Can freshwater runoffs control marine systems in the Baltic and the North Seas? - Ecosystem approach

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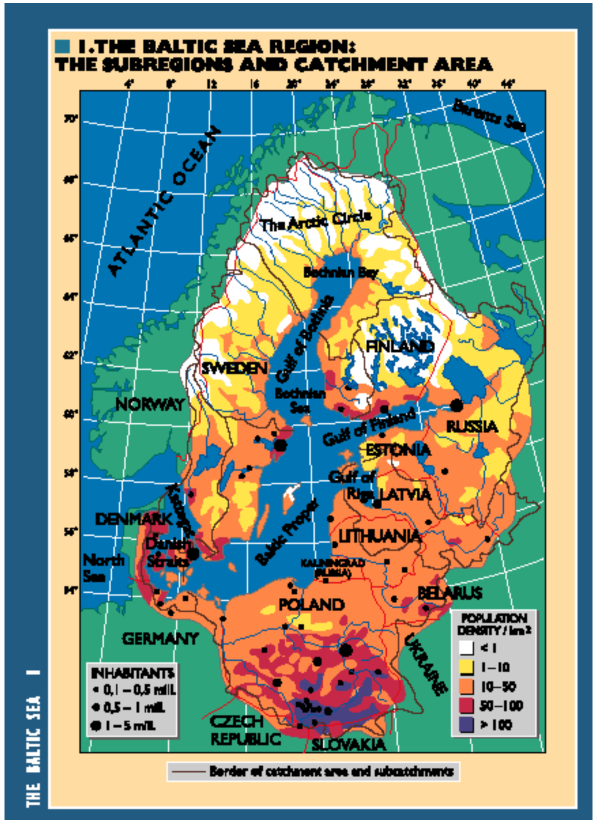
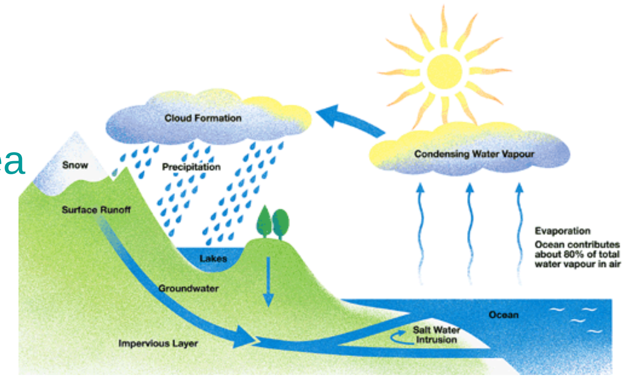
AMBER Annual Meeting

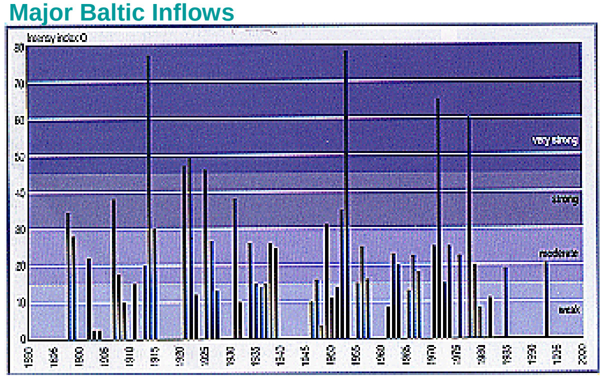


- Origin of all Baltic Sea water is the North Atlantic Ocean
- Freshwater, originally evaporated in the Atlantic, enter the catchment area via precipitation and finally reach the Baltic Sea as freshwater runoffs
- Salinity is maintained by seawater intrusions from the North Sea through the Danish Straits – *Saline water pulses (MBI)*
- The Baltic water circulation is generally rather well-known – all oceanographical events are ultimately regulated by freshwater runoffs, now intensified due to climatic change
- Less effort has been put to Baltic outflows:

Can Baltic runoffs also control the North Sea marine ecosystem?



Major Baltic Inflows



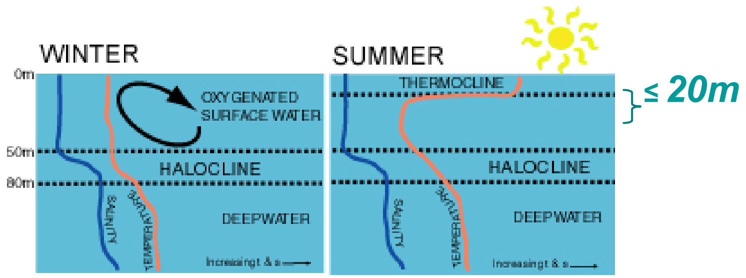
Materials and Methods:

- Numerical analysis of monthly marine environmental data during the study period 1970-2000
- The basic idea – "*The study of extremes*"

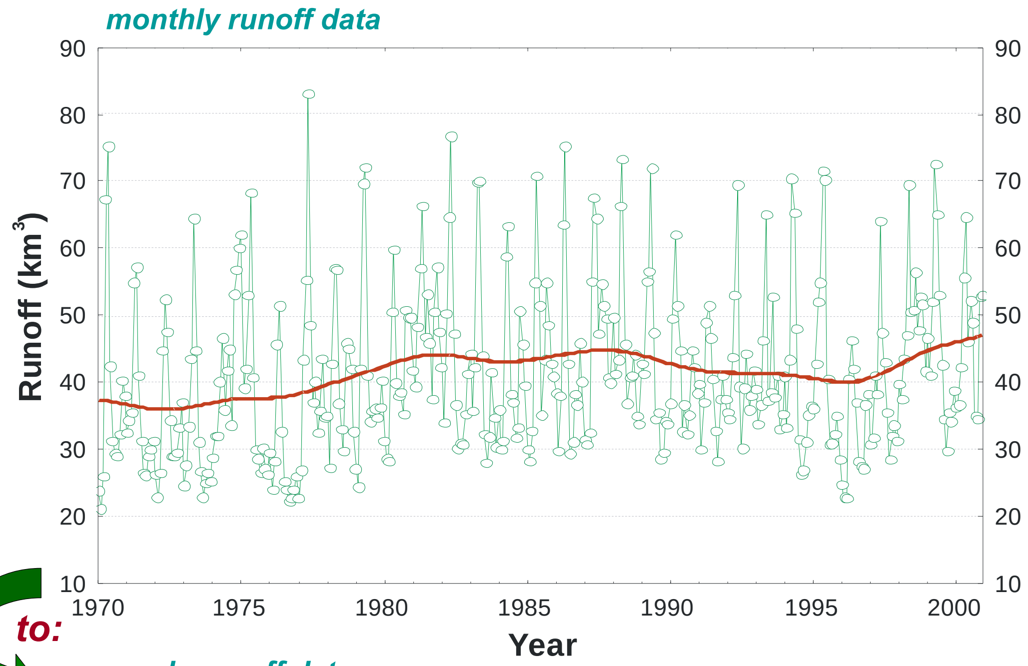
  Special attention to periods of very high and low Baltic runoffs –

  Can regulating effect of opposite runoff events really be detected parallel way in environmental marine data, as well?

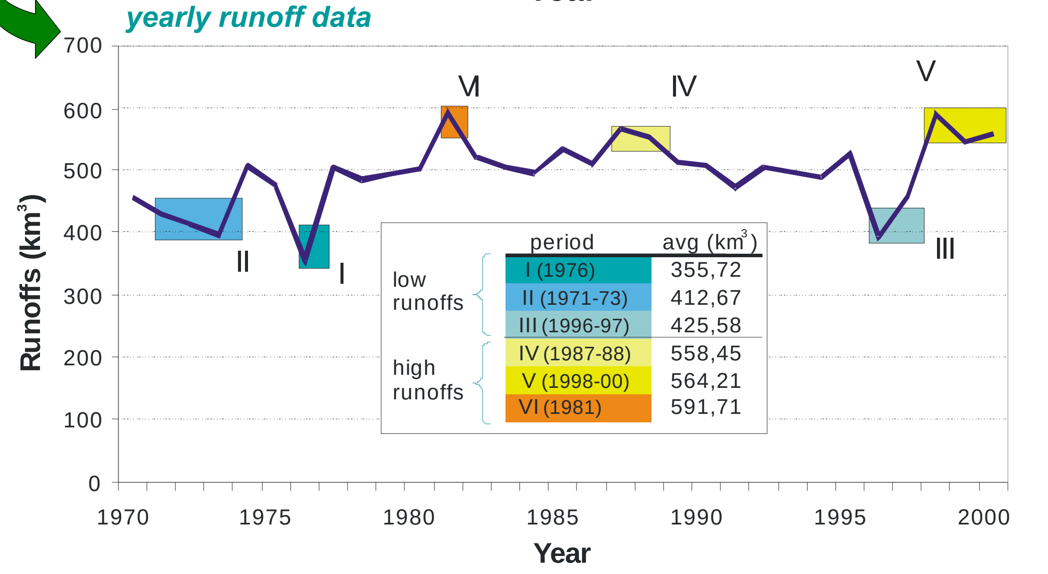
- Conducted with comparably manner both in the Baltic and the North Seas
- Applied only to well mixed 20m productive surface layer above thermocline



Total Baltic Runoffs 1970-2000



to:



Materials and Methods:

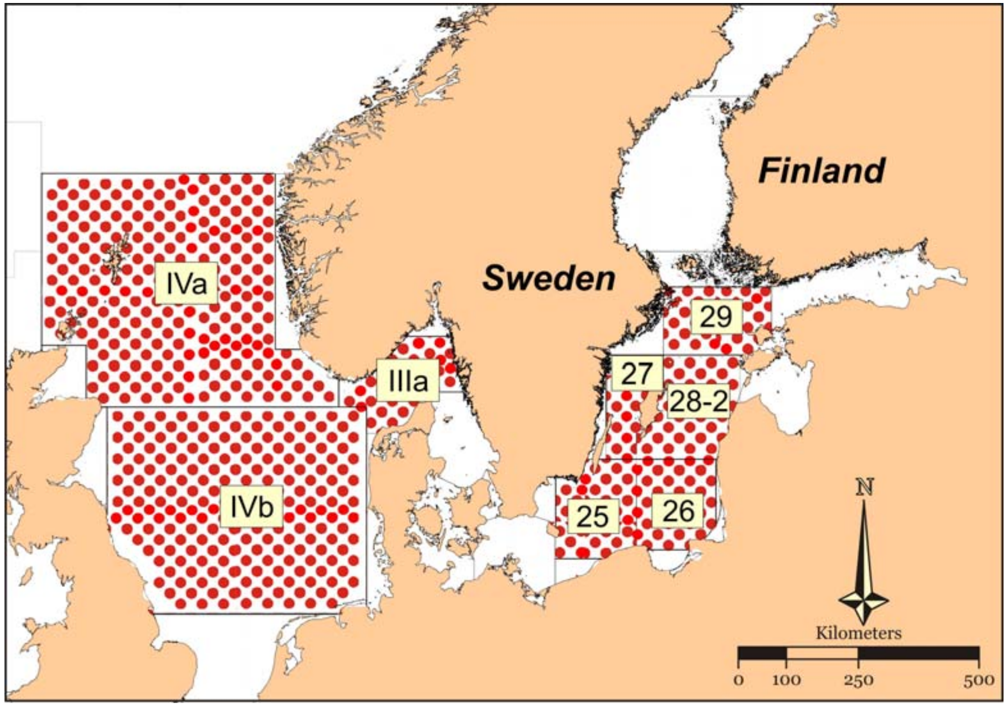
- Three study sites at both seas, loosely following the ICES subdivisions (applied mostly ICES monitoring network):

  I. *The Baltic Sea*:

  SD 29, SDs 27-28.2 and SDs 25-26

  II. *The North Sea*:

  SD IIIa, SD IVa and SD IVb



- Data compiled from various sources to hydrographical database, then observations averaged to monthly series over each sites (3 x 372 obs./full series).

	ICES		*HELCOM*		*LatFRI*	*SAHFOS*
	Bottle	**CTD**	**Bottle**	**CTD**	**Nets**	**CPR**
Physical variables:						
1. TEMP = Temperature [deg C]	X	X	X	X		
2. PSAL = Salinity [psu]	X	X	X	X		
3. DOXY = Oxygen [O2, ml/l]	X	X	X	X		
4. H2SX = Hydrogen Sulphide Sulphur [H2S-S, umol/l]	X		X			
5. PHPH = Hydrogen Ion Concentration [H]	X		X			
6. ALKY = Alkalinity [meq/l]	X		X			
Chemical variables:						
1. PHOS = Phosphate Phosphorus [PO4-P, umol/l]	X		X			
2. TPHS = Total Phosphorus [P, umol/l]	X		X			
3. AMON = Ammonium [NH4-N, umol/l]	X		X			
4. NTRI = Nitrite Nitrogen [NO2-N, umol/l]	X		X			
5. NTRA = Nitrate Nitrogen [NO3-N, umol/l]	X		X			
6. NTOT = Total Nitrogen [N, umol/l]	X		X			
7. SLCA = Silicate Silicon [SiO4-Si, umol/l]	X		X			
Biological variables:						
1. CPHL = Chlorophyll a [ug/l]	X		X			
2. PCI = Phytoplankton Color Index [0,..,6.5]						X
3. RotiBM = Rotifera Biomass [wwt mg/m^3]					X[1]	
4. CladoBM = Cladocera Biomass [wwt mg/m^3]					X[1]	X
5. CopeBM = Copepoda Biomass [wwt mg/m^3]					X[1]	X

[1] complemented with ICES zooplankton data

Materials and Methods:

- Statictical analyses performed with ***Generalized Linear Mixed Models*** (GLIMMIX – SAS®Inst. 9.2 for Windows)
- Extremely handy because e.g.…

  I. can deal with various data distributions ("*exponential family" of distributions*)

  II. can deal with correlations or non-constant variability (e.g. *autocorrelated time series*)

  III. can deal with random effects (*all possible effects not covered in sampling*)

➡ the better the data is known beforehand, the better the GLIMMIX model is optimized!

- First, distributions and serial structures of each series verified
- Second, two separate analyses, supporting each other, first at Baltic and then at North Sea

  I. "*The basemodel analyses*" (*analysis with "original" untransformed data*)

  II. "*The dynamic variables analyses*" (*analysis with anomalized Principal components*)

Example of GLIMMIX executable:

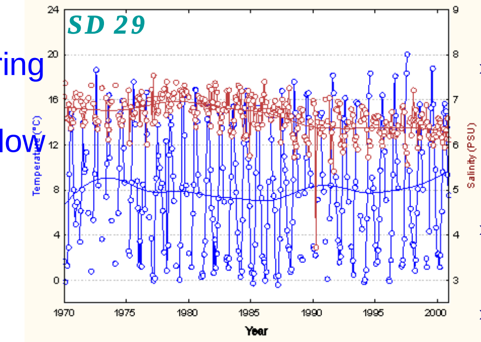
```
proc glimmix data=data.Baltic;
  class area period;
  model SLCA=area period area*period Runoff/ solution ddfm=satterth cl
                  dist=lognormal link=identity;
 /*  - Areal comparisons - */
   estimate 'SD 29 vs. Other SDs' Area 2 -1 -1 / cl ;
   estimate 'SD 27-28.2 vs. Other SDs' Area -1 2 -1 / cl ;
   estimate 'SD 25-26 vs. Other SDs' Area -1 -1 2 / cl ;
   estimate 'SD 29 vs. SD 25-26' Area 1 0 -1 / cl ;
   estimate 'SD 29 vs. SD 27-28.2' Area 1 -1 0 / cl ;
   estimate 'SD 25-26 vs. SD 27-28.2' Area 0 1 -1 / cl ;

 /*  - Periodical comparisons - General effect - */
   estimate 'Low Runoff vs. High Runoff Periods' Period 1 1 1 -1 -1 -1 0 / cl ;

 /*  - Periodical comparisons against high/low runoff years - */
   estimate 'I. 1976 vs. High Runoff Periods' Period 3 0 0 -1 -1 -1 0 / cl ;
   estimate 'II. 1971-73 vs. High Runoff Periods' Period 0 3 0 -1 -1 -1 0 / cl ;
   estimate 'III. 1996-97 vs. High Runoff Periods' Period 0 0 3 -1 -1 -1 0 / cl ;
   estimate 'IV. 1987-88 vs. Low Runoff Periods' Period -1 -1 -1 3 0 0 0 / cl ;
   estimate 'V. 1998-00 vs. Low Runoff Periods' Period -1 -1 -1 0 3 0 0 / cl ;
   estimate 'VI. 1981 vs. Low Runoff Periods' Period -1 -1 -1 0 0 3 0 / cl ;

 /*  - Periodical comparisons against Grand Mean - */
   estimate 'I. 1976 vs. Grand Mean' Period 6 -1 -1 -1 -1 -1 -1 / cl ;
   estimate 'II. 1971-73 vs. Grand Mean' Period -1 6 -1 -1 -1 -1 -1 / cl ;
   estimate 'III. 1996-97  vs. Grand Mean' Period -1 -1 6 -1 -1 -1 -1 / cl ;
   estimate 'IV. 1987-88 vs. Grand Mean' Period -1 -1 -1 6 -1 -1 -1 / cl ;
   estimate 'V. 1998-00 vs. Grand Mean' Period -1 -1 -1 -1 6 -1 -1 / cl ;
   estimate 'VI. 1981 vs. Grand Mean' Period -1 -1 -1 -1 -1 6 -1 / cl ;

  random _residual_/  group=period subject=area type=arh(1);
  covtest 'Common variance' homogeneity;
  lsmeans area /cl ilink;
  lsmeans period /cl ilink;
  lsmeans area*period /cl ilink;
  run;
```

Results:

The Baltic Sea

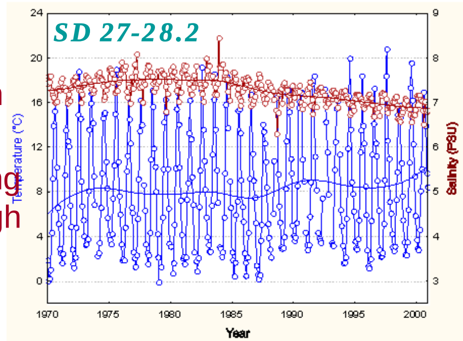
1. Temperature

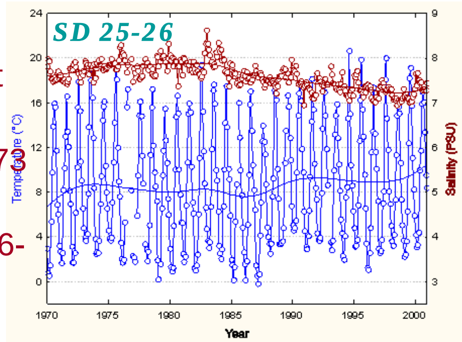
- runoff induced, long term control not evident
- no obvious parallel changes during high/low runoffs although lower temperatures measured during low runoff periods and v.v.
- year 1976 exceptionally cold
- years 1998-00 exc. warm
- missing values 7,6%



2. Salinity

- runoff induced, inverse long term control highly evident
- parallel short term changes during high/low runoffs obvious, e.g. high salinities measured during low runoff periods and v.v.
- model fits better, however, the general trend occurred in Baltic
- highest salinities at south, lowest at north
- high saline periods: 1976, 1971-73 and 1981 (early years)
- low saline periods: 1987-88, 1996-97 and 1998-00 (late years)
- missing values 7,5%

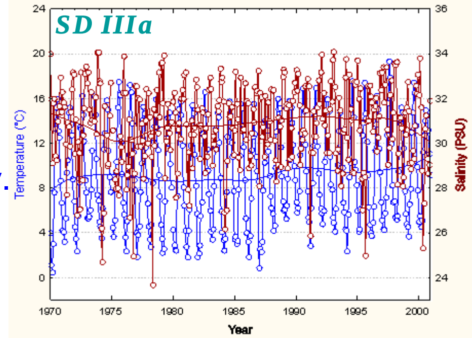




The North Sea

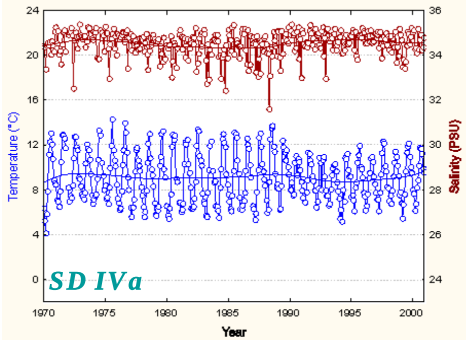
1. Temperature

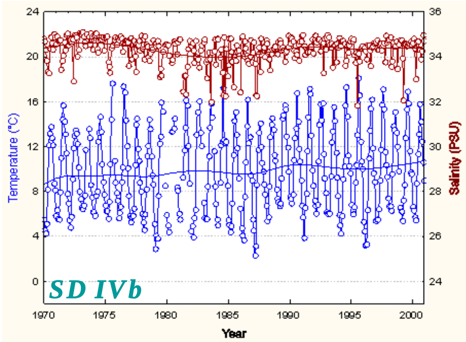
- runoff induced, long term control not evident
- no obvious parallel changes during high/low runoffs although lower temperatures measured during low runoff periods and v.v.
- years 1998-00 exceptionally warm
- missing values 2,7%



2. Salinity

- runoff induced, inverse long term control noticeable (Skagerrag)
- parallel short term changes during high/low runoffs highly obvious, e.g. high salinities measured during low runoff periods and v.v.
- the effect evident only if lag >1 year!
- highest salinities at western areas, lowest at Skagerrag
- high saline periods: 1971-73 and 1996-97 (low runoff years)
- low saline periods: 1987-88 and 1998-00 (high runoff years)
- missing values 2,6%





Results:

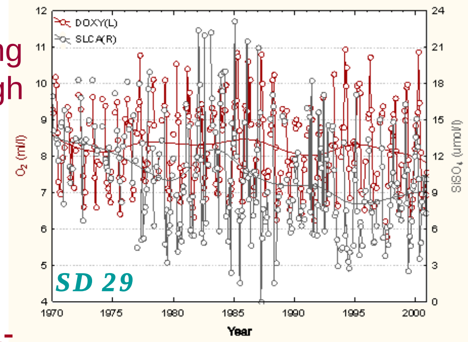
The Baltic Sea

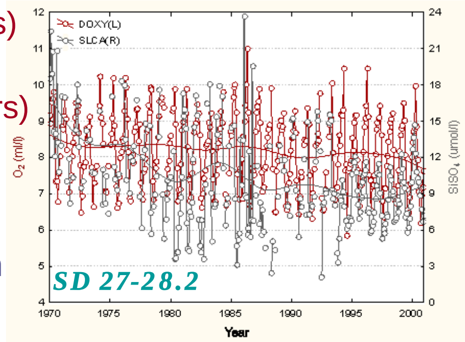
3. Oxygen

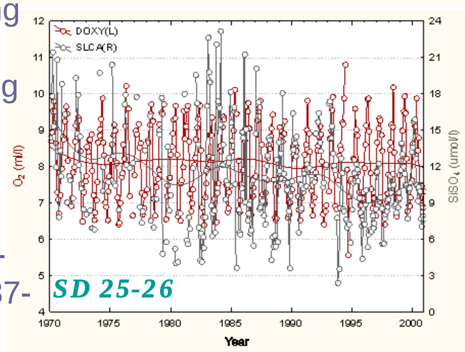
- runoff induced, inverse long term control noticeable
- parallel short term changes during high/low runoffs obvious, e.g. high oxygen measured during low runoff periods and v.v.
- changes expalined by some indirect mechanism, e.g. temperature, org. content or…?
- high oxygen periods: 1976, 1971-73 and 1996-97 (low runoff years)
- low oxygen periods: 1981, 1987-88 and 1998-00 (high runoff years)
- missing values 10,1%

4. *Silicates*

- runoff induced, inverse long term control evident and pronounced
- parallel short term changes during high/low runoffs also noticeable, e.g. low silicates measured during high runoff periods and v.v.
- model fits better to describe long term trends in silicates
- high silicate periods: 1976, 1971-73 (e.y), low silicate periods: 1987-88, 1996-97 and 1998-00 (l.y)
- missing values 25,8%







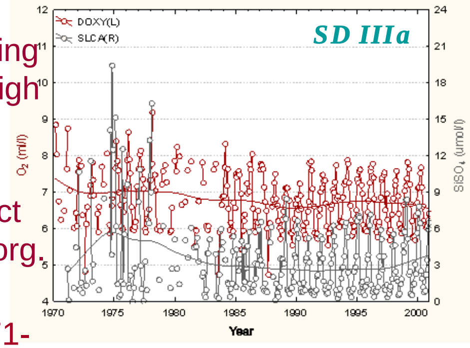
The North Sea

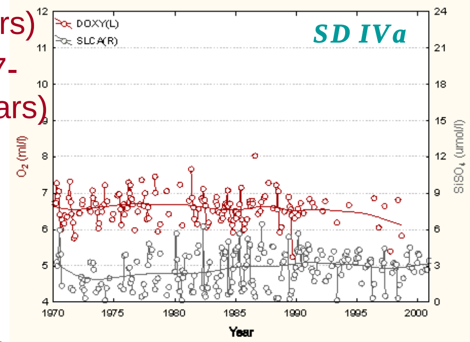
3. Oxygen

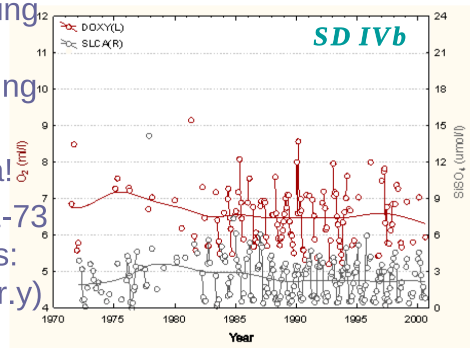
- runoff induced, inverse long term control probable
- parallel short term changes during high/low runoffs obvious, e.g. high oxygen measured during low runoff periods and v.v.
- expalined again by some indirect mechanism, e.g. temperature, org. content or…?
- high oxygen periods: 1976, 1971-73 and 1996-97 (low runoff years)
- low oxygen periods: 1981, 1987-88 and 1998-00 (high runoff years)
- missing values 46,6%!

4. *Silicates*

- runoff induced, direct long term control detectable
- parallel short term changes during high/low runoffs highly obvious, e.g. low silicates measured during low runoff periods and v.v.
- the Baltic "feeds" the North Sea!
- low silicate periods: 1976, 1971-73 and 1996-97 (l.r.y), high periods: 1981, 1987-88 and 1998-00 (h.r.y)
- missing values 36,6%







Results:

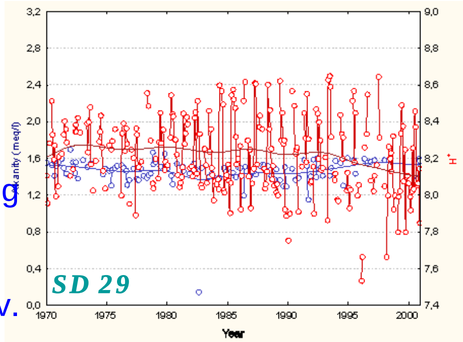
The Baltic Sea

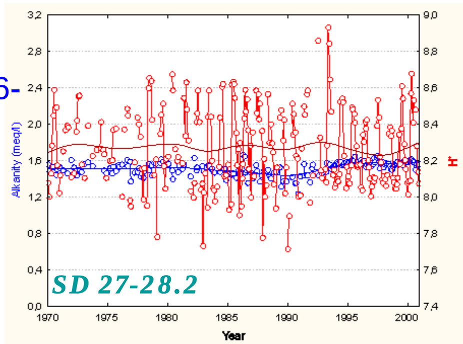
5. Hyd.sulphide sulphur

- *No model (too scarce data)*

6. Alkalinity

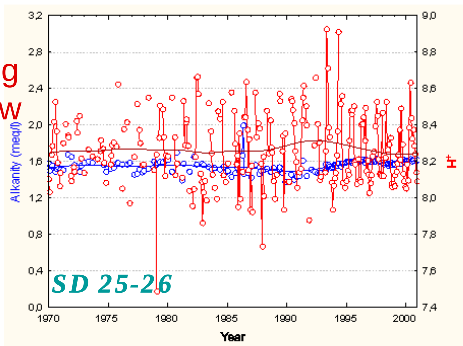
- runoff induced, inverse long term control probable
- parallel short term changes during high/low runoffs not so clear, although low alkalinity measured during high runoff periods and v.v.
- model describes "mixed" effect, fitting better to long term trends
- high alkalinity periods: 1976,1996-97 and 1998-00
- low alk.periods: 1981,1987-88
- missing values 57,6%!





7. Hydrogen Ion conc.

- runoff induced, inverse long term control noticeable
- parallel short term changes during high/low runoffs probable, e.g. low pH measured during high runoff periods and v.v.
- evident only when lag >1 year!
- high pH period: 1971-73, low pH period: 1998-00
- missing values 31,7%



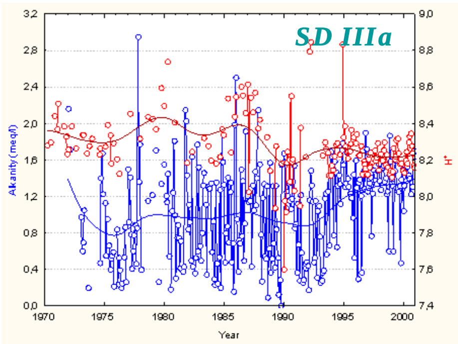
The North Sea

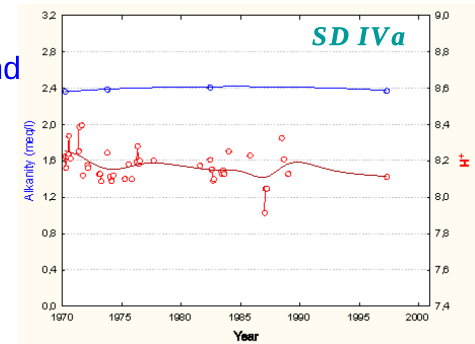
5. Hyd.sulphide sulphur

- *No model (too scarce data)*

6. Alkalinity

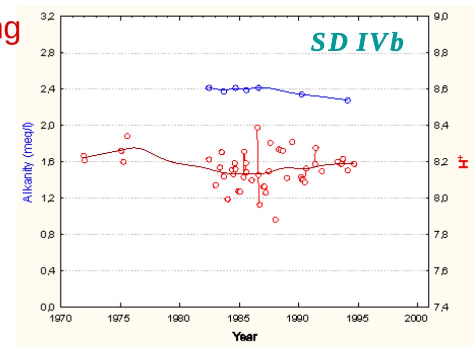
- runoff induced, long term control probable (but not clear)
- no obvious parallel short term changes during high/low runoffs
- results stressed strongly to Skagerrag
- the lowest alkalinities at 1976
- the highest values at 1996-97 and 1998-00
- missing values 72,8%!





7. Hydrogen Ion conc.

- runoff induced, long term control potential (but not very evident)
- parallel short term changes during high/low runoffs not clear
- results stressed strongly to Skagerrag
- high pH period: 1971-73, low pH periods: 1996-97 and 1998-00
- missing values 77,6%!



Results:

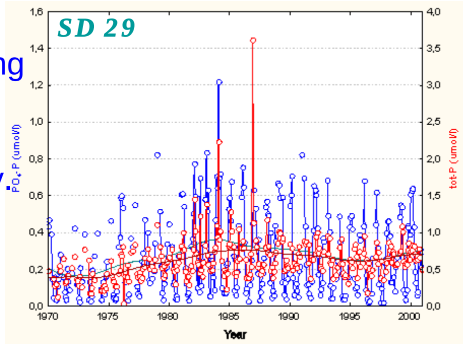
The Baltic Sea

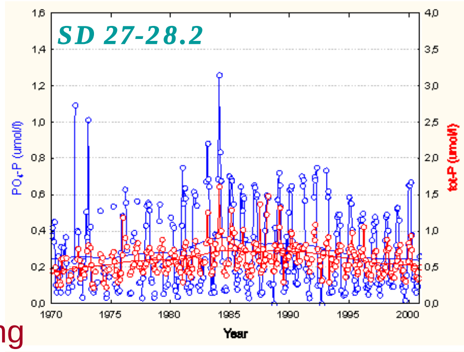
8. Phosphate

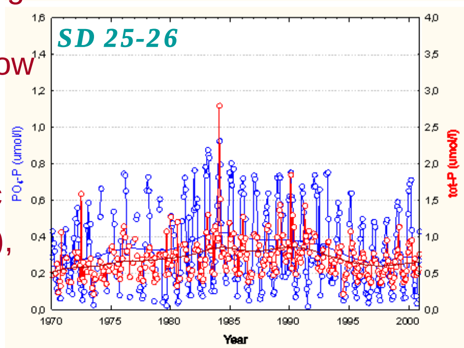
- runoff induced, direct long term control evident
- parallel short term changes during high/low runoffs also noticeable, e.g. low phosphates measured during low runoff periods and v.v.
- the effect evident only when lag >1 year!
- high phosphate period: 1987-88 (high runoff years)
- low phosphate periods: 1971-73 and 1996-97 (low runoff years)
- missing values 15,0%

9. Total phosphorus

- runoff induced, direct long term control evident
- parallel short term changes during high/low runoffs also noticeable, e.g. low tot-P measured during low runoff periods and v.v.
- evident only when lag >1 year
- highest values at southern Baltic
- high tot-P period: 1987-88 (h.r.y), low tot-P periods: 1971-73 and 1996-97 (l.r.y)
- missing values 20,0%







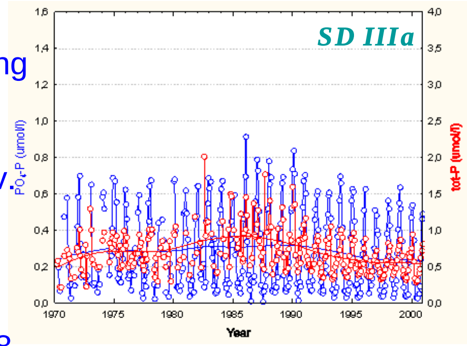
The North Sea

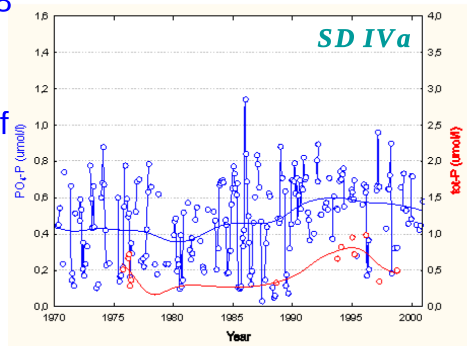
8. Phosphate

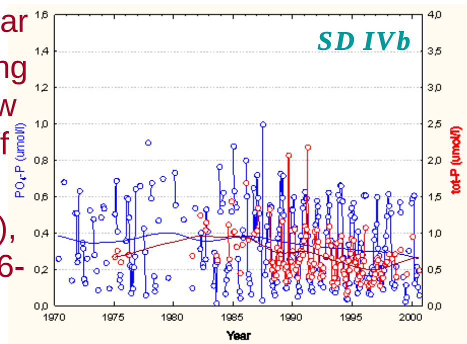
- runoff induced, direct long term control noticeable
- parallel short term changes during high/low runoffs highly evident, e.g. low phosphates measured during low runoff periods and v.v.
- lowest values measured at Skagerrag, highest around Shetland
- high phosphate periods: 1987-88 and 1998-00 (high runoff years)
- low phosphate periods: 1976, 1971-73 and 1996-97 (low runoff years)
- missing values 28,0%

9. Total phosphorus

- runoff induced, direct long term control probable but not very clear
- parallel short term changes during high/low runoffs obvious, e.g. low tot-P measured during low runoff periods and v.v.
- high tot-P period: 1987-88 (h.r.y), low tot-P periods: 1976 and 1996-97 (l.r.y)
- missing values 60.4%!







Results:

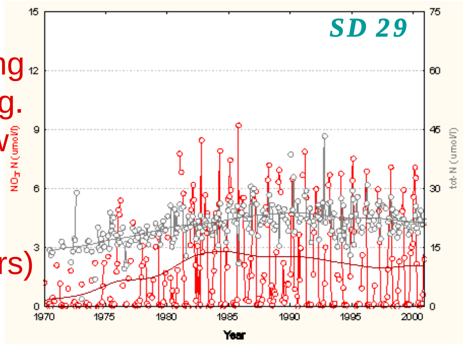
The Baltic Sea

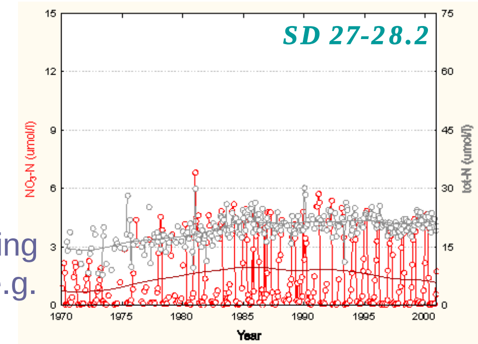
10. Nitrate

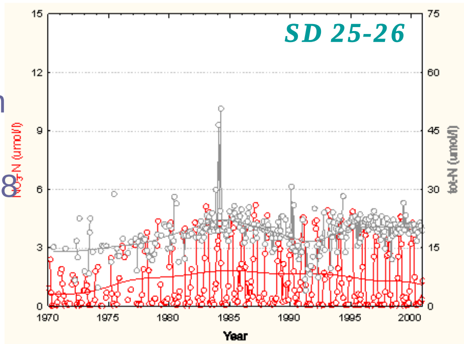
- runoff induced, direct long term control evident
- parallel short term changes during high/low runoffs also obvious, e.g. low nitrates measured during low runoff periods and v.v.
- high nitrate periods: 1981, 1987-88 and 1998-00 (high runoff years)
- low nitrate periods: 1971-73 and 1996-97 (low runoff years)
- missing values 16,9%

11. Total nitrogen

- runoff induced, direct long term control evident
- parallel short term changes during high/low runoffs also obvious, e.g. low tot-N measured during low runoff periods and v.v.
- evident only when lag >1 year
- highest values at north, lowest in south.
- high tot-N periods: 1981, 1987-88 and 1998-00 (high runoff years)
- low tot-N periods: 1971-73 and 1976 (low runoff years)
- missing values 30.6%







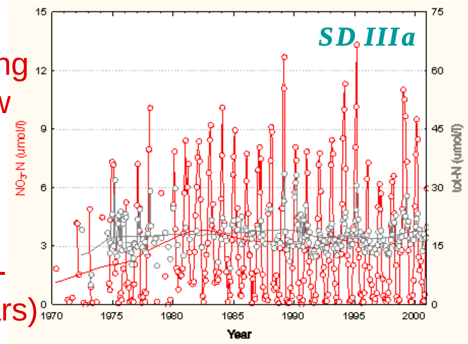
The North Sea

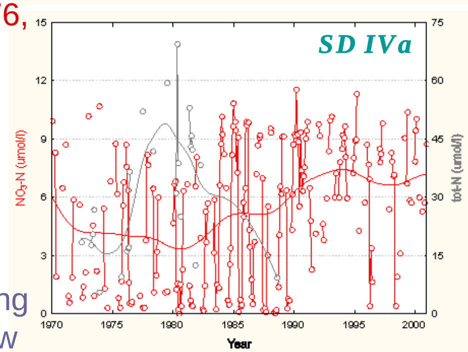
10. Nitrate

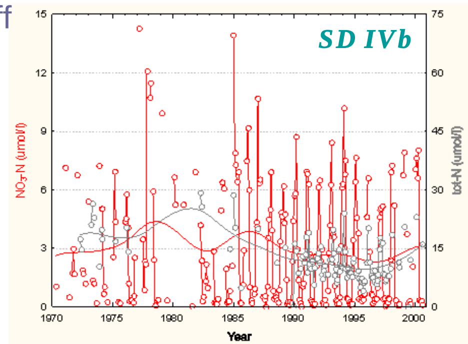
- runoff induced, direct long term control noticeable
- parallel short term changes during high/low runoffs evident, e.g. low nitrates measured during low runoff periods and v.v.
- highest values around Shetland
- high nitrate periods: 1981, 1987-88 and 1998-00 (high runoff years)
- low nitrate periods: 1971-73 1976, and 1996-97 (low runoff years)
- missing values 31,4%

11. Total nitrogen

- runoff induced, direct long term control probable
- parallel short term changes during high/low runoffs obvious, e.g. low tot-N measured during low runoff periods and v.v.
- highest values around Shetland
- high tot-N period: 1987-88 (high runoff years)
- low tot-N period: 1996-97 (low runoff years)
- missing values 67,1%!







Results:

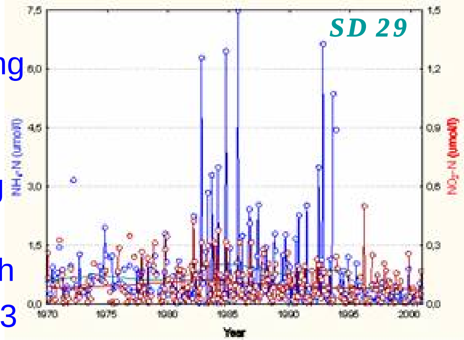
The Baltic Sea

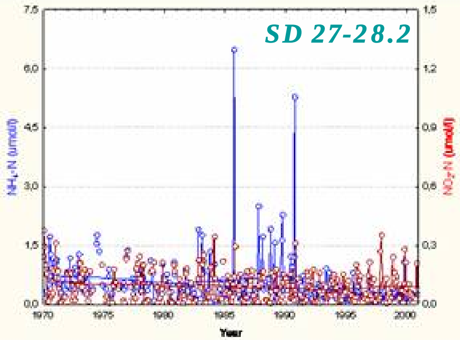
12. Ammonium

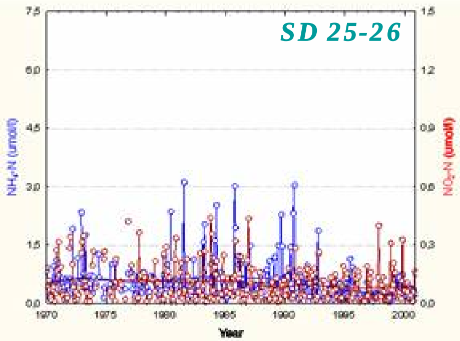
- runoff induced, direct long term control evident
- parallel short term changes during high/low runoffs conflicting and unclear
- model fits better to describe long term trends in ammonium
- highest values measured at north
- high ammonium periods: 1971-73 and 1987-88
- low ammonium periods: 1996-97 and 1998-00 (late years)
- missing values 21,0%

13. Nitrite

- runoff induced, direct long term control not evident
- no obvious parallel short term changes during high/low runoff periods
- missing values 22,9%







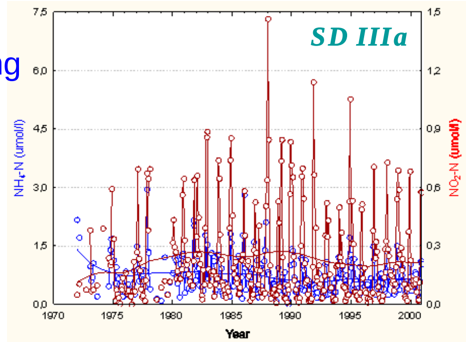
The North Sea

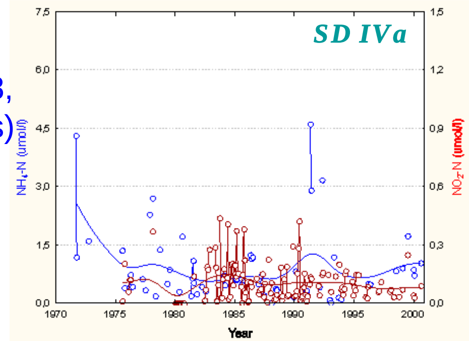
12. Ammonium

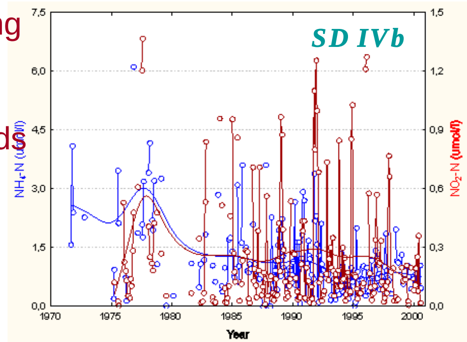
- runoff induced, direct long term control potential
- parallel short term changes during high/low runoffs conflicting and unclear
- model fits better to describe long term trends in ammonium
- highest values measured around Dogger Bank, lowest around Shetland
- high ammonium period: 1971-73
- low ammonium periods: 1987-88, 1996-97 and 1998-00 (late years)
- missing values 51,3%!

13. Nitrite

- runoff induced, direct long term control not evident
- parallel short term changes during high/low runoffs neither obvious, although low nitrite measured generally during low runoff periods and v.v.
- lowest values around Shetland
- results pronounced strongly to Skagerrag
- missing values 42,7%!





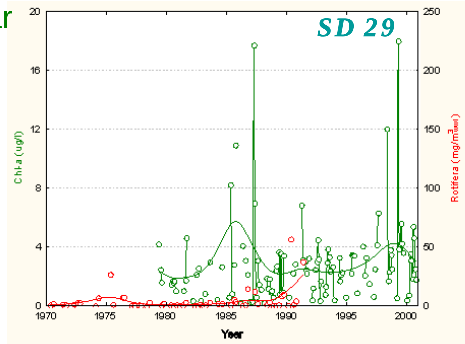


Results:

The Baltic Sea

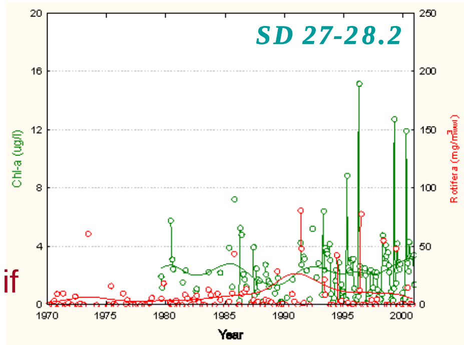
14. Chlorophyll

- runoff induced, direct long term control probable but not very clear
- no obvious parallel short term changes during high/low runoff periods
- low chlorophyll period: 1987-88
- missing values 65,8%!



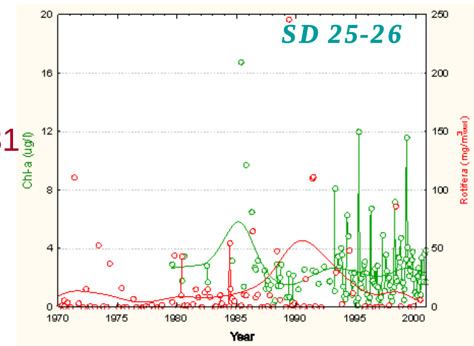
15. Phytopl. Color Index

- No model (missing data)



16. Rotifera

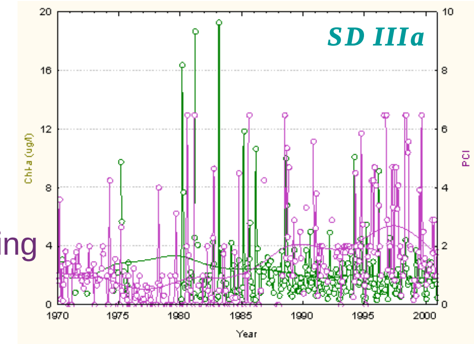
- runoff induced, direct long term control potential and pronounced if existing (missing first 10 years)
- no obvious parallel short term changes during high/low runoff periods
- low Rotifer biomass periods: 1981 and 1987-88 (high saline years)
- missing values 75.4%!



The North Sea

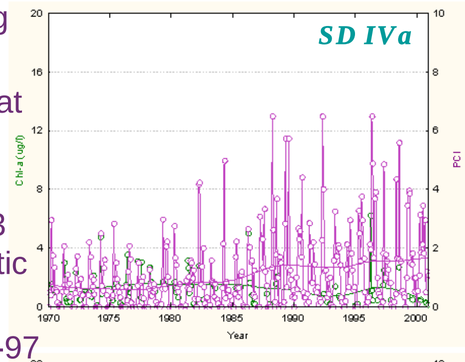
14. Chlorophyll

- No model (too scarce data)



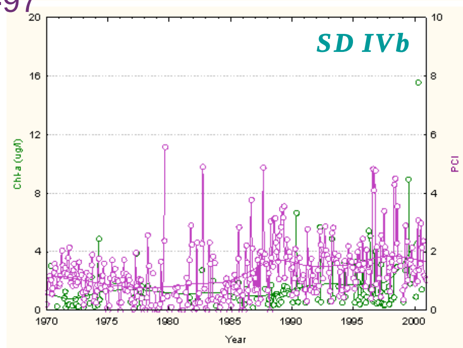
15. Phytopl. Color Index

- runoff induced, direct long term control highly potential
- parallel short term changes during high/low runoffs conflicting and unclear
- model fits better to describe long term trends in PCI
- highest color indices measured at Skagerrag, lowest around Shetland
- high PCI periods: 1976, 1971-73 and 1981 (early years when Baltic runoffs generally low)
- low PCI periods: 1987-88, 1996-97 and 1998-00 (late years when Baltic runoffs generally high)
- missing values 11,3%



16. Rotifera

- No model (missing data)



Results:

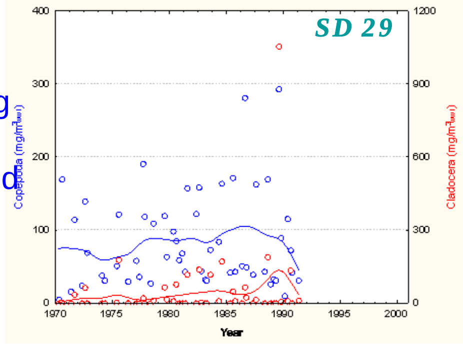
The Baltic Sea

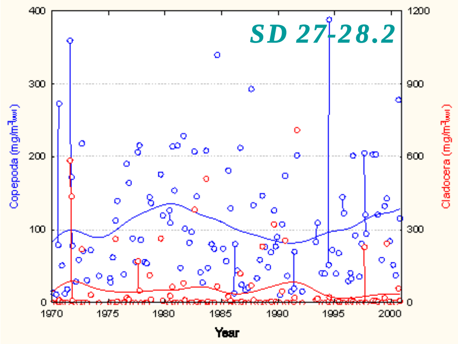
17. Copepoda

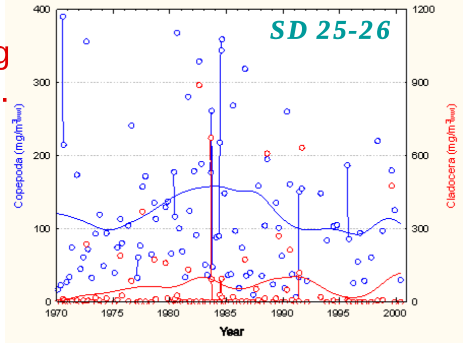
- runoff induced, direct long term control noticeable (although missing late years in SD29)
- parallel short term changes during high/low runoffs not very clear, although low biomasses measured during low runoff periods and v.v.
- model describes sort of "mixed" long/short term controlling effect
- high biomass periods: 1981 and 1987-88 (high runoff years)
- low biomass periods: 1976 and 1996-97 (low runoff years)
- missing values 75,4%!

18. Cladocera

- runoff induced, direct long term control noticeable (although missing late years in SD29)
- parallel short term changes during high/low runoffs also obvious, e.g. low biomasses measured during low runoff periods and v.v.
- high biomass period: 1987-88 (high runoff years), low biomass periods: 1976 and 1996-97 (low runoff years)
- missing values 75,4%!







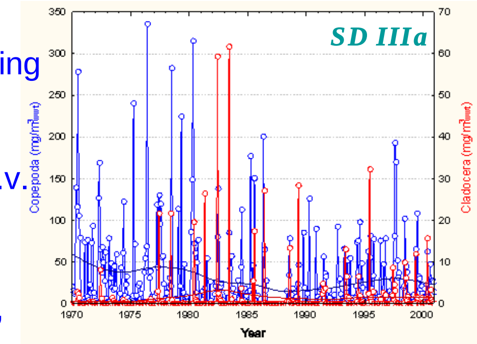
The North Sea

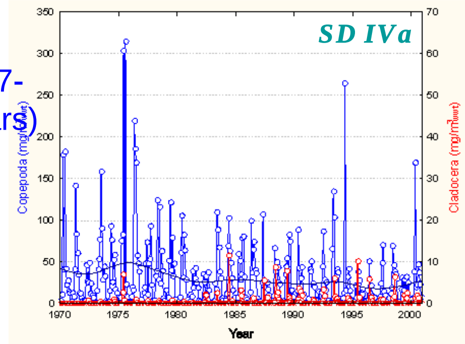
17. Copepoda

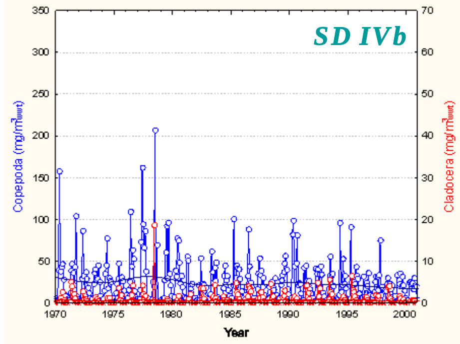
- runoff induced, inverse long term control evident
- parallel short term changes during high/low runoffs highly obvious, e.g. high biomasses measured during low runoff periods and v.v.
- highest biomass at Skagerrag, lowest around Dogger Bank
- high biomass periods: 1971-73, 1976 and 1996-97 (low runoff years)
- low biomass periods: 1981, 1987-88 and 1998-00 (high runoff years)
- missing values 8,8%

18. Cladocera

- runoff induced, direct long term control not evident
- no obvious parallel short term changes during high/low runoffs, either
- highest biomass measured at Skagerrag
- low biomass period: 1971-73
- missing values 8.8%







Conclusions:

1. The answer to the question presented: *YES!* Baltic freshwater runoffs can really influence on the North Sea surface marine system (depending on the variable, of course…)
2. In the Baltic the control is pronounced more to long term "trendsetting" regulation, whereas in the North Sea temporary, parallel short term control is more evident
   ⟶ *Major Baltic Outflows (MBI vs. MBO)?*
3. Any potential to explain observations about North Sea *Regime Shift* in late 80's?

Forthcoming peer reviewed publication plan:

1. the present work will produce 1-3 papers
2. one paper is presently under revision
3. three papers under construction (in addition to point one)
4. one already published

Relevance of the results for policy and stakeholders:

1. no direct potential of practical applications
2. increases the basic understanding of the relevance of Baltic runoffs to ecology/economy in much more larger area…