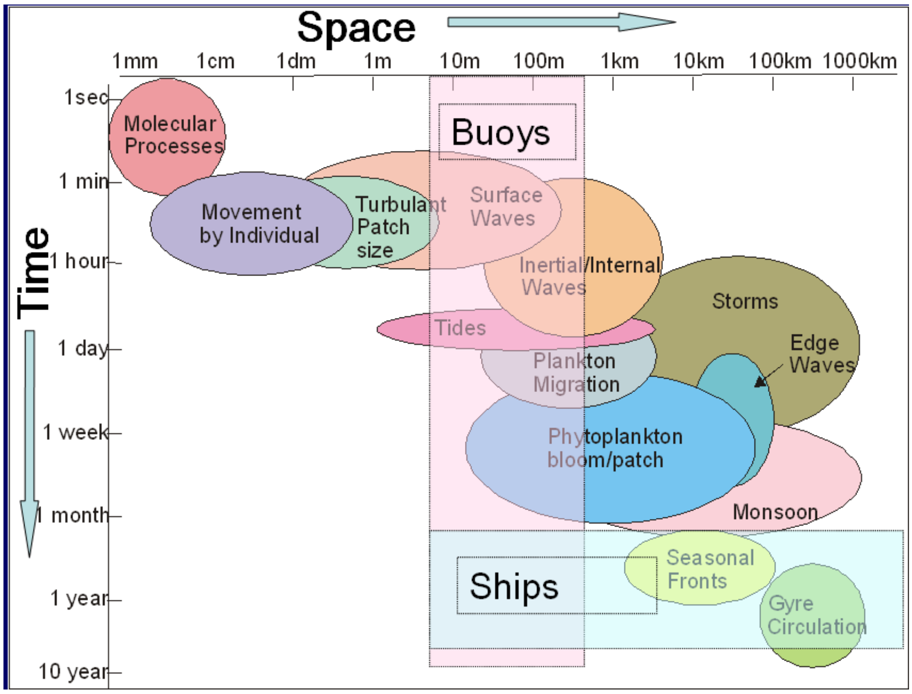


Figure 8. Relationship between scales in time and space and the types of observation system most suited to their assessment.

Knowing where natural boundaries occur in an ecosystem, e.g. those which define specific seabed habitats types or water body masses, and what factors (both natural and anthropogenic) determine such boundaries, is an essential part of understanding and defining the scales of variability and hence defining the scope of associated monitoring and assessment programmes. It should be expected that with increasing spatial scale that wide-scale ocean forcing via natural oceanographic processes will increasingly explain greatest part of the observed variation in the status LME. However, where human factors (e.g. pressures) are being exerted at comparable 'large' scales (e.g. through fishing practices or the cumulative impact of multiple human activities) then the ecosystem properties when assessed at that scale may be influenced more by human activities than natural processes. There is therefore a continuum of spatial and temporal scale variation in ecosystem state which can be generally related to the relative effects of either natural and/or human pressures– this is depicted in Figure 9.

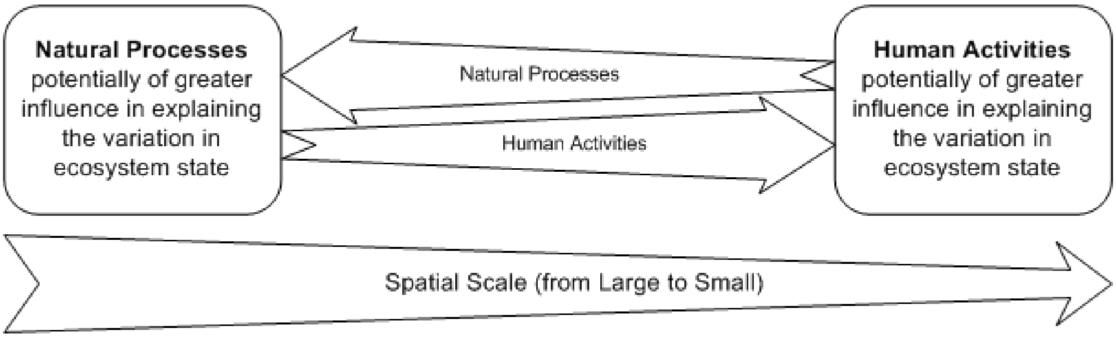


Figure 9. Schematic relationship between spatial scale and the relative importance of natural processes *vs.* human activities in determining the status of marine ecosystems.

For example, it is widely understood that the biogeographic ranges of species are strongly controlled by natural gradients in latitude (temperature) and depth (light). At the European scale this pattern of variation largely provides the basis for the delineation of bio-geographic regions and the latitudinal boundaries between some of the European LMEs (http://dataservice.eea.europa.eu/atlas/). However, within a biogeographic region, additional natural factors become increasingly important such as the sediment or substrate type of the seabed, particularly for the benthos. It is also at the scale of LME's that human pressures, such as the effects caused by fisheries, are more likely to be important in determining ecosystem state.

For each regional sea (provided sufficient data exits) it should therefore be possible to quantify the spatial and temporal variation in the system properties in relation to the natural and human pressures acting upon it. Clearly defining such relationships should be a prerequisite for defining the most cost-effective management actions to take in regulating a human activity, because it would not make much sense in over managing a particular human activity if the variation in your system properties when measured at the scale of your assessment unit were shown to be determined mainly by natural and unmanageable processes. Only when your system properties are shown to be influenced by the manageable activity should your management system intervene.

5.2 North Sea integrated assessment – scale dependant system level responses.

5.2.1 Trends in North Sea sub-regional state

The aim of this exercise was to repeat the analysis undertaken in Section 3 (notably, to reproduce Figures 3, 4 and 5) at a much smaller scale within the North Sea, where other sources of disturbance, particularly that arising from marine aggregate dredging and shipping activity are known to be important. The selected sub-region for this integrated assessment is shown in Figure 10.

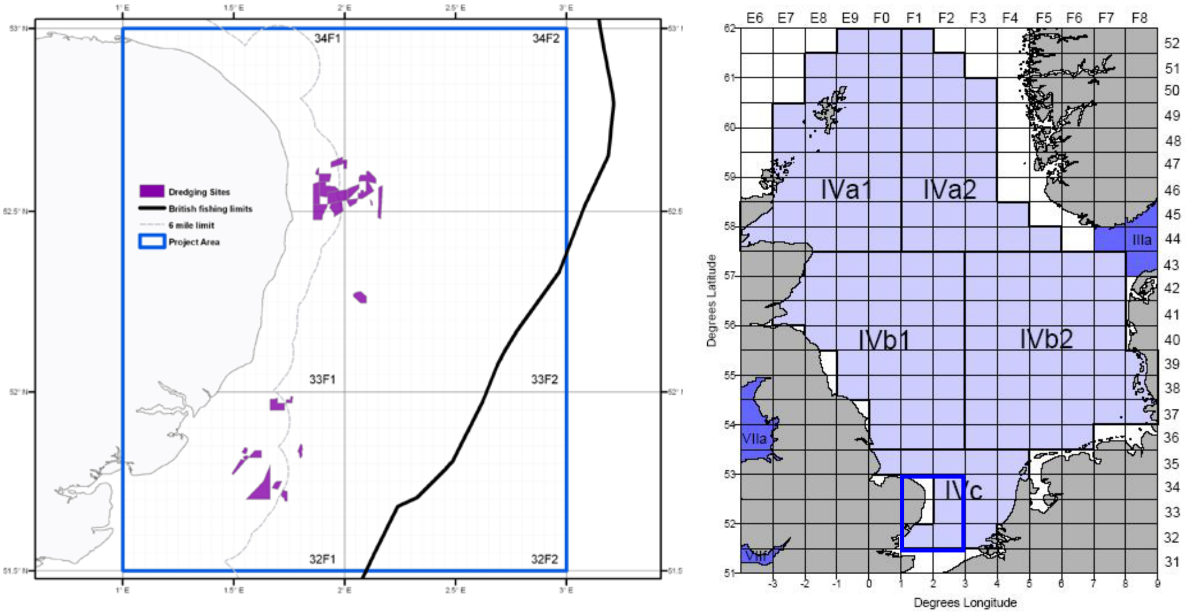


Figure 10. Map showing the boundary for the North Sea integrated assessment sub-region used to directly compare results in function and state with that observed at the North Sea scale. The purple shapes denote marine aggregate dredging licenses in the UK sector of the North Sea. The black cutting through the SE corner of the assessment region is the UK EEZ boundary. Grid cell units (squares) are ICES statistical rectangles.

To ensure the results were directly comparable between the different scales of assessment it was important to ensure the data used for the sub-regional analysis was derived from the same source as that used for the entire North Sea. The methods of data extraction and types of variables were the same, the only difference being that data (observations) obtained within the defined smaller region were used for the sub-regional analysis. In total 45 variables were included in the sub-regional analysis compared to 106 variables at the scale of the North Sea – see Table 1. Plotting the 6 principal variables describing the North Sea (whole) for the sub-regional system we see some important differences and similarities in trends (see Figure 11). It is noteworthy that cod and skate landings along with Otter Trawling effort and bottom seawater temperatures show a similar trend between the different spatial scales, whereas total *Calanus helgolandicus* and the average pelagic fish length do not. Principal components analysis of the sub-regional data shows an overall similar ordination of the years, but on PC1 the principal variates are total diatoms, sprat and seawater temperature – all showing an increase over the years.

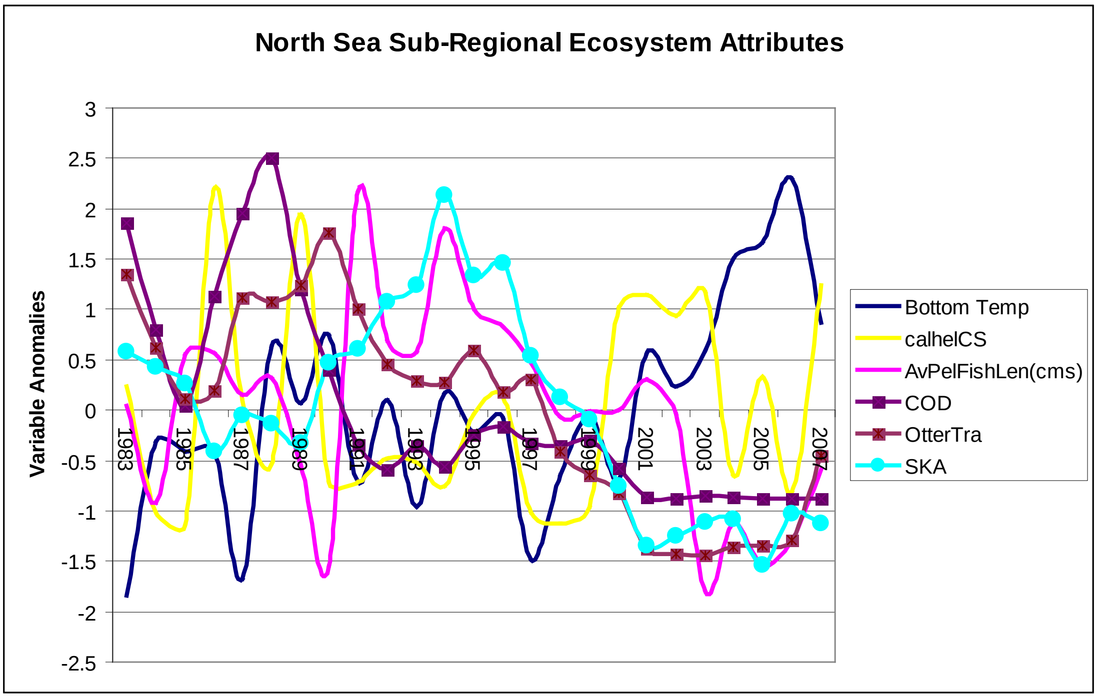


Figure 11. Trends in the principal North Sea sub-regional ecosystem attributes – these are the same attributes used in to describe the North Sea (whole) – compare with Figure 3. Note the consisten –ve anomalies for Skate, Cod and Otter Trawling from about 1998 onwards. This is consistent with the observation seen at the scale of the North Sea.

In considering the trends across all variables (e.g. ecosystem level state changes) at the sub-regional system level we plotted the variable anomalies as a shade diagram (Figure 12). In comparing the North Sea sub-region with the North Sea (whole) we observe that the overall systems exhibit comparable shifts in state, albeit with some notable differences in the principal variates e.g. total diatoms replace *Calanus helgolandicus* and *Sprattus sprattus* replace the average pelagic fish length at the sub-regional scale

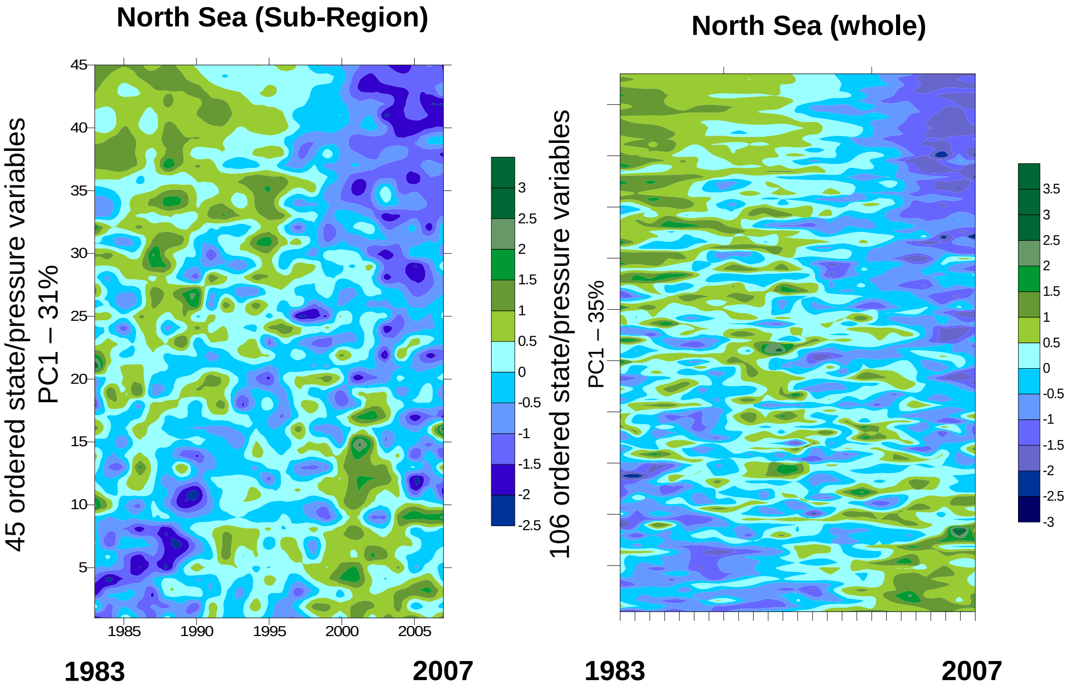


Figure 12. Shades plots of state and pressure variables representing the North Sea whole and a sub-region of the North Sea. Note that both plots reveal a change in state in 1995.

5.2.2 Trends in North Sea sub-regional function (ecosystem component relatedness)

Repeating the analysis between sets of ecosystem component variables described in Section 3.3 we note again some striking similarities in addition to some differences, (see Figure 13) between systems assessed at different scales. First the overall pattern of variation is very similar, that is both systems are initially predominantly influenced by top-down fishery pressures which progressively decline in dominance through the first part of the time-series. The striking difference however, is the point (in time) at which the systems change from being top-down to bottom-up driven. At the whole North Sea scale we observe that a change from top-down to bottom-up occurred in 1998 for the pelagic part of the ecosystem and in 1999 for the demersal part of the system. However, for the sub-regional ecosystem (measured on a smaller scale) this occurred about 4 years later, e.g. in 2002 and 2003, for the pelagic and demersal components respectively. What is noteworthy is the area defined by each of the curves representing the top-down pressure (fisheries/fish stock Rho values) and bottom-up pressure (environment/plankton Rho values). The area represents a measure of the total pressure over a given period of time, either top-down or bottom-up.

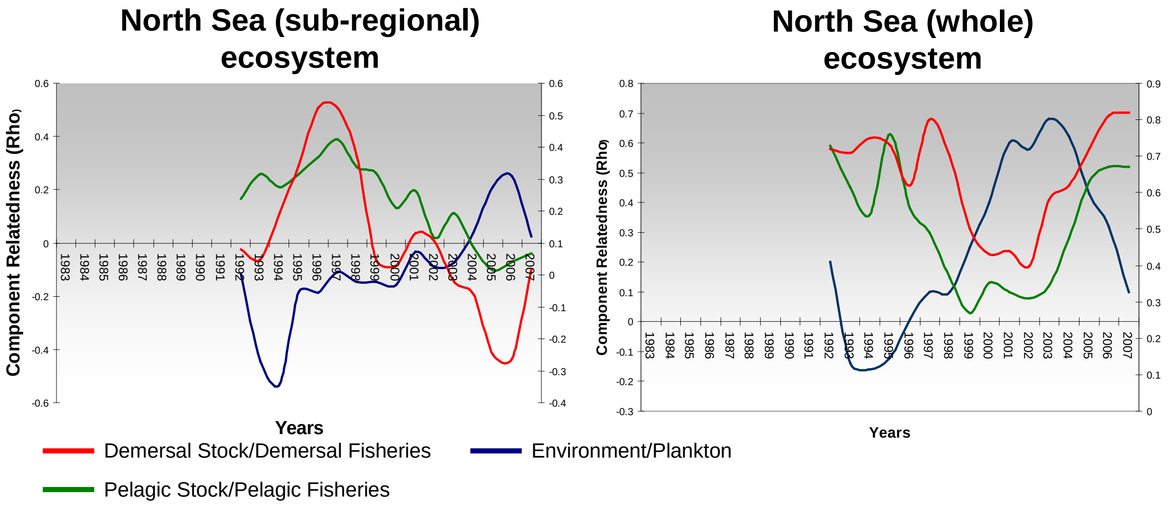


Figure 13. Plots showing trends in ecosystem component relatedness (Rho) for two different spatial scales in the North Sea. Whilst the green and red lines are above the blue line then the system is predominantly under top-down fishery pressure. Note how the sub-regional system for both the pelagic and demersal components become bottom-up driven much later than that shown at the scale of the whole North Sea – this possibly indicates a scale dependant level of stress exhibited by the two systems.

When the area under the curves is compared for the two spatial scales (North Sea whole and the North Sea sub-region – Figure 13) it can be seen that the areas under each part of the curves are very different. Overall between 1983 and 2007 the sub-regional system is subjected to 4 years additional top-down pressure compared to the North Sea as a whole over the same period. The fact that the sub-regional system is known to be under greater human pressure through dredging, shipping, disposal activities may mean the system in this area of the North Sea is less resilient than the North Sea as a whole. Reductions in fishing effort applied at the North Sea scale therefore appear less effective when assessed at the sub-regional level, especially when the sub-region in question is already under considerable human pressure from other sources of human activity. This analysis appears to reveal for the first time some evidence of spatially dependant variations in ecosystem resilience or 'health' which may have significant implications for spatial management and the setting of control measures needed to be applied at different spatial scales. Knowing and quantifying the state of a system already under stress from human activities would allow more appropriate controls to be put in place, by knowing what contribution each activity has on the overall system properties would allow control to be directed to the most significant source of activity.

6 Comparative analysis of marine ecosystem dynamics (item e)

6.1 Background

Despite the complexities of all possible interactions among ecosystem components described above, there is growing evidence that ecosystem change can have some large-scale coherence. Integrated time-series analysis of several large marine ecosystems (North Sea - Kenny *et al.*, 2009; Nova Scotia Shelf - Choi *et al.*, 2005; Baltic Sea - Möllemann *et al* ?, and Mediterranean, Molinero *et al.*, 2008; Mariotti *et al.*, 2002) all reveal large-scale changes in ecological state (or regime shifts[1]) affecting many trophic levels. These studies also present further insight into how ecosystems change state, for example the rates and magnitudes of change are not the same for the different systems reflecting regional specific differences in the forcing factors. Indeed, such regime shifts may simply be part of a multi-annual or multi-decadal oscillations related to climatic shifts occurring at large (hemispherical or global) scales (discussed below). In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing pressures appear to be at greater risk to this phenomena (Kenny *et al.*, 2009, Kirby *et al.*, 2009).

6.2 Atmospheric forcing on North Atlantic Large Marine Ecosystems

A variety of indices and atmospheric modes exist that describe large-scale climatic influences which have been related to a number of biological phenomena in the past (Hemery *et al.*, 2008; Alheit *et al.*, 2005; Brander and Mohn, 2004; Beaugrand, 2004). In this study we describe four atmospheric forcing modes (indicators) which are probably the most influential on the dynamics of North-East Atlantic ecosystems. For the analysis of these indicators we used winter monthly values (*i.e.* from December to March) averaged and plotted against time. Furthermore we identified years where the modes potentially changed to a new "state" by using a sequential t-test following the STARS method developed by Rodionov (2004).

6.2.1 North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is a climatic phenomenon in the North Atlantic Ocean and the related index describes the difference of atmospheric pressure at sea-level between the Icelandic Low and the Azores High. The relative strengths and positions of these systems vary from year to year. Positive anomalies lead to increased westerly winds and, consequently, cool summers and mild and wet winters in Central Europe and its Atlantic façade. In contrast, in years with negative anomalies westerlies are suppressed and winters are colder. The NAO is highly correlated with the Arctic oscillation, as it is a part of it. In the past decades the NAO has shown an overall increasing trend with exceptionally high anomalies in the Winter NAO index around the 1990s (Figure 14). This step-change in values in the late 1980s was also identified in the STARS analysis (see Figure 15).

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[1] Changes in marine system function that are relatively abrupt, persistent, occurring at a large spatial scale and observed at different trophic levels and related to climate forcing (B. deYoung, R. Harris, J. Alheit, G. Beaugrand, N. Mantua, L. Shannon. 2004. Detecting regime shifts in the ocean: Data considerations. Prog. Oceanogr. 60: 143-164.)

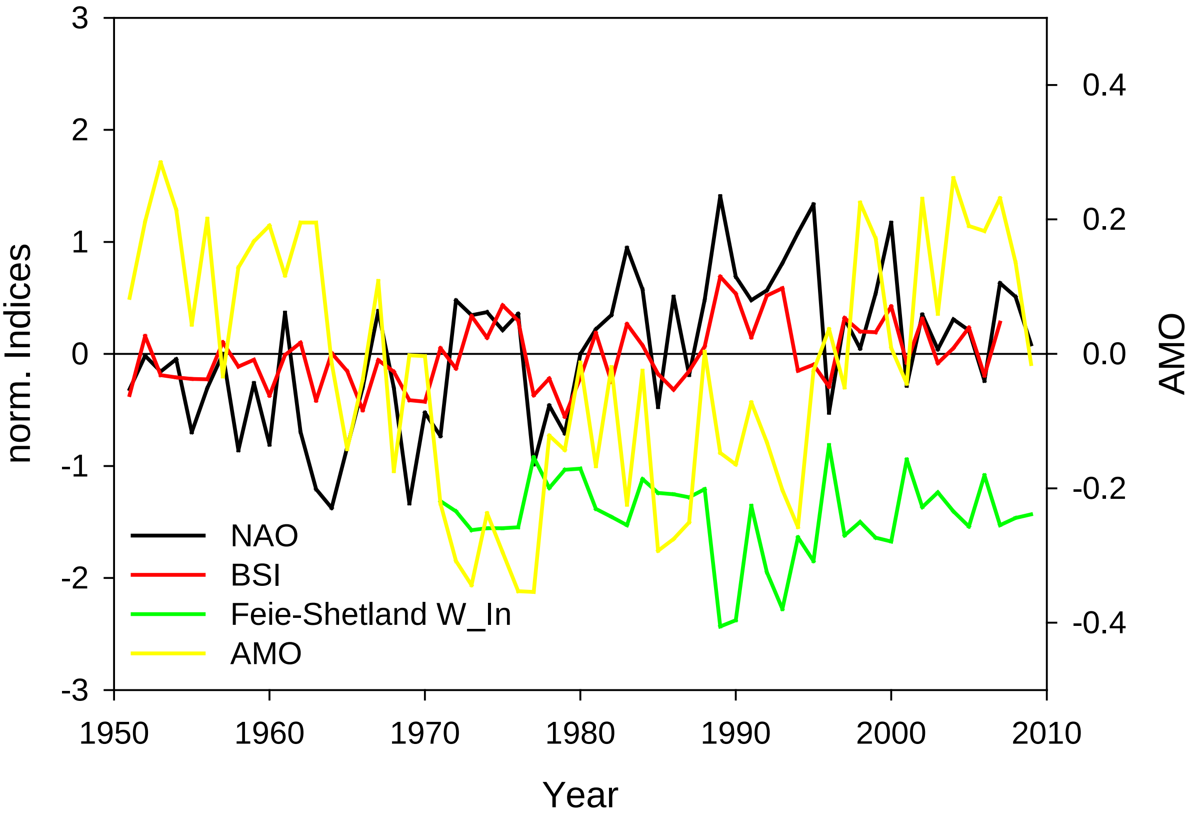

Figure 14. Climatic and hydrographic indices relevant to North-East Atlantic ecosystems: North Atlantic Oscillation (NAO, black), Baltic Sea Index (BSI, red), Influx of seawater into the North Sea (green), and the Atlantic Multidecadal Oscillation (AMO, yellow) from 1950 until 2009.

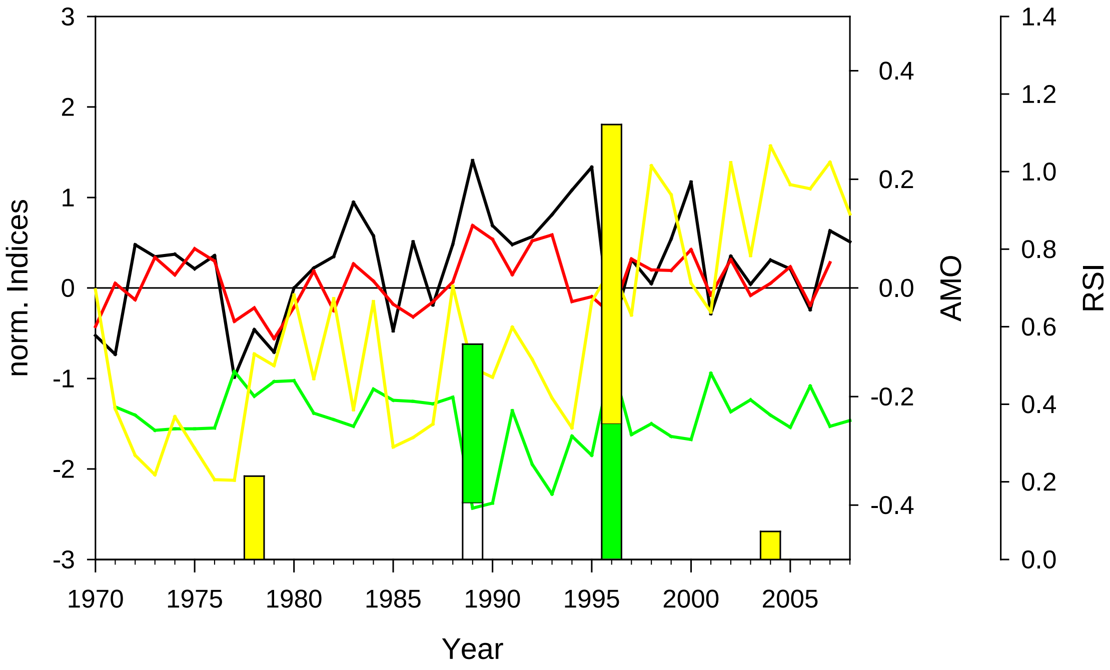

Figure 15. Shifts in climatic and hydrographic indices relevant to North-East Atlantic ecosystems identified by STARS: North Atlantic Oscillation (NAO, black), Baltic Sea Index (BSI, red), Influx of seawater into the North Sea (green), and the Atlantic Multidecadal Oscillation (AMO, yellow) from 1970 until 2007.

6.2.2 Baltic Sea Index

The Baltic Sea Index (BSI) is a regional homologue to the NAO and describes the atmospheric forcing in the Baltic Sea region. It is defined as the difference of normalized sea level pressure anomalies between Szcecin, Poland and Oslo, Norway. Positive values of the index correspond to approximately westerly winds over the Baltic, whereas a negative index corresponds more to easterly winds (Lehmann *et al.*, 2002). Here, we used the averages of the BSI for December, January, and February. Overall, the index is well correlated with the NAO index (Hurrell, 1995) and the BSI was generally negative during the 1970s and 1980s, while it turned positive during the late 1980s (Figure 14). However, no step-change shift was observed in the BSI within this time period (see Figure 15).

6.2.3 Atlantic Multi-decadal Oscillation

In contrast to the above atmospheric pressure related indices, the Atlantic Multidecadal Oscillation (AMO) is a naturally occurring cycle in Sea Surface Temperature (SST) with a frequency that varies from 50 to 80 years. The relationship between the NAO and AMO is comparably week and the AMO shows a different temporal dynamic. Lowest AMO values in the past decades were measured in the 1970s, whereas since the late 1990s very high values comparable to the values in the 1950s have been observed (Figure 14). However, some notable step-changes are identified in the AMO time-series, for example in 1978 when the magnitude of change was relatively small, but this was followed by a strong shift in 1996 when the AMO started to increase (Figure 15).

6.2.4 North Sea modelled flux of seawater (NORWECOM)

The strong shift in 1996 identified for the AMO was mirrored in the modelled flux of seawater flowing into the North Sea between December and March crossing a west-east transect between Feie and the Shetlands in the northern part of the North Sea (NORWECOM, Hjøllo *et al.*, 2009) (Figure 14). Here only the flux across the western part of the transect is considered and negative values indicate a flow in a southern direction. In 1996 the peak in the value indicates a low net inflow from the north and it remained relatively low in the following years. The modelled seawater flux is also strongly correlated with the NAO and thus a further shift was identified in 1989, when the net inflow in winter was highest (*i.e.* a low flux value) within the available time-series (Figure 15).

6.3 Ecological state changes in Large Marine Ecosystems – 'regime shifts'

During the meeting a number of studies describing state changes in large marine ecosystems were reviewed representing different regions of the Atlantic, namely; European region (North Sea, Baltic Sea, the Black Sea, the Irish Sea the Norwegian Sea) North West Atlantic and Arctic region (Scotian Shelf, NE USA coast, Gulf of Alaska, Bering Sea) and the southern Atlantic region (Northern and Southern Benguela systems). The characteristics of all these regional LMEs are described in Table 3 and any significant changes observed in their ecological status were then identified and summarized in Table 4. The information presented in Table 4 was then reviewed alongside the trends in atmospheric and ocean climate forcing presented in Figures 14 and 15 (above) and both sources of data were combined into a summary plot showing the timing and duration of significant events (Figure 16).

From the overview results presented Figure 16 it can be seen that there is a possible correspondence between the timing of the major atmospheric/marine climate events (Figure 15) and the significant changes observed in several LME's spanning a very wide geographic area in the late 1980s and mid 1990s. Specifically the changes observed in the NAO and influx of seawater into the North Sea are dominant events in 1989 whereas in 1996 a significant positive trend in the AMO was witnessed.

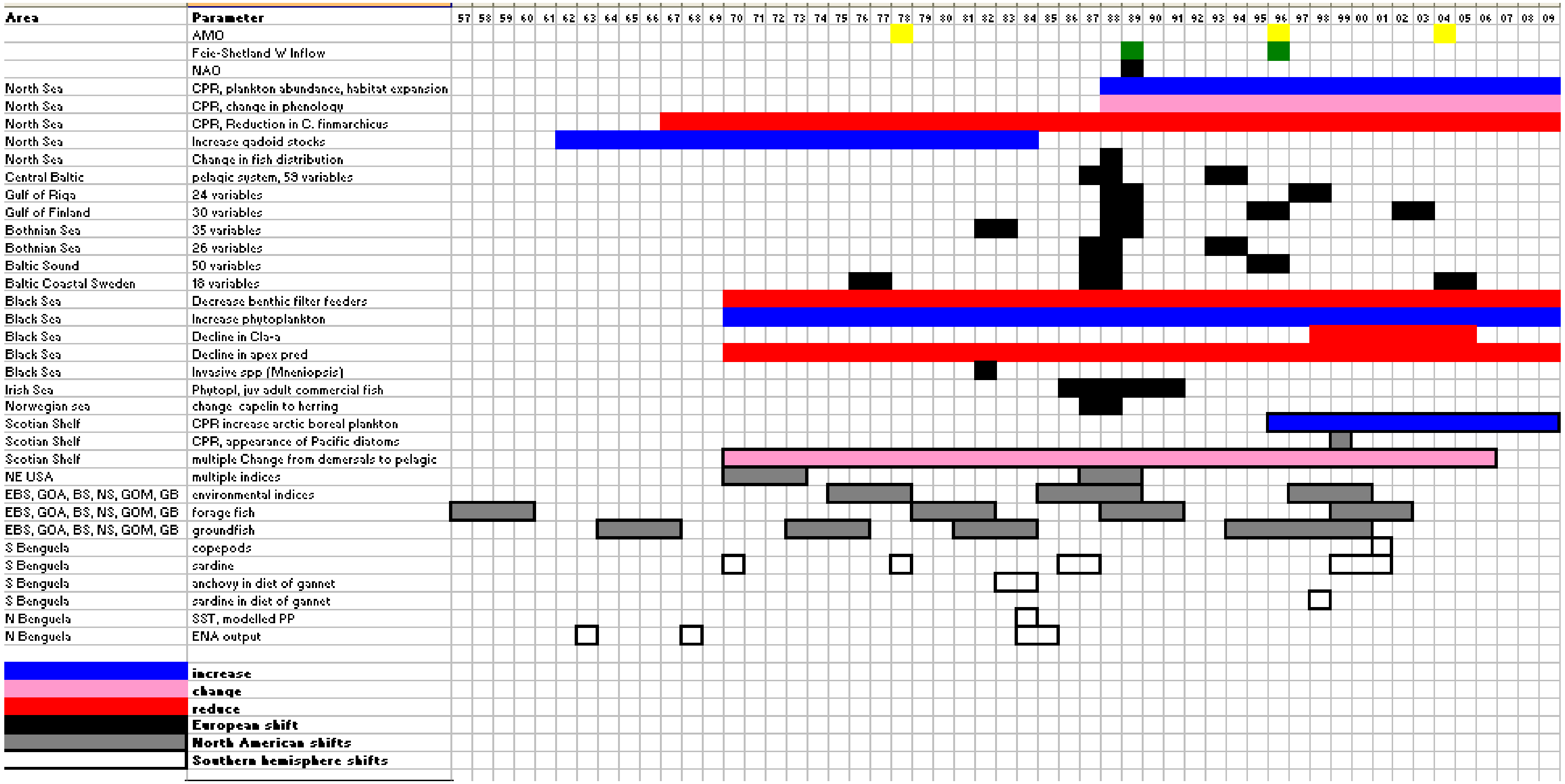

Figure 16. Comparison of ecological shifts in LME status from several different regions across Europe, north and south Atlantic areas. In addition significant changes in atmospheric/ocean climate forcing events from 1957 2009 are highlighted in green, yellow and black at the top of the figure.

Indeed other studies have already highlighted the importance of the AMO in explaining variations in many diverse marine ecosystems; in particular well established links have been made between the long-term trends in spawning-stock biomass of Norwegian spring-spawning herring and the long-term averaged sea surface temperature or AMO (Figure 17)

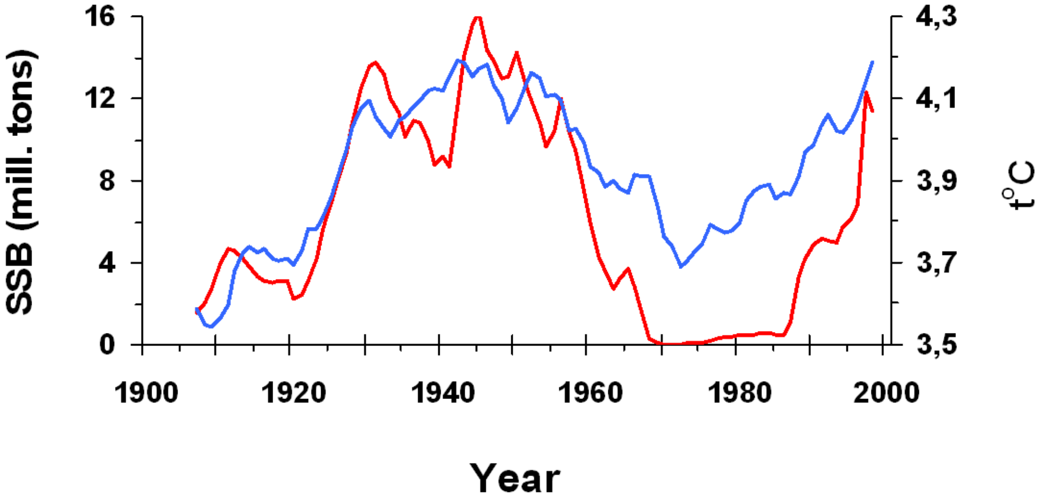

Figure 17. Spawning stock biomass of Norwegian spring-spawning herring and the long-term-averaged sea surface temperature or AMO (Toresen and Østvedt, 2000).

It should be noted that the information analysed within this meeting was heavily weighted to systems that have been subject to systematic assessments and to information known to the WG members. The results combine information on specific ecosystem components as well as more general groups and indicators. Dates of the observed changes are determined from the literature but the determination was not always based on objective analysis or criteria. Nevertheless, It can be seen that many of the long-term changes are very closely linked to climatic events as Table 4 and Figure 16 reveal, and given the wide spatial scale over which such forces operate it is perhaps not surprising to find several seemingly unconnected regional marine ecosystems changing at similar times (Megrey *et al.*, 2009). The fact that many North Atlantic ecosystems (including the Barents Sea, Baltic Sea, Bay of Biscay, North Sea and Mediterranean) have responded to ocean climate events centred on the North Atlantic, demonstrates an interconnection between adjacent large marine ecosystems. For example, in the Norwegian Sea the inflowing Atlantic water has shown a warming trend and an increase in salinity from the late 1970s to the early 2000s. However, these trends are influenced by pronounced fluctuations related to variations in the NAO index (Mork and Blindheim, 2000; Blindheim 2004). The late 1980s and mid 1990s were periods of rapid warming of the inflowing Atlantic water in the south-eastern Norwegian Sea, corresponding in time to the stepwise changes seen in the North Sea ecosystem. It seems likely that a cascade of interconnected oceanographic processes are at work that influence to a greater or lesser extent the climate of all European regional seas.

6.4 The benefits of further comparative ecosystem analysis

An understanding and quantification of such inter-dependencies is at the heart of being able to predict and therefore manage the impacts of human activities which operate across vastly different scales in time and space. As more research is conducted at the scale of large marine ecosystems such interdependencies between systems will be defined, allowing adaptive management measures which anticipate ecological state changes to be developed and applied across the range of scales needed. Further meta-analysis of LME state changes through more comparative studies may allow us to test this hypothesis and to disentangle the often confounding effects of climate and human activities. To address these shortcomings and to test hypotheses about large-scale drivers of observed ecosystem changes it will be necessary to further investigate the responses presented so far. In particular, a series of consistent variables of interest will be developed and datasets of the predetermined variables will be compiled prior to the next meeting. Specific hypotheses can then be tested and discussed in advance of the next meeting to ensure that the appropriate variables are included in each dataset.

Table 3. Summary characteristics of the regional large marine ecosystems reviewed as part of this comparative exercise.

LMEs	Physical/chemical characteristics	Biological/ecological characteristics	System drivers (Abiotic)	Pressures (Human)	References
North Sea		Plankton abundance	Temperature (mainly)		
North Sea	Shallow mixed southern North Sea/ Deeper stratified northern North Sea. Physical characteristics influenced by NAOI, GSI, and others that Jürgen Mentioned. Warming temperatures	Productive ecosystem that has been over exploited. The system has changed in the last 100 years. Demersal white fisheries have declined, plankton communities have shifted in structure, (REGNS can provide more info.)		Over-fishing, climate change, other anthropogenic	Alheit and Hagen (1997), Beaugrand (2004), Beaugrand et al (2002, 2003), Benson and Trites (2002), Fromentin and Planque (1996), Genner et al (2004), Hislop (1996), Hurrel et al (2003), ICES stock assessments, Parsons and Lear (2001), Planque and Fromentin (1996), Planque and Taylor (1998), Reid et al (1998), Reid et al (2001) Taylor (1995), Taylor (2002), Kenny *et al* (2009)
Baltic	Estuarine system, strong W-E salinity gradient, permanent halocline in deep basins	Several subsystems geographically separated and/or separated by sills; low diversity with freshwater species in the Northern and Eastern bays	Climate (T, S, inflow events), Invasive species, HAB	Fisheries (esp. on cod, sprat, herring) Eutrophication (linked to climate by e.g. river run-off, recycling of nutrients)	Eero et al. (2008), Håkanson and Lindgren (2008), Haslob et al. (2007), Matthäus and Franck (1992), Möllmann et al. (2002), Köster et al. (2005), Wasmund and Uhlig (2003)
Black Sea	Eutrophication in coastal waters	Divided into two subsystems – shallow (<200m) shelf and deep (>1000m) central area	Invasive species, HAB	Nutrient loading, Over fishing (esp. large predatory species)	McQuatters-Gollop et al. (2008), Langmead et al. (2008)
Irish Sea	The Irish Sea (ICES VIIa) lies between Britain and Ireland and covers approximately 58,000km². A north to south running deep-water	The Irish Sea supports valuable pelagic, demersal, and inshore fisheries. Many stocks are exploited together in different combinations and often include important		Overfishing, climate change, other anthropogenic	Parker-Humphreys, (2004), Pawsons et al (2002), ICES Stock Assessments

LMEs	PHYSICAL/CHEMICAL CHARACTERISTICS	BIOLOGICAL/ECOLOGICAL CHARACTERISTICS	SYSTEM DRIVERS (ABIOTIC)	PRESSURES (HUMAN)	REFERENCES
	channel (St. Georges Channel) with a maximum depth of 150m separates the relatively shallow western and eastern regions of the Irish Sea. The main flow of water through the relatively narrow western Irish Sea flows south to north from the North Channel, whilst an anticlockwise gyre dominates circulation patterns in the eastern Irish Sea. There are two main seasonal fronts in the Irish Sea: the Western Irish Sea Front, which separates mixed waters to its southeast from the stratified waters to its northwest and the Celtic Sea Front that separates the cooler, mixed waters of St. Georges Channel from the warmer surface waters of the Celtic Sea. Seasonal fronts may also occur in the eastern Irish Sea and Cardigan Bay. The temperature in the Irish Sea ranges from 6ºC in winter to 16ºC in summer.	bycatch. *Nephrops* is one of the most valuable fisheries in the Irish Sea and occurs predominantly on the extensive mud ground in the Northwest Irish Sea (Figure 1d). Otter trawls target *Nephrops*, cod, haddock, whiting, and plaice. Important bycatch include, hake, sole, skates, and rays. Pelagic trawlers in the Irish Sea target herring. Beam trawls fisheries principally land sole, plaice, rays, brill, turbot, and anglerfish. There are also important inshore fisheries for bass, cod, grey mullet, sole, plaice, brown cabs, and lobster.			CPR data
Scotian Shelf	Shelf, Gulf Stream and Labrador Slope waters	Shifted from demersal to small pelagic and invertebrate oriented system	Climate	Fisheries	Choi et al. (2004), Nye et al. in press
Northeast US	Temperate Shelf, Gulf Stream	Productive ecosystem, convergence of biodiversity from arctic and subtropical	Climate	Fisheries	Nye et al. in press, Link et al. (2009), EcoAP (2009), Megrey et al. (2009),

LMEs	Physical/chemical characteristics	Biological/ecological characteristics	System drivers (Abiotic)	Pressures (Human)	References
		zones			Drinkwater et al. (2009)
Norwegian Sea	Boreal Sea, notable currents	Productive ecosystem, species exhibit long migrations	Climate, Oceanographic	Fisheries	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)
Gulf of Alaska	Boreal Sea, upwelling prominent	Species known to shift related to climate factors	Climate, Oceanographic	Fisheries	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)
Bering Sea	Boreal shelf, ice impacts	Productive ecosystem, a range of tax	Climate, Oceanographic	Fisheries	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)
Southern Benguela	Upwelling	Pelagic and demersal system, pelagic oscillations between sardine and anchovy	SST, upwelling positioning	Fisheries	Andrews and Hutchings (1980), Travers et al., (2006), Howard et al., (2007), Shannon. et al., (2009), Siegfried, (1980, Nelson and Hutchings (1983), Shannon, (1985), Shannon, and Pillar, (1986), Crawford et al., (1987), Okes et al., (2009)
Northern Benguela	Upwelling, Hypoxia	Pelagic dominated system changed to more demersal (hake dominated)	SST, Wind stress at Lüderitz	Fishing, Human induced climate change	Heymans et al. (2009), Monteiro et al. (2008)

Table 4. Summary of significant ecological shifts in the status of regional large marine ecosystems reviewed.

LME	YEAR-START	YEAR-END	ATTRIBUTES	TYPE OF CHANGE	PRESSURES/DRIVERS IDENTIFIED	REFERENCES	COMMENTS
North Sea	1988	ongoing	Plankton taxa abundance – CPR data: Large changes in the North Sea plankton. Habitat expansion of the temperate province and subsequent contraction of boreal province (as evidenced by northwards shift of plankton community)	Gradual	Increase in Sea Surface Temperature	Beaugrand et al.(2002)	Gradual, ongoing shift on decadal time period (10° latitude northwards so far)
North Sea	1988	ongoing	Change in phenology of a number of plankton taxa (notably decapoda and echinodermata larvae	Gradual		Edwards and Richardson, (2004)	Gradual change, mainly from 1988 onwards
North Sea	1967		Reduction in the dominant copepod (*Calanus finmarchicus*) and community shift	Gradual		Helaouet and Beaugrand, (2007)	Gradual decline since late 1960s. Despite an increase in the warmer water species *C. helgolandicus*, total numbers of Calanus have dropped by 70% (Calanus are an important group as they are a major food source for larval fish)
North Sea	1962		Increase in gadoid stocks	Abrupt increase	Associated with negative NAOI Regime	Hislop (1996), Beaugrand et al (2003)	May have been an artifact of increased fishing
North Sea	Late		"crash" of demersal whitefish stocks, "radical" change in	Abrupt	Positive NAOI Regime,	Benson and Trites (2002), Parsons and	

LME	YEAR-START	YEAR-END	ATTRIBUTES	TYPE OF CHANGE	PRES-SURES/DRIVERS IDENTIFIED	REFERENCES	COMMENTS
	1980s		plankton community structure, change in fish distribution.		overfishing	Lear (2001), Genner et al (2004), Also see Table 1 North Sea references.	
Baltic (Central Baltic Sea)	1987	1988	1974-2006; 59 variables, pelagic system (phys., nutr., phyto., zoo., fish, fisheries mortality)	Abrupt	S (Inflow events), Oxygen, T, Fishing pressure	Möllmann et al. (2009), Alheit et al. (2005), ICES (2009)	
	1993	1994					
Baltic (Gulf of Riga)	1988	1989	1974-2006; 24 variables (phys., nutr., phyto., zoo., fish, fishing pressure)	Abrupt	S (Inflow events), T, Eutrophication (run-off), Fishing pressure	ICES (2009)	
	1997	1998					
Baltic (Gulf of Finland)	1988	1989	1979-2007; 30 variables (phys., nutr., phyto., zoo., fish, landings)	Abrupt, Oscillatory	S (Inflow events), Oxygen, T, Eutrophication (run-off), Fishing pressure	ICES (2009)	
	1995	1996					
	2002	2003					

LME	YEAR-START	YEAR-END	ATTRIBUTES	TYPE OF CHANGE	PRESSURES/DRIVERS IDENTIFIED	REFERENCES	COMMENTS
Baltic (Bothnian Sea)	1982 1988	1983 1989	1979-2006; 35 variables (phys., nutr., phyto., zoo., zoobenthos, fish, fishing effort, seals)	Abrupt	S (Inflow events), T, Eutrophication (run-off), Fishing pressure, top-predator increase	ICES (2009)	
Baltic (Bothnian Bay)	1987 1993	1988 1994	1979-2006; 26 variables (phys., nutr., phyto., zoo., zoobenthos, fish, fishing effort, seals)	Abrupt	S (Inflow events), T, Eutrophication (run-off), Fishing pressure, top-predator increase	ICES (2009)	
Baltic (The Sound)	1987 1995	1988 1996	1979-2005; 50 variables (phys., nutr., phyto., zoo., zoobenthos, fish, landings)	Abrupt, Oscillatory	Eutrophication, Water transport, T	ICES (2009), Lindegren et al. (submitted)	
Baltic (Coastal site, Sweden)	1976 1987 2004	1977 1988 2005	1971-2006; 18 variables (phys., nutr., phyto., zoo., zoobenthos, macrophytes, fish, seals)	Abrupt	T, S, Eutrophication (run-off), top-predator increase	ICES (2009)	
Black Sea	1970	1980s	Increase in certain phytoplankton species, leading to large blooms and hypoxia. This is turn led to decline benthic	Abrupt / Gradual	Eutrophication, climate change.	Daskalov (2002)	

LME	YEAR-START	YEAR-END	ATTRIBUTES	TYPE OF CHANGE	PRESSURES/DRIVERS IDENTIFIED	REFERENCES	COMMENTS
			filter-feeders and fish groups.				
Black Sea	1900	Ongoing	Invasive species – ongoing since records began in 1900	Gradual	Increase in maritime transport activity	McQuatters-Gollop et al. (2008)	
Black Sea	1998	2005*	Decline in Chl a (except in winter 2000-01, anomalous warm period)	Gradual	Reduction in nutrient loading and climate change	Langmead et al. (2008)	* Data in publication only goes until 2005
Black Sea	1970s	Ongoing	Decline in apex predatory fish	Gradual	Overfishing	Prodanov et al. (1997)	
Irish Sea	1986	1991	Change in phytoplankton abundance, Change in juvenile and adult commercial fish abundance.	Abrupt decline	NAOI, fishing pressure	ICES stock assessments, CPR data, Rogers and Ellis, Others	
Scotian Shelf	1970	2006	multiple species of fish	Some Abrupt, most Gradual	Fishing, Climate (AMO, NAO)	Nye et al., in press	
Scotian Shelf	1996	ongoing	From CPR: Increase in arctic – boreal plankton species (both phyto- and zooplankton). Winter blooms of the dinoflagellate *Ceratium arcticum*	Oscillatory	Large-scale hydro-climatic forcing (Increase in Labrador Sea Water, increase in stratification on the Grand Banks etc.)	Johns et al., 2004	Plankton taxa abundance – CPR data
Scotian Shelf	1999		Appearance of Pacific diatom species	Abrupt	Reduction in ice cover, increase in Pacific inflow	Reid et al., 2007	

LME	Year-start	Year-end	Attributes	Type of change	Pressures/drivers identified	References	Comments
					into Atlantic		
Northeast U.S.A.	1963	2008	Multiple indices of multiple species of fish, zooplankton, phytoplankton, marine mammals, benthos, temperatures	Some Abrupt, most Gradual	Fishing, Climate (AMO, NAO)	Nye et al., in press, Link et al. (2009), Megrey et al. (2009), EcoAP (2009), Drinkwater et al. (2009)	STARS routine indicates major shift in biological variables in later 1980s, with more minor shifts in mid 1970s
Norwegian Sea	1950	2006	Multiple indices of multiple species of fish, zooplankton, temperature	Some Abrupt, most Gradual	Fishing, Climate (AMO, NAO)	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)	STARS routine indicates major shift in biological variables in later 1980s, with more minor shifts in mid 1970s
Gulf of Alaska	1982	2006	Multiple indices of multiple species of fish, zooplankton, temperature	Some Abrupt, most Gradual	Fishing, Climate (PDO, ENSO)	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)	STARS routine indicates major shift in biological variables in later 1980s, with more minor shifts in mid 1970s
Bering Sea	1982	2006	Multiple indices of multiple species of fish, zooplankton, temperature	Some Abrupt, most Gradual	Fishing, Climate (PDO, ENSO)	Link et al. (2009), Megrey et al. (2009), Drinkwater et al. (2009)	STARS routine indicates major shift in biological variables in later 1980s, with more minor shifts in mid 1970s
Southern Benguela	1988	2005	Shifts in copepods	Abrupt	Sea surface temperature at 32°S	Howard et al. (2007)	

LME	YEAR-START	YEAR-END	ATTRIBUTES	TYPE OF CHANGE	PRESSURES/DRIVERS IDENTIFIED	REFERENCES	COMMENTS
Southern Benguela	1998	2000	Shifts in sardine and anchovy recruitment	Abrupt	Upwelling at 30°S	Howard et al. (2007)	Since 1950, two major long-term ecosystem changes were identified for the southern Benguela. The first change occurred during the 1960s, caused predominantly by heavy fishing pressure but with some environmental forcing. The second change occurred in the early 2000s, caused mainly by environmental forcing.
Northern Benguela	1960	2004	Primary production anomaly obtained from Ecosim model (changes in the ecosystem not explained by fishing)	Oscillatory	Annual average windstress (m^{-2} s^{-2}) for Luderitz upwelling cell from 1960-2004	Klingelhoeffer, (2006), Heymans et al., (2009)	The Ecosim forcing anomaly showed a significant positive correlation with windstress from Klingelhoeffer (2006) and a significant negative correlation with sea surface temperature from Sherman et al. (2007).
Northern Benguela	1957	2006	Primary production anomaly obtained from Ecosim model (changes in the ecosystem not explained by fishing)	Gradual	SST (°C) trend from 1957-2006	Sherman et al., (2007), Heymans et al., (2009)	The Ecosim forcing anomaly showed a significant positive correlation with windstress from Klingelhoeffer (2006) and a significant negative correlation with sea surface temperature from Sherman et al. (2007).
Northern Benguela	1982	2005	Hake biomass	Gradual	Hypoxia caused by SST increase	Monteiro et al., (2008)	Two long-term trends consistent with global warming emerged from this study: the 23-year warming trend at Angola Benguela Front and the 16-year increase in the lag between seasonal warming at Cape

LME	Year-start	Year-end	Attributes	Type of change	Pressures/drivers identified	References	Comments
							Frio and the following upwelling peak at the Luderitz upwelling centre. Both these factors contribute to the intensification of seasonal hypoxia and, in the context of a decline of windstress at Luderitz, predict a long-term decline in the ecosystem function that supports fisheries.
Northern Benguela	1952	1999	Sardine biomass, and mean age of population	Gradual	Fishing, climate change?	Fossen et al., (2001)	Increase in total mortality, due to increased fishing pressure in the 1970s and 1980s and increased natural mortality subsequently.

7 Quantitative/objective methods for assessing the cumulative impacts of multiple human activities on LMEs (item f)

7.1 Background

An analytical methods subgroup was convened during the meeting to address this ToR; the subgroup consisted of 6 members of the group. A number of steps were agreed at the outset to define the appropriate data types and methods for integrated ecosystem assessments (see below). It was also agreed that the methods discussed in the first instance should focus on objective numerical methods because expertise in the group dealing with methods for expert judgement based management and dissemination approaches was more limited. It was also noted that methods for multiple data integration to elucidate cause/effect relationships in complex systems (ecosystems) are equally applicable for the investigation of cumulative impacts of multiple human activities as well undertaking more targeted integrated assessments of a particular activity such as fishing.

7.2 Steps in objective numerical data analysis

7.2.1 Data selection:

The selection and quality of data used is of critical importance in reaching a realistic and credible conclusion. Whatever data are selected a meta-record of its attributes should be made using the template suggested in Section 4.4. The following points are considered particularly important when selecting data and adequate consideration of these should be documented as part of the data selection process:

i) The number of data types should not be overly skewed in representing just one or a few of the trophic levels or ecosystem components being jointly assessed,

ii) Wherever possible raw sample data should be sought from recognized data quality sources (e.g. data centres such as ICES).

iii) Temporal considerations – how long should a time-series be? At present the minimum appears to be about 20 years, but this simply reflects the availability of the most comprehensive sets of data currently used for the well monitored regional seas such as the Baltic Sea, North Sea and the Canadian Scotian Shelf. The subgroup recommends that some sensitivity analysis – using annual and seasonal averages (winter, spring, summer, and autumn) be conducted and applied to varying lengths of time-series data in order to evaluate the effects on the overall observed trends.

iv) Spatial considerations – how spatially representative should the data be? At present only datasets which are observed (not statistically tested) to be spatially representative of a regional sea have been used. The subgroup recommends that more specific criteria and guidance be developed to define what is 'spatially representative' and suitable in the context of IEA.

v) Special consideration should be made in relation to ensuring a balance between data representing the seabed and pelagic components of the marine ecosystem.

7.2.2 Data pretreatment

Once your data has been selected it is often necessary to undertake some form of data pretreatment to ensure it is appropriate for the final analysis step, this usually involves transforming, normalizing and weighting the variables. There is also the possibility of filling gaps in data using interpolations such as creating spatially gridded data through averaging. The manipulation of the raw data at this step again will have a large bearing on the end result following analysis and therefore the pre-treatment methods applied should be fully documented. The following points are considered particularly important when considering the pretreatment of data:

i) Appropriate standardization (normalization) and transformation methods should be considered and applied:

ii) Minimise cross correlation by excluding the principal dependant co-covariables in the dataset.

iii) The weighting of data types representing each component (or trophic level) should be assessed for all components being integrated – to date this has not been undertaken in any of the studies reported, but the subgroup feels that this is an important area for further investigation and the development of specific guidance in this area should be given priority.

iv) Methods for querying and extracting data from original data sources should be fully documented so that the same assessment dataset can be independently reproduced in future by other groups.

v) Methods for data interpolation and gridding (gap filling and smoothing) should be fully documented and further developed. One area which requires special consideration is how to reconcile the significant differences which exist between scales of monitoring. For example certain benthic datasets have very few wide-spatial scale surveys repeated on an annual basis, where as many pelagic datasets have long time-series covering wide spatial areas.

vi) Models also provide valuable sources of data to be used in IEA. Data from such sources again needs to be highlighted in any subsequent analysis, especially with regard to assumptions and levels of uncertainty associated with their accuracy.

7.2.3 Commonly used methods?

There are many methods to choose from, here we list the most common types which are often used in the context of integrated ecosystem assessments. However, this is not meant to be an exhaustive description of the statistical numerical approaches available but simply a brief overview of what appears to be in common use and widely reported (and therefore accepted) in the scientific literature.

Most integrating numerical methods are by definition largely multivariate and time-series in nature. Several of the methods have known limitations and assumptions implicit in their use which the user should be aware of. The following methods are considered particularly important when considering the analysis of multivariate data:

i) Simple (univariate) line plots of time and spatial trends of all variables standardized in one figure by trophic groups and ordered within groups.

ii) Ordination using Principal Components Analysis (PCA) applied to different components separately and on all data (in a fully integrated analysis). As an ordination technique PCA has been widely used on multivariate datasets consisting of widely varying types of data from multiple sources, however when using biological data alone, other ordination methods, such as non-metric Multidimensional Scaling (MDS), are often preferred. Some of limitations and assumptions of PCA are highlighted in Section 7.3.

iii) A sequential version of the partial CUSUM method combined with the t-test (see Rodionov, 2004), otherwise known as STARS to detect significant shifts in spatial and time-series data. Can be applied to different trophic levels and on PCA scores.

iv) STARS applied to each variable analysed in the combined 'integrated' dataset. For example if your integrated datasets consists of 100 variables then you would perform STARS on each of the 100 variables. A probability distribution of significant shifts can then be generated across all variables in the dataset to see if there is an specific point in time or space where a shift occurs in the system as a whole. Clearly this can be repeated for groups of variables associated with a specific ecosystem component or trophic level.

v) Cluster analysis and Chronological clustering.

vi) Canonical correlation and correspondence analysis between ecosystem components to investigate possible relationships between ecosystem components or trophic levels.

vii) Redundancy Analysis between ecosystem components relative to pressures acting on the system.

viii) BV-STEP between ecosystem components to pressures acting on the system.

ix) Dynamic Factor Analysis (DFA) used to identify the number of common trends for each species/time-series within or across ecosystems. DFA is an extension of factor analysis to time-series data to incorporate temporal autocorrelation into multivariate analysis. It is a data reduction technique which reduces the number of time-series to a fewer number of similar time-series. DFA minimizes variance among multiple time-series and can be seen as a data reduction technique to reduce the number of time-series to a smaller number of similar time-series (Zuur *et al.*, 2003). Explanatory variables can be incorporated into the DFA to determine if they help to predict trends in response metrics.

x) Min/max autocorrelation factor analysis (MAFA) is used to identify the number of common trends among time-series by maximizing autocorrelation. MAFA creates a linear combination of variables (variable=each time-series) to maximize autocorrelation with lag=1.

The group recognizes that there are many more numerical techniques available which integrate data and reduce its dimensionality, the above list is not exhaustive, but it does reflect the most commonly used methods cited in the literature in undertaking integrated assessments. Nevertheless, there is clearly a need for specific guidance on the most appropriate methods for conducting multivariate analysis in support of IEAs conducted on a more routine basis. WGHAME therefore recommends that a workshop be held in collaboration with other relevant expert groups to develop such guidance with specific consideration of their routine application.

7.3 Using PCA to characterize ecosystem data

Principal Components Analysis is one of the most commonly cited multivariate ordination methods for analysing patterns of variation in complex data (usually consisting of multiple data types with different scales of measurement). However, the user should be aware of some of its limitations and assumptions it makes:

i) Assumption on linearity. It assumes the observed dataset to be linear combinations. Non linear methods such as kernel PCA have been developed without assuming linearity.

ii) Assumption on the statistical importance of the mean and covariance. PCA uses the eigenvectors of the covariance matrix and it only finds the independent axes of the data under the Gaussian assumption. For non-Gaussian or multimodal Gaussian data, PCA simply de-correlates the axes. When PCA is used for clustering, its main limitation is that it does not account for separate classes because it makes no use of the class label of the feature vector. There is no guarantee that the directions of maximum variance will contain good features for discrimination.

iii) Assumption that large variances have important dynamics. PCA simply performs a coordinate rotation that aligns the transformed axes with the directions of maximum variance. It is only when we believe that the observed data has a high signal-to-noise ratio that the principal components with larger variance correspond to interesting dynamics and lower ones correspond to noise.

Shade plots (see Figure 4) have also been produced to generate quantitative evidence of state changes in ecosystem variables. Typically the variable anomalies are ranked according the variable eigenvalues of PC1 using the Single Value Decomposition PCA method. There are two generally used methods of PCA; Single Value Decomposition (SVD) method and Covariance Matrix method, for details see http://www.snl.salk.edu/~shlens/pub/notes/pca.pdf. If the PCA analysis is performed using the covariance matrix method, the patterns are not evident in the shade plot (see Figure 18).

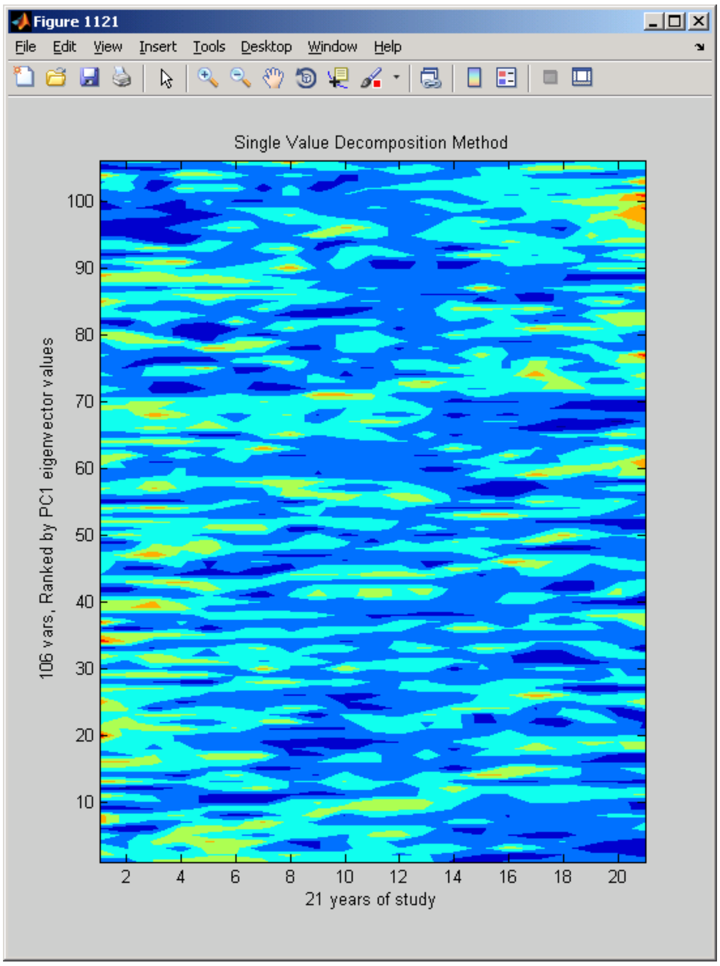

Figure 18 Reproduction of data used by Kenny et al. (2009). 106 normalized datasets are ranked in order of the eigenvector values on the first principal component. The figure is produced by a contour plot of these datasets. The PCA method used was the covariance matrix method.

During the process of calculation of SVD the variables are ranked in order of their singular values. Thus the pattern of the ranking on PC1 in the SVD method is related to the variance of the sample data. While this is an interesting and important consideration and the figure is a good way to visually assay the data in total it may be more tractable, to an observer unfamiliar with the detail of the PCA, to rank the datasets on a more simple basis - for instance the first value of the normalized datasets or by the variance of the normalized dataset. We therefore did this for the North Sea data between 1978 to 2004. The variable anomalies were first grouped by their respective component (or trophic level) then within each component ranked according to their mean dominance. The results are shown in Figure 19 which reveal a comparable change in the North Sea state to that described by the previous analysis, although it is perhaps more clear in this presentation which components have changed the most (e.g. plankton, fish and fisheries components).

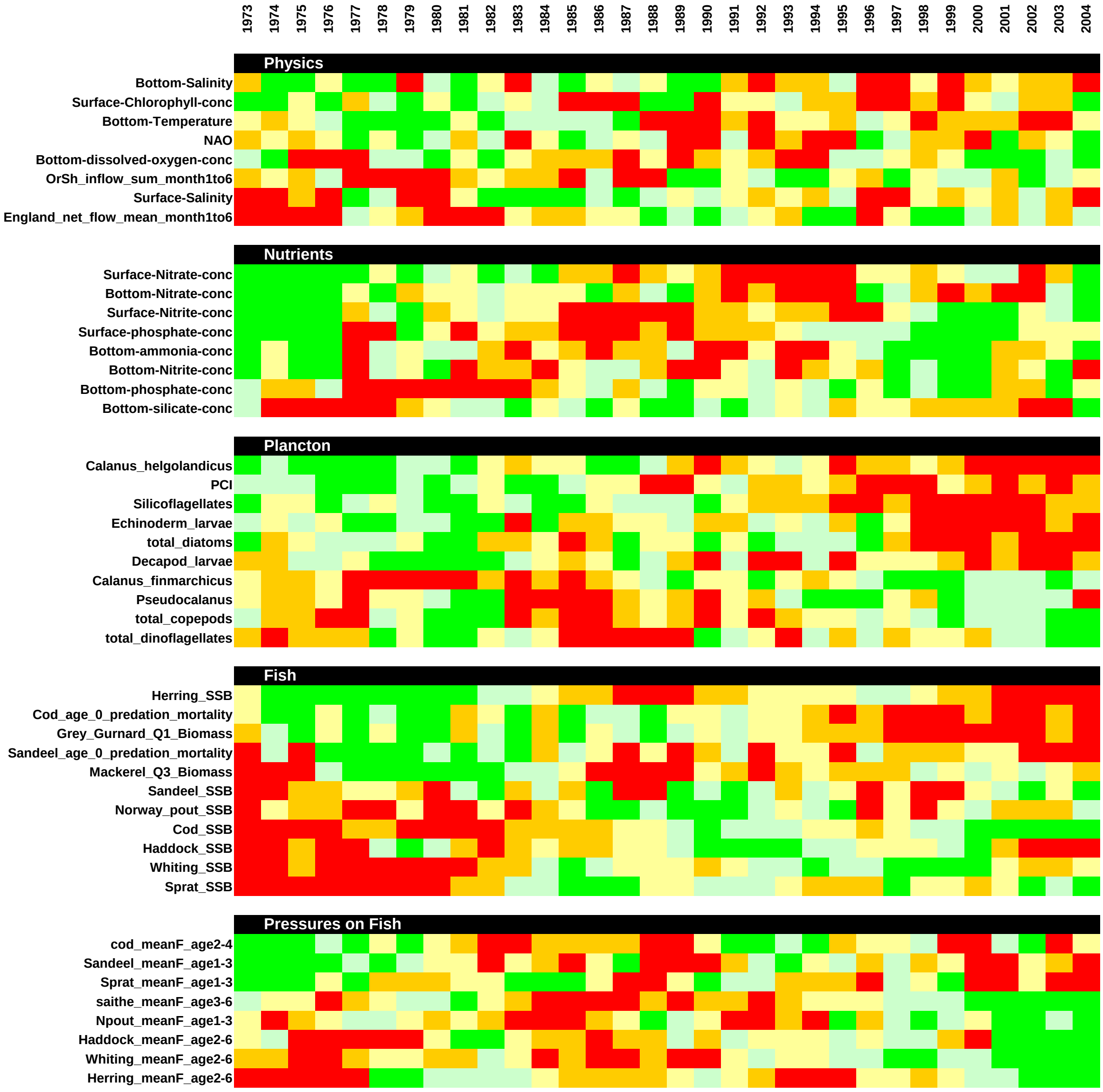

Figure 19. Shade plot of North Sea data from 1974 to 2004 ranked in order of mean dominance within each of the ecosystem components.

8 Review the methodology used at the OSPAR biodiversity assessment workshop (Utrecht), with specific reference to assessment criteria and thresholds, plankton communities, and differences in spatial scale (item g)

8.1 Background

OSPAR has requested ICES:

"To review the methodology used by the OSPAR workshop on the development of Chapter 11 of the QSR 2010 (Utrecht workshop)[1] *and taking into account, inter alia, ICES work on integrated assessment, provide advice on the following aspects:*

1. *improvements that could be made to the thresholds between different assessment classes, including any scientific basis for proposed thresholds;*
2. *extending the methodology to support the assessment of plankton communities;*
3. *improving the method for working at different scales, such as the level of an OSPAR Region, the level of sub-Regions such as the Irish Sea or the Channel or the level of an estuary or an MPA;*

[1] *Although the workshop title referred to Chapter 1, the output has subsequently been reflected in Chapter 10 of the QSR."*

OSPAR is preparing a new Quality Status Report for the OSPAR area, to be completed next year (QSR 2010). As part of the QSR 2010, a chapter on regional assessments was planned based on a "matrix approach". This method was applied at a workshop in Utrecht in February 2009 attended by experts from many countries. The approach has been seen as a pilot for assessment of status of ecosystem components and the main pressures acting on them. The approach and some results from the Utrecht workshop are presented in Chapter 11 (towards an ecosystem assessment) in the 2nd draft version of the QSR (30 October, 2009).

The approach used at the expert workshop is described in the document "Methodology for assessing the status of species and habitats at the OSPAR Region scale for the OSPAR Quality Status Report 2010" (by Robinson *et al.*, 2009), which was attached to the Report of the "Utrecht" Workshop (available from the OSPAR webpage as document MAQ(2) 09/2/10 Add.3).

The methodology was applied to broad ecosystem components: 4 groups of species and 4 broad scale habitats. The species groups were: fish, cetaceans, seals, and seabirds. The habitats were: rock and biogenic reefs (0-200 m depth), coastal sediments (0-50 m depth), shelf sediments (50-200 m depth), deep sea (below 200 m). For each of the 8 components, the process included:

i) a broad assessment of the likely status relevant to former natural conditions,

ii) assessment of the contribution to overall impact by relevant pressures, and the ability for the component to recover if pressures were removed,

iii) a summary by OSPAR Region of the current status of the ecosystem components, indicating key pressures and recent trends and future prospects in these.

The final assessment process was largely based on expert judgment guided by a set of criteria and using the best information available. Three criteria were applied; **i.** *geographical range*, **ii.** *areal extent* (within range) (for habitats) or *population size* (for species), and **iii.** *condition*. The criteria were essentially the same for species groups and habitats but the threshold descriptors were different. The same sets of criteria were used to determine status (relative to former natural conditions) and the degree of impact of pressures for the species groups or broad scale habitats.

Status was evaluated as Good, Moderate or Poor based on the three criteria. The pressures were then evaluated in a similar manner (Low/No, Moderate, High) and ascribed scores (1, 3, 9). The scores were summed across all pressures in each region to give a cumulative *Total impact score* for each ecosystem component. This allowed a categorization of total impact into five classes (from very low to very high).

Chapter 11 was planned as an important part of the OSPAR QSR which will be of interest to the general public, the media and politicians. Therefore it is critically important for all those involved that what is presented it as robust and credible as it can be.

8.2 The Utrecht Approach (Draft Chapter 11 – QSR 2010) – General View

To address this ToR a subgroup was convened consisting of 4 working group members representing Canada, USA, UK and Norway. The findings of the subgroup were then discussed in plenary involving the full group.

WGHAME has started a process to identify and define the essential steps which constitute an IEA – this involved taking into account the recent findings of United Nations group of experts in preparing a global review of the "Assessment of the Marine Environment" (http://www.unep-wcmc.org/marine/GMA/), and a recent joint study by ICES, EFARO and the European Science Foundation Marine Board on the ecosystem approach to marine management (MB-ESF, 2009). The steps considered by WGHAME provide the basis for a pragmatic and objective delivery of some important elements of an Integrated Ecosystem Assessment (IEA) (cf. Levin *et al.*, 2009). This framework is presented in Section 8.4 (see below).

The suggested framework starts with a scoping step of the process of conducting an IEA, which should be seen as a component within a broader framework of ecosystem approach to management (EA). The next step is to characterize and evaluate the status of the ecosystem as reflected in ecosystem components. The third step addresses the drivers for ecosystem impacts and change and ways to link drivers with impacts and status of ecosystem components. The fourth and fifth steps address establishment of decision criteria and assessment of impacts and status relative to decision criteria. A further step as part of an adaptive management system is consideration of management scenarios and options. The final step is communicating the outcome of the IEA in the form of a QSR or similar reports.

The Utrecht approach attempted to do the second and third steps in this framework in one go, using the same criteria to assess status of ecosystem components and impacts from the various pressures. In the preparation for the workshop, emphasis was given to the first scoping step. One useful outcome of the workshop is that it has contributed to the overall scoping of linkages between pressures and ecosystem components in the context of IEA. The criteria and thresholds that were used to assess status and impacts at the Utrecht workshop are somewhat different from those of steps 4 and 5 of the proposed framework which are decision criteria in relation to scientific advice and management actions.

On a general level, we observe that step 2, the cataloguing and compilation of relevant information and the development of one or more Status Reports for each of the principal ecosystem components, was not completed prior to or during the Utrecht workshop. We also note that although this is an important step as part of the overall process, status reporting in and of itself is not an IEA. Data and information gaps were mentioned as a concern by participants and information available was documented during the process. However, it would have benefited the outcome of the Utrecht workshop if a clear statement describing the sources of evidence, their findings and how the information was used to reach a judgement were included.

We note that there are a number of sources of information that could have been used for this purpose, including:

- OSPAR assessments of status of threatened and declining species and habitats
- ICES assessments on the status of commercial fish stocks (and the summary supplied for the North Sea EcoQO)
- Status of seabirds being assessed by BirdLife International and IUCN (International Union for Conservation of Nature)
- Status of marine mammals being assessed by ICES, IWC, and NAMMCO
- Status and trends in zooplankton by ICES
- Status and trends in plankton, including HABs and invasive species, by SAHFOS
- ICES Ocean Climate Status Report
- Integrated Regional Sea Assessments by ICES REGNS and WGIAB.

These sources of information were no doubt known and used by workshop participants when they produced their expert judgements, but the careful and sufficient documentation on how they were used we feel is lacking.

The Utrecht Workshop relied on expert judgement, and this appears to have worked to some extent as reflected in subjective confidence assessments by the workshop participants. However, the outcome of the exercise would have benefited from a complimentary integration of objective empirical evidence at the final step of the overall assessment. This gap and associated uncertainty was recognized by the workshop participants, as were other aspects of the methodology related to the criteria and the scale of application (see Annex 5 – present report). There is an inherent danger in relying too heavily on one method, particularly that of 'expert' opinion, that the result is presented with too much confidence, certainty and therefore undue scientific credibility (again a limitation acknowledged by the authors).

We recognize that at each step in the process there is a need to go with what is available and feasible to do. We also note that moving toward more quantitative and empirical methods is generally desirable, although more difficult in areas where data are not so readily available. We consider that a balance has to be achieved between expert opinion and a more empirical, objective and model-based approach, backed up by expert judgement in the final sign-off of an assessment. The objective integration of evidence from several sources (including expert judgement) is challenging, WGHAME considers that one possible approach would be to conduct numerical analyses of empirical monitoring data linking each of the components and human pressures in the assessment matrix presented ion the Utrecht report. In essence the multivariate correlations between ecosystem components described in Figure 5 of the present report could be used to quantify the degree of connection between components in the Utrecht assessment matrix (e.g. they become the values in the cells of the matrix). In doing this it also becomes apparent that the degree of connection between components and human activities is dependent not only on the chosen spatial scale, but also the time period selected.

Existing evidence in the form of thematic or sectoral assessments play an important role in providing information on linkages between pressures and ecosystem components. Examples of successful thematic assessments can be found in pollution assessments by OSPAR and by the Arctic Monitoring and Assessment Programme (AMAP) for OSPAR Region I, as well as in fisheries assessments carried out by ICES. A key task is to link the outcome of such assessments with the assessment of status of ecosystem components that are being impacted by the various pressures examined in the thematic or sectoral assessments. There are two main considerations that need to be kept in mind at this step. They both relate to ecosystem dynamics.

The first is that ecosystem components are interlinked through foodwebs and interdependencies between species and habitats. There are therefore always (or nearly always) indirect effects from impacts that may be as important as the direct effects. Indirect effects on seabird populations through impacts on their food base by fisheries can serve as one example. The second consideration is that ecosystems are always changing. They are dynamic and never static or constant. We are therefore assessing status and impacts on ecosystem components in a system which is constantly changing and where the "baseline" is shifting due to physical forcing and ecological interactions. Use of expert judgements without proper documentation or delineation of thresholds needs to be viewed against this backdrop. Clearly the multiple disciplines, sectors and management objectives which constitute a holistic IEA make the process of objectively integrating multi-sectoral empirical programmes with expert judgement all that more difficult.

Without seeing the detailed evidence we have reservations about the selection and use of the criteria and threshold values for evaluating status and impacts on ecosystem components, as it appears insufficient account has been taken of either the spatial or temporal dynamics of the systems being assessed (see section below). Ideally, the assessment should be based on defined relationships between drivers and response variables (ecosystem components) at a range of spatial and temporal scales so that a more precise level of uncertainty (variability) can be defined for such properties. For example if the variability in extent and status of a species or habitat cannot be quantified (with a level of certainty), then there is a risk that an assessment based upon limited monitoring data will result in a wrong conclusion being reached. For relatively well studied parts of the coastal environment the weight of evidence may be sufficient to provide confidence in defining a species or habitat extent and status, but for many offshore areas this will not be the case. Whilst this uncertainty can be evaluated in subjective terms by expert judgement it must be clearly defined and presented in the assessment.

The Utrecht Workshop used a prescribed methodology (Robinson *et al.*, 2009) that attempts to relate pressures from human activities to state changes in the environment. The intention was to assess the current state, recent trends (past 10 years) and future trends. In so far as this covers the period since the last QSR this makes sense. However, WGHAME consider that both longer and shorter time-scales should be evaluated and the results of these presented separately, as it is important to identify and illustrate temporal pattern of variability in ecosystem components. There was also concern that the grouping (or lumping) of responses into large ecologically heterogeneous groups (for example fish), although having their place and valuable, may average out changes where more specific groups respond in inverse ways to the system drivers. The multivariate nature of system responses should be taken into consideration.

WGHAME have reviewed the data and methods employed to carry out regional sea IEAs by REGNS for the North Sea and WGIAB for the ICES-HELCOM Baltic Sea region. The group also conducted a separate comparative analysis of ecosystem dynamics from a range of LMEs in the northern and southern hemispheres (see Section 3.5). A consistent feature of all of these studies was the influence of large-scale decadal fluctuations in the measures of climate variability such as the North Atlantic Oscillation (NAO), the Atlantic Multi-decadal Oscillation (AMO) and the position of Subpolar Gyre. Such features may control similar large-scale fluctuations in abiotic and biotic features, and are not amenable to management control. Rather they may require adaptive responses on the part of resource managers and users. Similarly, there is considerable evidence of indirect controls, due to trophic interactions which may result in significant fluctuations in the status of particular plankton species, fish stocks and seabirds. These may be wholly independent of human pressures or may interact in a complex manner. This illustrates the need to conduct an initial assessment of system dynamics to which the thematic assessments can be added, before conducting the final threshold-based IEA.

We consider that the matrix in Table 10.4 (in the draft OSPAR Chapter 11 text) provides a good way of visualizing linking direct pressures with state changes but, in its present form, it does not include many important indirect effects. This illustrates the need to move towards using a variety of techniques including integrated data analysis and dynamic modelling as well as basic ecological knowledge. This would permit a more nuanced and appropriately focused approach which would minimize the possibility of recommending mitigation measures that are inappropriate or ineffective.

The North Sea assessment work undertaken by the present group (WGHAME) clearly demonstrates that there are an almost equal number of state variables increasing in value or level, as there are variables which are decreasing in level at any one time, e.g. there will always be “winners” and “losers” in a naturally dynamic system. Therefore we see the advantage in using a variety of analytical approaches, requiring different levels of information and not being overly drawn to those things in the system going down in level or value.

8.3 The Utrecht Approach (Draft Chapter 11 – QSR 2010) – Specific Issues related to criteria, thresholds and scales of application [2]

8.3.1 Criteria

The criteria used to judge status and impacts on species and habitats are basically decline criteria: decline in range, decline in extent or population size, and decline in condition. They stem from criteria used to assess status of species and habitats for the purposes of the EC Habitats directive.

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[2] This section draws largely from a document prepared by IMR, Bergen, Norway in response to Section 11 of the draft OSPAR QSR 2010.

8.3.2 Habitats

For habitats the criteria for status (Good, Moderate, and Poor) and degree of impact (Low, Moderate, and High) are <1%, 1-10%, and >10% decrease in range and loss in extent. For condition, the threshold values are <10%, 10-25%, and >25% damage.

The habitats that were assessed at the Utrecht workshop were defined at a very broad scale. For OSPAR Region II, shelf sediments in the 50-200 m depth range are the plateau of the central and northern North Sea. The geographical range of this habitat does not change (except when considering the geological time-scale); neither does the areal extent of this habitat except for smaller parts occupied by structures such as offshore platforms and pipelines. While these criteria make sense when applied at a finer scale to well-defined habitats, it is meaningless to apply them to habitats at this broad scale.

This leaves the condition criterion which considers the area (extent) of the habitat which has been damaged. Undamaged habitats are those where "structures and functions (including typical species) are in good condition". In reality it may be very difficult to evaluate whether a habitat is in good condition and to what degree it has been damaged. At the Norwegian Institute for Marine Research an assessment has been done for *Lophelia* (cold-water coral reefs), where it has been estimated that between 30-50% of the reefs on the Norwegian shelf have been damaged to a greater or lesser extent. This estimate is based on a fairly comprehensive study of information from fishers and ground-truthing, yet this figure remains uncertain due to the assumptions made (see Fosså *et al.*, 2002). One difficulty is that many of the reefs are known only by point coordinates where they occur and their fine-scale distribution and extent have not yet been mapped. Using coral reefs as an example, it could be possible to provide an estimate of the degree of damage for this habitat type. However, this habitat makes up a small percentage of the total area within the broad scale habitats (rocks and biogenic reefs 0-200 m, shelf sediments 50-200 m, and deep sea >200 m). For the remaining parts of the broad scale habitats there is little comparable information and it is therefore very difficult to assess the degree of damage on these habitats in a credible manner.

We therefore find the criteria not to be appropriate at the scale on which they were being applied. The range and extent criteria cannot be applied at the broad scale unless more detailed information on the various types of habitats that make up the broad scale habitat is known. Such information is not available except for smaller areas in some of the OSPAR Regions. The same consideration applies to the condition (or damage) criterion. The outcomes of the expert's evaluations of the status and impacts on the broad scale habitats are clearly conjectural in nature and may well be wrong and misleading.

A more robust approach would be to start on a scale where an appropriate assessment can be made then extend this in spatial scale in steps with each step reflecting an increase and quantifiable level of uncertainty. Assessment criteria which are able to reflect spatially dependant levels of uncertainty are much more credible, and do not lull the user into a false sense of security!

8.3.3 Species

The criteria for evaluation of decline for species use the proportion of species within each group which has experienced decline. Good, Moderate, and Poor status (or No - Low, Moderate, and High degree of impact) are when <10%, 10-50%, and >50% of the species have undergone decline. The decline is set as a contraction by >10% for *range*, and a reduction by >25% for *population size*. For population *condition* the decline is formulated as "strong deviations in reproduction, mortality or age structure relative to former natural conditions" ("trend information required for clear deviation in reproduction, mortality or age structure showing a significant deviation from former natural conditions").

The parts of the criteria on decline in *range, population size*, and *condition* are difficult enough when applied to single species, but the use of the criteria for groups of species (communities) pre-supposes that an appropriate overview of the status for the various species within a group already exist. This is only partly the case. Again it is important that uncertainties in assumptions are explicitly taken into account. To be meaningful, species within groups must change in similar ways in response to external pressures otherwise grouping them will tend to obscure trends and responses to important ecosystem drivers. Conversely, multispecies or aggregate models would help to explore different facets of this system, but are hard to do without an explicit analytical framework.

Geographical range and population size of species are dynamic entities that change over-time. For commercial fish populations there is a large empirical body of evidence to show this. Typical range of variation in stock size is one order of magnitude over some decades. We know that some or most of this variation is due to physical forcing and climate variability, while fishing pressure and biological interactions can have strong contributing influences. Fishing pressure may dominate in some cases, contributing to stock collapse (often in concert with unfavourable environmental conditions) and to keeping stocks low, whilst at other times changes in ocean climate conditions have the greatest influence on overall ecosystem state.

The geographical range of a fish species or of distinct stocks of a species is difficult to determine as this requires extensive surveys. Where surveys have been carried out over long time periods, the results generally show variation and shifts in distribution patterns. Some of this variation is related to environmental variability and there are now ongoing shifts associated with climate change. Even where good data exists, it is difficult to establish whether there have been declines in range for single stocks of fish.

Due to the large variation in population size of commercial fish stocks, it is difficult to establish a reference period for comparison with the current or recent situation. The fish stocks of the North Sea can serve to illustrate this (see Figure 20). During the 1960s there was the "gadoid outburst" when favourable recruitment conditions led to high stock levels of cod, haddock and saithe. Following declines to minima in the early 1990s, haddock and saithe have because recovered to relatively high levels while North Sea cod has continued to decline. North Sea herring has shown large fluctuations (with a pronounced collapse in the 1970s due to overfishing) but has been at high level in the first part of the 2000s followed by a more recent decline.

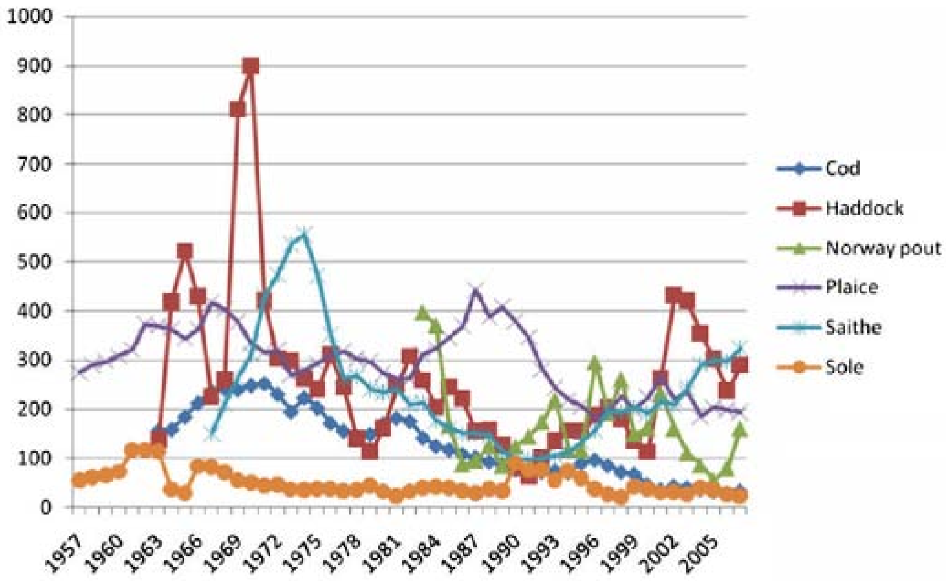

Figure 20. Total North Sea Spawning Stock Biomass of the 6 most commercially important demersal species between 1957 and 2006. Values are 1000's of tons. (Data from ICES, 2007). From Kenny *et al.* 2009 (An integrated approach for assessing the relative significance of human pressures and environmental forcing on the status of Large Marine Ecosystems. Progress in Oceanography 81: 132–148).

Fishing inevitably leads to a reduction in the size of fish stocks. The mortality is increased and fewer individuals remain in the stock, compared to a situation with no fishing. Foodweb and other ecological interactions contribute to make the effect of fishing on stock level complex by altering predation, food availability and competition. It is therefore difficult to estimate how much fishing leads to a reduction in stock size. However, it is likely or possible that fishing reduces the stock size by >25% for many commercially exploited stocks.

The large whales were much depleted by whaling in former times. This led to extinction or extirpation of several species or stocks, such as grey whale from the North Atlantic, northern right whale from the North-East Atlantic, and the Spitsbergen stock of bowhead or Greenland whale. Blue, fin, sei and humpback whales were strongly depleted, as were sperm and northern bottlenose whales. Some of these species have recovered to near pre-whaling levels (e.g. fin and humpback whales); whereas blue whale has been slow to recover despite protection.

Seabirds have undergone large changes in the last century. Many species were strongly depleted due to harvesting for feathers, meat and eggs, or because they were considered pests. During the 20th century there were pronounced increases in the abundance of many species due to protective measures and increased abundance of food for surface-feeding seabirds due to discarding practices in fisheries (see Figure 3.9 in Assessment Report prepared for the IMM in Bergen 1997). Changes in distribution and size of populations of seabirds are still ongoing, reflecting probably complex interactions of many factors including food, predation, fisheries, and climate change.

Decline criteria are used in different ways to evaluate and assess the status of species of fish, birds, mammals and other groups of animals. ICES is using a system of reference points on stock size and fishing mortality. For stock size (spawning-stock biomass), two reference points are used: a limit (B-lim) and a precautionary limit (B-pa) separated from B-lim by a buffer zone. The two reference points define three zones on the stock size axis: a "red" zone below the limit, an "orange" zone between the limit and the precautionary limit, and a "green" zone above the precautionary limit. This system allows a classification of the stocks at the aggregate level, as exemplified by the EcoQO on commercial fish stocks (see OSPAR Background Document). It also allows a comparison across regions based on the evaluations that ICES does on the status of the various fish stocks in each region.

IUCN uses a set of criteria including decline to assess the conservation status and extinction risk for species. Species are classified into three categories of **threatened** (Critically endangered, Endangered, and Vulnerable). The decline criteria occur with a number of variants but are basically continuing decline in population size of 80%, 50% and 30% over 10 years or 3 generations for critically endangered, endangered and vulnerable, respectively. In addition to decline, other criteria are also used in the assessment, including geographic range, area of occupancy and population size. BirdLife International performs the assessment of status of birds for the IUCN Red List.

OSPAR has its own decline criteria as part of the Texel-Faial criteria for the identification of species and habitats in need of protection by OSPAR. For species, the decline criterion is formulated as:

"Decline: means an observed or indicated significant decline in numbers, extent or quality (quality refers to life-history parameters). The decline may be historical, recent or current. 'Significant' need not be in a statistical sense".

In the guidance for the application of this criterion, it is made clear that decline needs to be assessed in relation to the natural dynamics for the species or populations. One reason why this criterion is not strictly quantitative like the IUCN criteria was a clear recognition that marine fish and invertebrate species may undergo pronounced variation due to their mode of reproduction with a large number of pelagic eggs and/or larvae. Episodic recruitment is a common phenomenon for many marine species. If the IUCN decline criterion of 30% was to be used, we might end up with up to half the number of species being identified as **vulnerable** at any time due to the typical amplitude of natural variability which may exceed the criterion. The results from the REGNS IA for the North Sea illustrate this point for a number of fish stocks and zooplankton species.

The decline criterion for population size used at the Utrecht workshop (25%) is about the same as the IUCN criterion for the **vulnerable** category. It would be very difficult (or nearly impossible) to use this criterion in practice and it would also not be appropriate for marine fish and invertebrates, for the reasons argued above. The application of the criterion does not become simpler or more appropriate if applied to a group of species rather than to single species.

The third criterion, on population *condition*, is also challenging to use for single species. The way it is formulated ("strong deviations in reproduction, mortality or age structure relative to former natural conditions") is in line with the Texel—Faial criteria which include quality as reflected in life-history parameters. Use of this criterion requires substantial information and expertise for the selected species. Moving on to groups of species (community level responses) is valuable but may not be entirely straightforward. Interspecific differences in response to pressures and drivers may mask directional change. Multivariate analysis methods may be more appropriate than lumping all species within a group into a single comparison. Here again the assumptions and levels of uncertainty need to be explicitly recognized and fully understood by all those involved in making decisions based on these analyses, the point being there needs to be quantitative analyses to support the interpretations provided.

8.3.4 What is the confidence in the results?

The experts were put in a difficult position at the Utrecht workshop. The conveners and facilitators were eager to see an output according to the plans that had been made, and there was little time set aside for discussion of the methodology. Several participants expressed reservations and came away from the exercise feeling not very comfortable.

The broad habitat types are considered to be of Medium status in all cases for Regions I-IV except for shallow sediment habitats in the North Sea (Region II) which is in poor condition, and for deep-sea habitats >1000 m, which is in good condition. Given that many contaminants accumulate with the finer sediments in the lower slope off the shelves, and that many soft corals may occur and be sensitive to impact in this zone, we are not sure that the situation here is better than for the upper slope or deeper shelf.

For seals, the status is poor in Region I. This reflects the situation for hooded seal which has had lowered pup production in the last survey (2005) than previously. This could be related to less ice in the pupping area north of Jan Mayen due to warmer climate. In the summary table for pressure assessments (table A5.6) this gives high scores for climate change and habitat loss as two pressures in the table. In reality they are the same thing. Hooded seal contribute to poor status for seals also in region V, perhaps along with the loss of Mediterranean monk seal from the Azores 300 years ago.

Contamination by hazardous substances is in all regions and for all species groups and broad habitats considered to have low impact. We caution against this. The effects of contaminants on biota are really not well understood and documented. Ecotoxicological assessment criteria are exceeded in many cases, yet documentation of effects is lacking. However, this does not mean that effects could not occur or indeed be occurring as we write. The monitoring of effects may not be sufficient and effects could be masked and/or compounded by other impacts such as those caused by fisheries or climate change.

A scoring system has been used were pressures ranked as Low, Medium and High impact are given the scores of 1, 3 and 9, respectively. By summing the scores over the total of 22 pressures, total impact scores are calculated for each of the ecosystem component in each region.

Without comparable tables explicitly highlighting the assumptions and uncertainties in assessment the end result can be very misleading for managers. The question then arises as to "what is the real benefit of this assessment in support of an IEA?" Given the limitations of the data and knowledge base as well as the criteria as discussed above, this exercise is better viewed as a preliminary evaluation of possible status and used to identify the information needed to improve the empirical basis for a full assessment.

8.4 A proposed 7 step pragmatic approach for implementing an IEA

It should be noted that this is a draft framework proposed by WGHAME to objectively evaluate the OSPAR Chapter 11 assessment. It is not definitive or final, but is subject to ongoing development and refinement, particularly in respect of better defining the relationship between integrated ecosystem assessments and management.

However, WGHAME recognizes the urgent need to establish a pragmatic integrated assessment and management framework in order to ensure future regional IEAs are objectively drafted, with all steps in the process at least considered and explained, if not fully addressed based on present levels of knowledge.

8.4.1 First, scoping out the process with stakeholders

a. What are the goals of an IEA? (in terms of specific ToR and objectives)
b. What are the needs, perceptions, and information requirements?
c. What are the requisite outputs for an IEA?
d. How integrated is the issue- multiple biota, multiple disciplines, multiple ocean use sectors?
e. What are the expectations for/from the IEA?
f. What venues are going to be established to engage stakeholders, to have interactive meetings, to conduct and review intermediate analyses and final assessments, etc.?

8.4.2 Second, sequentially (within scientific groups) or iteratively (with stakeholders and managers), what levels of information are needed for any given IEA and how can the collective status be catalogued?

a. Qualitative evaluation of an ecosystem
b. Identification of major processes
c. Identification and vetting of indicators representative of those processes
d. Sourcing of indicators via data identification and selection
    i. Identify data gaps, items for monitoring, items for process oriented study
e. Establishing or accessing common databases
f. Produce Ecosystem Status Report

8.4.3 Third, sequentially (within scientific groups) or iteratively (with stakeholders and managers), what levels of analysis are appropriate for exploring drivers in an IEA?

Building on the Ecosystem Status Report, identify major relationships among ecosystem drivers and component responses.

a. Qualitative ecosystem assessments
b. Expert Assessment
    ii. Risk assessment (Tabular approach, cf. Ospar *et al.*)
c. Empirical Analysis
    iii. Time series analysis (MAFA, DFA, STARS, etc.)
    iv. Multivariate analysis (PCA, CCA, RDA, CanCorr, etc.)
    v. Other statistical approaches
d. Analytical Modelling
    vi. Simulation models- full system, bulk biomass, biophysical, etc.
    vii. Functional relationships- subsets of processes of interest
e. Comparative Analysis
    viii. Are patterns robust and replicated in other ecosystems?
    ix. Are drivers routine and similarly directional in other ecosystems?

8.4.4 Fourth, what are the best methods to establish or explore thresholds (reference points/directions/surfaces) of decision criteria for an IEA?

This reflects the need to determine the overall status of an ecosystem relative to management benchmarks, which are often based upon nationally or internationally mandated legislation or policies that need to be scaled down (unpacked). These are based upon the known or anticipated relationships among drivers and responses.

These methods are used as appropriate, not necessarily sequentially.

a. Qualitative modelling
b. Expert Assessment
    i. Risk assessment (Tabular approach, cf. Ospar *et al.*)
c. Empirical Analysis
d. Analytical Modelling
e. Comparative Analysis
    i. Are patterns robust and replicated in other ecosystems?
    ii. Are similar decision criteria suggested, empirically or analytically, from elsewhere?
    iii. Is local system and analytical process employing best practices?

8.4.5 Fifth, once thresholds or decision criteria are established, what is the assessment of the current status of the ecosystem relative to the germane IEA decision criteria?

These methods are used as appropriate, not necessarily sequentially.

a. Qualitative modelling
b. Expert Assessment
    i. Risk assessment (Tabular approach, cf. Ospar *et al.*)
c. Empirical Analysis
d. Analytical model
e. Review of assessment determinations by external (to ecosystem) experts
    i. Full System (IE) reviews
    ii. Sub-Component reviews in other, established venues (e.g. stock assessments)

8.4.6 Sixth, explore management scenarios or options under a wide range of scenarios to recommend best decisions that will most robustly achieve IEA goals (or mitigate negative states) by meeting decision criteria.

This should be done in an adaptive management module (in practice, *in situ*), but also first virtually (*in silico*) using the following possible approaches as operating models (aka an MSE, management strategy evaluation). These should include the full range of drivers at the appropriate level of integration and account for short to medium term, but strategic predictions. These should also include a full range of hypothetical (but reasonable) management measures.

a. Qualitative modelling
b. Empirical modelling
c. Analytical Modelling

8.4.7 Seventh, communicate results in regular, but low frequency (not more than once every 2 years) assessment and scenario descriptions as part of full IEA reports.

One could envision starting at step 3 and working through to step 6 at the qualitative modelling/expert analysis level, providing an initial IEA, while progress is made on more analytical approaches at each of those steps, such that future iterations increase in level of quantitative rigor. This framework of process mitigates the tension between managers (who need any available information to make decisions, often imminently) and scientists (who are very conservative and cautious about providing information without fuller understanding of uncertainty or mechanistic relationships).

a. Interact with stakeholders, managers, interest groups as need be, but certainly report upon results at conclusion of IEA report
b. Iterate starting at step 5 above every 1-2 years
c. Iterate starting at step 3 or 4 above if significant, novel information arises, if increased quantitative capacity develops, else every 4-6 years
d. Iterate starting at step 1 above every 7-10 years

8.5 Extending the OSPAR methodology to support the assessment of plankton communities

Despite covering a number of groups (fish, cetaceans, seals, seabirds, rock and biogenic reef habitats, shallow and shelf sediment habitats and deep-sea habitats), it has been suggested that the assessment of the plankton community could be added to the current list.

The data provided by the Continuous Plankton Recorder (CPR) Survey and by other time-series at single sites and along-transects in the OSPAR area may be used to monitor plankton abundance, biodiversity and population dynamics (e.g. phenology) as well as plankton species that act as indicators of climate change. Plankton monitoring should be expanded to cover some un-sampled and poorly sampled areas in the OSPAR regions and zooplankton should be included as a mandatory biological variable in the management of the marine OSPAR area. The analysis of plankton data should monitor the changes observed in the plankton that have been related to hydroclimatic changes (see Report of WGZE to OSPAR, 2007).

Regional scale data such as that provided by the CPR is needed in order to put local scale data (such as coastal sampling stations) into context. The comparison of indicators between open ocean and nearshore waters ensures that regionally occurring changes are not misinterpreted as localized anthropogenic impacts – for example, the sudden increase in phytoplankton biomass observed in coastal North Sea waters in the late 1980s may have been attributed to anthropogenic eutrophication instead of a climatically driven North Atlantic regime shift if the same pattern of change had not been simultaneously observed in oceanic data (Beaugrand, 2004; McQuatters-Gollop *et al.*, 2007). The comprehensive spatial scale on which the CPR sample also allows the development of complex biogeographic indicators such as those describing shifts in biogeographic species range (Figure 21) and spatial changes in biodiversity that cannot be developed from parameters measured at a single sampling station, no matter how frequently samples are collected. In light of this, indicators for plankton, using both CPR and non-CPR data, have been suggested, see below:

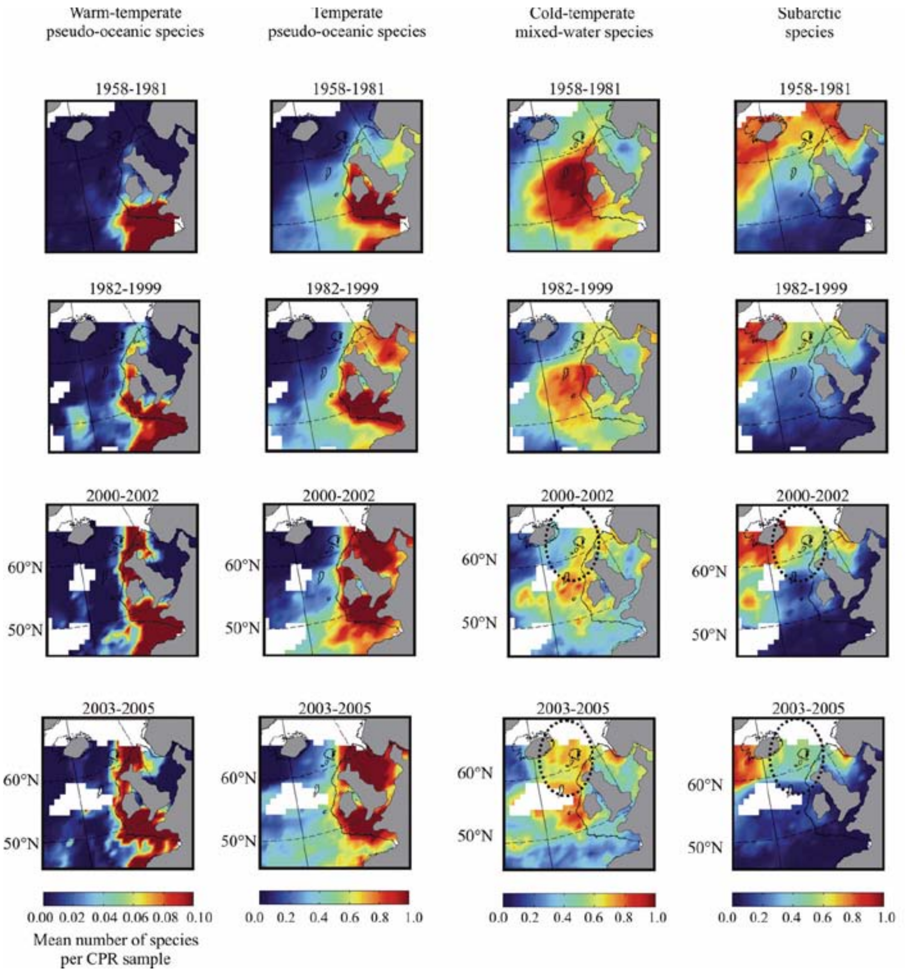

Figure 21. Biogeographical changes in four plankton assemblages spanning five decades. Warm water plankton are moving north and cold water plankton are moving out of the North Sea.

8.5.1 CPR indicators

These indicators have been developed by SAHFOS using data from the Continuous Plankton Recorder (CPR) survey (Batten *et al.*, 2003). The CPR survey is one of the longest ecological time-series in the world (>75 years), with over 2.5 million samples analysed for more than 500 plankton taxa in the Atlantic, North Sea and North Pacific. The CPR's long time-series and extensive spatial coverage enable the development of complex multivariate indicators encompassing many levels of ecosystem state, structure, and functioning. The CPR also has sister surveys in the Southern Ocean, Australia and USA. The CPR indicators suggested are:

i) Phenology index
ii) Biogeographical shifts/Northward movement index
iii) Spatial and temporal changes in primary production and the marine growing season
iv) Phytoplankton community change
v) Zooplankton community change
vi) Plankton as indicators of future climate scenarios
vii) Geographical distribution and trends in biodiversity
viii) Invasive species
ix) Ecosystem stability and non-linear climate change impacts

x) Harmful Algal Bloom taxa
xi) Calcareous taxa change
xii) Fish and plankton interactions
xiii) Plankton-wildlife interactions (prey fields)

8.5.2 Non-CPR indicators

This group contains plankton indicators which have not been developed from CPR data. They come from various sources and are generally simpler in design than CPR indicators.

i) Phytoplankton chlorophyll from remote sensing (as proxy for biomass)
ii) Plankton community change
iii) In situ phytoplankton chlorophyll (as proxy for biomass)
iv) Harmful Algal Bloom taxa
v) Phytoplankton multi-metric toolkit for the Water Framework Directive

9 Concluding remarks

The Utrecht assessment and several other similar efforts being carried out in different jurisdictions around the world highlight the need for development and application of holistic assessment frameworks. These assessments represent a mix of quantitative information on status and trends of ecosystems and their components and normative analysis of the relevance to humans as stewards of the environment. Because we humans have the power to significantly alter our environment without fully understanding the consequences, assessments as the basis for informed action are urgently needed. The detailed approach and the very careful documentation used in this assessment make it easy to determine the weaknesses both in terms of information gaps and methodology thus facilitating improvement of the process and identifying target areas for further study.

The Utrecht matrix approach is a variant of the "traffic light" approach that has been developed and used in Canada and other places. The methodology developed by Robinson *et al.* (2009) for the OSPAR assessment is designed to blend quantitative and qualitative evaluations into a meaningful and reliable analysis of the current situation for marine ecosystem components within the OSPAR regions. The approach used mixes the information-based approach common to toxicological, fisheries or biodiversity assessments with sociological weighting of opinion. This blend of two approaches is a major weakness of the methodology. While the scientific method can be applied to sampling and analysing opinion, opinion is not part of the scientific method per se unless it is carefully documented in written form e.g. as a scientific review. A sampling of expert opinion as was done in this methodology does not equate to peer review.

The assessment methodology used was carefully prepared and followed. The results were scrutinized to ensure that the application of the methodology was consistent. Background material used and instances where the component assessments relied on expert opinion were documented. As a result, participants had high confidence that the assessment was done in a consistent, transparent manner. The main problem with this approach is that a similar level of rigor and comfort with the resulting assessment might have been achieved regardless of the ratio of supporting documentation to expert opinion or of the weighting applied to the voice of each expert. The methodology attempts to mitigate the former problem using a confidence scale for each component of the assessment. However, this may reflect lack of information about the component and/or its response to pressures, lack of expertise at the table, excessive lumping of ecosystem characteristics masking real and "important" change within the component, or differing interpretations of scientific certainty. The latter might be mitigated by training and coaching as is done for expert witnesses in the legal system but it is not an accepted part of current scientific curricula.

Proper determination of the components is one key element in an approach like this. Excessive splitting will lead to extra weight being given to similar change within the ecosystem while excessive lumping will mask real and meaningful change. Components should be ecologically meaningful, variability within components should be less that variability among them, and explanatory power should be optimized. The inclusion of "worst case" situations is an interesting approach to mitigating the lumping of many groups into ecosystem components. However, the selection of the case will depend on who is at the table and may reflect species or habitats most studied or of highest media profile.

Expert evaluations are important but not without careful review and documentation of existing knowledge that form the basis for the evaluations and any conclusions drawn. Given the limitations of the criteria and the potential arbitrary nature of the evaluations, the approach may easily represent misuse of the experts and their expertise. Conversely, the approach with criteria, expert judgments and scores may imply a scientific credibility which is not warranted.

Status of species and habitats can be evaluated based on existing information. Commercial fish populations are routinely assessed by ICES. Conservation status of birds and mammals are evaluated by IUCN and BirdLife International. Status of marine mammals is also assessed by IWC, NAMCCO and ICES. Status and trends in plankton communities are regularly reported by ICES and SAHFOS. These are examples of existing knowledge that can be used for status assessments, and OSPAR should work with these other organizations to draw upon those bodies of work. Assessment of status needs also to take into account biological interactions in foodwebs. Examples of integrated assessment of status of ecosystems across many groups of organisms have been piloted for the Baltic and North Seas by ICES.

Linking status of ecosystems and ecosystem components with pressures remain a major task, and the Utrecht approach has to limited extent been successful in doing this in a scientifically credible manner. It simply needs to continue to do so for it to be a full IEA. The ICES REGNS provides one example of how some pressure variables (reflecting fishing) can be linked with status variables in an integrated analysis.

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Annex 1: List of participants

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Annex 2: Agenda

DAY 1	
Time	**Activity**
10.00	**House Keeping and Introductions** (Opening of the meeting – background info, ICES instructions, ToR, agenda, tasks for the day and round table introductions)
10.30	**(Part 1) Finding out what we do – sharing knowledge in the group** 1. Up-date on North Sea Integrated Assessment (ToR item a) and the issue of scale (ToR item d). 2. Comparative Ecosystem Dynamics and Regime Shifts (ToR item e)
13:00	**Lunch**
14:00	3. OSPAR Integrated Assessment Methods (ToR item **g**) and other methods for conducting IA (ToR item **f**). 4. New data on human pressures and procedures for managing the data. (ToR item **b** and **c**)
16.00	**(Part 2) Agreeing how we should work as a group** - Assignment of breakout groups and specific tasks? (who will take on sections of the report) - Breakout groups begin work on ToR
18:00	**End Day 1**
Day 2	
Time	**Activity**
09.00	- Breakout group activities continue (from Day 1)
12.00	**(Part 3) Plenary update on breakout group activities** (Each group will have defined the key issues to address in relation to their associated ToR, the material and content for their sections/contributions and include key work activities to be undertaken during the meeting)
	1. Up-date on North Sea Integrated Assessment (ToR item **a**) and the issue of scale (ToR item **d**). 2. OSPAR Integrated Assessment Methods (ToR item **g**) and other methods for conducting IA (ToR item **f**).
13.00	**Lunch**
14.00	3. Comparative Ecosystem Dynamics and Regime Shifts (ToR item **e**) 4. New data on human pressures and procedures for managing the data. (ToR item **b** and **c**) - Discussion on how these are related and meet the overall objectives of the ICES Regional Seas Programme and ICES Science Plan
17.00	**(Part 4) Agreeing the way forward for the report and subgroup activities – what can we realistically achieve in the time have?**
	- Breakout group activities continue (taking into account Plenary feedback)
18:00	**End Day 2**
Days 3 - 5	**Breakout groups continue drafting activities with *ad hoc* plenary discussions as required**

Annex 3: WGHAME terms of reference for the next meeting

The **Working Group on Holistic Assessment of Regional Marine Ecosystems (**WGHAME) chaired by A. Kenny, UK and H. R. Skjoldal, Norway will meet at ICES HQ, Copenhagen, 18–22 October 2010 to:

a) Up-date the integrated analysis of the North Sea in conjunction with analyses of ecosystem component interactions to better understand the factors which control the status and function of the North Sea.

b) Develop a specification type for a North Sea Ecosystem Benchmark assessment drawing upon material agreed, presented and prepared at the workshop on regional sea IEA guidance.

c) Test hypotheses about large-scale drivers of observed ecosystem changes using consistent information on many LMEs to identify their rate, magnitude and direction of change. The timing of the identified changes should then be examined to determine relationships between the climatic, oceanographic and anthropogenic drivers. A series of consistent variables of interest should be identified and datasets of the predetermined variables compiled prior to the meeting. Specific hypotheses will be tested and also discussed in advance of the meeting to ensure that the appropriate variables are included in each regional system dataset.

WGHAME will report by 1 December 2010 (via SSGRSP) for the attention of SCICOM and ACOM.

Supporting Information

Priority	The work of the Group is essential if ICES is to progress the developments of integrated assessment in the context of the EAM.
Scientific justification	In order to help develop stronger links between science and advice in ICES it will be necessary to have regional assessment groups which can objectively integrate datasets corresponding to a wide range of ecosystem components. A pilot study was undertaken in the North Sea in 2006 to undertake such an integration exercise (REGNS), an approach which has since been adopted in ICES by a Baltic Sea Working Group. These assessments show the value of creating assessment databases (including the development of methods) for the evaluation of spatial and temporal trends in the state of LMEs, and more importantly to provide evidence of what is driving such changes. The available evidence on comparative ecosystem dynamics through the application of consistent and comparable integrated assessment techniques applied at the scale of LMEs offers great potential in better understanding what controls the observed large-scale and significant changes in marine ecosystems. Whilst the focus for this group will be the North Sea it is inevitable that what controls the dynamics of the North will be driven by forces beyond its immediate boundaries, so working with other groups will be essential. In this respect ICES has established a new WG on operational oceanographic products for fisheries and environment (WGOOFE) that includes a continuation of NORSEPP (North Sea Pilot Project). The WG on holistic assessments will seek to cooperate with WGOOFE to include updated information on physical conditions and drivers in the integrated assessment. It is now clear that the outputs of REGNS can add considerable value in supporting the developing OSPAR Integrated Assessment framework by providing quantitative numerical outputs which can be used directly in

	the OSPAR assessment matrix. It would be an objective of the WGHAME to work in collaboration with OSPAR and EC MSFD (WG on GES criteria) to ensure the outputs of the group support their policy objectives. The group would plan on meeting in Autumn each year (probably in late October) so as to prepare its scientific assessment on integrated ecosystem state ahead of the preparation of ICES advice in the following year. The group would ensure datasets are updated ahead of the meeting in order to maximize the time at the meeting for analysing the data using the methods applied by REGNS.
Resource requirements	No specific resource requirements beyond the need for members to prepare for and participate in the meeting.
Participants	Membership of the group will include those who were involved in the REGNS process plus additional members drawn from existing relevant WGs such a WGIAB and WGNARS. Support for such a group has so far been offered by the Chair of WGSE (Jim Reid), Hein Rune Skjoldal (IMR) and the ICES data centre (Neil Holdsworth).
Secretariat facilities	This group is likely to have high demand on the computing resources of the Secretariat, but no additional software/hardware is anticipated beyond that which is currently available.
Financial	None specific.
Linkages to advisory committees	An obvious very close link with ACOM activities.
Linkages to other committees or groups	Methodological issues are within the mandate of this Group but for the purpose of this meeting this issue is not on the agenda. Fish stock assessment methods are referred to the Methods WG that has been set up.
Linkages to other organizations	ICES will seek widened participation for this group including contact with relevant academic and intergovernmental organizations (including FAO, OECD, and IIFET) for this meeting.

Annex 4: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. WGHAME recommends that a workshop be held in collaboration with WGIAB and WGNARS from 11 – 15 October 2010 to develop guidelines for the conduct of IEAs. An important part of the workshop will be to examine in more detail the different aspects of IEA in line with the framework provided in this report. It would use examples of different types of evidence and assessment to support a more systematic and practical approach for delivering and IEA for management and policy applications. Specific guidance would be developed on the application of numerical integrated analysis methods (including data pretreatment) along with approaches to integrate evidence from a wide range of sources including expert judgement. Approval of this request requires agreement from other relevant groups in the ICES RSP notably WGIAB and WGNARS, it also requires support and approval from ICES SCICOM	Chair of ICES Regional Seas Programme to request SCICOM approval following consultation with the Chairs of WGIAB and WGNARS.
2. WGHAME request that the ICES data centre explores links with other institutes and data centres that can provide access to data on other types of human activities such as shipping, oil and gas exploration in the North Sea. Some guidance and advice on how this can best be achieved to support periodic updates of the North Sea pressure data would be very welcome.	ICES data centre manager.
3. WGHAME request that the Benthic Ecology (BEWG), Seabird Ecology (WGSE), Marine Mammal Ecology (WGMME), Marine Chemistry (WGMC) and Biological Effects (WGBEC) working groups consider, respectively, how their data sources can be integrated into a comprehensive North Sea integrated assessment as outlined by WGHAME, specifically in relation to accommodating differences in the spatial and temporal scales within their data and how this can be used for periodic assessments of the North Sea in support of OSPAR QSR.	Chairs of BEWG, WGSE, WGMC, WGMME, WGBEC.

Annex 5: OSPAR QSR 2010 Chapter 10 extract "Lessons learned and advice for future work"

The workshop was innovative, especially regarding the method and scale of the assessment. Therefore, experiences and lessons learned are probably as important as the results themselves.

Good points

a. The workshop brought together 66 people with good knowledge of pressures and ecosystem components, reasonably covering the 5 OSPAR Regions;
b. a consistent assessment framework was used across ecosystem components and OSPAR Regions, following specified assessment criteria and threshold values and leading to a clear assessment of status, supported by an audit trail and confidence assessment;
c. this framework enabled semi-quantification of cumulative impacts of pressures and successive ranking of pressures;
d. the workshop delivered a contribution to a holistic assessment at the scale of the OSPAR Regions;
e. GIS maps with pressure information and distribution of habitat types provided easily accessible information during the workshop.

Lessons learned

a. An improved and more thorough job could have been achieved with more time and more experts. Although the QSR thematic assessments were available during the workshop, there was limited time to properly consult these (although the relevant authors were available during the workshop to contribute information from the assessments). Some parts of the assessment could have been prepared in advance. Therefore the outcome of the workshop needs to be further checked with the results of the other thematic assessments;
b. limited expert knowledge was available for some Regions (leading to reduced confidence in some cases); where confidence is not sufficient, the assessments should remain blank to prevent misinterpretations; Additionally, the overall results may imply that a sufficient level of quality can be achieved based on expert judgement alone, whereas much greater certainty is needed for taking management actions;
c. some ecosystem elements (*e.g.* plankton, cephalopods, reptiles, oceanographic features) were not covered due to limited expertise and time constraints during the workshop;
d. in future the status of the marine environment and the pressures /impacts need to be assessed on a smaller scale, at least in some sub-regions;
e. the method does not take into account relationships between ecosystem components (i.e. indirect effects), which was considered a major shortcoming by a number of participants.