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Report of the Regional Ecosystem Study Group of the North Sea (REGNS)

15-19 May 2006

ICES Headquarters, Copenhagen

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Contents

Executive summary

A meeting of the ICES Regional Ecosystem Group for the North Sea (REGNS) took place in May 2006 which continued the ambitious task of drawing together different types of data relating to pressure and state changes in the North Sea Ecosystem and to undertake an integrated assessment. The assessment has provided some valuable insights into the significance of the relationships between different pressure and state changes at different scales and the time scales over which changes take place. For example, plankton community data in relation to the physical and chemical oceanography reveals both gradients of response to the major riverine inputs of nutrients into the North Sea and sources of nutrients from the Atlantic. In addition, an assessment of all variables reveals two relatively stable states in the North Sea, one pre-1983 and the other post-1997. The intervening years are dominated by high ecosystem variability which represents a transition from one state to another and in part explains the number of studies which highlight different years for regime shifts. We conclude that defining such shifts is sensitive to the number and type of variables included in such analysis. Further evidence of a gradual regime shift in the ecosystem is presented for ICES sub-region IVb2 a region subjected to relatively high human pressure, but here this shift appears to have occurred between 1991 and 1998. The sensitivity of such analysis to changes in temporal and spatial scales is explored as is the dependency on the number and type of ecosystem variables. By better understanding the relationship between the causes of change at different scales in time and space it should be possible to set more realistic targets for the management of human pressures.

1 Opening of the meeting

Andrew Kenny opened the Workshop and welcomed the participants. These consisted of representatives of WGSE and PGNSP, an additional REGNS participant, an expert on eutrophication, an SQL database expert, a GIS expert and 2 external participants from the University of Tennessee with expertise in advanced computational methods. No other WGs were represented.

2 Adoption of the agenda

The **Regional Ecosystem Study Group for the North Sea** [REGNS] (Chair: A. Kenny, UK) will meet at ICES Headquarters from 15–19 May 2006 to:

During the first 3 days:

a) Hold a workshop to evaluate and plan the finalization of the 2006 integrated ecosystem assessment for the North Sea, to be presented at the 2006 ASC;

i) review the outcome of the work of an intersessional correspondence group (sub-group of REGNS) with compilation and analyses of a comprehensive integrated data set for different aspects and components of the North Sea ecosystem,

ii) review the outcome of intersessional work on relating state variables of the ecosystem with human pressures according to themes (eutrophication, pollution, conservation, fisheries, climate, and management),

iii) prepare plans for finalization of the integrated ecosystem assessment which must take account of the relationship between the thematic human pressures assessments (in ii above) and the overview integrated assessment (in (i) above),

iv) prepare for presenting the outcome of the integrated ecosystem assessment at the 2006 ICES Annual Science Conference;

During the last 2 days:

b) Advise on follow-up work to translate the experiences of REGNS in producing an integrated ecosystem assessment into a regular process in ICES of producing or contributing to the production of updated integrated assessments for the North Sea ecosystem;

c) Based on the experience with the production of the 2006 North Sea integrated assessment; consider requirements that need to be taken into account in a design of a holistic monitoring of the North Sea ecosystem.

REGNS will report by 30 June 2006 for the attention of the Resource Management Committee, ACFM and ACE.

3 Compilation of a comprehensive integrated data set for different aspects and components of the North Sea ecosystem (ToR a (i))

3.1 Information from Expert Groups

As described in REGNS 2005, the REGNS assessment successfully received inputs from various source Working Groups in the form of written reports and this represents a huge amount of knowledge on the North Sea ecosystem and is an invaluable source of reference material for any North Sea ecosystem assessment. Annex 4 highlights the WG reports available, but the content of the reports is not included here as it would be too large to reproduce, however the individual reports are available through ICES.

Obviously it would be of value to review all the material and compile an assessment report from the WG reports alone. However, limited resources in REGNS resulted in this not happening and we apologise to the expert groups for not making more use of their outputs in this instance, but the material is there and can be used in the future either by a permanent REGNS WG or by an existing expert group. Clearly such a review would complement the existing operational assessment of data undertaken by REGNS and we hope that the assessment outputs presented here will help the expert groups interpret their own material and in a small way contribute to the further the understanding of the North Sea.

3.2 Initial REGNS database

One of the outcomes of the May 2005 REGNS Workshop was the production of a metadata table showing the geographical and temporal extent of available data, grouped by category (abiotic, biotic and human pressures) and allocated a priority. The assignment of the priority was based on the relative importance of that data type for the overview integrated assessment (e.g. as a major controlling factor, such as fishing pressure) and the spatial and temporal extent of the data (i.e. the overview assessment demanded North-Sea-scale distribution over a minimum of a decade). This inevitably led to several types of data, which were considered important, for example: fish diseases; ecotoxicology (e.g. imposex); contaminants in sediment, water and biota; time-series of benthos data being excluded from the over-view assessment.

An intersessional correspondence group (ICG) supervised the collation of data made available at the May 2005 workshop and the development of a REGNS database, hosted at FRS Aberdeen. This was moved to JRC Ispra when the developer Doug Beare took up an appointment there. As additional data became available these were added to the database which was loaded on an ftp server, allowing password-protected access. Data additions and extractions necessitated intervention by Doug Beare, who was required to write appropriate queries to provide data in the required format. Andrew Kenny and Peter Kershaw (Cefas) visited Ispra in February 2006 to discuss the extent of the data holdings, the database architecture, methods of subdividing the holdings for analysis, remote access to the database (through the JRC firewall) and access restrictions. A link to the database was provided to the chairs of the source working groups but difficulties were experienced in gaining access. To facilitate data access it was decided to export flat files that could be manipulated on standard software packages, such as spreadsheets, to allow the ISG to continue the revision of the overview assessment. In addition, the data files were made available to an independent group based at the University of Tennessee, led by Mike Langston, to test complex correlation methods on the REGNS data, for inclusion in the 2006 assessment. This followed fruitful discussions with Bob Gauldie (formerly Univ. Hawaii) at the 2005 Workshop. The development and maintenance of a complex database requires a certain level of support and it is difficult to provide this without specific additional funding.

3.3 Preparations for the May 2006 Workshop

The original intent had been to complete a second iteration of the overview assessment and circulate the results to the chairs of the source working groups prior to the 2006 spring round of WG meetings. This was to be guided by the response to the first overview assessment presented at the 2005 ASC. The timetable proved to be over-optimistic. One of the reasons was the delay in the submission of additional data that had been recognised as critical, for example: model output of tide and wave-induced bottom stress, bathymetry, sediment types, updated plankton from the CPR, fish landings, benthos, and model output of fluxes (NORWECOM). Some of these data only became available a few days before the 2006 Workshop and some were obtained during the workshop. This meant that the updated overview assessment had to be conducted during the 2006 Workshop. To guide the source WGs we provided the output from the first overview assessment, including the presentation given at the ASC 2005, together with tabulated data from the ISG database (complete to February 2006) and requested additional comment, according to the ToRs given to each WG. The responses of the WGs were reviewed during the workshop.

The data compilation exercise illustrated a number of issues of data availability, and data manipulation, some of which might have been resolved more easily given increased institutional support for, and additional expert input to, the ISG. In some cases we were unaware of data sources or unfamiliar with the holdings (e.g. data on industrial fisheries and limitations of CPUE data for certain fish species, such as sandeels). In some cases data that had been promised did not materialise (e.g. Met Office model output) and we had to resort to using other sources at a late stage (e.g. Cefas modelling expertise). To obtain the CPR data we needed to find funding (from Defra) for SAHFOS to carry out the data extractions and manipulation. To obtain the fish landings data we were required to negotiate with the data holders (over data security and conditions of use) and data were forthcoming only for Scotland and England. The most readily-available and complete dataset on sediment types proved to be the North Sea benthos survey data, which were obtained from the VLIZ website (http://www.vliz). Much higher resolution data are available but these appear to be restricted geographically and can carry significant cost (e.g. UK sector, British Geological survey). We would wish to use higher resolution data in future assessments. Information on marine landscapes provided by JNCC and the WGMHM did not provide an improved data source on bottom types for the present purposes.

3.4 Data management for the May 2006 Workshop

All appropriate data made available either before or during the workshop (including the initial Ispra-hosted database) were incorporated in an SQL database hosted remotely at Cefas, with queries being written on demand by SQL (Keith Winpenny, Cefas), to meet the requirements of the assessment (including re-formatting). This overcame some of the practical difficulties of dealing remotely with Ispra. In addition, Cefas provided a GIS expert (Carla Houghton) to manipulate and display primary spatial data and the results of the spatial analysis.

3.5 Data used in second overview assessment

3.5.1 Abiotic data

Abiotic data were selected to ensure adequate spatial and or temporal coverage, using single sources where possible to minimise uncertainty (See Table 1).

Table 1: Abiotic data used in the overview assessment.

DATA TYPE	SOURCE	TIME-SCALE (USED FOR ANALYSIS)	SPACE-SCALE
Bathymetry		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 (depth-integrated)	NORWECOM (PGNSP)	1955-2005 monthly	13 sections
Sediment type	North Sea benthos survey	Single record	NSBS grid converted to stats.sq.
Salinity (surface & bottom)	ICES	monthly	Converted to stats. sq.
Temperature (surface & bottom)	ICES	monthly	Converted to stats. sq.
NAO index	Univ. East Anglia	1955-2005 winter index (DJFM)	n/a
Freshwater flows	FRS Aberdeen (Sarah Hughes)	monthly	By river & region
Nutrient concentrations (nitrate, nitrite, phosphate,)	ICES	monthly	Converted to stats. sq.

DATA TYPE	SOURCE	TIME-SCALE (USED FOR ANALYSIS)	SPACE-SCALE
Oxygen concentration	ICES	monthly	Converted to stats. sq.
Chlorophyll a	ICES	monthly	Converted to stats. sq.

3.5.2 Biotic data

Biotic data available in the REGNS database and used for the assessment is shown in Table 2.

Table 2: Biotic data analysed in the assessment.

DATA TYPE	SOURCE	TIME-SCALE (USED FOR ANALYSIS)	SPACE-SCALE
Phytoplankton	CPR (SAHFOS)	monthly	Converted to stats. sq.
Zooplankton	CPR (SAHFOS)	monthly	Converted to stats. sq.
Fish abundance (CPUE)	ICES (IBTS)	annual	Converted to stats. sq.
Seabird abundance	WGSE/ESAS	monthly	Converted to stats. sq.
Marine mammals	WGSE/ESAS	Monthly	Converted to stats. sq.

3.5.3 Human pressures data

Human pressures data available in the REGNS database and used in the assessment is shown in Table 3.

Table 3: Human pressures data analysed from the REGNS database.

DATA TYPE	SOURCE	TIME-SCALE (USED FOR ANALYSIS)	SPACE-SCALE
Fish landings	Scotland, England & Wales authorities	monthly	Converted to stats. sq.
Nutrient river loadings	(Mills *et al*., 2006)	monthly	by region

4 Analytical methods

4.1 Standard multivariate statistical methods – Cluster analysis, MDS, PCA etc.

Traditional strategies for identifying subsets of variables with highly correlated elements rely on various clustering algorithms. Clustering is an attempt to organize multivariate data into groups with approximately similar observational profiles. A wealth of clustering approaches has been proposed [1-5]. The various methods build upon a correlation measure between pairwise combinations of variables, which is used to calculate a distance metric of similarity (or dissimilarity) between each variable pair. The most common clustering algorithms are either hierarchical, in which all variables begin in their own clusters and are eventually merged into one, or centroid, in which variables are organized into a predefined number of clusters by iterative adjustments based on similarity [6]. There are several important limitations, however, to the vast majority of clustering algorithms that lie in contrast to the realities of ecosystems. One such limitation is that the clusters these methods produce are disjoint, requiring that a variable be assigned to only one cluster. While this simplifies the amount of data to be evaluated, it places an artificial limitation on the system under study in that many variables play important roles in multiple but distinct relationships [7]. There are recent clustering techniques, for example those employing factor analysis [8], that do not require exclusive cluster membership for single variables. Unfortunately, these tend to produce uninterpretable factors without the incorporation of prior information [9]. Another important limitation is that most of the measures of similarity used by current clustering algorithms do not permit the recognition of negative correlations, which are common and often equally meaningful from a systems-level perspective. Nevertheless, the main evidence presented in this assessment report is based upon upon 'traditional' multivariate clustering techniques.

4.2 Advanced computational techniques

4.2.1 Overview

By contrast to the approach described above, the notion of relevance networks has been developed [7, 10, 11] as a means to overcome the limitations of traditional clustering methods. Relevance networks begin with a matrix of the correlation coefficients between all pairwise combinations of variables, and identify both positive and negative relationships. In a relevance network, variables are denoted by vertices and correlations between them exceeding a defined threshold are represented as edges. Additional types of data can be incorporated to recognize relationships between variables and other metrics. Unfortunately, without an algorithmic means to extract the aggregate relationships between multiple variables, many of the most interesting relationships – those with tight connections between multiple variables – remain embedded within the vast sea of correlations.

The main objectives of this research component center on elucidating complex relationships between variables of significance to the North Sea ecosystem. These variables may be biotic or abiotic, and may have divergent periodicities and other diverse properties. To uncover these relationships, we design and synthesize powerful graph algorithms to generate distilled variable sets. We also produce scalable, high performance parallel and distributed implementations of these algorithms to run on workstation clusters and a variety of super-computing platforms as needed.

4.2.2 Benefits of a graph theoretical approach

It is therefore necessary to develop more powerful tools to extract subsets of correlated variables from large aggregates of diverse ecosystem data in order to fulfil the promise of high-throughput data mining. The field of graph theory offers unique advantages to this problem. Many innovative graph algorithms are based on decades of basic research, and constitute a class of tools that can help identify relationships in highly complex data structures, in our case as matrices of correlations across tens, hundreds or even thousands of variables. In this respect, graph algorithms offer a means to extract meaningful aggregates of variables from within the relevance network framework. Weighted graphs are produced from this type of data. They consist of vertices representing variables and edges whose weights indicate the correlation between each pair of vertices (variables). Given a suitable threshold, t, edges with weights less than t are discarded; edges with weights at least t are retained. This produces an unweighted graph, G, whose structural properties are of interest.

4.2.3 The clique problem and densely-connected subgraphs

The challenge, once the graph is created, is not to study the graph in its entirety but rather to extract its densely embedded subgraphs. These are small, tightly connected regions of the graph that represent subsets of variables with strong correlations between every pair of its members. Thus these are likely to represent significant relationships and interactions. In the most extreme case, in which a subgraph contains all possible edges between its vertices, this structure is called a *clique*. A clique on four vertices is illustrated in Figure 1.

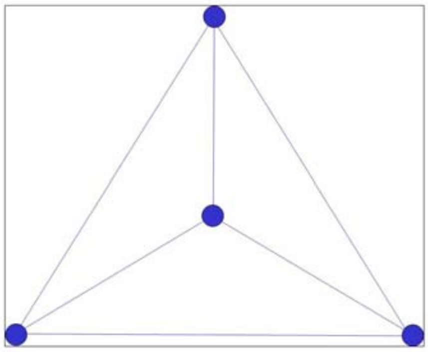

Figure 1: A clique of size four.

Clique is widely known for its application in a variety of combinatorial settings. It is particularly noteworthy that cliques need not be disjoint. A vertex can reside in more than one clique, just as a variable may be in more than one relationship. Moreover, negative correlations are easily handled in a variety of ways, for example, by two-colouring the graph's edges prior to thresholding. In terms of correlation density, clique represents the most trusted potential for identifying sets of interacting variables [7].

4.2.4 Context

This general methodology is placed in the broader context of clustering in Figure 2, with our approach illustrated in blue. Our work centers on solving immense instances of the clique problem and applying the solutions to raw ecosystem data. Solving clique is a major computational bottleneck, however, and a classic graph-theoretic problem in its own right. A considerable amount of effort has been devoted to solving clique efficiently [12]. There is also considerable interest in solving the dense *k*-subgraph problem [13]. Here the focus is a cluster's edge density, also referred to as clustering coefficient, curvature, and even cliquishness [14, 15]. In this respect, clique is the "gold standard." A cluster's edge density is maximized with clique by definition. We especially seek to solve the *maximum* clique problem, whose goal is to find the largest *k* for which *G* contains a clique of size *k*.

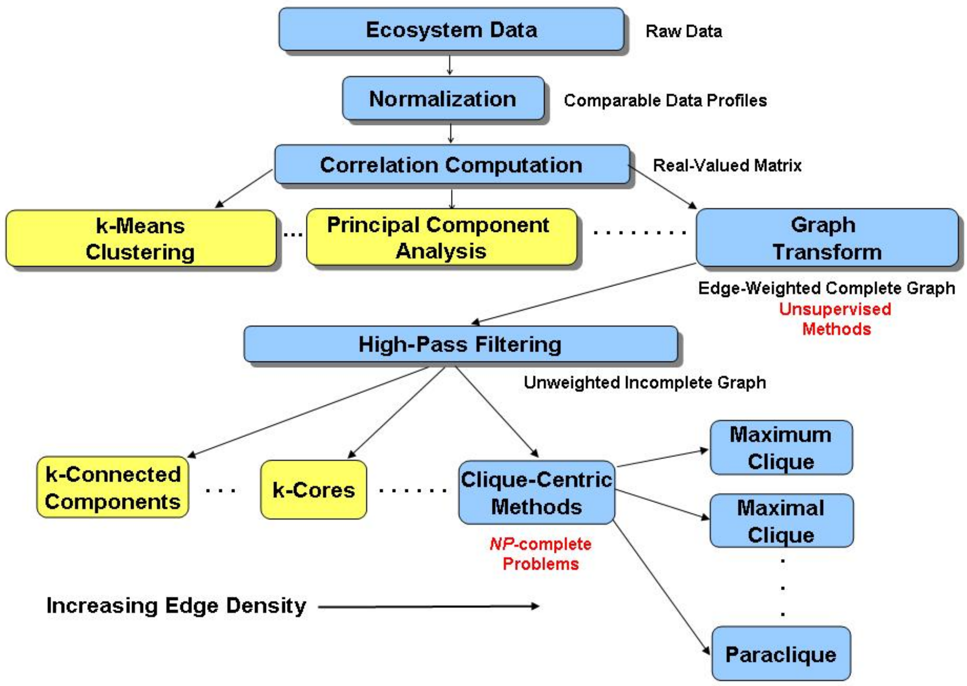

Figure 2: An overview of clustering for multivariate analysis. The approach used in this effort is shown in blue.

We hasten to point out that our use of thresholding and clique is distinct from a superficially similar approach employed in "signature algorithms," including those described in [16] and [17]. Signature algorithms are designed to group variables into sets along with the conditions under which each set may form a relationship. Randomization, iteration and scoring are key ingredients. Given a starting seed (variables called a "reference set"); each condition is scored dependent upon how well it seems responsible for any relationship observed with that seed. Once conditions are scored, each variable is then scored by how well it appears to be controlled by the current set of conditions whose score exceeds a preset threshold. Results of this back and forth action are variable clusters that, like maximal cliques, are allowed to overlap. Unfortunately, there is no notion of requiring extreme edge density as there is with clique-based methods. Instead, modules derived with signature algorithms depend heavily upon the seeds chosen, the number of iterations employed, and other factors. Likewise, the time required to run these algorithms depends on seeds, iterations and convergence criteria.

In [18] is another interesting approach to relationship discovery that differs from this effort on at least two fronts: partial correlations are used without thresholding, and clusters are identified by variables sharing partial correlations that are stronger within the cluster than surrounding correlations. While the idea of partial correlations is intriguing, there is also a danger that true relationships may be statistically adjusted away. For example, if three variables are highly correlated, partial correlations between any two, adjusted for the third, could be zero, and that cluster would disappear.

4.2.5 Technical's, and revolutionizing the search for cliques

The inputs to the standard decision version of clique are an undirected graph G with n vertices, and a parameter $k \leq n$. The question asked is whether G contains a clique of size k, that is, a subgraph isomorphic to K_k. Subgraph isomorphism, clique in particular, and is *NP*-complete. From this it follows that there is no known algorithm for deciding clique that runs in time polynomial in the size of the input. One could of course solve clique by generating and checking all candidate solutions. This brute force approach requires $O(n^k)$ time, however, and is thus prohibitively slow, even for problem instances of only modest size. One might be tempted to try to solve clique approximately rather than exactly. Clique is so difficult, however, that guaranteeing solutions even to within only n^{ε} cannot be accomplished within polynomial time for any $\varepsilon>0$ unless $P=NP$ [19].

Dramatically better approaches are clearly required if clique is to be applied to huge ecosystem data sets. In this context, we employ *fixed parameter tractability* (FPT), whose roots can be traced at least as far back as the work of Fellows and Langston [20, 21]. *A problem is FPT if it has an algorithm that runs in $O(f(k)n^c)$ time, where n is the problem size, k is the input parameter, and c is a constant independent of both n and k* . Clique is not FPT, however, unless the *W* hierarchy collapses [22]. The *W* hierarchy, whose lowest level is FPT, can be viewed as a fixed-parameter analogue of the polynomial hierarchy, whose lowest level is *P*. Such a collapse is widely viewed as an exceedingly unlikely event, roughly on a par with the likelihood of the collapse of the polynomial hierarchy [23].

Thus we focus instead on clique's complementary dual, the *vertex cover* problem. Consider *G'*, the complement of *G*. (*G'* has the same vertex set as *G*, but edges present in *G* are absent in *G'* and vice versa.) The question now asked is whether *G* contains a set *C* of *k* vertices that covers every edge in *G*, where an edge is said to be covered if either or both of its endpoints are in *C*. Like clique, vertex cover is *NP*-complete. Unlike clique, however, vertex cover is FPT. The crucial observation here is this: a vertex cover of size *k* in *G* turns out to be exactly the complement of a clique of size $n - k$ in *G'*. Thus, we search for a minimum vertex cover in *G*, thereby finding the desired maximum clique in *G'*. Currently, the fastest known vertex cover algorithm runs in $O(1.2759^k k^{1.5}+kn)$ time [24]. Contrast this with $O(n^k)$. The requisite exponential growth (assuming $P \neq NP$) is therefore reduced to a mere *additive* term, making it realistic now to consider the search for cliques of huge sizes in immense collections of ecosystem data. Our recent work on this subject is featured in [25-31].

4.2.6 Preliminary Results

Figure 3 illustrates the power of this approach when applied to North Sea historical data. Using a correlation threshold of 0.50, we find a clique that suggests a strong relationship between salinity and certain species of plankton/birds, and another that suggests a strong relationship between plankton/birds and certain species of fish. Note the significance of overlapping cliques. Thus bottom salinity and horse mackerel, for example, are at most weakly correlated, and in fact may be uncorrelated or even inversely correlated. (A check of correlation coefficients reveals that bottom salinity and horse mackerel are at best only very weakly correlated, with a correlation coefficient of 0.13.) Traditional clustering methods would either have forced salinity and mackerel to reside in the same cluster, or have removed plankton/birds from the cluster with salinity or the one with mackerel (or both). In all cases, the fidelity with which the resultant clusters represent the underling ecosystem data would have been severely compromised.

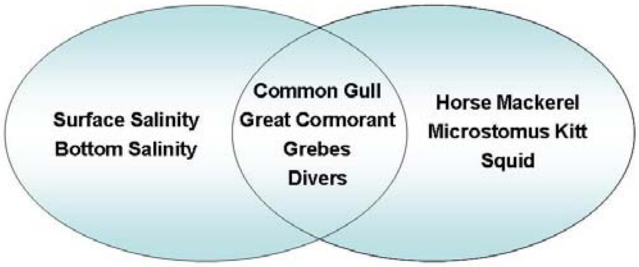

Figure 3: Cliques elucidate complex relationships.

4.2.7 Dealing with noise and the utility of the paraclique algorithm

To account for the many sources and varieties of noise inherent in data generated with current technology, we have recently developed a clique relaxation technique to identify what we call "paracliques." Informally, a paraclique is an extremely densely-connected subgraph, but one that may be missing a small number of edges and thus is not, strictly speaking, a clique. In our application, this corresponds to a very highly correlated group of variables whose representational levels, as reflected in real and often noisy data, show highly significant but not necessarily perfect pair-wise correlations. Let us illustrate, beginning with a clique C of size k, where k is perhaps the size of the largest clique in the list. We set a connectivity factor, f, at some value strictly less than k. We also set an edge weight bound, b, at some value strictly less than the threshold, t, used to build the correlation graph. We now consider each non-clique vertex, v, in turn. We mark v if and only if it is adjacent to at least f vertices in C and if and only if the weight of the correlation coefficient on any "missing" edge is at least b. (Recall that the coefficients were used to build an edge-weighted graph that was later replaced by an unweighted graph via the use of a high-pass filter. Thus the weight of any edge missing from the unweighted graph is still available.) After each vertex has been considered, we define a paraclique, P, to be the union of C and the set of all marked vertices. We remove P from the graph and iterate. Figure 4 illustrates this method, in this case on proteomics data. Here a clique of size 28 is transformed into a paraclique of size 46, thus providing a robust form of clustering that is resistant to sharp and artificial edges caused by noise or measurement imprecisions. Details on the paraclique method, couched in terms of transcriptomic data analysis, may be found in [32].

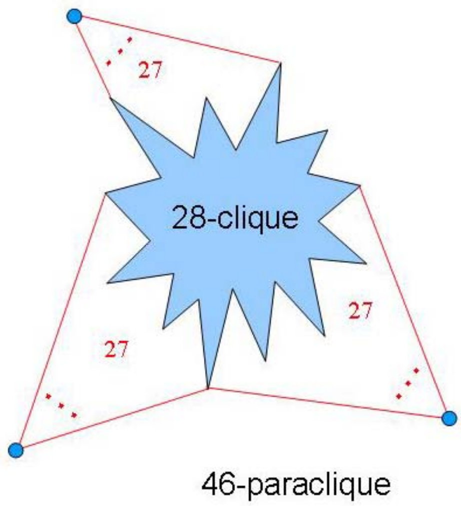

Figure 4: Paraclique helps analyze noisy data.

By harnessing the computational power of FPT and then isolating paracliques, we are able to identify considerably denser subgraphs than are typically produced with traditional clustering algorithms. While we have observed edge densities ranging in the 10-20% range with simple cores and neighborhoods, and in the 50-60% range with HCS-based methods, on real data paraclique consistently seems to return subgraphs with densities upwards of 95%. We intend to refine and further evaluate our paraclique methods, devise objective criteria for parameter selection, and analyze the properties of paraclique interaction graphs in the setting of multivariate ecosystem data.

4.2.8 Exploring Variable Relationships at Higher Levels of Granularity

Graphs can be used to represent relationships and connections between sets of variables, as well as between individual variables. In the same way that cliques may point to relationships, networks and interactions, clique intersection graphs can highlight and pinpoint connections between these relationships (that is, relationships between relationships). In this setting, a coarsened graph is constructed by representing a clique by a vertex. Two vertices are joined by an edge if and only if the intersection of their respective cliques is nonempty (that is, if at least one variable is common to both cliques). The multi-scale, recursive nature of this view is depicted in Figure 5. (This particular figure was derived from mRNA transcriptomic data, in this case from our work [33] on recombinant inbred *Mus musculus* microarray data.) The maximum clique size is 17. Vertices representing cliques of size 15 are shown in green, cliques of size 16 are shown in black, and cliques of size 17 are shown in red. This graph illustrates the multiple relevant applications of clique and other graph algorithms, and the “networks of networks” view of highly complex multivariate data.

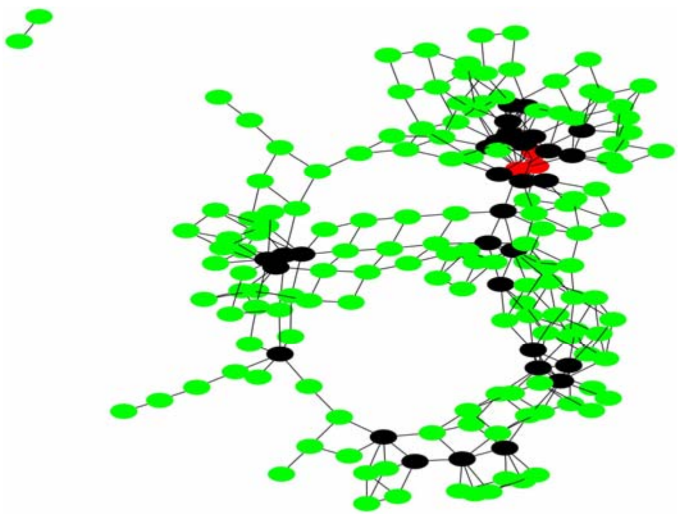

Figure 5: A clique intersection graph for a large data set.

4.2.9 Literature Cited

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5 Assessment of North Sea ecosystem state variables

5.1 Variations in the Atlantic inflow and other abiotic variables

5.1.1 NORWECOM

NORWECOM is a coupled physical-chemical-biological model of the whole North Sea. The coupled model system is based on a sophisticated three-dimensional physical model that is able to represent vertical exchanges realistically. The parameterization of the chemical biological interactions is based on information from available literature, and fine-tuning calibration has been avoided. The biological-chemical module simulates among others, primary production, nutrients, and diatom and flagellate concentrations. The NORWECOM model has been run with historical meteorological driving forces to simulate the circulation of the North Sea over the period 1955–2004. Monthly mean flux values for Qtr. 1over this period were presented by Skjoldal *et al.* (2005; REGNS 2005 working paper) relating to the North Sea boundaries shown in Figure 6. The results of the variations in seawater flux into the North Sea across three of these boundaries are presented in Figure 7.

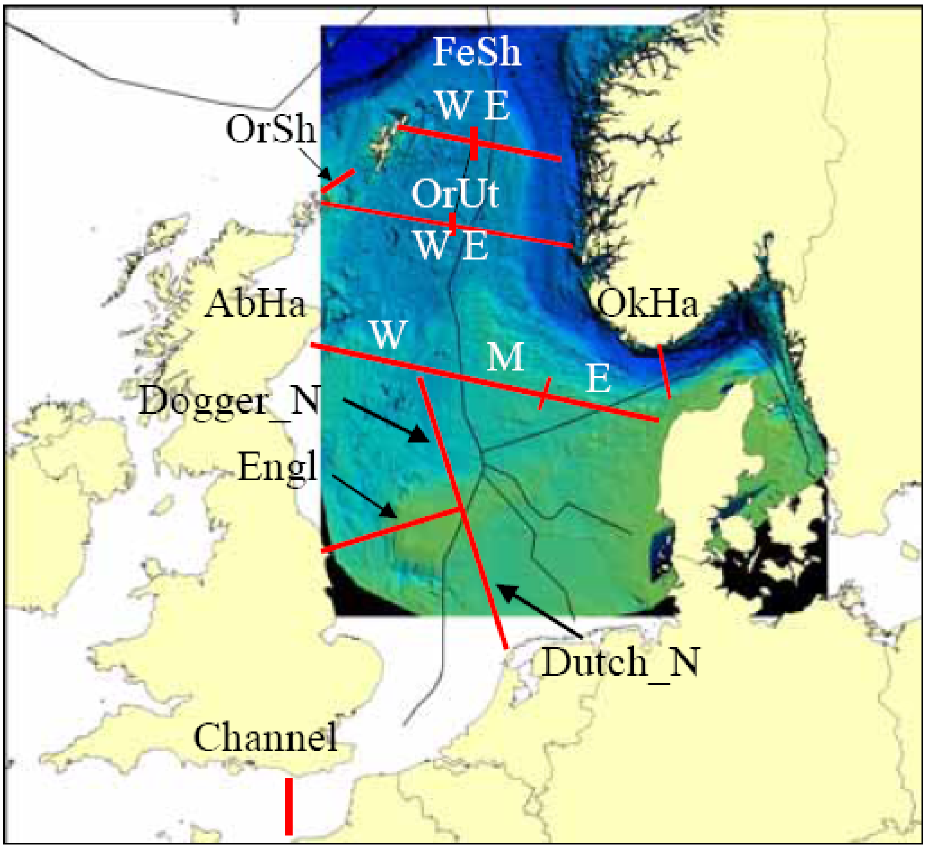

Figure 6: Cross sections for calculating the sea water flux into and out of the North Sea.

The data show that inflows into the northeastern North Sea increased sharply in 1988 with associated consequences for temperature, nutrients, plankton and fish (see following sections).

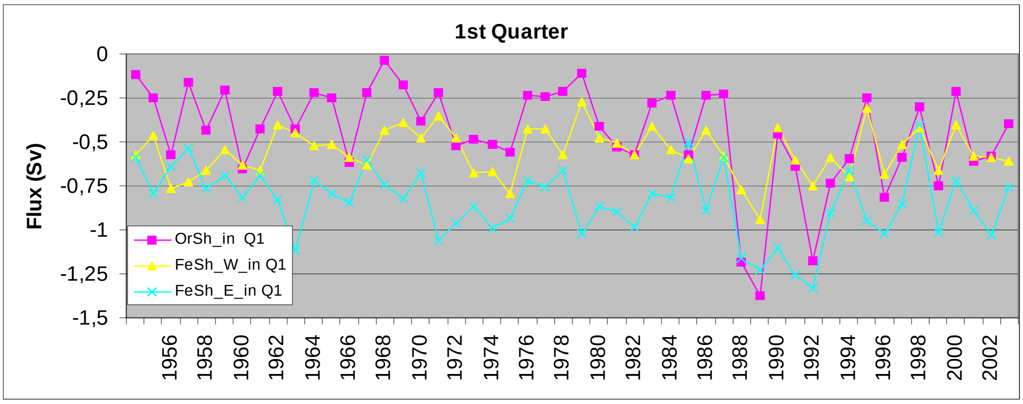

Figure 7: Sea water fluxes across different sections of the North Sea for the 1st quarter between 1955 and 2004.

The variation in seawater flux are closely related to changes in the winter north Atlantic atmospheric pressure gradients between Iceland and the Azores. The direction and extent of the gradient drives the NAO index which is associated with predictable changes in weather including marine climate conditions such as changes in seawater flux into the North Sea. Calculation of the NAO and fluxes of seawater into the North Sea are now the subject of quarterly reporting via a Joint ICES/EuroGOOS Planning Group known as the North Sea Pilot Project (PGNSP) which was established in 2001. The Pilot Project - NORSEPP - is focussing on the relationships between oceanography and fish stocks and is promoting the development of operational oceanography for biological applications such as in fish stock assessments. PGNSP (the Planning Group for NORSEPP) decided in 2005 to start producing quarterly update reports on the conditions of the North Sea, with emphasis on the physical conditions as drivers for biological variability. The quarterly reports for 2005 are available at the ICES web-page: http://www.ices.dk/marineworld/norsepp.asp

5.1.2 Other abiotic variables

Additional time-series abiotic data was spatially resolved for the entire North Sea at the scale of ICES statistical rectangle. This has been possible due to the extensive number of observations that have been made on a wide range of parameters over many years throughout the North Sea. The most complete time period and coverage for a range of parameters is from 1973 to 2004. In the first instance, and as reported in REGNS (2005), each parameter was averaged over the time period (1973–2004) before subjecting the resultant time averaged data set to hierarchical cluster analysis[1]. The data were first transformed and normalised to create a dissimilarity matrix using the Euclidean distance metric. The output of this analysis is presented in the form of a dendrogram shown in Figure 8 and is also spatially represented in Figure 9. What is apparent is that the spatial clusters are contiguous suggesting significant spatial trends which remain relatively constant through time. Clearly for some of the seabed variables such as sediment type, bathymetry and nearbed tidal currents this is to be expected. Table 4 presents average values for each parameter for the identified spatial clusters.

1 It is important to understand the limitations of such an approach, first the raw observational data from each statistical square has been averaged to provide annual means. No account has been taken of the seasonal timing or weighting of the number of observations in each square. Such considerations were considered too time consuming to address and it was agreed that the initial assessment would simply present mean values for different spatial and temporal scales to highlight possible trends worthy of further investigation.

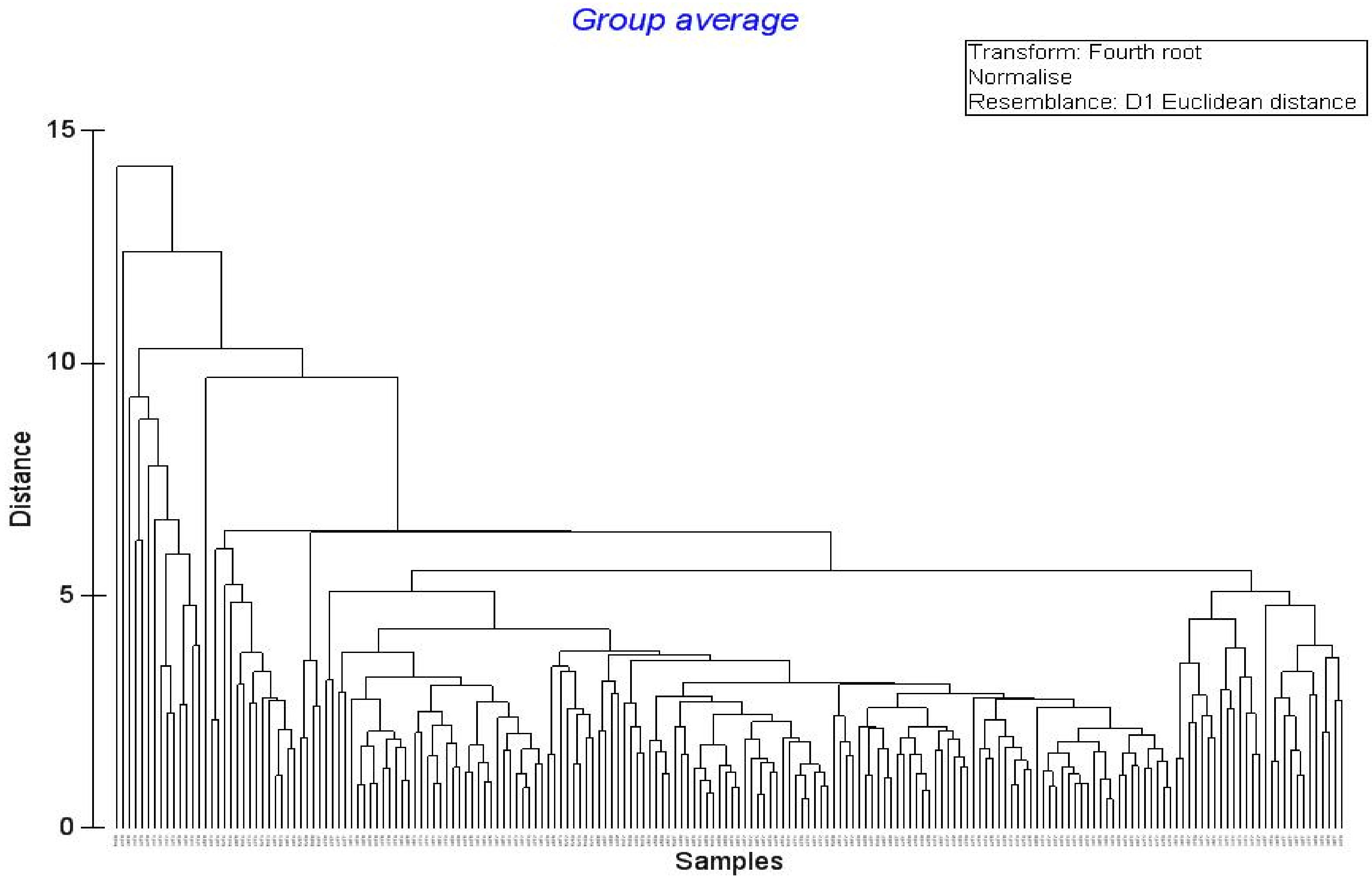

Figure 8: Group-average linkage cluster analysis on fourth root transformed and normalised abiotic data showing 5 principal clusters at about the 5% level. The large central cluster (1) was further sub-divided into 3 clusters at about the 3 % similarity level. The clusters are shown spatially in Figure 9.

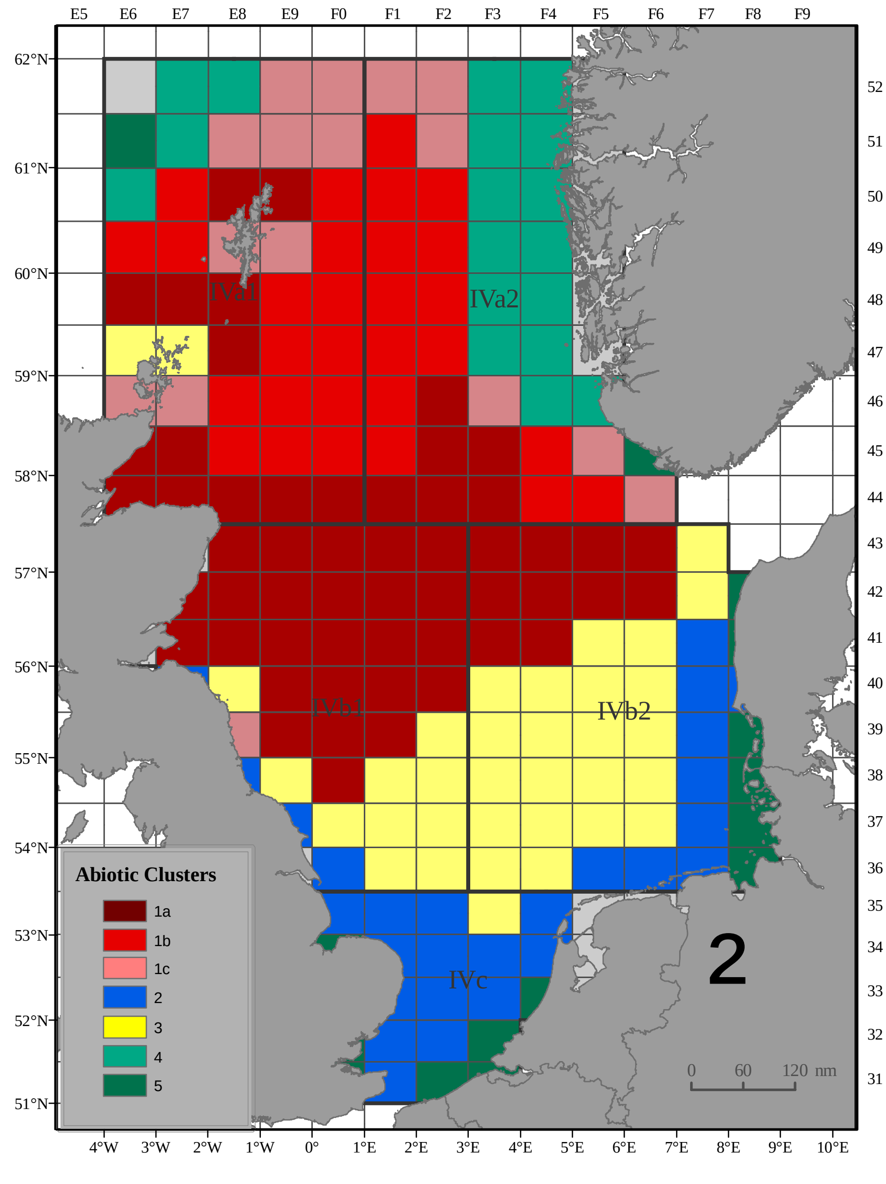

Figure 9: Map showing the spatial distribution of clusters based upon cluster analysis output in Figure 8. Note the contiguous nature of the clusters and the clear separation between Clusters 5, 2 and 3 in the South from Cluster 1a, b & c in the North.

Table 4: Average values for the determinands analysed according to each cluster.

	Clusters (average values)						
Parameter	**5**	**2**	**3**	**1c**	**4**	**1a**	**1b**
Bottom-dissolved-oxygen-conc	298.63	281.19	276.89	271.94	277.89	277.73	279.03
Bottom-Nitrate-conc	24.41	10.07	3.36	9.72	11.46	5.94	9.65
Bottom-Nitrite-conc	0.71	0.47	0.30	0.11	0.08	0.16	0.11
Bottom-phosphate-conc	1.20	0.60	0.42	0.72	0.80	0.58	0.71
Bottom-Salinity	32.18	33.89	34.60	35.14	35.11	34.91	35.21
Bottom-silicate-conc	11.23	4.68	3.07	4.52	6.21	3.45	4.36
Bottom-Temperature	8.85	9.87	8.94	8.23	6.85	7.74	7.69
Surface-Chlorophyll-conc	5.34	3.15	1.70	0.87	0.75	0.75	0.67
Surface-dissolved-oxygen-conc	103.22	83.64	85.35	71.58	76.81	57.16	53.89
Surface-Nitrate-conc	34.86	12.18	3.19	6.66	5.65	4.51	6.26
Surface-Nitrite-conc	1.00	0.59	0.27	0.11	0.12	0.10	0.09
Surface-phosphate-conc	1.91	0.62	0.36	0.53	0.45	0.43	0.49
Surface-Salinity	30.12	33.40	34.46	34.49	33.58	34.74	34.86
Surface-Temperature	10.15	10.35	10.24	9.87	9.41	9.96	9.93
Bathymetry	12.81	30.63	45.22	179.93	413.78	65.89	109.69
Wave Stress	0.09	0.05	0.03	0.01	0.01	0.01	0.00
Tidal Stress	0.54	0.77	0.19	0.18	0.02	0.14	0.06
Mud/Silt (<63u)	7.41	5.67	6.85	10.49	45.61	5.59	19.13

It is clear from Table 4 and Figure 8 that Clusters 5 and 2 are dominated by relatively high concentrations of surface Chlorophyll and DIN, and that this region also has relatively high annual mean surface water temperatures compared to Clusters 4, 1a and 1b. Also of significance is the relatively shallow depth in this region as indicated by the low bathymetry values for Clusters 5 and 2 and the associated high tidal and wave bed stress values. The relatively high levels of nitrate is perhaps to be expected as the major riverine pressures acting in the North Sea (which are a significant source of nutrients) enter in this region and are therefore most likely to influence phytoplankton production as evidenced by the high mean values of Chlorophyll for these coastal regions. Figures 10 to 14 present maps of total surface dissolved inorganic nitrogen, Chlorophyll, bottom temperature, sediment grain size <63 microns and tidal stress. The variation in these variables corresponds largely with the variation shown for the abiotic clusters based upon all the data shown in Figure 8.

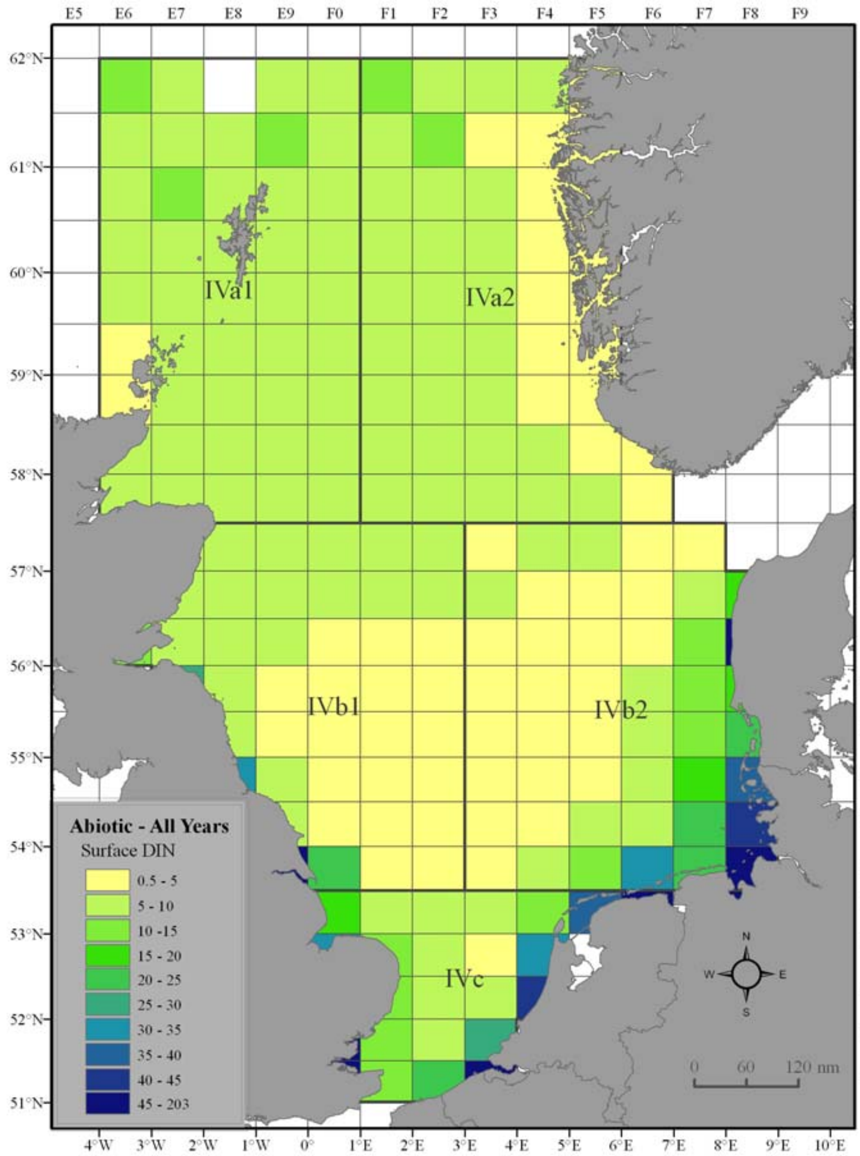

Figure 10: Spatial variation in dissolved inorganic nitrogen taken as an average value over the period 1973 to 2004 and presented as a single map.

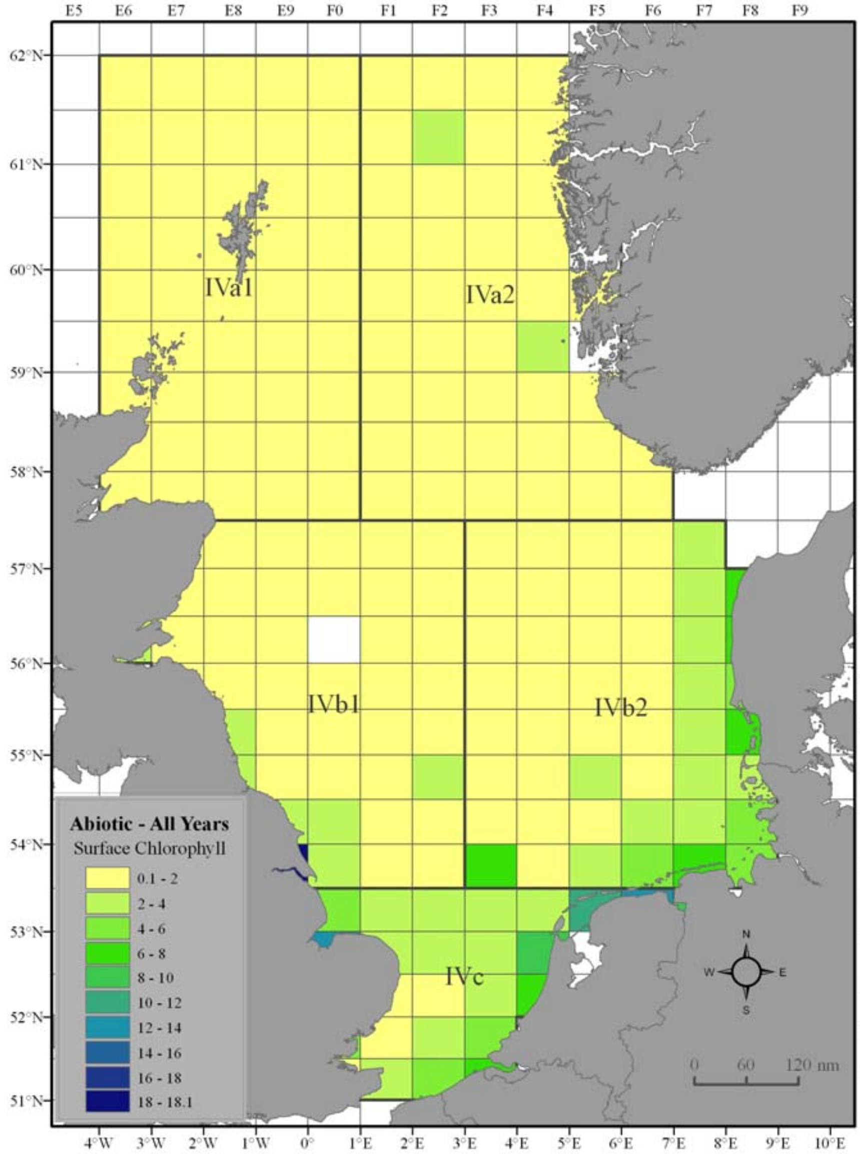

Figure 11: Spatial variation in surface Chlorophyll taken as an average value over the period 1973 to 2004 for each statistical square and presented as a single map.

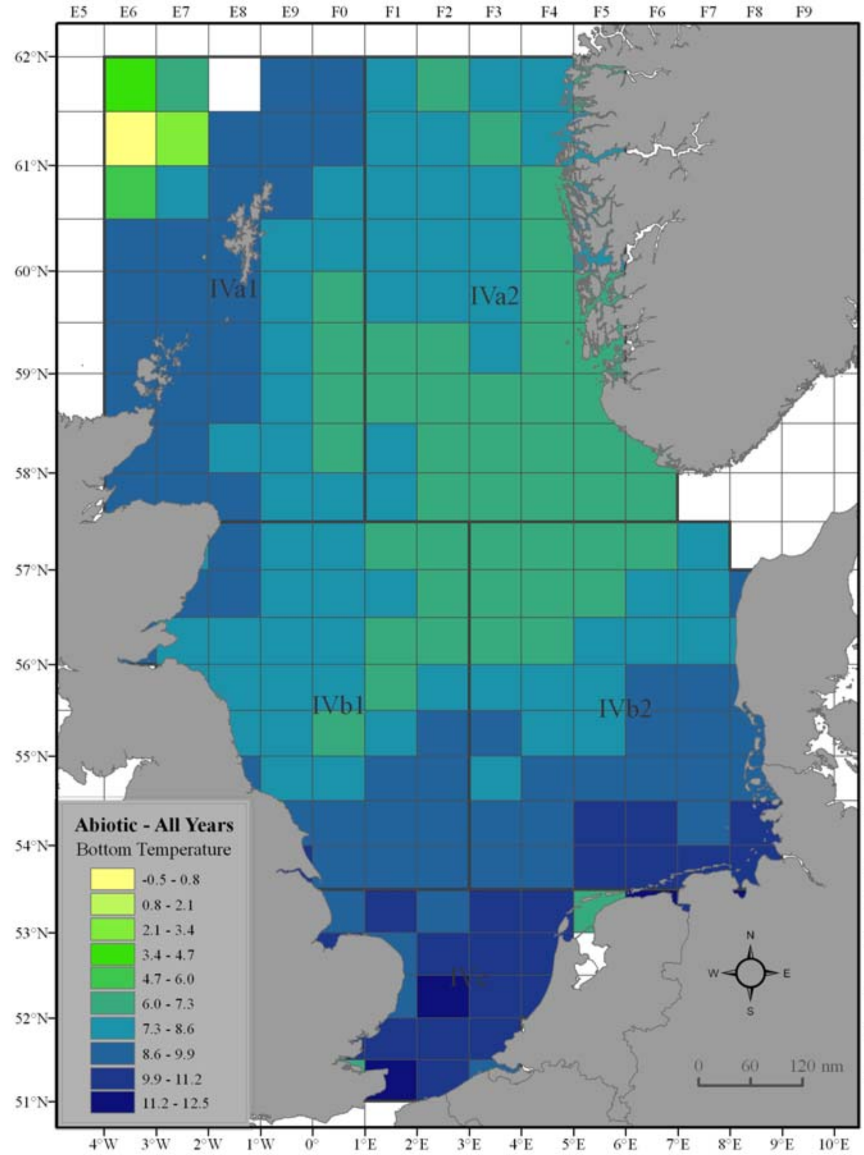

Figure 12: Spatial variation in bottom temperature (degrees Celsius) taken as an average value over the period 1973 to 2004 for each statistical square and presented as a single map.

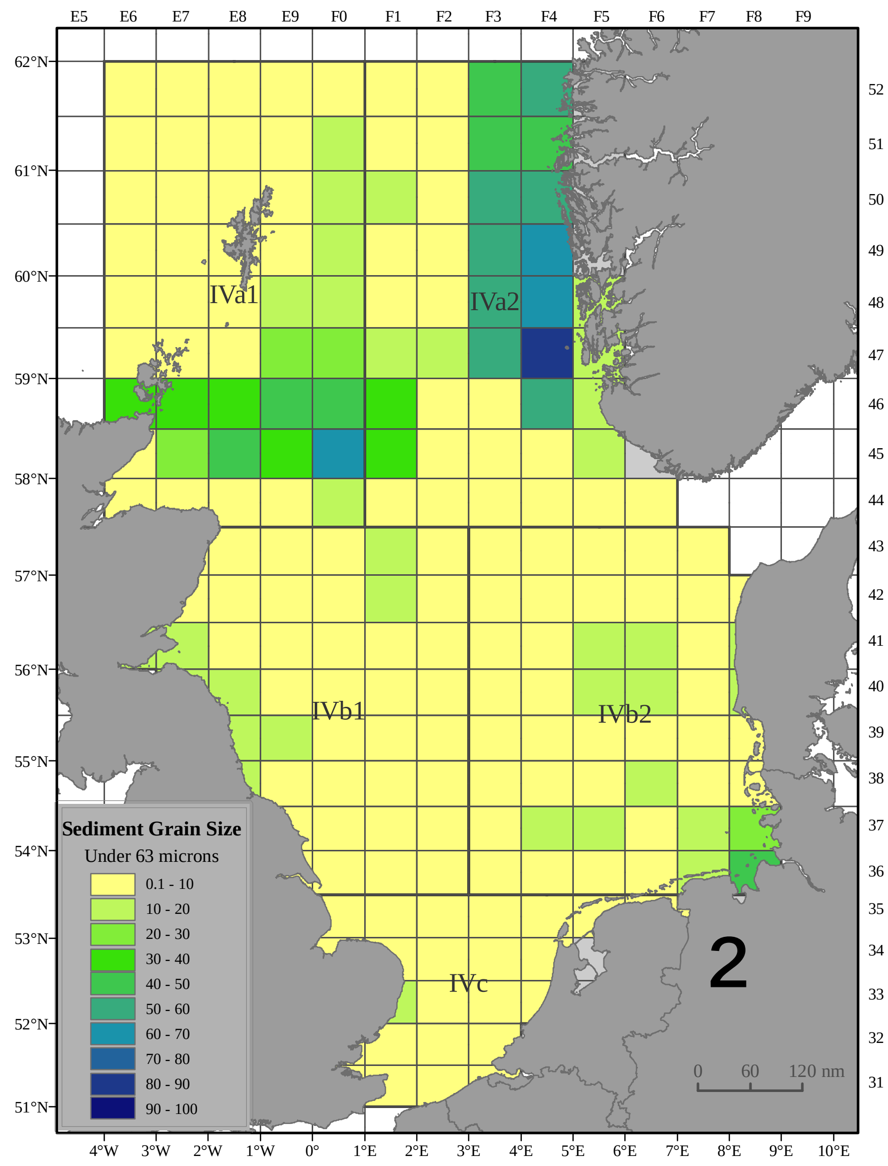

Figure 13: Spatial variation in sediment grain size as a percentage of particles < 63 microns in diameter. The muddiest sediment is therefore represented by a darker shade.

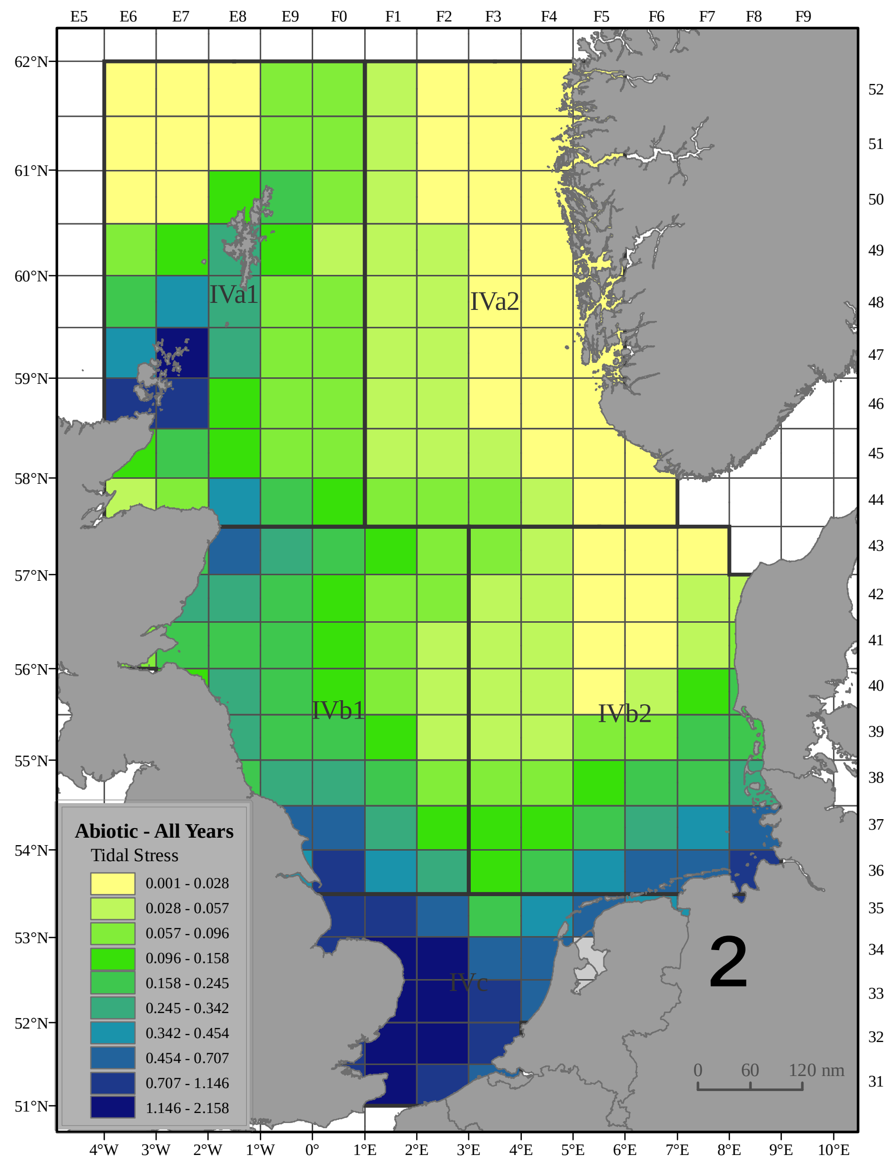

Figure 14: Spatial variation in nearbed tidal stress in NM^2.

To investigate trends over time annual averages for the entire North Sea were calculated for each year before subjecting the data to PCA (Figure 15).

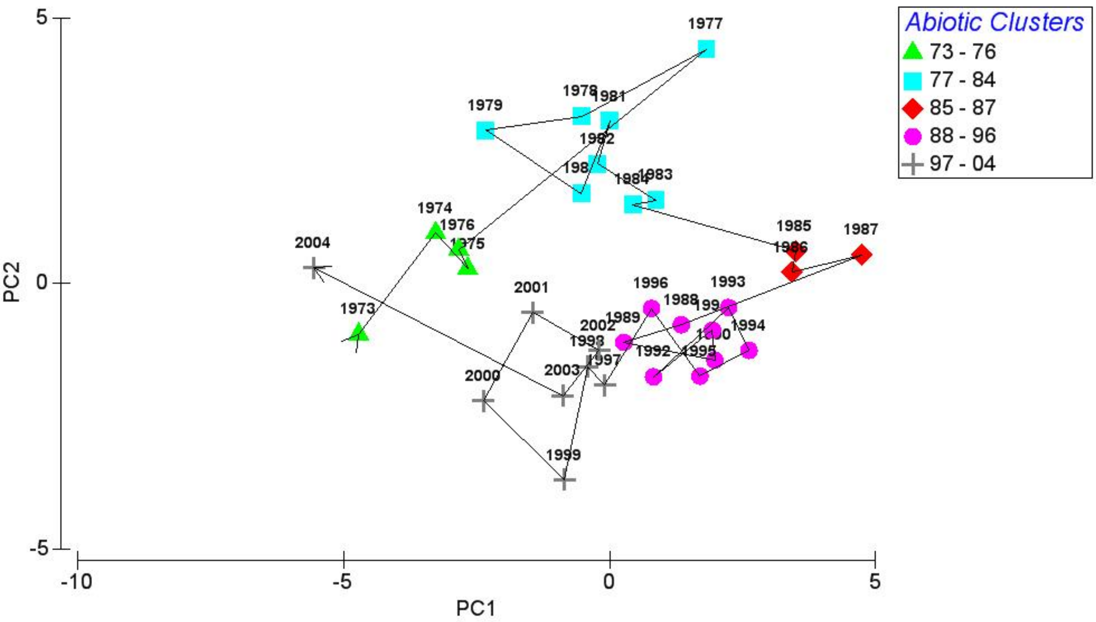

Figure 15: PCA ordination of sample years (normalised) for the entire North Sea. PC1 accounts for 30% of the total variation and is dominated by surface nitrite (+ve) and surface salinity (-ve). PC2 accounts for 23% of the total variation and is dominated by bottom phosphate (+ve) and bottom/surface temperature (-ve).

PCA1 accounts for about 30% of the total abiotic variation and is characterised by low surface/bottom salinities and high surface nitrite concentrations. By contrast PCA2 is characterised by low bottom and surface temperatures and high bottom phosphate concentrations and accounts for an additional 23% of the abiotic variation. Trends over time for these principal variates are shown in Figures 16–19 and these show discontinuities in the time series which largely correspond to the clusters of years shown in the PCA (Figure 15). It should be noted that the surface salinity value for 2004 are biased owing to missing data off the UK coast in the vicinity of the major east coast rivers – see Figure 20.

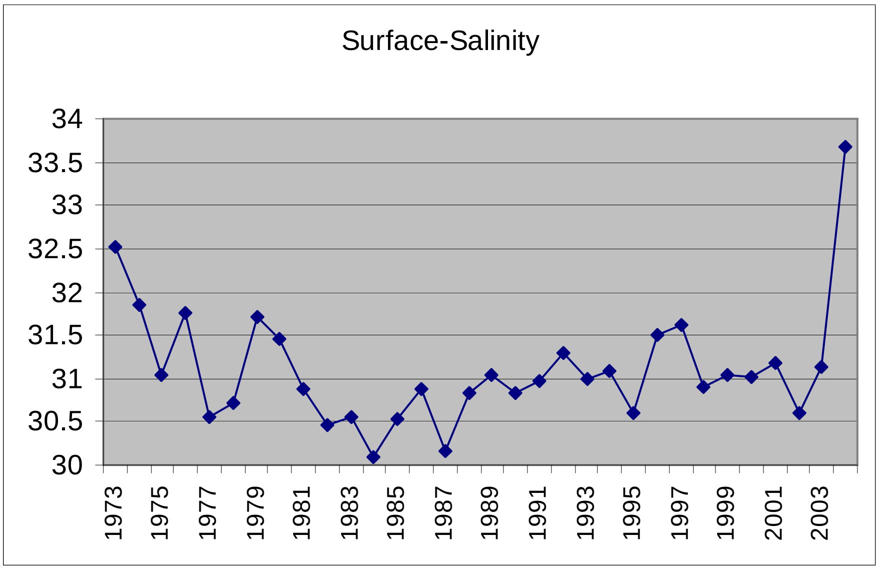

Figure 16: Annual mean values of surface salinity for the North Sea between 1973 and 2004. Note 2004 data are biased due to missing data from around the UK major east coast rivers in 2004 (see Figure 20) this value should therefore be ignored.

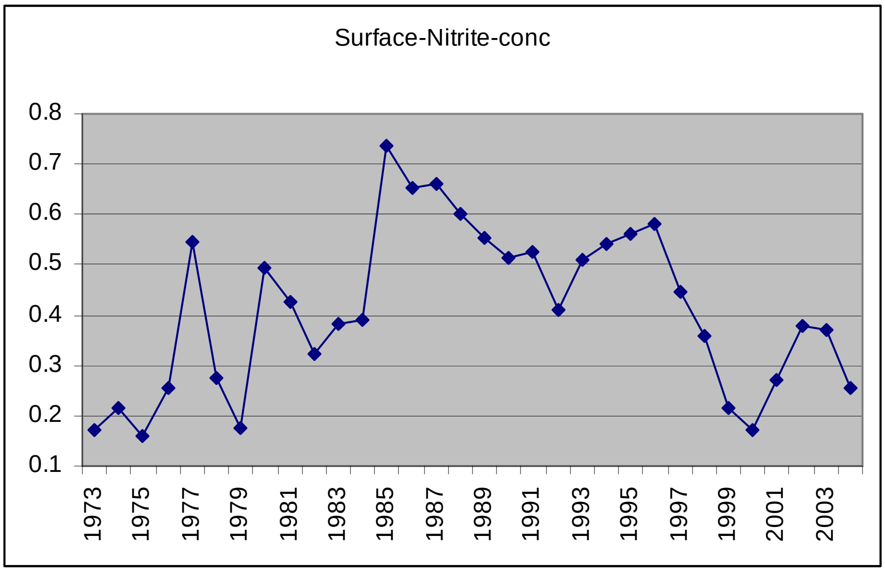

Figure 17: Annual mean values of surface nitrite for the North Sea between 1973 and 2004.

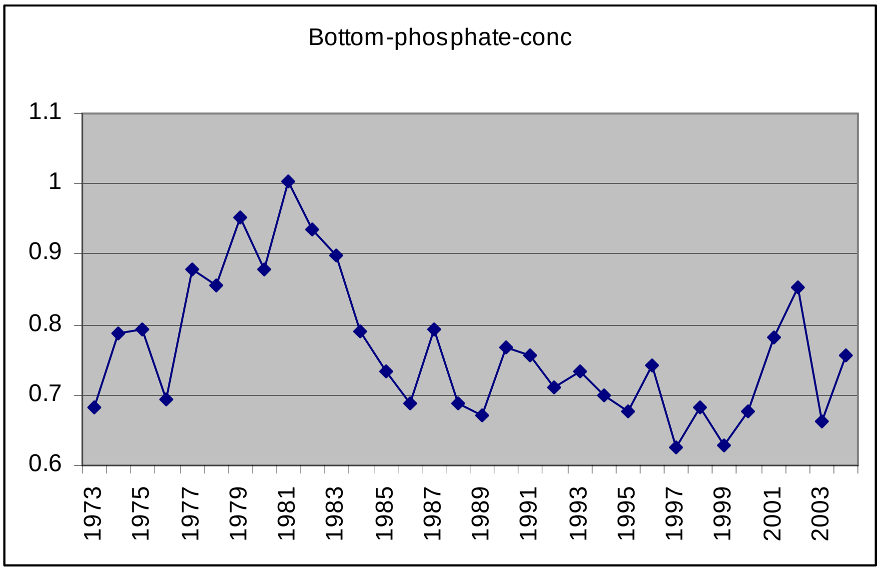

Figure 18: Annual mean values of bottom phosphate for the North Sea between 1973 and 2004.

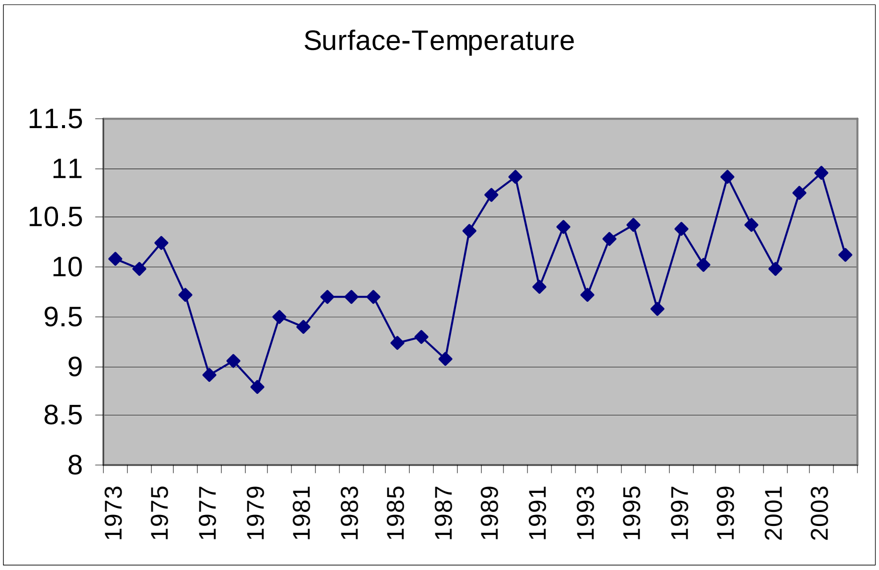

Figure 19: Annual mean values of surface temperature for the North Sea between 1973 and 2004.

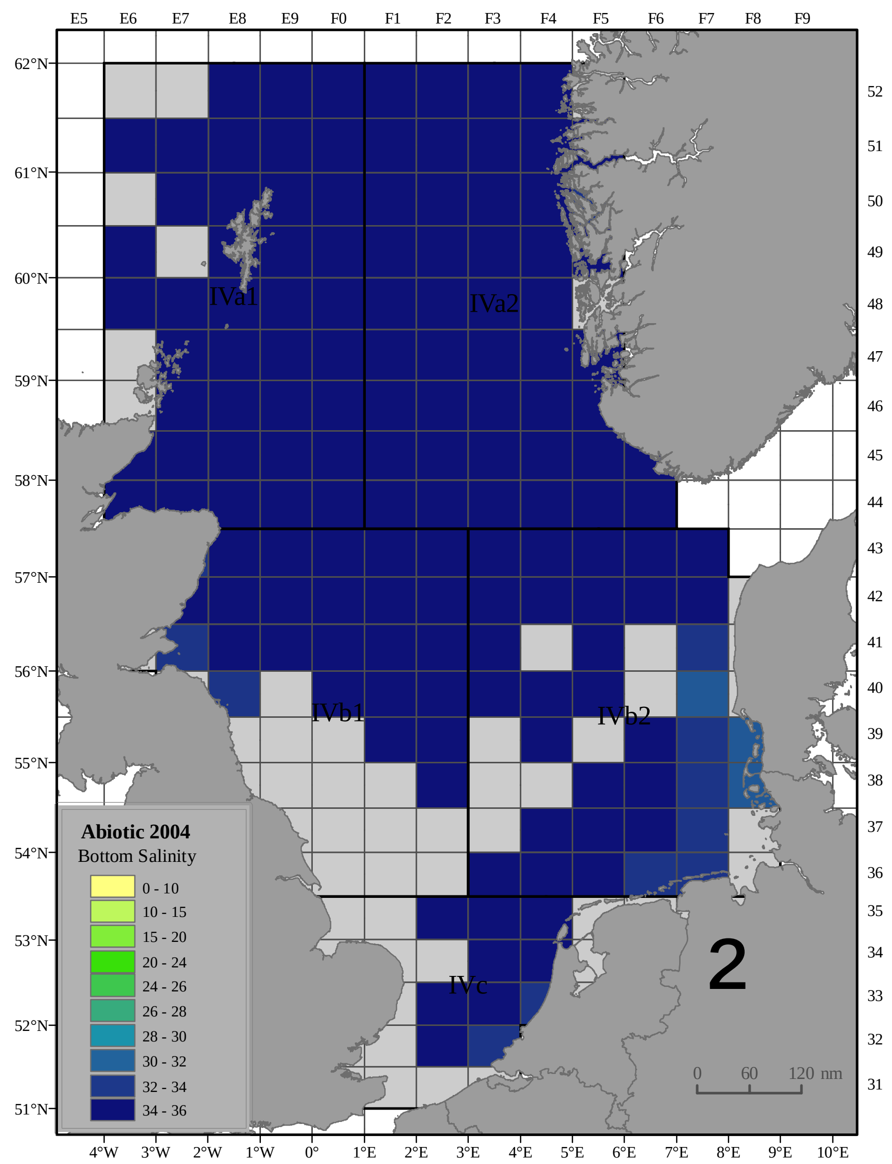

Figure 20: Spatial variation in annual mean salinities for 2004 in the North Sea showing the gaps in data associated with the UK east coast.

Data for the principal variates were then averaged according the identified time intervals from the PCA in Figure 15, namely; time period **i**. (1973–1976), time period **ii**. (1977–1984), time period **iii**. (1985–1987), time period **iv**. (1988–1995) and time period **v**. (1996–2003). The spatial variations in bottom salinity, bottom temperature and surface dissolved inorganic nitrogen for the different time periods can then be assessed as presented in Figures 21 to 31. From this it is apparent that clear trends are associated with changes in temperature and total DIN. For example, there has been a general warming of the North Sea since 1979, as evidenced in the surface and bottom water temperatures of the northern North Sea in area IVa2 shown in Figure 32. By contrast there is no clear rising trend in region IVc (southern North Sea), although specific large inter-annual variations in temperature can be observed, such as the increase in temperature in 1988 (Figure 33) which are also discernable in other regions (e.g. IVa2, Figure 32). A possible explanation for the lack of a rising trend for area IVc is the large spatial variation in the data for this region which shows rising and declining trends depending on your specific location (Joyce, 2006). This may be as a result of relatively large fresh water inputs into the region giving rise to localised temperature extremes; clearly further analysis of the raw data is required to examine this assertion and cause of variability.

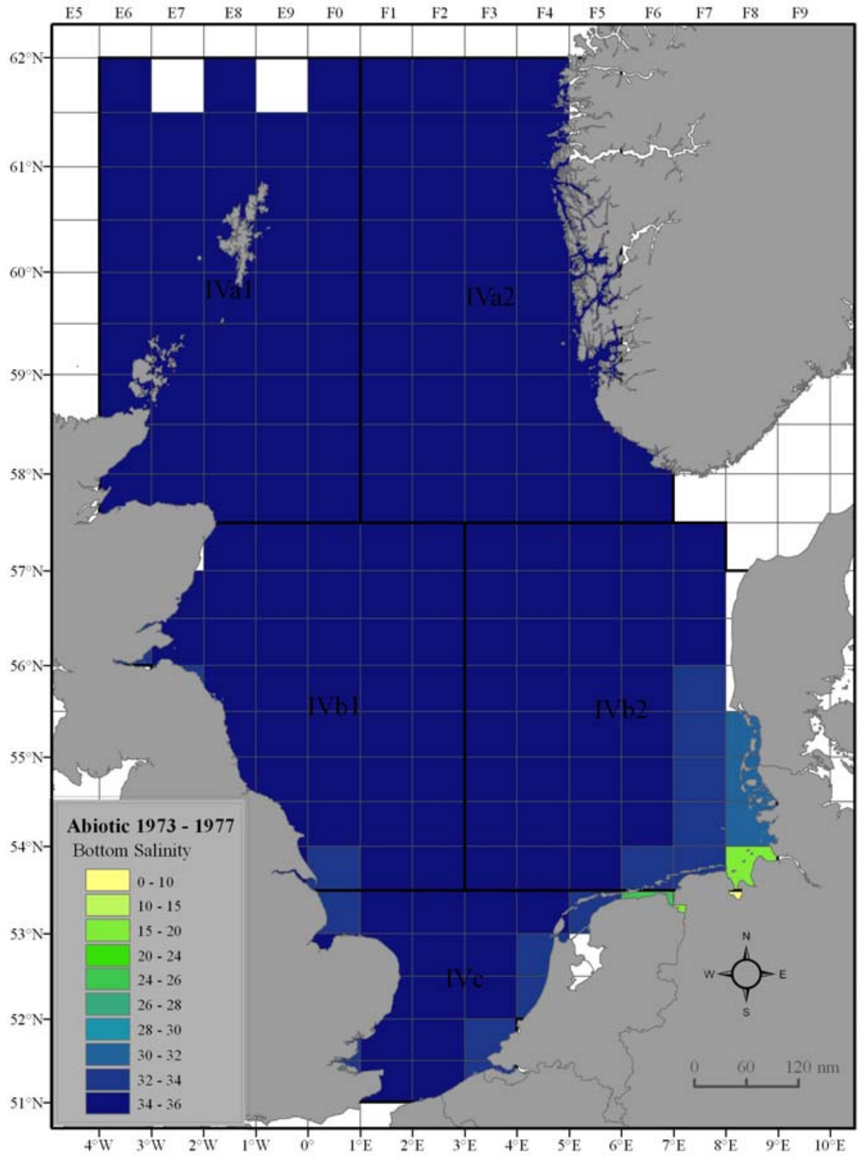

Figure 21: Average bottom salinity between the period 1973 and 1976 (not 1977) for the North Sea.

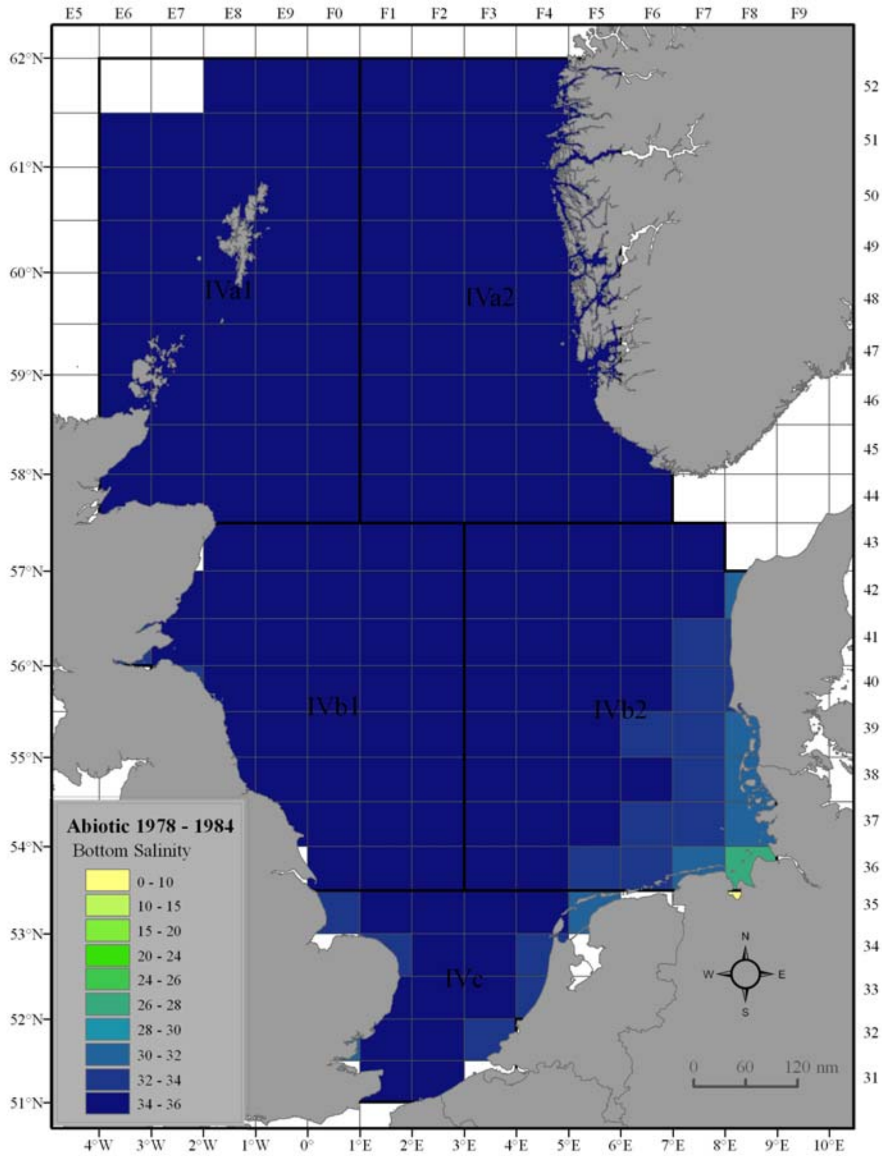

Figure 22: Average bottom salinity between the period 1976 and 1984 (not 1978) for the North Sea.

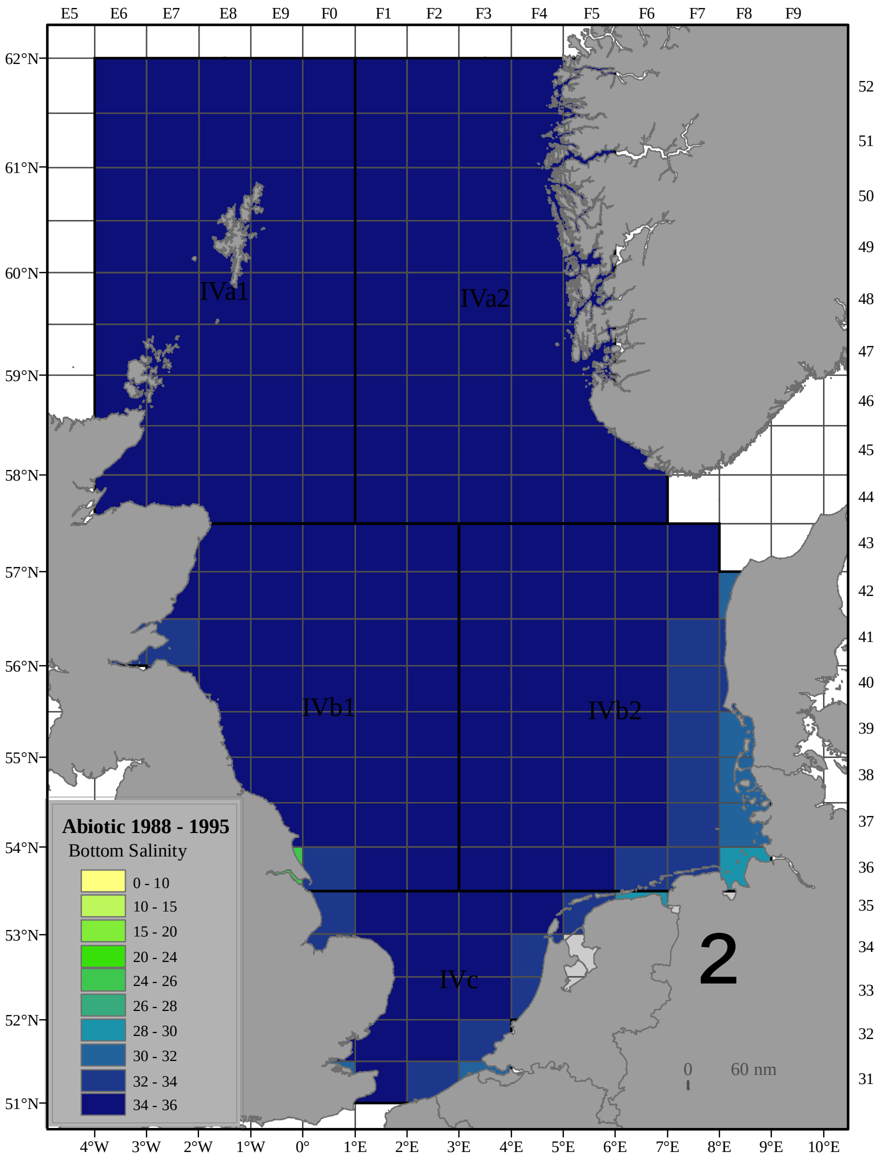

Figure 23 Average bottom salinity between the period 1988 and 1995 for the North Sea.

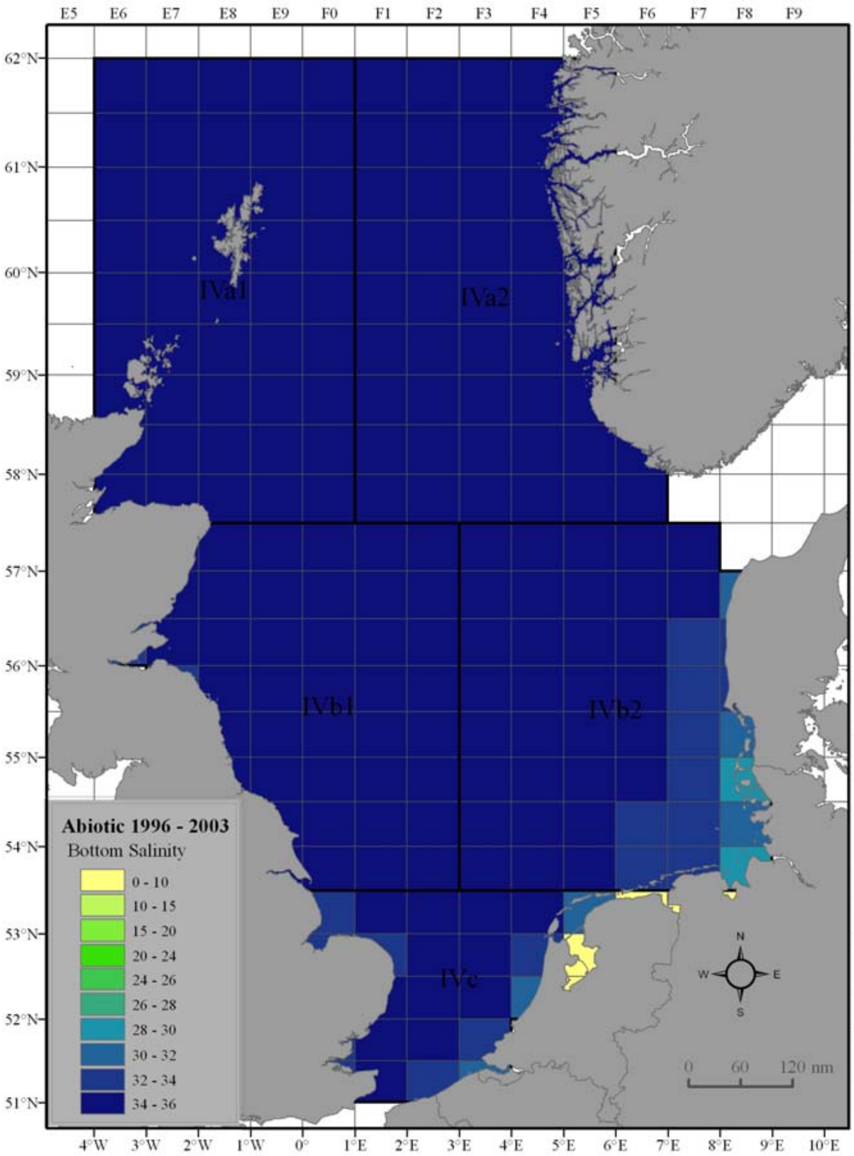

Figure 24: Average bottom salinity between the period 1996 and 2003 for the North Sea.

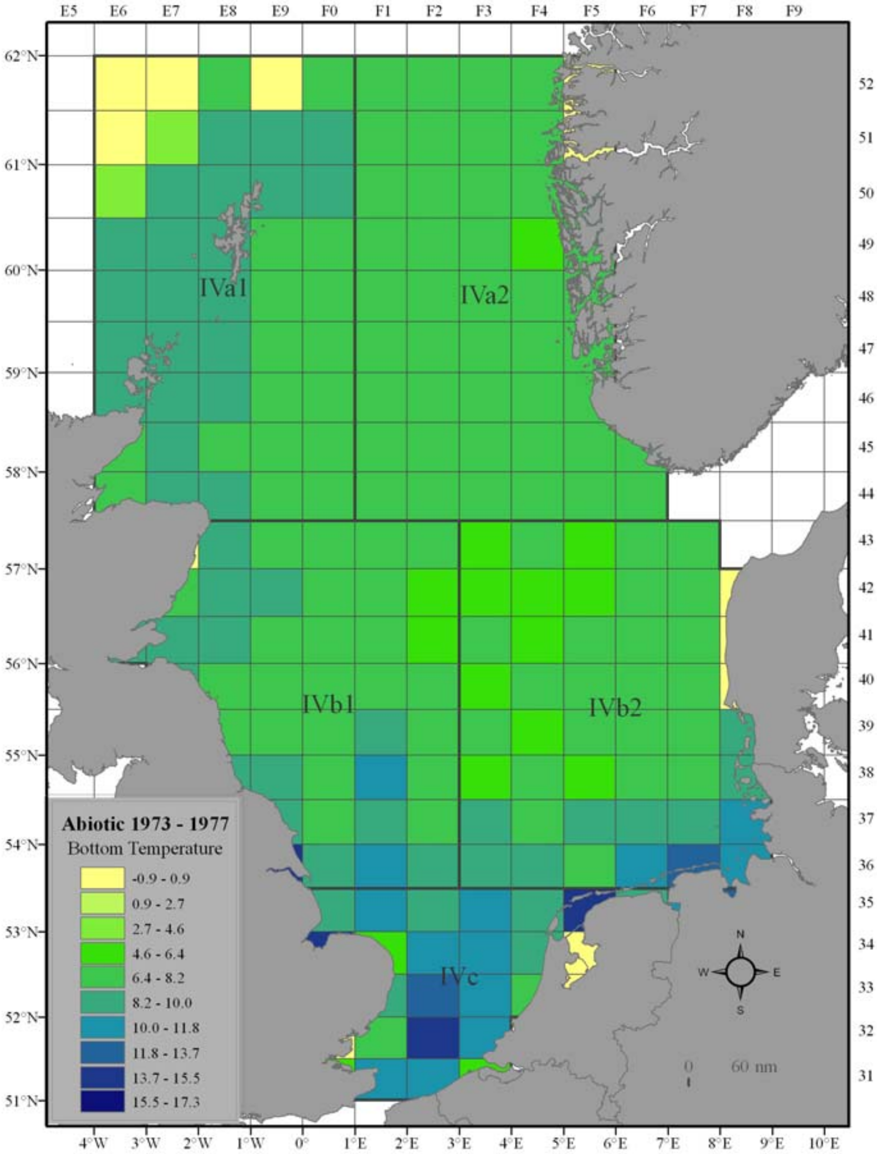

Figure 25: Average bottom temperature between 1973 and 1976 (not 1977) for the North Sea. Some coastal temperatures appear to be anomalous, notably off Denmark, Thames Estuary and Netherlands.

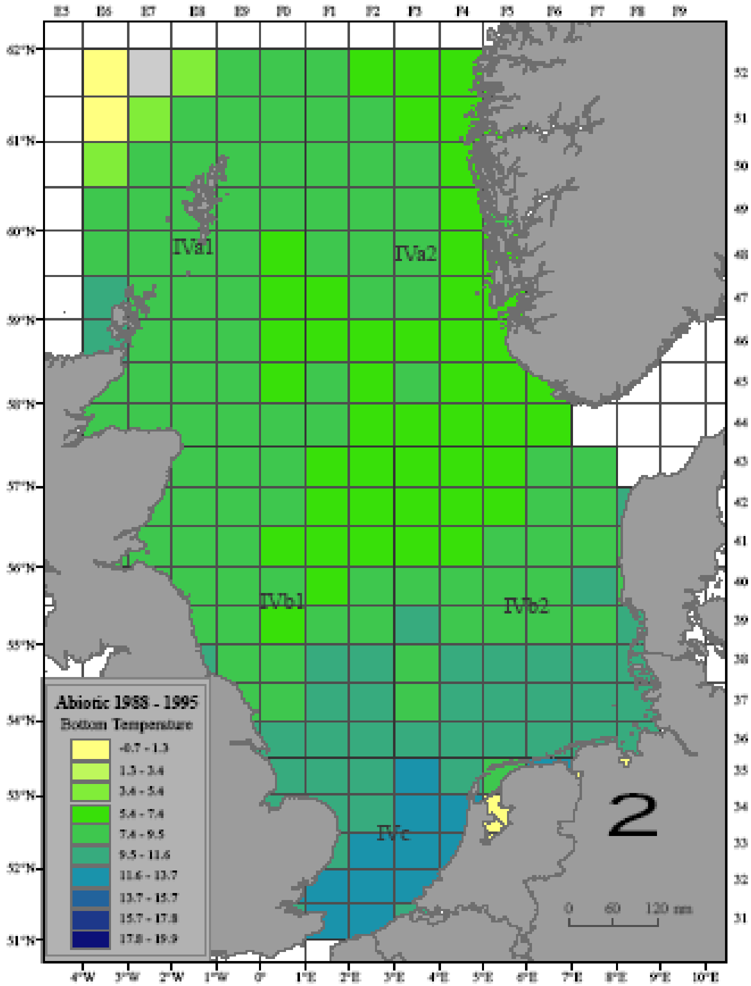

Figure 26: Average bottom temperature between 1988 and 1995 for the North Sea. Some coastal temperatures appear to be anomalous, notably off the Netherlands.

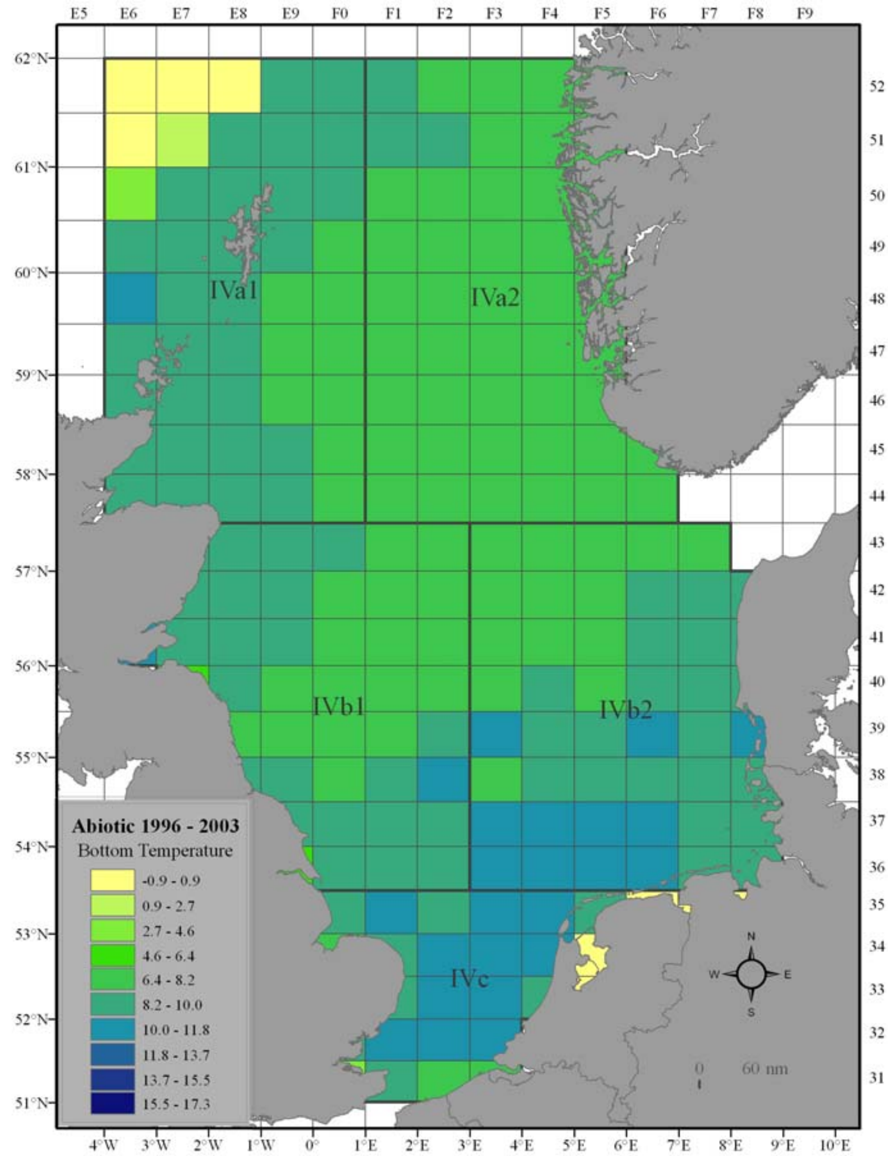

Figure 27: Average bottom temperature between 1996 and 2003 for the North Sea. Some coastal temperatures appear to be anomalous, notably off the Netherlands.

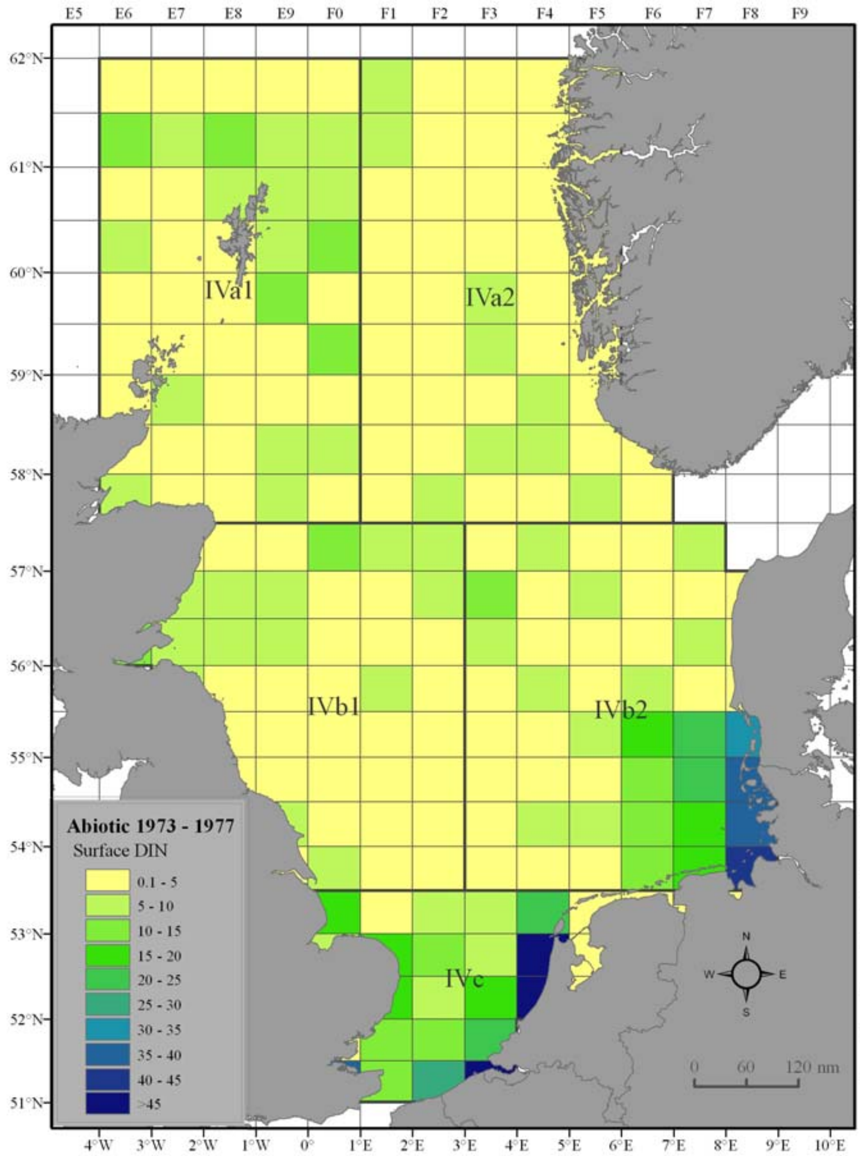

Figure 28: Average surface concentration of total dissolved inorganic nitrogen between 1973 and 1976 (not 1977).

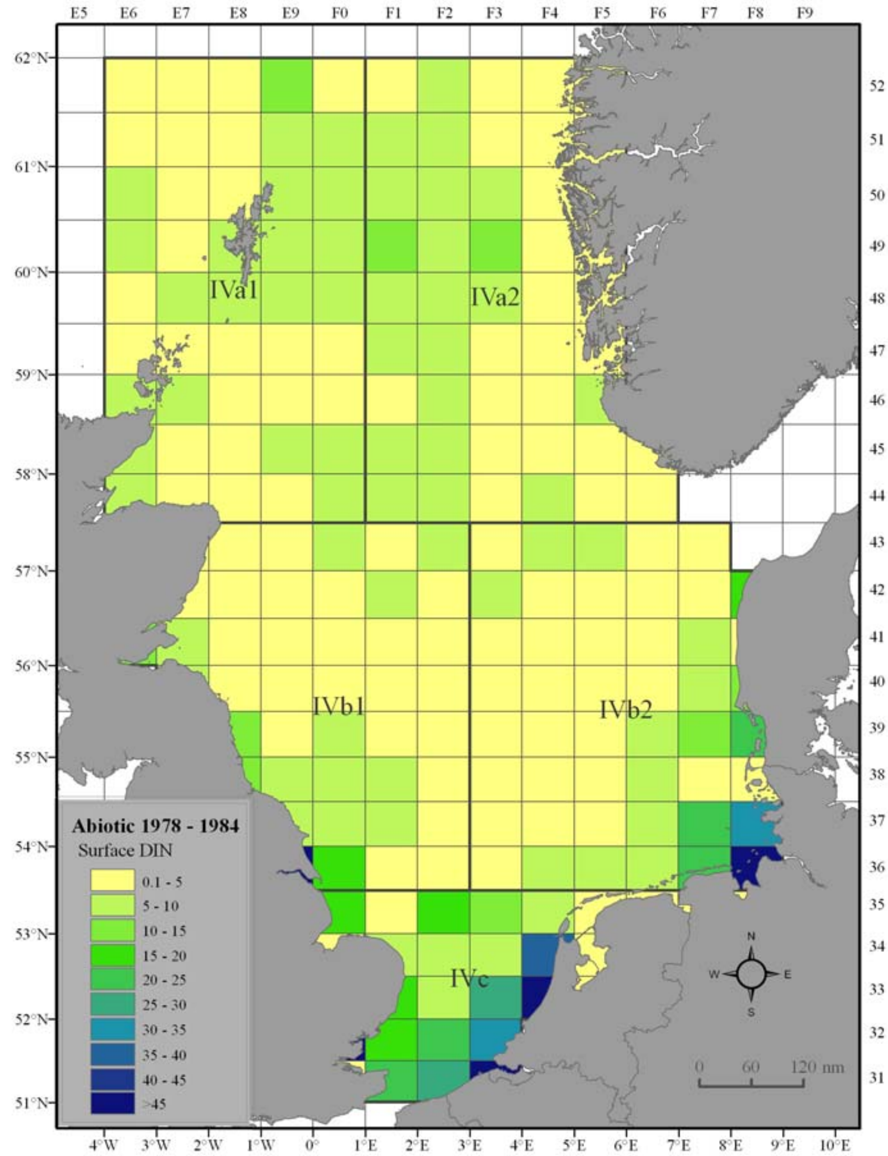

Figure 29: Average surface concentration of total dissolved inorganic nitrogen between 1977 and 1984 (not 1978).

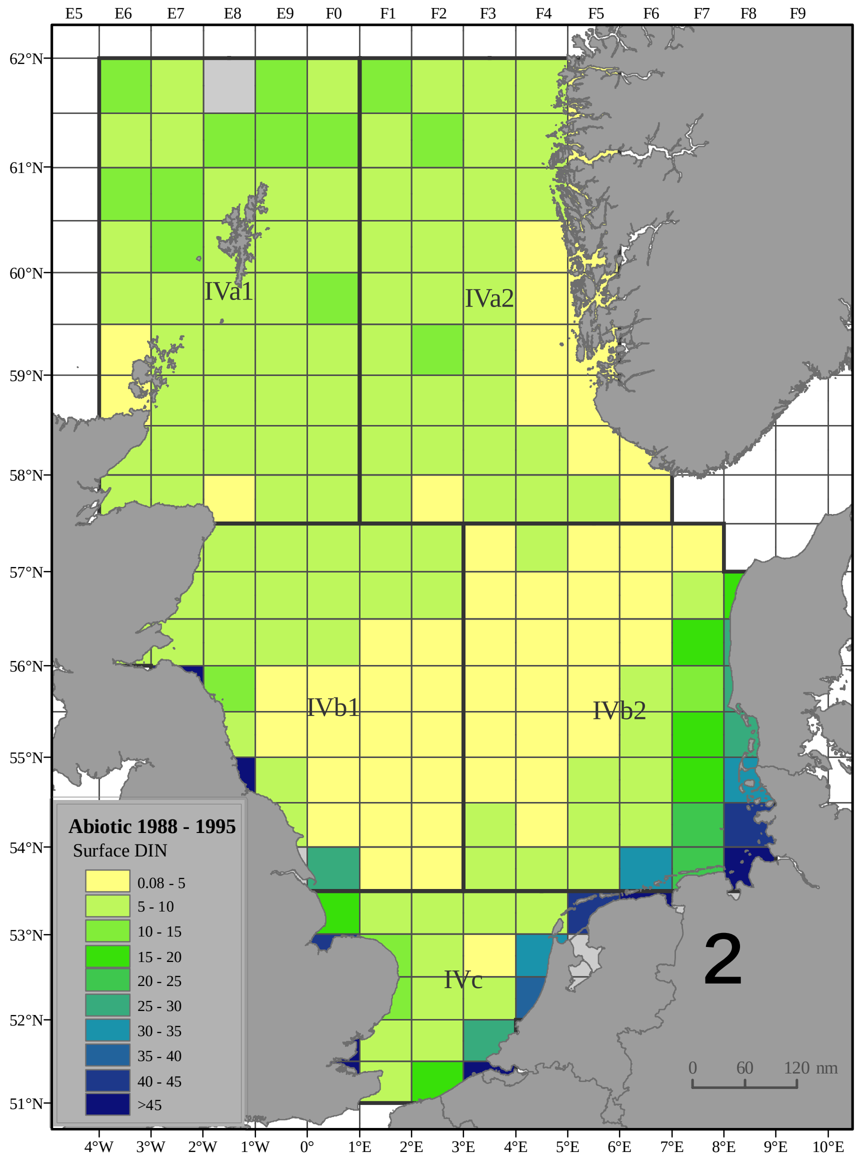

Figure 30: Average surface concentration of total dissolved inorganic nitrogen between 1988 and 1995.

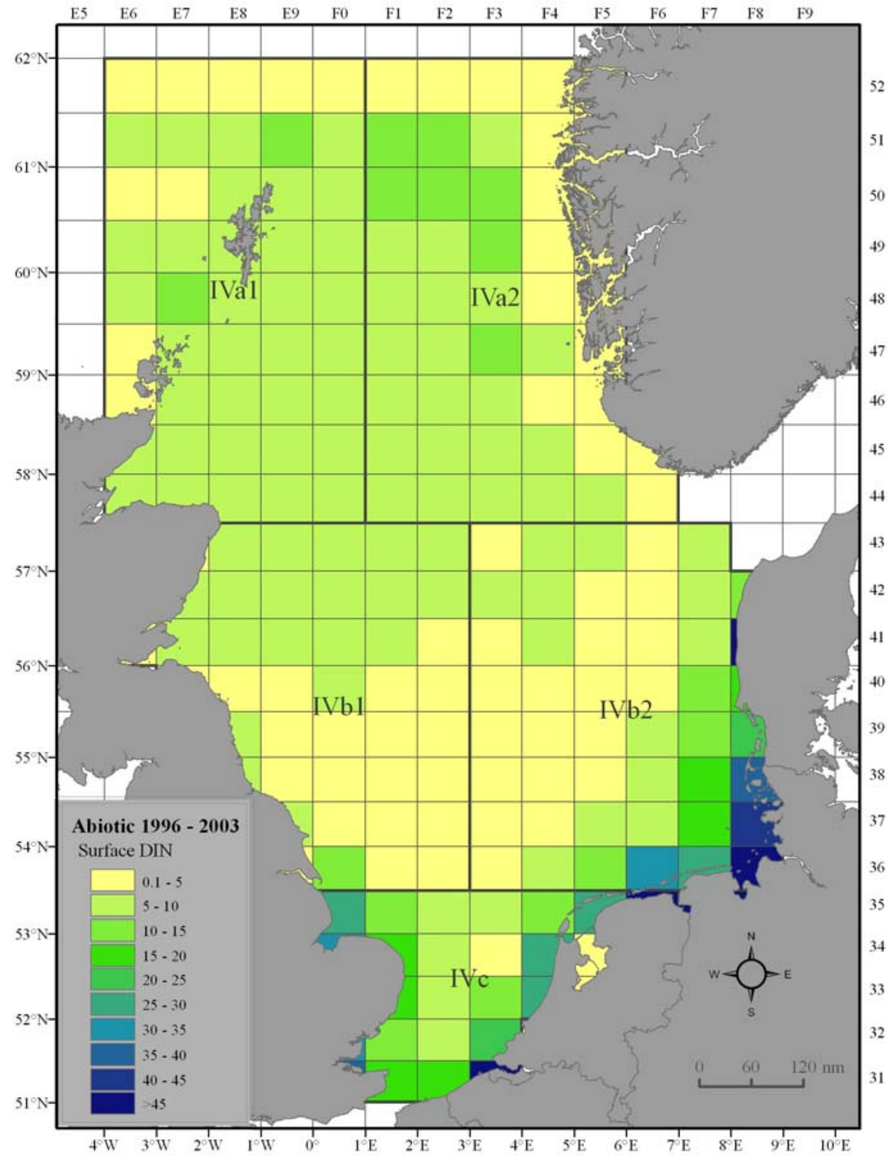

Figure 31: Average surface concentration of total dissolved inorganic nitrogen between 1996 and 2003.

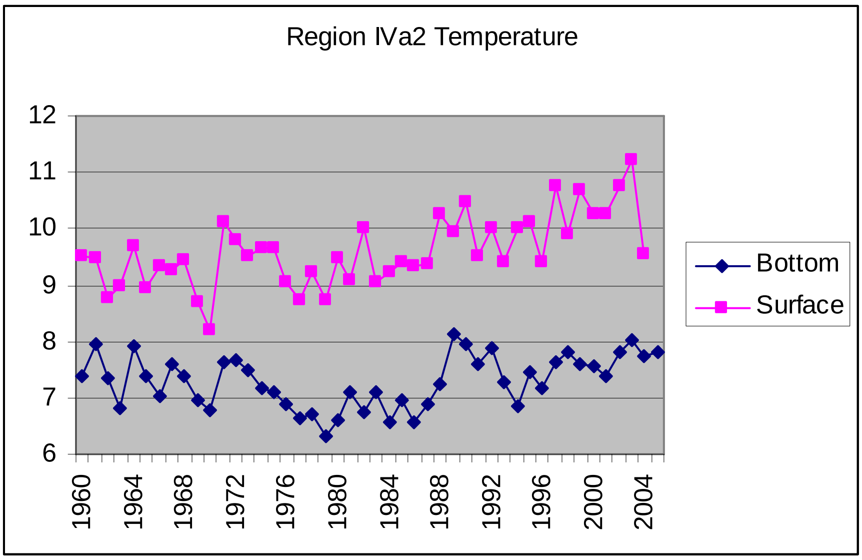

Figure 32: Average bottom temperature for region IVa2 since 1960 showing inter-annual variations in the order of 1.5 degrees Celsius.

Considering now the trends in DIN for the North Sea there are some similarities with those described for temperature (Figures 33 and 34). For example, a rising trend can be observed for surface nitrate in region IVa2 (Figure 33) but this is not so apparent in region IVc (Figure 34). The large difference in nitrate concentration between the regions is noteworthy since the scale of the observed rising trend in the north is relatively small compared to as the high nutrient concentrations observed in the south.

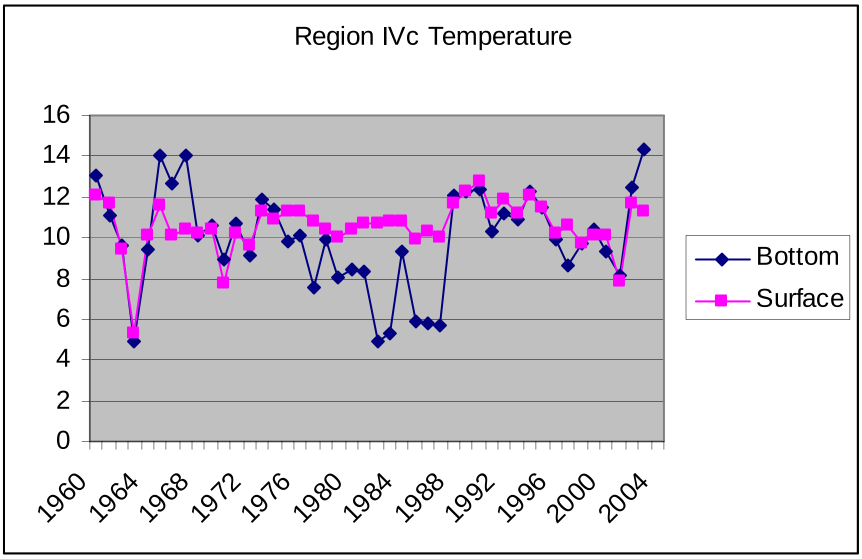

Figure 33: Average bottom temperature for region IVc since 1960 showing inter-annual variations in the order of 8 degrees Celsius.

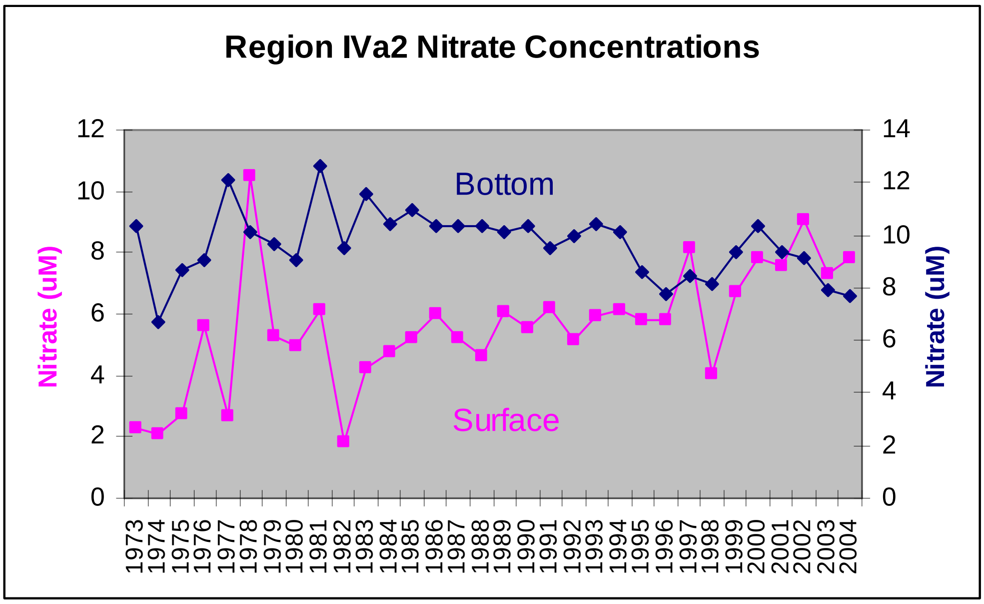

Figure 34: Annual average values for all observations in ICES Region IVa2 of surface and bottom nitrate concentrations between 1973 and 2004.

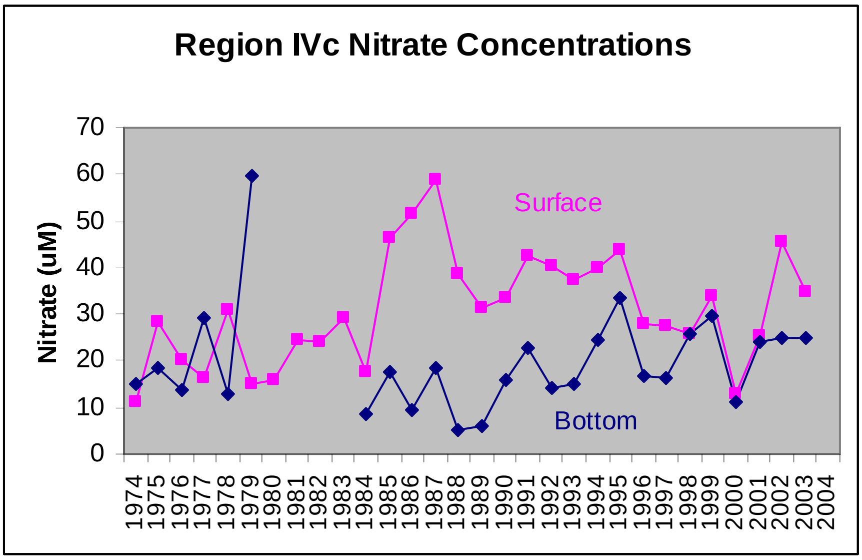

Figure 35: Annual average values for all observations in ICES Region IVc of surface and bottom nitrate concentrations between 1974 and 2003.

5.2 Plankton

5.2.1 Selection of data

Data from the CPR survey for the North Sea was kindly supplied by SAHFOS covering the period from 1948 to 2004 and was gridded using the ICES Statistical Rectangles for the North Sea. Key plankton taxa were selected on the basis of their ecological relevance and sensitivity to changes in environmental state. The selection was undertaken in consultation with staff in SAHFOS. Table5 (below) highlights the zooplankton and phytoplankton species selected for analysis from the total list of species in the REGNS assessment database.

Table 5.

ZOOPLANKTON Species name	PHYTOPLANKTON Species name
Acartia spp.	*Actinoptychus spp.*
Anomalocera patersoni	*Asterionellopsis glacialis*
Branchiostoma lanceolatum	*Bacillaria paxillifera*
Calanus copepodites I-IV	*Bacteriastrum spp.*
Calanus finmarchicus	*Bellerochea malleus*
Calanus helgolandicus	*Biddulphia alternans*
Calanus hyperboreus	*Cerataulina pelagica*
Calanus total traverse	*Ceratium bucephalum*
Caligoida	*Ceratium furca*
Candacia armata	*Ceratium fusus*
Caprellidea	*Ceratium horridum*
Centropages hamatus	*Ceratium lineatum*
Centropages typicus	*Ceratium longipes*
Chaetognatha eyecount	*Ceratium macroceros*
Chaetognatha traverse	*Ceratium minutum*
Cirripede larvae	*Ceratium tripos*
Clione limacina	*Chaetoceros [Hyalochaete] spp.*
Copepod nauplii	*Chaetoceros [Phaeoceros] spp.*
Corycaeus spp.	*Corethron criophilum*
Cumacea	*Coscinodiscus concinnus*
Cyphonautes larvae	*Coscinodiscus wailesii*
Decapoda total	*Cylindrotheca closterium*
Echinoderm larvae	*Dactyliosolen antarcticus*
Echinoderm post-larvae	*Dactyliosolen fragillissimus*
Euchaeta hebes	*Dinophysis spp.*
Euphausiacea calyptopis	*Ditylum brightwellii*
Euphausiacea total	*Eucampia zodiacus*
Evadne spp.	*Fragilaria spp.*
Fish eggs	*Guinardia delicatula*
Gammaridea	*Guinardia flaccida*
Harpacticoida total	*Guinardia striata*
Hyperiidea	*Gyrosigma spp.*
Isias clavipes	*Lauderia annulata*
Isopoda	*Leptocylindrus danicus*
Labidocera wollastoni	*Leptocylindrus mediterraneus*
Lamellibranch larvae	*Navicula spp.*
Larvacea	*Odontella aurita*

ZOOPLANKTON Species name	**PHYTOPLANKTON** Species name
Limacina retroversa	*Odontella granulata*
Metridia lucens	*Odontella regia*
Mysidacea	*Odontella rhombus*
Oithona spp.	*Odontella sinensis*
Oncaea spp.	*Paralia sulcata*
Paraeuchaeta norvegica	*Phytoplankton Colour*
Parapontella brevicornis	*Proboscia alata alata*
Para-Pseudocalanus spp.	*Proboscia alata indica*
Podon spp.	*Proboscia alata inermis*
Polychaeta larvae	*Prorocentrum spp.*
Pseudocalanus elongatus	*Pseudo-nitzschia delicatissima*
Rhincalanus nasutus	*Pseudo-nitzschia seriata*
Salps	*Rhizosolenia hebetata semispina*
Temora longicornis	*Rhizosolenia imbricata*
Tomopteris spp.	*Rhizosolenia setigera*
Total Copepods	*Rhizosolenia styliformis*
Young fish	*Skeletonema costatum*
	Stephanopyxis
	Thalassionema nitzschioides
	Thalassiosira spp.
	Thalassiothrix longissima

5.2.2 Time-series analysis

Selected plankton data for each statistical rectangle were averaged for the entire time series and then analysed using MDS for the North Sea as a whole (Region IV) and five ICES sub-regions (IVa1, IVa2, IVb1, IVb2 and IVc). The outputs from this analysis are shown in Figure 36 (a to f).

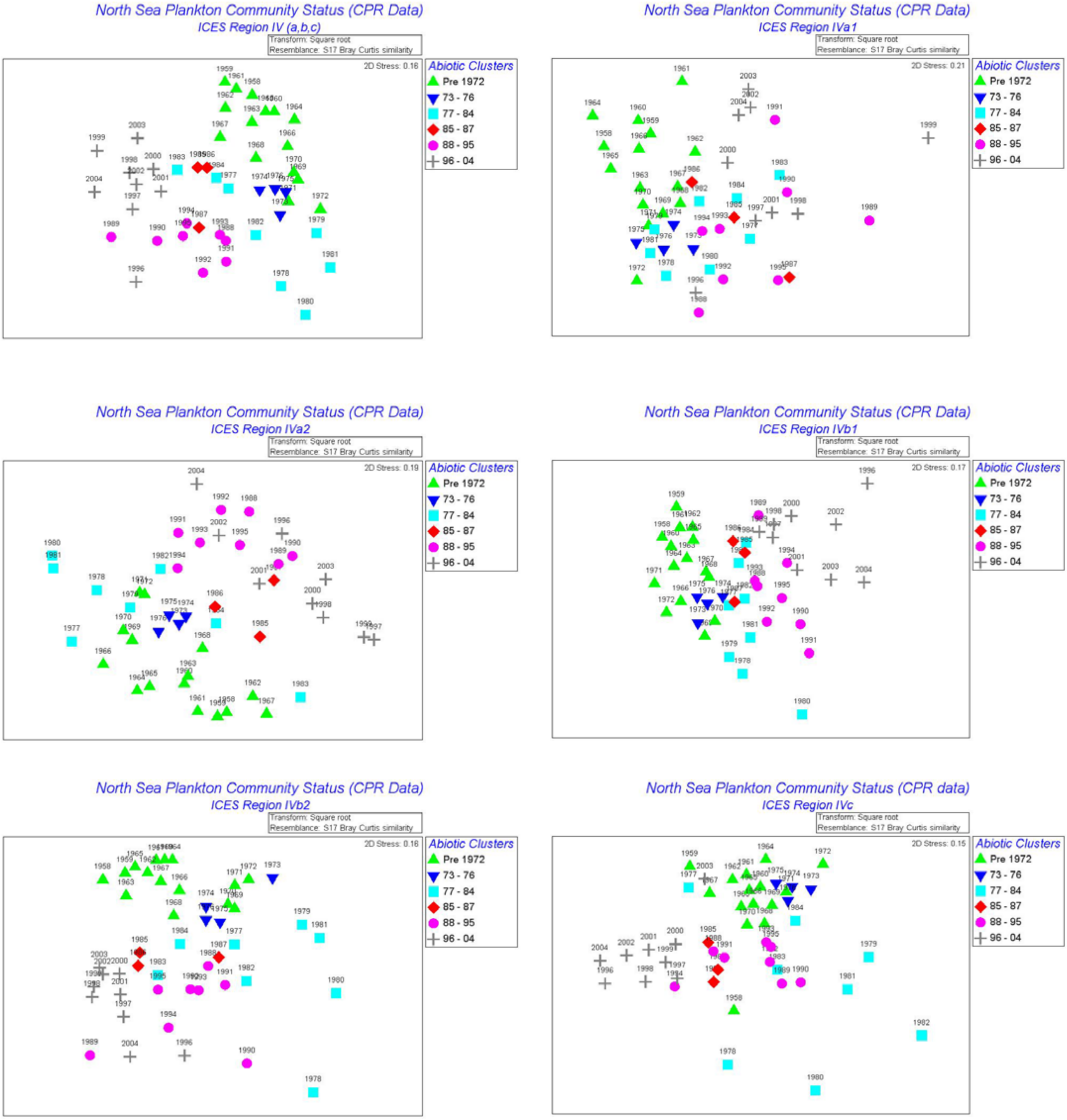

Figure 36: MDS plots of selected plankton species abundance data for the North Sea Region IV and sub-regions IVa1,a2,b1,b2 & c from 1958 to 2004. The years have been assigned to clusters defined by the PCA analysis in the previous section.

Upon close examination of the ordinations it is apparent that the plankton communities in Regions IVa1 and IVc are responding over time in different ways, whilst Regions IVa2, b1 and b2 exhibit a gradient of characterises between the two spatial states. For example, it is noteworthy that the years 1978, 1979, 1980 and 1981 all appear to the far right of the ordination plots for Regions IVb2 and IVc, whereas these years appear more closely related to the main cluster of years in Regions IVa1 and IVa2. Since this is evidence of the plankton communities not responding consistently over time throughout all parts of the North Sea, it suggests that there are different pressures (in terms of type and/or magnitude) acting on the North Sea plankton community in different regions.

A possible explanation for this difference is provided in Section ?, but it appears to be related to a balance between the riverine inputs of nutrients which predominate in the southern region of the North Sea compared to fluxes of North Atlantic sea water which predominate in the northern regions.

5.2.3 Spatial analysis

The CPR time-series data for each ICES statistical rectangle was averaged so as to provide a matrix of selected plankton species (see Table 5) for each grid cell averaged for the entire time series. This (spatial) matrix was then subjected to hierarchical cluster analysis following the creation of a similarity matrix using the Bray-Curtis Index on root transformed species abundance data. The output of this analysis is shown in the form of a dendrogram in Figure 37 which shows 5 principal clusters discernable at the 95% similarity level. Two of the principal clusters can be further subdivided at the 97% level.

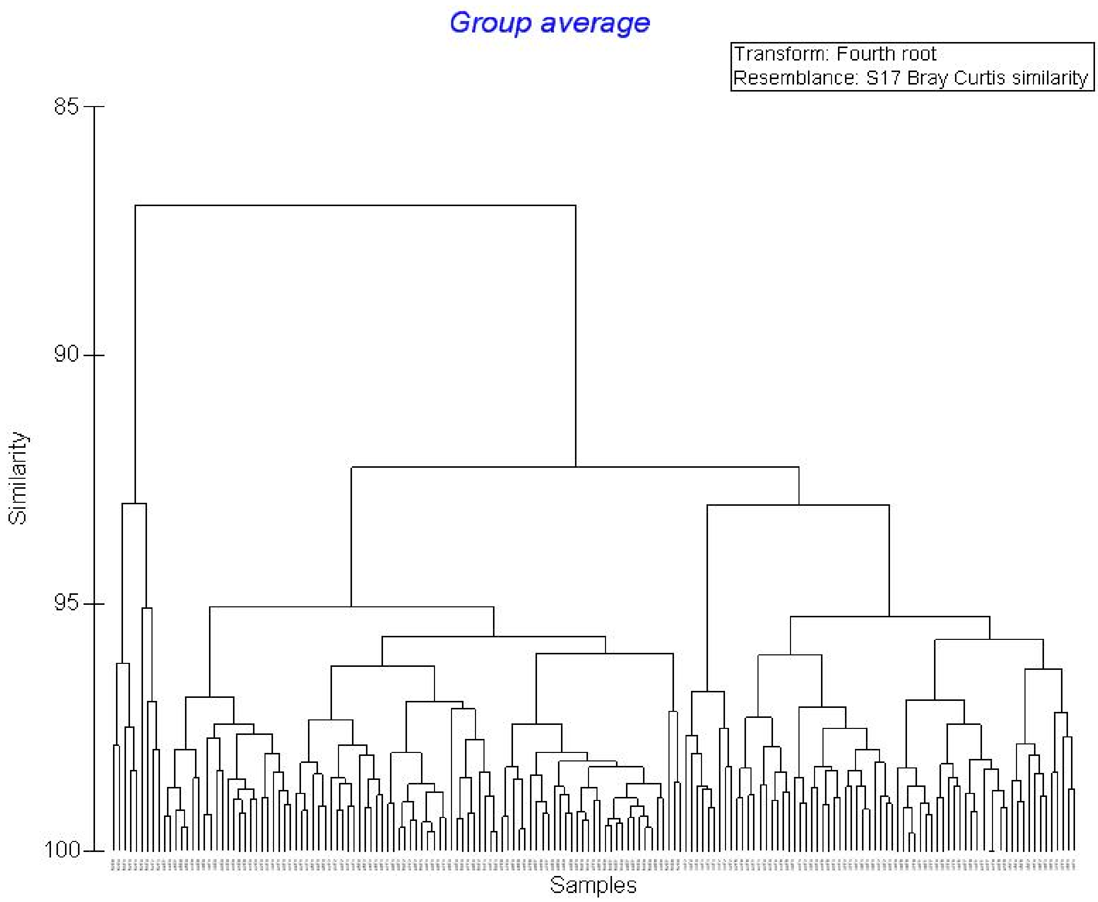

Figure 37: Plankton species abundance data for all statistical squares showing the principal clusters of statistical squares in the North Sea.

The spatial distribution of the clusters is shown in Figure 38 which clearly shows a number of distinctive sub-regions within the North Sea. These regions, by chance, broadly correspond to the ICES sub-regions, with the exception of sub-region IVb1, and are therefore consistent with the regional differences observed in the time series analysed above. The dominant species of plankton associated with these spatial clusters is shown in Table 6.

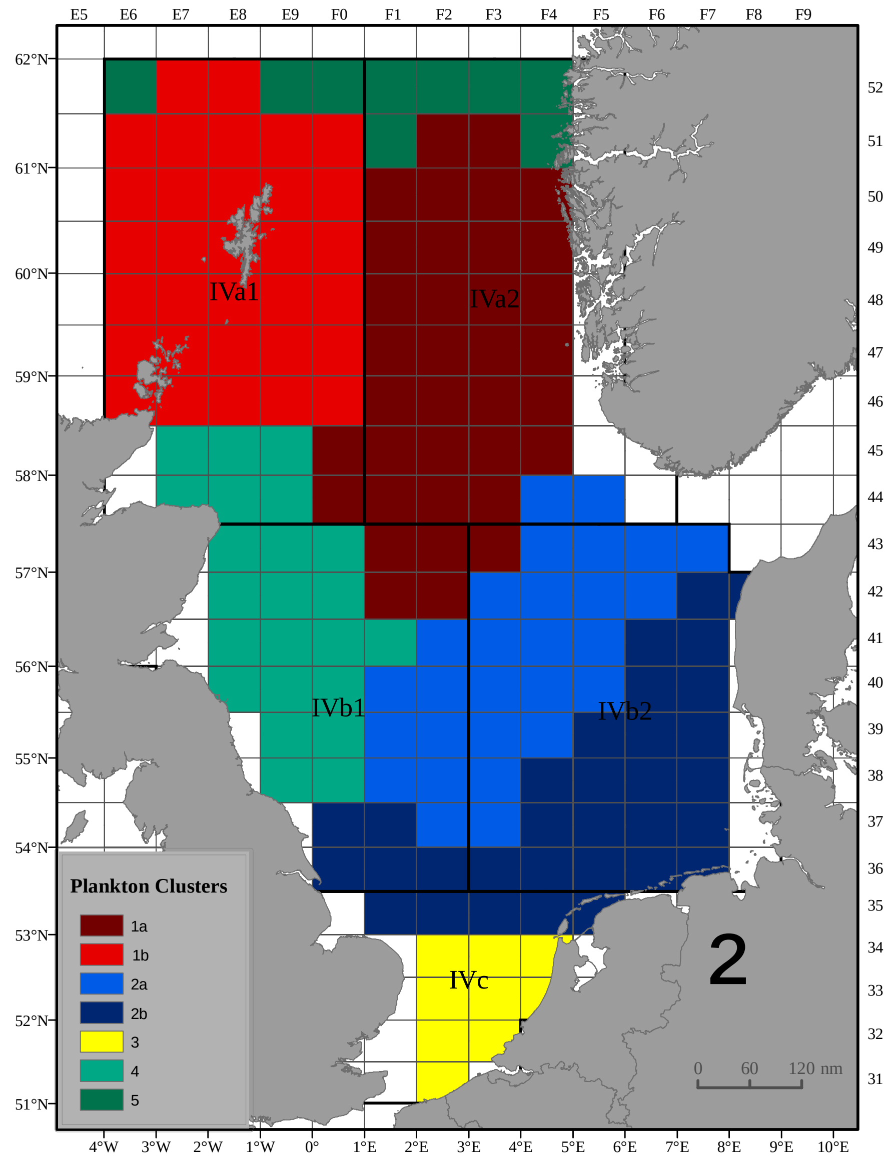

Figure 38: Principal plankton community clusters based upon WinCPR data kindly provided by SAHFOS.

Table 6: The dominant plankton taxa associated with the principal clusters for the North Sea. Based upon WinCPR data from 1948 to 2004 kindly provided by SAHFOS.

CLUSTER 2A				CLUSTER 2B		
	%MD	Cum.%MD			%MD	Cum.%MD
Tot.Copepods	11.43	11.43		Tot.Diatoms	13.74	13.74
Tot.Diatoms	9.97	21.40		Tot.Copepods	11.85	25.59
Para-Pseudocalanus spp.	7.69	29.09		Para-Pseudocalanus spp.	8.63	34.23
Ceratium fusus	7.17	36.26		Phytoplankton Colour	8.59	42.82
Phytoplankton Colour	6.97	43.23		Ceratium fusus	6.84	49.67
Ceratium furca	6.34	49.57		Ceratium furca	5.61	55.28
Chaetoceros [Phaeoceros] spp.	5.25	54.83		Temora longicornis	5.16	60.44
Calanus total traverse	4.65	59.48		Chaetoceros [Phaeoceros] spp.	4.53	64.97
Chaetoceros [Hyalochaete] spp.	4.52	64.00		Thalassiosira spp.	3.98	68.94
Thalassiosira spp.	4.35	68.36				

CLUSTER 1A				CLUSTER 1B		
	%MD	Cum.%MD			%MD	Cum.%MD
Tot.Copepods	12.15	12.15		Tot.Diatoms	16.58	16.58
Tot.Diatoms	9.72	21.87		Tot.Copepods	9.84	26.42
Calanus total traverse	7.25	29.13		Thalassiosira spp.	6.89	33.31
Ceratium fusus	7.20	36.32		Ceratium fusus	6.69	39.99
Para-Pseudocalanus spp.	6.88	43.20		Phytoplankton Colour	5.86	45.85
Ceratium furca	5.79	49.00		Chaetoceros [Hyalochaete] spp.	5.66	51.51
Phytoplankton Colour	5.54	54.54		Para-Pseudocalanus spp.	5.37	56.89
Thalassiosira spp.	5.00	59.54		Calanus total traverse	5.27	62.16
Chaetoceros [Hyalochaete] spp.	4.86	64.39		Ceratium furca	4.68	66.85
Chaetoceros [Phaeoceros] spp.	4.00	68.40		Chaetoceros [Phaeoceros] spp.	4.30	71.15

CLUSTER 5				CLUSTER 4		
	%MD	Cum.%MD			%MD	Cum.%MD
Tot.Copepods	14.49	14.49		Tot.Copepods	11.06	11.06
Calanus total traverse	9.71	24.20		Tot.Diatoms	8.70	19.76
Tot.Diatoms	6.92	31.11		Ceratium fusus	7.65	27.41
Ceratium fusus	6.89	38.00		Para-Pseudocalanus spp.	6.62	34.03
Para-Pseudocalanus spp.	6.55	44.55		Phytoplankton Colour	6.55	40.58
Thalassiosira spp.	5.66	50.21		Ceratium furca	6.21	46.79
Calanus finmarchicus	5.62	55.83		Chaetoceros [Hyalochaete] spp.	5.79	52.58
Chaetoceros [Hyalochaete] spp.	5.22	61.05		Thalassiosira spp.	5.59	58.17
Phytoplankton Colour	4.64	65.69		Calanus total traverse	4.73	62.90
Chaetoceros [Phaeoceros] spp.	3.99	69.68		Chaetoceros [Phaeoceros] spp.	4.45	67.35

CLUSTER 3		
	%MD	Cum.%MD
Tot.Diatoms	21.36	21.36
Tot.Copepods	12.07	33.44
Phytoplankton Colour	9.66	43.09
Para-Pseudocalanus spp.	8.86	51.95
Temora longicornis	6.28	58.23
Ceratium fusus	5.72	63.95
Chaetoceros [Phaeoceros] spp.	4.63	68.59

The dominant plankton species (total diatoms, total copepods, *Calanus finmarchichus* and *Calanus helgolandicus*) have been plotted as annual averages for the North Sea as a whole and these are shown in Figures 39–41. What is apparent is the significant increase in the North Sea average density of diatoms since the late 1980s coinciding with the abrupt change in surface sea water temperature and seawater flux. It is noteworthy that the 1980's witnessed relative high densities of diatoms in Region IVa1, but elsewhere they appeared relatively low. However by the 1990's diatoms had increased their dominance in the other regions of the North Sea this is further described below.

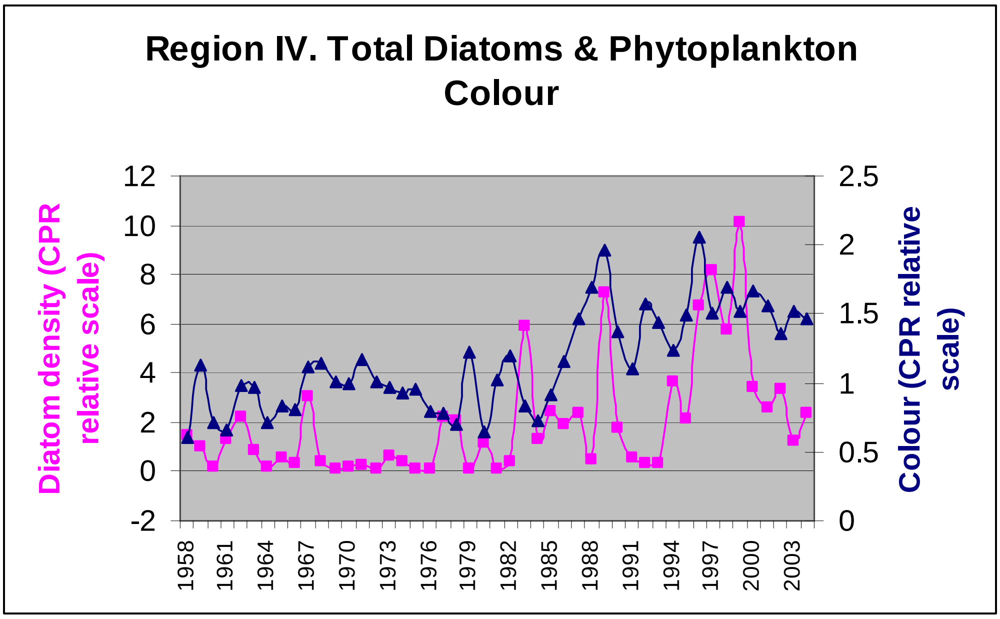

Figure 39: Total relative densities of diatoms and colour from the CPR survey. Data are annual averages for the entire North Sea from 1958 to 2004.

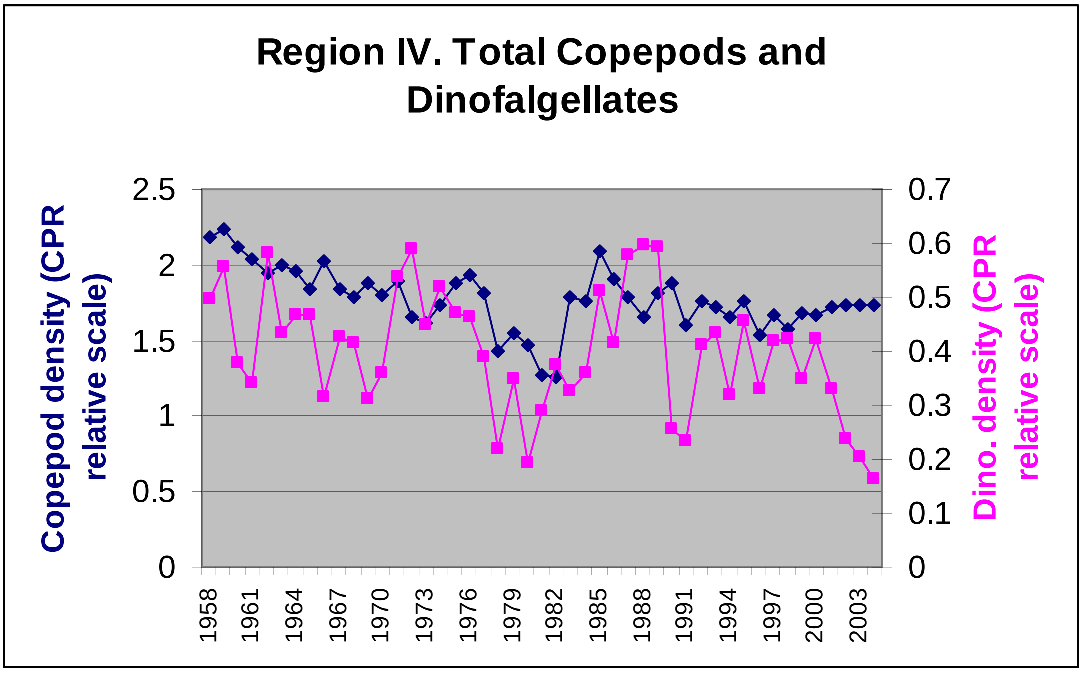

Figure 40: Total relative densities of copepods and dinoflagellates from the CPR survey. Data are annual averages for the entire North Sea from 1958 to 2004.

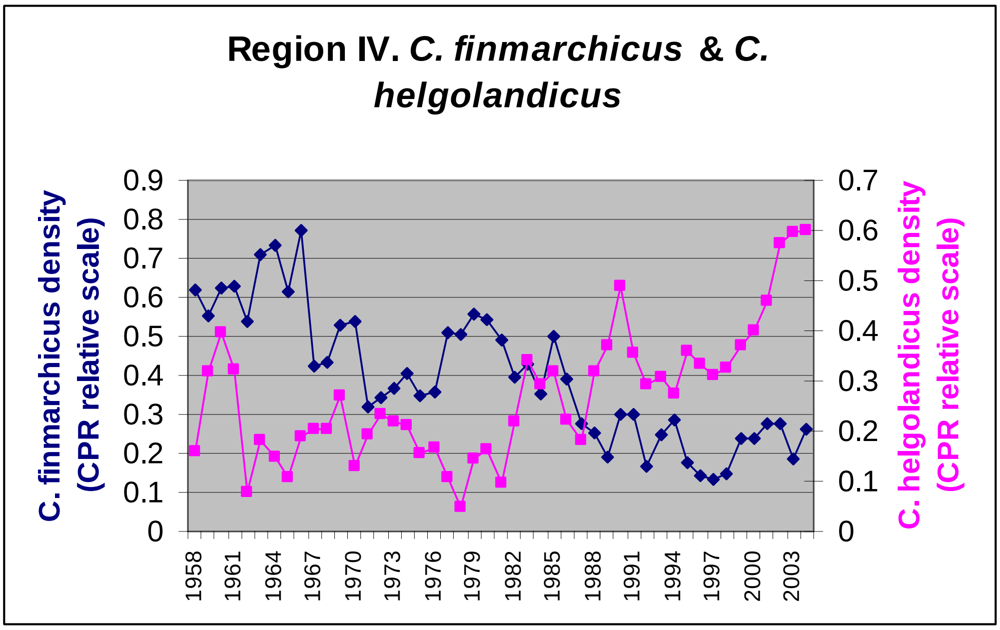

Figure 41: Total relative densities of *Calanus finmarchicus* & *C. helgolandicus* copepods and dinoflagellates from the CPR survey. Data are annual averages for the entire North Sea from 1958 to 2004.

In order to visualise how total diatoms and total copepods vary spatially over time in the North Sea we have grouped the data into decadal time periods, e.g. 1950s, 1960s, 1970s, 1980s, 1990s, and the 4 years making up 2000 to 2004, averaged the values for each stat. sqr and mapped the relative densities for the entire North Sea. These are shown in Figures 42 to 53.

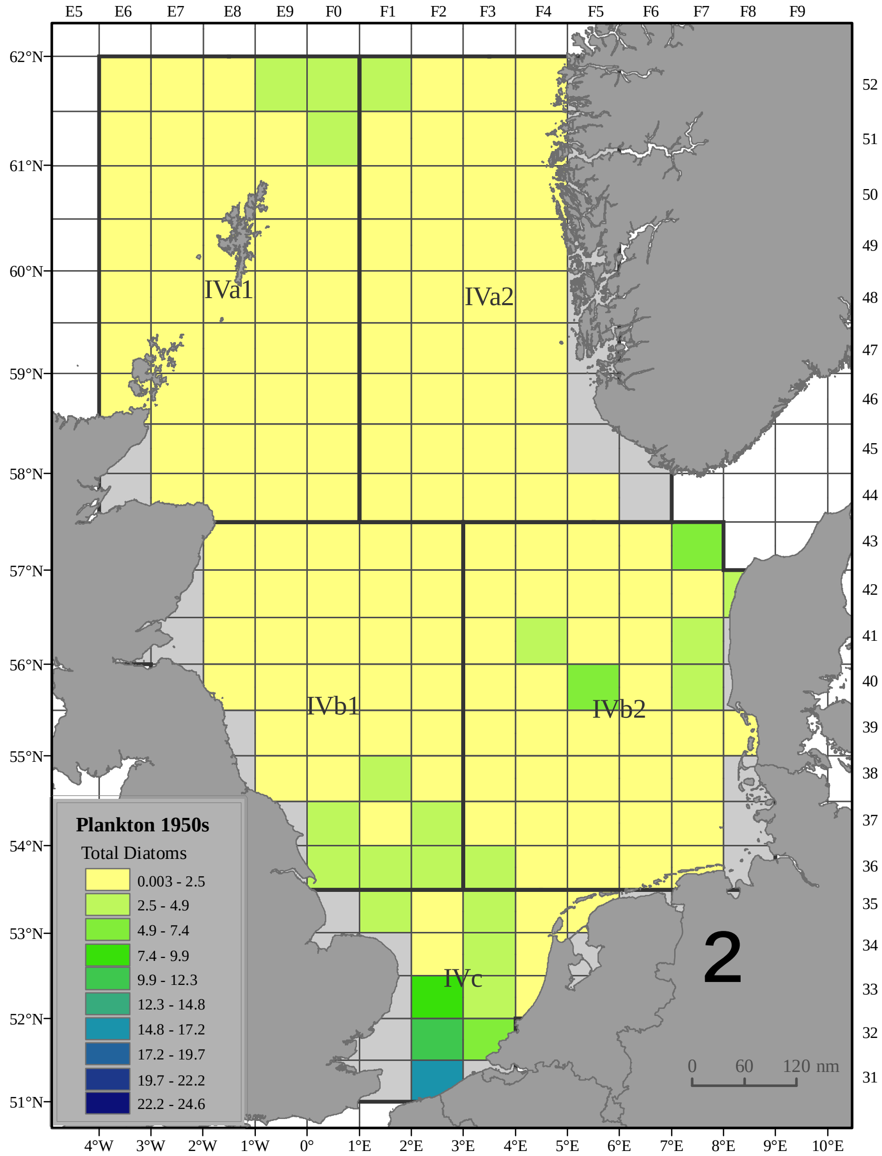

Figure 42: Average annual densities of diatoms from the CPR survey for the 1950s.

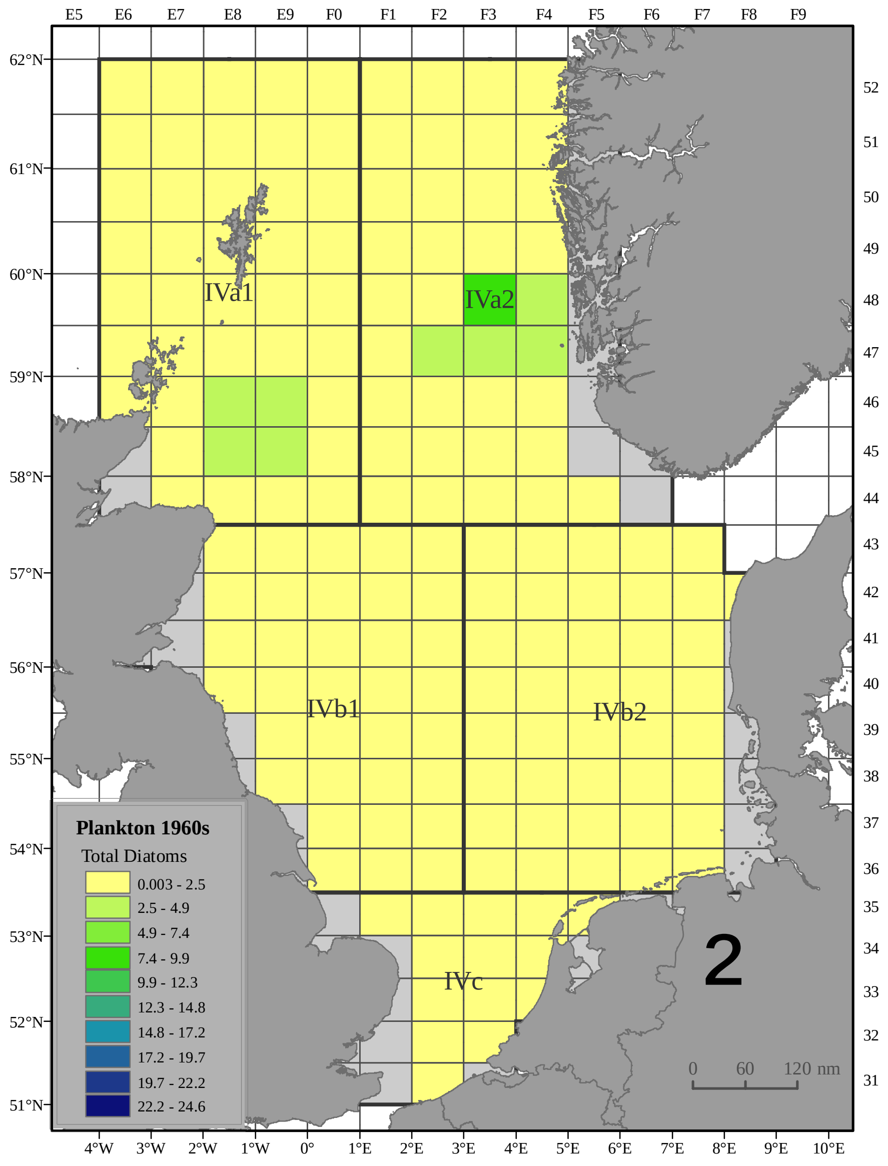

Figure 43: Average annual densities of diatoms from the CPR survey for the 1960s.

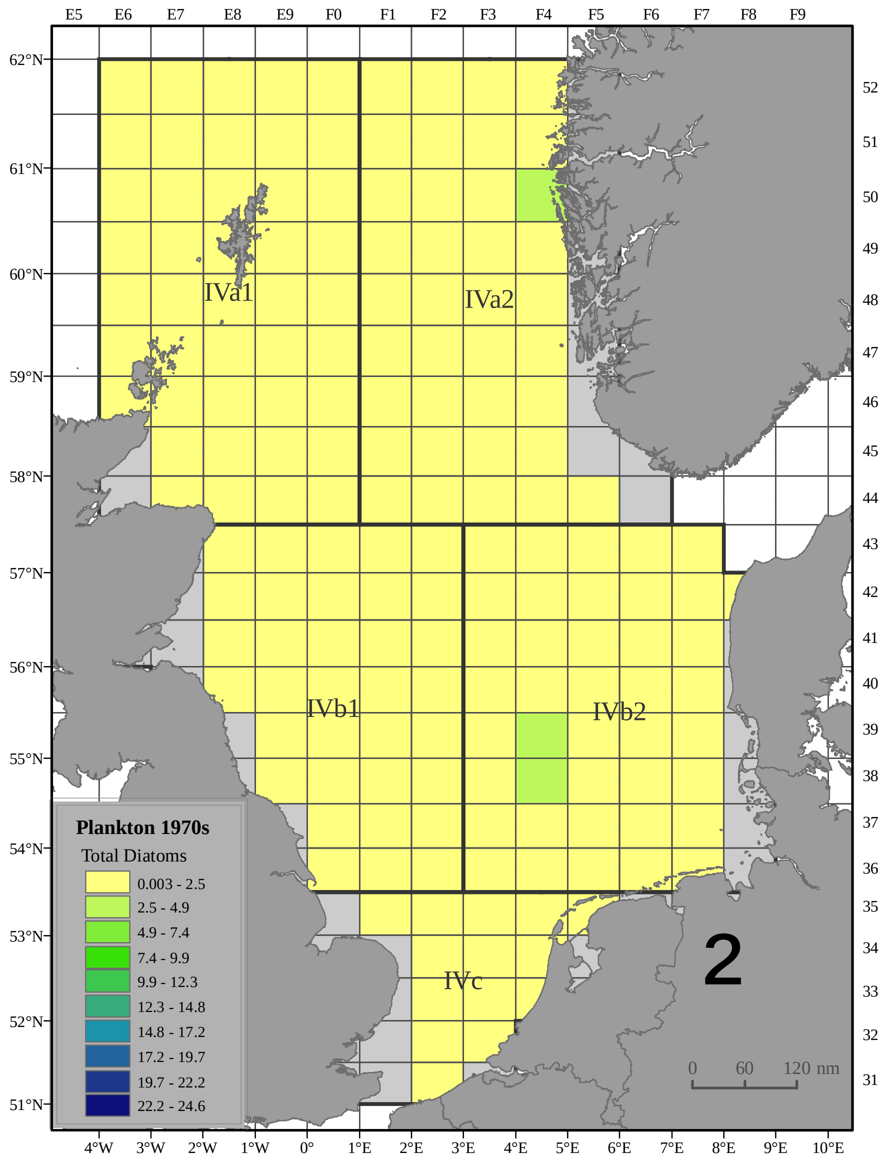

Figure 44: Average annual densities of diatoms from the CPR survey for the 1970s.

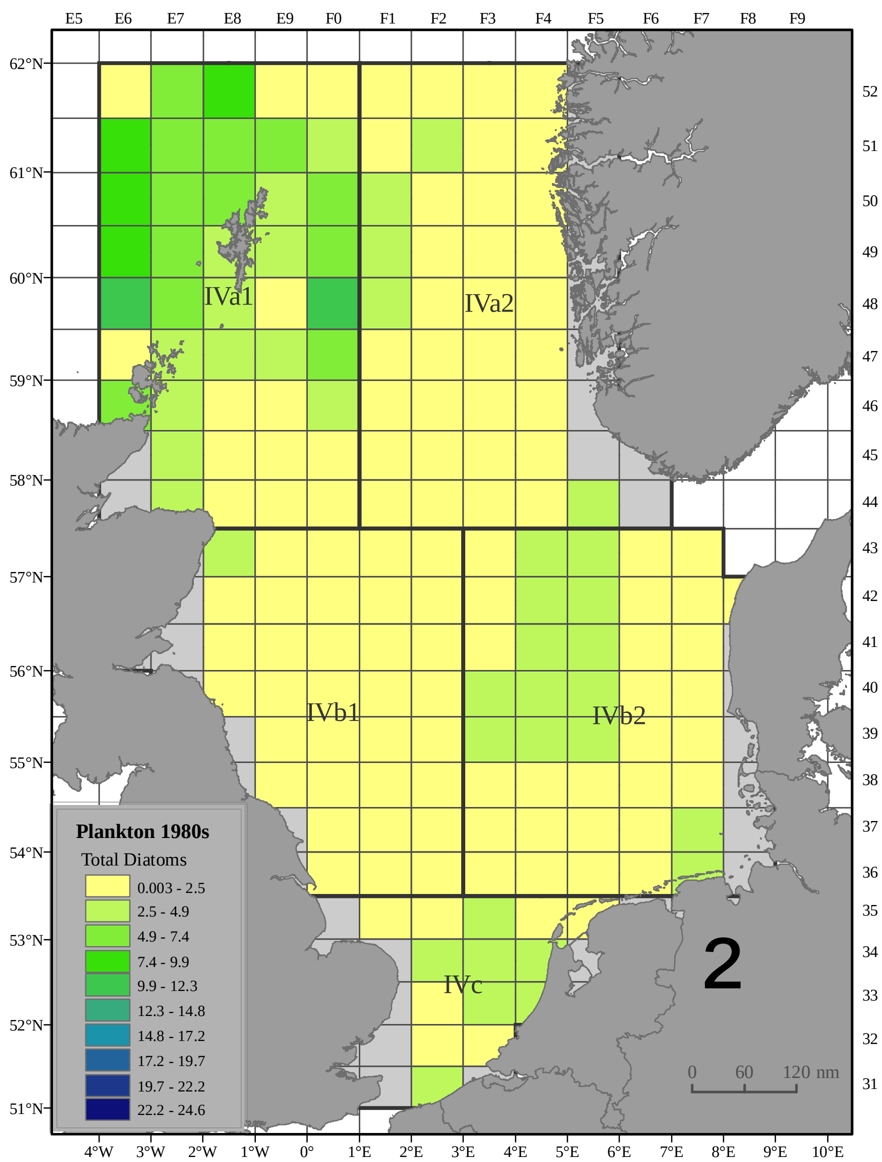

Figure 45: Average annual densities of diatoms from the CPR survey for the 1980s.

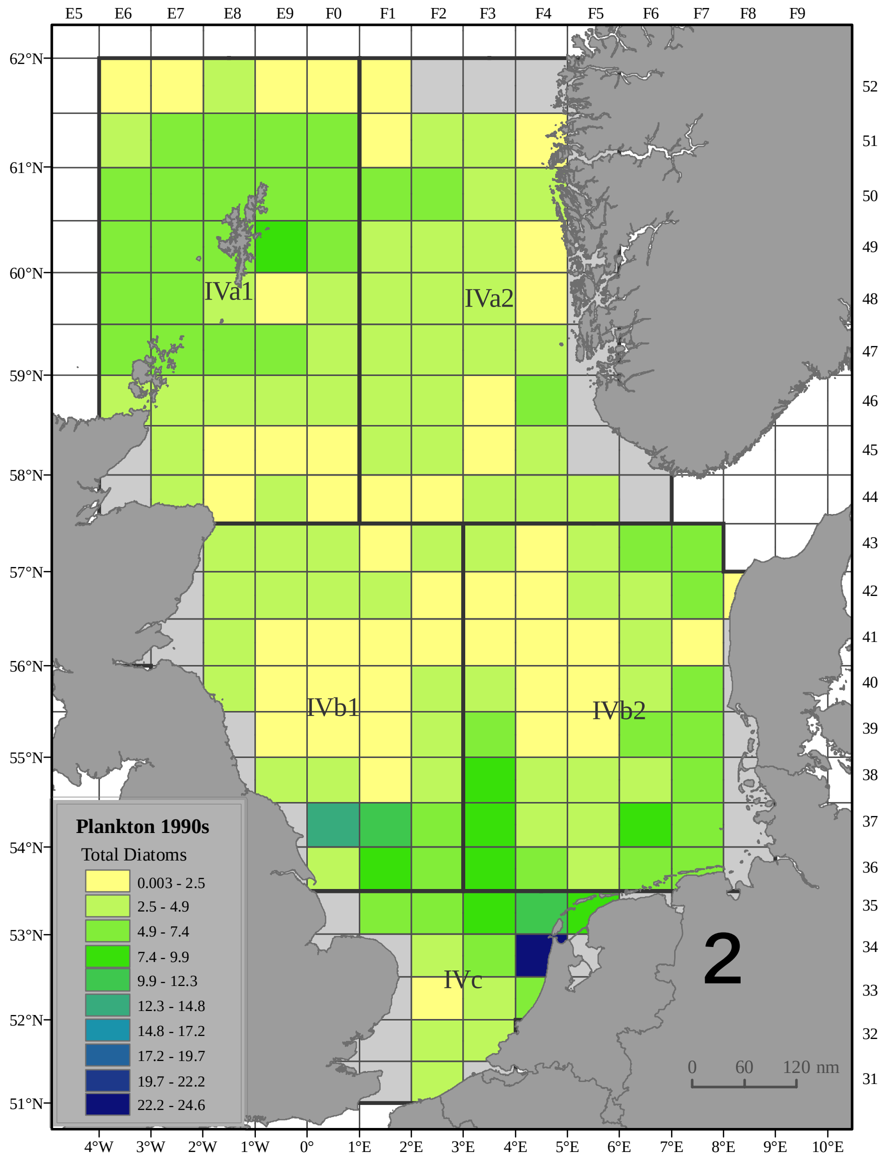

Figure 46: Average annual densities of diatoms from the CPR survey for the 1990s.

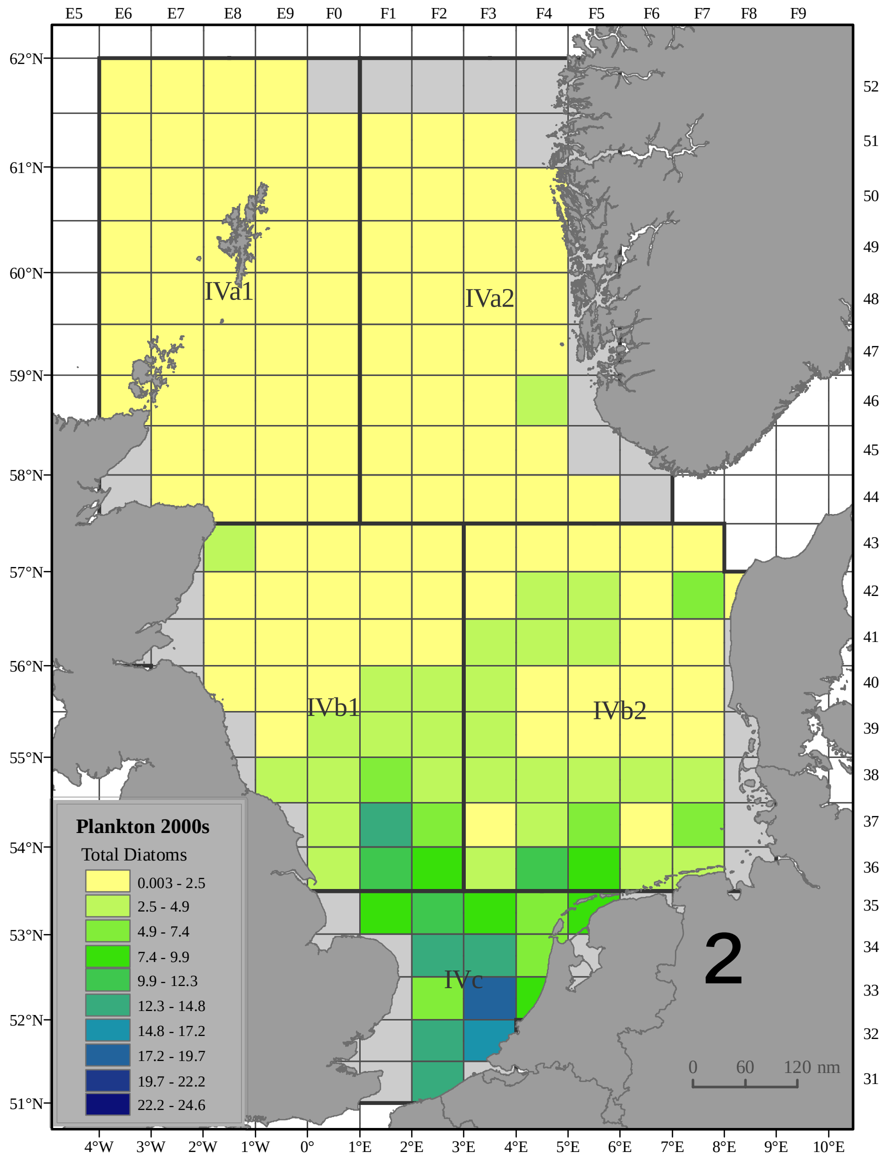

Figure 47: Average annual densities of diatoms from the CPR survey for the 2000s.

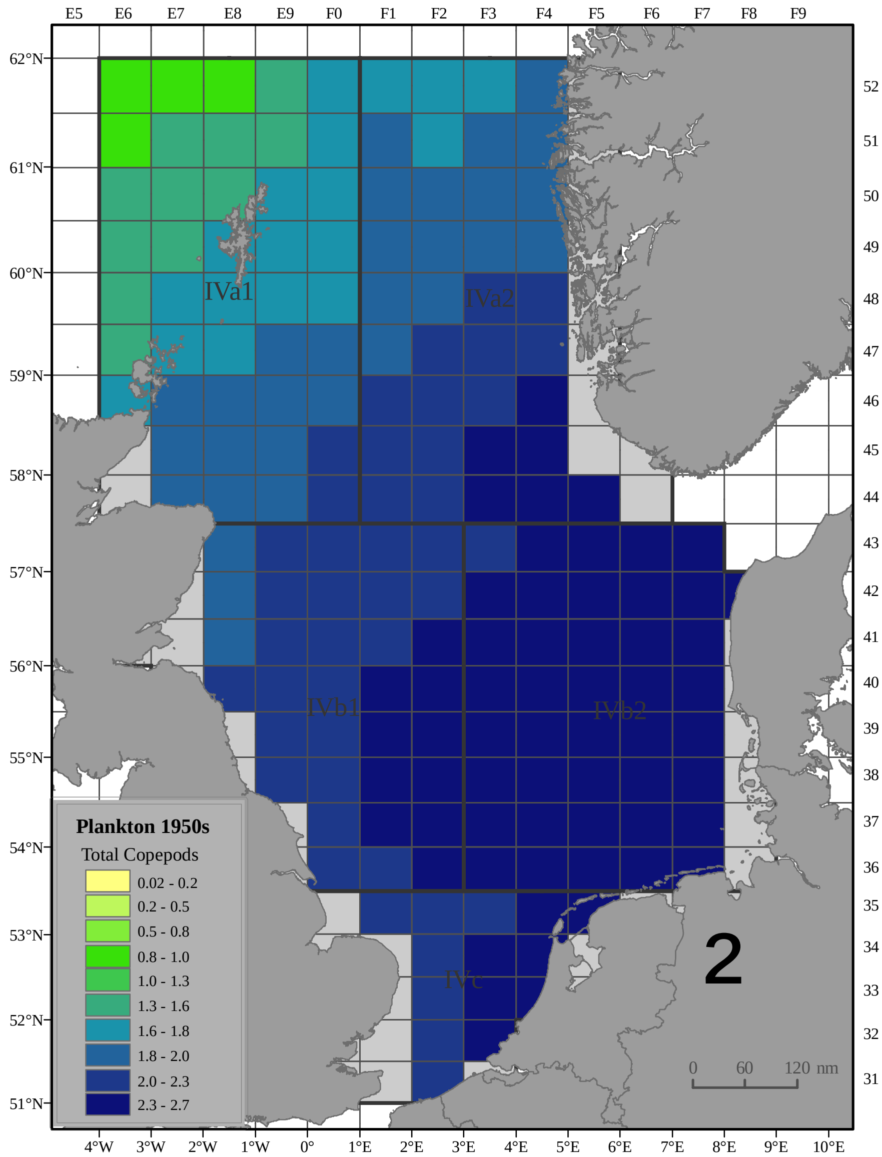

Figure 48: Average annual densities of copepods from the CPR survey for the 1950s.

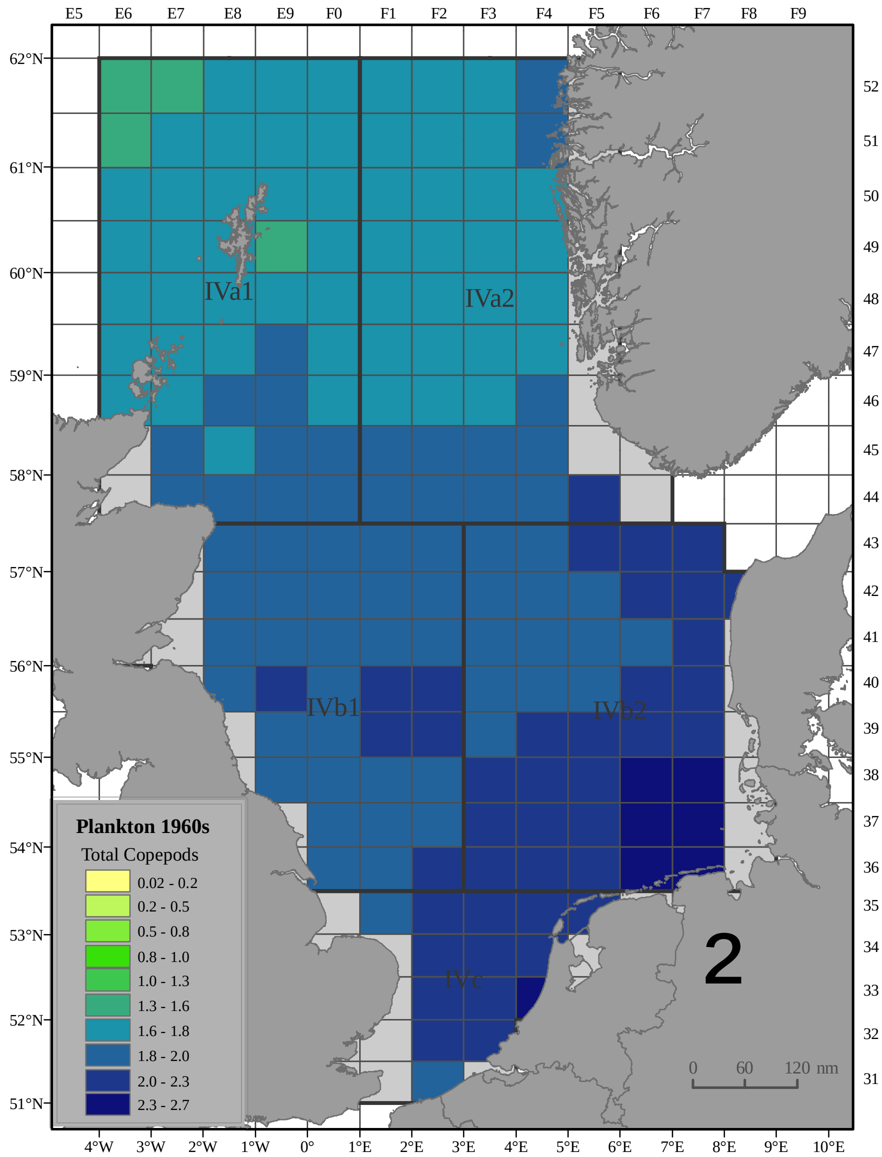

Figure 49: Average annual densities of copepods from the CPR survey for the 1960s.

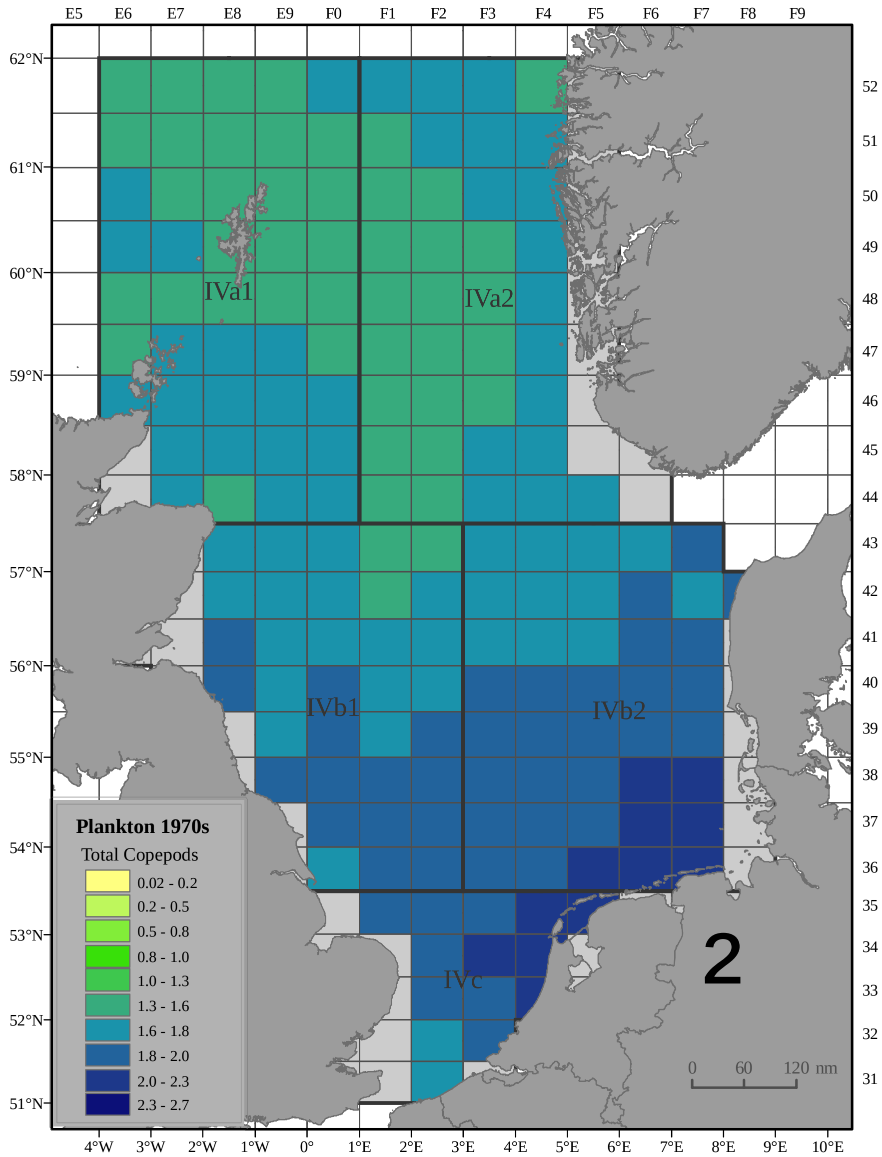

Figure 50: Average annual densities of copepods from the CPR survey for the 1970s.

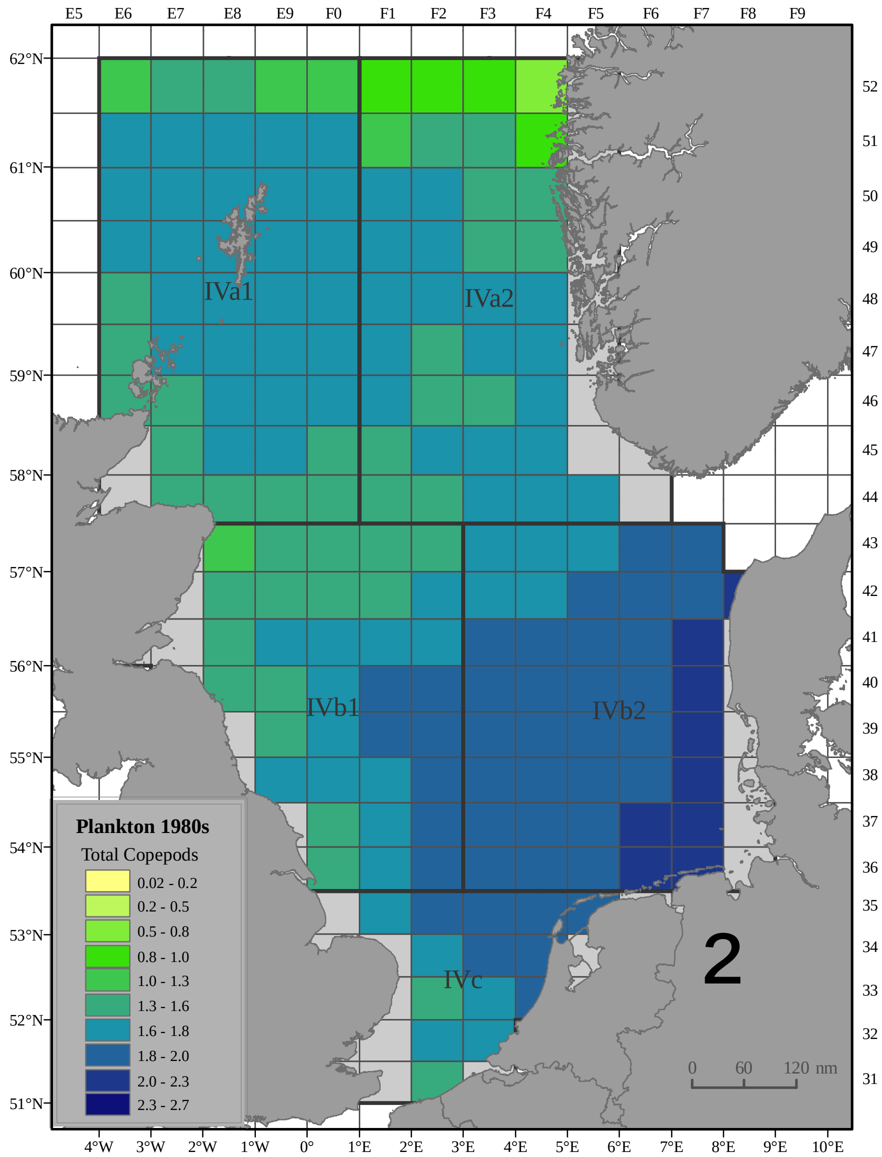

Figure 51: Average annual densities of copepods from the CPR survey for the 1980s.

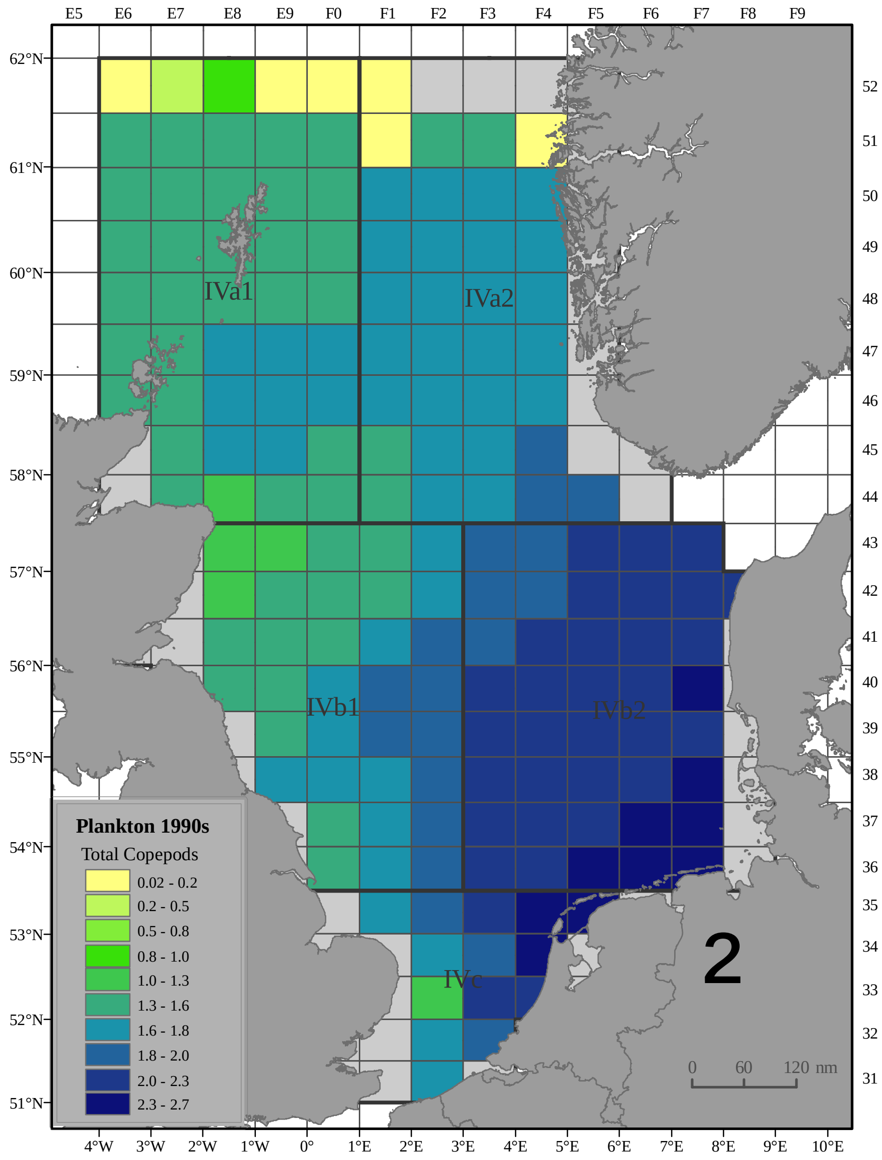

Figure 52: Average annual densities of copepods from the CPR survey for the 1990s.

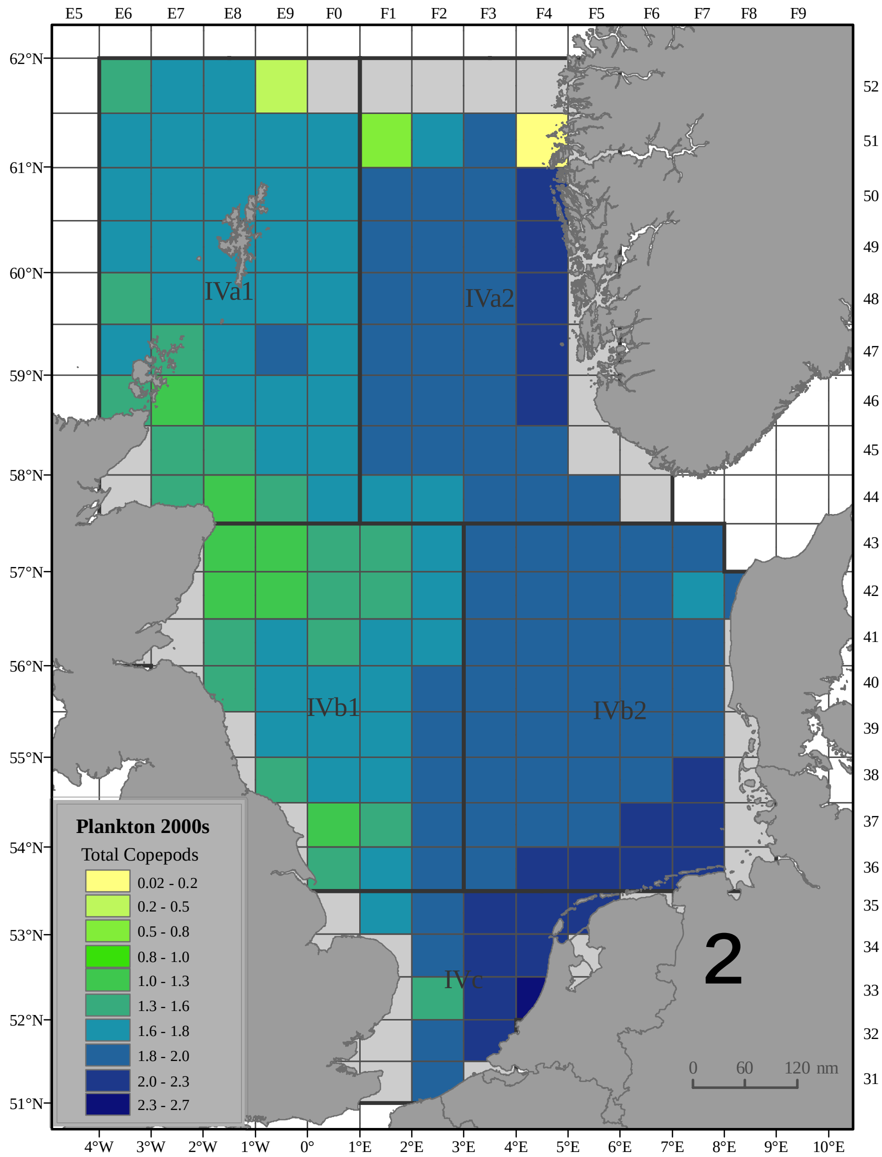

Figure 53: Average annual densities of copepods from the CPR survey for the 2000s.

5.3 Fish

5.3.1 Spatial analysis

The International Bottom Trawl Survey (IBTS) data are held in the DATRAS database in ICES. Stored per quarter as haul-based CPUE, mean CPUE per ICES rectangle and mean CPUE by index area (the latter only in the case of the 8 standard species: herring, sprat, mackerel, cod, haddock, whiting, and Norway pout). These "standard species" have length, age, sex and maturity data. The remaining species only have length data. In the case of rare and non-commercial species, the analysis would be better done at wider spatial scales or by presence-absence. Several species of marine fish have either a northern or southern boundary latitude in the North Sea. For such species, if data on relative abundance by latitude/longitude are insufficiently robust for analysis, analyses of maximum/minimum boundary latitude could be carried out. It must be noted that the GOV trawl used in IBTS surveys does not sample properly all species or substrate types.

The data assessed are as follows:

- Abundance at length: Available for all commercial and non-commercial species (although taxonomic level of the latter is more variable, i.e. not all recorded to species level).
- Weight at length: Recorded by most institutes for commercial and non-commercial species but not routinely submitted to ICES before 2005 (available by request to individual countries). From 2005 these data can be included in the DATRAS database.
- Age at length: Available as CPUE from the DATRAS database for the 8 standard species.
- Maturity at age: Data available for the 8 standard species at the subsample level so need to be raised to CPUE. The WGFE recommendation was to use these data at a coarser spatial scale, even where they are available at the ICES rectangle level.

The analysis was carried out from 1983, when data were available for all the species considered in this exercise (planktivore fish: herring, sandeel, Norway pout, sprat; pelagic piscivores: mackerel, horse mackerel; demersal piscivores: cod, haddock, whiting, saithe; and demersal benthivores: plaice, dab, sole, lemon sole). The initial spatial analysis was undertaken using entire time series averages for each species in each stat. sqr. of the North Sea so as to identify any significant major spatial trends in the CPUE community data over the entire time series. Hierarchical cluster analysis was performed on (logX+1) transformed data having used the Bray-Curtis similarity metric to generate a dendrogram of stat.sqr clusters shown in Figure 54. At about the 75% similarity level there are two principal clusters and these can be further subdivided at about the 82% level. Taking the clusters of stat. squares and spatially mapping them reveals their contiguous distribution and CPUE based community gradients across the North Sea (Figure 55). The dominant fish species associated with these clusters is presented in Table 7, which highlight the dominance of sprat and herring in the south and Bib? and Haddock? in the north.

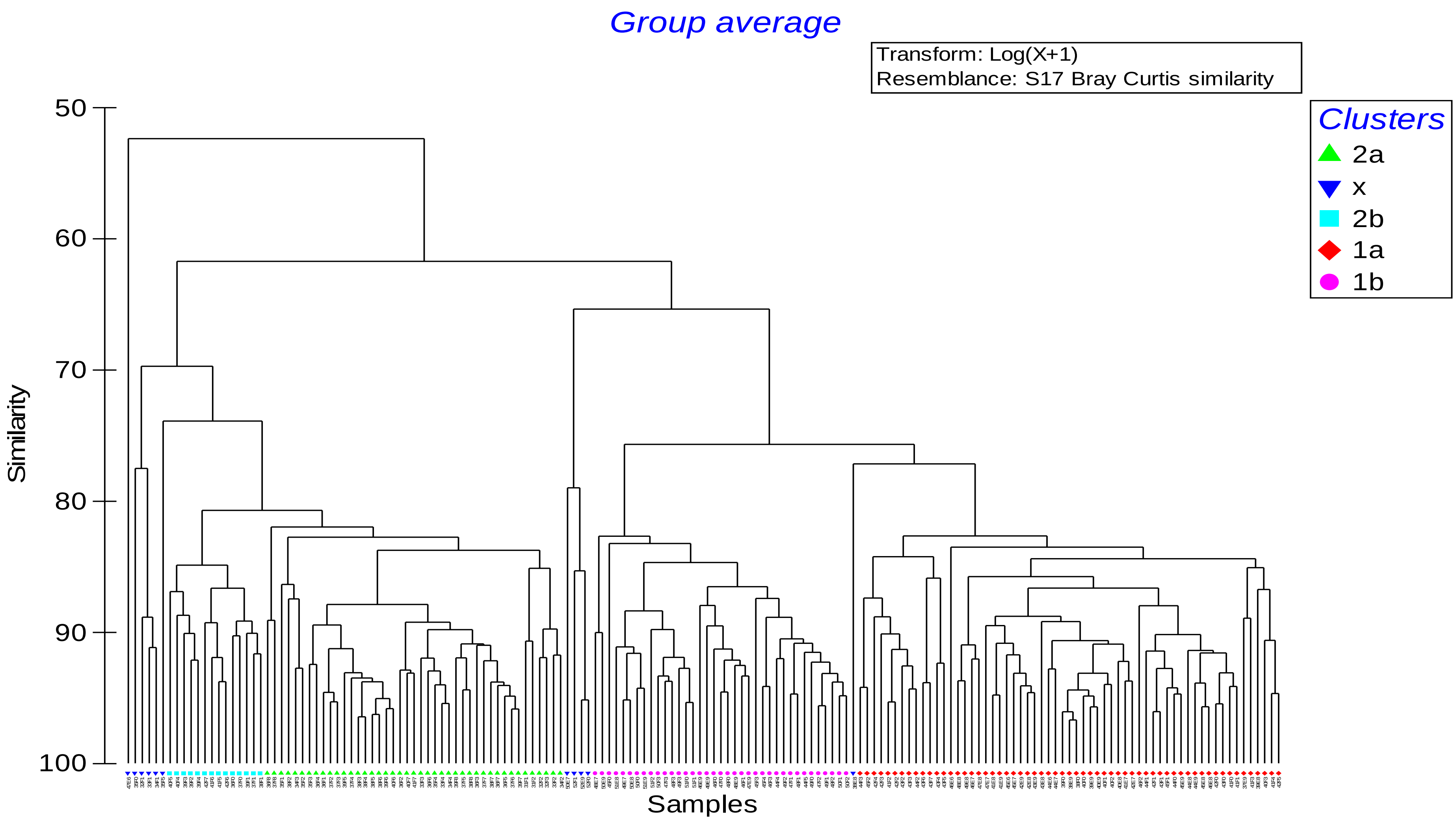

Figure 54: Group average linkage cluster analysis on IBTS CPUE data averaged from 1983 to 2004 for the North Sea – Samples are statistical squares.

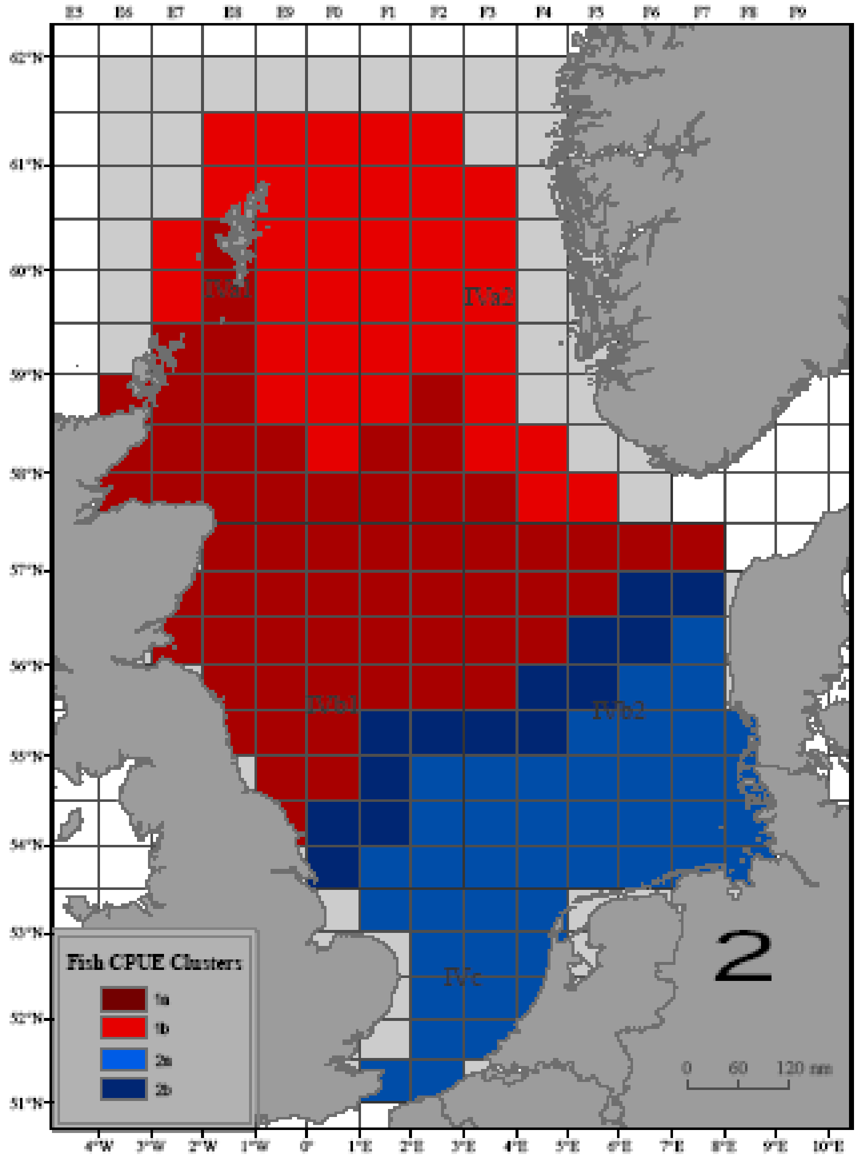

Figure 55: Clusters of CPUE communities as time-series average between 1983 and 2004 for the North Sea. For species which relate to each cluster see Table 7.

Table 7: Top ranked percentage mean dominance of fish species associated with each spatial cluster for the North Sea based upon time-series averaged data (1983-2004) from the IBTS CPUE data held by ICES.

Cluster 1a				Cluster 1b		
	Ave. CPUE	%MD			Ave. CPUE	%MD
Trisopterus esmarkii	3216.05	28.64		Trisopterus esmarkii	7881.50	68.46
Clupea harengus	2736.51	24.37		Melanogrammus aeglefinus	1570.22	13.64
Merlangius merlangus	2095.90	18.67		Clupea harengus	688.29	5.98
Melanogrammus aeglefinus	1823.10	16.24		Merlangius merlangus	485.08	4.21
Limanda limanda	561.49	5.00		Scomber scombrus	186.83	1.62
Cluster 2a				Cluster 2b		
	Ave. CPUE	%MD			Ave. CPUE	%MD
Sprattus sprattus	9577.72	50.93		Sprattus sprattus	5827.38	39.41
Clupea harengus	4589.21	24.40		Clupea harengus	5187.17	35.08
Merlangius merlangus	1753.57	9.32		Merlangius merlangus	2108.58	14.26
Trachurus trachurus	1301.79	6.92		Limanda limanda	1146.61	7.75
Limanda limanda	1119.68	5.95		Melanogrammus aeglefinus	138.86	0.94

5.3.2 Time-series analysis

Using the same source data a matrix of sample years (1983 to 2005) was generated based upon an average for the entire North Sea stat. square data. Subjecting this data set to Five main clusters of years were identified by MDS: 1983-86, 1987-90, 1991-2000, 2001-02 and 2003-05 (see Figure 56). When the equivalent analysis is carried out on stock assessment metrics such as SSB, derived from the stock assessment data published in the relevant stock assessment working group reports, the clusters are quite consistent with IBTS CPUE data (but note that these data were not available for all the species used in the CPUE analysis – see Figure 57. Between 1983–1986 the CPUE data was dominated by relatively large demersal fish and small pelagic fish, and Low numbers of pelagic fish. Between 1987-90 there were increases in whiting, dab and sole. Between 1991-2000 there were increases in sprat, horse mackerel, Norway pout and lemon sole and in southern fish species. Decrease in plaice and demersal fish length but increase in demersal fish numbers. In 2001-02 there were very high horse mackerel numbers and high densities of lemon sole, and finally between 2003 and 2005 there were low densities of Norway pout, cod and haddock (and demersal fish in general), yet high densities of mackerel.

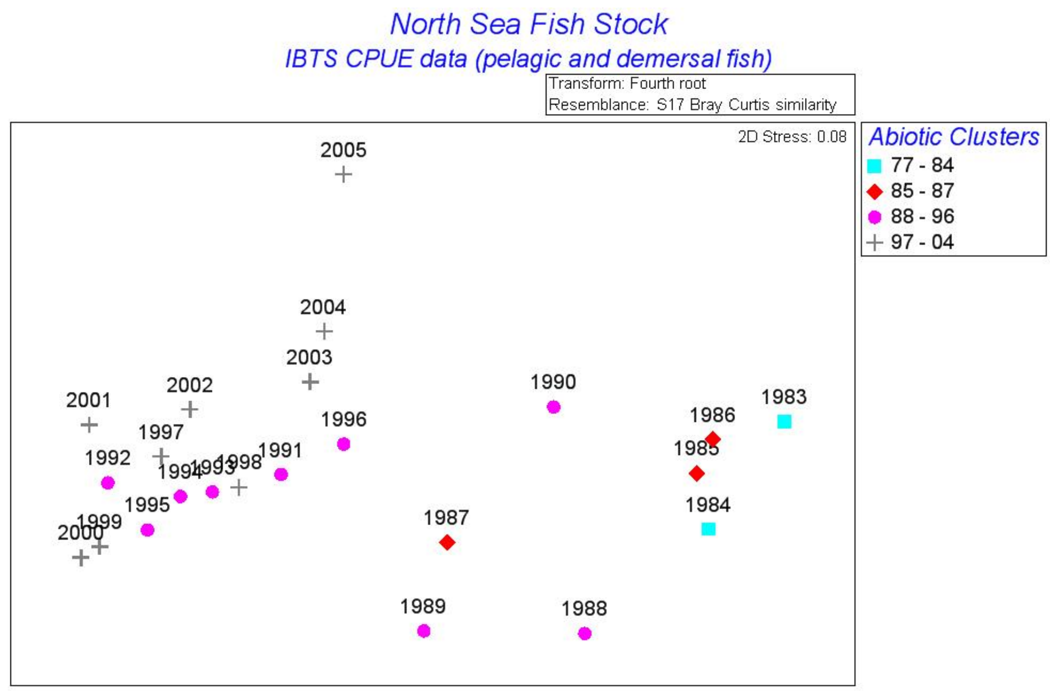

Figure 56. MDS ordination of sample years for the North Sea using IBTS CPUE data.

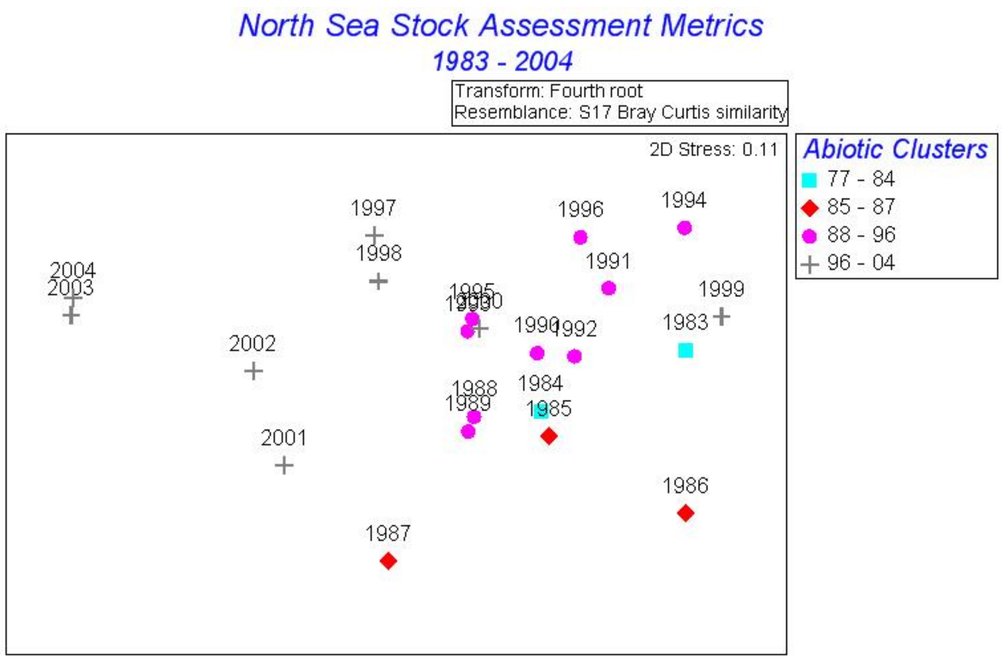

Figure 57: MDS ordination of fish stock assessment metrics (e.g. SSB) for the North Sea from 1983 to 2004. Years have been assigned to colours which are the clusters identified by PCA on abiotic data. There is a clear temporal trend from the 1980's to 2004 which is consistent with trends observed in the abiotic time-series.

5.4 Seabirds

Approximately 2.5 million pairs of seabirds breed around the coasts of the North Sea. The seasonal distributions, current and historical, of these populations are quite well-known. Various other life history data have been collected for seabirds at varying temporal and spatial scales, for example diverse aspects of breeding performance, diet, annual adult survival, etc. Few of these parameters offer much scope for integrated assessment or analysis at the large scale being considered here (i.e. the North Sea). They might usefully be applied in finer scale integrated studies, whose focus might be meaningfully determined by larger scale community analyses that are reported herein. Such wider consideration of seabird communities at sea is possible only by addressing data on the dispersion of birds away from land and the breeding colonies.

Seabird dispersion data at sea have been collected in the North Sea since 1979. Fewer data were collected in the North Sea from the mid-1990s than in earlier years especially the 1980s. Although there is much spatial and temporal variability in the available data they were considered adequate to allow at least an exploratory analysis to determine the identification and spatial distribution of possible seabird communities within the North Sea.

Typically, at-sea seabird data were collected using a standardised methodology applied from various platforms, including ships of opportunity, research vessels, and aircraft. Only data from relatively common species were included in the present study; infrequently recorded migrants were excluded. Seabird survey data are stored in the European Seabirds at Sea (ESAS) database. In the ESAS database, for every species or pseudospecies the data are resolved into densities (individuals recorded per km^2 of area surveyed) on a monthly basis for each ¼ ICES rectangles (i.e. cells measuring 15’x30’ lat/long).

In order to identify seabird communities, that is groups comprising seabird species that frequently co-occur, a spatial clustering analysis was performed on the ESAS data. Bird densities were computed for all 204 ICES rectangles by calculating a simple average for each species/pseudospecies of the four ¼ ICES rectangles comprising an ICES rectangle. These average densities are thus indicative of true mean densities and should be treated with caution as survey coverage may have differed between the ¼ ICES rectangles that comprise an ICES rectangle (though survey coverage within ICES rectangle appeared fairly similar over all years represented in the ESAS database).. Pseudospecies result from cases where identification of birds was uncertain. In order to use as much of the data as possible in the present analyses, bird data were further resolved into new pseudospecies categories where necessary. These are indicated in Table 8 along with the ESAS database species or pseudospecies that they include. In addition to making maximal use of the available data, the rationale behind the resolution into larger categories was to attempt to reflect broad ecological types. Thus the species/pseudospecies within each category have broadly similar feeding ecology/habitat requirements. This might also facilitate identification of geographically discrete seabird community clusters.

In order to detect any possible similarities or possible changes over time in seabird communities a temporal cluster analysis was also conducted. For temporal cluster analysis similar treatment was applied to the seabird data as for the spatial cluster analysis. For each ICES region an average density for each species or pseudospecies of bird for all ICES rectangles was computed for each year of data availability.

All data stored in the ESAS database (from 1979–2004) were used in the analyses.

5.4.1 Spatial analysis

The results of the spatial clustering analysis of seabird at-sea dispersion data (Figure 58) indicate a high degree of clustering, suggesting that broadly defined seabird communities show different geographical distributions. The analysis resulted in identification of four geographically discrete seabird community clusters across the North Sea, one of which could meaningfully be split further into two sub-clusters (Figure 58). The geographical extent of these clusters is depicted in Figure 59. The species compositions of these distinct zones are presented in Table 9.

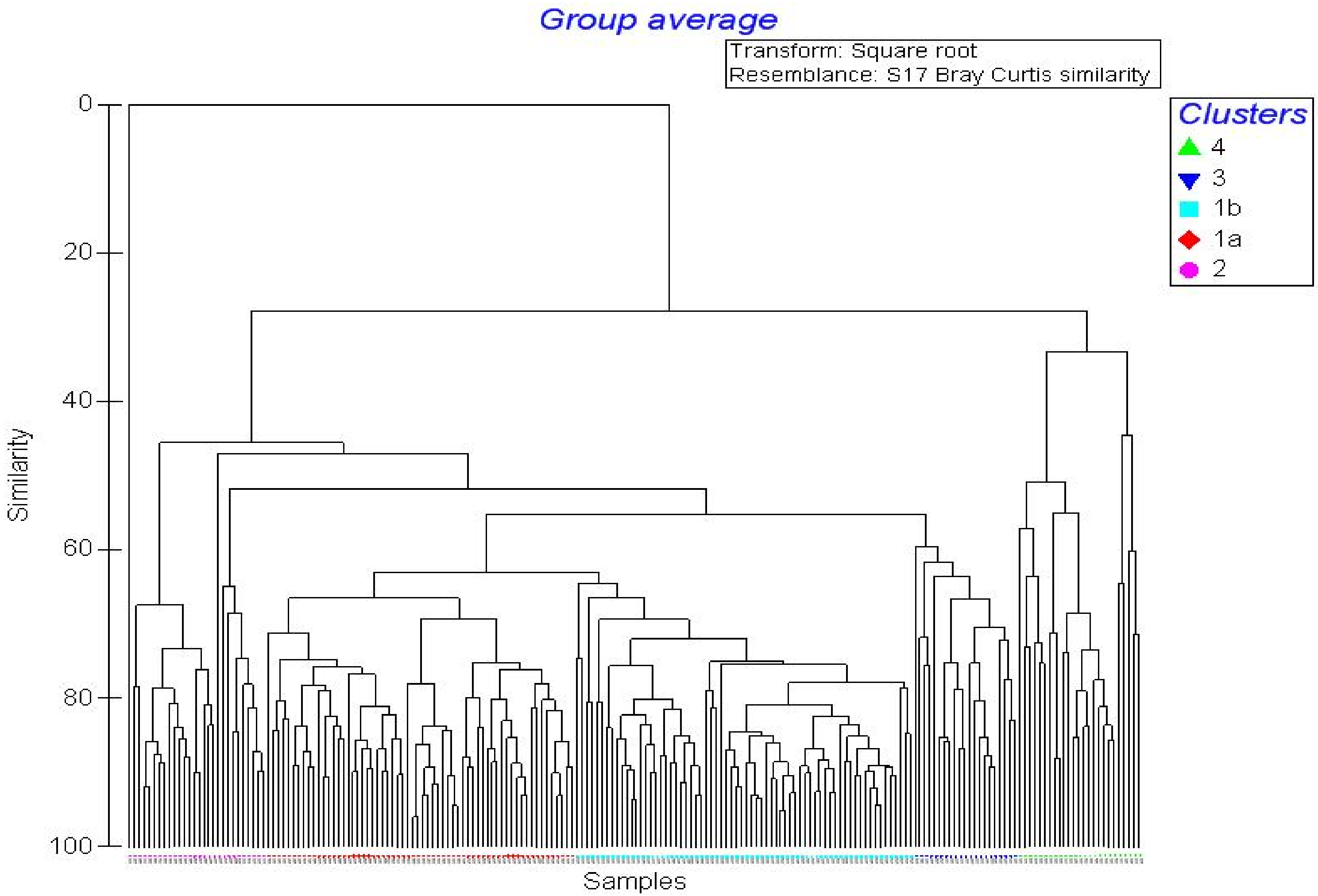

Figure 58: Group average linkage Dendrogram on sample statistical squares based upon bird density averages over the period 1980 to 2004 for the North Sea.

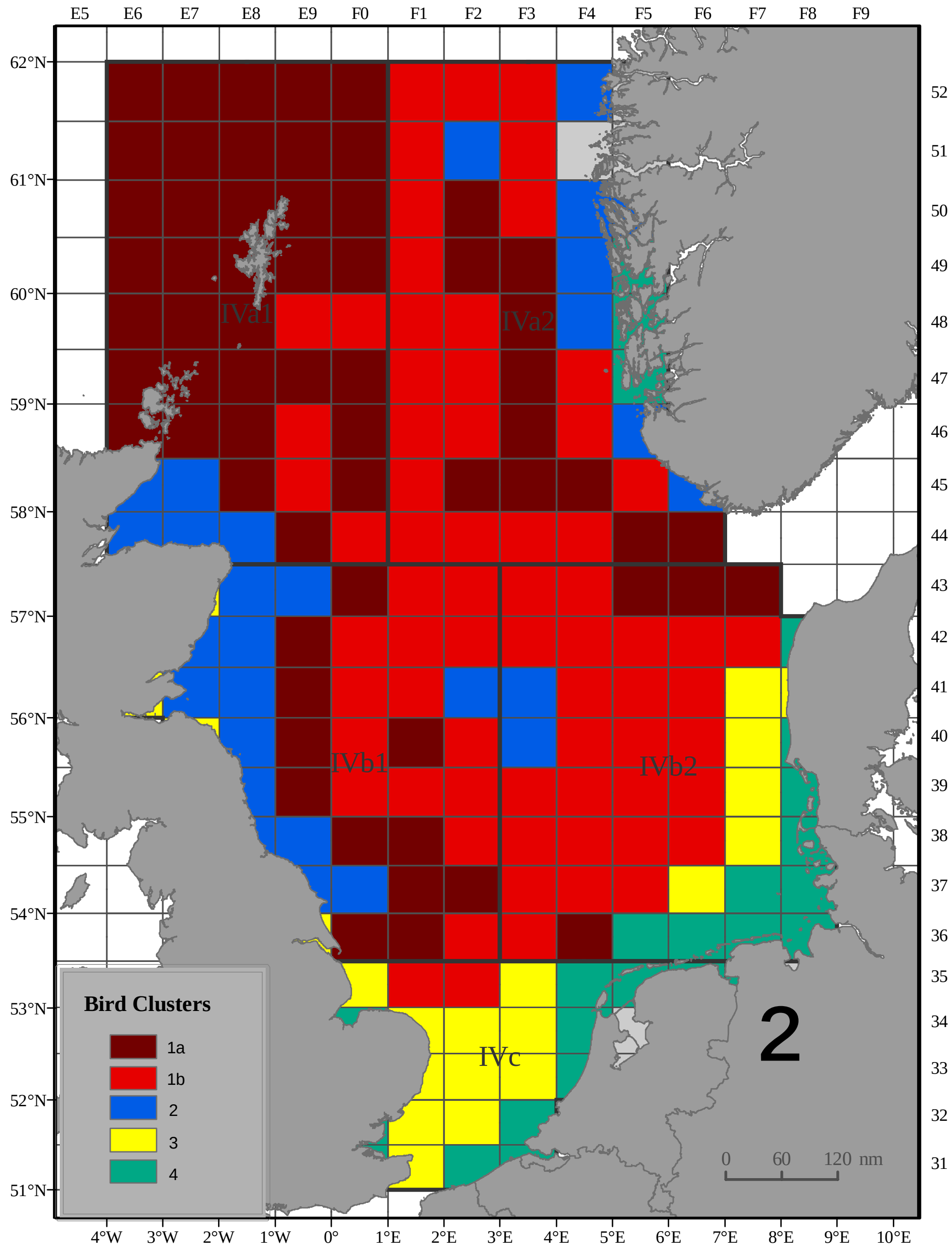

Figure 59: Distribution of sea bird clusters in the North Sea based upon species statistical .squares averages between 1980 and 2004. See Table 9 for a list of the bird species associated with each cluster.

Table 8: Species and pseudospecies used in the analysis and the ESAS species or pseudospecies that they comprise.

Species and pseudospecies used in this study	Equivalent species and pseudospecies in the ESAS database
auks	Atlantic Puffin Black Guillemot Common Guillemot Common guillemot/razorbill Little Auk Razorbill Unidentified auks
Black-legged Kittiwake	Black-legged Kittiwake
large gulls	Glaucous Gull Great Black backed Gull Herring Gull Lesser-black backed/herring gulls Lesser Black-backed Gull Unidentified black-backed gulls Unidentified large gulls
Northern Fulmar	Northern-Fulmar
seaduck	Common-Eider Common-Scoter Greater-Scaup Long-tailed-Duck Red-breasted-Merganser Unidentified scoters Velvet Scoter
Northern Gannet	Northern Gannet
European Shag	European Shag
shearwaters	Manx Shearwater Sooty Shearwater Unidentified shearwaters
terns	Arctic Tern 'commic' terns Common Tern Little Tern Sandwich Tern Unidentified terns
Common gull	Common gull
skuas	Arctic Skua Great Skua Long-tailed Skua Pomarine Skua
Little Gull	Little Gull
divers	Black-throated Diver Red-throated Diver Unidentified divers
Great Cormorant	Great Cormorant
Black-headed Gull	Black-headed Gull
storm-petrels	European/Leach's storm-petrel European-Storm-petrel Leach's-Storm-petrel
grebes	Great-crested Grebe Unidentified grebes

It is important to note that the factor driving the clustering is not bird densities *per se* but similarities in bird densities. Similarly low densities among ICES rectangles may be equally important in determining clustering as high densities. The generally similar densities of auks and large gulls among ICES rectangles for example indicate that these species generally co-occur throughout the study area.

From Table 9 it is clear that the dominant species complements within each community cluster differed to some degree. Auks, large gulls, skuas, terns and divers generally occurred at relatively higher densities in the clusters.

Cluster 1a appears to have a generally northerly and near coast (but nevertheless clearly offshore) bias, the similarity of its constituent ICES rectangles being accounted for principally by auks, large gulls and skuas. This species composition at high densities accords well with the general northerly (e.g. skuas) and near coastal offshore (e.g. auks) distribution of the birds. Skuas breed only in the Northern Isles of the UK within the North Sea study area (Mitchell *et al*. 2004). Large concentrations of auks occur off the east coast of the UK during the breeding season and off the coast of southern Norway after the breeding season when large numbers congregate in the Kattegat (Stone *et al*. 1995). Large gulls are widely distributed, however. Low average densities of Northern Fulmar in this cluster are probably accounted for by variation in survey coverage as well as actual low densities in many of the ICES rectangles that hosted very similar average densities of other species.

Cluster 1b is also typified by auks, large gulls and skuas, which occur in similar proportions to Cluster 1a. The geographical zone here though is rather diffuse and may be strongly influenced by the very similar winter distributions of large gulls and auks in the central and northern North Sea.

Cluster 2 is described by rectangles whose similarity to each other is strongly determined by auks and large gulls but also terns. With the exception of an area in the middle of the North Sea this cluster is represented by a strictly coastal zone, again mainly in the northern North Sea. Coastal areas off southern Norway host large numbers of auks, especially Common Guillemots and Razorbills, which appear to migrate after the breeding season from the north of Britain eastwards to the Norwegian coast and then south to winter in the straits between Norway and Denmark. Non-breeding terns are thought to use certain areas in the central North Sea.

The geographical extent of Cluster 3 has a largely southern North Sea bias, mainly on or near coastal areas. The species occurring in highest densities here are the terns. Auks and large gulls also occur here in similar, albeit relatively low densities.

The occurrence of divers in high densities in Cluster 4 is not surprising as the predominant (and very large) concentrations of these in the study area, especially red-throated divers, occur outside the breeding season along the coasts of the Low Countries and also in the Wash and Greater Thames area in SE England – largely corresponding to the geograohical extent of the Cluster 4 zone. Not surprisingly, terns also occur at relatively high densities in this zone, while very similar, but relatively low densities of auks occur here. The highest densities of seaduck also occurred within Cluster 4 – again according with known wintering concentrations of these.

It is worth reiterating that the (bio)geographical zones highlighted here are typified by similar densities within species, not necessarily high densities. The densities of species recorded within the zones (Table 9), however, do broadly accord with expectations based on published accounts of seabird dispersion (Stone *et al*., 1995). Table 10 indicates for those species/pseudospecies the cluster/zone in which highest average densities of each were recorded. Seeming anomalies, such as generally low densities of Northern Fulmar within most zones might be explained by spatial and temporal patchiness in survey coverage. The biogeographical zonation resulting from cluster analysis of the seabirds at sea data might then usefully be applied in exploring further relationships between seabird communities and other large-scale abiotic and biological attributes of the North Sea environment.

Table 9: Species composition of the five seabird community clusters, showing average densities of each species/pseudospecies and their relative importance to overall average bird density (individuals/km^2) in each cluster. Species densities >10% of the total average bird density are emboldened.

SPECIES/PSEUDOSPECIES	CLUSTER 2		CLUSTER 1A		CLUSTER 1B		CLUSTER 3		CLUSTER 4	
	Average density	%	Average density	%	Average density	%	Average density	%	Average density	%
auks	66.89	58.06	14.15	30.72	5.27	37.07	5.96	28.98	3.66	1.89
Black-legged-Kittiwake	<1	0.04	<1	0.02	<1	0.08	<1	1.14	4.30	2.22
large gulls	18.78	16.30	5.15	11.19	1.72	12.12	2.65	12.90	2.09	1.08
Northern-Fulmar	<1	0.21	<1	0.09	<1	0.34	1.38	6.69	7.05	3.65
seaduck	<1	0.07	<1	0.01	<1	0.06	<1	3.98	1.12	0.58
Northern-Gannet	1.84	1.60	<1	0.26	0.00	0.00	<1	0.16	<1	0.00
European-Shag	<1	0.06	<1	0.00	0.00	0.00	<1	0.14	<1	0.20
shearwaters	0.00	0.00	0.00	0.00	0.00	0.00	<1	0.04	<1	0.36
terns	12.81	11.11	3.09	6.71	<1	5.35	6.31	30.64	24.26	12.53
Common gull	<1	0.15	<1	0.02	<1	0.02	<1	0.37	<1	0.52
skuas	7.83	6.80	21.05	45.70	5.76	40.52	1.62	7.90	<1	0.24
Little-Gull	2.37	2.06	1.58	3.42	<1	3.39	<1	3.12	<1	0.23
divers	3.15	2.73	<1	0.04	<1	0.05	<1	1.88	144.90	74.89
Great-Cormorant	<1	0.28	<1	0.08	<1	0.05	<1	0.19	<1	0.00
Black-headed-Gull	<1	0.21	<1	0.70	<1	0.35	<1	0.30	<1	0.02
storm-petrels	<1	0.03	<1	0.68	<1	0.18	<1	0.01	<1	0.00
grebes	<1	0.27	<1	0.36	<1	0.40	<1	1.58	3.06	1.58

5.4.2 Time-series analysis

Results of the ordination of seabird density across the whole North Sea are depicted in Figure 60 which indicates some discrete clustering of the bird data into perhaps three, possibly four time periods within each of which there were high degrees of similarity in recorded bird species densities. Clusters for the most part comprised years that were temporally contiguous with each other (Table 10). These clusters are presented in Table 11. The possible reasons for variation in recorded bird density over the available time series are probably diverse. Certainly survey effort was greater in the earlier years of data collection (1980s) than in later years (say, since 1995). Similarly, spatial bias in survey effort over the years may also account for observed differences; differential survey effort over the years within the biogeographical zones identified clearly might result in spurious differences in temporal patterns of bird density.

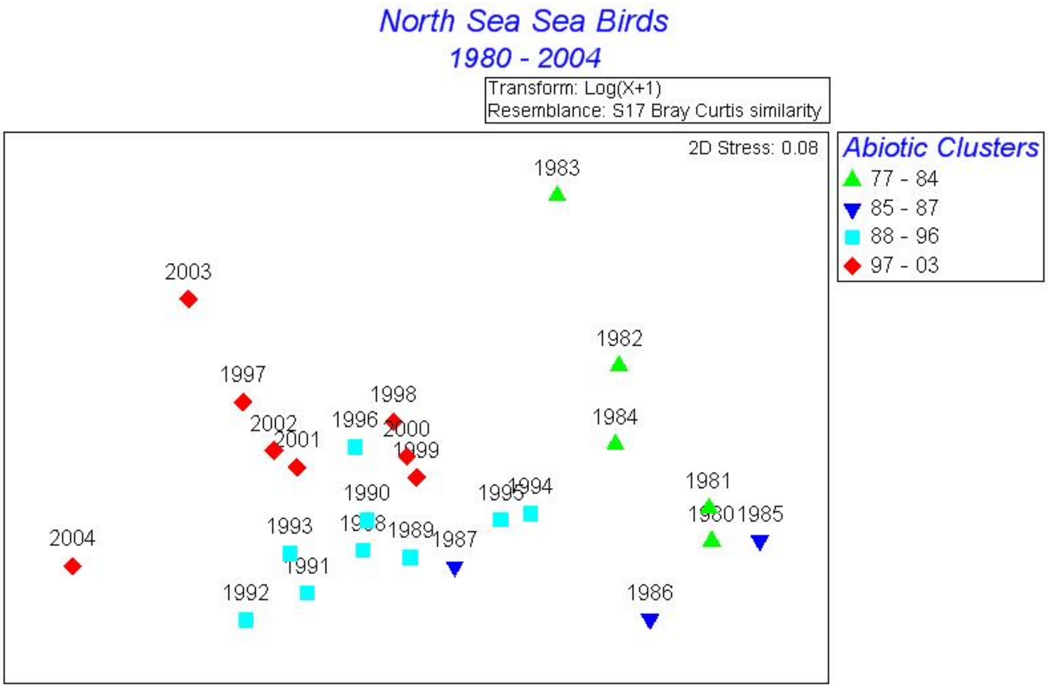

Figure 60: MDS ordination of seabird data based upon annual average densities for the entire North Sea between 1980 and 2004. The samples have been colour coded according to the abiotic clusters in the PCA.

Table 10: Years grouped into clusters within which there were high degrees of similarity in recorded bird species densities.

CLUSTER	YEARS
1	1980–1982, 1984–1986
2	1997, 2001–2003
3	1991–1993
4	1987–1990, 1994–1996, 1998–2000

Table 111: Species and pseudospecies recorded in significant average densities (see Table 2) and the biogeographical zone in which highest densities were recorded. An indication is offered whether these zones are those expected to host highest densities based on known ecology of the species.

SPECIES/PSEUDOSPECIES	DENSITY ZONE		ACCORDS WITH PUBLISHED SOURCES?
	Highest	Lowest	
auks	2	4	Yes
Black-legged-Kittiwake	4	1a, 1b, 2, 3	No
large gulls	2	1b	Yes
Northern-Fulmar	4	1a, 1b, 2	No
seaduck	4	1a, 1b, 2, 3	Yes
Northern-Gannet	2	1b	Yes
terns	4	1b	Yes
skuas	1a	4	Yes
Little-Gull	1b	1b, 3, 4	Yes
divers	4	1a, 1b, 3	Yes
grebes	4	1a, 1b, 2, 3	Yes

It is important to note here that the seabird data were resolved within (very large) ICES rectangles summed over a period of 25 years. Given the degree of caution that this demands of the results of the analyses, one outcome is a relatively coherent and meaningful biogeographical zonation of the North Sea, and one which may serve to place future integrated assessment involving seabirds in a coherent spatial framework. The temporal clustering of the data probably reflect differential survey coverage over the time of data collection, and perhaps merit more consideration as a contextual tool than is possible here, but what is apparent is a gradient in time which is consistent with the abiotic gradient observed over the same time period suggesting a degree of correlation between the marine environmental state and the North Sea seabird community structure.

5.5 Cetaceans

Data on the distribution of cetaceans in the North Sea are hosted in the Joint Cetacean Database (JCD), a composite database hosting effort-related data from Joint Nature Conservation Committee, Sea Watch Foundation, and Sea Mammal Research Unit databases (Reid *et al*. 2003). These data were collected from a variety of moving and static platforms including ships of opportunity, research vessels, and headlands.

The methods used in collecting the data varied but they were rendered compatible for inclusion in the JCD by generalised additive modelling (see Reid *et al*. 2003). The data that may be used in integrated assessments were collected between 1979 and 1999. In the JCD, encounter rate as a measure of relative abundance is of two possible sorts, dependent on species data richness – a species specific encounter rate corrected for sea state expressed in numbers of animals encountered per standardised hour (species with many data) or a simple encounter rate expressed as in terms of hours of survey (species with fewer data). Data in the JCD are stored at the scale of ¼ ICES rectangle (i.e. cells measuring 15’x30’ lat/long). Average densities might be computed for ICES stat squares by computing a simple average of the relative abundance data for each species for each of the four ¼ ICES rectangles comprising an ICES stat square. The resulting data should be treated with caution as survey coverage may have differed between the ¼ ICES rectangles that comprise an ICES stat square (though survey coverage within ICES stat squares appeared fairly similar over all years represented in the JCD).

Ideally, cetacean dispersion data should be subject to similar treatment as that for other higher marine vertebrates in the present integrated approach. However, data on these difficult to observe and rather elusive animals proved to be too few in order to conduct, for example, a spatial cluster analysis analogous to that carried out for other taxa (e.g. seabirds, plankton). The species for which most relative abundance data exist in the North Sea is the harbour porpoise. Over the time period in which the data were collected a clear geographical pattern in the species’ distribution is evident. Harbour porpoises appear to be rather more abundant in the northern North Sea than in the southern part. However in the period since these data were collected there would appear to have been changes in the relative abundance in these two broad areas, with decline in the north and growth in the south. This probably reflects a shift in the distribution of the species rather than change in population size (Hammond pers. comm.), a shift that might be attributable to other changes in the North Sea outlined in this report.

Other species of cetacean that occur frequently in the North Sea include the white-beaked dolphin (Figure 62), the bottlenose dolphin (Figure 63), and the minke whale (Figure 64). Changes in the distribution of these that might reflect more wide-ranging North Sea ecosystem changes are currently being investigated.

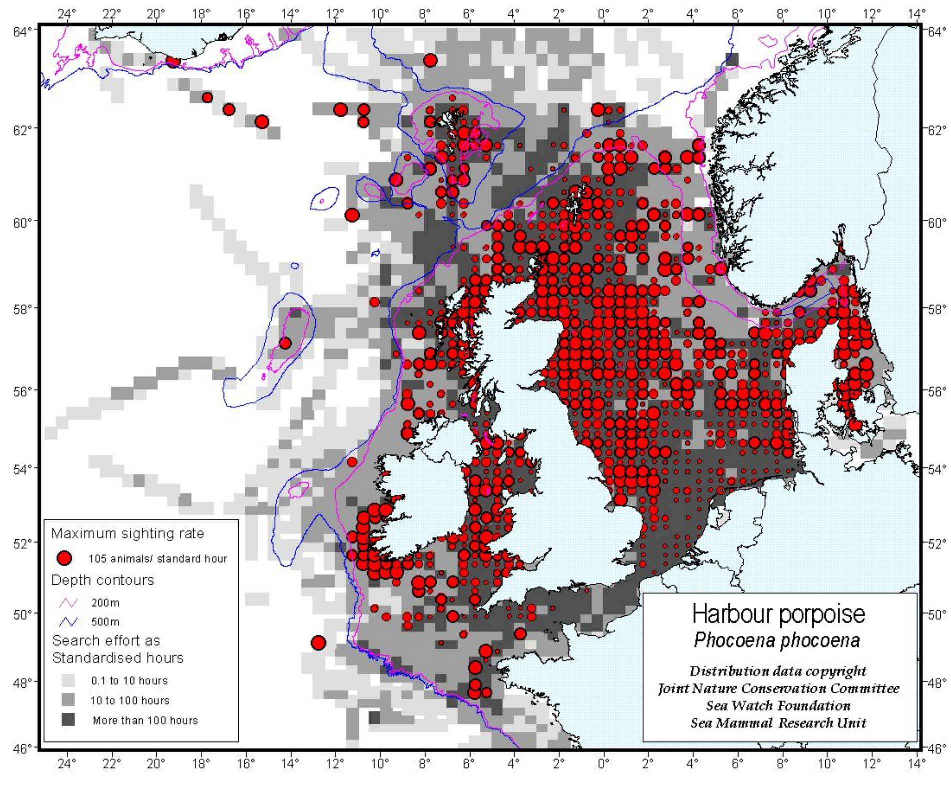

Figure 61: Distribution of the harbour porpoise (see Reid *et al.* 2003 for details).

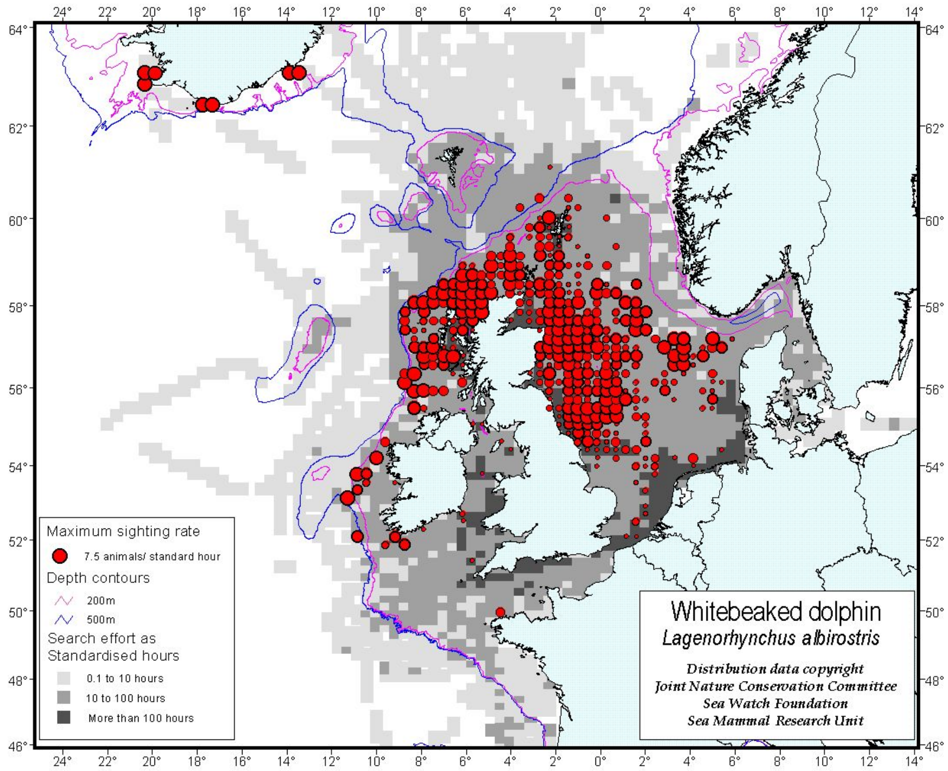

Figure 62: Distribution of the white-beaked dolphin (see Reid *et al.* 2003 for details).

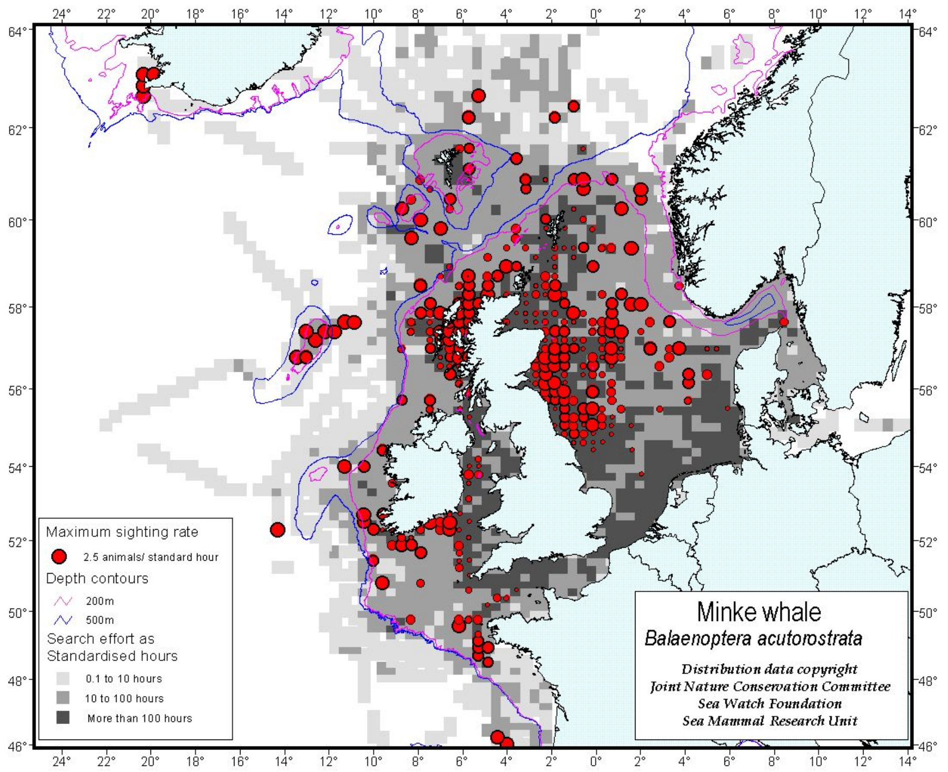

Figure 63: Distribution of the minke whale (see Reid *et al.* 2003 for details).

For future integrated analyses of North Sea data, the present JCD should be augmented by the inclusion of recently collected data. For example the Small Cetacean Abundance in the North Sea project (SCANS; Hammond et al. 200X) has recently (2005) been repeated, and various other data-sets exist that might usefully be brought within the JCD. Inclusion of these data-sets should enable wide-ranging analyses to be conducted, analyses that should aim to place the (changing) distribution and status of cetaceans in appropriate biogeographical and ecological contexts.

5.6 References

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich-Boran, S., Hiby, A.R., Leopold, M.F. and Øien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39: 361–376.

Reid, J.B., Evans, P.G.H. and Northridge, S.P. (eds.) 2003. Atlas of cetacean distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough.

6 Relating state variables of the ecosystem with human pressures according to themes (eutrophication, pollution, conservation, fisheries, climate, and management), (ToR a (ii))

6.1 Scope for May 2006 Workshop

It was not sensible to begin the assessment of impacts until sufficient work had been completed on the second overview. From a consideration of the availability of appropriate data, and the limited resources available to REGNS, it was decided to focus on the impact of ocean climate variability, state changes in plankton, fish and seabirds and two human pressures: nutrient inputs and fisheries. This task was undertaken during the latter part of the workshop. Contaminants and sediment extraction activities were not undertaken due to lack of data available to REGNS and their being no representatives from the relevant working groups. Indeed the issue of regional scale assessment and contaminants data particularly in sediments is the subject of intensive investigation by a number of ICES working groups and their individual members who are also contributing to an OSPAR MON assessment on this subject.

In the sections describing the state changes (above) we have integrated where possible changes in the abiotic and biotic state conditions using methods recommended by WGECO 2006. In the following sections we now try and identify significant relationships between nutrient pressures, state changes in plankton communities, fish and sea birds.

6.2 Impact of large-scale forcing on North Sea ecosystem

The factors influencing changes in North Sea temperature and circulation were discussed in Section 5.1 and these demonstrated a close relationship with the NAO and seawater fluxes in the North Sea. These climate forcing conditions, including their variability and trends, provide the basis of assessing the background ecological state conditions and to determine the significance of human impacts.

6.3 Impact of eutrophication on North Sea ecosystem

6.3.1 Definition of eutrophication

The EC definition (in the Urban Waste Water Treatment Directive, 1991). Eutrophication is:

"the enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned."

The **Redfield ratio**, which is often taken as the ratio of elements needed for 'balanced' or healthy growth of phytoplankters, is 16:1 (atoms of N:atoms of P), and this is roughly the nutrient element ratio observed in offshore marine waters during winter.

6.3.2 Introduction

The objective of this thematic assessment was to integrate data relating to the nutrient inputs from different sources, namely; rivers and the influx of oceananic nutrients, in order to assess their relative contribution to the state changes in the plankton communities in the North Sea. Clearly, the outputs from this assessment need to be integrated with those dealing with different components of the ecosystem such as fisheries (see Section 6.4) and seabirds (see Section 6.5) in order to identify the critical connections and the most relevant pressures to be managed and this is the subject of Section 7 in this report.

The components of the ecosystem assessed in this theme are; **i.** nutrient loads (as riverine inputs), **ii.** nutrient state (as ICES gridded data for the North Sea), iii. ocean climate forcing (measured as changes in seawater flux, temperature, etc) and, **iii.** plankton state (as gridded CPR data).

6.3.3 River Loadings

The North Sea has a catchment area of about 850,000 km. The annual freshwater river input is in the order of 300 cubic km, with major contributions from rivers such as the Elbe, Weser, Rhine, Meuse, Scheldt, Seine, Thames and Humber (Figures 64 and 65), and about one-third coming from the snow-melt waters of Norway and Sweden. In addition, a large quantity of fresh water is supplied by the outflow of the Baltic Sea.

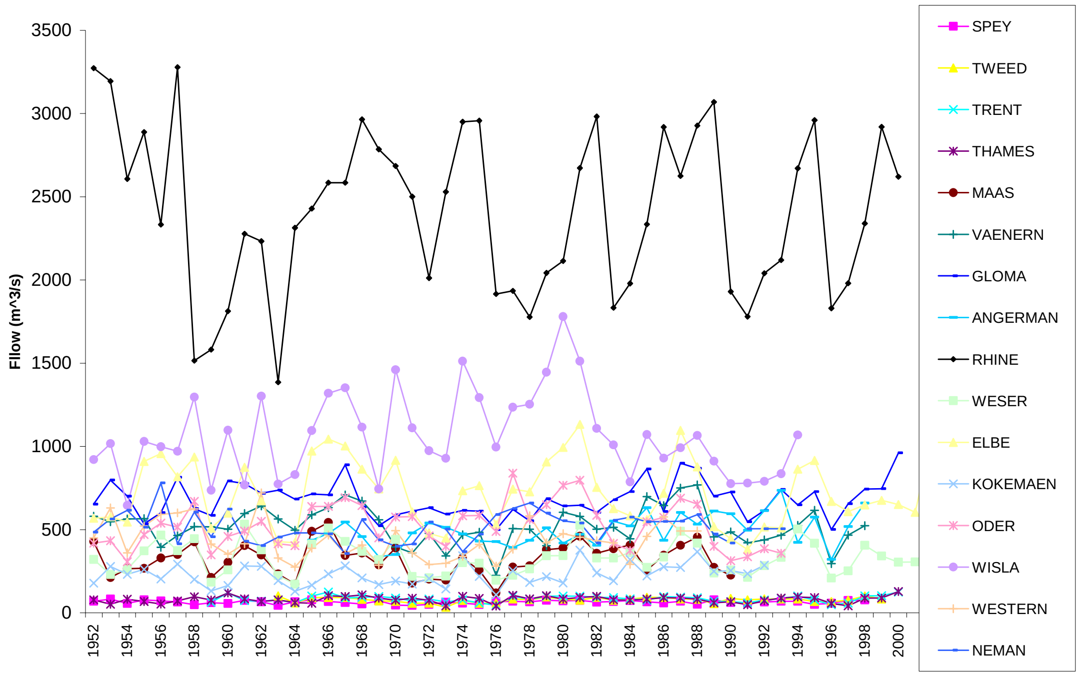

Figure 64: Freshwater flow into the North Sea, including inputs via the Baltic (e.g. River Wisla-Vistula, 1952–2001 (compiled by Sarah Hughes, FRS).

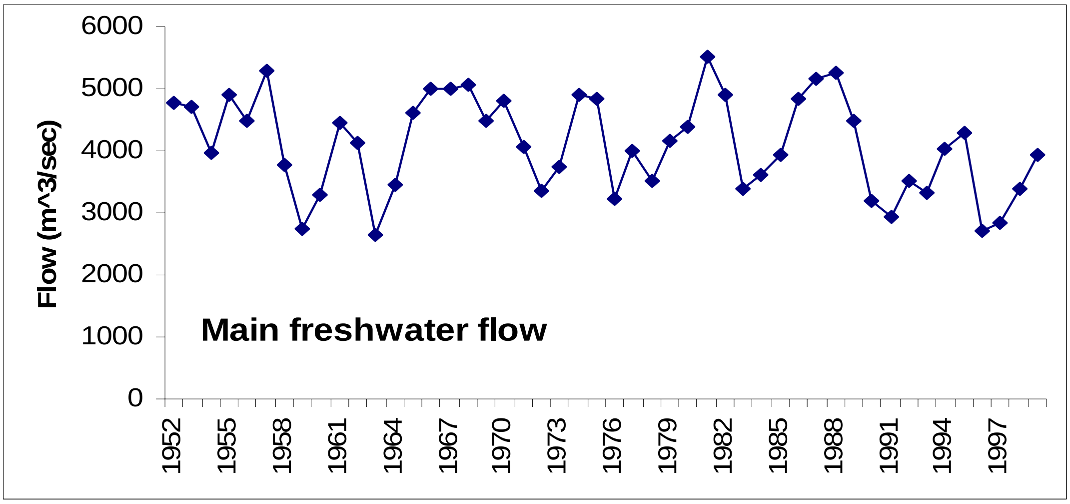

Figure 65: Combined freshwater flow into the North Sea from the 8 principal rivers, 1952-2001 (compiled by Sarah Hughes, FRS).

6.3.4 Nutrient Enrichment

Nutrient inputs enter the North Sea primarily as a result of seawater fluxes from the north east Atlantic and riverine (land based) inputs from the major rivers entering the southern parts of the North Sea. In addition atmospheric sources are also likely to be significant but these data have not been assessed. Riverine volume flow is dominated by a few large sources, however nutrient loading was calculated from all the main rivers discharging into the North Sea, including the UK rivers which tend to have low flows but relatively high nutrient concentrations, based on OSPAR RID and other sources compiled for model simulations using ERSEM (Mills *et al*, 2006). The annual-averaged total loading of DIN (dissolved inorganic nitrogen) and DIP (dissolved inorganic phosphate), for inputs direct into the North Sea, is shown in Figure 66. DIN and DIP have been subject to significant inter-annual variability, although loading does not correlate directly with the freshwater flow. Annual DIP loads decreased significantly from about 1987, presumably related to changes in land-based management of direct P sources (i.e. sewage treatment). Loadings into each of the five ICES sub-regions of the North Sea were estimated using the present data which revealed loadings to be much higher in region IVc, reflecting the considerable inputs from the Rhine and Elbe. In contrast, Scottish rivers discharging into region IVa1 have low nutrient loading and relatively low flows.

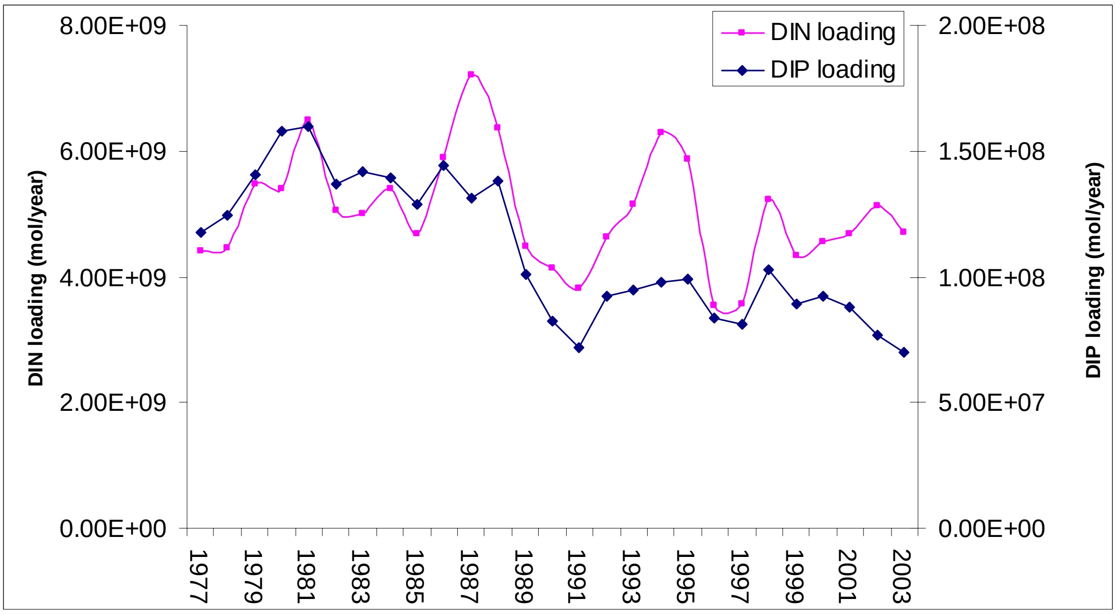

Figure 66: Total nutrient loading into the North Sea due to rivers (excluding minor sources).

We examined the correlation between nutrient loading and nutrient concentrations in each of the five regions of the North Sea (IVa1, IVa2, IVb1, IVb2 and IVc) based upon averaged ICES gridded data. Nutrient concentrations were taken as annual-averaged values from the ICES hydrographic database. A refinement of this approach would be to use winter values only. Without considering the sampling month the data may be biased by seasonal variations in the data. The results presented here should be considered as indicative of the observed trends but further data mining and analysis is required.

6.3.4.1 Region IVa1 and IVa2 (Northern North Sea)

Figure 67 shows that both regions IVa1 and IVa2 in the northern region of the North Sea are strongly influenced by the inflow of Atlantic water and that there is a significant increase in DIN since 1973 possibly associated with inputs from the north east Atlantic. In addition, the surface waters of Region IVa2 are influenced by the Baltic Sea outflow, and transport of waters from the southern North Sea, and these remain significant sources of both DIN and DIP for this region. Trends in DIP concentrations show similar trends (although not as significant) as DIN. By contrast both DIP and DIN loadings are highly variable and do not exhibit a clear trend over time. This would suggest that some other pressure (possibly associated with north east Atlantic or atmospheric inputs) represents a significant source of nutrients into the North Sea. Clearly this assertion requires further investigation.

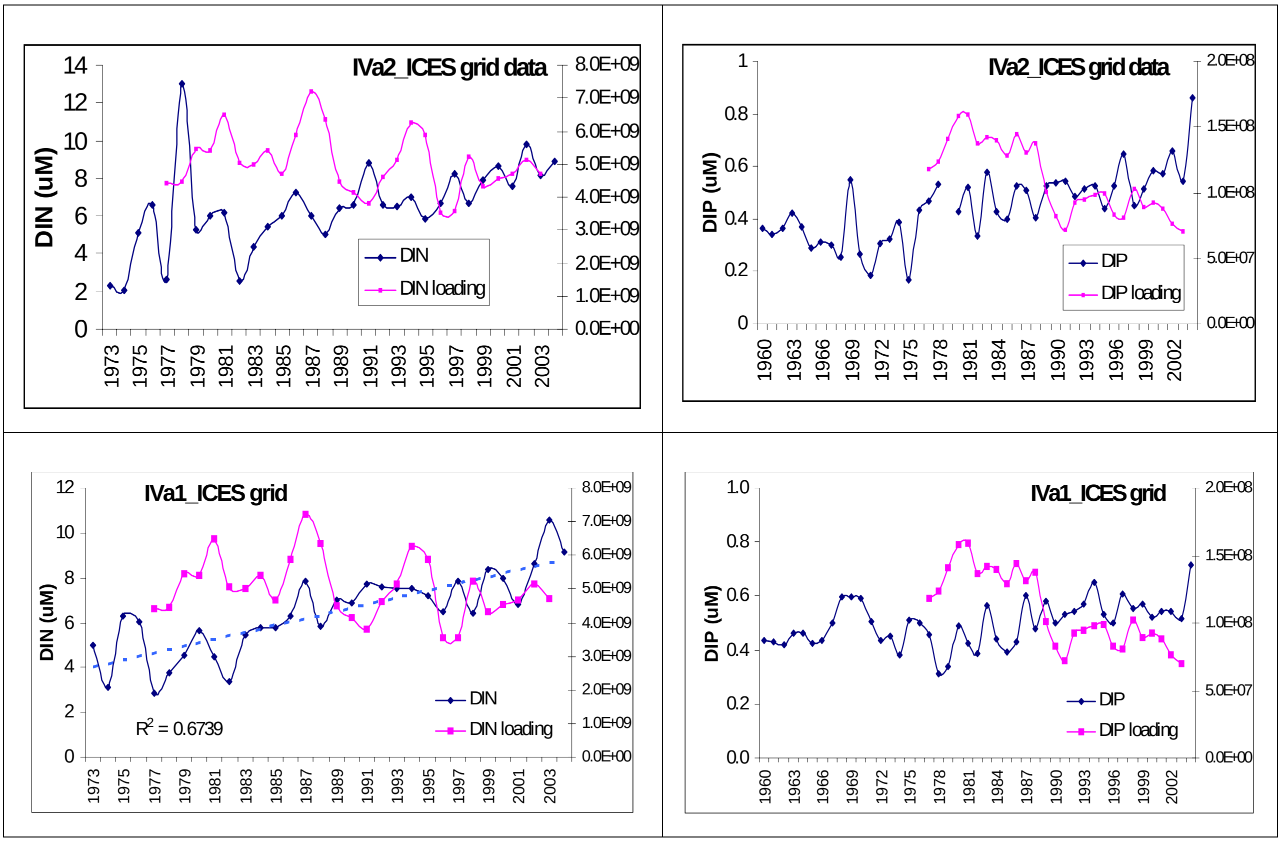

Figure 67: Estimated nutrient loading (Mills *et al.*, 2006) and observed mean annual DIN and DIP concentrations for northern regions of the North Sea using ICES gridded data.

6.3.4.2 Region IVb1 and IVb2 (West Central and East Central North Sea)

Figure 68 shows the average concentrations of DIP and DIN and the associated river loadings for regions IVb1 and IVb2. Unlike region IVa there is little discernable trend over time in either the DIP or DIN concentrations. However there is some evidence of a slight decreasing trend in the loadings associated with the river inputs. It is noteworthy that in region IVb2 (where the freshwater influence of river inputs is arguably at it greatest) there is a strong correlation between DIN loadings and DIN concentrations., with peaks in annual concentrations aligning with high nutrient loading, indicating a possible strong coupling of nutrient concentrations and riverine discharge for this area of the North Sea.

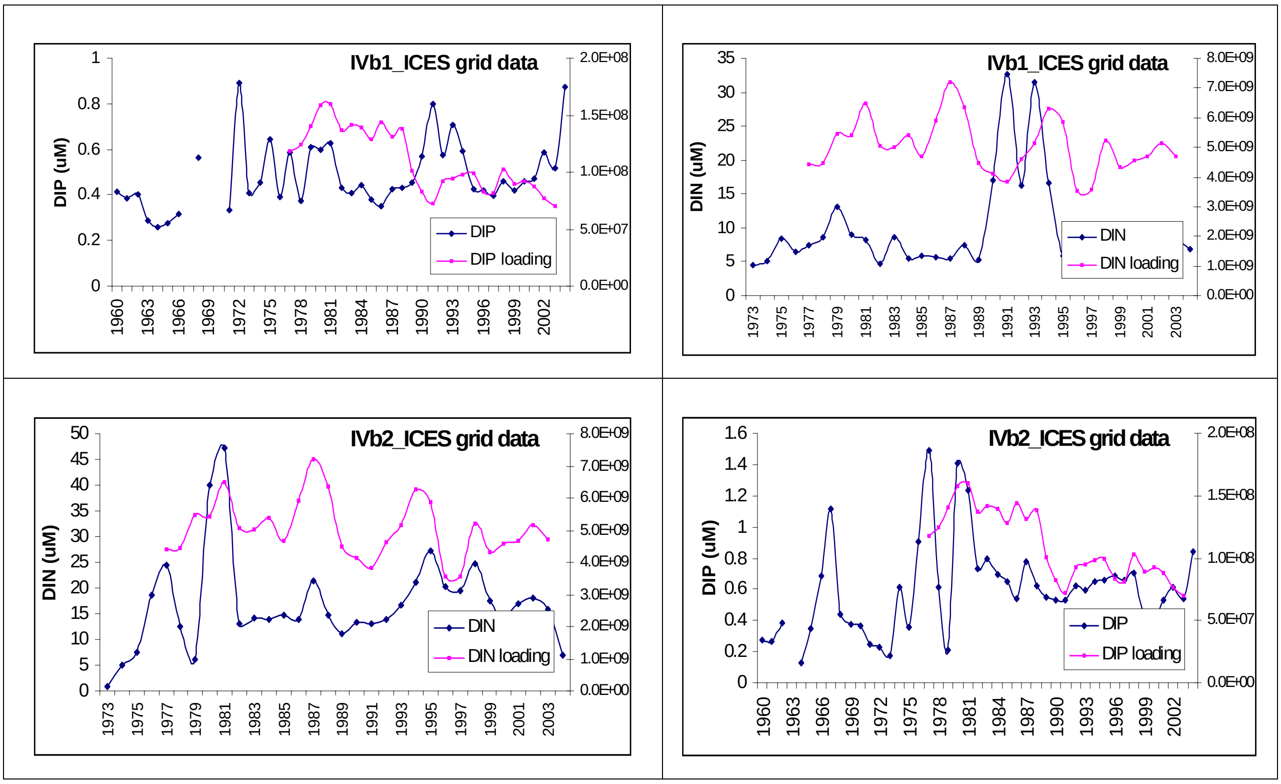

Figure 68: Estimated nutrient loading (Mills *et al*., 2006) and observed mean annual DIN and DIP concentrations for central regions of the North Sea using ICES gridded data.

6.3.4.3 Region IVc (Southern North Sea)

Region IVc is directly influenced by river loadings and also inputs from the English Channel. In general both the DIP and DIN concentrations have shown a decrease in concentration since the late 1980's and there is some evidence to suggest that this may be related to decreasing loadings from rivers as shown in Figure 69. However, the correlation between inputs and concentrations for DIN in this region is not as great as that seen in region IVb2. This is perhaps to be expected since the vast quantity of freshwater inputs into the southern North Sea enter region IVb2, principally the Rhine, whereas the relative freshwater inputs in region IVc are lower. Nevertheless the inputs of nutrients are high in this region (Table 12) but the lack of correlation with riverine sources may indicate some other significant sources which are not taken account of, principally sources from the English Channel and possibly atmospheric sources. It is interesting to note that in terms of regional average concentrations of DIN and Chlorophyll which have been averaged between 1975 and 2004 that there is a strong spatial correlation (Figure 70) with regions IVb1 and IVb2 and IVc having higher concentrations than regions IVa1 and IVa2.

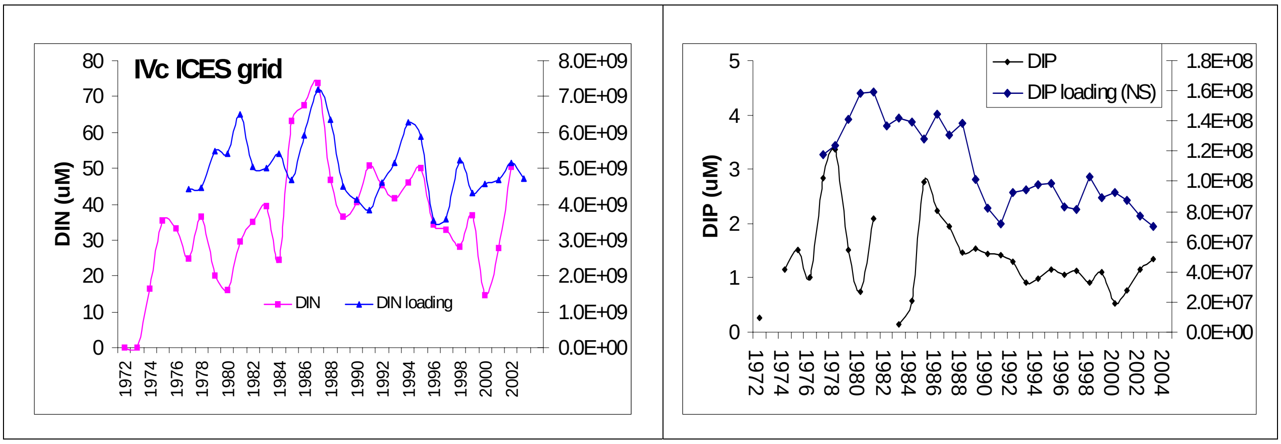

Figure 69: Estimated nutrient loading (Mills *et al.*, 2006) and observed mean annual DIN and DIP concentrations for southern regions of the North Sea.

Table 12: Annual average values for DIN and Chlrophyll as 5 year averages.

	75-79	80-84	85-89	90-94	95-00	00-04	Ave.			
Region	Annual average DIN concentrations (uM) over 5 year period									
IVa1	4.9	5.1	6.7	7.4	7.3	8.7	6.68			
IVa2	7.3	5	6.1	7.1	7.7	8.8	7.00			
IVb1	8.8	7.5	5.9	22.8	5.2	7.3	9.58			
IVb2	13.8	25.7	15.2	15.6	21.8	14.6	17.78			
IVc	9.8	10.2	13.4	14.9	14.5	17.3	13.35			
	1960-64	65-69	70-74	75-79	80-84	85-89	90-94	95-00	00-04	Ave.
Region	Annual average chlorophyll concentrations (ug/L) over a 5 year period									
IVa1	0.14	0.08	0.4	1.86	1.66	1.49	0.7	1.14	0.63	1.25
IVa2	0.1	0.1	0.65	1.19	1	1.07	1.63	1.16	0.43	1.08
IVb1	0.61		0.66	1.13	1.4	0.99	1.93	5.76	0.66	1.98
IVb2			1.02	6	2.28	3.79	4.14	4.1	3.43	3.96
IVc				10.18	1.2	2.35	4.59	7.48	6.27	5.35

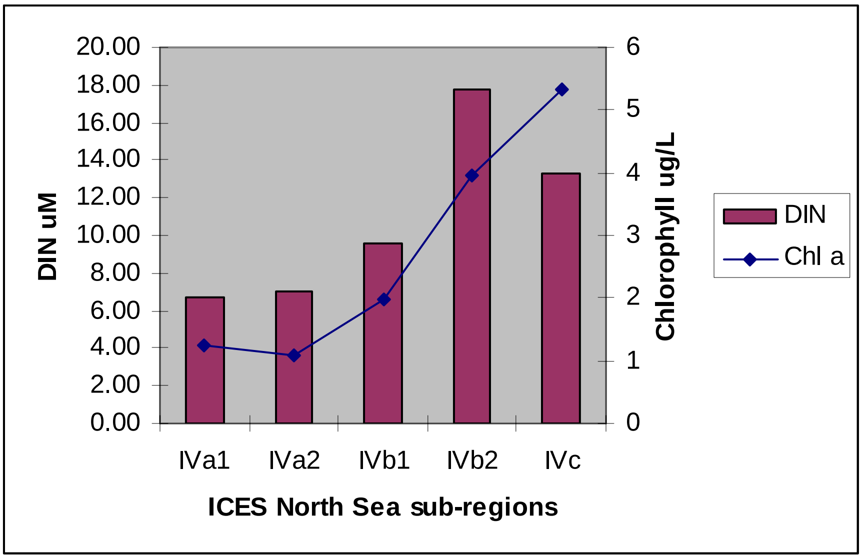

Figure 70: Average concentrations of DIN and Chlorophyll for each ICES sub region averaged between 1975 and 2004.

Perhaps of greater significance is how DIN and phytoplankton densities have changed over time in the North Sea. Figures 42 to 47 show the spatial densities of diatoms for different decades from 1950s and Figures 28 to 31 show the concentrations of DIN based upon time intervals derived from the PCA analysis of the abiotic time series data. There is seemingly a consistent pattern in both the trends for DIN concentrations and diatom densities in the northern part of the North Sea particularly in the 1980s and 1990s, suggesting oceananic sources of DIN may be an important factor in determining offshore eutrophication in parts of the North Sea. However, it should be noted that these are averages over all years by ICES Statistical square so details about changes in seasonality and inter-annual variability are not resolved. The plankton communities also reveal different trends over time for the different sub-regions. Further analysis is required but it is interesting to note that sub-regions IVc and IVb2 show some similarity and that these are both distinctive from IVa1.

6.4 Impact of fisheries on the North Sea ecosystem

6.4.1 Background to North Sea fisheries

WGFE provided much useful information, which is included as an annex. The fish assemblages in the northern North Sea (ICES Division IV a) and northern parts of the Central North Sea (ICES Division IV b) are very different to those further south, with this latitudinal gradient mirrored with corresponding gradients in depth and water temperature. The dominant fish species in trawl catches include whiting and haddock and pelagic species including mackerel and horse mackerel in the summer. In shallower waters (50–100 m depth), populations are dominated by haddock, whiting, herring, dab and plaice, while at greater depth (100–200 m), Norway pout dominate. The northern North Sea also contains a number of boreoarctic species that are rarely found further south (e.g. Vahl's eelpout and Esmark's eelpout). Further north, and in the Norwegian Deep, various species of deep-water fish (e.g. macrourids) are more abundant. The southern North Sea (ICES Division IVc), is generally shallow (<50m deep) and the dominant fish species are those that are more characteristic of inshore waters. Plaice, sole, dab and whiting are some of the dominant commercial species, and non-commercial species such as lesser weever, grey gurnard and solenette are also an important component of the fish assemblage. Sandeels (*Ammodytidae*) and sand gobies, which are poorly sampled by research trawls, are also abundant and are important prey species for many species of demersal fish. Other important fish communities/assemblages that are sampled by some national and international surveys include estuarine and inshore fish communities.

Some species of fishes that occur in the North Sea have been listed as “threatened and declining”. These include elasmobranchs (e.g. common skate and spotted ray), diadromous fishes (e.g. sea lamprey, shad and houting) and commercial species (e.g. cod). The status of these species in the North Sea may serve as another useful indicator for the health of the North Sea ecosystem.

6.4.2 Spatial analysis of Scottish and English North Sea fisheries landings data (1965-2004):

A spatial analysis of Scottish and English North Sea fisheries landings data for the period of 1965-2004 was carried out for the following species: anglerfish, cod, haddock, herring, mackerel, *Nephrops*, skate, squid and whiting. The analysis was based upon log transformed species abundance data which was then subject to group-average linkage hierarchical cluster analysis which is shown in Figure 71. The analysis revealed 6 clusters, namely; Cluster 1a was dominated by haddock landings, while all the remaining ones were dominated by cod. These are spatially shown in Figure 72 Table 13 summarises the relative importance in each cluster of the species considered (ranking of the average landings over all ICES rectangles that belong to the same spatial cluster). It is apparent that there is an order of magnitude difference in the landings between Cluster 1 and 3 and this is to be expected as the figures are based upon Scottish and English landings data only and therefore Cluster 3 which is on the eastern side of the North Sea receives less fishing pressure from the UK fishing fleet. The significant difference therefore relates to the North South divide in terms of Clusters 1a, 1b and 1c. For example 1a and 1c lie to the north of the Flamborough front, an area of water which generally divides the northern stratified region of the North Sea from the well mixed advective southern part of the North Sea, whereas cluster 1b lies to the south of the front and supports larger landings of Cod and Skate which is not included in clusters 1a and 1c. The fisheries for Scotland and England therefore are related to to a north south gradient previously described for the CPUE data from the IBTS.

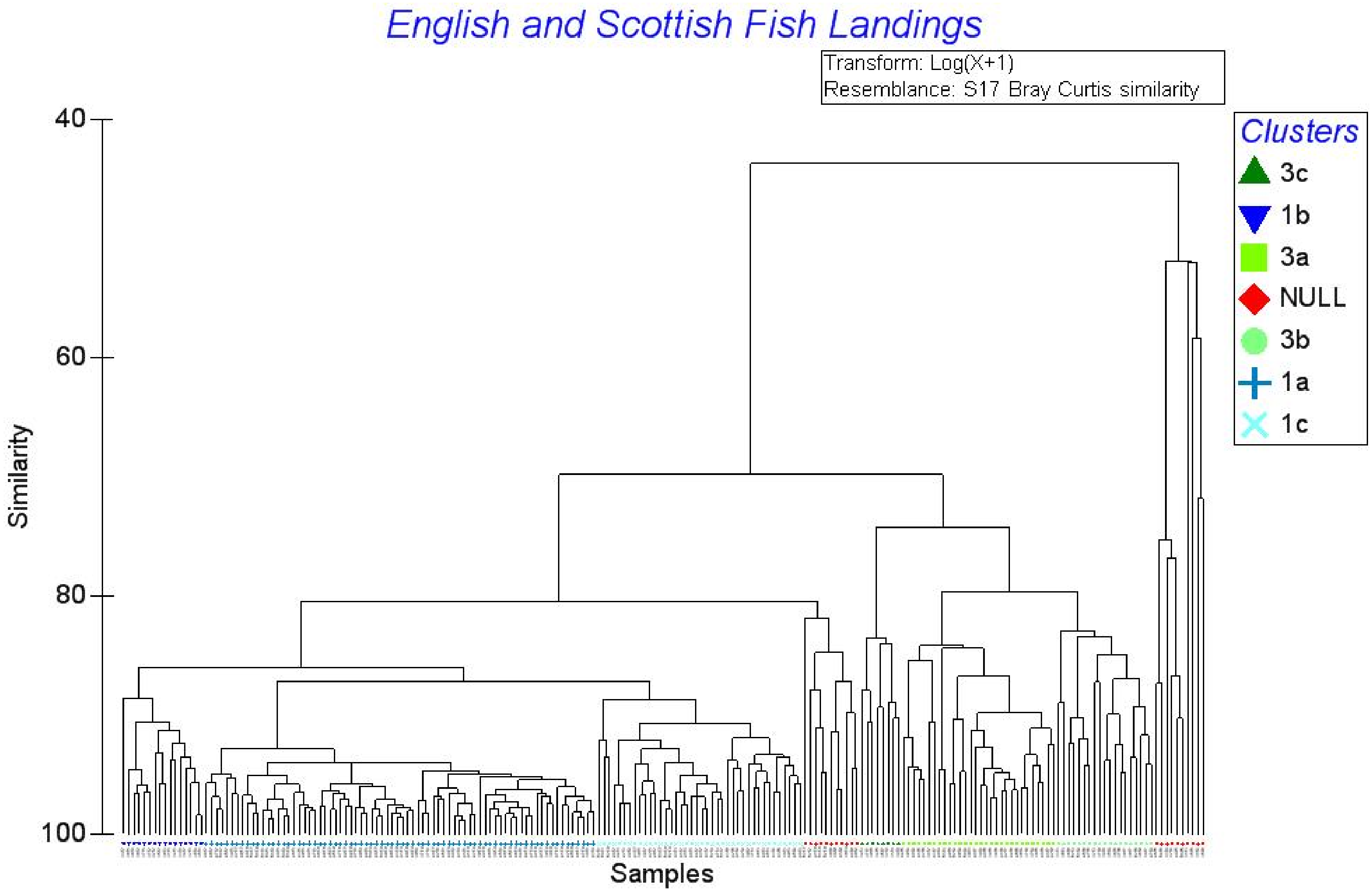

Figure 71: Dendrogram showing the relationship between stat. sqrs for the North Sea. 6 principal spatial clusters have been identified.

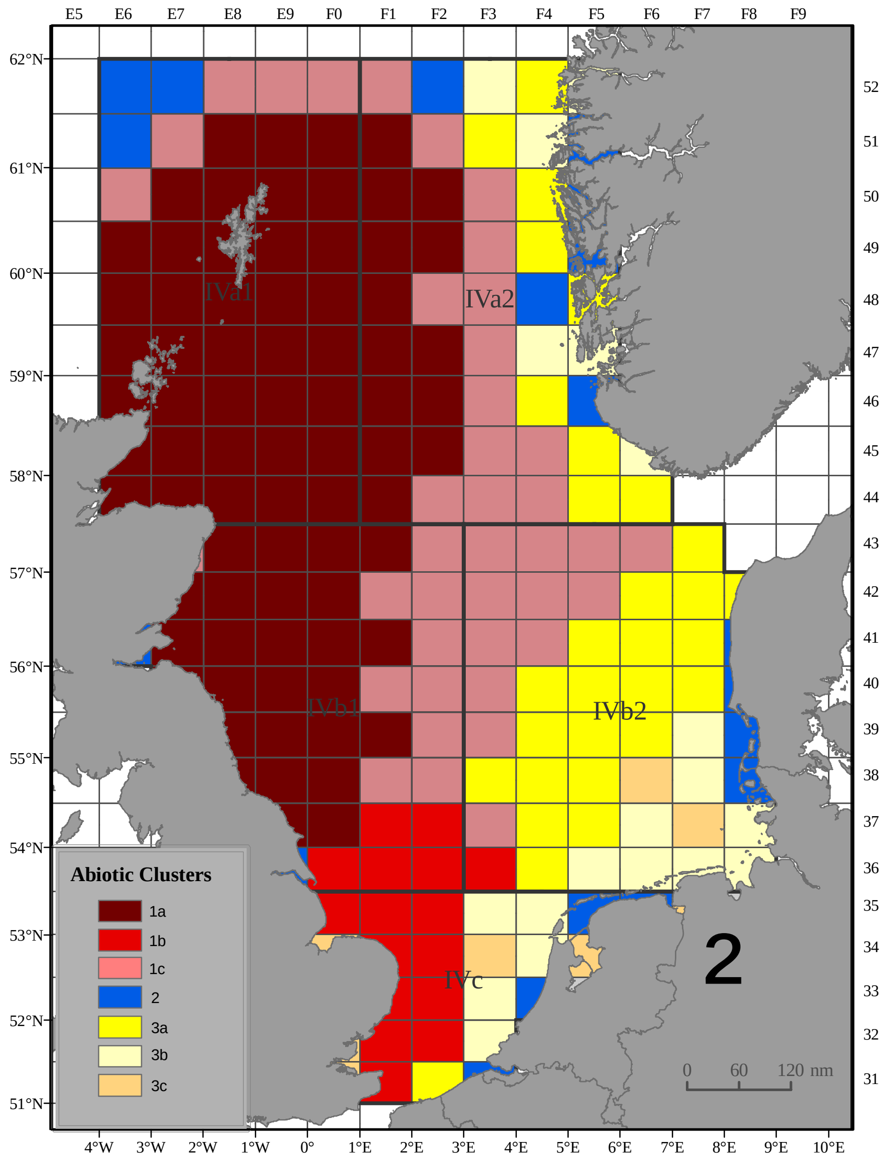

Figure 72: Spatial clusters of fish landings (not Abiotic Clusters as indicated on the key) mapped according to the outputs from Figure 71. Cluster 2 = NULL in Figure 71.

Table 13: Total fish landings for England and Scotland an average of annual landings between 1965 and 2004.

Cluster 1a				Cluster 1b				Cluster 1c		
	Ave	%MD			Ave	%MD			Ave	%MD
Haddock-Landings(kgs)	35743948.44	35.14		Cod-Landings(kgs)	15644586.85	72.61		Cod-Landings(kgs)	10220200.51	52.15
Cod-Landings(kgs)	24001293.31	23.60		Skate-Landings(kgs)	1952340.02	9.06		Haddock-Landings(kgs)	7095595.28	36.21
Whiting-Landings(kgs)	15988631.00	15.72		Herring-Landings(kgs)	1572346.08	7.30		Mackerel-Landings(kgs)	994154.72	5.07
Herring-Landings(kgs)	13221711.32	13.00		Whiting-Landings(kgs)	1093366.15	5.07		Whiting-Landings(kgs)	664212.26	3.39
Mackerel-Landings(kgs)	4811155.88	4.73		Haddock-Landings(kgs)	1035643.47	4.81		Anglerfish-Landings(kgs)	340463.07	1.74
Cluster 3a				Cluster 3b				Cluster 3c		
	Ave	%MD			Ave	%MD			Ave	%MD
Cod-Landings(kgs)	3943717.94	77.55		Cod-Landings(kgs)	538602.49	91.97		Cod-Landings(kgs)	3365097.94	83.03
Haddock-Landings(kgs)	942868.19	18.54		Haddock-Landings(kgs)	28611.42	4.89		Herring-Landings(kgs)	364067.07	8.98
Skate-Landings(kgs)	87914.61	1.73		Whiting-Landings(kgs)	10155.31	1.73		Skate-Landings(kgs)	170377.15	4.20
Whiting-Landings(kgs)	48051.72	0.94		Skate-Landings(kgs)	4859.53	0.83		Whiting-Landings(kgs)	94758.16	2.34
Anglerfish-Landings(kgs)	39374.65	0.77		Nephrops-Landings(kgs)	1873.50	0.32		Haddock-Landings(kgs)	52755.99	1.30

6.4.3 Temporal analysis of Scottish and English North Sea fisheries landings data (1965-2004):

A time series analysis of Scottish and English North Sea fisheries landings data for the period of 1965-2004 was carried out for the following species: anglerfish, cod, haddock, herring, mackerel, *Nephrops*, skate, squid and whiting. The landings data were log transformed and then subjected to the Bray-Curtis similarity index before presenting sample (year) similarities as an MDS ordination. Figure 73 shows the sample years colour coded according to the significant abiotic clusters and it is clear there is a temporal gradient in the fishery which is similar to the gradient in the PCA ordination for the abiotic data. However, it is possible that the increasing fishing pressure over that period is it self causing the greatest change to the fishery and not changes in the marine climate – but this assertion requires further investigation. The analysis identified several clusters of years: 1965, 1966–1972, 1973–1977, 1978–1981, 1982–1985, 1986–1988 and 1989–2004 and these are shown in Figure 73. The dominant species during these time periods are as follows; **1965,** what seems to separate 1965 from subsequent years is relatively lower landings of cod. The Scottish and English landings are dominated by haddock and whiting. **1966–1972,** these years were characterised by high gadoid landings (cod, haddock, whiting) and relatively high landings of skate. **1973–1977,** although gadoid landings still dominated, cod and haddock landings decreased slightly and there was an increase in herring landings. **1978–1981,** these years are still dominated by gadoid landings, where whiting reached the highest values in the series for the species. **1982–1985,** gadoid landings were still high but there was an increase in herring and *Nephrops* landings in this period. **1986–1988,** high haddock and herring landing characterise this cluster, while *Nephrops* landings continue to increase. **1989–2004,** declining gadoid landings and relatively high landings of *Nephrops*, herring and mackerel.

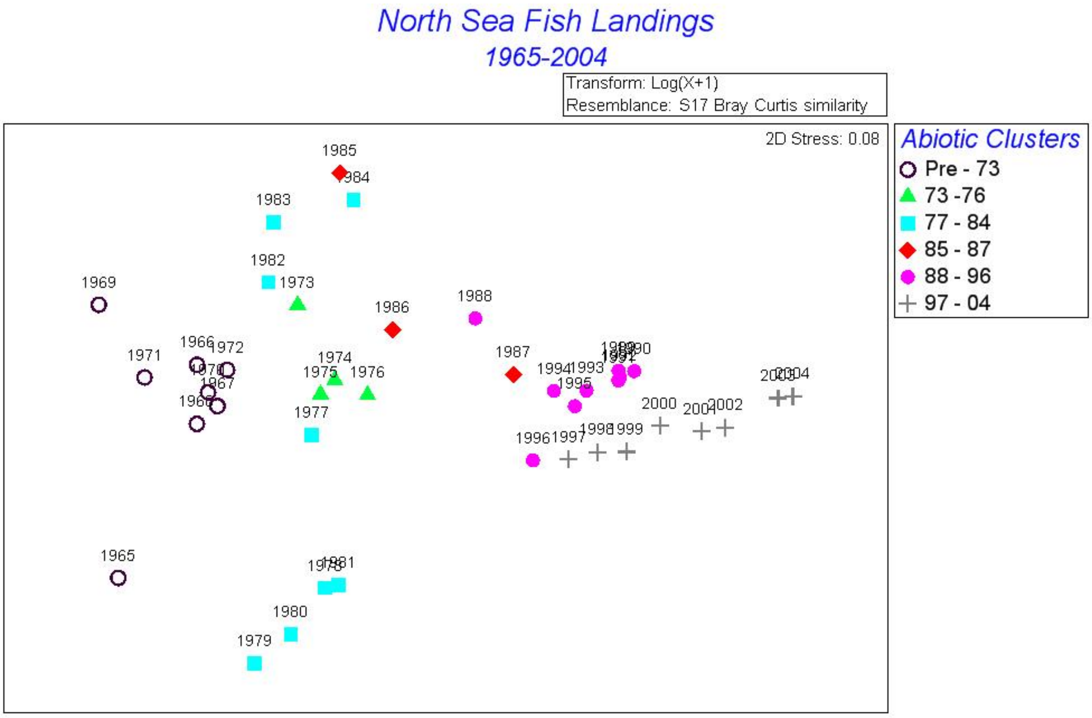

Figure 73: MDS ordination of sample years for North Sea commercial fish landings by Scottish and English vessels between 1965 and 2004.

It is interesting to note the differences observed between trends over time in the fisheries landings data, stock assessment data (SSB) with that of the CPUE data, presented in Section 5.3. The CPUE data is based upon the IBTS which are standardised and designed in such a way as to support stock assessments. The trends in the CPUE, SSB and fish landings should therefore be similar given that the CPUE is assessed when calculating fishery quotas. Figure 74 shows data for North Sea cod and it is clear that trends in fish landings and SSB for cod track each other well, whereas the CPUE data is much more variable over time.

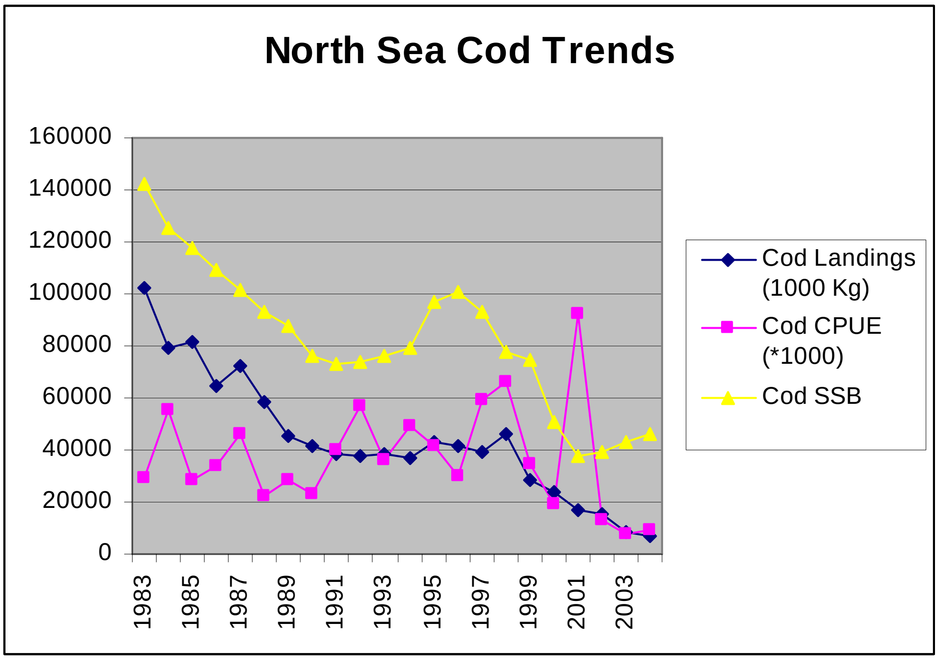

Figure 74: North Sea cod landings (Scottish and English), cod spawning stock biomass (SSB) and CPUE data from 1983 to 2004. Cod landings are in Tonnes (1000's Kg) and the CPUE data has been multiplied by 1000 to facilitate the comparison to trends on the same scale.

To compare the community level responses between the CPUE, stock assessment metrics and the fisheries data it is necessary to recalculate the fisheries MDS using only 1983 – 2005 data. This is presented in Figure 75 and the ordination of years has been coloured according to the principal abiotic cluster of years in the PCA. The resemblance with the abiotic PCA is striking. For example the years of 1983 to 1988 all track towards a tight cluster from 1989 through to 1995. This is then flowed by jump to 1996 and then another gradient until 2002 then another jump in 2003. The CPUE and stock assessment data whilst showing similar gradients over time do not fit as closely as the fisheries landings do with the abiotic data. This is difficult to explain and a surprise since the expectation would be that the fishery would be responding to socio-economic factors not related to the state of marine climate and therefore would not strongly correlate with changes in environmental state – but then it does. By contrast the expectation would be that the CPUE data and stock assessment metrics would more closely reflect changes in environmental state compared to the fishery, but they do not. Clearly this observation in the data requires further investigation especially by fisheries scientists before any assertions can be made.

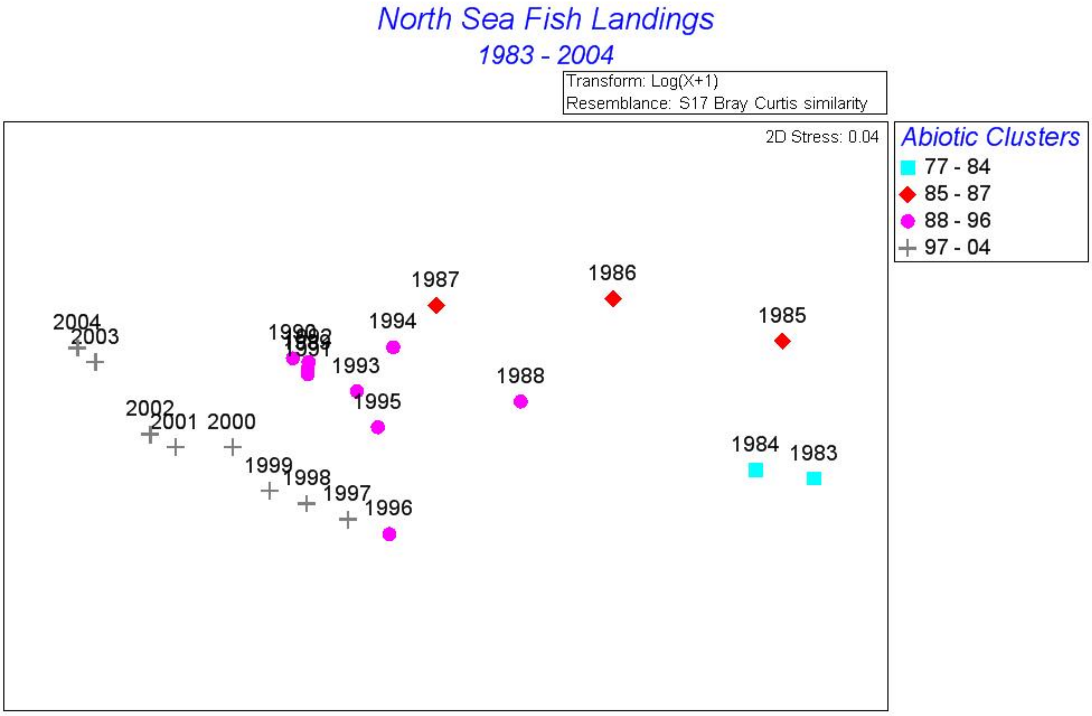

Figure 75: MDS ordination of North Sea fish landings between 1983 and 2004.

6.5 Bird density in relation to climate

Various studies have reported temporal variation in seabird population parameters in relation to climatic effects. For example Durant *et al*. (2004) showed that the timing of Atlantic Puffin breeding was influenced by the strength of the North Atlantic Oscillation (NAO) in winter. In order to highlight any possible relationship with this climate index and recorded seabird densities at sea over the period 1980-2004 the average species densities (see above) were examined in relation to this index. Overall, there were no correlations between average densities of any species or pseudospecies and the strength of the winter NAO (all $r < 1$, df = 32, $P > 0.05$).

6.5.1 Bird density in relation to seabird prey

Seabirds spend the major part of their lives at sea, principally in search of food. While commercial fisheries data (such as catch per unit effort, CPUE) may not necessarily serve as a proxy for seabird prey availability there is merit in exploring possible uses of such data in relation to seabird population ecology. Previous studies have shown that the composition of the diet of Atlantic Puffins is an accurate indicator of the availability to them (and possibly to fisheries) of certain fish species. In order to examine more closely possible links (albeit at a large and coarse scale) between bird distribution at sea (presumably mainly pertaining to feeding birds) and their prey, commercial catches of certain fish commonly recorded in seabird diets were compared to average recorded at-sea densities of selected bird species. As a first step, the average CPUE per ICES rectangle for three of the most common small prey fish of seabirds, sandeels, sprat and herring, were examined in each of the five seabird biogeographical zones that resulted from the spatial clustering analysis of the seabird data. The results are shown in Figure 76. Sandeel catches over the time period of seabird data collection (1980–2004) were relatively similar with the exception of much greater exploitation in bird zone 3. Herring and sprat catches also were fairly similar within bird zones in the time period, though with greater catches of sprat in bird zone 4.

Given the dependence of various seabird species on these fish the relationships between selected species and these fish data were examined in further exploratory analyses. The birds selected were those known to exploit sandeels, sprat and herring, at early stages of their lives. These were the auks (all three species of fish), skuas (all three fish, albeit parasitized mostly from other species), terns (all three fish), and the Northern Gannet (herring). The analyses were restricted to within the biogeographical zones in which these species were recorded in highest densities. These were Zone 2 (auks, Northern Gannet), Zone 4 (terns) and Zone 1a (skuas). No analyses were conducted on Black-legged Kittiwake or Northern Fulmar (both sandeels) data in view of the fact that highest densities of these appeared to occur atypically in Zone 4. The results of these comparisons are presented in Table 14. In Zone 2 auk density was positively correlated with sandeel CPUE. The only surprising aspect of this result is that such a relationship was detected at such a coarse scale of analysis. The auks, principally Atlantic Puffins are major consumers of sandeels. This result might suggest that when sandeel availability to commercial fisheries is high then the fish are also readily available to puffins. This accords with previous work on Atlantic Puffins on the Isle of May, Scotland (see above). Similarly, positive relationships were found between recorded tern densities and CPUE of both sprat and herring, known to be important prey for terns. The same arguments might be made here with respect to the availability of these species to commercial fisheries and the birds. A positive correlation between skua density and herring CPUE in Zone 1a is also similarly suggestive, though whether the birds catch these fish directly, obtain them by parasitizing other bird species, or, perhaps more likely, by scavenging at fishery discarding operations cannot be inferred here. Caution in interpreting these results must prevail, but these tentative conclusions might suggest viable hypotheses that could merit further study at more relevant functional scales.

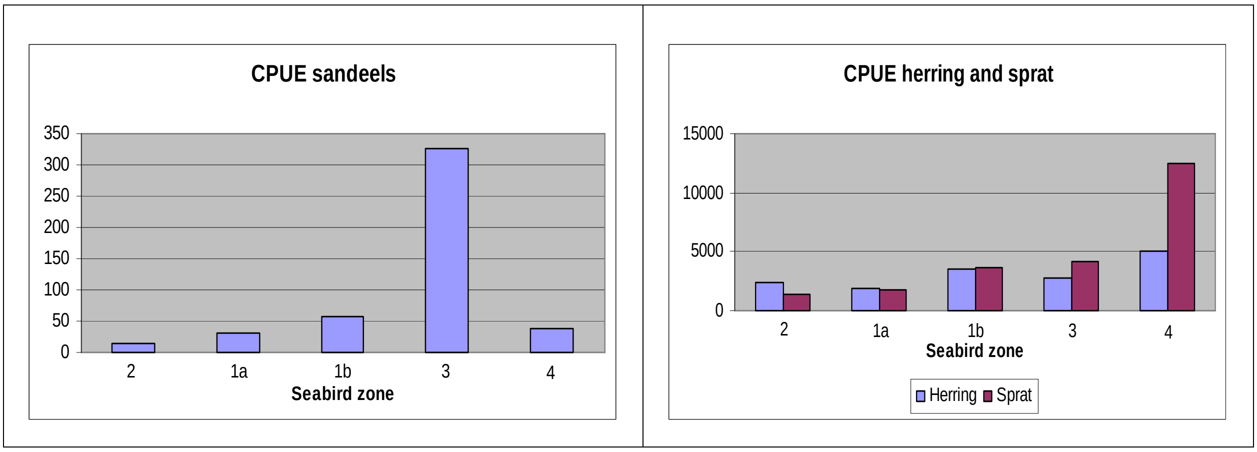

Figure 76: Mean CPUE of sandeels (a) and herring and sprat (b) for all ICES rectangles in each of the five bird zones for years for which seabird data were available (1980–2004).

Table 14: Results of comparisons (Pearson r correlations) within those bird biogeographical zones in which relevant bird species were recorded in highest average densities and CPUE for important prey fish. Analyses carried out ICES rectangles data; statistically significant comparisons are emboldened.

BIRD ZONE	BIRD SPECIES	FISH SPECIES	R	DF	P
Zone 2	auks	Sandeel	0.51	40	**<0.001**
		Sprat	0.27	40	NS
		Herring	0.12	40	NS
	Northern Gannet	Herring	0	40	NS
Zone 1a	skuas	Sandeel	-0.15	53	NS
		Sprat	-0.16	53	NS
		Herring	-0.29	53	**<0.05**
Zone 4	terns	Sandeel	0.15	26	NS
		Sprat	0.86	26	**<0.01**
		Herring	0.49	26	**<0.01**

The analyses presented here offer indications as to possible future integrated assessments of the functional relationships between seabirds and other environmental factors within the North Sea. They should be regarded as a preliminary exercise and must be interpreted cautiously within the various caveats highlighted throughout. The general approach of establishing an appropriate biogeographical framework for integrated assessment would appear to be a sound one, provided it is achieved by the application of an objective, repeatable classification technique. Future work should focus on refining the biogeographical analyses, customising them with respect to relevant issues that require integrated solutions.

6.5.2 References

Durant, J.M., Anker-Nilssen, T., Hjenmann, D.Ø., and Stensseth, N.C. 2004. Regime shifts in the breeding of an Atlantic puffin population. Ecology Letters 7: 388–394.

Mitchell P.I., Newton S.F., Ratcliffe N. and Dunn T.E. 2004. Seabird Populations of Britain and Ireland. T & AD Poyser, London.

Stone, C.J., A. Webb, C. Barton, N. Ratcliffe, T.C. Reed, M.L. Tasker, C.J. Camphuysen and M.W. Pienkowski. 1995. An atlas of seabird distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough.

7 Prepare plans for finalization of the integrated ecosystem assessment which must take account of the relationship between the thematic human pressures assessments (in ii above) and the overview integrated assessment (in (i) above), (ToR a (iii))

In the preceding sections we have attempted to provide an assessment of the key marine environmental state changes (biotic and abiotic) against an assessment of nutrient/eutrophication and fisheries pressures using available data in the REGNS database. What remains is to provide the holistic assessment which attempts to integrate the multiple human pressures with the observable state changes. WGECO sets out a management framework for such an assessment which provides an essential link between the types of analysis and assessment presented here and the need to provide ecosystem advice to manage a range of human activities. A key consideration in developing such a framework (and acknowledged by WGECO and others) is the issue of scale. Clearly some pressures are more localised than others in terms of their influence or impact on the ecosystem. But to ensure the sustainability and productivity of marine resources it is important to understand how such pressures interact across a range of scales. For example, the preliminary assessment undertaken here highlights different trends in nutrient levels arising from North East Atlantic and riverine sources, and that they impact on the state measures of nutrients and the plankton communities in different ways. By considering the sub-regions of the North Sea we have demonstrated that riverine inputs of nutrients in regions IVb2 and IVc have a measurable influence on the plankton communities in these regions whereas Atlantic sources of nutrients and changing sea surface temperatures are influencing the plankton communities in region IVa1 in a different way. Considering the fisheries data, it is notable that the years 1978 to 1981 appear in a separate cluster in Figure 73 and this same cluster of years is also seen in the plankton community data (Figure 36, most notably for regions IVc and IVb2) and in the abiotic data (Figure 15). This grouping of years has also been identified by Edwards *et al* (2006) for the North Sea CPR data and attributed to a cold water Boreal incursion into the southern North Sea at this time. Indeed relatively low sea surface temperatures are seen during this period as is a relatively low negative flux in seawater into the North Sea. (Figures 19 and 7, respectively). The weight of evidence presented here linking climate, plankton and fisheries is compelling and is worthy of further investigation, since marine climate models are fast evolving and may offer some credible predictive capability in managing ecological resources at the scale of the North Sea.

The North Sea ecosystem is complex but it has been well studied in terms of the physical processes and the results presented here support our current understanding of these processes and how they influence the ecological state of the North Sea. The present assessment demonstrates the significant influence of natural climate forcing in structuring and regulating the function of the North Sea at a number of levels. We note the emphasis in ICES to consider human pressures, particularly the effects of fisheries, on the ecosystem, but these results serve to highlight the significance of marine climate change on plankton, fisheries and seabirds when assessed at the North Sea scale. It is therefore important to understand the relative significance of different pressures when assessed at different scales. For example, the physiograhic variation in the seabed and water column largely determine the habitats in which the species live and these do not change spatially when measured at the scale of the North Sea as a result of variations in human pressures. The distinction between the advective south and stratified north is constant (and has probably been the case over thousands of years) and it is this which determines much of the macro-variability in space observed, for example the preponderance of a sandeel fishery along the Flamborough front may be specific to a unique set of environmental conditions in this region which are unlikely to change as a result of localised human pressures. In addition, the fluxes of seawater driven by NAO is a natural pressure and the present assessment suggests that changes in seawater temperature and nutrients largely determine the inter-annual variability observed in the fisheries, plankton and fish stocks when measured at the scale of the North Sea. Again it is important to emphasise that this assertion may simply be a reflection of the limitations in the data and the fact that current state conditions for the North Sea may be so heavily modified that the impacts of nutrient inputs and fisheries are no longer discernable and therefore the only clear predictor of change is the climate forcing conditions. But the close relationship seen between changes in ocean climate, plankton communities and fisheries is surprising, especially when there is so much attention given to the impacts and regulation of human activities particularly nutrient inputs and fishing pressures.

The question we now raise for consideration by relevant experts is “why should the North Sea fisheries data most closely reflect the trends in abiotic state?” The answer to such questions may be simple, but it requires the expert input from other others to provide further insight.

REGNS recommends that the data is further assessed in joint session with expert groups meeting in 2007. In the first instance it would be beneficial if this could be done with

WGECO so as to facilitate the incorporation of outputs from the present analysis in to the integrated assessment framework presented in WGECO 2006.

8 Prepare for presenting the outcome of the integrated ecosystem assessment at the 2006 ICES Annual Science Conference (ToR a (iv))

This will be taken forward by the ISG with expert guidance solicited from appropriate WGs, for presentation at the ASC 2006.

9 Advise on follow-up work to translate the experiences of REGNS in producing an integrated ecosystem assessment into a regular process in ICES of producing or contributing to the production of updated integrated assessments for the North Sea ecosystem

9.1 Lessons for Data Management

A large factor affecting the success of REGNS has been the need to establish a regional assessment database. Such a database addresses the need for getting relevant data in the same format for numerical analysis and assessment purposes. The database is dynamic in nature and serves only the purpose of the regional assessment group and as such has none of the user-friendly interface attributes associated with more established (archive) databases such as those held by ICES and CEFAS etc. The main requirement is for trained personnel to support access to the data by running SQL queries to aggregate the data in different ways and to output matrices in formats suitable for other statistical or GIS software.

During REGNS a considerable amount of effort was made in getting the data together for the present assessment, and whilst this represents the bulk of the time and effort needed to set the database up it will need up-dating on an annual basis. The mechanism to support this annual up-date needs to be addressed. One option would be to assign responsibility for an attribute or group of attributes to an individual or organisation to ensure they provide annual up-dates. Alternatively the data could be chased by one individual contacting the relevant sources to get the necessary up-dates. The latter approach is easier to set-up, but it places a much greater burden on an individuals time to deliver and is also more risky in terms of getting the data from the relevant sources. The former approach is more difficult to set up in the first instance as it will require written agreements with individuals and/or organisations but it is less risky in terms of delivery and getting the necessary data. In either case it will require resource to support the administration of the assessment database with annual up-dates.

In the experience of REGNS, it is simply to ambitious to expect that we can simply download all the relevant data with appropriate QA from the numerous sources on the fly for assessment purposes. The systems are simply not sufficiently well developed at a consistent level across the various organisations to do this efficiently. This is not likely to change significantly over the next 5 years, so the need for regional assessment databases is a solution for our immediate needs and will also help to prioritise access to the most relevant data from the archive databases.

Problem with getting sustained input from all the groups. Some were very supportive, others.

9.2 General Issues

There was confusion about the meaning and nature of Integrated Assessment which took time to resolve in REGNS – in fact the first two meetings (2 years) were spent resolving this issue. For example we concluded that Integrated Assessment should be considered at three levels, namely: **(i)** policy drivers; (**ii)** scientific understanding of ecosystem processes; and (**iii)** the provision of advice and the development of management tools. REGNS recognised that most of what is being called Integrated Assessment can be assigned to at least one of these three areas. It is also important to recognise that the objectives for integrated assessment vary significantly between these three areas of interest since the end users each have very different needs. **So the key message is try to understand who the Integrated Assessment is primarily aimed at** namely: (i) the policy makers; (ii) the research scientists; or (iii) the environmental managers – as the products required for all three are very different and so deciding this at the earliest opportunity helps focus your efforts most appropriately.

9.3 Assessment Issues

Within REGNS we decided to concentrate our efforts in undertaking an Integrated Assessment in support of increasing our scientific understanding of the relationship between different types of data mainly collected through a diverse range of monitoring programmes in the North Sea. The issues we have faced have therefore focused on: (**i)** how to deal with data which is collected on very different scales of time, space and units of measurement; (**ii)** which analytical techniques should be used to collectively assess the data in order to identify and understand complex patterns within it; (**iii)** how to manage the data and; (**iv)** how to get buy-in from the scientific community (within ICES) to assist in the assessment and analysis.

A more detailed account of how we addressed these aspects of the REGNS process can be found in our reports available from ICES but in summary:

Issue of scale: it is important to identify the data sets which are applicable to the whole region of interest – these tend to be the physical oceanographic and fisheries data sets which in part can be modelled to fill gaps. The data which has wide spatial coverage and has been measured over many decades allowed REGNS to undertake an overview assessment of the North Sea Ecosystem although this only involved a relatively few parameters it nevertheless allowed REGNS to understand the changes at a scale most influenced by ocean climate forcing. The spatial analysis helped to identify sub-regions which are now the subject of more localised thematic assessments since the data often associated with thematic assessments is discontinuous in both space and time. **So the key message here is at an early stage develop a meta-data table to identify which types of data you have and attribute it to an overview assessment or more targeted thematic assessments.**

Which techniques: we are still exploring this, but what we have learnt is that the traditional multivariate numerical techniques are not sufficiently robust to handle such complex data – the key issue here is one about scaling and weighting parameters. For example, if you undertake a cluster analysis on your data which is 90% composed of plankton abundance values then your observations relating to temperature, or a single macrobenthic organism or seabird are overwhelmed by the similarities calculated between all the plankton data – not what you necessarily wish. So the question of how to rescale and weight data is critical.

How to manage the data (also see above): In REGNS we generally found getting data difficult. Knowing where the data is, is OK and we were able to generate the meta-data tables fairly easily – but some data sets are difficult to get hold of and this is where you need buy-in from the data generators who may be very busy and protective of what they see as their data. What is important is to get the data providers involved in the assessment and this is not as easy as it sounds since they often see what is happening as a threat to their specific interests and area of work/expertise. The attention an integrated assessment can give to any one specialism is obviously not as great as the specialist expert group can afford to do– so you face the criticism of poor quality science. In addition the term *Value Added* tends to treated with scepticism and that an integrated assessment will not be able to do their data justice. We worked closely with the ICES data centre and they have provided a useful source of data. What we would like to do is identify the critical data sets that they will need to hold for future REGNS assessment – this is on-going. A key lesson learnt was that you need to establish an assessment database. as you need to be able to access the data freely for different types of analysis and this is not always possible from existing data centres who are constrained by staff resources and don't have the time to deal with repeated requests.

Getting buy-in: if the Integrated Assessment is aiming to deliver a report for policy makers, research scientists and environmental managers then it is necessary to establish three sub-groups to deal with their specific needs. REGNS made the mistake of trying to do it all at the same time with representatives from each area – the result was difficult to Chair as each end user group tended to pull the work programme to meet their own needs. The policy makers tend to be most interested in indicators of marine ecosystem health etc. and smiley faces. They want integrated outputs to show how effective or otherwise their marine stewardship policies are. Likewise research scientists have specific needs to do with testing significance and understanding cause/effect relationships whereas the environmental managers wish to maximise the effectiveness of their monitoring programmes. The key point is getting all three groups integrated so the monitoring programmes can be adapted based upon good scientific evidence which in turn serves the policy needs. We have yet to do this last step in REGNS but it should be taken forward in ICES.

9.4 Future periodic assessments of the North Sea ecosystem

Based upon our experience the best way to ensure the operational assessment of the North Sea is to have an assessment group permanently established to meet every year with the following aims:

1) to update the REGNS database – check its content and undertake QA.

2) to undertake further exploratory analysis of the data using different spatial temporal aggregations to examine trends between pressures and state changes and up-date existing assessment.

3) work in joint session with other expert groups so as to maximise efficient use of peoples time, to progress thematic assessments. This would operate at two levels;

   a) working with scientific expert groups to help interpret the meaning of the data and identified relationships, e.g. WGSE, WGEXT, PGNSPP, WGBE, WGFE etc.

   b) Working with groups who report directly to ACE as they need to translate the scientific evidence into management actions through the setting of indicators and targets, e.g. WGECO, WGRED.

Item 3 will require REGNS to meet over two weeks (10 days) in order to generate a product at the end of the working group meeting. The present experience of meeting for 1 week is not sufficient to complete the above tasks. It will also enable greater opportunity and flexibility in working in joint session with existing expert group meetings.

10 Based on the experience with the production of the 2006 North Sea integrated assessment; consider requirements that need to be taken into account in a design of a holistic monitoring programme of the North Sea ecosystem

10.1 Introduction

A joint session was held with members of REGNS and the IBTS Working Group in Lysekil, Sweden in 2006 to initiate discussions on the feasibility of designing and implementing an ecosystem based monitoring programme for the North Sea. The oceanographic data underpinning the present REGNS assessment is largely derived from the ICES data centre and from observations already undertaken by the IBTS programme. The purpose of this joint session was therefore to look at possible improvements, including standardising the methods, for the collection of existing determinands, and to prioritise any potential future requirements to meet the needs of an ecosystem programme.

The existing set of determinands routinely monitored by members of the IBTS programme includes profiles of temperature, salinity (conductivity) and depth (pressure). This activity does not cause any disruption to the core IBTS effort and adds value to the analysis undertaken by fisheries biologists.

Additional determinands (not routinely collected) relate more to the needs of the other sectoral interests, namely: (**i**) nutrients and eutrophication; (**ii**) chemical contamination and; (**iii**) habitats and species. An important part of the discussion recognised that there are different levels of coordination and integration of these parameters within the IBTS, some are more practical and cost effective than others, but in all cases additional funding outside the IBTS would be needed to cover the time and effort required for such observations. We discussed the concept of 3 levels of integration: level 1 represents the existing position with minimal disruption to the survey; level 2 would require additional observations and effort, although this is happening already in some cases (e.g. benthos in trawl); and, level 3 would require significant additional effort and close coordination with other fisheries and oceanographic fieldwork. In order of priority we concluded that a coordinated programme of seabird and cetacean observers could be developed in the first instance, followed by nutrients and chlorophyll analysis of the water samples collected for salinity analysis on the CTD casts, and finally the collection of sediment and water samples for contaminants analysis. Additional tows for plankton or benthos data are expensive additions in terms of time and effort required and is therefore unlikely to be funded at this stage. Other observations could be made at night (e.g. towed CTD, acoustic survey of seabed) but this would not be part of the integrated IBTS survey.

10.2 Seabirds and Cetaceans

Accommodating seabird and cetacean observers on the IBTS cruises would appear to be a relatively straightforward way of adding value to the cruise programme in the context of integrated assessment. Seabird surveys at sea have been conducted over the NW European shelf for more than 25 years; all countries with a seaboard in this area co-operate to ensure that the data are, as far as possible, collected using standardised methods; the data are hosted in a customised database (the European Seabirds at Sea, ESAS, database), periodically updated. This database is a shared resource among various stakeholder institutions and individuals in Europe and has already been the focus of analyses within the REGNS initiative; it is also accommodated within the REGNS database itself.

The success of the ESAS initiative relies on a pool of expert observers. All new data that are accommodated within the ESAS database must be collected by ESAS accredited observers, and there is a training scheme in operation to ensure the highest possible standard of data collection. These observers are not only skilled in identifying seabirds (species, age, sex, behaviour) at sea but also cetaceans. Not surprisingly, the ESAS (co-ordinating) group is comprised to a large extent of members who are also members of ICES WGSE.

Assuming that berth space is available, little in the way of other resources is required of IBTS; seabird observations are made while the vessel is steaming, ideally from the bridge wing, monkey platform, or other suitably high position as far forward as possible. A purpose-built observation box may be required to be place at the viewing platform. Ideally, there needs to be access (not necessarily continuous) to the vessel's GPS.

Seabird observers apply survey methodology tailored specifically for seabirds. All seabirds are recorded within moving strip transects, usually 300 m wide.

Cetacean (and other taxa that break the sea surface) observations are also recorded opportunistically during seabirds at sea surveys. The ESAS database also hosts the cetacean data, although these again are accommodated within another resource shared with various partners - the Joint Cetacean Database. Although cetacean sightings in the past have been recorded in the same way as seabird sightings, a slight modification of the method would be applied on the IBTS cruises – a method aimed at improving the usefulness of the data in assessing relative abundance of the animals. Again, the requirements here are minimal and have no impact on IBTS protocols. A simple angle board would be the only additional piece of equipment required. However, if there were scope to tow hydrophones on 200m cables this would improve the power of the survey as a monitoring tool for these animals. This might be better seen as a longer term aim, however.

Seabird and cetacean observers need not be different personnel. Indeed, there is added value in their being the same people. In view of the requirement that seabird observers be ESAS accredited (see above) then there is every sense in ensuring that those personnel collecting cetacean data are in fact seabird observers; dedicated, skilled cetacean observers do not always have the necessary seabird skills for surveying that group. We have the agreement of ICES WGMME in this respect.

In ideal circumstances two seabird and cetacean observers would be accommodated on IBTS cruises. This would maximise the time available for recording as well as allow appropriate division of labour when either or both group is particularly abundant.

Although the longer term aim would be to ensure proper integration of higher predator data with other physical, chemical and biological data, the proposed immediate extension of the IBTS survey to include these taxa would have virtually no impact on IBTS protocols. The only constraining factor at present would be the availability of berths.

In the aftermath of the WG IBTS meeting in Lysekil 2006 we would propose that the possibility of placing seabird/mammal observers on board IBTS cruises be referred to ICES WGSE (and thereby ESAS) and WGMME. Assuming an agreement in principle for such accommodation and co-operation, WGSE needs to devise a strategy for exploiting the IBTS cruise programme to maximise its value for investigating dispersion patterns of seabirds and other taxa at sea. Such a strategy needs to be tempered with consideration of the available or potentially available resources. Direct liaison with the appropriate IBTS cruise leaders over the feasibility and practical application of this strategy would be the stage just prior to its realisation at sea.

All seabird (and cetacean) data that have been collected by ESAS partners are accommodated within the ESAS database. We would envisage this to continue in future but would also note that possibilities exist to also host the data within other applications, such as the REGNS database, the ICES data centre and, indeed, other global initiatives. Of course, proper protocols for data access by third parties would need to be formulated, and there are various models for this, including the IBTS database itself.

The adoption of a seabird/cetacean component to the IBTS programme creates an important precedent within ICES. It is a practical application of the REGNS process and one that contributes directly to an integrated (regional) assessment. It also establishes cross-cutting work among three WGs – IBTS WG, WGSE and WGMME. Such a model of working is essential in future if proper ecosystem assessment, monitoring and management are to be effected.

10.3 Nutrients and Eutrophication

The availability and distribution of nutrients provide the means of primary production and hence supports the whole marine food web. Clearly nutrients represent an important ecosystem component which needs to be included in ecosystem-based fisheries management or other form of integrated assessment. In addition to oceanic inputs, river catchments provide conduits for nutrients resulting from natural run-off and human activity (fertilizer, sewage) and these may give rise to enhanced concentrations in coastal seas. This in turn may result in eutrophication, defined as '…. *enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned*.' (www.ospar.org). This is regulated under the OSPAR Common Procedure. The presence of enhanced concentrations may not lead to eutrophication, for example in areas where growth is light-limited, so an understanding of the receiving environment is critical.

Nutrient measurements, and associated measurements such as chlorophyll/fluoresence and dissolved oxygen, are not routinely collected on IBTS surveys. However, technically it would be quite straight forward to include these using water bottle samples and/or underway samples, given suitable protocols being in place. The main challenge is to fund the analysis. We would expect to make use of remote sensing information and use the measurements for 'sea-truthing'.

10.4 Contaminants monitoring

The collection of samples for contaminants monitoring could form part of an integrated IBTS survey. Collection of water samples might be accomodated in the existing water sampling efforts and sediment sampling could be achieved using a simple grab sampler at night. However, additional staff would be required and there are significant implications for funding the analysis of such samples which would need to be addressed prior to implementing an extension to the survey. In addition, some contaminants monitoring requires particular sampling techniques or sample treatments so that the objectives, target contaminants and protocols would have to be very clearly defined.

10.5 Additional measurements

A number of other measurements were discussed. Of these improved underway sampling would be likely to be of most benefit, although there are cost implications and the need to establish strict protocols to maintain monitoring equipment. One solution would be to adopt the Ferrybox system (e.g. nutrients, turbidity, temperature, conductivity, chlorophyll).

Night time observations could include additional measurements of salinity and temperature (CTD casts or towed bodies) in relation to particular features such as measurements of the structure of the thermocline or across frontal systems. Acoustic seabed mapping could also be included, dependent on equipment availability, with associated grab sampling or operation of other devices such as Sediment Profile Imaging cameras. These measurements would be making use of the ship as a platform rather than forming part of an agreed integrated IBTS survey.

Finally we discussed the possibility of towing additional gear for plankton or epibenthos, and of including infaunal analysis. It was agreed that it would not be practical to include such measurements within the existing IBTS surveys. A significant amount of additional seatime, staff and analytical effort would be required. Such observations would need to be undertaken on separate RV cruises.

Annex 1: List of participants

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Alejandro Gallego	FRS, Aberdeen, UK		
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Annex 2: REGNS terms of reference 2006

The **Regional Ecosystem Study Group for the North Sea** [REGNS] (Chair: A. Kenny, UK) will meet at ICES Headquarters from 15–19 May 2006 to:

During the first 3 days:

c) Hold a workshop to evaluate and plan the finalization of the 2006 integrated ecosystem assessment for the North Sea, to be presented at the 2006 ASC;

v) review the outcome of the work of an intersessional correspondence group (sub-group of REGNS) with compilation and analyses of a comprehensive integrated data set for different aspects and components of the North Sea ecosystem,

vi) review the outcome of intersessional work on relating state variables of the ecosystem with human pressures according to themes (eutrophication, pollution, conservation, fisheries, climate, and management),

vii) prepare plans for finalization of the integrated ecosystem assessment which must take account of the relationship between the thematic human pressures assessments (in ii above) and the overview integrated assessment (in i above),

viii) prepare for presenting the outcome of the integrated ecosystem assessment at the 2006 ICES Annual Science Conference;

During the last 2 days:

d) Advise on follow-up work to translate the experiences of REGNS in producing an integrated ecosystem assessment into a regular process in ICES of producing or contributing to the production of updated integrated assessments for the North Sea ecosystem;

e) Based on the experience with the production of the 2006 North Sea integrated assessment; consider requirements that need to be taken into account in a design of a holistic monitoring of the North Sea ecosystem.

REGNS will report by 30 June 2006 for the attention of the Resource Management Committee, ACFM and ACE.

Supporting information

<table>
<tr><td>Priority:</td><td>High.</td></tr>
<tr><td>Scientific Justification and relation to Action Plan:</td><td>
The Workshop will review the material that is generated for the purpose of the REGNS process and investigate how this material can be interpreted in the context of the framework developed by REGNS in 2005.
The 2006 Workshop is expected to be a significant step towards delivery of the thematic Integrated Assessments, with the Integrated Assessments being the subject of a Theme Session at the 2006 ASC. The data analysis will need to be undertaken (in part) intersessionally during 2005/6 with the outputs being presented and reviewed at the 2006 Workshop (April). The plan is to have prepared complete (although draft) thematic integrated assessments for review at the 2006 ASC. This timetable was set out in the 2004 REGNS report Section 4.1.
The success (and timeliness) of the Workshop products will depend on excellent preparation and sustained support through to completion. It is unlikely that this can be provided entirely at the national level, and input from the Secretariat may be required. The task will include good communication with a wide range of “source” Working Groups; compiling their material in a standard form for joint analysis; facilitating early availability of data information and indicators for analysis by Workshop members, and other interested scientists; early compilation and dissemination of working documents and draft to workshop participants; overseeing additional work to ensure timely production of the report (editing, preparation of figures and tables, etc.). Individual members of REGNS will take responsibility for facilitating (but not necessarily leading or drafting) the work on each of the six themes identified in the table below:
<table>
<tr><th>.Theme</th><th>WGs</th><th>Facilitator</th></tr>
<tr><td>Eutrophication</td><td>WGPE, WGHABD, WGZE, WGPBI, BEWG, WGFE</td><td>Hein-Rune Skjoldal</td></tr>
<tr><td>Conservation of Habitats and Species</td><td>WGMME, WGSE, WGEXT, WGITMO</td><td>Mark Tasker</td></tr>
</table>
</td></tr>
</table>

	Chemical Pollution	WGPDMO, WGMS, MCWG, WGBEC	Andy Kenny
	Fisheries	WGECO, WGFE, WGEF	Clive Fox
	Climate and Natural Variations	WGOH	Bill Turrell
Resource Requirements:	Staff time from ICES may be needed in order to adequately prepare for the Workshop and to provide the necessary support in compiling the report. Otherwise, the Workshop requires few other resources.		
Participants:	The Workshop will include participants from REGNS and IBTSWG and some additional experts who have the necessary experience in ecological monitoring.		
Secretariat Facilities:	None		
Financial:	None		
Linkages to Advisory Committees:	ACE and ACFM		
Linkages to other Committees or Groups:	All Science Committees		
Linkages to other Organisations:	OSPAR		
Cost share	ICES 100%		

Annex 3: Recommendations

RECOMMENDATION	ACTION
1. To extend REGNS for a further year to allow completion of the current North Sea assessment, making optimum use of the existing database (collected with some effort) – which represents a valuable resource for the application of integrated assessment of complex data.	CONC
2. The ICES Data Centre should investigate cost-effective mechanisms for supporting and maintaining the existing REGNS database (currently held at Cefas, formerly held at FRS and Ispra), which contains a wide-range of data types, recognising that some data sources are held outside the ICES system (e.g. nutrient loadings, CPR). In this respect it may be possible to identify lead countries or organisations to provide selected data on an operational basis (e.g. annually), as practised by OSPAR. This would also link in with the QSR assessment needs of OSPAR in the run up to 2010.	ICES Data Centre
3. To extend the time available to 10 days for future assessments to allow adequate time for data collation, analysis and synthesis of results, ideally in parallel session with PGNSP and/or WGECO for part of the time – (it did not prove practical to complete the preparatory work in isolation by the ISG and, therefore, the time available for the REGNS May 2006 workshop was too short).	ICES Delegates
4. To establish a permanent assessment working group that will allow the update and improvement of periodic regional ecosystem assessments for the North Sea. To improve the efficiency of the assessment group it will need to run in joint session with other established WGs, notably PGNSP.	CONC
5. ICES should consider (via Delegates) giving higher priority to the attendance of experts at the regional assessment groups, rather than specialist working groups – it is essential to have the direct involvement of experts in the provision, collation and analysis of data and subsequent interpretation (given that resources are limited and many comments were received from the source WGs that they were not funded sufficiently to support REGNS in the manner which had been requested).	ICES Delegates
6. ICES should take full advantage of the unique opportunity for bringing together data, knowledge and expertise represented by the 100+ specialist groups, which the REGNS pilot study has shown can provide insights not apparent when expertise remains within its established expert groups. The regional integrated approach should therefore be encouraged through the establishment of a permanent assessment working group for the North Sea .	CONC.

Annex 4: List of source working group reports

Expert Group	2004	2005	2006
WGFE	y	y	y
WGMME	y	y	y
WGECO	y	y	y
WGPE	y	y	
PGNSP	y	y	y
WGSE	y	y	
WGZE	y	y	y
WGSAEM	y	y	y
WGFE		y	y
WGMHM	y	y	
WGOH	y	y	
WGITMO	y	y	y
WGHABD		y	
WGMS	y	y	y
MCWG	y	y	y
WGBEC	y	y	y
BEWG	y	y	
WGPDMO	y	y	
WGEXT	y	y	y