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Integrated Assessments in Support of Large Marine Ecosystem Science, Management & Advice: Beyond Quality Status Reporting.

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Introduction

The work presented here was produced by an ICES study group (REGNS) which has undertaken an Integrated Ecosystem Assessment of North Sea ecosystem data, essentially to investigate the trends and links between abiotic (climate) pressures (including nutrients), plankton, commercial fish populations, fisheries and seabirds over the last 30 years. Some of these results are presented in Kenny *et al* (2006).

In undertaking this exercise for the North Sea (LME) a number of important lessons were learnt that contribute to our scientific understanding of LME dynamics, the management of ecosystems (by way of appropriate monitoring programmes) and the provision of advice. One of the first lessons was to recognise that IA is both a process (a service) and a product and that both are aimed at different groups of end-users. The REGNS process identified three groups of end-user, namely; **i**. to better understand the causality of ecosystem dynamics (scientific applied R&D community), **ii**. those dealing with improving the efficiency and delivery of monitoring and assessment programmes (managers), and finally **iii**. those responsible for developing marine environmental protection policy (policy makers). In practical terms, Integrated Assessments are developed in one of two ways, namely; **i**. at a thematic level in response to a specific policy driver such as the reduction of nutrient inputs to manage eutrophication effects and **ii.** at the holistic level which attempts to consider all aspects of the ecosystem and to provide the wider context for policy objectives such as defining good environmental status.

The REGNS process took the holistic approach for the North Sea with its efforts focused towards furthering our understanding of ecosystem dynamics and its value in helping identify important components to monitor for management purposes.

Climate and the North Sea Ecosystem (links between nutrients, plankton, fish, fisheries & seabirds)

The data used in the assessment covered a period of 1973 to 2004 and was spatially resolved at the scale of ICES stat. rectangle (30km by 30km). A temporary assessment database was created containing 8,433,120 spatially & temporally explicit ecosystem observations. This is the first time such a comprehensive data set and analysis had been undertaken. The list of abiotic and biotic parameters used is presented in Tables 1 and 2, respectively.

Table 1. List of abiotic parameters used.

Data type	Source	Frequency	Space-scale
Bathymetry	UKHO	Single record	Converted to stats. sq.
Tide-generated bottom stress (max.)	GETM (Cefas)	Monthly	Converted to stats. sq.
Wave-generated bottom stress	GETM (Cefas)	Monthly	Converted to stats. sq.
Water mass fluxes	NORWECOM (PGNSP)	1955-2005 monthly	13 sections
Sediment type	North Sea benthos survey	Single record	Converted to stats.sq.
Salinity (S&B)	ICES	Monthly	Converted to stats. sq.
Temperature (S&B)	ICES	monthly	Converted to stats. sq.
NAO index	Univ. East Anglia	1955-2005 winter index (DJFM)	n/a
Freshwater flows	FRS Aberdeen	monthly	By river & region
Nutrients (DIN, DIP)	ICES	monthly	Converted to stats. sq.
Oxygen concentration	ICES	monthly	Converted to stats. sq.
Chlorophyll a	ICES	monthly	Converted to stats. sq.

Total of 12 abiotic parameters equating to18 variables

Table 2. List of biotic parameters used.

Data type	Source	Frequency	Space-scale
Phytoplankton	CPR (SAHFOS)	Monthly	Converted to stats. sq.
Zooplankton	CPR (SAHFOS)	Monthly	Converted to stats. sq.
Fish abundance (CPUE)	ICES (IBTS)	Quarterly	Converted to stats. sq.
Seabird abundance	WGSE/ESAS	Monthly	Converted to stats. sq.
Stock Assessment	ICES	Annual	Region IV (a, b & c)
Fish landings	Scotland, England & Wales authorities	Monthly	Converted to stats. sq.
Macrobenthos	ICES NSBS	1983 & 2000	Converted to stats. sq.
Marine mammals	WGSE/ESAS	Monthly	Converted to stats. sq.

Total of 100 biological variables equating to: 14 species of zooplankton, 20 species of phytoplankton, 19 fish abundance species, 21 stock assessment metrics, 9 fish landings species & 17 seabird species.

For our initial analysis two types of data matrix were constructed from these, namely; **i**. data to undertake spatial analysis (for each parameter an average for each ICES grid cell over all years was performed) and ii. data to undertake time-series analysis (for each parameter annual averages over all squares was performed).

Spatial Analysis

Abiotic data were in the first instance treated separately by transforming and normalising the data so as to facilitate a direct comparison between differently scaled variables. The integrated (multivariate) analysis was undertaken using Principal Components Analysis (PCA) which attempts to present in a two dimensional space the variation in the abiotic status of individual ICES grid cells. The results of this analysis are shown in Figure 1 (below), which clearly shows some dominant abiotic gradients in the North Sea (running North to South). Each ICES rectangle (cell) has been assigned a colour according to its assigned cluster following hierarchical cluster analysis. The gradients are consistent with current understanding and also serve to provide some reassurance in terms of the quality of the data and the design of the monitoring programmes.

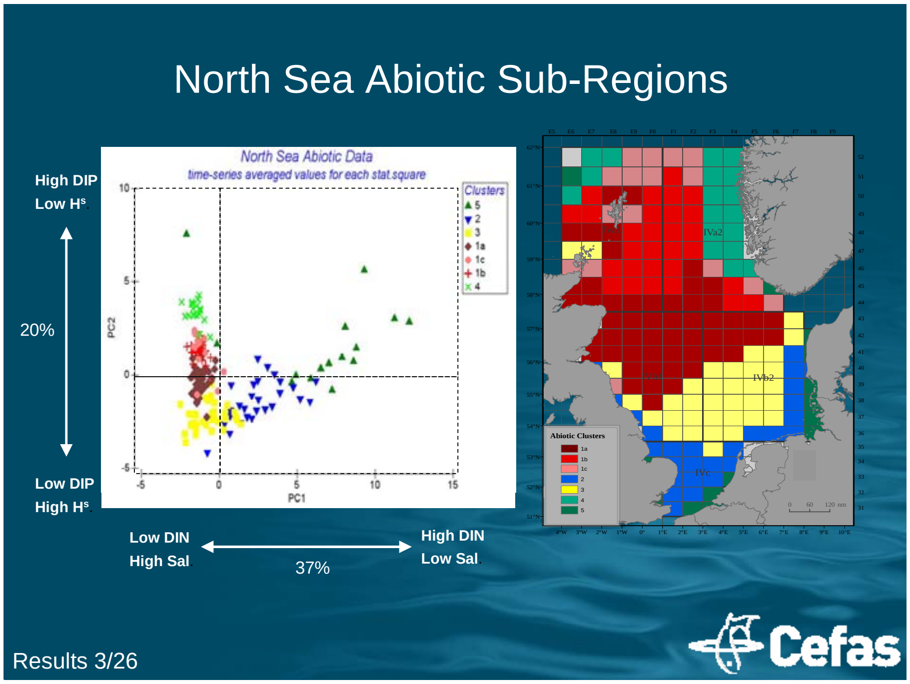

Figure 1. Spatial PCA using ICES abiotic data for each ICES rectangle. The abiotic status of each rectangle is defined in the PCA and then mapped – Note the clusters are spatially contiguous and consistent with current understanding.

Highly significant levels of relatedness ($p>0.01$) were found between the abiotic data and the plankton, fish populations (CPUE), fisheries(landings) and seabird data. The most important abiotic spatial components explaining the biotic variation are dissolved inorganic phosphate, salinity and wave stress. It is noteworthy that spatial variations in temperature appear less significant in explaining the spatial variation in the biota, but it should be expected that temperature will be more significant in explaining biotic variation over-time.

In conclusion:

- Abiotic sub-regions for the North Sea have been defined using readily available monitoring data & verified.
- Variations in nutrients, salinity and wave stress are the most significant parameters in terms of explaining assemblages of Plankton, Fish & Seabird – but the causal links (if they exist) require further explanation.
- Boundaries are consistent with other scientific studies, but not current policy assessment and management boundaries. This difference requires further quantification and assessment.
- Also how spatial trends change over different time periods requires further investigation.

Time-series analysis

Performing PCA on the abiotic data for the entire North Sea for years 1973 and 2004 reveals some clear trends in the North Sea state over time (Figure 2). Again the samples (years) have been coloured according to their assigned clusters in a separate cluster analysis. What is interesting is that the previously described regime shift in 1989 does not stand out, rather there appears to be a group of years between 1985 and 1995 which are noteworthy, with a couple of outliers denoted as blue triangles. These years were characterised by relatively high levels of dissolved inorganic nitrogen, low salinity, high temperature and low dissolved inorganic phosphate. The present analysis suggests that this group of years (which includes 1989) represents a transitionary period where several biotic components changed significantly both negatively and positively during this period, but not all biotic components changed in state in the same year ie.1989. Figure 3 shows the example for commercial fish populations derived from IBTS catch per unit effort data.

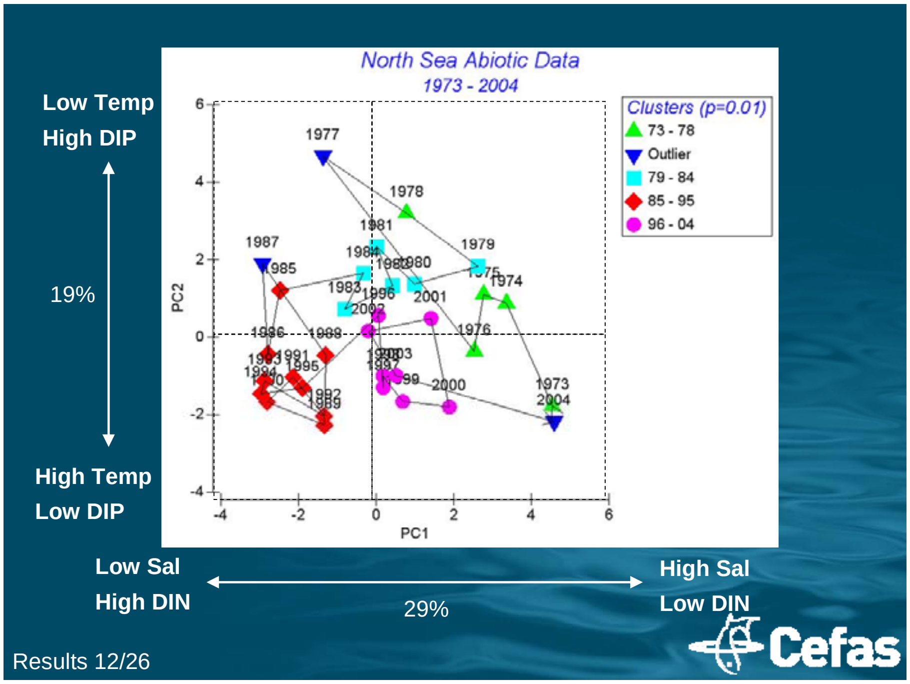

Figure 2. PCA on biotic data - sample years from 1973 to 2004.

What this shows is that in the North Sea there was a change in the commercial fish populations around 1990 from one which included a dominant presence of whiting to one which now includes a dominant presence of sprat. In terms of statistical significance trends in bottom temperature appear to be important drivers of this response, but there is also the likelihood that changes in fishing pressure and gear type could account for this difference – further analysis is required..

All biotic responses exhibit an increasing trend in dissimilarity over this period such that the biotic state pre-1985 is most different from the state post-1995. This is in contrast to the abiotic state which has moved closer to the pre-1985 condition (see Figure 2).

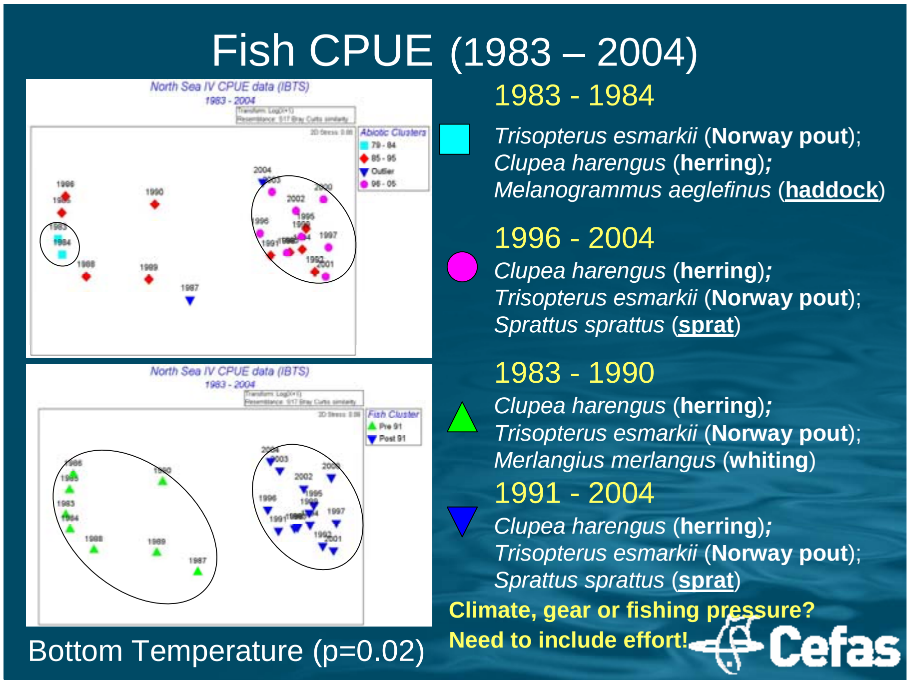

Figure 3. Changes in the state of commercial fish populations. The top figure has sample years coloured according to the abiotic clusters in Figure 2 where as the bottom figure has samples years coloured according to their own ordination groups.

The strength of having multiple sources of pressure and state ecosystem variables gridded for most of the North Sea is that allows the data to be integrated and comparatively assessed in one step. The relative contribution of one variable against another can then be examined for the entire time series to help determine and understand their importance in the context of the wider ecosystem response.

Figure 4 shows one example of such an integrated assessment (a traffic light plot) based upon 56 variables using a method first demonstrated by Choi *et al* (2005). The method clearly shows the change in state from one dominated by high cod and skate landings, possibly driven by high negative flux of North Sea sea-water and relatively low NAO index before 1983 to one which has become dominated by high landings of *Nephrops* and squid and increased bottom temperatures. However, the change at the ecosystem level is not abrupt (which is no surprise) as not all variables respond in the same way at any one time. Some variables appear to be changing state earlier than others, whilst others may have some level of trophic dependency that introduces time-lags into the ecosystem response. This process of transition clearly merits closer examination to elucidate its properties such as reclassifying the data according to trophic status and weighting the variables according to their ecological significance.

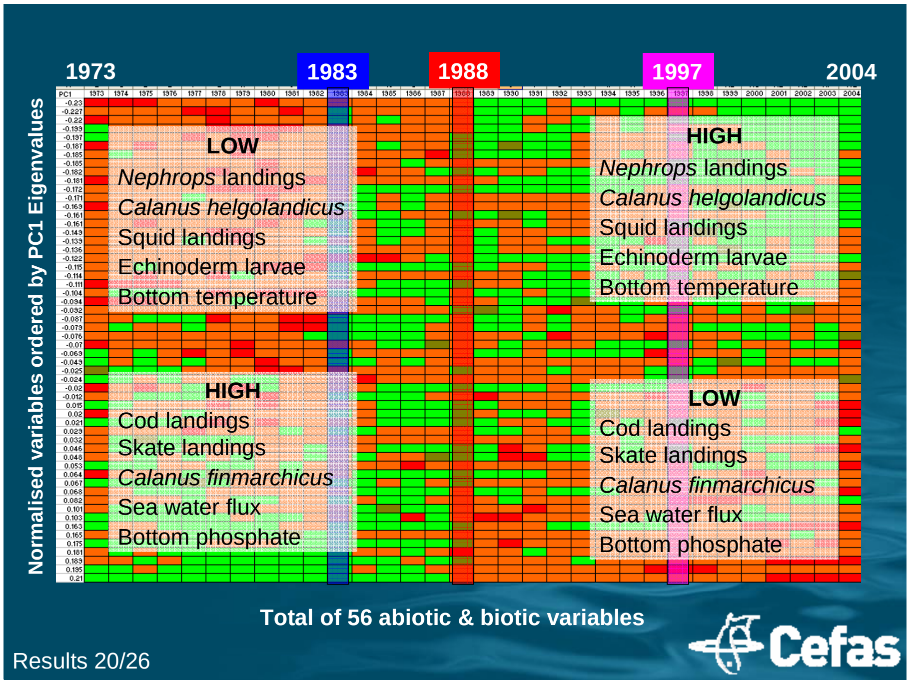

Figure 4. Integrated Assessment of the North Sea ecosystem showing trends in state between 1973 and 2004. Note some early indication of a possible regime change in 1983 a full 6 years before a change in regime occurred.

In conclusion:

- The North Sea ecosystem does not change abruptly.
- Evidence of a steady rise in DIN and fall in salinity between 1979 and 1988.
- An increase in NAO coupled to an increase in negative sea water flux in 1988/9 and a sharp increase in surface and bottom sea water temperatures.
- A 10 year period of increased ecosystem variability between the two regimes from 1987/88 to 1997/88.
- In 1991 a change in the commercial fish stock community, from one where whiting was a dominant species to one where sprat became more dominant.

Messages for management:

- The weight of evidence is crucial if we wish to predict ecosystem change with any degree of certainty.
- Early indicators of state change may not be the same as indicators of good ecological state.
- Predicting (and therefore monitoring) changes in nutrients, salinity, temperature and plankton are especially important variables in predicting changes at the ecosystem level and may help to support the management of fish stocks in the future.