



Project acronym: ECODRIVE

Project title: Ecosystem Change in the North Sea: Processes, Drivers, Future Scenarios

Project Reference number:

Periodic activity report

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Project coordinator name: Jürgen Alheit

Project coordinator organisation name: Leibniz Institute for Baltic Sea Research (IOW)

Project participants

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1 Report on deliverables and milestones

In Table 1 and Table 2 the Milestones and Deliverables, as formulated in the Description of Work, should be listed.

Those Deliverables and Milestones not included in the original description of Work should be clearly marked as NEW.

Progress to be marked as:

- “Completed” for completed task. Details should be given on publications or other presentation of results in the column for Comments if applicable
- ”On track” for tasks still going on.
- “Delayed” for tasks that are not past their due date but are delayed. The reasons/corrective measures should be given in the column for Comments.
- “Not achieved” for tasks exciding their due date. The reasons/corrective measures should be given in the column for Comments.

Table 1: Milestone List

Item	Acitivity	Date due (month)	Partner responsible	Progress	Comments
	Workpackage 1		AWI (Boersma), IMR (Sundby)		
M1.1	Completion of time series analyses of climate-related long-term ecosystem change for ecosystem analyses in WP 3	12	IOW (Alheit, Wagner), AWI (Boersma)	First round completed for WP 3	It emerged that this analysis should be kept up until end of project.
M1.2	Data set describing ecophysiological tolerances and optima to abiotic factors for key species and assemblages (phyto, zooplankton and fish) for ecosystem analyses in WP 3	12	IHF (Peck)	completed (emphasis on thermal windows of survival / tolerance)	Physiological characteristics of phytoplankton have been summarized. Data sets on for key copepod and fish species (the latter by life stage)
M1.3	Database on key trophic links (phyto, zooplankton, and fish) for ecosystem analyses in WP 3	12	IHF (Temming)	on track	Focus on higher trophic levels
..					
	Workpackage 2		UiB-GFI		

			(Schrum), IFM (Pohlmann)		
M2.1	Validated decadal runs with hydrodynamic models and available for ecosystem analyses in WP 3	9	IFM (Pohlmann, Mayer) UiB-GFI (Schrum),	completed	additional validation are on-going
M2.2	Modelled data available on lower trophic levels (NPZD) from validated decadal runs and available for ecosystem analyses in WP 3	12	UiB-GFI (Schrum), IHF (Peck/Paetsch)	completed	IHF - Modelled estimates are available for WP3 work for projections in WP4 is ongoing
M2.3	Age-specific abundance estimates of commercially exploited fish species from Multispecies Model available for ecosystem analyses in WP	12	IHF (Temming)	completed	
	Workpackage 3		IHF (Möllmann), IMR (Dingsør)		
M3.1	Analyses on structural ecosystem changes completed	16	IHF (Möllmann)	on track (IHF)	
M3.2	Analyses on relative importance of pressures and processes acting on foodweb structure completed	20	IHF (Möllmann)	on track (IHF)	
M3.3	Informed proxies for key ecosystem components available for scenario predictions in WP 4	24	IHF (Peck)	on track (IHF)	
	Workpackage 4		IMR (Adlansvik), IHF (Peck)		
M4.1	IPCC scenario (A2, B1) driven hydrodynamic model runs	18	IMR (Adlansvik), IHF (Pohlmann, Mathis)	on track slightly delayed	due to unexpected problems with forcing data
M4.2	Eutrophication scenarios using ECOHAM4 based on IPCC driven hydrodynamic model runs	24	IHF (Paetsch), IMR (Skogen)	on track	
M4.3	Multispecies prediction of commercially exploited	24	IHF (Floeter)	on track	

	fish stock abundance using predictive hydrodynamic model runs				
M4.4	Scenario forecasts on future ecosystem structure based on informed proxies, predictive hydrodynamic, NPZD and Multispecies Model runs completed	30	IHF (Möllmann)	on track	
M4.5	Project Synthesis completed	33	IOW, IMR, IHF, UiB-GFI, AWI, SAHFOS, IMARES, MII	on track	
	Workpackage 5		IOW (Alheit), IMR (Skogen)		
M5.1	Project Kick Off meeting	2	IOW (Alheit), IMR (Skogen)	completed	
M5.2	Project website installed	4	IOW (Wagner)	completed	
M5.3	Expert workshop	6		completed	A series of focus group meetings have been held at two international conferences (GLOBEC, Victoria, June 2009) and ICES ASC, Berlin September 2009). This saved program costs and allowed thorough discussions of ECODRIVE program objectives and methodology within the international community.
M5.4	International Conference on Drivers of Ecosystem Change (in collaboration with other funded	34	IOW (Alheit), IMR (Skogen)		

	MarinEra project(s)				
M5.5	Final Project Report finalised	36	All partners		
M5.6-10	Steering Committee and annual meetings	12,18,24, 34,36	IOW (Alheit), IMR (Skogen)		

Table 2: Deliverable List

Deliverable number	Deliverable name	Date due (month)	Partner responsible	Progress	Comments
D1.1	Report on climate-related long-term ecosystem change based upon time series analyses	16	IOW (Alheit, Wagner), AWI (Boersma)	→	Will be completed in Feb 2011. First publications have been written.
D1.2	Report describing ecophysiological tolerances and optima to abiotic factors for key species and assemblages (phyto-, zooplankton and fish)	16	IHF (Peck)	→	One paper published (see Annex 1), others are being prepared
D1.3	Report on key trophic links acting within the North Sea Ecosystem (phyto, zooplankton, and fish)	16	IHF (Temming)	→	
D2.1	Report on decadal hydrodynamic model runs	12	IFM (Pohlmann), UiB-GFI (Schrum)	→	Will be completed Feb 2011
D2.2	Report on decadal NPZD-model runs	16	UiB-GFI (Schrum) IHF (Peck/Paetsch)	→	Paper will be completed in Jun 2011
D2.3	Report on Multispecies Model runs	16	IHF (Temming)	→	
D3.1	Report on structural ecosystem changes	20	IHF (Möllmann)	→	
D3.2	Report on relative importance of pressures and processes acting of foodweb structure	24	IHF (Möllmann)	→	
D3.3	Report on creation of informed	30	IHF	≈	

	proxies for key ecosystem components		(Peck)		
D4.1	Report on IPCC scenarion (A2, B1) driven hydrodynamic model runs	21	IMR (Adlansvik), IHF (Pohlmann, Mathis)	→	
D4.2	Report on eutrophication scenarios using ECOHAM4 based on IPCC driven hydrodynamic model runs	27	IHF (Paetsch), IMR (Skogen)	≈	
D4.3	Report on multispecies prediction of commercially exploited fish stock abundance using predictive hydrodynamic model runs	27	IHF	≈	
D4.4	Report on scenario forecasts on future ecosystem structure based on informed proxies, predictive hydrodynamic, NPZD and Multispecies Model runs	33	IHF (Möllmann)	≈	
D4.5	Project Synthesis Report	36	IOW, IMR, IHF, UiB-GFI, AWI, SAHFOS, IMARES, MII	≈	
D5.1	Organisation of Kick-off meeting	2	IOW (Alheit), IMR (Skogen)	✓	
D5.2	Organisation of Steering Committee and Informal Cluster Meetings with other MarinEra projects		IOW (Alheit)	✓	
D5.3	Organisation of International Conference on "Drivers of Marine Ecosystem Change"	34	IOW (Alheit), IMR (Skogen)	≈	
D5.4	Final Project Report	36	IOW, IMR, IHF, UiB-GFI, AWI, SAHFOS	≈	

			S, IMARES , MII		
D5.5	Annual progress reports to EU Commission and national funding agencies.	8	IOW (Alheit)	✓	
D5.6	Annual progress reports to EU Commission and national funding agencies.	20	IOW (Alheit)	✓	

Key: ✓ - completed; Δ - reformulated; → - activity in progress;
≈ - activity 'frozen' (waiting to get started after request/activity from other WP)
fa – future activity

2 Problems/challenges/deviances

List changes within the participant group, unanticipated expenses/earnings etc and any other issues pertinent to progress not covered in the tables above.

Gjert Dingsør (IMR) has moved to a new position and will not work anymore for ECODRIVE. He has been replaced by Tore Johanneson.

3 Indications, preliminary conclusions and results

Account for indications, preliminary conclusions and results that have been revealed thus far in the project. Published results.

A list of publications is in Annex 1.

- **Work Package 1**

Task 1.1 Time series analysis of climate-related long-term ecosystem changes

1) Results and Analysis of Helgoland Roads Data (Boersma)

The Helgoland Roads Data show large inter-annual changes in species composition. For example the variation in the densities in gelatinuous zooplankters is enormous (Fig 1). We analysed the datasets in order to explain this variation.

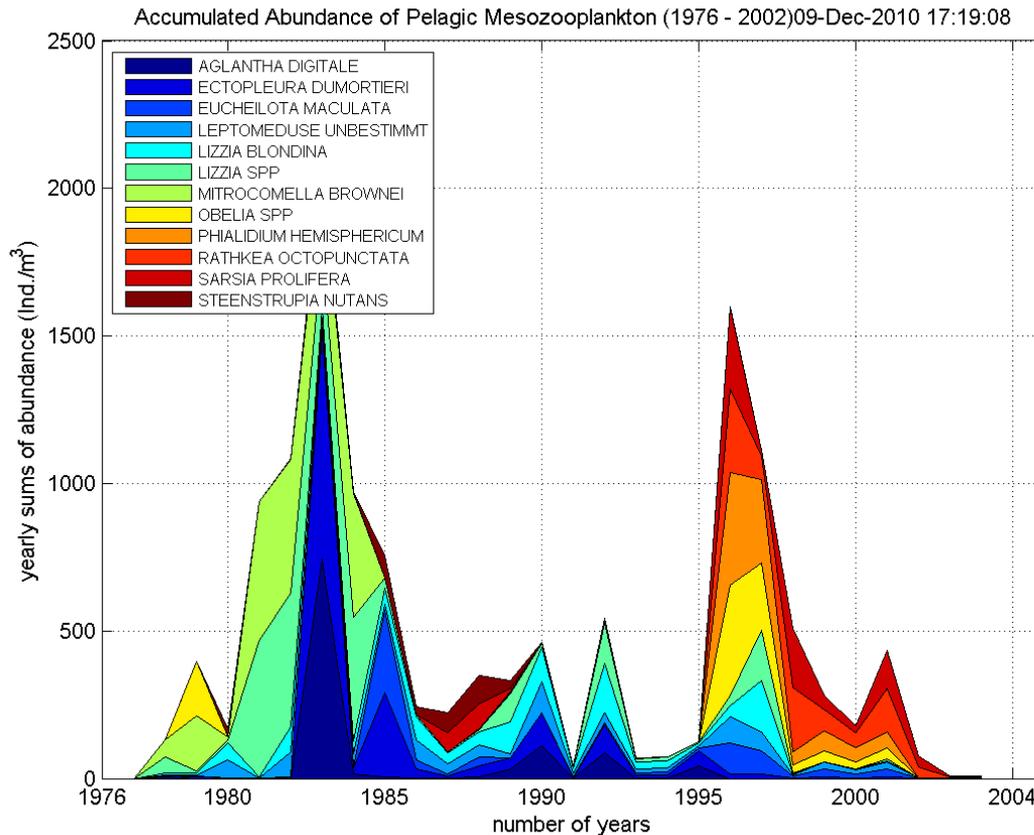


Fig 1: Abundance changes in the densities of gelatinous zooplankton at Helgoland Roads.

Fluctuations and temporal changes in abiotic parameters

Abiotic parameters are shown to be the main drivers of the ecosystem long-time and short-term behavior at Helgoland. Densities are responding to the changes in temperature as well as nutrients such as silicate, phosphate and other chemicals. The scaling behavior of the main abiotic parameters is estimated based on Detrended Fluctuation Analysis for the five decadal periods (length of the time series). The power exponent is evaluated for the intermediate time scale : for interval from 20 days to 1 years. As can be noted from Table 1 all five parameters have relatively low magnitude of fluctuations power behavior for the decade from 1981-1990.

Climate variables	1962-1970	1971-1980	1981-1990	1991-2000	2001-2010
Silicate	0.381	0.415	0.179	0.4	0.482
Salinity	0.373	0.352	0.122	0.332	0.14
Nitrate	0.461	0.436	0.144	0.431	0.497
Nitrite	0.062	0.610	0.135	0.551	0.334
Phosphate	0.291	0.541	0.167	0.364	0.057

Table 3: Hurst exponent estimates from the detrended fluctuation analysis of the climate variables at Helgoland for decadal periods. The power scaling behavior of the fluctuation functions is calculated for the time interval from 20 days to 1 year.

The long term behavior of chemical concentrations is also changing. The yearly distribution pattern of silicate is characterized by a slow build-up of concentrations in winter and a slow dissipation rate of the concentrations during spring for earlier years (1972-1982). This pattern is different for the later period (1995-2005) where the highest concentrations rapidly decay to the low concentrations near zero (see Figure 2). The pattern of silicate yearly distribution is well described by the skewness coefficient γ , which alternates from mostly positive for the earlier period 1962-1982 to negative for the period 1982-2009 (Fig. 3). Hence, annual silicate concentrations decay much faster throughout the year in recent years.

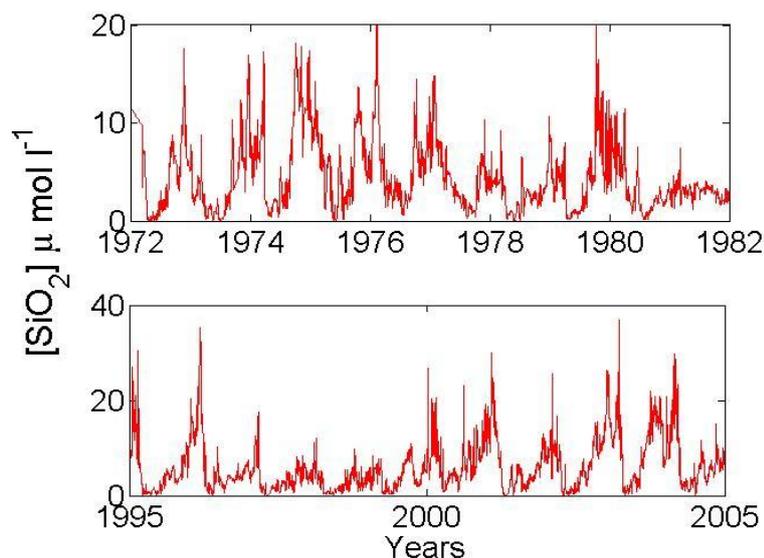


Fig. 2: Two time periods 1972-1982 (1995-2005) of the silicate concentrations at Helgoland show positive (negative) skewness of the yearly silicate distribution .

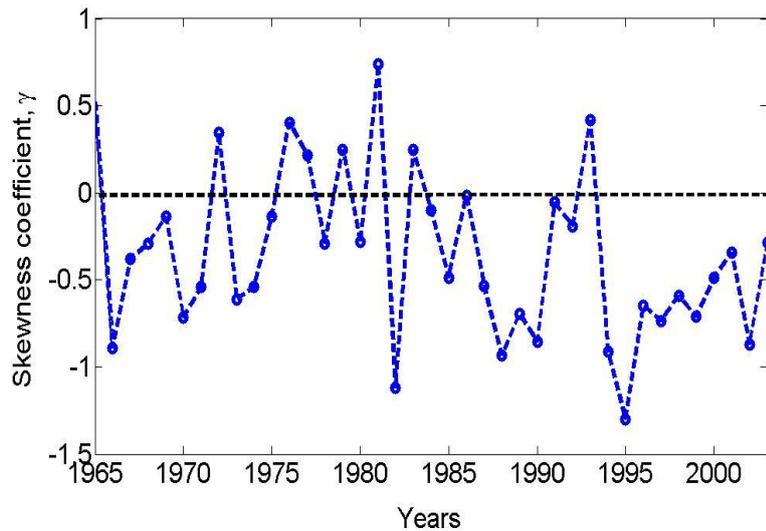


Fig. 3: Skewness coefficient calculated from the yearly distribution of silicate concentrations at Helgoland .

Changes in diversity and blooming timing for biotic parameters

The alternation in silicate distributions is likely to be induced by the shifts in blooming pattern of phytoplankton as well as diversity composition. To estimate diversity changes in the biotic parameters two diversity factors are studied: the standard Shannon-Wiener diversity index and the co-occurrence index. The co-occurrence counts each time whenever concentration reaches an assigned minimal threshold (in our case 10 cells per litre). The averaged patterns of yearly co-occurrence for two distinct intervals (1972-1982 and 1995-2005) indicate a shift in phytoplankton blooming behavior and diversity. In Figure 4 the peak in diversity of phytoplankton is shifted to later time and diversity distribution changed from bi-modal to a singular peak. This indicates that a more diverse species composition tend to occur during the later time period. This pattern is well confirmed by the mean summed phytoplankton concentrations in Figure 5. The temporal shifts to the later blooming and diversity is likely to affect the changes in silicate dissipation rates for the two indicated time periods. In Figure 6 the averages of silicate concentrations over two decades (1975-1985 and 1995-2005) are plotted versus the co-occurrence patterns for the same periods. The high diversity index in the late summer and autumn might be responsible for the slow build-up of the silicate in the second half of the year.

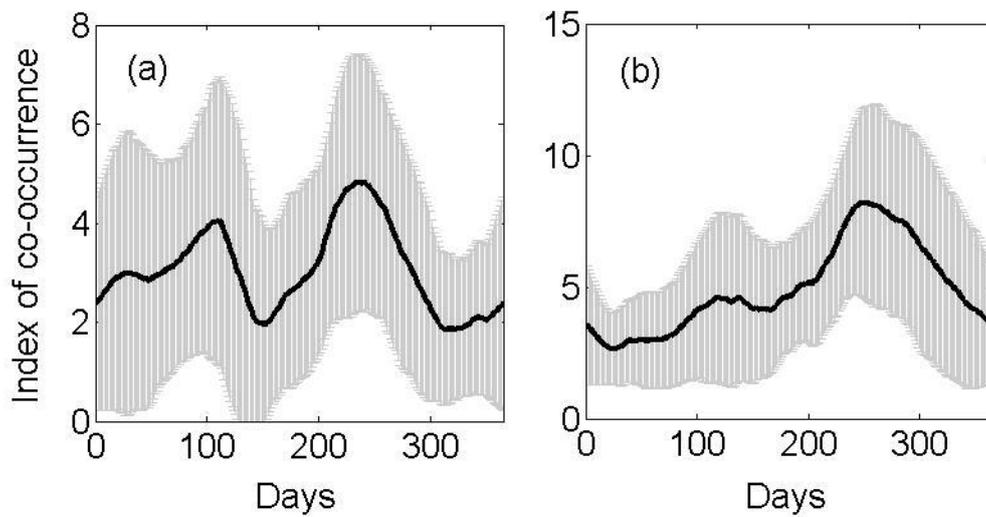


Fig. 4: The mean index of co-occurrence with the standard mean deviation for phytoplankton concentrations at Helgoland given for two different decadal periods: (a) 1972-1982; (b) 1995-2005.

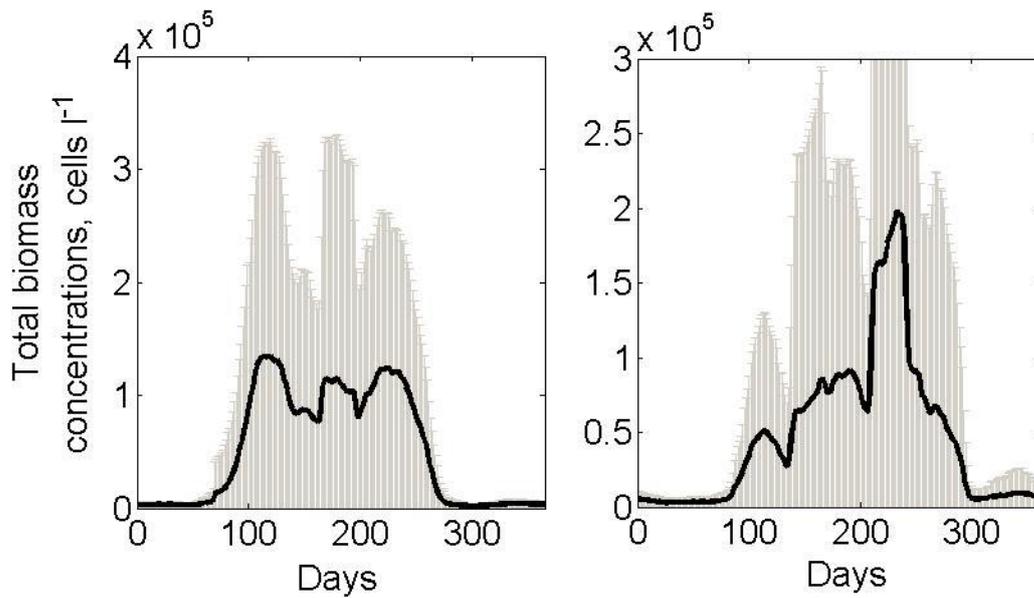


Fig. 5: The mean pattern of total biomass concentrations with the standardized mean measured for phytoplankton at Helgoland for two periods: (a) 1972-1982; (b) 1995-2005.

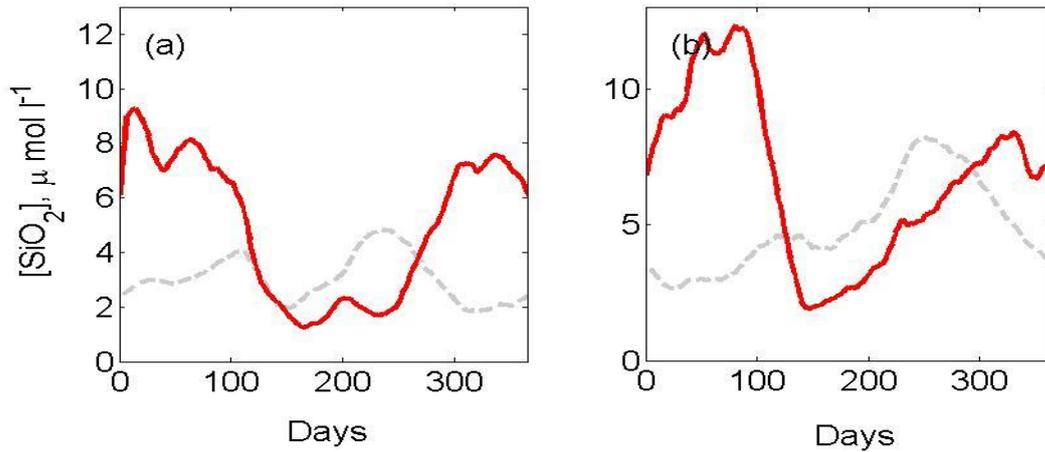


Fig. 6: The mean concentrations of silicate during periods 1975-1985 (a), 1995-2005 (b). Superimposed (dashed line) are the mean patterns of co-occurrence from Figure 3.

Similar analysis of mean yearly co-occurrence index is performed for the zooplankton data at two time periods (1976-1982, 1995-1999). In Figures 7 and 8 the co-occurrence patterns and summed concentrations are shown for given time periods. The diversity has increased substantially for 1995-1999. The timing of the maxima densities and diversity remains the same in both cases. The std patterns indicate that the deviations from the averaged behavior are more significant for the zooplankton than they are for the phytoplankton. In future more detailed study of zooplankton community timing needs to be done.

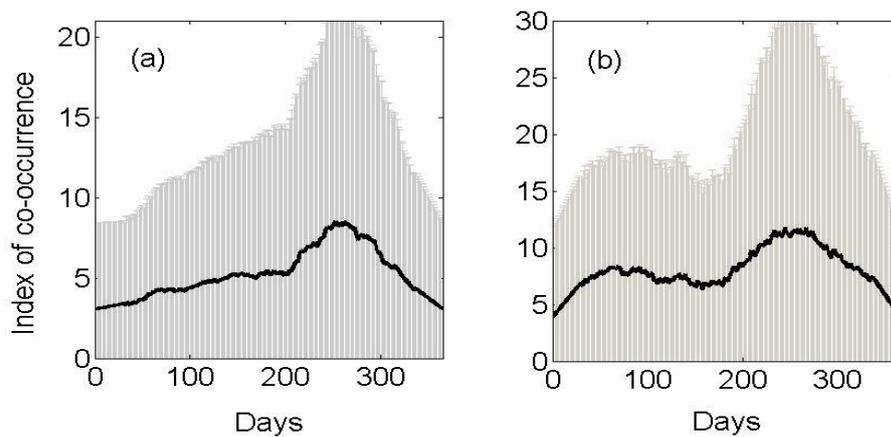


Fig. 7: The mean index of co-occurrence with the standard mean deviation for the zooplankton concentrations at Helgoland given for two different decadal periods: (a) 1976-1982; (b) 1995-1999.

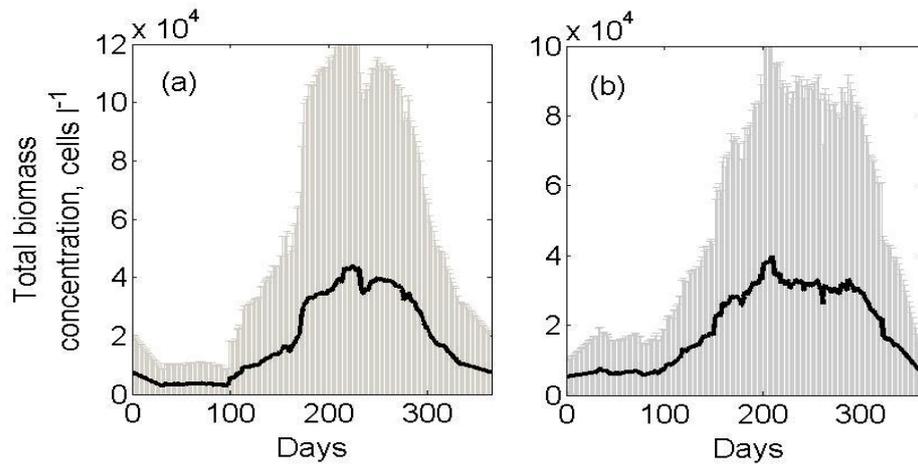


Fig. 8: The mean pattern of total biomass concentrations with the standardized mean measured for the zooplankton at Helgoland for two periods: (a) 1976-1982; (b) 1995-1999.

Long term diversity changes for phytoplankton and zooplankton communities

There was a strong difference between the long-term pattern of the phytoplankton densities and the zooplankton densities (Fig. 9.). Whereas the total densities were fairly constant for phytoplankton, densities have gone up for zooplankton.

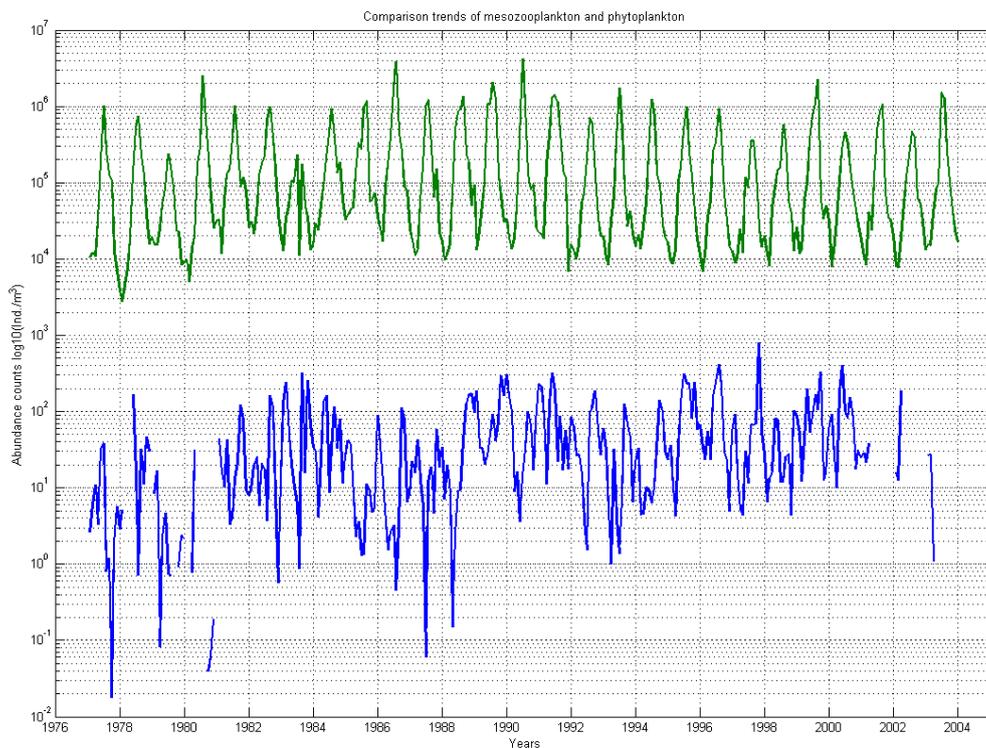


Fig 9: Changes in abundances of Phytoplankton (green) and zooplankton (blue) at Helgoland Roads. There is a significant positive trend in total numbers of zooplankton with time .

We performed diversity calculations for the years 1962-2005 for phytoplankton and for the period 1976-1999 for zooplankton community. As shown in Figures 10 and 11 the two diversity indices are in a very good agreement and demonstrate a considerable increase in diversity of species composition starting from 1992 for the phytoplankton and a gradual increase of zooplankton diversity from 1976 up to 1999. There is a subtle decrease in co-occurrence observed at 1995 for the zooplankton and at the same a slight rise of the co-occurrence index for this year. Interestingly, the low diversity in phytoplankton is observed for the time span 1981-1992, which is the period of lowest fluctuations among nutrients (Table 1).

Apparently, the two measures of biodiversity show a slight mismatch for some years. The Shannon-Wiener index was higher than the co-occurrence pattern for the phytoplankton community starting from 1970 until 1995. Also the Shannon-Wiener index showed less variations than the co-occurrence pattern that rose up sharply starting from 1995. This feature indicates that while the number of observed species increased during period 1995-2000 their population densities were less equally distributed as they were during years 1970-1995. During 1976-1985 the co-occurrence for the zooplankton fell below the diversity index while during later time interval 1985-1999 both measures matched well. Thus for the zooplankton diversity increases from 1976 to 1985 but the populations densities became less comparable.

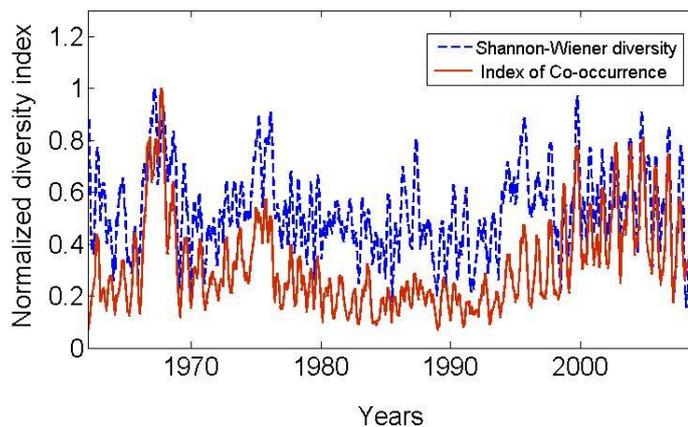


Fig. 10: Normalized Shannon-Wiener diversity (dash line) and index of co-occurrence (solid line) shown for phytoplankton concentrations at Helgoland. The diversity and co-occurrence patterns were averaged over a 60-days time span.

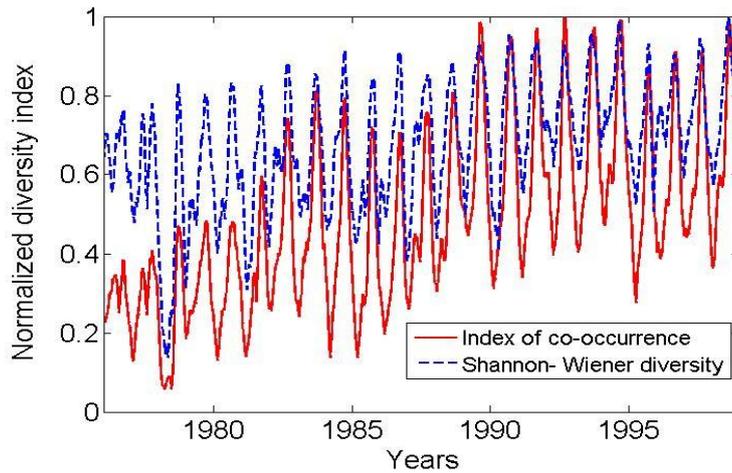


Fig. 11: Normalized Shannon-Wiener diversity (dash line) and index of co-occurrence (solid line) shown for zooplankton concentrations at Helgoland. The diversity and co-occurrence patterns averaged over the 60 days time span.

Cross-correlation analysis in comparing specific time periods (1976-1979, 1980-1990, 1991-2002) made clear that time lag between phytoplankton succession and mesozooplankton succession has shifted towards shorter time periods, in fact the mesozooplankton peaks even precede total phytoplankton biomass during the more recent time period 1991-2002. Shifting patterns in co-occurrence indicate alterations in interaction and/or behavior of one or more taxa (Figure 12).

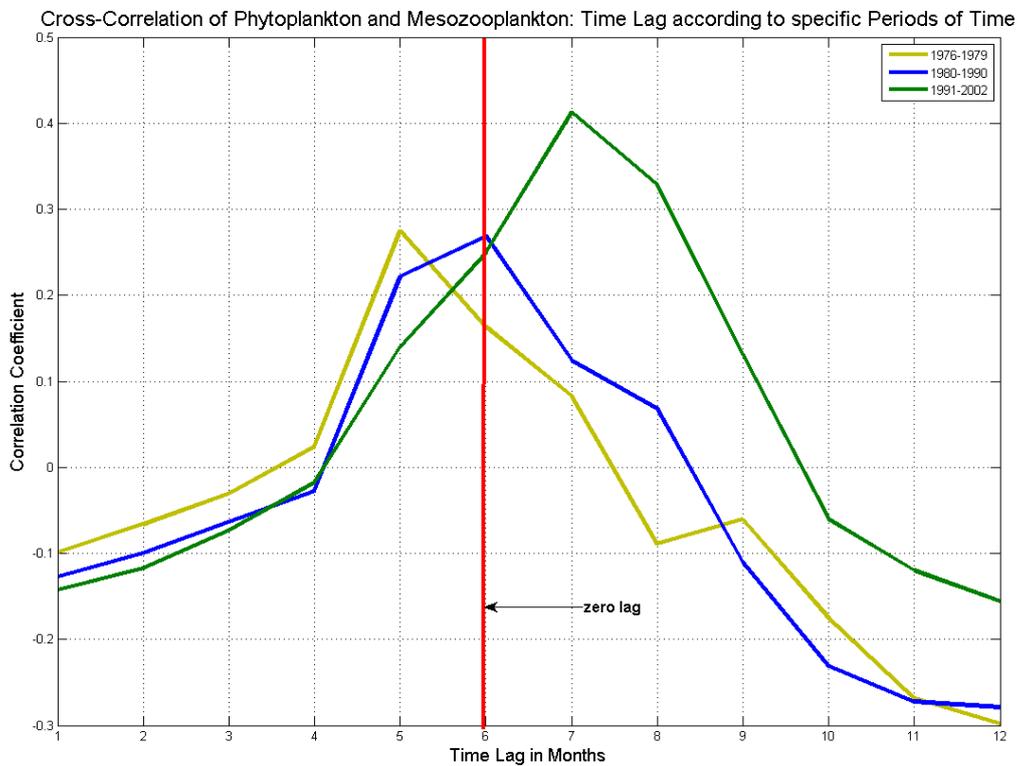


Fig. 12: Cross-correlation patterns between phytoplankton and zooplankton densities in three different time periods.

Conclusions

Analysis of decadal periods of the time series for silicate, salinity, phosphate, nitrite and nitrate indicates the difference in fluctuation behavior for the abiotic parameters over intermediate scales (from 20 days to one year). However there is a consistently low magnitude of fluctuation found during 1981-1990 decade for all five parameters studied.

Two diversity indices are applied to measure the long time changes in community composition for the phyto- and zooplankton data. The peak in biodiversity is observed from 1965 up to 1969, after this period the indices drop for phytoplankton. Another diversity increase for phytoplankton is detected in 1999. In the later years an overall increase of biodiversity of the phytoplankton community is observed. Apparently the interval of low fluctuations in nutrients and salinity measured by fluctuation analysis coincides with the period of the low biodiversity observed for the phytoplankton community at Helgoland. For the zooplankton the gradual increase of biodiversity is indicated by both indices.

Two decadal periods that are distinguished by fast and slow decay rates of yearly silicate concentrations were studied. We show that during the period 1995-2005 characterized by slow decay of the silicate concentrations the phytoplankton diversity converges to bi-modal distributions with almost equally high diversity observed during early and late blooms. At the same time a slow buildup of the silicate concentrations dominates for the period 1995-2005. It is consistent that a later timing of the maxima of a yearly diversity pattern and summed concentrations for the phytoplankton community occurs for years 1995-2005. Similar analysis carried for zooplankton community shows no major difference between diversity and the blooming behavior for the periods 1975-1985 and 1995-1999.

2) Time series analysis of climate-related long-term ecosystem change in the North Sea (Wagner)

1. Available zooplankton time series

For the comparative time series analysis approach, four different North Sea time series of biological long-term data were used: from the CPR, Helgoland, the Dove sampling station and the Wadden Sea (Fig. 13).



Fig. 13: Location of sampling stations. Data from the CPR were averaged over areas around the sampling stations (blue boxes). Picture was taken from Google Maps.

While Helgoland, Dove and Wadden Sea are geographically fixed sampling stations, the CPR sampling provides data from the entire North Sea. Thus, CPR data in this analysis were chosen from an area around the fixed sampling stations to avoid comparing data from different regions within the North Sea. Information on the time series are listed in Table 4. For detailed description of sampling and sample processing see main references.

	Helgoland Roads	Wadden Sea	Dove	CPR
Location	54°11' N, 7°54' E	55°01' N, 8°27' E	55°N, 1°20' W	A) 54°N-56°N, 6°E-9°E "Box" for Helgoland and Wadden Sea B) 54°N-56°N, 0°-2°W „Box“ for Dove
Period	1974 - 2006	1984 - 2008	1971 - 2002	1958 - 2007
Sampling frequency	three times a week	twice a week	once per month	several per month (different routes)
Mesh size	150 µm and 500 µm	76 µm	65 µm	270 µm
Sampling procedure	vertical hauls from surface to bottom	35l of surface water	Vertical hauls, 18.5 km per sample	horizontal tows in 7m depth over
Affiliation	Alfred-Wegener-Institute for Polar and Marine Research	Alfred-Wegener-Institute for Polar and Marine Research	CEFAS	SAHFOS
Contact person	M. Boersma	J.v. Beusekom	S. Pitois	M. Edwards
References	Greve et al. 2004	Martens and Beusekom 2008	Pitois et al. 2009	Batten et al. 2003

Table 4: Characteristics of zooplankton time series from the North Sea.

Taxa lists of copepods and cladocerans were harmonized, and common taxa were analyzed at the lowest possible taxonomic level (in general on genus level). Additionally, we calculated sum parameters for those groups, like e.g., total copepods (see Table 5). Other zooplankton were compared on higher aggregated level (Table 5).

	Helgoland Roads	Wadden Sea	Dove	CPR
Calanus	x		x	x
Acartia	x	x	x	x
Centropages	x	x	x	x
Corycaeus	x		x	x
Euterpina acutifrons	x			x

Isias clavipes			X	X
Metridia			X	X
Microcalanus			X	X
Oithona	X	X	X	X
Paracalanus/ Pseudocalanus	X	X	X	X
Temora	X	X	X	X
calanoid copepods	X	X		X
cyclopoids copepods	X	X	X	X
harpacticoid copepods	X	X	X	X
total copepods	X	X	X	X
Podon	X	X	X	X
Evadne	X	X	X	X
Penilia	X			X
cladocerans	X	X	X	X
chaetognatha	X	X	X	X
cyphonautes	X			X
echinodermata	X		X	X
euphausids	X			X
polychaeta	X		X	X
appendicularia/tunicates	X		X	
lamellibranchia larvae	X		X	X

Table 5: Taxa list of zooplankton for the four different plankton time series from Helgoland Roads, Wadden Sea, Dove sampling station and the CPR survey. “x” indicates the occurrence of taxa and the calculation of sum parameters, respectively, in the respective data set.

2. Climate indices

Climate indices, in particular the NAO and the AMO

(<http://www.cdc.noaa.gov/data/climateindices>), were used for exploring the relationship between long-term changes in the zooplankton and changing climate. We used the winter NAO index (i.e., December to February), and the yearly average of the AMO.

3. Comparative analyses

Due to different sampling and processing techniques, time series could not be compared in terms of absolute abundances. Thus, for comparing long-term changes we conducted a Principal Component Analysis (PCA) on log-transformed zooplankton abundances (species or genus level for cladocerans and copepods, higher aggregated level for other zooplankton, no redundant variables) and extracted the first two principal components for each data set. The temporal evolution of those indicators for the state of the zooplankton system component was then determined by calculating the long-term trend. The similarity of system states was determined by calculating the correlation between the first and second principal components, respectively. The relationship between the zooplankton systems state (expressed by principal component 1 and 2) and climate indices and water temperatures was analyzed by means of correlation analysis. The overall aim of this study was to evaluate in how far the North Sea zooplankton time series showed coherent temporal trends and responses to changing environmental conditions (i.e., climate and temperature) despite different sampling and

processing techniques. Focus was put on the similar patterns of change in the late 1980s and the mid 1990s, as those periods are shown (1980s) and expected (mid 1990s) to reveal coherent responses (so called regime shifts) in marine ecosystems due to teleconnections as a consequence of changes in the climate and other forcings, respectively. The entire analysis was run separately for the spring (March to May) and the summer (June to September) season.

4. Results

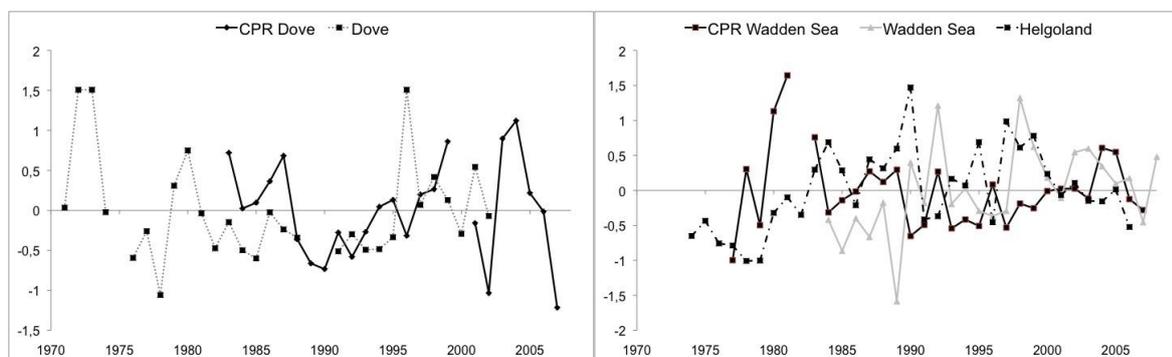
a. Long-term trends

The long-term trends of first and second principal components (as a result from the PCA analysis), i.e. their Pearson correlation coefficients with time, are presented in Table 6. Remarkable trends were observed mainly for the second PCs, which, however, differed strongly between seasons. The first PCs did not show pronounced trends.

	<i>spring</i>	<i>summer</i>
CPR Dove	-0,041	0,272
CPR WaddenSea	-0,399	0,243
PC1 Wadden Sea	-0,133	-0,106
Helgoland	0,243	0,056
Dove	,446(*)	0,125
CPR Dove	,486(*)	0,217
CPR WaddenSea	,377(*)	0,324
PC2 Wadden Sea	-,533(**)	-,484(**)
Helgoland	-0,098	,782(**)
Dove	,532(**)	-0,132

Table 6: Long-term trends of first and second principal components for spring and summer. Significant correlations are indicated with * ($p < 0.05$) and ** ($p < 0.01$). Please note that time periods differ between time series (see Fig. 2).

However, as trends were not necessarily expected to be monotonous, but may rather show abrupt changes and cycles (and thus no significant correlations with time), we also analyzed the temporal evolution of the first principal components (Fig. 14).



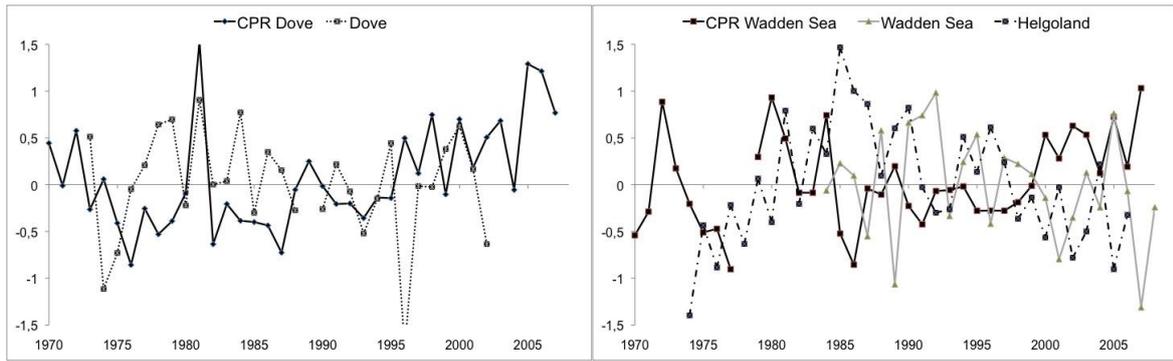


Fig. 14: Temporal evolution of the first principal components for the time series of the Dove region (left column) and the Wadden Sea/ Helgoland region (right column), separated for spring (upper panel) and summer (lower panel).

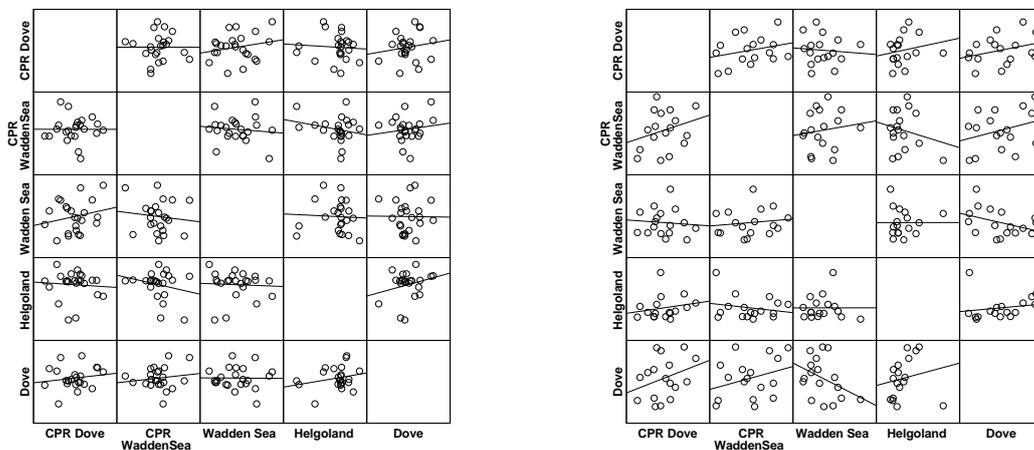
There were no striking patterns of change in terms of abrupt shifts in the first PCs. However, there was some evidence for shifts in the late 1980s (see, e.g., CPR Dove, Wadden Sea). Interestingly, the Dove first PCs in spring and summer showed an exceptional year 1995.

b. Coherence between principal components

Correlation matrices and relationships between first and second principal components (PCs) for spring and summer are presented in Fig. 15. In spring, we found surprisingly little conformity for the first PCs, whereas correlations were a little bit higher for the second PCs. During the summer, the PCs were consistently higher than during the spring, furthermore, in this season the conformity of the first PCs was a lot stronger than in spring.

The little agreement of the first PCs in spring suggests that the zooplankton system state in this season may differ between regions much more than during the summer, where we found a high agreement for almost all of the first PCs. Highest correlations to other systems were found for the Helgoland Roads data in summer, whereas the Wadden Sea had lowest correlations with other systems.

Interestingly, the Wadden Sea PCs were more distinct from other time series than the CPR PCs. In general, the regional coherence between the CPR data and the data from the fixed sampling stations was not higher than between data from different regions or between the CPR regions. CPR data from the different regions were not more related to each other than to other data either.



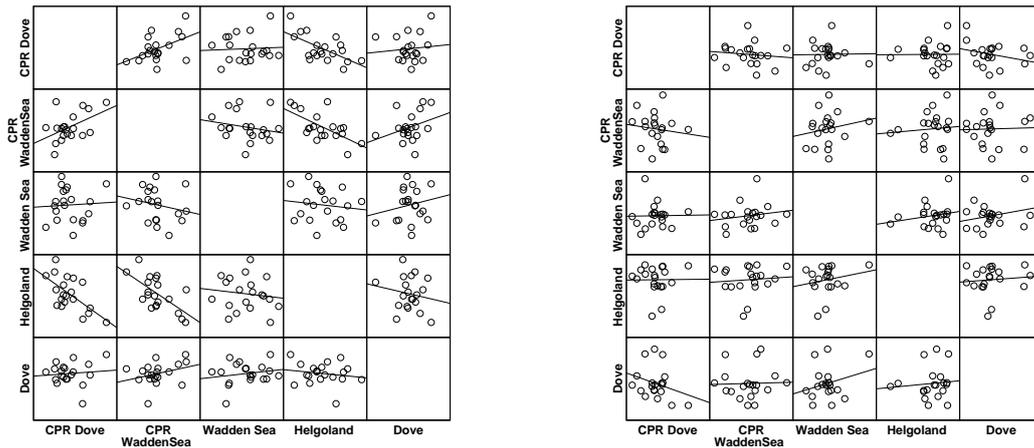


Fig. 15: Relationships between the first (left column) and second (right column) principal components of the four time series, separated for spring (upper panel) and summer (lower panel).

c. Responses to climate forcing

		AMO		NAO		AMO		NAO	
		spring				summer			
		until 1989	since 1990						
PC1	CPR Dove	-0,579	0,198	-0,435	-0,051	-0,01	0,219	0,17	
	CPR WaddenSea	-0,516	-0,441	-0,588	-0,144	-0,013	0,388	0,286	
	Wadden Sea	0,326	,530(*)	0,505	-0,219	0,202	-0,25	-0,327	
	Helgoland	0,133	0,031	-0,329	-0,177	-0,043	-0,328	0,042	
	Dove	0,298	0,224	-0,208	-0,156	0,146	0,267	-0,195	
PC2	CPR Dove	-0,103	,554(*)	0,196	-0,105	-0,183	0,007	,458(**)	
	CPR WaddenSea	0,259	-0,146	,611(*)	0,182	-0,113	0,314	-0,459	
	Wadden Sea	-0,055	-0,393	-,521(*)	-0,193	,490(**)	0,413	-0,316	
	Helgoland	-0,247	0,432	0,189	-,822(**)	0,165	0,453	0,416	
	Dove	-0,334	0,104	-0,202	-0,121	0,255	-0,042	0,029	

Table 7: Correlations of first two PCs with AMO and NAO for spring and summer. Significant correlations are indicated with * ($p < 0.05$) and ** ($p < 0.01$). Please note that time periods differ between time series (see Fig. 14).

Relationships between climate indices, in particular the AMO and the NAO, were analyzed separately for the periods until 1989 vs. since 1990 to account for a possible decoupling of relationships between indices and biological response (Table 4). For the first PCs, i.e., the main variation in the zooplankton data, we found only one significant correlation to either index (Wadden Sea in spring after 1990). This is surprising as we expected stronger relationships for the time series until 1989, in particular for the NAO. In general, relationships were in a similar dimension for the two periods.

3) Impact of climate variability (NAO, AMO) on North sea ecosystem (Alheit)

The impact of NAO and AMO on the North Sea ecosystem was analysed using the example of anchovy and sardine extension into the North Sea. A respective paper was presented at the Annual ICES Conference in Nantes, France:

Climate Variability drives Anchovies and Sardines into North and Baltic Seas (ICES CM 2010/S:14)

By: Jürgen Alheit, Thomas Pohlmann, Michele Casini, Wulf Greve, Rosmarie Hinrichs, Moritz Mathis, Kieran O'Driscoll, Anne Sell, Ralf Vorberg, Carola Wagner

Abstract:

European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) are southern, Lusitanian species needing warmer temperatures than boreal ones. After about 40 years of absence, they were observed again in increasing quantities in the North and Baltic Seas. Sardines re-invaded the North Sea around 1990, probably as a response to warmer temperatures associated with the strengthening of the North Atlantic Oscillation (NAO) in the late 1980s. However, surprisingly, increasing numbers of anchovy eggs, larvae, juveniles and adults were recorded only since the mid-1990s, indicating that the temperature rise in the winter months due to the NAO was not sufficient for triggering the re-appearance and spawning of this species in more northern waters. Presumably, changes in current structures and increased summer temperatures since the mid-1990s, in association with the contraction of the subpolar gyre, were responsible for the expansion of the anchovy distributional range into the North Sea. Apparently, climate variability drives anchovies and sardines into North and Baltic Seas. We will discuss, which atmospheric (e.g., AMO, East Atlantic Pattern) and oceanographic (e.g. contraction of subpolar gyre) drivers might be responsible for the occurrence of anchovies and sardines in North and Baltic Seas and other changes observed in fish populations at the same time.

- **Work Package 1**

- Task 1.2. Responses of (key) species to abiotic factors (Ecophysiology) (Peck)*

A review of the experimental (laboratory) and field literature on the thermal windows supporting the productivity of key copepod species was undertaken. This work supports the time-series analysis presented in Task 1.1 (Wagner). The chosen indicator for fitness was adult reproductive potential (rates of egg production, EPR). In total, the results of 19 studies on calanoid copepods were reviewed, data were digitized for temperature-dependent EPR for 12 key species inhabiting the North Sea. Special emphasis was placed on *Pseudocalanus elongatus*, *Acartia congens*, *Tempora longicornis* and the *Calanus congens* (*C. finmarchicus* and *C. helgolandicus*). The results will be used to gauge suitable habitats for species based upon temperature-specific feeding thresholds (e.g., phytoplankton carbon) and optimal thermal windows. Optimal thermal windows were defined as temperatures where observed EPR remained above 50% of the maximum value (see Figure 16) – this defined the pejus (= getting worse) temperatures. Examples of the pejus limits for six species are provided in Figure 17.

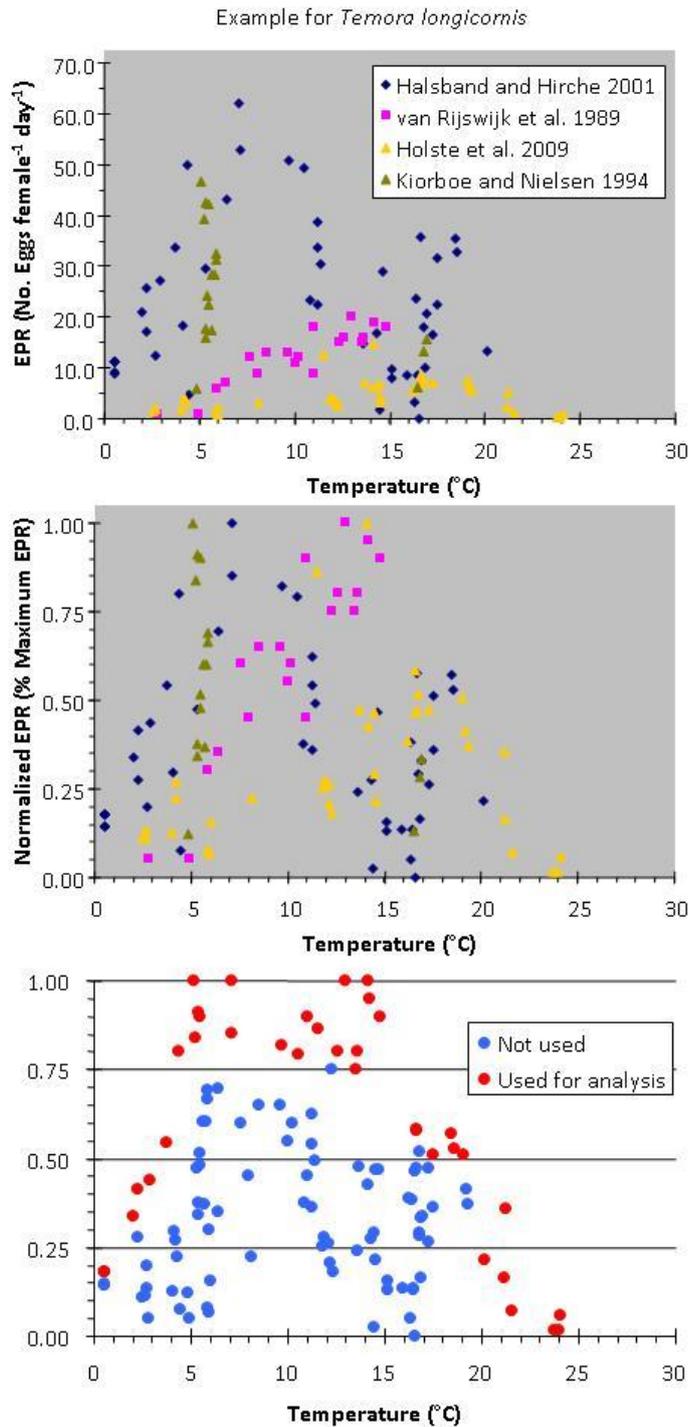


Fig. 16: Example of calculations of thermal windows for egg production rates starting with data reported in four studies (top panel), normalized to study-specific maximum values (middle panel) and then combined for analyses (red points, bottom panel).

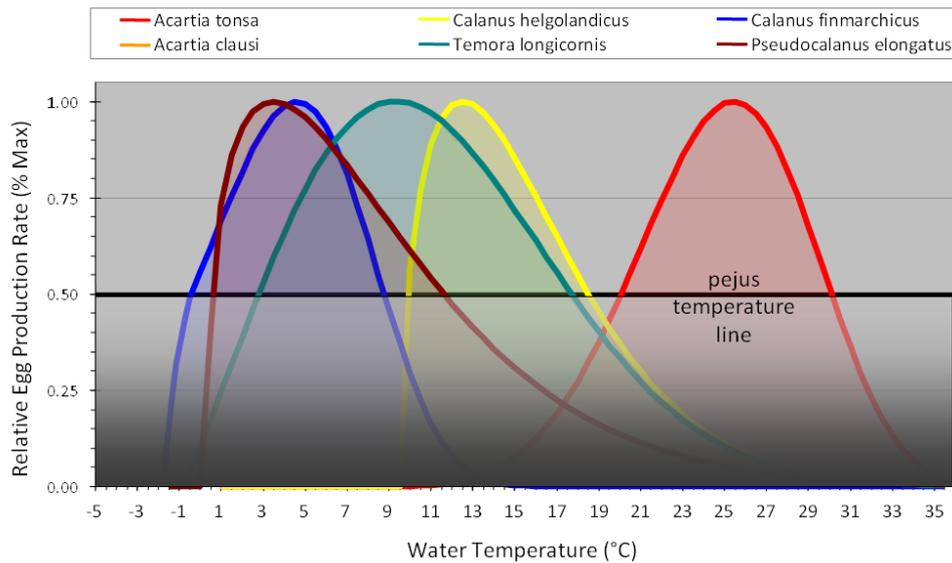


Figure 17: Example of thermal windows for six different species of calanoid copepods. The pejus line is arbitrarily set to the point where egg production rate is 50% of its maximum values for each species. Relatively narrow windows denote thermal specialist most likely to alter their distributions with climate warming.

Understanding physiological thresholds regulating growth and survival should be a priority for managers and/or scientists hoping to explore historical dynamics in fish stocks and project future changes in a meaningful way. A template for these activities was provided by reviewing the impacts of key abiotic and biotic factors on the vital rates of all life stages of small pelagic fish with emphasis on comparing and contrasting species inhabiting Northwest Pacific and Northeast Atlantic (European) waters including the North Sea. The review included a matrix of abiotic and biotic extrinsic factors (e.g., temperature, salinity, light, prey abundance/concentration and prey preference) and life stages / vital rates (e.g., spawning by adults, survival and development of eggs and yolk sac larvae, and feeding and growth of young-of-the-year fish). Although endogenous feeding life stages have been well studied, gaps in knowledge exist regarding basic elements of the growth bioenergetics of late larvae, juveniles and adults. The impact of temperature on vital rates was clearly species-specific and is a characteristic that only partly explains changes in the distribution and/or productivity of populations in both regions. In terms of identifying critical periods, there was no common pattern among species with respect to changes in temperature tolerance among eggs, larvae, juveniles and adults. However, prey availability during the late larval and early juvenile period was one of the most important factors and a density-dependent regulator of populations operating in both the Northwest Pacific and Northeast Atlantic. Population characteristic of small pelagic fish (short life spans, high rates of growth and reproduction, zooplanktivory) make them excellent bio-indicators of climate change world-wide and our review highlights stage-specific, ecophysiological constraints underpinning climate-driven responses in five different species. We identify the most fruitful avenues of future research required to meet the challenges of developing mechanistic (physiologically-based) models that can provide robust projections of the productivity of small pelagic fish stocks in a changing ocean environment. The review also reveals how recent changes in abiotic factors in the North Sea have allowed the re-establishment of European sardine and anchovy. An example of stage-specific thermal windows for different small pelagics species is shown in Figure 18.

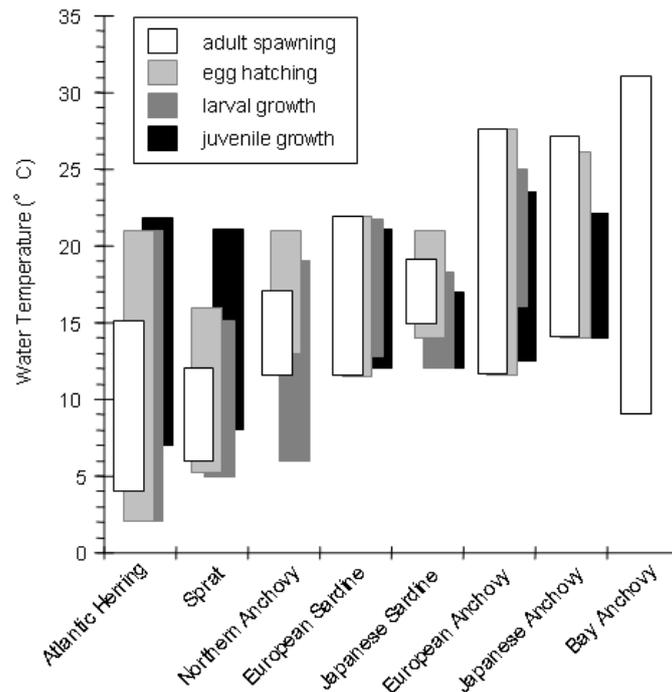


Fig. 18: Thermal windows supporting survival and growth of different stages of small pelagic fishes. Atlantic herring, sprat, European sardine and European anchovy currently co-exist in the North Sea (the focus area of ECODRIVE).

Spawning windows for North Sea Herring (Hufnagl)

A physiological individual-based model (IBM) for the foraging and growth of Atlantic herring (*Clupea harengus*) larvae was constructed and validated using a variety of published data from laboratory and field studies and a sensitivity analysis was also conducted. The model was then forced with randomly-varied annual temperature, prey and photoperiod (latitude dependent day length) scenarios to examine how natural (phenological and magnitude) changes in key environmental factors could impact the survival and development of spring- and autumn-spawned larvae. The most suitable, hatching seasons agreed well with time periods of larval abundance in northeastern Atlantic ecosystems with larval survival highly unlikely in June, July and November. Mean annual temperature significantly influenced larval development of both, autumn- and spring-spawners. In autumn-spawned larvae, prey availability and latitude (photoperiod) were also important drivers whereas the phenology of the spring bloom was important for spring-hatched larvae. Thus, climate-driven changes in bottom-up factors are predicted to affect spring- and autumn-spawned larvae in different ways. To avoid unfavourable conditions, autumn-spawners appear unable to shift their spawning time or utilize more northern spawning habitats due to limitations in day length while earlier spawning in the spring will be tightly constrained by match-mismatch dynamics with the spring zooplankton bloom.

- **Work Package 1**

Task 1.3 Responses of (key) species to biotic factors (Trophic Coupling)

Downs herring recruitment under the influence of predation and hydrography (Temming and Hufnagl)

The Downs herring component of the North Sea autumn spawners is characterised by the latest spawning time. These larvae drift during winter and spring along the Belgian- Dutch and German coasts towards the German Bight. The Downs component of the recruitment is visible in length distributions in the quarter 2 IBTS survey as the smallest mode of the length frequency distribution. Based on these data it is possible to isolate the recruitment of the Downs component which displays a special decadal pattern. From 1975 to 1986 a strong recovery from the collapse of the stocks in the early 70s is visible, but the pattern is reversed after 1986. The working hypothesis for this investigation is that the reversal is related to the invasion of horse mackerel into the North Sea following the very strong year class of 1982. The hypothesis is supported from stomach content data of North Sea horse mackerel, containing considerable amounts of late herring larval in the German Bight. When these data were included in the MSVPA model runs for the North Sea a strong peak in predation mortality was predicted for the period 1987 – 1997. The main limitations of the MSVPA model approach are 1) the fact that only in 1991 a limited number of stomachs were collected and 2) the crude estimation of the North Sea horse mackerel stock, which is simply assumed to be a certain fraction of the Western Stock.

This study aims at two improvements: 1) Instead of using MSVPA parameterised with the limited stomach data predation risk will be estimated from spatial overlap of predator and prey and 2) The fluctuations in the stock of North Sea horse mackerel will be estimated from IBTS survey data.

The approach to analysing the spatial overlap was to inspect distributions of horse mackerel in Quarters 2 and 3 from IBTS. Since the most relevant data for quarter 2 are only available for the years 1991 – 1997, the additional hypothesis was tested, that the distribution of immigrating horse is strictly following the 9°C isotherm. This pattern was clearly confirmed in the data analysis of IBTS survey data and model outputs from the HAMSOM model. Based on this it can be assumed, that any herring larvae drifting within the warm water body limited by the 9°C isotherm, is at risk of horse mackerel predation. Therefore the inter annual variability of overlap of drift routes and warm water masses in the Southern North Sea serves as a proxy for horse mackerel predation risk. The drift is calculated using the HAMSOM model outputs and a particle tracking module. The adult horse mackerel density in quarter 3 is used as scaling factor for the proxy. The combined index will be correlated either with observed recruitment success or with a survival proxy that is derived from a comparison of early yolk sac larvae and recruits.

• Work Package 2

Validation of the hindcast runs (Pohlmann)

In the frame of ECODRIVE some additional validation exercises have been performed by comparing the simulation results with short-term measurements from three stations (waterbase.nl), which are located between England and the Netherlands (Euro platform and K13) and between Scotland and Danmark (Aukfield) (Fig. 19). It can be inferred that the long-term average annual cycle is reasonable simulated. Maximal monthly deviation ranges from 0.41 °C at Euro to about 1.47 °C at Aukfield. Correlations between observations and hindcast SST range from 0.79 – 0.89 and biases are generally smaller than -0.04 °C. This is

comparable to the results reported in Hjøllø et al. (2009) for monthly mean SST, indicating that SST anomalies on daily and longer timescales are reasonably simulated in our hindcast. The only long-term time-series of SST measurements covering more than 13 decades of years is available for Helgoland Roads (Wiltshire and Manly, 2004). In the German Bight, there are also available three time series (~1950 – ~1988) from light vessels. For these stations some additional comparisons are done to access the degree of accuracy to which our hindcast simulate observed long-term variability.

In general, correlations are relatively high varying between 0.83 and 0.89. Bias and root-mean-square-error vary between 0.31 °C and 0.66 °C and between 0.82 °C and 1.20 °C respectively. These error statistics appear some what larger than for the stations Aukfield, Euro and K13. We propose that this maybe partly an effect of specific conditions of the island, which cannot be resolve adequately with the current model resolution. Despite the warm bias found for Helgoland roads and for the three light vessels inter-annual and longer term fluctuations appear to be reasonably reproduced.

Apart from sea surface temperature, we also compared our model results with a vertical temperature profile along a cross-section between Aberdeen (Scotland) and Hanstholmen (Denmark) from Kangas et al. (2006). An objective comparison with the results produced by Kangas et al. (2006; section 4.1) indicate that the large-scale structure of the temperature pattern is reasonably simulated, while smaller-scale details are missing which maybe be partly attributed to the limited horizontal and vertical resolution of our model hindcast.

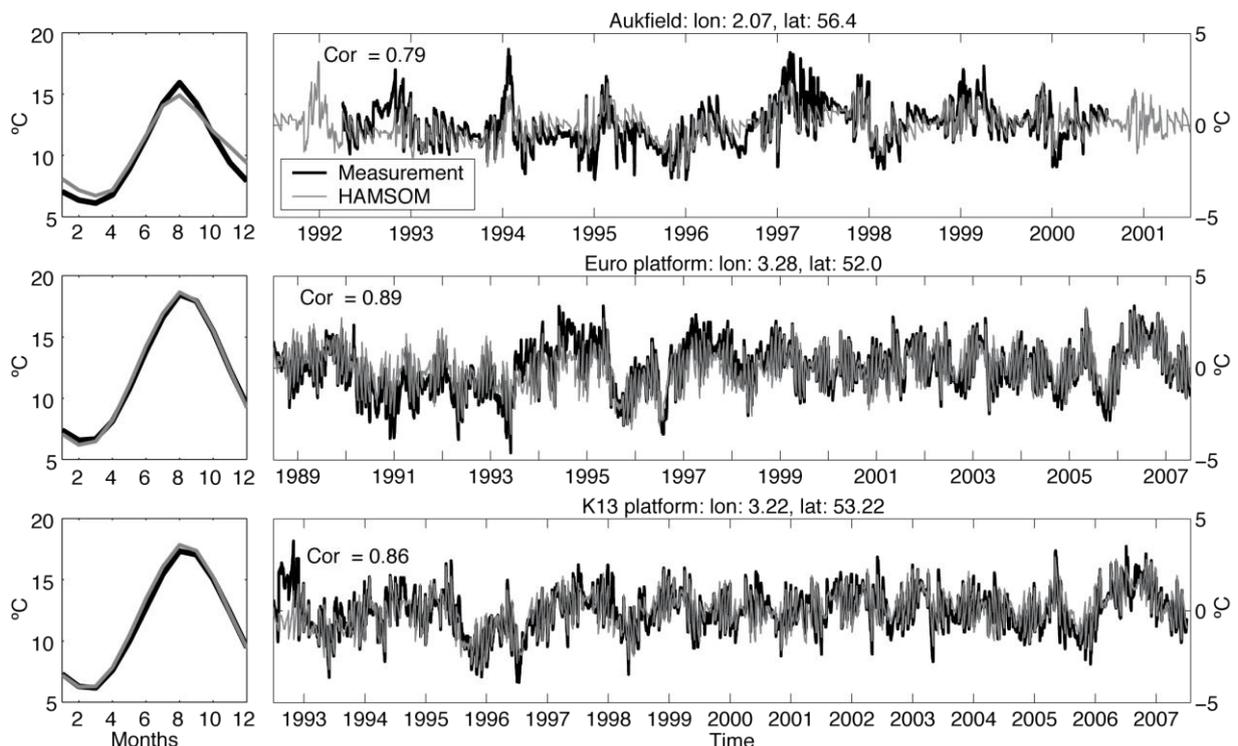


Figure 19: In the left column the seasonal cycles of temperature are calculated from observed (black) and simulated (grey) data for the stations Aukfield, Euro and K13 during the observed period (waterbase.nl). In the right column is shown the diurnal anomaly (diurnal data(station) – seasonal cycle(station)) of observed (black) and simulated (grey) data from these stations.

Modelling long term changes in the lower trophic level dynamics in the North Sea and the Baltic Sea: Evidence for regime shifts and environmental controls (Schrum, Pushpadas)

The 3D bio-physical coupled model ECOSMO (Schrum et al., 2006) was further developed and improved to be appropriate for application in the Baltic Sea. Cyanobacteria were introduced as an additional plankton group, with the functionality as nitrogen fixers at the sea surface, hence they may grow on phosphate only. Moreover, two sediment groups were introduced, the formulation of denitrification was improved and feeding mortality of higher trophics with removal of biomass from the system is now considered. The parameterisations used are similar to those presented by Neumann et al. (2002) and Eilola et al. (2009). The updated model version was used to simulate the long-term changes in lower trophic level dynamics in the North Sea and Baltic Sea ecosystems and the aptness of the model to realistically simulate the lower trophic levels in both regional seas was investigated. We presented the preliminary results of the long term hind cast simulation from 1948-2006 forced by NCEP/NCAR reanalysis data. A verification of the modelled long-term variability of the cyanobacteria production against remote sensing observations presented by Kahru (1997) were presented, more detailed validations of chlorophyll, zooplankton, nutrients and physical parameter are under way.

The modelled long-term variability was more closely investigated and preliminary results of modelled productivity vs. climatic variability were discussed. For our analysis we separated the model domain into five regions as Northern North Sea, western North Sea, Southern North Sea, Central Baltic Sea and Bothnian Bay and Sea since the long term changes in the ecosystems is driven by separate forces in different regions. In the northern and western areas of the North Sea long-term changes are predominantly influenced by climatic fluctuations, while in the southern and eastern areas of the North Sea, the lack of stratification and the large inputs of nutrients indicates that primary productivity is more strongly influenced by variations in anthropogenic nutrient inputs, and is only weakly related to climatic variation (Clark and Frid, 2001). Time series analysis of modelled primary and secondary productions in different regions show the evidence of ecosystem regime shift in the North Sea and the Baltic Sea as early reported by Reid et al. (2001), Beaugrand (2004), and Alheit et al. (2004) in mid/late 1980's. In order to study the environmental controls over primary productions in both the ecosystems we performed correlation analysis and FFT analysis. It is inferred that the influence of environmental variability in primary production varies in different parts of the North Sea. The analysis show that the Baltic Sea primary production is stronger correlated to short wave radiation than the North Sea primary production. In the North Sea the influence of climatic variability is predominate in the northern part. Influence of NAO in primary production of North Sea and Baltic Sea is also studied. It was found that the climate variability acts on the lower trophic level dynamics of North Sea and Baltic Sea ecosystems and the influence is large in the Baltic Sea ecosystem. We conclude that ECOSMO is able to simulate the long term variability of primary and secondary production in the North Sea and the Baltic Sea ecosystems. In the North Sea the influence of climate variability is predominant in the northern part rather than the southern part. It is also found that the Baltic Sea ecosystem is more sensitive to the environmental variability when compared to North Sea. The research presented is a part of an ongoing work and further development of ecosystem module is on the way.

Consequences of nutrient reductions to survival of key fish species (Peck / Paetsch / Hufnagl / Daewel)

Using a coupled modelling approach, we are examining the potential consequences of mandated (OSPAR-related) reductions in river nutrient loads to the North Sea on zooplankton productivity and the survival and growth of the larvae of three commercially-important marine fish species. An ecosystem model (ECOHAM4) provided spatially-explicit, weekly estimates of net primary production and zooplankton biomass during 2002 (Fig. 20).

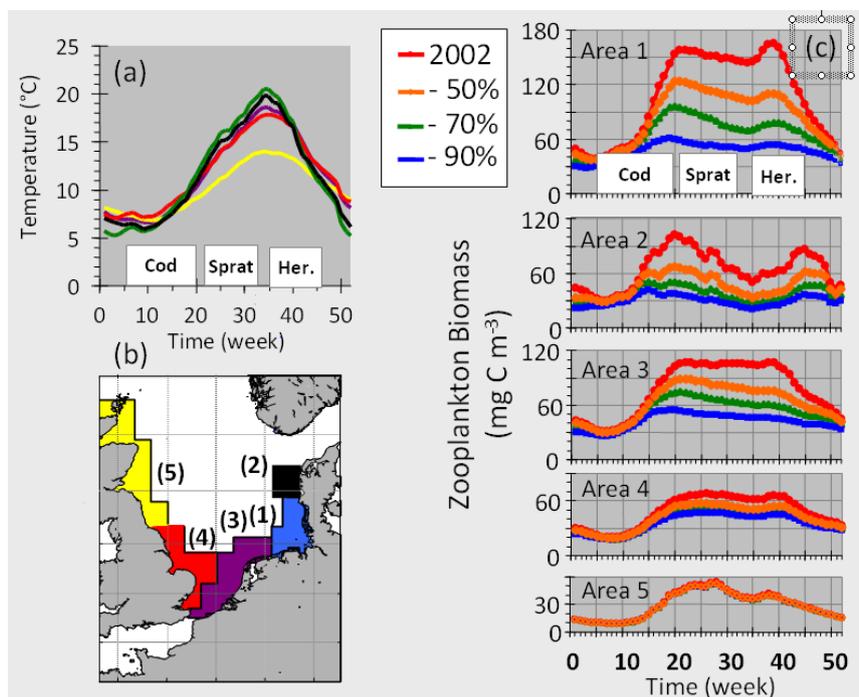


Fig. 20: Differences in modeled temperature (panel A) within five different North Sea regions (shown in panel B) and corresponding estimates of zooplankton biomass each week (panel C) during 2002 (and for -50, -70 and -90% nutrient reductions) as predicted by the ecosystem model (ECOHAM4).

Modelled estimates of zooplankton biomass were compared with estimates of temperature-specific prey thresholds required for the survival and growth of larval Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*) and sprat (*Sprattus sprattus*) based on physiological-based foraging and growth models. Nutrient reductions of 50% to 70% were required to obtain OSPAR water quality criteria. These reductions in nutrients caused declines in phytoplankton productivity and, hence, peak zooplankton biomass by 40 to 60% (from ~125 to ~70 mg C m⁻³) in productive, southern areas of the North Sea. Much smaller reductions in zooplankton biomass were estimated in less productive (central, northern) regions. The biomass of zooplankton required for the survival of early feeding larvae was vastly different among the species due to differences in growth physiology and foraging capacity (e.g., prey sizes ingested at first-feeding) (Fig. 21). Preliminary results suggest that

nutrient reductions may directly decrease larval survival in warmer-water (spring- and summer-spawning species) via to starvation. Indirect effects on the survival of most species are expected due to bottom-up limitation of growth rate which make larvae more vulnerable to mortality via predation.

However, threshold requirements for survival and growth were extremely sensitive to the seasonal changes observed in the slope of the zooplankton size spectrum (Fig. 22). Thus, nutrient-driven changes in phytoplankton and zooplankton species composition may have additional, large impacts on the productivity of higher trophic levels. Slopes of the size spectrum appear to be a conservative property of oligotrophic (offshore) waters but change seasonally in areas such as the Bay of Biscay and North Sea (Fig. 23). A method to estimate spatial and temporal changes in the size spectrum slope is being pursued which should allow more dynamic prey fields to be produced from NPZD model estimates – advancing our ability to estimate future conditions in the North Sea given nutrient reduction scenarios.

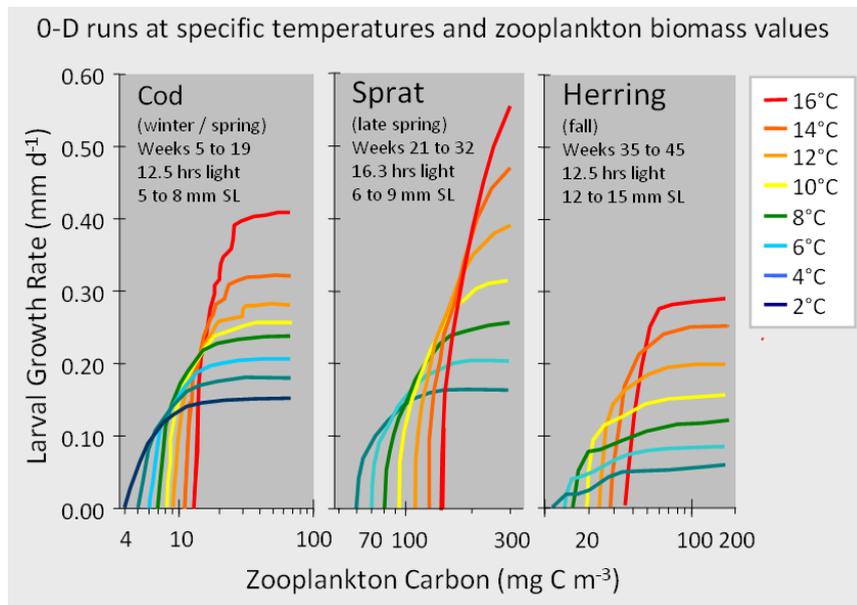


Fig. 21: Estimates of the larval growth rates at different prey abundance (values of zooplankton carbon) at different temperatures between 2 and 16°C for cod, sprat and herring.

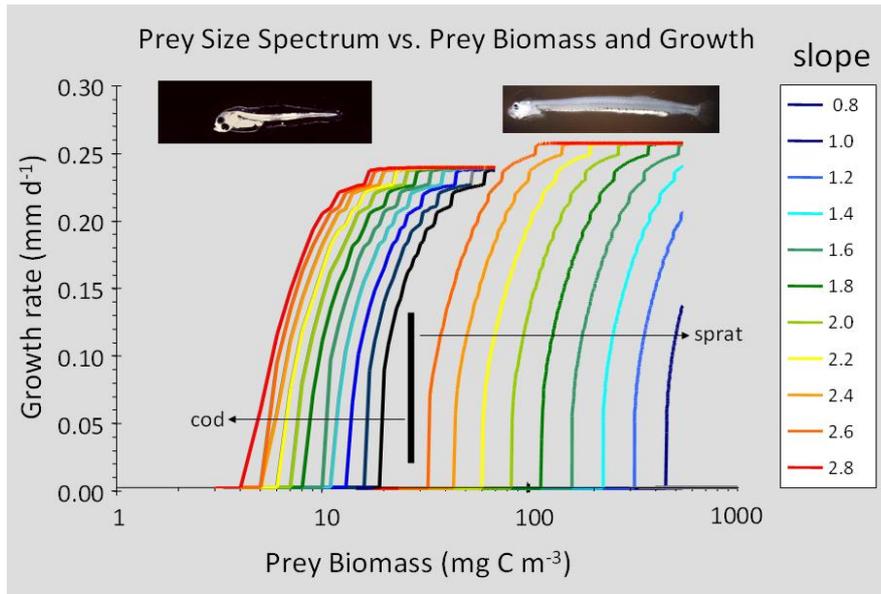


Fig. 22: Changes in the modelled growth rates of cod and sprat larvae versus prey biomass. All simulations were conducted at one temperature (8°C). Note the sensitivity of (changes in) the threshold biomass levels required for 0 (zero) growth (intercepts with x-axis) for the different slope values of the prey size spectrum (shown here from -0.8 /dark blue to -2.8 / red). Note, the x-axis has a log scale.

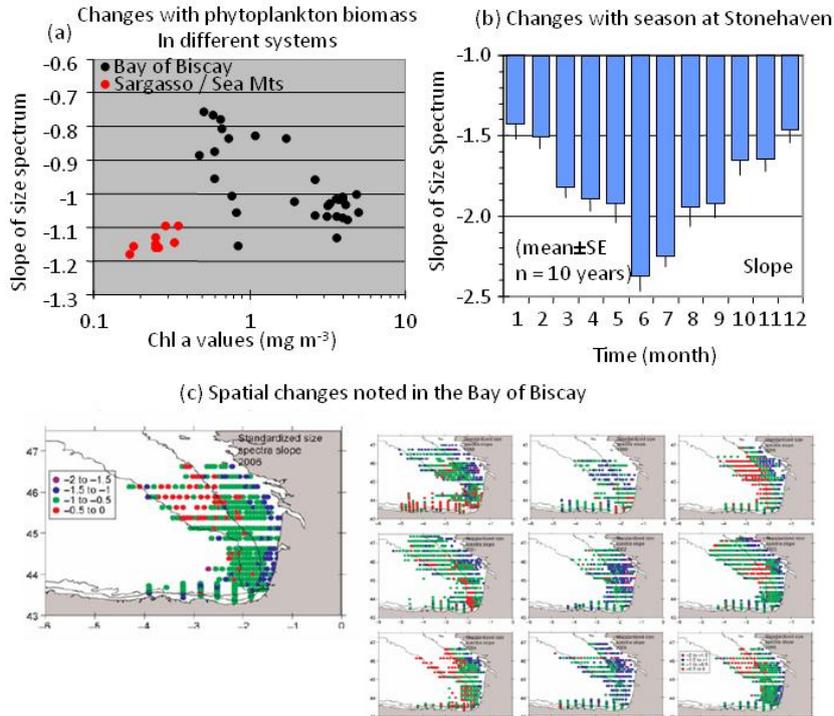


Fig. 23: Changes in the slope of the zooplankton size spectrum in different areas. (Panel A) Atlantic sea mounts (Quinones et al. 2003) and the Bay of Biscay (Fernandez et al. 1993) related to phytoplankton biomass (Chl a values); (Panel B) pronounced, seasonal changes in the slope of the size spectrum were noted in Stonehaven (Scotland, North Sea coast); (Panel

C), marked spatial variability in slopes reported by (Irigoien et al. 2010). The data from Stonehaven were kindly provided by Jens Rasmussen (Marine Scotland, Aberdeen).

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Using a coupled modelling approach, we are examining the potential consequences of mandated (OSPAR-related) reductions in river nutrient loads to the North Sea on zooplankton productivity and the survival and growth of the larvae of three commercially-important marine fish species. An ecosystem model (ECOHAM4) provided spatially-explicit, weekly estimates of net primary production and zooplankton biomass during 2002 (Fig. 24).

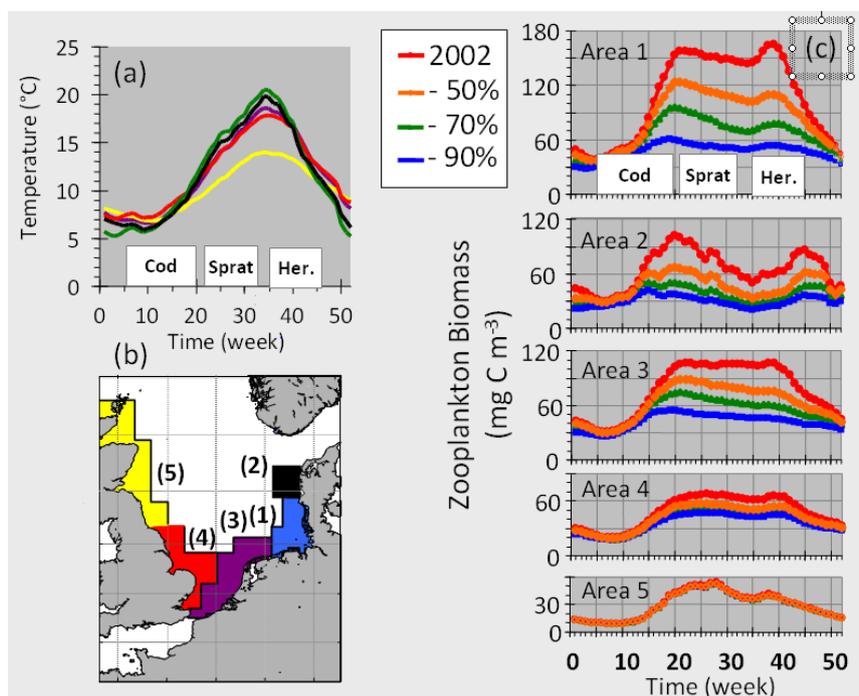


Fig. 24: Differences in modeled temperature (panel A) within five different North Sea regions (shown in panel B) and corresponding estimates of zooplankton biomass each week (panel C) during 2002 (and for -50, -70 and -90% nutrient reductions) as predicted by the ecosystem model (ECOHAM4).

Modelled estimates of zooplankton biomass were compared with estimates of temperature-specific prey thresholds required for the survival and growth of larval Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*) and sprat (*Sprattus sprattus*) based on physiological-based foraging and growth models. Nutrient reductions of 50% to 70% were required to obtain OSPAR water quality criteria. These reductions in nutrients caused declines in phytoplankton productivity and, hence, peak zooplankton biomass by 40 to 60% (from ~125 to ~70 mg C m⁻³) in productive, southern areas of the North Sea. Much smaller reductions in zooplankton biomass were estimated in less productive (central, northern) regions. The biomass of zooplankton required for the survival of early feeding larvae was vastly different among the species due to differences in growth physiology and foraging

capacity (e.g., prey sizes ingested at first-feeding) (Fig. 25). Preliminary results suggest that nutrient reductions may directly decrease larval survival in warmer-water (spring- and summer-spawning species) via to starvation. Indirect effects on the survival of most species are expected due to bottom-up limitation of growth rate which make larvae more vulnerable to mortality via predation.

However, threshold requirements for survival and growth were extremely sensitive to the seasonal changes observed in the slope of the zooplankton size spectrum (Fig. 26). Thus, nutrient-driven changes in phytoplankton and zooplankton species composition may have additional, large impacts on the productivity of higher trophic levels. Slopes of the size spectrum appear to be a conservative property of oligotrophic (offshore) waters but change seasonally in areas such as the Bay of Biscay and North Sea (Fig. 27). A method to estimate spatial and temporal changes in the size spectrum slope is being pursued which should allow more dynamic prey fields to be produced from NPZD model estimates – advancing our ability to estimate future conditions in the North Sea given nutrient reduction scenarios.

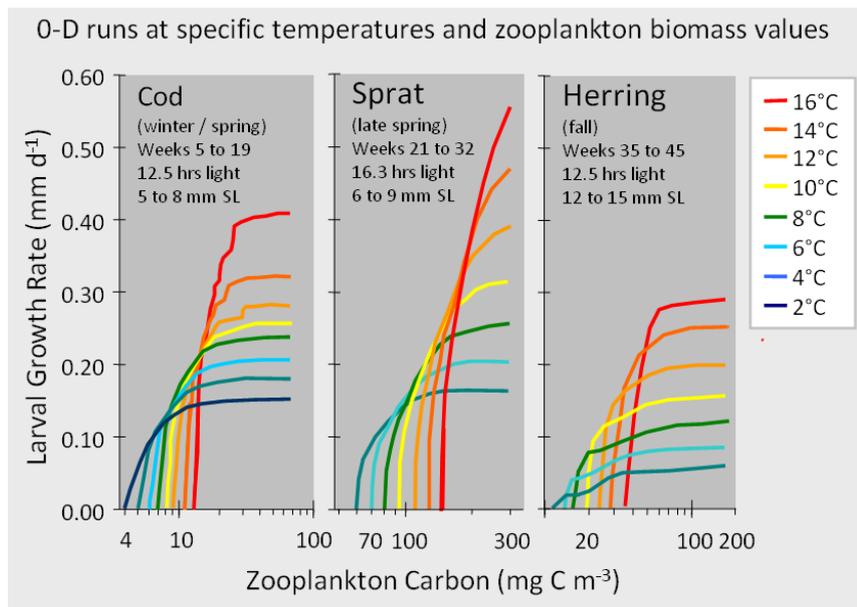


Fig. 25: Estimates of the larval growth rates at different prey abundance (values of zooplankton carbon) at different temperatures between 2 and 16°C for cod, sprat and herring.

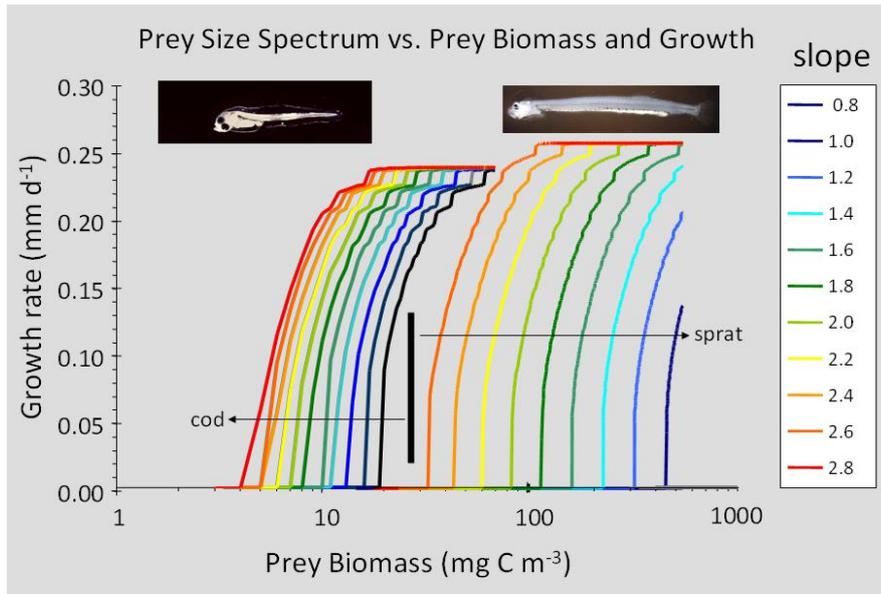


Fig. 26: Changes in the modelled growth rates of cod and sprat larvae versus prey biomass. All simulations were conducted at one temperature (8°C). Note the sensitivity of (changes in) the threshold biomass levels required for 0 (zero) growth (intercepts with x-axis) for the different slope values of the prey size spectrum (shown here from -0.8 /dark blue to -2.8 / red). Note, the x-axis has a log scale.

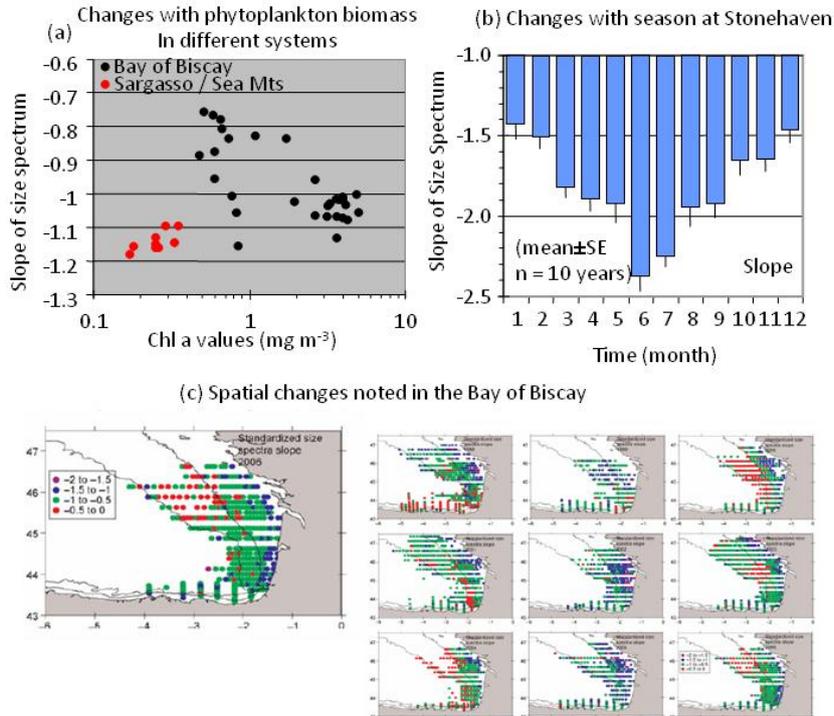


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- **Work Package 3**

- Task 3.1 Identification of ecosystem structural changes

- Task 3.2 Analyses of pressures and processes causing food web structural change

Structural changes in the North Sea ecosystem (Möllmann)

In order to investigate structural changes in the North Sea ecosystem and its drivers two sets of analyses have been conducted on time-series representing the whole North Sea ecosystem. First, Principal Component Analyses (PCA) have been conducted on seasonal matrices of time-series (1963-2007) including phyto- and zooplankton variables from the CPR-survey as well as planktivorous and piscivorous fish derived from a Stochastic Multispecies (SMS) Fisheries Model. By this main trends in the data set were extracted and were evaluated for abrupt changes using the Sequential Regime Shift Detection Method (STARS). Additionally Constrained Clustering (CC) was applied to identify structural changes in the multivariate dataset. Second, a trophic control analysis was conducted to evaluate the influence of climate and fisheries on the functioning of the pelagic North Sea ecosystem.

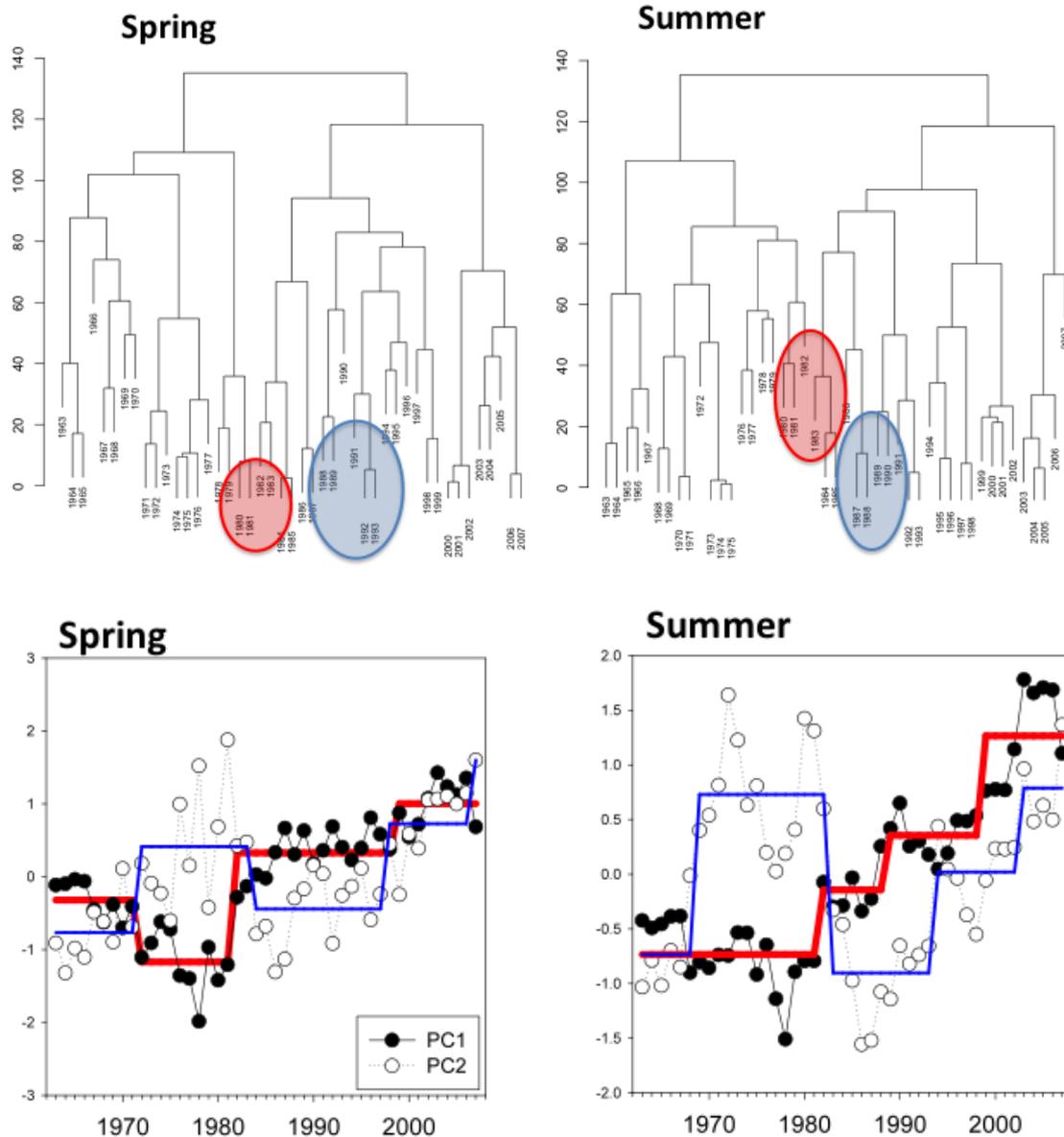


Fig. 1. Results of „regime shift analyses“ for the North Sea ecosystem in spring and summer using Constrained Clustering (upper panels) and STARS on PCA-output (lower panels). Red circles in the upper panels show main „regime shifts“ identified by CC, while blue circles represent the next important structural change. Red lines in the lower panels display „regimes“ identified through STARS on PC1, while blue lines show „regimes“ on PC2.

1. Ecosystem Regime Shifts

Fig. 1 shows results of the „regime shift analyses using CC and STARS. Both methods identified major structural changes in the ecosystem during the early 1980s. Further ecosystem regime shifts could be identified during the end of the 1980s and in the middle of the 1990s. The results show important reorganizations in the ecosystem in a multivariate fashion summarizing the published changes on the different trophic levels. The analyses show furthermore that multivariate analyses of ecosystem change are very sensitive to the period used in the analyses. This was revealed by a shorter analysis starting in the late 1970s which identified mainly the late 1980s shift, confirming published results. The longer time-series however put emphasis on the early 1980s shift.

2. Changes in trophic control

To investigate changes in trophic control as mechanisms for the above identified structural changes, trophic level indicators were constructed. Phytoplankton is represented by the CPR phytoplankton colour index, zooplankton by the CPR „all copepods“ index, plantivorous fish represent biomasses of herring, sandeel and Norway pout while piscivores include cod, haddock, saithe and whiting,

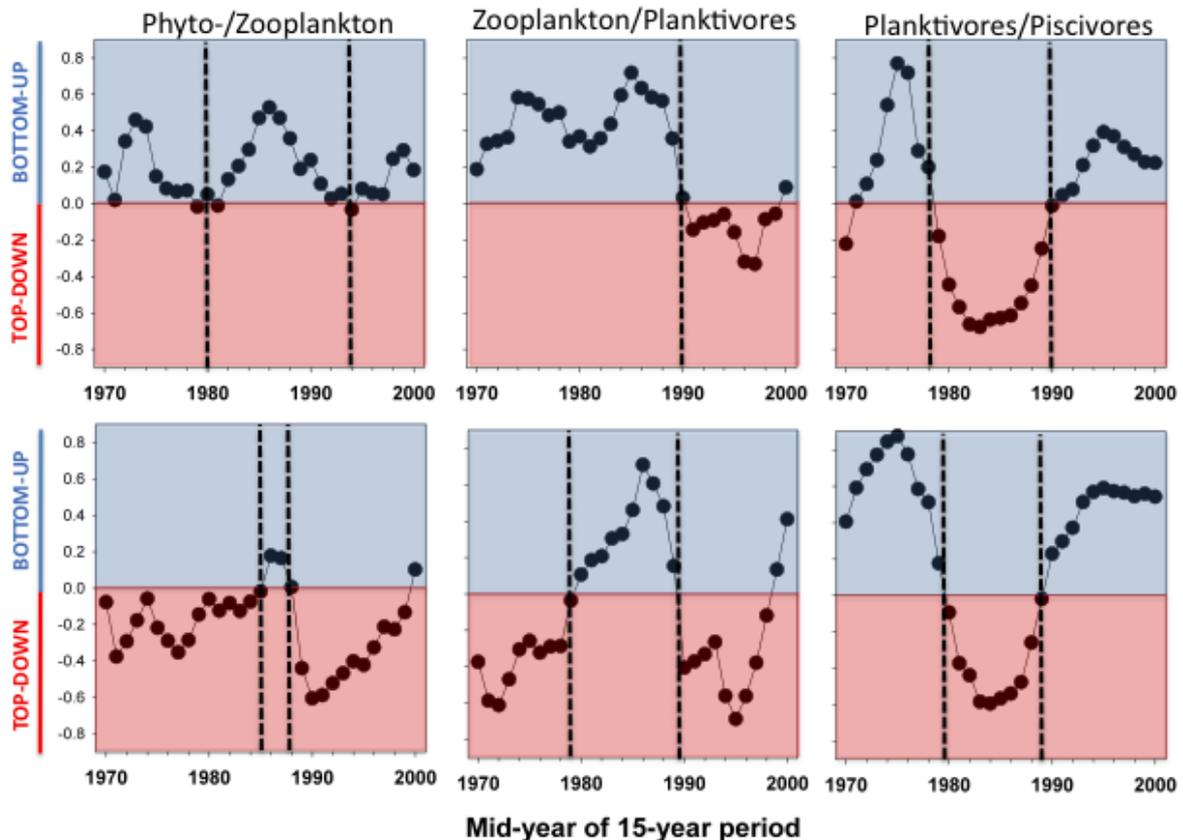


Fig. 2. Results of the „trophic control analysis“: Correlation coefficients (r) on they-axis represent either bottom-up control (positive r) or top-down control (negative r); r is based on 15-year moving correlations between trophic levels; vertical lines indicate major changes in the trophic control.

A simple trophic control analysis was conducted by assuming that positive correlations between trophic levels indicate „bottom-up – BUC“ and negative „top-down – TDC“ controls (Fig. 2). The analyses showed firstly an overall difference in trophic control between the plankton indicators. On average, BUC prevailed in spring while TDC dominated in summer. BUC dominated as well the spring zoopankton and planktivore interaction, however changing to TDC around 1990. Summer Zooplankton/planktivore interaction and spring and summer planktivore/piscivore interaction showed oscillating controls. The major periods of change were the late 1970s/early 1980s and the late 1980s/early 1990s, hence coinciding with structural changes identified above.

Next, trophic controls were modelled using Generalized Additive Models (GAMs) with a climate index (AMO – Atlantic Multidecadal Oscillation), piscivore fishing mortality (F) and an indicator of ecosystem state (PC1 – from PCA, see above) als explanatory variables (examples of the analyses in Fig. 3).

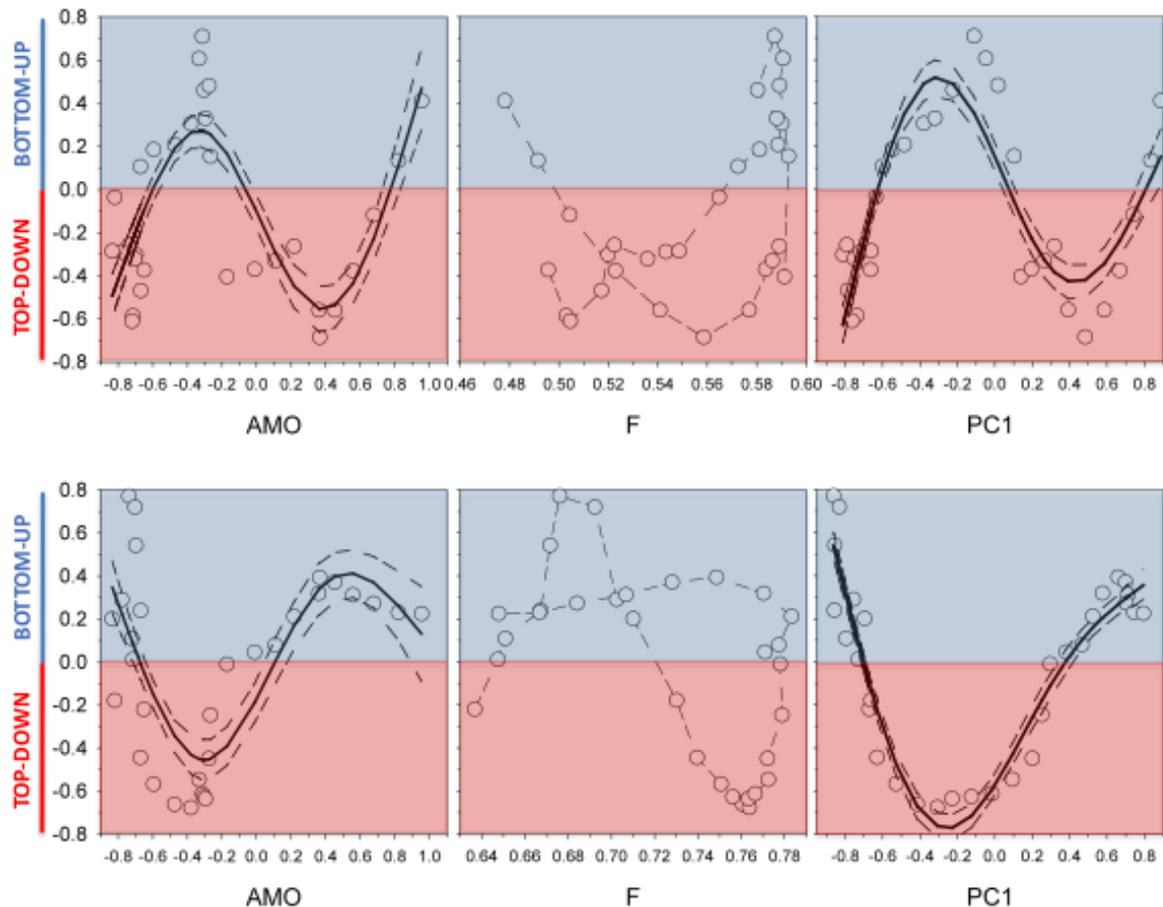


Fig. 3. Examples of univariate GAMs for the zooplankton/planktivore interaction in summer (upper panels) and the planktivore/piscivore interaction in spring (lower panels). Solid lines represent the effects of the predictors. Broken lines show confident limits.

GAMs showed that large proportions of the variability in trophic control (represented by correlation coefficients) can be explained by climate state represented by the AMO and by overall ecosystem state. Statistical models with F revealed as well significant results however with lower model explained deviances. However, the results indicate an interaction between climate and fisheries in determining trophic controls which will be further investigated, especially using Threshold-GAMs.

3. Conclusions

Alternative stable state theory predicts however that „phase transitions“ (regime shifts) result from the interaction between an external and an internal driver. We assumed climate and/or fishing pressure to be external drivers and trophic control as the internal driver. Our results show (i) major structural changes in the North Sea ecosystem, and (ii) that these coincide with changes in trophic control, especially between „upper trophic levels“, i.e. the interaction between piscivores and planktivores as well as zooplankton. Preliminary results further indicate the importance of AMO-related climate process in determining the control state, however indicate as well the importance of fisheries effects. Further analyses will concentrate on this interaction in order to reconcile climate and fisheries effects on the reorganization of the North Sea ecosystem.

• **Work Package 4**

Current state of climate scenario runs for the 21st century (Mathis)

To drive the shelf ocean model HAMSOM, oceanic forcing variables (MPI-OM data) as well as atmospheric forcing variables (REMO data) are prescribed at the open lateral boundaries of the North Sea domain and at the air-sea interface, respectively. Since the atmospheric variables show a large temporal variability and since the North Sea reacts sensitively on changes in the atmospheric forcing, a validation of the atmospheric forcing variables was carried out. All forcing variables are created by a free model run (MPI-OM and REMO) without any data assimilation incorporated and hence, a direct comparison of single data sets with any hindcast data is not applicable. Thus, for the validation monthly climatological means of the REMO data were compared with monthly climatological means of reanalysis data (NCEP and ERA40) for the period 1958-2000 (Fig. 1).

This comparison revealed a bias inherent in the REMO data which is anticipated also to be present in the scenario period 2001-2100. A correction scheme for the REMO data was introduced in order to eliminate the bias and to assure consistent annual cycles of the used variables (Fig. 2). The suggested delta-field correction accounts for regional deviations in the REMO data relative to ERA40 data on a monthly time scale but without affecting the short-term temporal variability of the REMO data. Besides the implementation of the correction scheme a HAMSOM test run, driven with the uncorrected REMO data was carried out. Promising preliminary results and detailed analysis of the thermocline were presented. Fundamental structural characteristics of the thermocline as well as periodicities in the time series of some physical quantities could be identified.

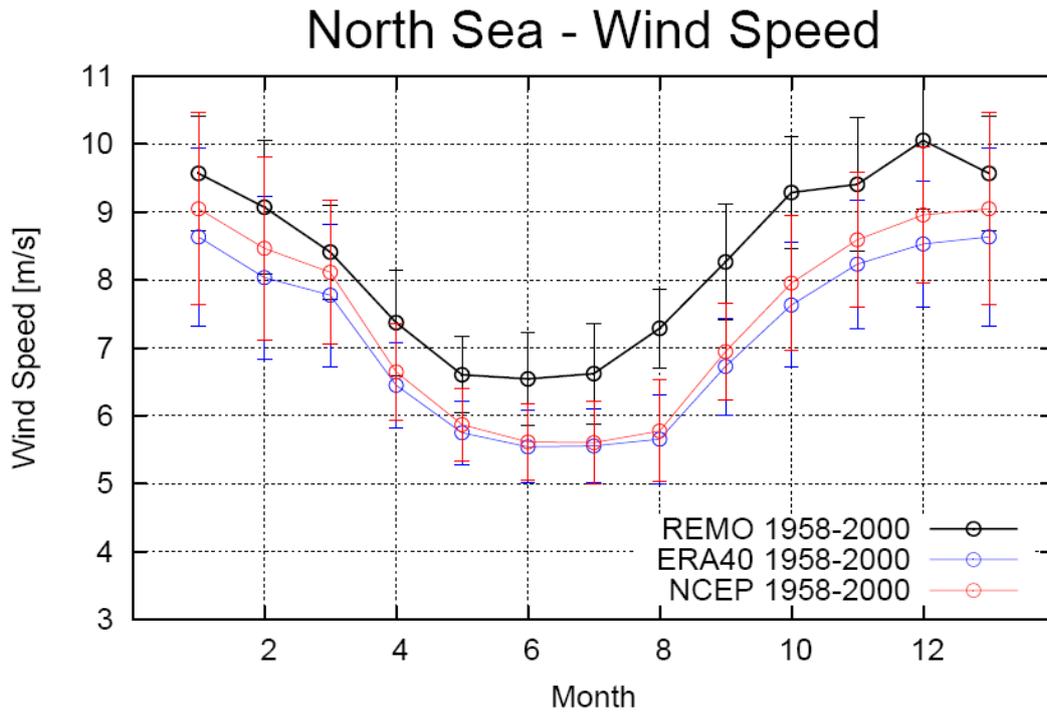


Figure 1: North Sea average wind speed (m/s). Comparison between uncorrected REMO (black), ERA40 (blue) and NCEP (red).

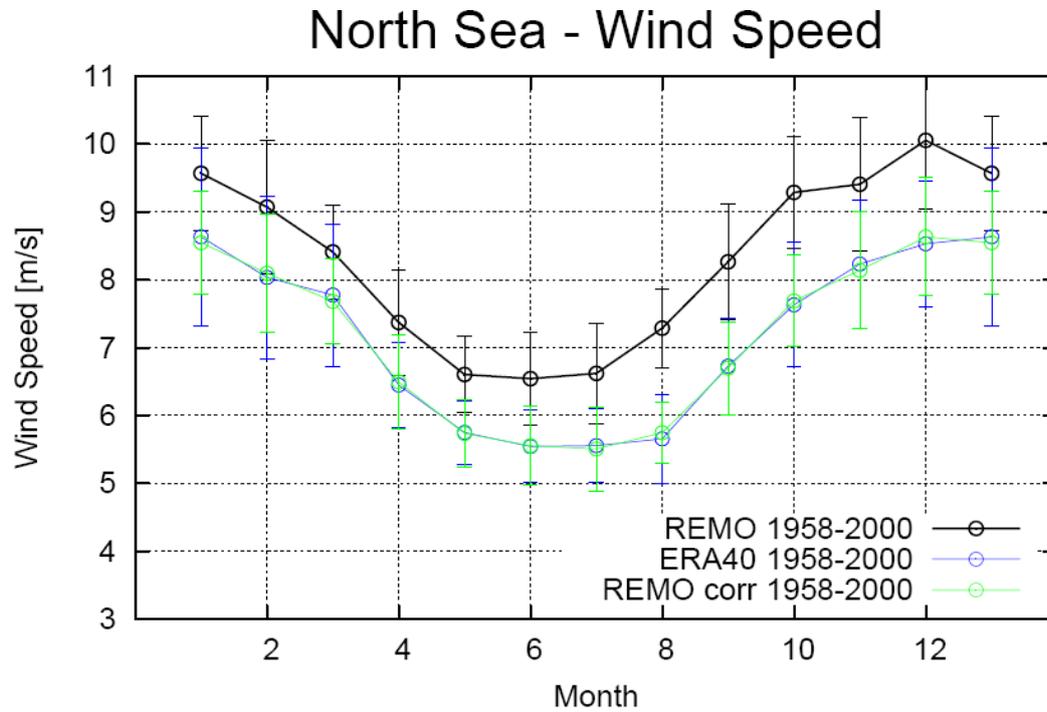


Figure 2: North Sea average wind speed (m/s). Comparison between uncorrected REMO (black), ERA40 (blue) and corrected REMO (green).

4. Other comments/suggestions

none

5. Person months used.

Partner organisation	Contact person	Person month so far
IOW	Alheit	1.5
IHF	Möllmann	12
IFM	Pohlmann	13
AWI	Boersma	12
IMR	Skogen	
UiB-GFI	Schrum	15.5

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