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SCICOM/ACOM STEERING GROUP ON INTEGRATED ECOSYSTEM ASSESSMENTS

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Final Report of the Working Group on Integrated Assessments of the North Sea (WGINOSE)

14–18 March 2016

ICES Headquarters, Copenhagen, Denmark

International Council for the Exploration of the Sea
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Executive summary

The Working Group on Integrated Assessments of the North Sea (WGINOSE) met in ICES, Copenhagen, between 14 and 18 March 2016. The meeting was chaired by Andrew Kenny (UK). There were six participants (two by Skype) representing three nations (Annex 1).

An important task of the group, following from the conclusions of the group last year, was to identify appropriate spatial scales (strata) to apply the Integrated Ecosystem Assessment (IEA) methods including the development of Bayesian Belief Networks (BBNs) to support ecosystem advice.

The identification of appropriate spatial scales for assessment requires the spatial optimization of the data to ensure the best spatial fit between, human activities, pressures, and ecological processes, which drive ecosystem state changes due to natural causes while taking into consideration spatial gradients in pressures arising from human activities (Section 5).

Spatial strata identified by the ICES Workshop to Plan and Integrate Monitoring Program in the North Sea in the 3rd quarter (WKPIMP) were used to undertake strata specific IEAs (Section 4). The results reveal a close correspondence between some of the spatial strata identified and seabed abrasion caused by bottom fishing activities.

To further the work of the group and to provide a sound basis for the development of strata specific IEAs the group concluded that it should work towards:

1) Performing integrated analysis of ecosystem trends for each of the defined strata from 1991 onwards with more extensive datasets for fish;

2) Completing whole North Sea IEA trend analysis to better understand the differences between the status and functioning of ecosystem strata;

3) Identify 'key' activities and pressures operating within each strata and determine their extent;

4) Determine the most appropriate modelling approach to support ecosystem management for each strata and liaise with the Working Group on Resilience and Marine Ecosystem Services (WGRMES);

5) Liaise with ICES Working Groups with responsibility for developing integrated monitoring in the North Sea (e.g. WKPIMP, WGMSFDemo[1])

Andrew Kenny and Erik Olsen were elected to stand as chairs for four meetings over three years from 2017 to 2020.

A discussion on multi-annual ToRs for the next three years was also discussed and and it was recommended that the following set of ToRs be adopted by WGINOSE following ICES approval:

1 Working Group to Demonstrate a Celtic Seas wide approach to the application of fisheries related science to the implementation of the Marine Strategy Framework Directive (WGMSFDemo)

Recommendation	For follow up by:
Update strata specific ecosystem trends analysis utilizing data from ICES Data Centre and other data sources, e.g. CPR, OSPAR, EEA, and Member States.	WGINOSE
Identify and develop additional strata and associated monitoring programmes for the inshore/coastal areas of the North Sea and the Norwegian Trench.	WGINOSE
Establish data pathways and obtain data to operationalize the integration of human activity and pressure data, distinguishing between fixed structures (e.g. pipelines, windfarms) and ongoing activities (e.g. dredging, fishing, shipping, underwater noise, litter), accidents (emergency response).	WGINOSE
Develop strata specific decision support tools to support ecosystem man-agement and advice (e.g. BBNs and expert systems, ecosystem models, ecosystem goods and services modelling) in collaboration with end-users (OSPAR, DG-ENV, DG-MARE)	WGINOSE
Contribute to the coordination and integration of strata specific assess-ments with the development of integrated ecosystem monitoring in the North Sea, e.g. redesign of the Q3 IBTS surveys.	WGINOSE

1 Opening of the meeting

This year's meeting of WGINOSE was held at ICES, Copenhagen, Denmark, between the 14 and 18, March 2016. Participants of the meeting (Annex 1) were welcomed by Andrew Kenny (Chair of WGINOSE), who also provided a presentation describing the results from previous meetings of the group.

2 Adoption of the agenda

The agenda (Annex 2) was adopted by the group after a short discussion and consideration of the specific tasks to be progressed by the group during the week.

3 Introduction to meeting

WGINOSE is a working group, which develops the links between the science-base of Integrated Ecosystem Assessments (IEA) and ecosystem management advice in the ICES greater North Sea ecoregion. The group works towards this goal in cooperation with similar groups within the ICES SCICOM Scientific Steering Group on Integrated Ecosystem Assessment Programme (SSGIEA). Specifically the group aims to provide:

1) Annual status reports, through the application of multivariate statistical analyses, of the principal activities, pressures and state indicators operating at the subregional level of the ecoregion. (Sections 4 and 5);
2) Probability based analysis of the interactions between 'key' components of the greater North Sea subregions using stochastic models, (Section 6) and;
3) An assessment of the possible outcomes of management actions at the ecosystem level through its contribution to the greater North Sea ecosystem overview.

This is the third and final year of working on a set of multi-annual ToRs (Annex 3) which essentially cover, i) updating the status and trend analysis, ii) reviewing and updating the ecosystem overview report, iii) develop and apply a dynamic BBN model to assess the cumulative effects of multiple human activities, and iv) reviewing the data needs and gaps for IEA of the ICES greater North Sea Ecoregion.

An important task, following from the conclusions of the group last year, was to identify appropriate spatial strata to apply the IEA methods including the development of BBNs to support ecosystem advice. This task has been made easier by the ongoing discussions in ICES to explore the development of integrated monitoring programmes, specifically under the auspices of an ICES workshop WKPIMP, the possible redesign of the IBTS Q3 survey to take account of policy driven ecosystem assessment requirements. The identification of appropriate spatial scales for assessment requires the spatial optimization of the data to ensure the best spatial fit between human activities, pressures, and ecological processes which drive ecosystem state changes due to natural causes (Section 5).

4 Updating North Sea status and trend analysis (ToR a)

4.1 Using appropriate spatial strata

The analysis of North Sea ecosystem monitoring data undertaken by ICES (2006) and subsequently by other Working Groups (JMP NS/CS) highlights the importance of spatial gradients in system attributes (such as bathymetry, and sediment grain size) which define significant differences in the status of the North Sea. An important task the group addressed this year was an analysis of the time-series data at a subregional scale corresponding to the identified spatial strata shown in Figure 4.1.

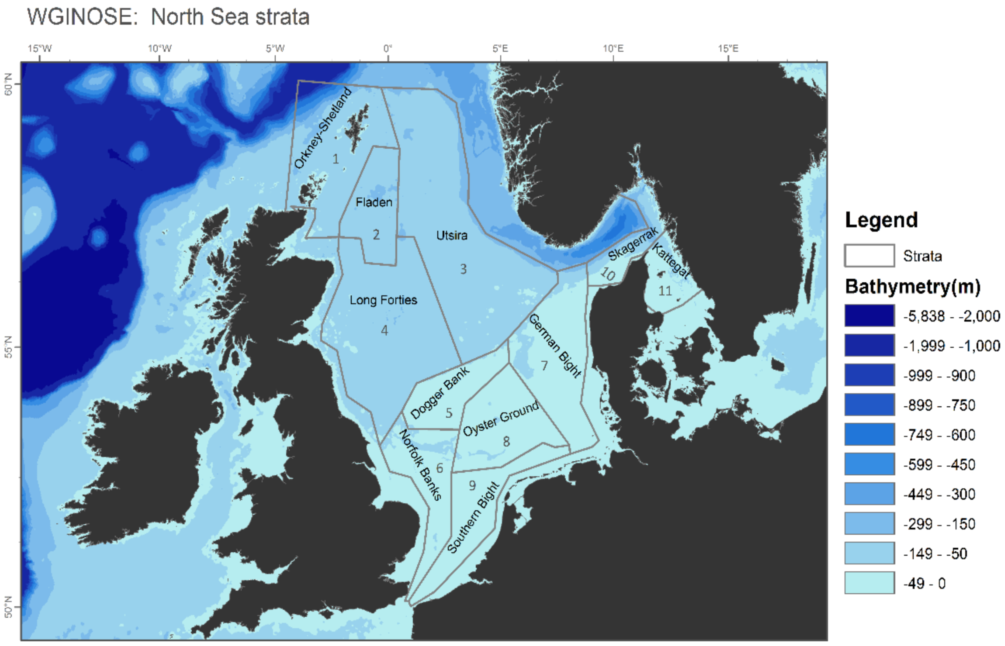

Figure 4.1. Spatial strata used for subregional IEAs and to optimize the development of BBNs. (Strata defined by WKPIMP).

The strata correspond to physical and ecological gradients in the North Sea, for example Area 1 to 4 are characterized by being in substantially greater water depths compared to Areas 5 to 11. Furthermore, the strata share similarities with some of the historically named regions of the North Sea defined by their unique habitat and physical characteristics, namely; the Oyster and Fladen grounds (Figure 4.2).

Figure 4.1. North Sea place names used to identify strata
https://commons.wikimedia.org/wiki/File:North_Sea_map-en.png

4.2 Integrated ecosystem assessments

4.2.1 Data

Two primary sources of data were used in the present analysis, namely; i) cpue fish species abundance data from the DATRAS database and ii) oceanographic data from water samples taken during the IBTS surveys in Q1 and Q3. The list of variables by strata is shown in Table 4.2.1.1. For each strata, annual mean values for each of the variables were calculated from observations within each strata thereby generating a time-series of annual mean values for the period 1983 to 2014.

Table 4.2.1.1. Table of variables included in analysis for each of the North Sea Strata

North Sea Assessment Strata	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
	Orkney-Shetland	**Fladen**	**Utsira**	**Long Forties**	**Dogger Bank**	**Norfolk Banks**	**German Bight**	**Oyster Ground**	**Southern Bight**	**Skagerrak**	**Kattegat**
Atlantis model codes	**OSN1**	**OS N2**	**NC NS**	**UK N2**	**DB**	**UK S2**	**Ger 2**	**NL3**	**NL2**	**Sk1**	**Kattegat**
Bottom_mean_AMON(µmol/l)							Y			Y	Y
Bottom_mean_CPHL(mg/m³)										Y	
Bottom_mean_DOXY(µmol/l)							Y			Y	Y
Bottom_mean_NTOT(µmol/l)										Y	Y
Bottom_mean_NTRA(µmol/l)	Y	Y	Y	Y			Y			Y	Y
Bottom_mean_NTRI(µmol/l)							Y			Y	Y
Bottom_mean_PHOS(µmol/l)	Y	Y	Y	Y			Y			Y	Y
Bottom_mean_PSAL	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Bottom_mean_SLCA(µmol/l)	Y	Y	Y	Y			Y			Y	Y
Bottom_mean_TEMP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Bottom_mean_TPHS(µmol/l)							Y			Y	Y
Surface_mean_AMON(µmol/l)									Y	Y	Y
Surface_mean_CPHL(mg/m³)										Y	Y
Surface_mean_DOXY(µmol/l)							Y			Y	Y
Surface_mean_NTOT(µmol/l)										Y	Y
Surface_mean_NTRA(µmol/l)	Y	Y	Y	Y	Y			Y	Y	Y	Y

North Sea Assessment Strata	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
	Orkney-Shetland	**Fladen**	**Utsira**	**Long Forties**	**Dogger Bank**	**Norfolk Banks**	**German Bight**	**Oyster Ground**	**Southern Bight**	**Skagerrak**	**Kattegat**
Atlantis model codes	**OSN1**	**OS N2**	**NC NS**	**UK N2**	**DB**	**UK S2**	**Ger 2**	**NL3**	**NL2**	**Sk1**	**Kattegat**
Surface_mean_NTRI(μmol/l)					Y			Y	Y	Y	Y
Surface_mean_PHOS(μmol/l)	Y	Y	Y	Y	Y			Y	Y	Y	Y
Surface_mean_PSAL	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Surface_mean_SLCA(μmol/l)	Y	Y	Y	Y	Y			Y	Y	Y	Y
Surface_mean_TEMP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Surface_mean_TPHS(μmol/l)								Y	Y	Y	Y
Clupea harengus	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Gadus morhua	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Melanogrammus aeglefinus	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y
Merlangius merlangus	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sprattus sprattus	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y
Trisopterus esmarkii	Y	Y	Y	Y		Y	Y			Y	Y
Pollachius virens	Y	Y	Y	Y							
Scomber scombrus	Y	Y	Y	Y							
***Buccinum* sp.**							Y	Y			
***Astropecten* sp.**							Y	Y	Y		
***Liocarcinus* sp.**							Y	Y	Y		
***Asterias* sp.**							Y	Y	Y		

North Sea Assessment Strata	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
	Orkney-Shetland	**Fladen**	**Utsira**	**Long Forties**	**Dogger Bank**	**Norfolk Banks**	**German Bight**	**Oyster Ground**	**Southern Bight**	**Skagerrak**	**Kattegat**
Atlantis model codes	**OSN1**	**OS N2**	**NC NS**	**UK N2**	**DB**	**UK S2**	**Ger 2**	**NL3**	**NL2**	**Sk1**	**Kattegat**
***Corystes* sp.**							Y	Y	Y		
Cancer pagurus							Y		Y		
***Ophiura* sp.**							Y	Y	Y		
***Aphrodita* sp.**							Y	Y	Y		
***Nephrops* sp.**								Y			
***Acanthocardia* sp.**								Y			
***Alcyonium* sp.**								Y			
***Arctica* sp.**								Y			
TOTAL Variables	**18**	**17**	**18**	**18**	**13**	**10**	**26**	**26**	**21**	**28**	**27**

4.2.2 Data manipulation

A python script was used to calculate the mean values for each environmental variable present from 1984 to 2014 within each of the strata for bottom and surface datasets. These datasets were then combined and joined with aggregated cpue data for the same strata and period. This output was then used as the primary input for the Principal Component Analysis (PCA; see results below). In addition, this dataset was also combined with macrobenthic data where available e.g. strata 7, 8, and 9. Datasets were also created which included standard deviation values as well as means. These datasets were used for exploratory data analysis and the creation of variance plots to help identify trends and patterns within the core variables identified within the PCA for the identified strata specific principal components. All data were standardized and $\log_{10}$ transformed prior to applying.

4.2.3 S1 (Orkney-Shetland)

A PCA ordination was performed on a total of 18 state variables (Figure 4.2.3.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.3.2).

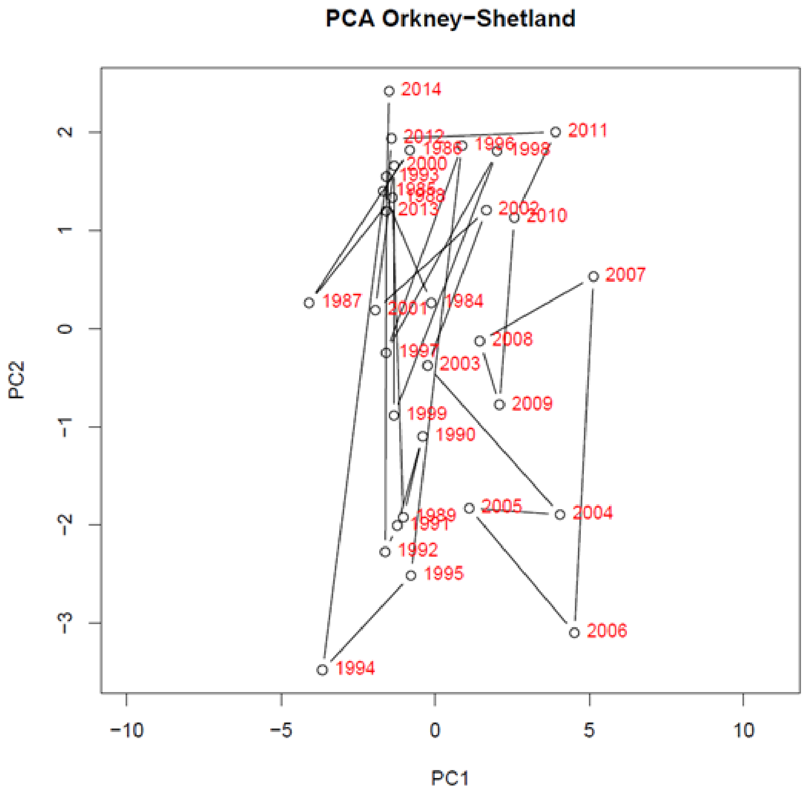

Figure 4.2.2.1. PCA ordination of time-series associated with Orkney-Shetland strata.

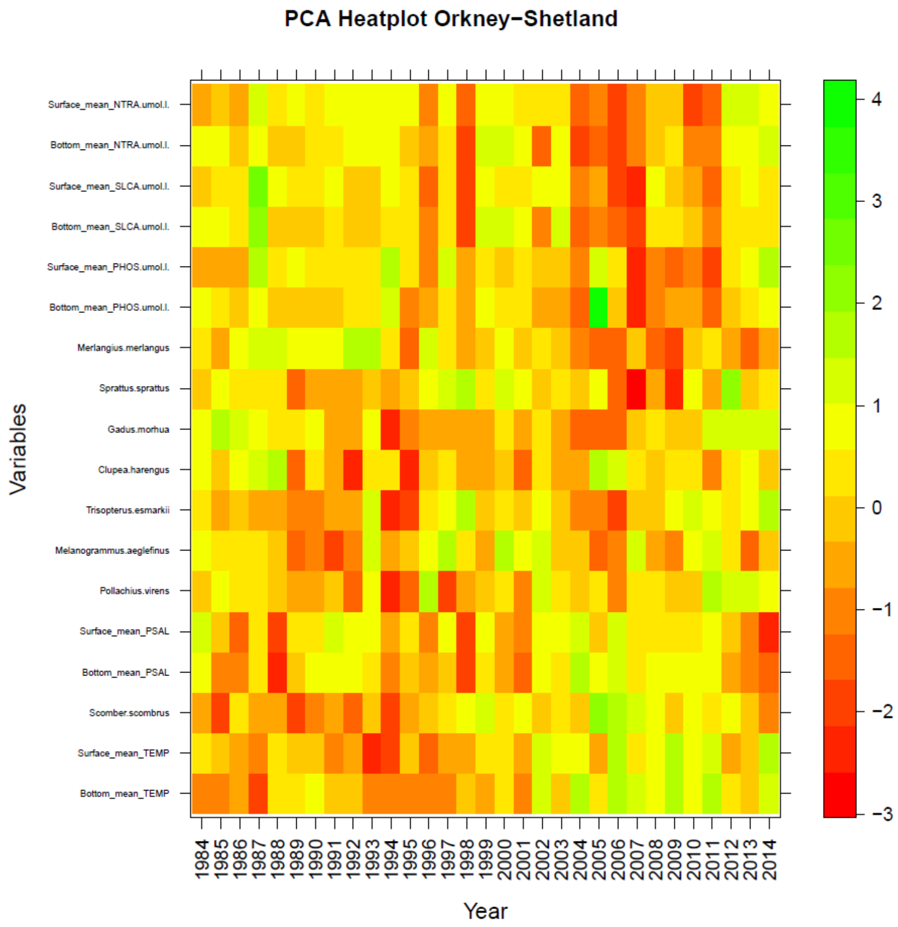

Figure 4.2.3.2. Heat map of variable anomalies ranked by PC1 component loadings for Shetland-Orkney strata.

Figure 4.2.3.2 shows that between 1984 and 2014 there has been a general decreasing trend in seawater nutrient concentrations if you discount 2012 to 2014 data, whereas seawater temperature has been increasing, as has the abundance of mackerel and pollock.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.3.3, which highlights a clear positive trend in bottom seawater temperatures over this period.

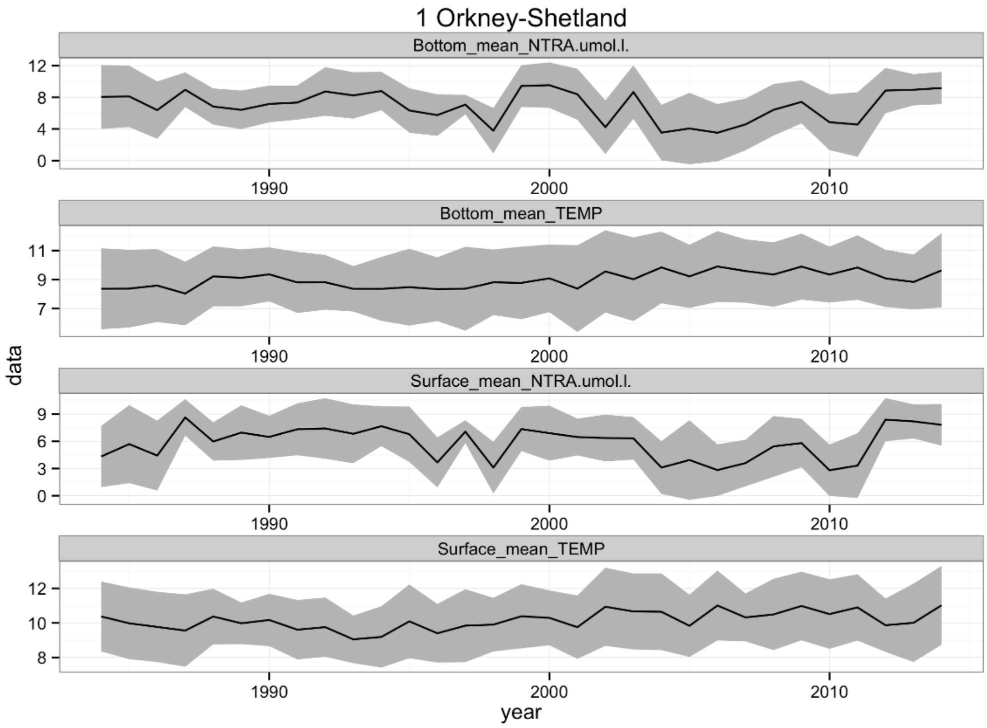

Figure 4.2.3.3. Time-series of principal components showing standard deviation.

4.2.4 S2 (Fladen)

A PCA ordination was performed on a total of 17 state variables (Figure 4.2.4.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.4.2).

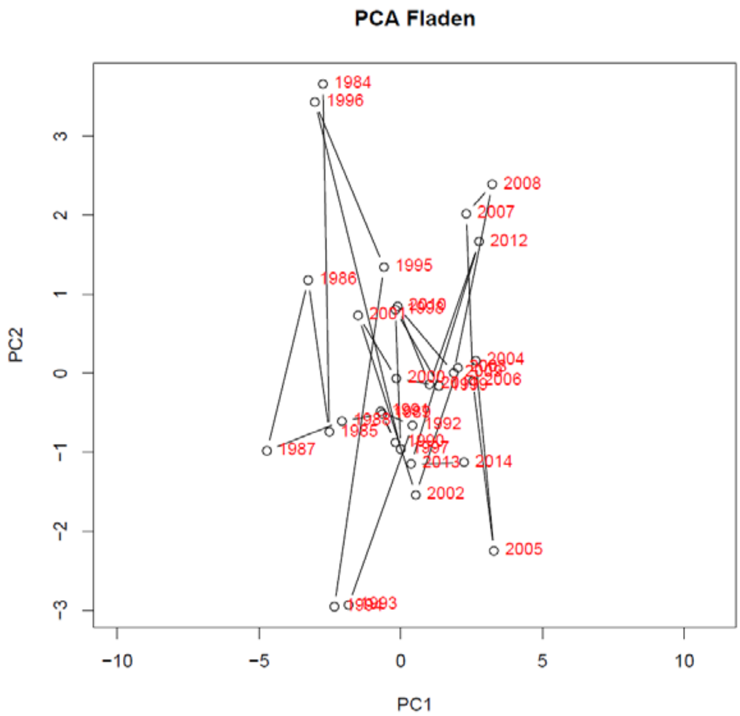

Figure 4.2.4.1. PCA ordination of time-series associated with Fladen strata.

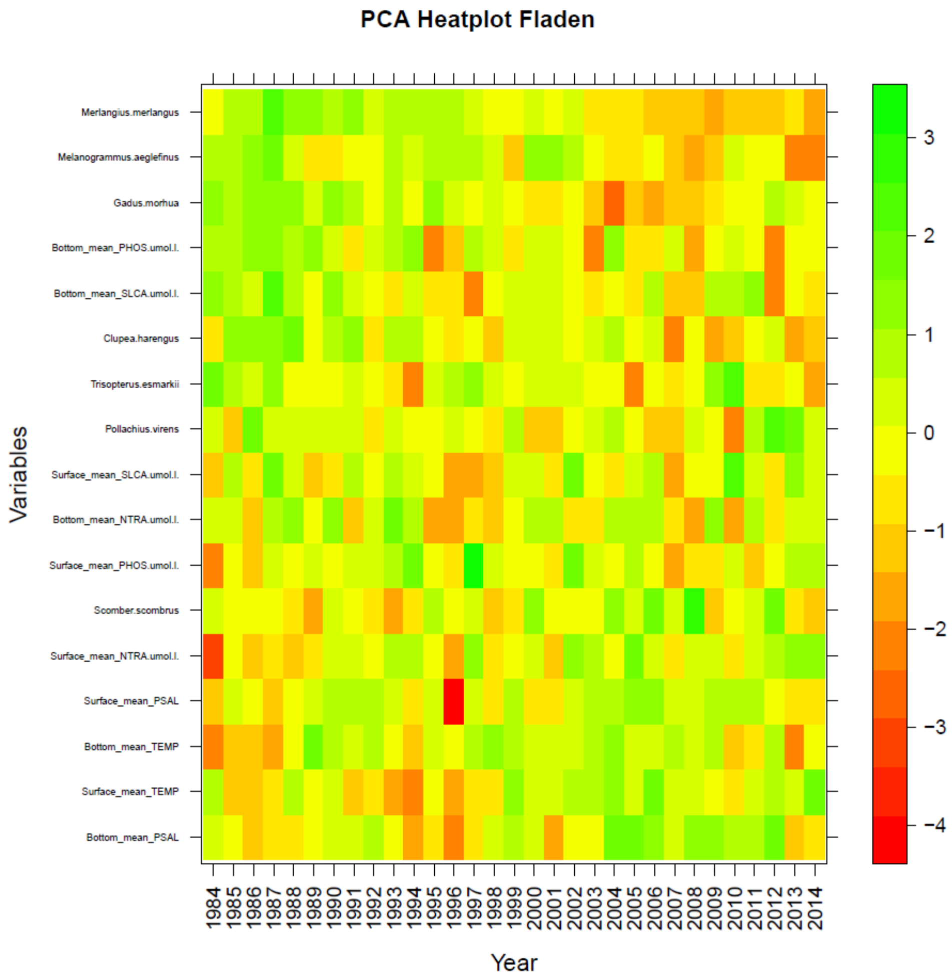

Figure 4.2.4.2. Heat map of variable anomalies ranked by PC1 component loadings for Fladen strata.

Figure 4.2.4.2 shows that between 1984 and 2014 there has been a general decrease in the abundance of whiting, haddock, and cod, whereas there has been a general increasing trend on salinity and sea surface temperatures.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.4.3, which highlights a clear positive trend in surface seawater temperatures over this period.

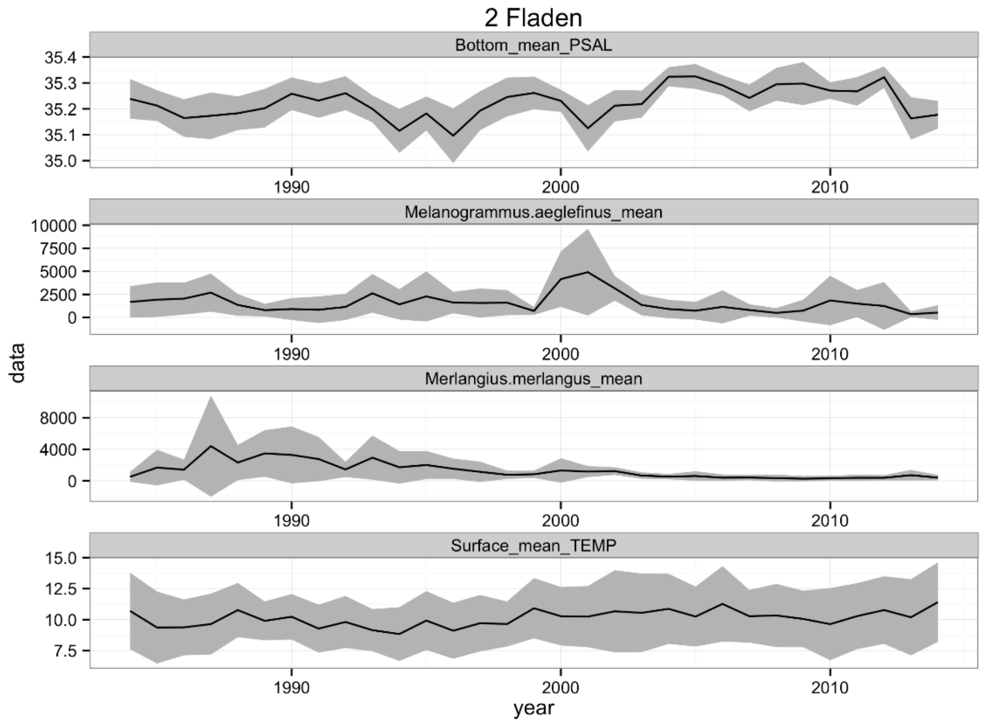

Figure 4.2.4.3. Time-series of principal components showing standard deviation for Fladen strata.

4.2.5 S3 (Utsira)

A PCA ordination was performed on a total of 18 state variables (Figure 4.2.5.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.5.2).

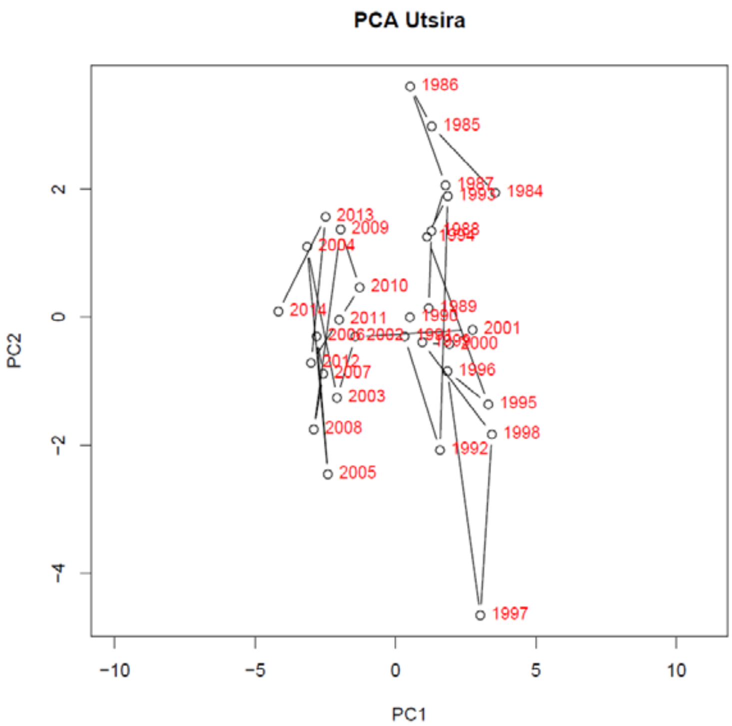

Figure 4.2.5.1. PCA ordination of time-series associated with Utsira strata.

Figure 4.2.5.2 shows that between 1984 and 2014 there has been a profound increase in nutrients especially nitrate and silicate concentrations, whereas there has been a general decrease in cod, haddock and whiting.

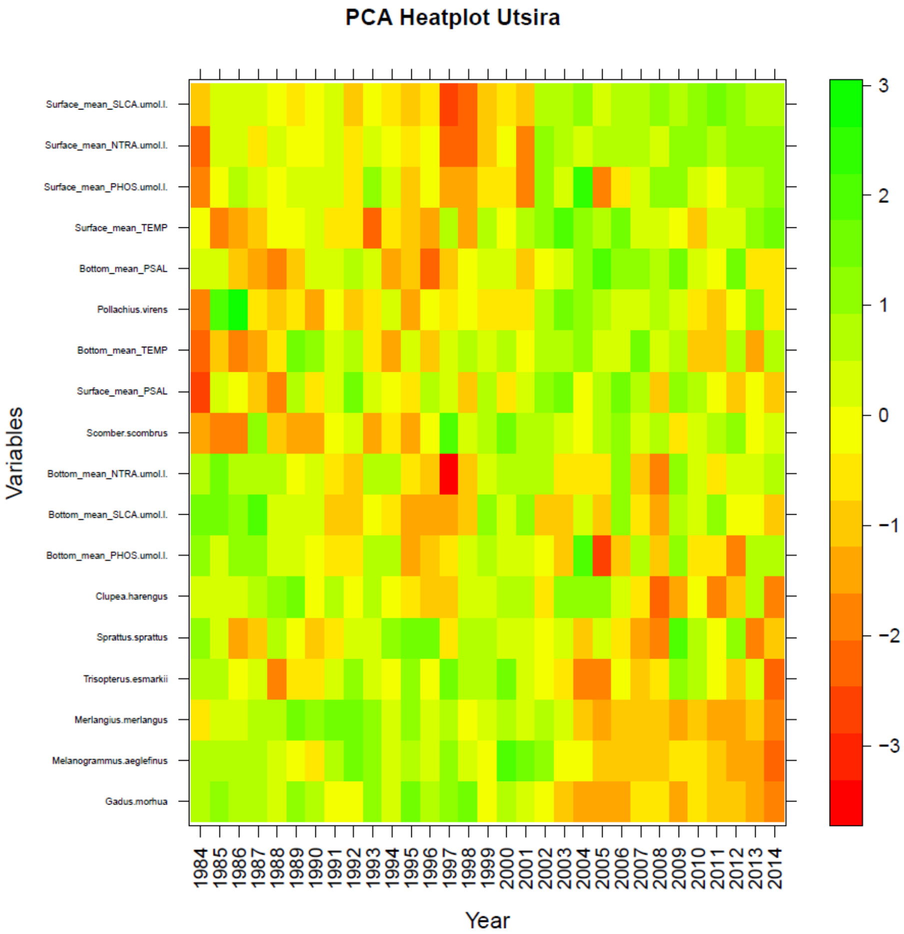

Figure 4.2.5.2. Heat map of variable anomalies ranked by PC1 component loadings for Utsira strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.5.3, which highlights a clear positive trend in surface nitrate and silicate over this period.

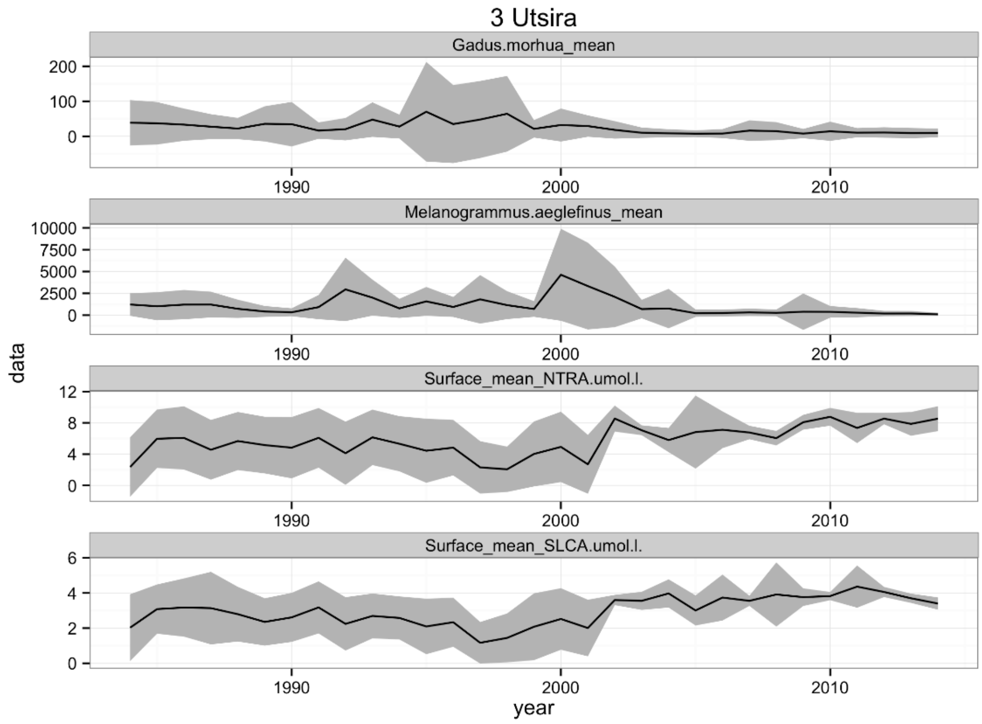

Figure4.2.5.3. Time-series of principal components showing standard deviation for Utsira strata.

4.2.6 S4 (Long Forties)

A PCA ordination was performed on a total of 18 state variables (Figure 4.2.6.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.6.2).

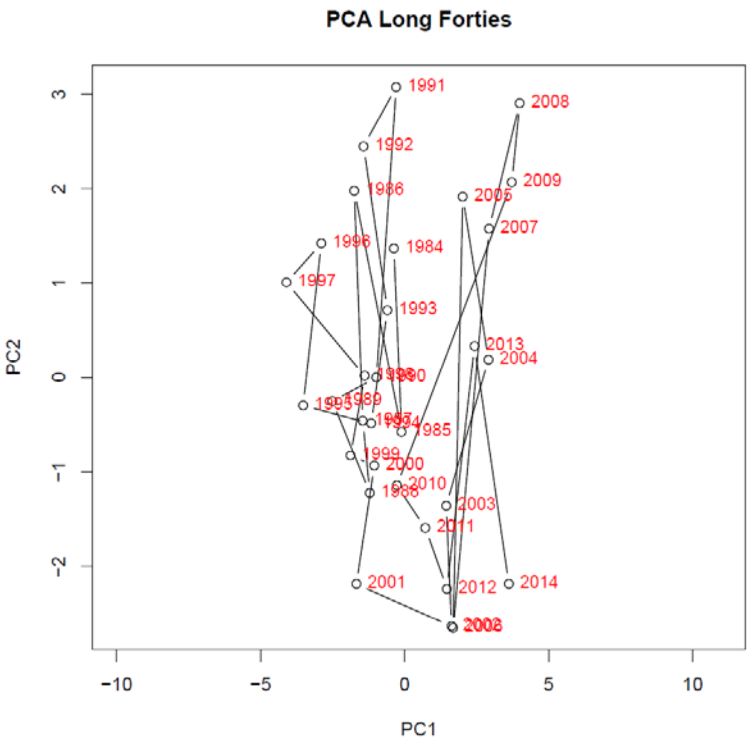

Figure4.2.6.1. PCA ordination of time-series associated with Long Forties strata.

Figure 4.2.6.2 shows that between 1984 and 2014 there has been an increase in nutrients especially nitrate and phosphate concentrations, whereas there has been a general decrease in cod, haddock, and whiting over the same period.

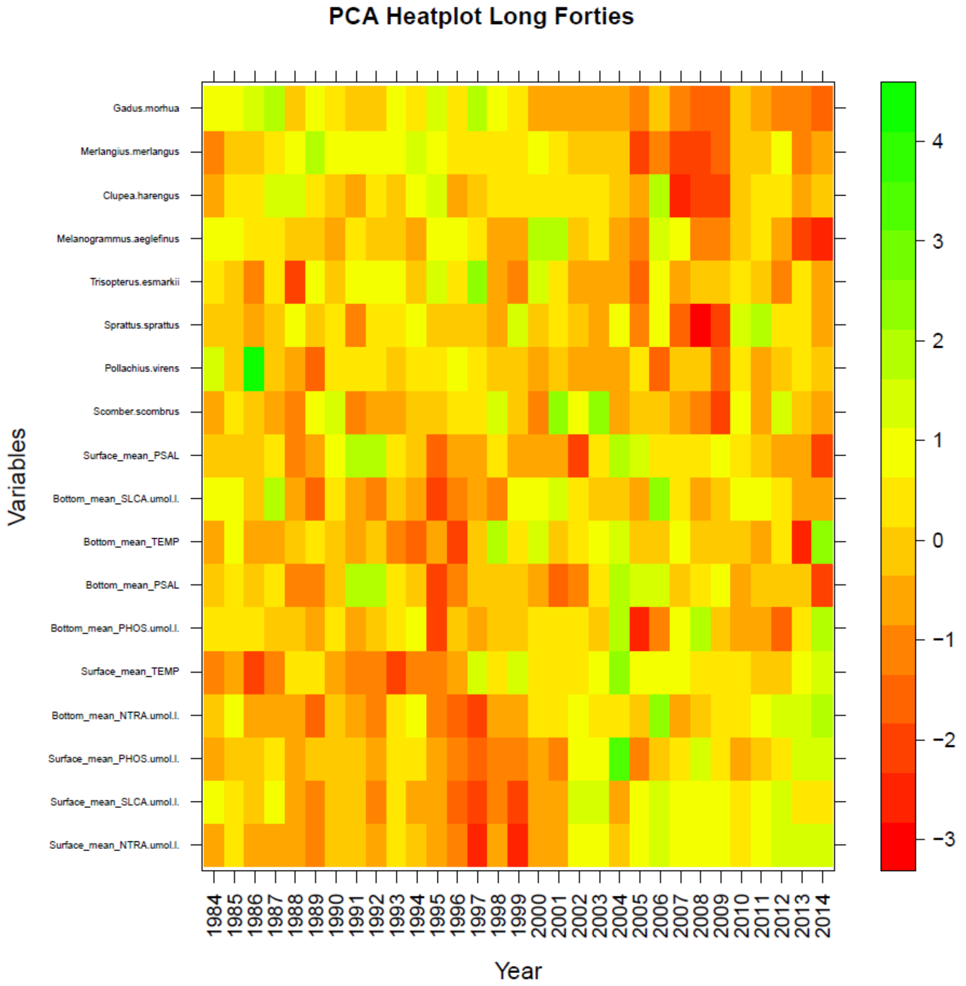

Figure 4.2.6.2. Heat map of variable anomalies ranked by PC1 component loadings for Long Forties strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.6.3, which highlights a clear positive trend in surface nitrate over this period.

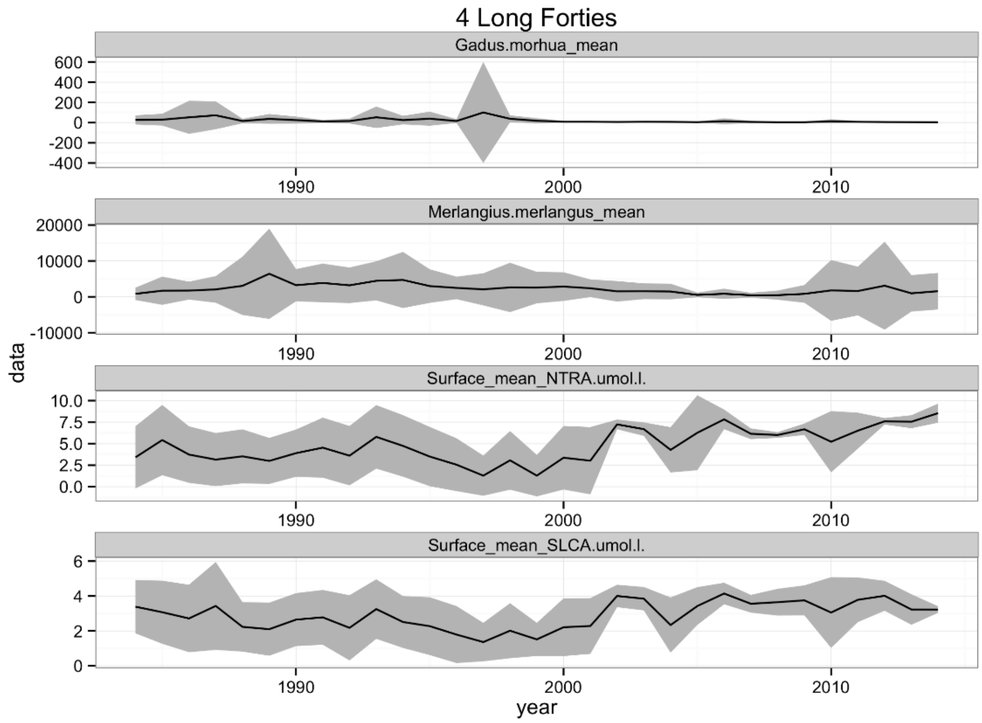

Figure4.2.6.3. Time-series of principal components showing standard deviation for Long Forties strata.

4.2.7 S5 (Dogger Bank)

A PCA ordination was performed on a total of 13 state variables (Figure 4.2.7.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.7.2).

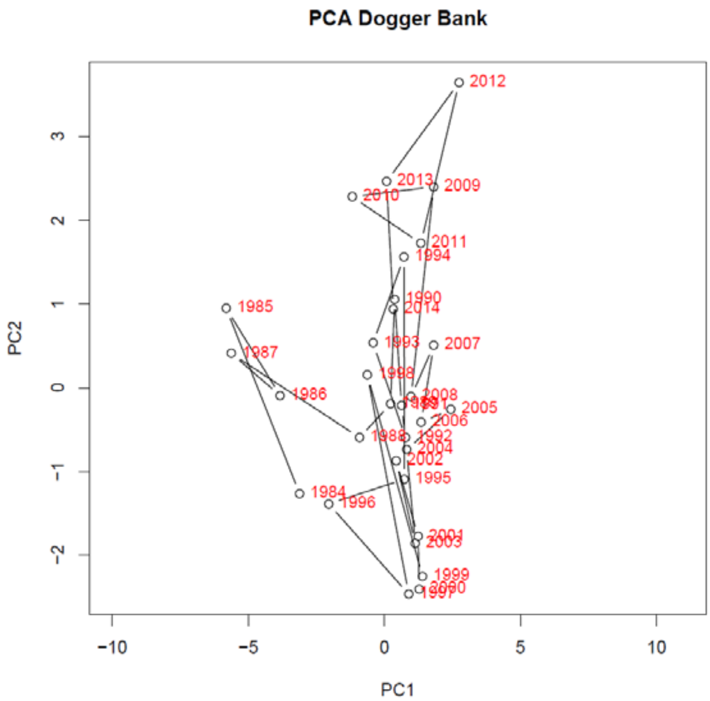

Figure4.2.7.1. PCA ordination of time-series associated with Dogger Bank strata.

Figure 4.2.7.2 shows no clear trend in the time-series, other than perhaps a general decline in silicate and nitrite over the period, and a possible increase in surface salinity and temperature.

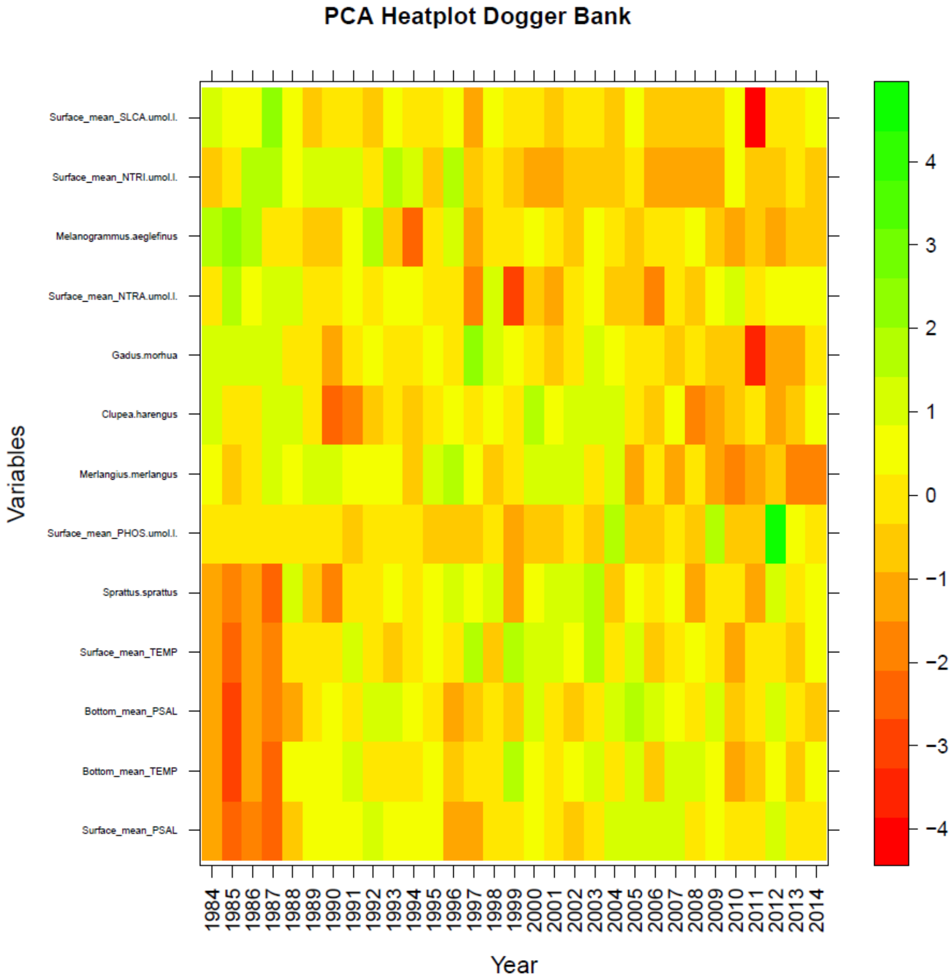

Figure4.2.7.2. Heat map of variable anomalies ranked by PC1 component loadings for Dogger Bank strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.7.3.

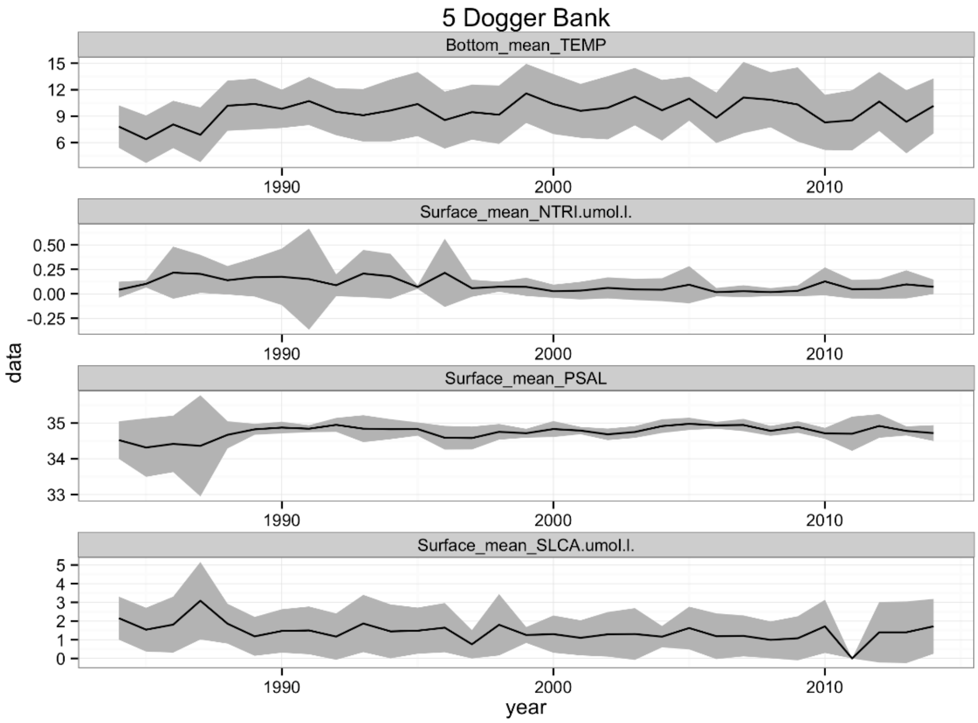

Figure4.2.7.3. Time-series of principal components showing standard deviation for Dogger Bank strata.

4.2.8 S6 (Norfolk Banks)

A PCA ordination was performed on a total of 10 state variables (Figure 4.2.8.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.8.2).

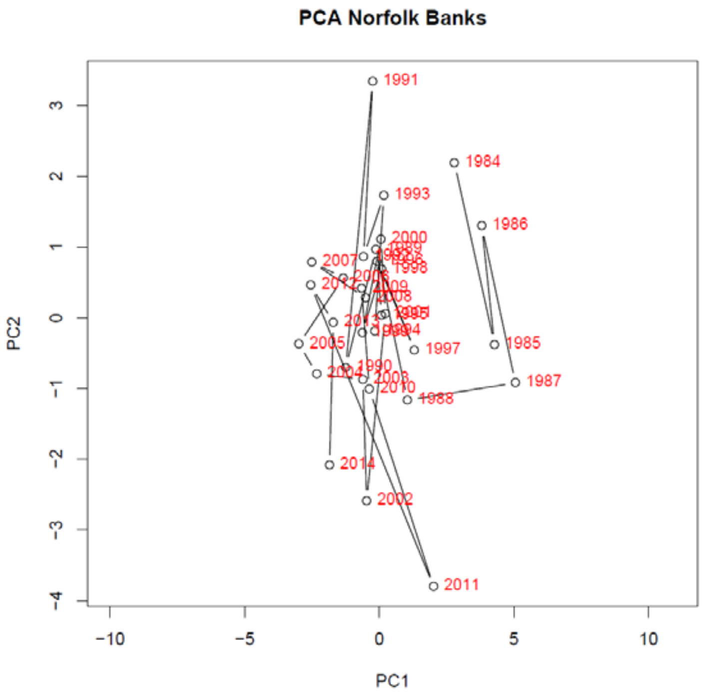

Figure 4.2.8.1. PCA ordination of time-series associated with Norfolk Banks strata.

Figure 4.2.8.2 shows that between 1984 and 2014 there has been a marked increase in temperature and sprat abundance, whereas there has been a decrease in cod over the same period.

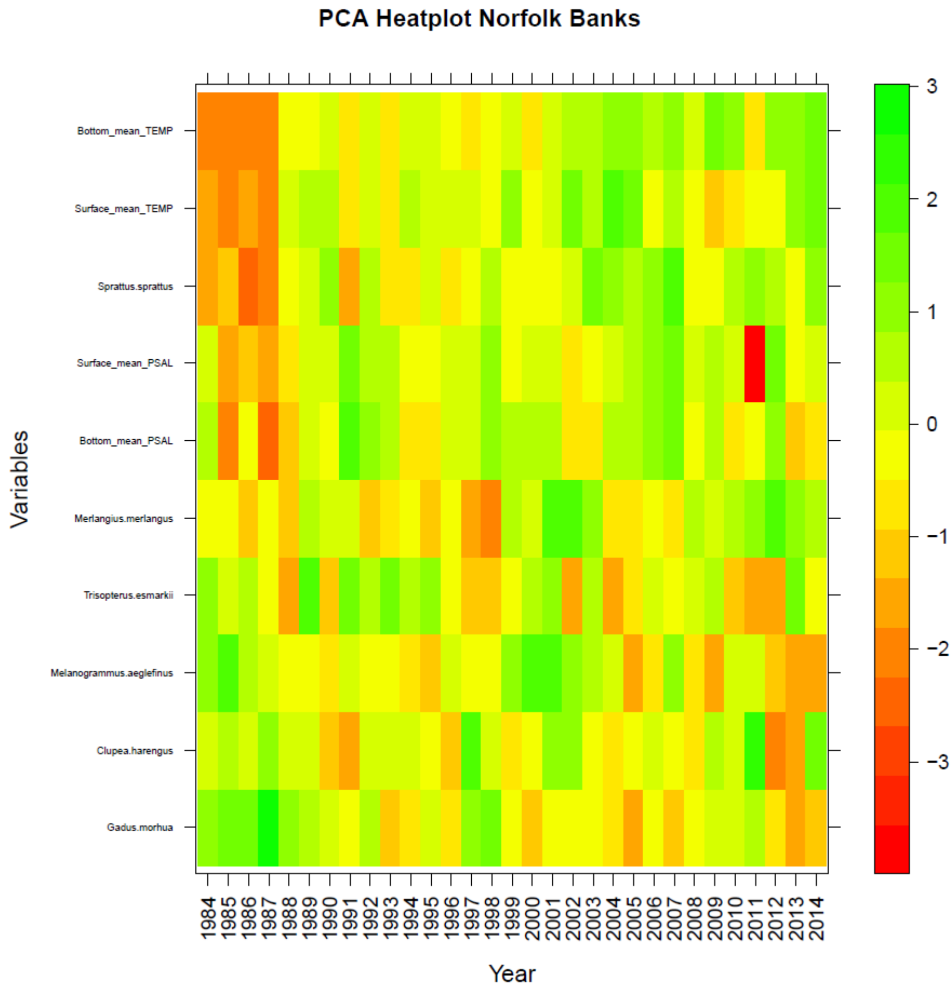

Figure 4.2.8.2. Heat map of variable anomalies ranked by PC1 component loadings for Norfolk Banks strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.8.3, which highlights a clear positive trend seabed temperature over this period.

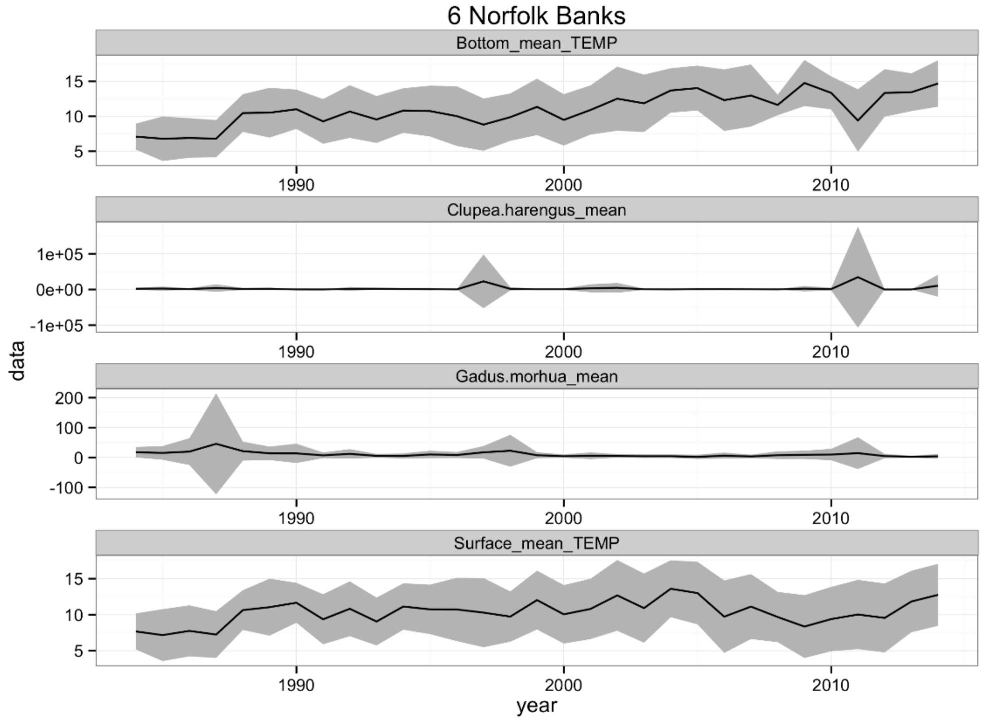

Figure 4.2.8.3. Time-series of principal components showing standard deviation for Norfolk Banks strata.

4.2.9 S7 (German Bight)

A PCA ordination was performed on a total of 26 state variables (Figure 4.2.9.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.9.2).

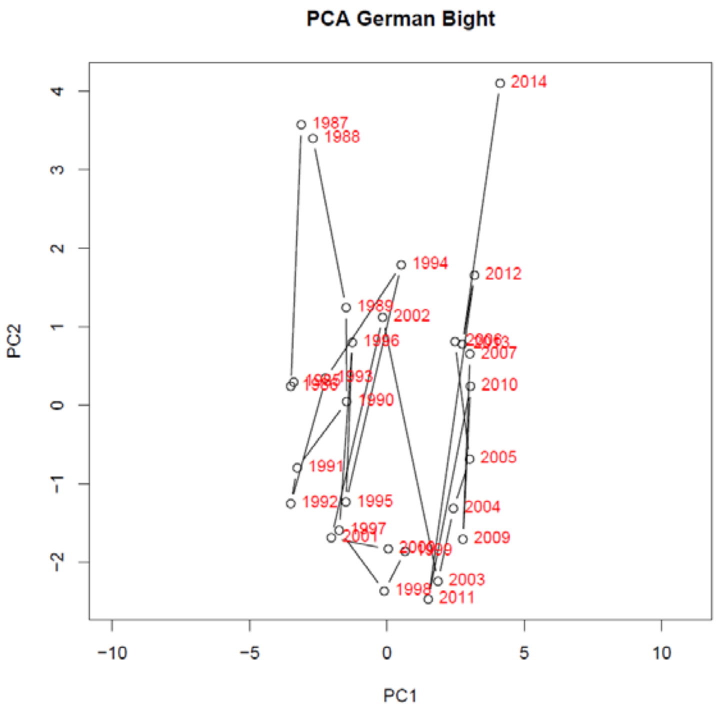

Figure4.2.9.1. PCA ordination of time-series associated with German Bight strata.

Figure 4.2.9.2 shows that between 1984 and 2014 there has been an increase in *Astropecten* sp. and nutrients especially nitrate and silicate concentrations, whereas there has been a general decrease in *Buccinum* sp., whiting, and cod over the same period.

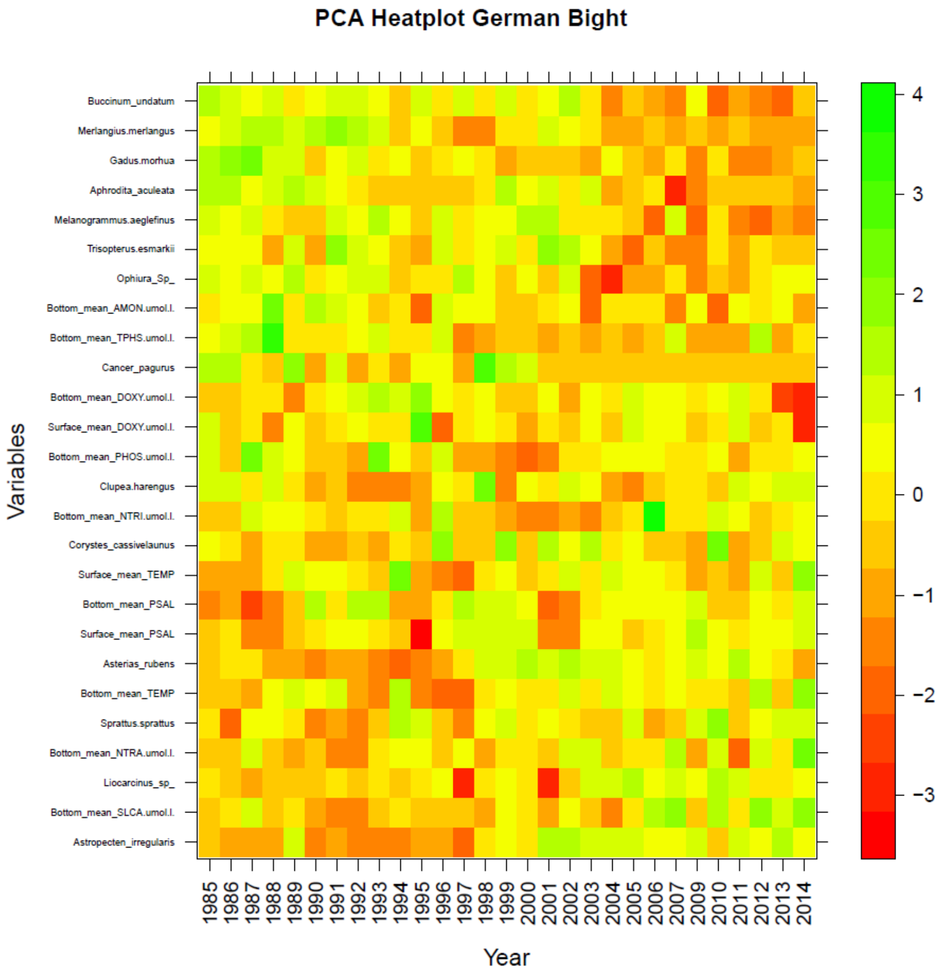

Figure 4.2.9.2. Heat map of variable anomalies ranked by PC1 component loadings for German Bight strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.9.3, which highlights clear positive trends in *Astropecten* and bottom silicate, and clear declines *Buccinum* and cod.

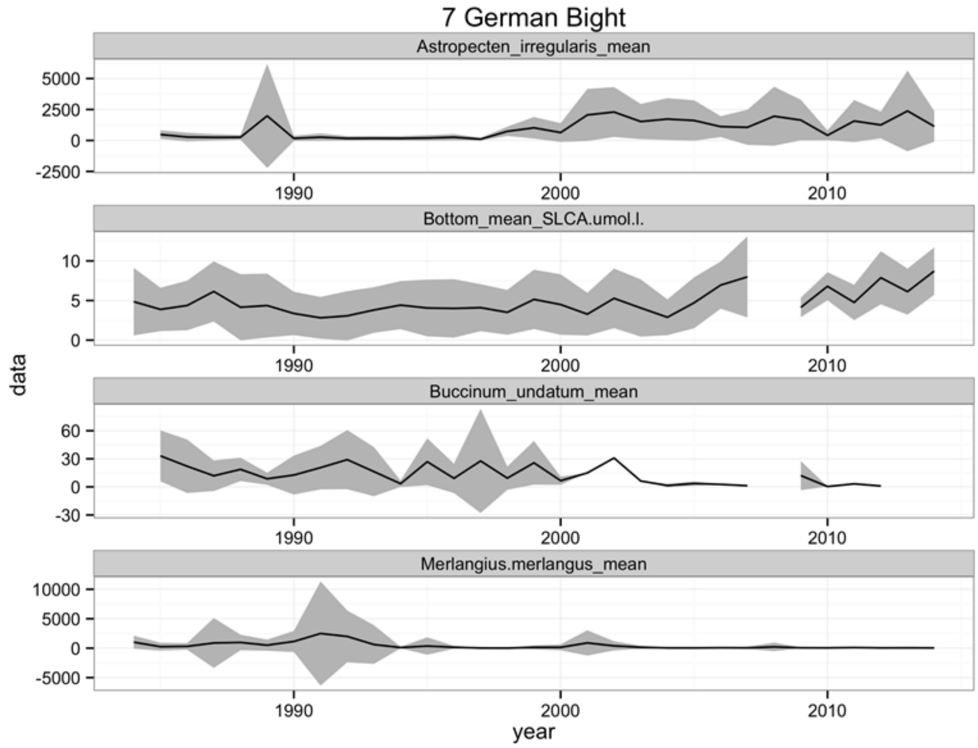

Figure 4.2.9.3. German Bight. Time-series of mean (black line) and standard deviation (grey ribbon) for the four most important variable for the 1st principal components in the PCA analysis.

4.2.10 S8 (Oyster Ground)

A PCA ordination was performed on a total of 26 state variables (Figure 4.2.10.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.10.2).

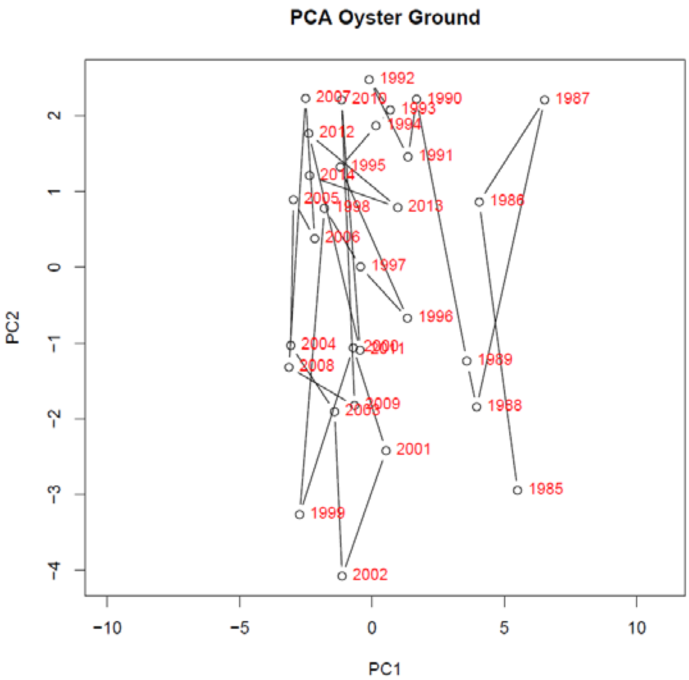

Figure 4.2.10.1. PCA ordination of time-series associated with Oyster Ground strata.

Figure 4.2.10.1 shows that between 1984 and 2014 there has been an increase in nutrients especially nitrate and phosphate concentrations, whereas there has been a general decrease in cod, haddock and whiting over the same period.

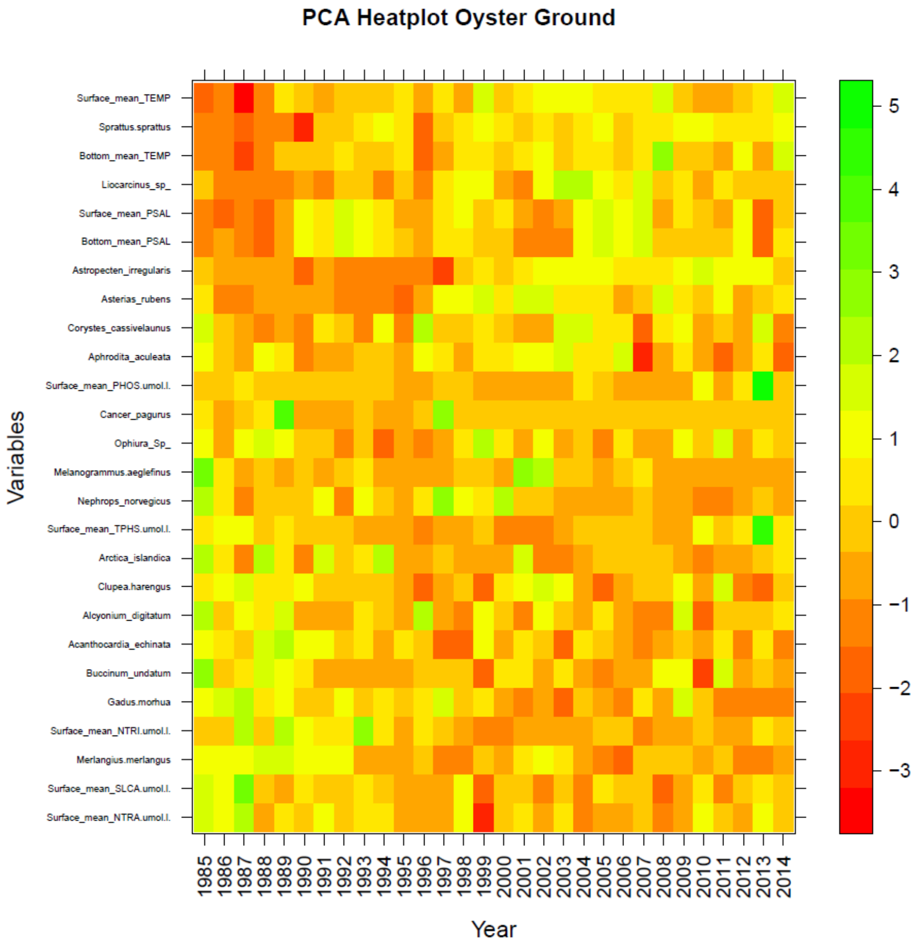

Figure 4.2.10.2. Heat map of variable anomalies ranked by PC1 component loadings for Oyster Ground strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.10.2, which highlights a clear positive trend in temperature and sprat over this period.

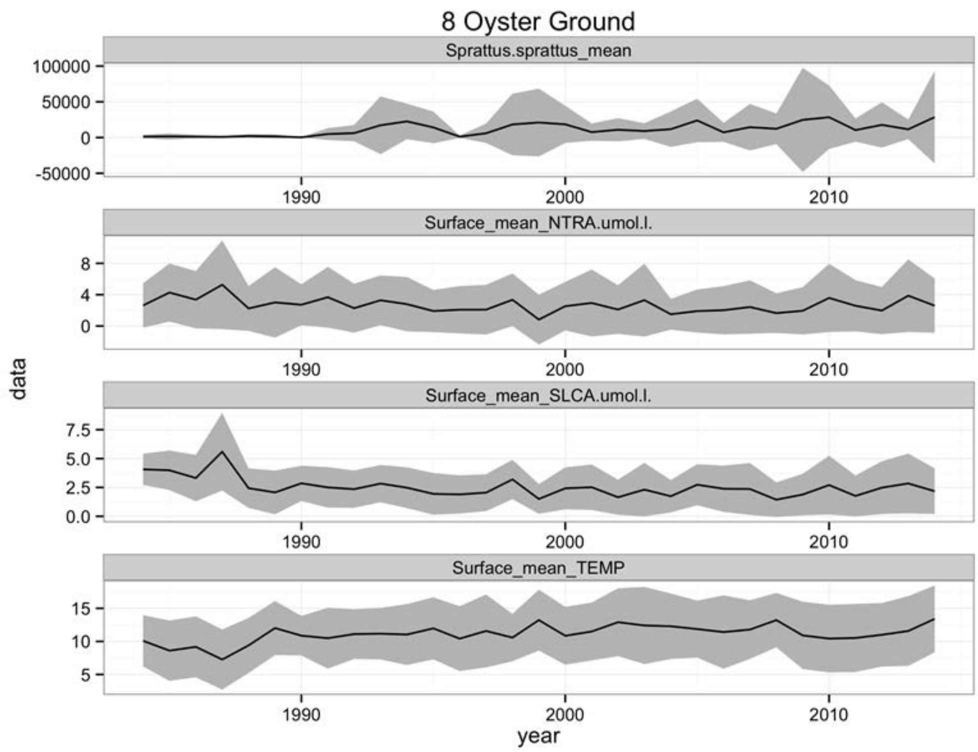

Figure 4.2.10.3. Oyster ground. Time-series of mean (black line) and standard deviation (grey ribbon) for the four most important variable for the 1st principal components in the PCA analysis.

4.2.11 S9 (Southern Bight)

A PCA ordination was performed on a total of 21 state variables (Figure 4.2.11.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.11.2).

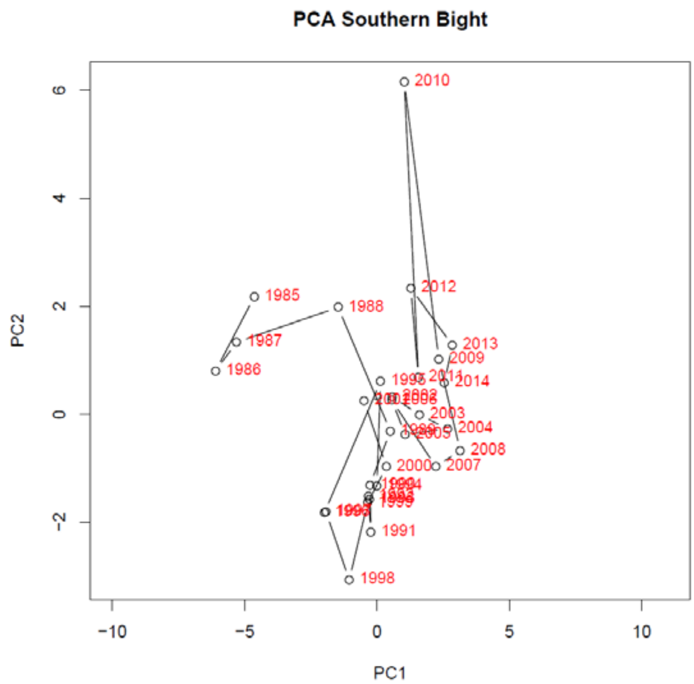

Figure 4.2.11.1. PCA ordination of time-series associated with Southern Bight strata.

Figure 4.2.11.2 shows that between 1984 and 2014 there has been a general increase in temperature and numbers of *Liocarcinus* sp., whereas nitrate has shown a decline in concentration over the same period.

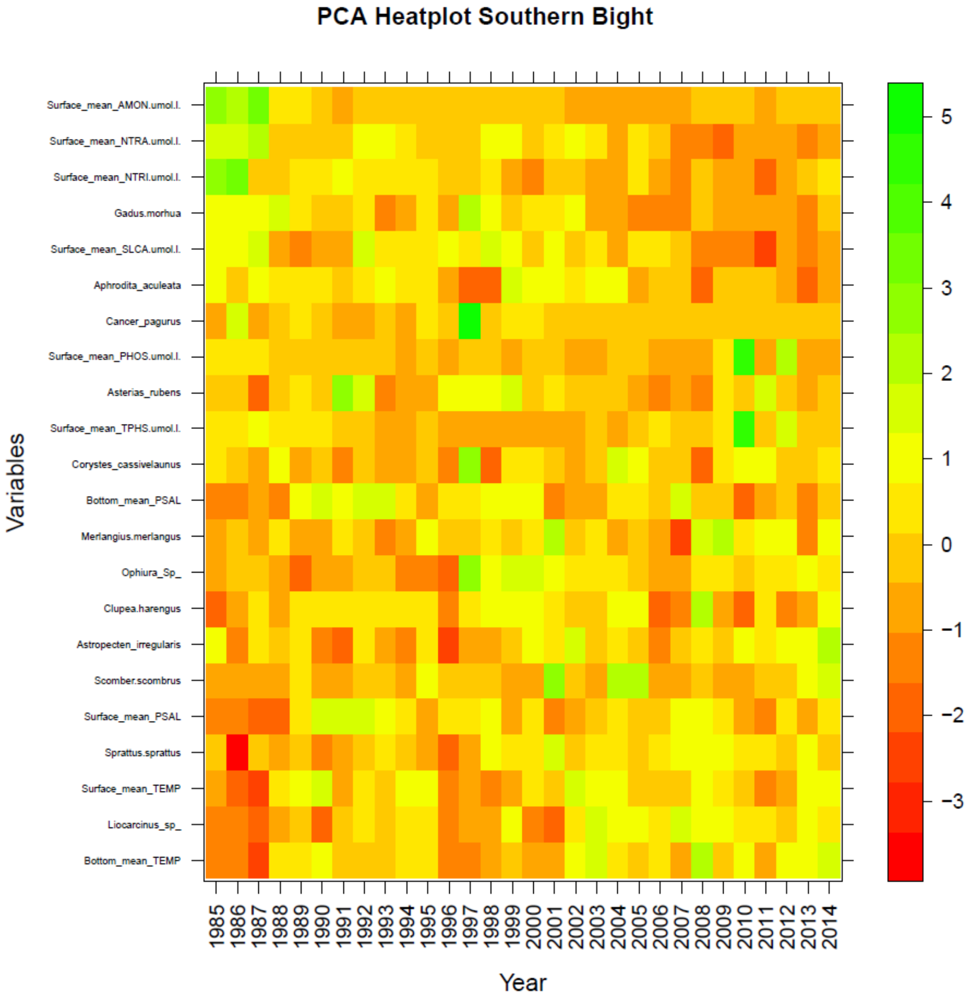

Figure 4.2.11.2. Heat map of variable anomalies ranked by PC1 component loadings for Southern Bight strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.11.3, which highlights a clear negative trend for nutrients whereas temperature and *Liocarcinus* sp. are increasing over the same period.

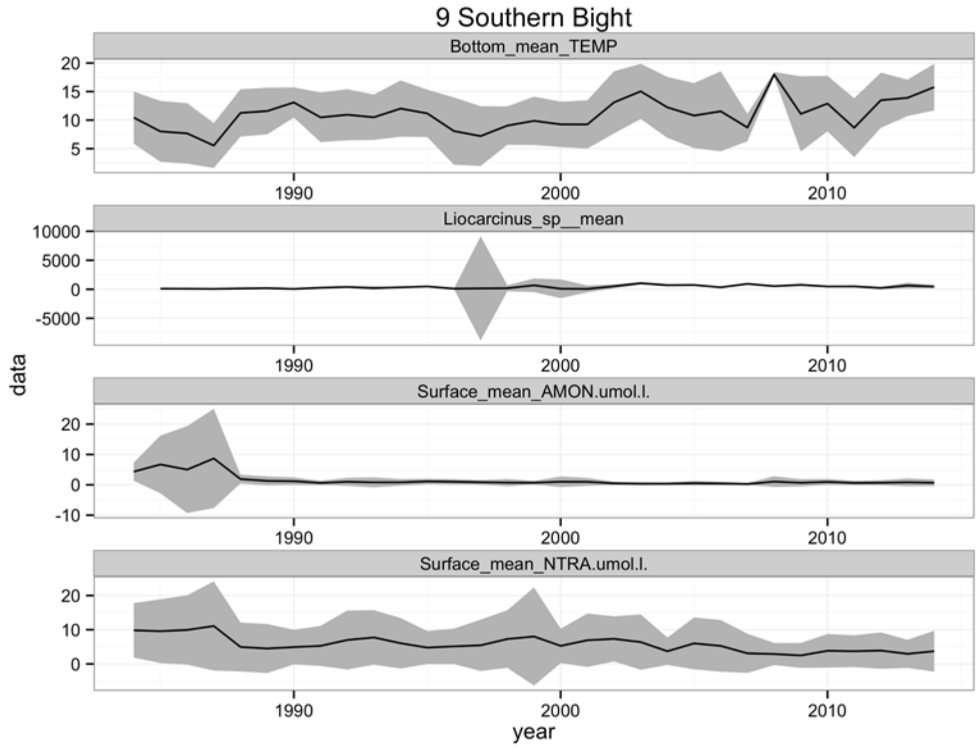

Figure 4.2.11.3. Southern Bight. Time-series of mean (black line) and standard deviation (grey ribbon) for the four most important variable for the 1st principal components in the PCA analysis.

4.2.12 S10 (Skagerrak)

A PCA ordination was performed on a total of 28 state variables (Figure 4.2.12.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.12.2).

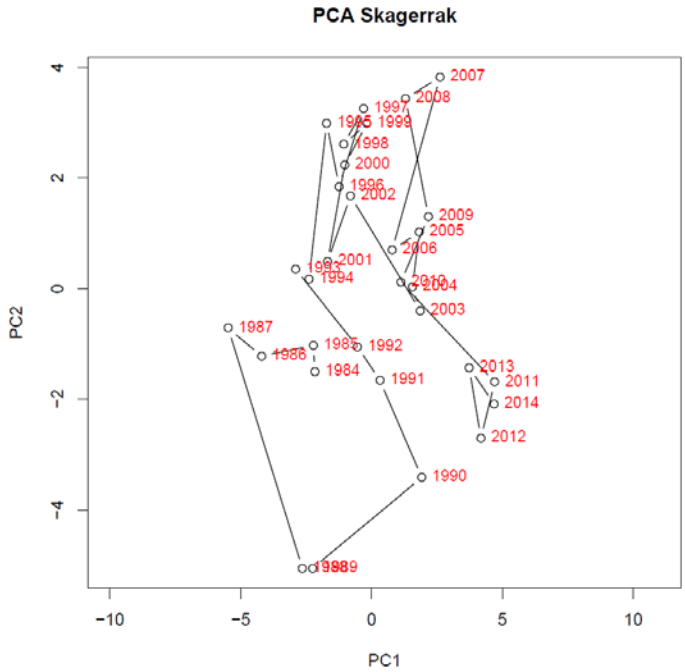

Figure 4.2.12.1. PCA ordination of time-series associated with Skagerrak strata.

Figure 4.2.12.2 shows that between 1984 and 2014 there has been a general decrease in nutrients and oxygen, whereas seawater temperature has increased.

Figure 4.2.12.2. Heat map of variable anomalies ranked by PC1 component loadings for Skagerrak strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.12.3, which highlights a clear positive trend in seabed temperature and a decline in total nitrogen over this period.

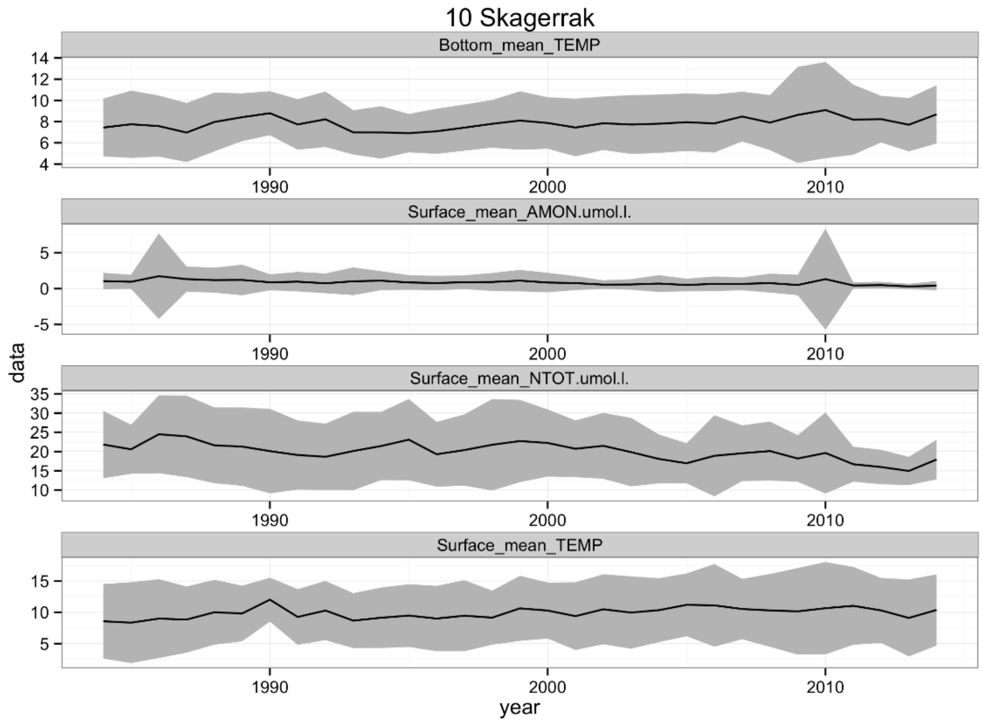

Figure 4.2.12.3. Time-series of principal components showing standard deviation for Skagerrak strata.

4.2.13 S11 (Kattegat)

A PCA ordination was performed on a total of 27 state variables (Figure 4.2.13.1) and the ranked PC1 loadings used to construct a heat map of variable anomalies (Figure 4.2.13.2).

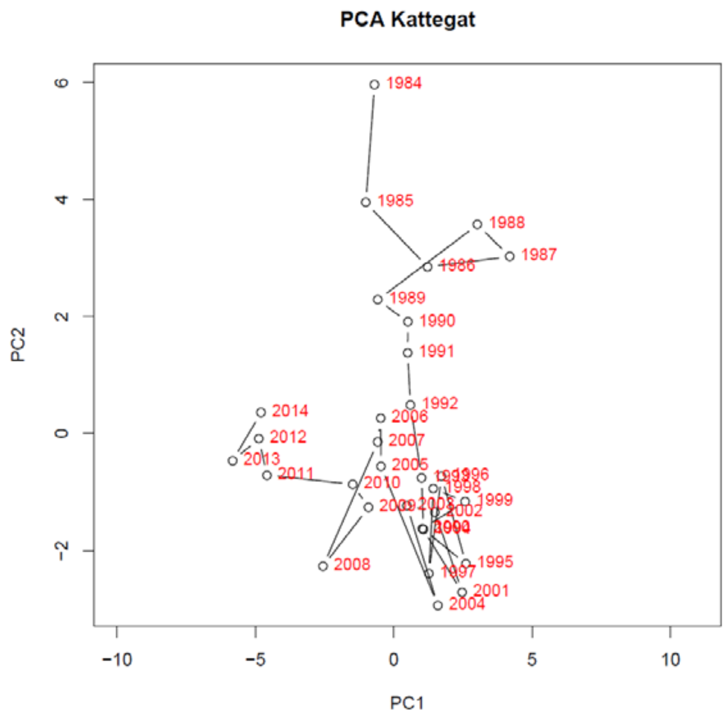

Figure 4.2.13.1. PCA ordination of time-series associated with Kattegat strata.

Figure 4.2.13.2 shows that between 1984 and 2014 there is a clear trend in increasing sea surface and bottom oxygen while concentrations of nutrients have significantly declined in recent years.

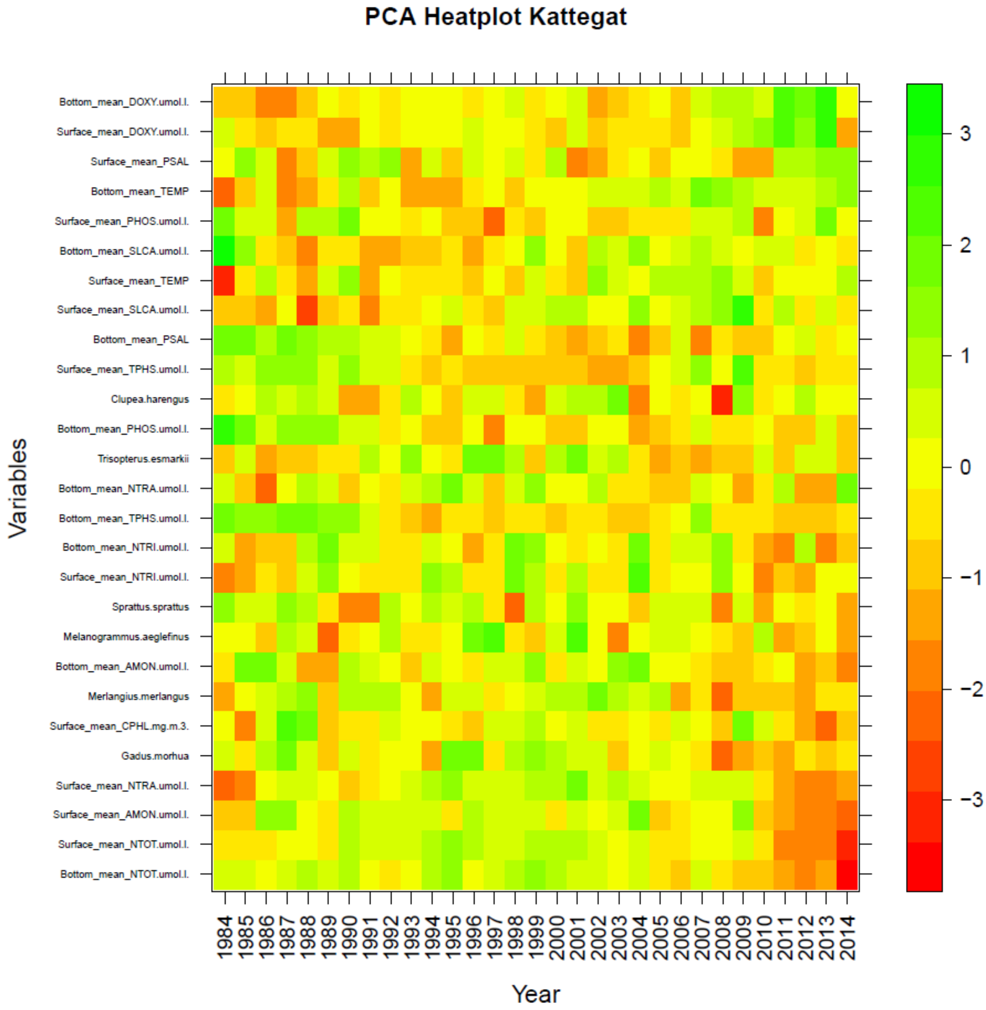

Figure 4.2.13.2. Heat map of variable anomalies ranked by PC1 component loadings for Kattegat strata.

Trends of the principal component time-series (including their standard deviation) are shown in Figure 4.2.13.3, which highlights a clear positive trend in oxygen (with the exception of 2014) and a declining trend in total nitrogen over this period.

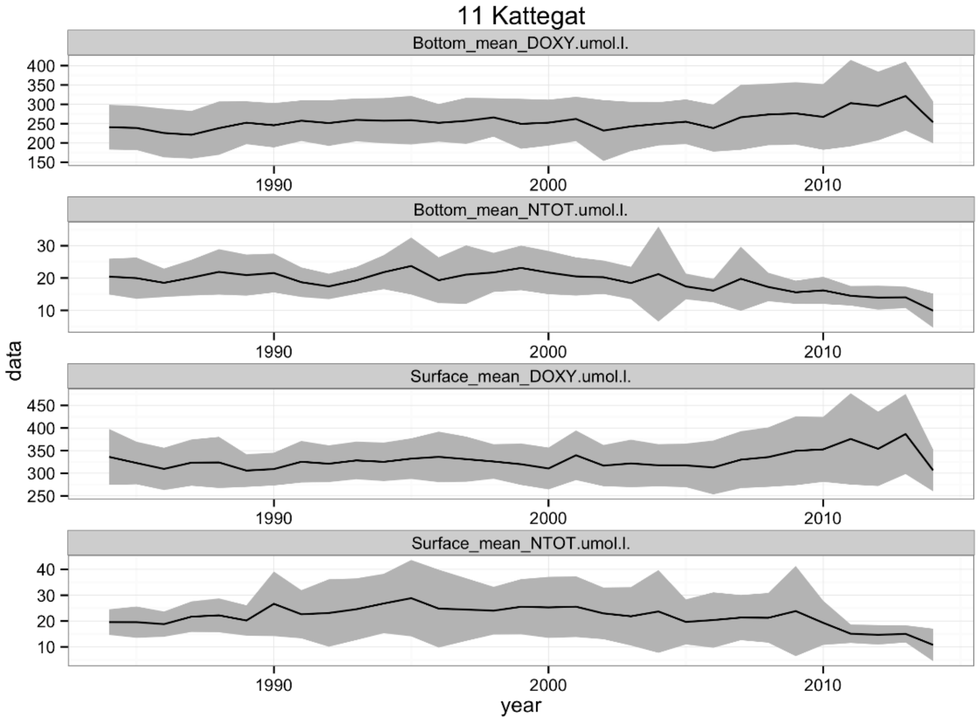

Figure 4.2.13.3. Time-series of principal components showing standard deviation for Kattegat strata.

4.3 Relative importance of variables (rank analysis)

To evaluate the overall North Sea relative importance of each variable in the PCA analyses the absolute rank of each variable along PC1 and PC2 was calculated for each regional PCA. These rank scores were combined and plotted as box plots in Figure 4.3.1 (PC1) and Figure 4.3.2 (PC2). For the PC1 ranks (Figure 4.3.1), the surface Nitrogen (NTOT), AMON, Nitrate and cod were all above 0.8 in absolute rank, with some of them consistently highly ranked (narrow quartile ranges). No bottom variables were above the 0.8 threshold for the PC1 ranks. In contrast, along PC2 three of the four variables above 0.8 were bottom variables: TPHO, DOXY and PHOS, in addition to surface TPHS (Figure 4.3.2). This indicates that the environmental variables were more important in driving the PCA and hence system variability than the fish cpues.

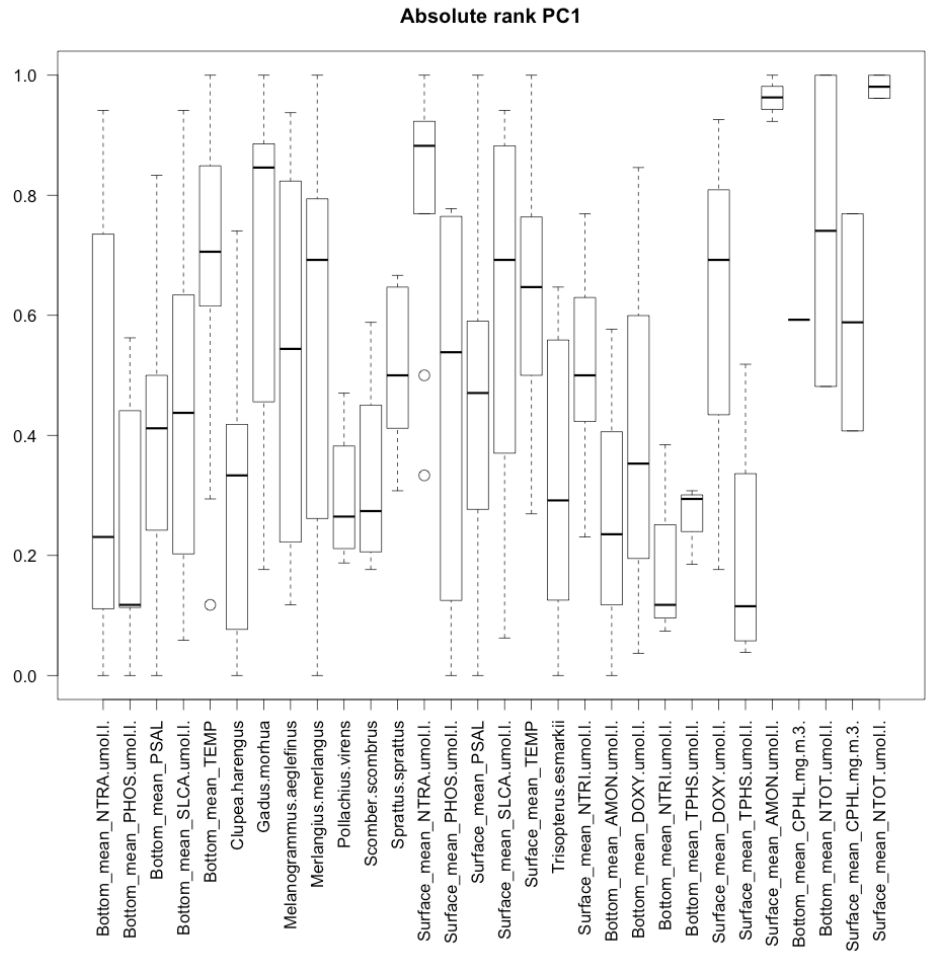

Figure 4.3.1. Boxplot showing the median, and quartiles of the absolute rank along PC1 for all variables included in the regional North Sea IEA PCA analysis.

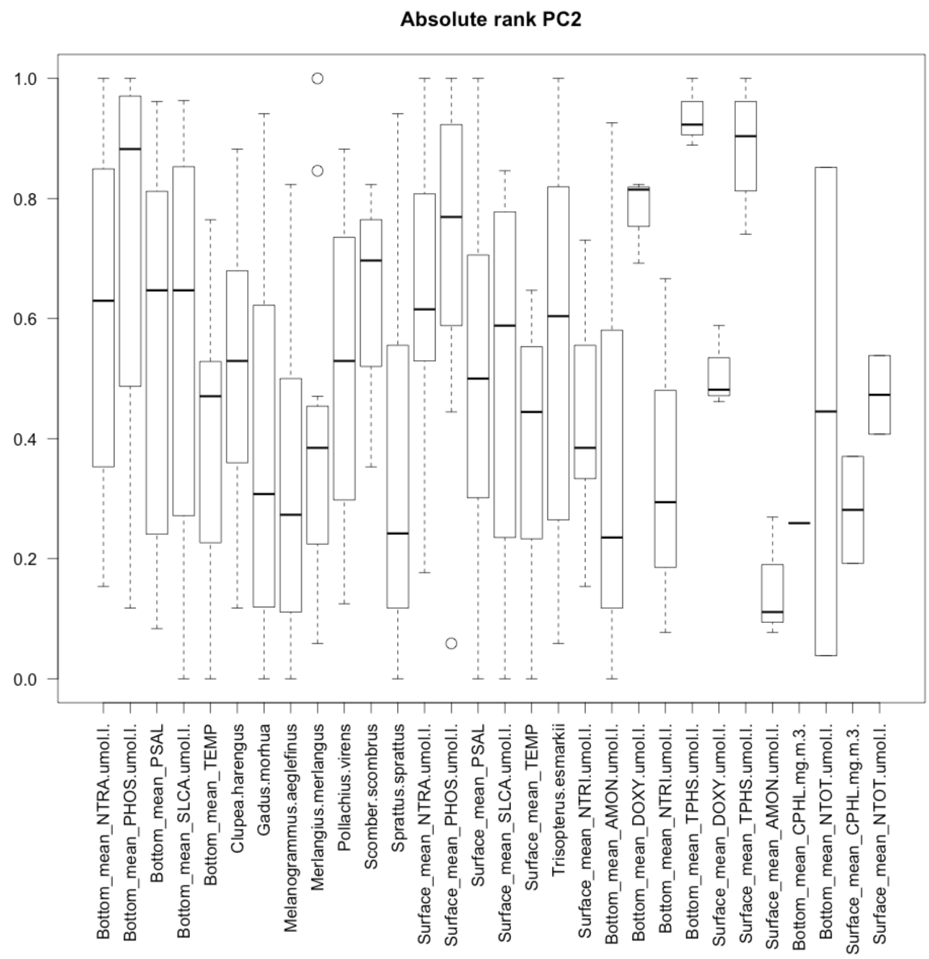

Figure 4.3.2 Boxplot showing the median, and quartiles of the absolute rank along PC2 for all variables included in the regional North Sea IEA PCA analysis.

4.4 Conclusions

It is apparent that temperature and nutrient concentrations dominate the time-series trends in Orkney-Shetland strata with the temperature rising and nutrient level falling over the period. There is then some common trends observed between the Fladen, Utsira and Long Forties strata, in that they all show a clear and strong declining trend in demersal fish abundances, notably whiting, cod, and haddock. By contrast, in these strata seawater temperatures and nutrients levels are all generally increasing. All of these strata are to the north of the Dogger Bank and are located in deeper water.

To the south, the Dogger Bank, Norfolk Banks, Oyster Ground, and Southern Bight all show strong increasing trends in temperature, salinity and numbers of sprat, as well as some indication of declining trends in nutrients. However, the German Bight appears to be a region of the North Sea, which has a mix of northern and southern North, attributes in that cod and whiting show clear negative trends while nutrient levels some increasing trend. Interesting for the Dogger Bank, Norfolk Banks, Oyster Ground, and to some extent the Southern Bight there is a marked change in 1989 associated with an abrupt and sustained increase in seawater temperatures.

The Skagerrak and Kattegat appear to be dominated by abiotic factors notably strong increasing trends in seawater temperature and decreasing trends in nutrient concentrations. There also appears to be some clear distinction between these two strata in that increasing trends in oxygen dominate the Kattegat, which may correspond to the marked declines in nutrients observed in this stratum.

5 Human activities and pressures mapping (ToR d)

WGINOSE considered how to integrate in the modelling approach, currently being developed, other types of activities (other than fishing), and pressure data relevant to moving toward a holistic IEA for the Greater North Sea ecoregion (ICES, 2016). The inclusion of the cumulative effects of pressures as part of an IEA is also highly relevant to the consideration of the Marine Strategy Framework Directive (MSFD) indicators under development to track progress towards Good Environmental Status (GES).

ICES (2016) provided an overview of major regional pressures for the Greater North Sea ecoregion linked mainly to human activities (Figure 5.1).

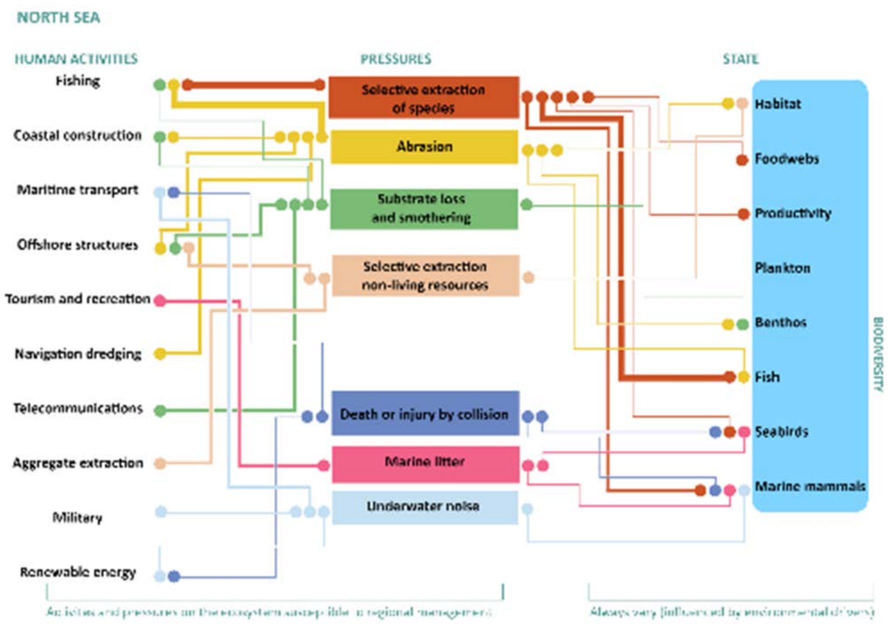

Figure 5.1. Greater North Sea Ecoregion overview with the major regional pressures, human activities, and state of the ecosystem components. The width of lines indicates the relative importance of individual links.

According to this study, the following pressures were identified:

- Selective extraction of species;
- Abrasion;
- Substrate loss and smothering;
- Selective extraction non-living resources;
- Death or injury by collision;
- Marine litter;
- Underwater noise.

The links between these pressures and the state of the monitored and assessed ecosystem components under the MSFD is work which is currently in progress under the auspices of OSPAR (ICG-COBAM).

The OSPAR Correspondence Group – Cumulative Effects (ICG-C 2016) provided an overview on how cumulative effects may be incorporated in the context of the QSR and GES to consolidate the link between Pressure Common Indicators and Biodiversity

Common Indicator for the OSPAR Maritime Area to accomplish the OSPAR Cumulative Effects Assessments.

ICG-C indicated a schematic configuration of a CEA based on the approach proposed by Mastrandrea *et al.* (2010) that included mechanism to describe uncertainties including cause–effect relationship. ICG-C also noted the relevance of previously proposed methods (i.e. HARMONY, CUMULEO, and ODEM) to be used for CEA. ICG-C listed the following pressures arising from human activities:

- Eutrophication;
- Contaminants: Hazardous substances – Radioactive substances – Offshore substances;
- Other human activities, e.g. – Dumping of waste;
- Marine litter;
- Underwater energy; noise.

and that the cumulative effects of these pressures are linked to the biodiversity status of the seabed in relation to MSFD descriptors and indicators. ICG-C used different case studies to describe some of these pressures including the work in progress within ICG-COBAM on benthic habitats and the assessment for pressures associated with fishing activities.

The UK Defra project (Final Report, Rev. 06/11) on: "Pressure assessment methodologies to support risk based management", provides an overview on pressure data requirements in relation to the development of a UK marine biodiversity monitoring programme, considering the MSFD pressure data requirements of different indicators across the MSFD and GES descriptors.

WGINOSE based on the current available information will explore the possibility to integrate the cumulative effects of pressures and other activities using the strata characterizing the Greater North Sea as described in WKPIMP 2016.

WGINOSE used the available pressure data related to fishing abrasion pressure maps for 2009–2013 collated from Vessel Monitoring System (VMS) and logbook data (ICES Advice, 2015) to produce pressure maps for surface and subsurface abrasion arising from fishing activities in the North Sea (Figures 5.2a and 5.2b).

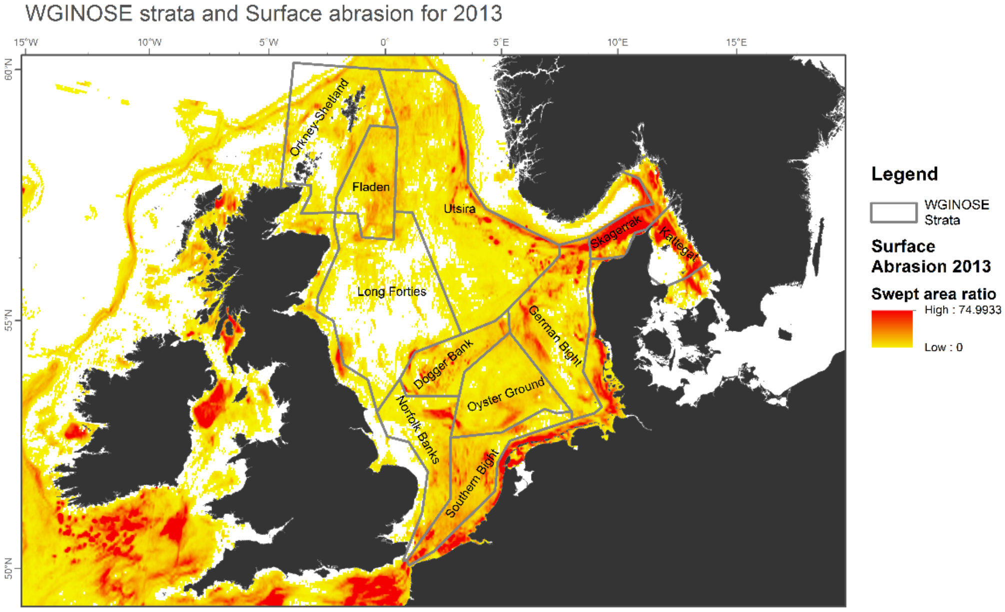

Figure 5.2a. WGINOSE strata and surface abrasion map (ICES, 2015).

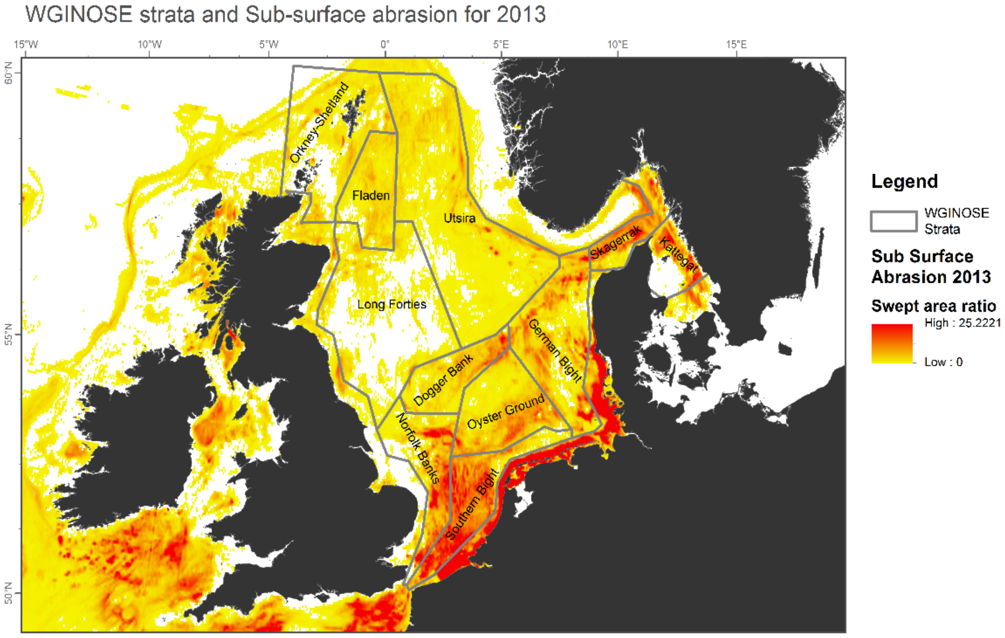

Figure 5.2b. WGINOSE strata and subsurface abrasion map (ICES, 2015).

It is apparent from the overlay of strata against fishing pressure that there is a close correspondence between the strata identified and differences in the magnitude and extent of fishing pressure in the North Sea. For example the Long-Forties stratum has very little fishing pressure whereas the coastal margin of the 'Benelux' countries (Germany, Netherlands, Belgium, and France) have a high level of fishing pressure.

WGINOSE will further develop the use of pressure data and maps within the IEAs of strata (Section 4 of this report). This analysis will also be used to optimize the spatial boundaries for the development of BBN and other ecosystem modelling approaches to support management advice.

6 Development of strata specific BBNs (ToR b) and other modelling approaches

6.1 Other modelling approaches

WGINOSE will also explore other available modelling assessment tools, in particular tools developed to assess marine biodiversity in relation to the EU MSFD. The assessment tool NEAT – 'Nested Environmental state Assessment Tool', developed under the DEVOTES project: http://www.devotes-project.eu will be explored as a potential tool to facilitate and consider the inclusion of MSFD biodiversity indicators in the WGINOSE Integrated Ecosystem Assessment approach. This aspect will provide a coherent link between human activities – cumulative pressures – state (biodiversity) toward the development of a holistic IEA for the Greater North Sea.

6.2 Analysis on the interlinkages between environmental and fisheries variables in a small-scale ecosystem of the Southern North Sea

An important consideration in developing BBNs, as explained in a previous section, is the need to define appropriate spatial scales, which describe coherent ecological processes, which can be matched spatially with relevant human pressures. The optimization of spatial scales will ensure that the most relevant variables, processes, functions are parameterized in the model while at the same time ensuring overall model utility.

Ahead of recognizing the present strata (Figure 4.1) multivariate analyses was performed on the same data as presented in Table 4.2.1.1, but with the inclusion of fishing effort and landings data for UK fishing fleets operating in the North Sea. The analysis explored:

1) the relationships between environmental, biological, and fisheries variables;
2) ecosystem dynamics in time and space;
3) causality tests between all variables considering different spatial units and the requirements for Bayesian modelling.

The highest resolution spatial unit used was the ICES statistical rectangle, these were then analysed to look for similarities between them and to define coherent spatial units for the state, pressure variables analysed (Figure 6.2.1).

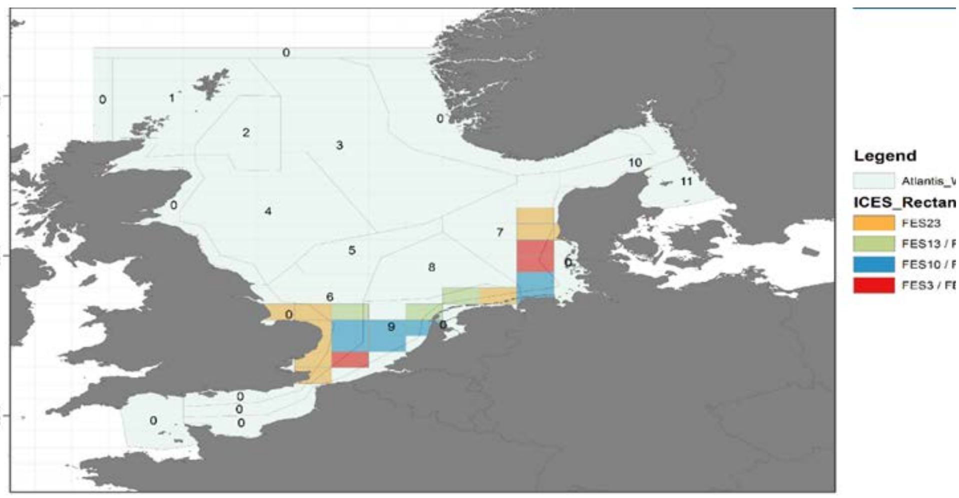

Figure 6.2.1. Spatial clusters identified through multivariate analysis state, pressure data.

From this analysis, it was observed that fishing effort and total landings were highly correlated (as expected). Significant 'causal' links were also identified in spatial cluster 10 (FES10), between selected environmental and benthic invertebrate variables.

Overall this preliminary analysis reveals spatial clusters which are comparable to the strata previously defined, furthermore the parameterization of the BBN's is scale dependent, e.g. at the scale of spatial cluster FES10, bottom oxygen and selected benthic invertebrates are found to be good predictors of cpue for plaice (*Pleuronectes platessa*), whereas at the scale of all 23 rectangles nutrients are a better predictor.

Future BBN model development will now utilize the spatial strata identified in this report and further time-series datasets integrated to establish strata specific models to support management advice.

7 Conclusions

It is clear from the analysis presented in this report that the spatial strata identified by WKPIMP has utility in furthering the objectives of IEA in the North Sea, specifically in relation to the development of models and support tools for management advice. In addition, the spatial strata provide a means of mapping human activities and associated pressure layers for IEA at a scale appropriate to the scale of processes driving natural boundaries in ecosystem functions in the North Sea.

To further the work of the group and to provide a sound basis for the development of strata specific IEAs the group has concluded that it should work towards submitting a peer reviewed journal paper on "appropriate spatial scales for North Sea Integrated Ecosystem Assessments", by 2017. In addition, it was concluded and agreed that WGINOSE would undertake the following in preparation for the meeting in 2017:

1) Perform integrated analysis of ecosystem trends for each of the defined strata from 1991 onwards with more extensive datasets for fish;
2) Complete whole North Sea IEA trend analysis to better understand the differences between the status and functioning of ecosystem strata;
3) Identify 'key' activities and pressures operating within each stratum and determine their extent;
4) Determine the most appropriate modelling approach to support ecosystem management for each stratum and liaise with WGRMES;
5) Liaise with ICES Working groups with responsibility for developing integrated monitoring in the North Sea (e.g. WKPIMP, WGMSFDemo)

8 Recommendations

WGINOSE will meet from 13 to 17 March 2017, at IMR, Bergen, Norway.

Andrew Kenny (UK) and Erik Olsen (NO) have been appointed as cochairs of WGINOSE for a further 3 years.

WGINOSE also recommends the following set of multi-annual ToRs be adopted for the period 2017 to 2020:

i. Update strata specific ecosystem trends analysis utilizing data from ICES Data Centre and other data sources, e.g. CPR, OSPAR, EEA, and Member States.
ii. Identify and develop additional strata and associated monitoring programmes for the inshore/coastal areas of the North Sea and the Norwegian Trench.
iii. Establish data pathways and obtain data to operationalize the integration of human activity and pressure data, distinguishing between fixed structures (e.g. pipelines, windfarms) and ongoing activities (e.g. dredging, fishing, shipping, underwater noise, litter), accidents (emergency response).
iv. Develop strata specific decision support tools to support ecosystem management and advice (e.g. BBNs and expert systems, ecosystem models, ecosystem goods and services modelling) in collaboration with end-users (OSPAR, DG-ENV, DG-MARE).
v. Contribute to the coordination and integration of strata specific assessments with the development of integrated ecosystem monitoring in the North Sea, e.g. redesign of the Q3 IBTS surveys.

Annex 1. List of WGINOSE participants

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Annex 2. Agenda

Monday 14 March 2016

START 13:00	INTRODUCTIONS	ALL
14:00	History of WGINOSE and ToRs	Andy
15:00	Coffee Break	
15:30	North Sea ecosystem processes and IEAs	Andy
16:00	North sea models for ecosystem advice	Andy
16:30	Agenda and Tasks for the week ahead – organising our work	All
19:00	Dinner @ RizRaz	For those that want!!

Tuesday 15 March 2016

START 09:00	ORGANIZE TASKS FOR THE WEEK	ALL
	1. Analysis of strata variance	
	2. Performing strata specific IEA with latest data	
	3. Integrate other activities and pressure data into the analysis	
	4. Advice based ecosystem models	
12:30 Lunch		
13:30	Plenary discussion on initial feedback on task results/direction/purpose	All
18:00	End of day	

Wednesday 16 March 2016

START 09:00	SUMMARY OF TASK PROGRESS	ALL
11:00	1. Analysis of strata variance	Skype call with Freya in Cefas
	2. Performing strata specific IEA with latest data	
	3. Integrate other activities and pressure data into the analysis	
	4. Advice based ecosystem models	
12:30 Lunch		

13:30	Plenary discussion on initial feedback on task results/direction/purpose	All
18:00	End of day	

Thursday 17 March 2016

START 09:00	SUMMARY OF TASK PROGRESS	ALL
	1. Analysis of strata variance	
	2. Performing strata specific IEA with latest data	
	3. Integrate other activities and pressure data into the analysis	
11:00	4. Advice based ecosystem models	Skype call with Eva in Cefas
12:30 Lunch		
13:30	Plenary discussion on initial feedback on task results/direction/purpose	All
18:00	End of day	

Friday 18 March 2016

Writing report and agreeing recommendations etc.

Meeting ends at 12:30

Annex 3. WGINOSE Multi-Annual ToRs

A **Working Group on Integrated Assessments of the North Sea** (WGINOSE), chaired by Andy Kenny, UK, will meet in Copenhagen, Denmark, from 14 to 18 March 2016, to work on their ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2014	10–14 March	ICES HQ, Copenhagen	Interim report by 30 April 2014 to SSGRSP	
Year 2015	9–13 March	Hamburg, Germany	Interim report by 30 April 2015 to SSGIEA	
Year 2016	14–18 March	ICES HQ, Copenhagen	Final report by 29 April 2016 to SSGIEA, SCICOM, and ACOM	

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Update the integrated ecosystem trend analysis for the North Sea using as many of the 'core'variables as identified by WGINOSE in 2013	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	1.1, 2.1 Input from relevant EWG as highlighted WGINOSE in 2013	Years 1, 2, and 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually.
b	Update the North Sea ecosystem overview report using findings from ToR a and ToRc where possible	a) Science Requirements b) Advisory Requirements	1.1, 2.1 To facilitate the provision of IEA advice	Years 1, 2 and 3	North Sea ecosystem overview updated annually
c	Develop and apply a dynamic Bayesian Belief Network model as a tool for integrated and combined effects assessments.	a) Science Requirements	2.2, 2.3, 3.2, 3.3	Years 1, 2 and 3	Results which explore the balance of trade-offs between ecosystem protection and sustainable resource use
d	Review the data needs and approaches to support the operational implementation of ToRa and ToRb (above)	a) Science Requirements	4.1	Years 1, 2 and 3	Recommedations and actions giving rise to the ongoing improvement to flow of data between EWG, the data centre and WGINOSE

e	Evalute use of the North Sea Atlantis Ecosystem model for combined effects and trade-off assessments.	a) Science Requirements	2.2, 2.3, 3.2, 3.3	Years 1,2 and 3	Output from current status quo model run to evaluate combined effects and system trade-offs.

Summary of the Work Plan

Year 1. In terms of delivery, the first year will focus on developing links between relevant expert groups (ICES and others external to ICES) and the ICES Data Centre to compile a core set of IEA variables for the North Sea. An update of the North Sea trends analysis will be performed and the results will be used to update the North Sea ecosystem overview.
Year 2. In addition to the annual update of the trend analysis and ecosystem overview, the focus for the second year delivery will be to demonstrate the utility of the developed dBBN North Sea model and the North Sea Atlantis model, especially in answering the 'key' questions around the balance of trade-offs between ecosystem protection and sustainable resource use for a range of human activities.
Year 3. In addition to the annual update of the trend analyses and ecosystem overview, the focus for the 3rd year will be a review of comparative performance of WGINOSE, especially in relation to the uptake and use of model results and trend analyses in the advisory and management processes.

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the development of Integrated Ecosystem Assessments for the North Sea (a data rich ecosystem) as a step towards implementing the ICES Science Plan and the ecosystem approach, these activities are considered to have a very high priority.
Resource requirements	Assistance of the Secretariat in maintaining and exchanging information and data to potential partcipants, especially the services of the ICES data centre to generate data tables for analysis from selected variables held in the database.
Participants	The Group is normally attended by some 10–20 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	Relevant to the work of ACOM and SCICOM
Linkages to other committees or groups	There is a very close working relationship with all the groups of SSGSRP. It is also very relevant to the EWG identified in WGHAME 2013 report..
Linkages to other organizations	OSPAR, EU, NAFO, NEAFC