RESILIENCE | NORTHEAST ATLANTIC MARINE ECOSYSTEMS

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University of Oslo

Instituto Español de Oceanografía

OUTLINE | of the talk

1. **intro**
   definition
2. **methods**
   Integrated Resilience Assessment
3. **study area & data**
   4 ecosystems, all main components, several decades
4. **results**
   North Sea | Baltic Sea | Barents Sea | Iceland Seas
   trafficlight plots, PCA, landscapes
5. **conclusions**

DEFINITION

Engineering resilience

- *The time required for a system to return to an equilibrium or steady state following a perturbation*

Gunderson (2000) *Annu Rev Ecol Syst*

Ecological resilience

- *The capacity of a system to absorb disturbance to stay in the same basin of attraction*

Walker *et al.* (2004) *Ecology and Society*

- *The magnitude of change that a system can experience without shifting into an alternate stable state*

Gunderson (2004)

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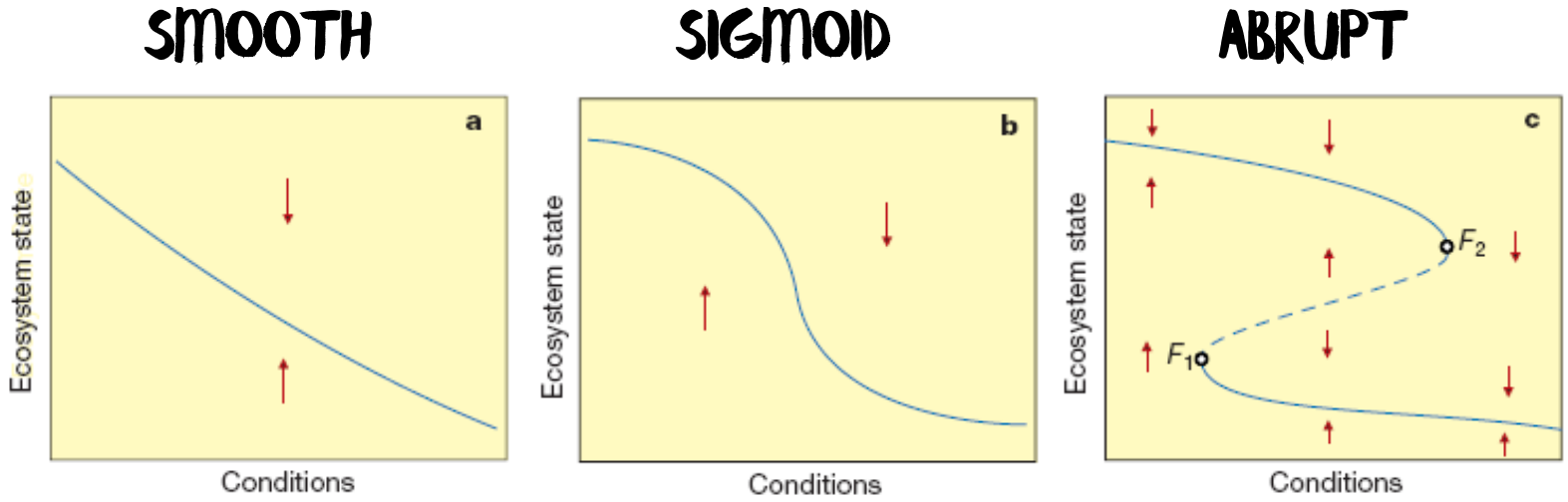
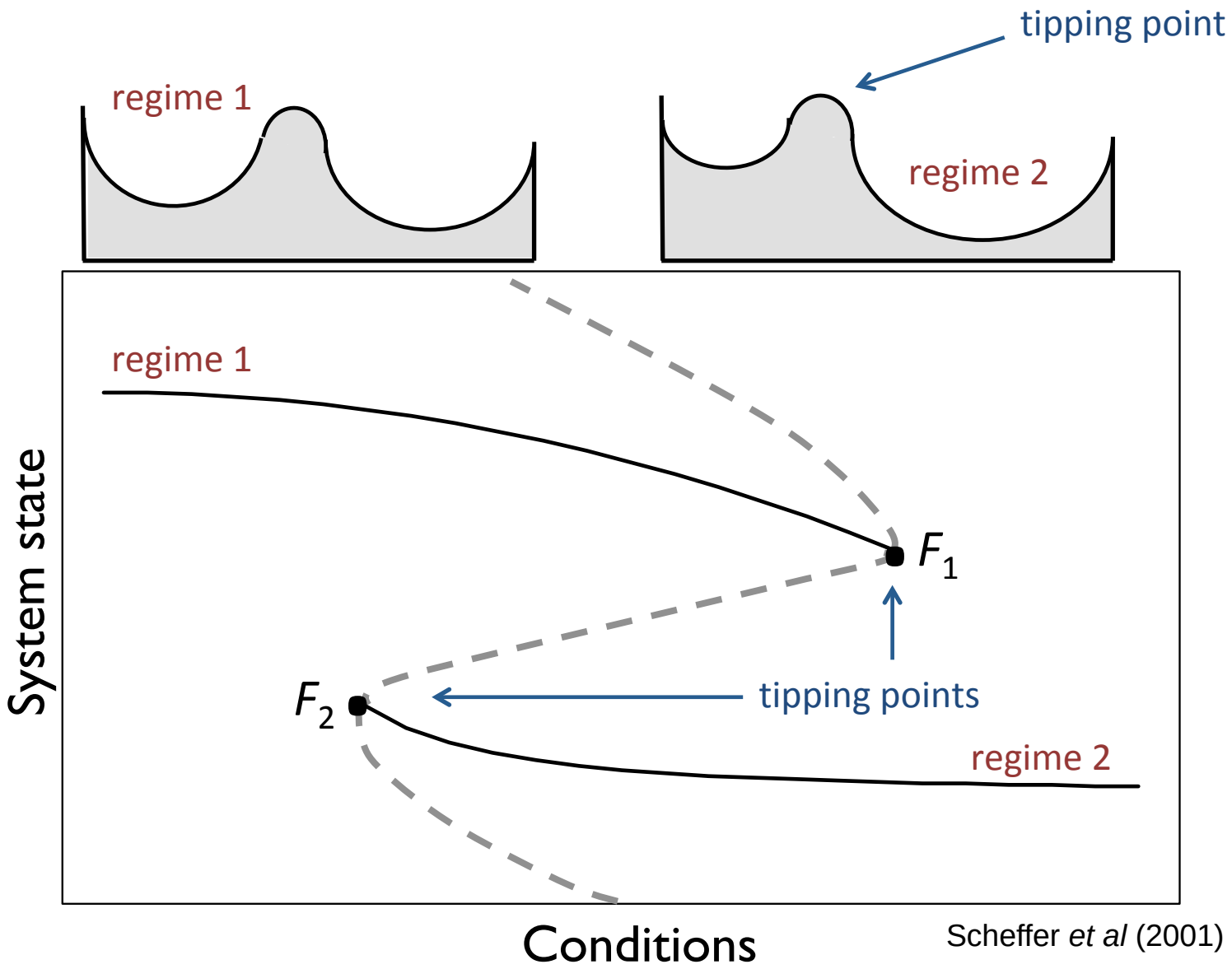
ECOSYSTEM RESPONSE TO STRESSORS



Three main ways in which ecosystems can respond to a gradual change in an external condition: (i) smooth continuous way, (ii) more responsive over certain ranges of conditions and (iii) abrupt changes between alternative stable states separated by an unstable equilibrium.

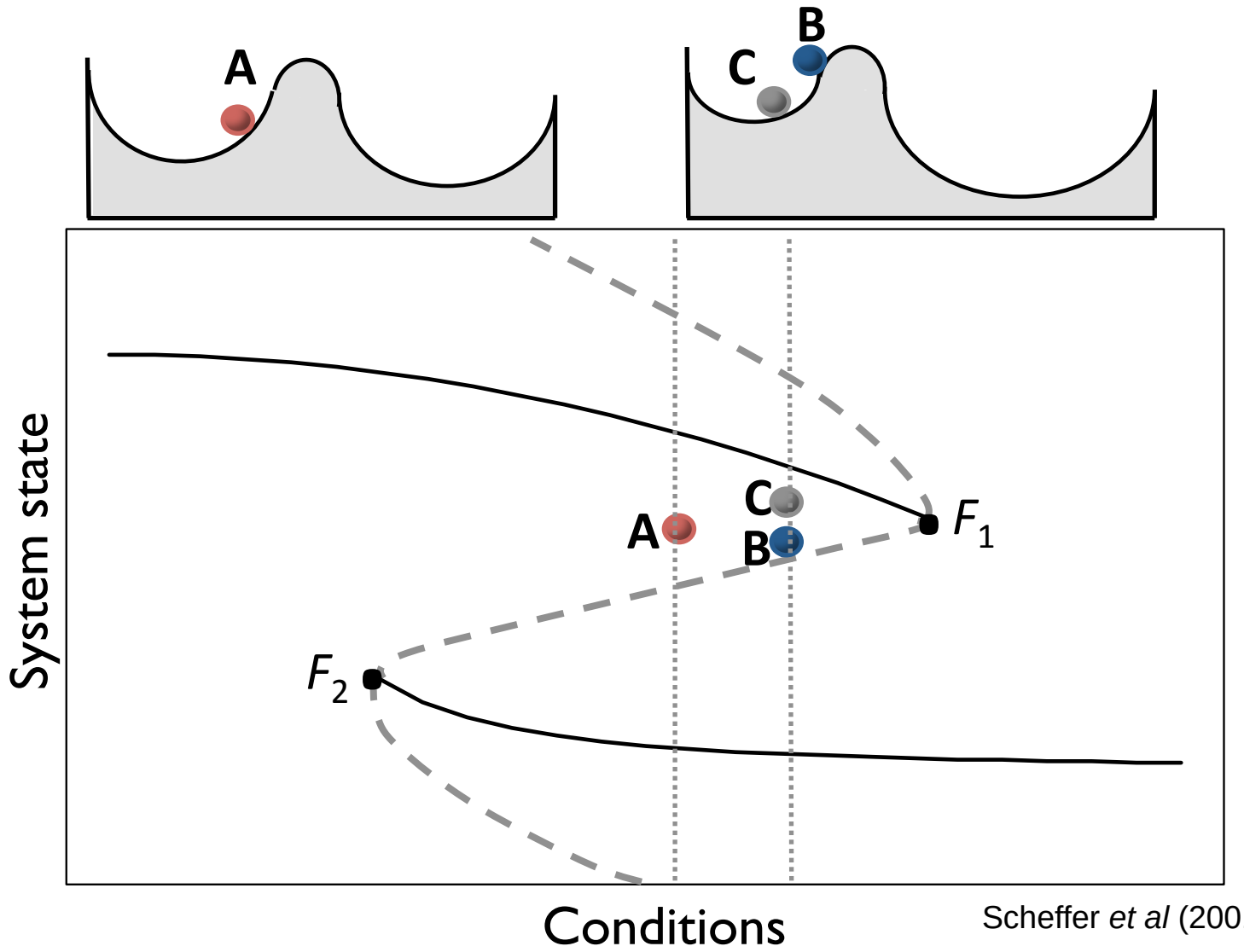
Scheffer *et al* (2001) *Nature*

QUANTIFYING RESILIENCE



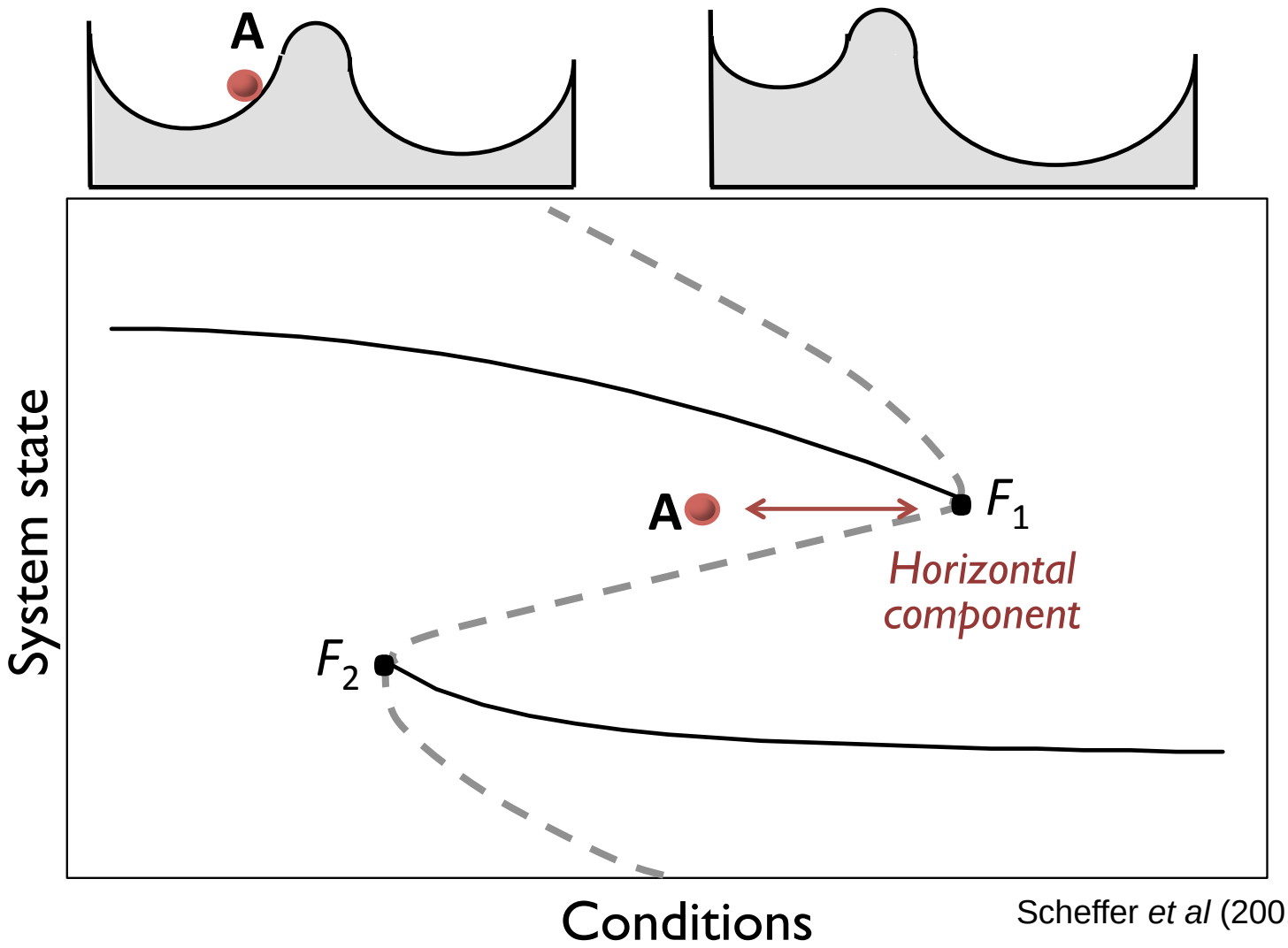
Scheffer *et al* (2001) *Nature*

QUANTIFYING RESILIENCE



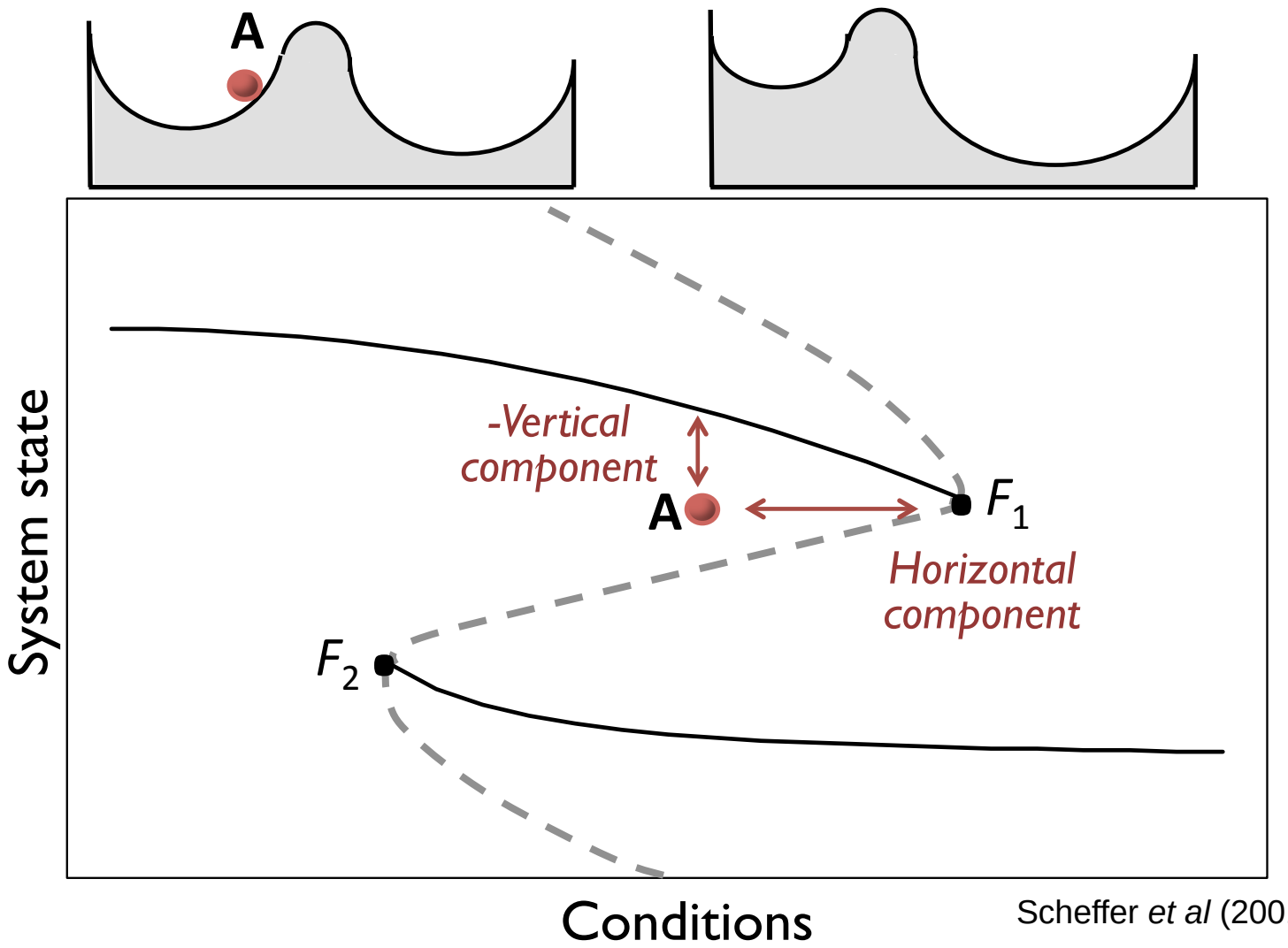
Scheffer *et al* (2001) *Nature*

QUANTIFYING RESILIENCE



Scheffer *et al* (2001) *Nature*

QUANTIFYING RESILIENCE



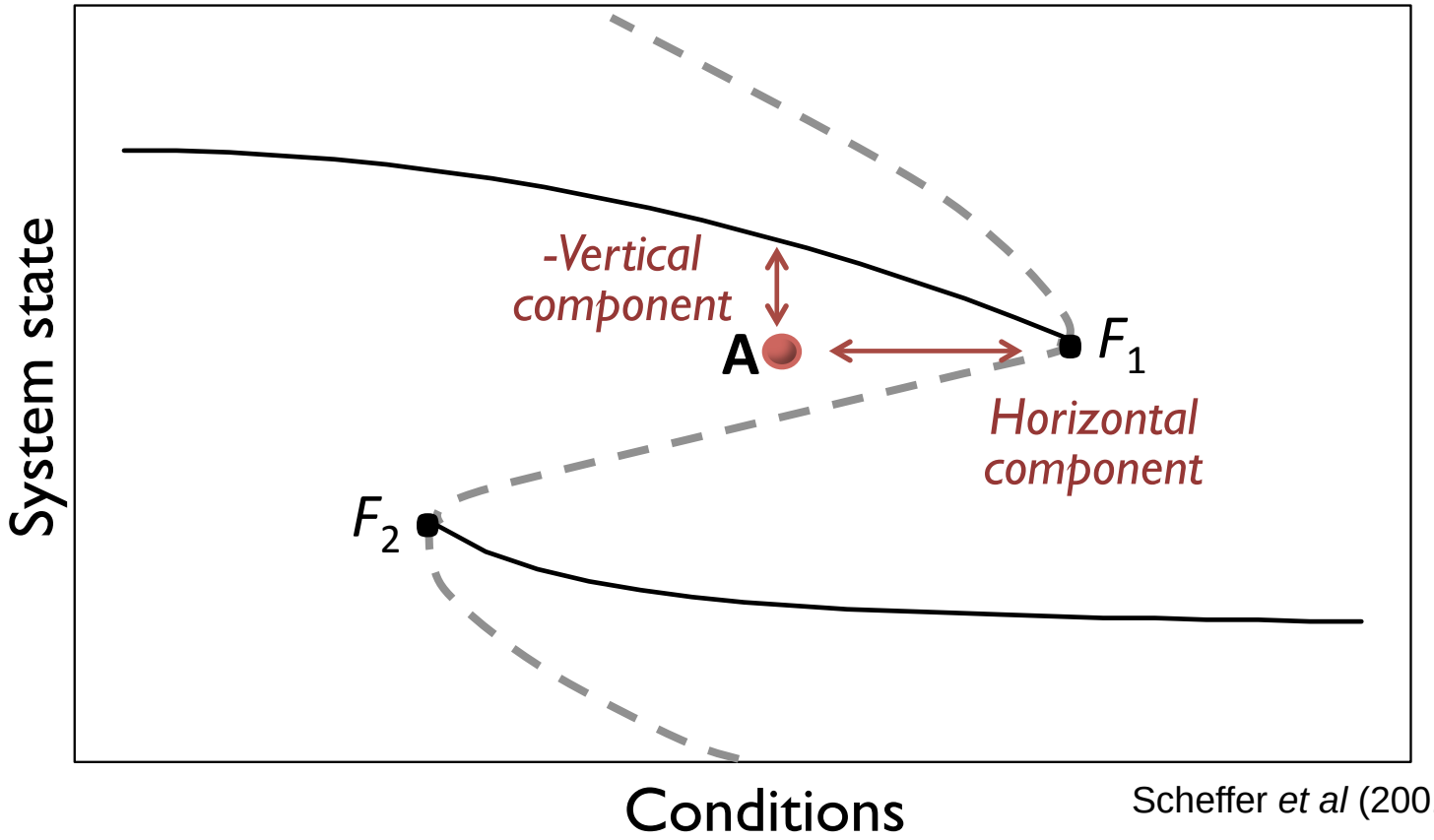
Scheffer *et al* (2001) *Nature*

QUANTIFYING RESILIENCE

Resilience =

Horizontal component + Vertical component

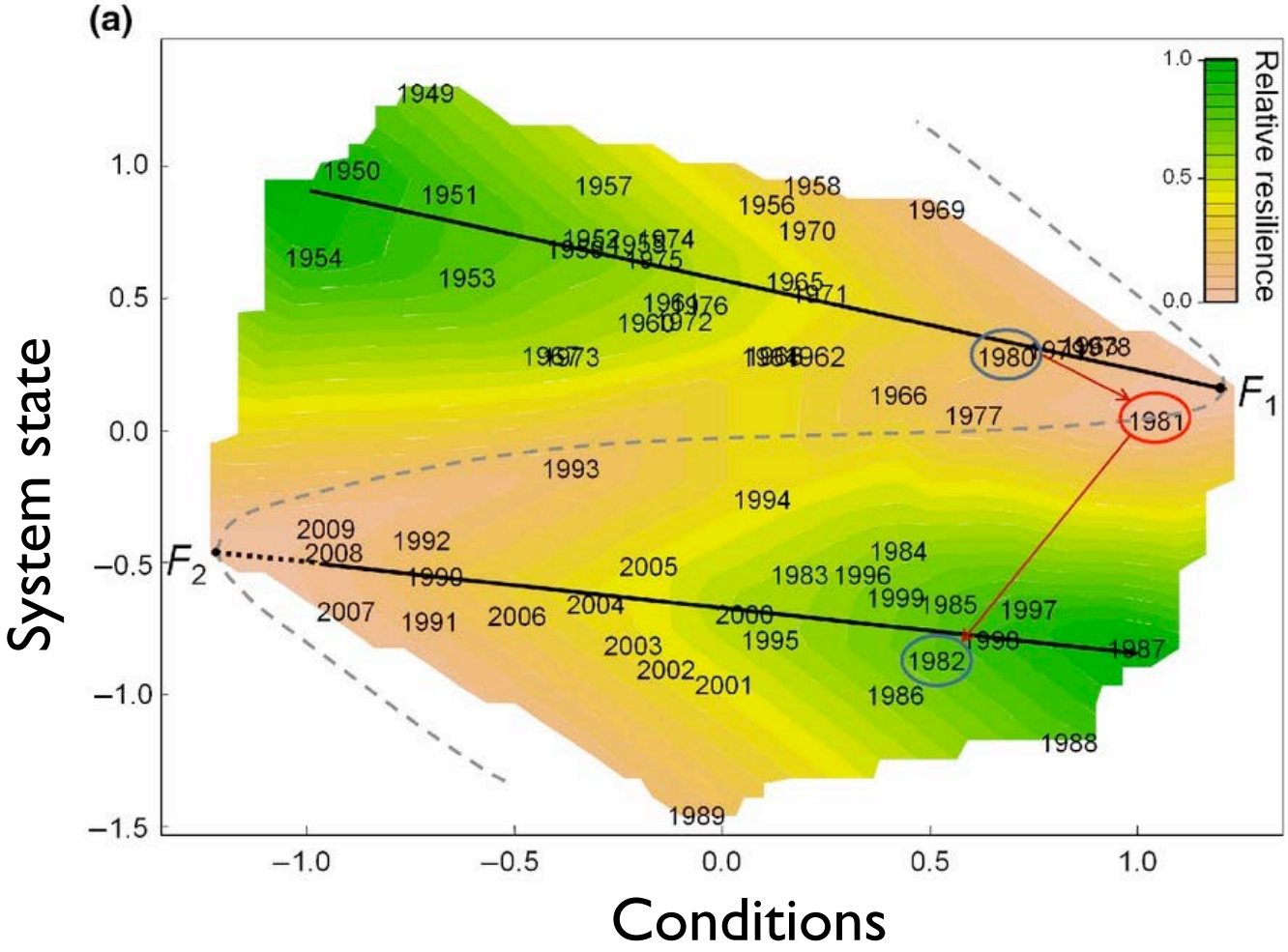
Vasilakopoulos & Marshall (2015) *Global Change Biol*



Scheffer *et al* (2001) *Nature*

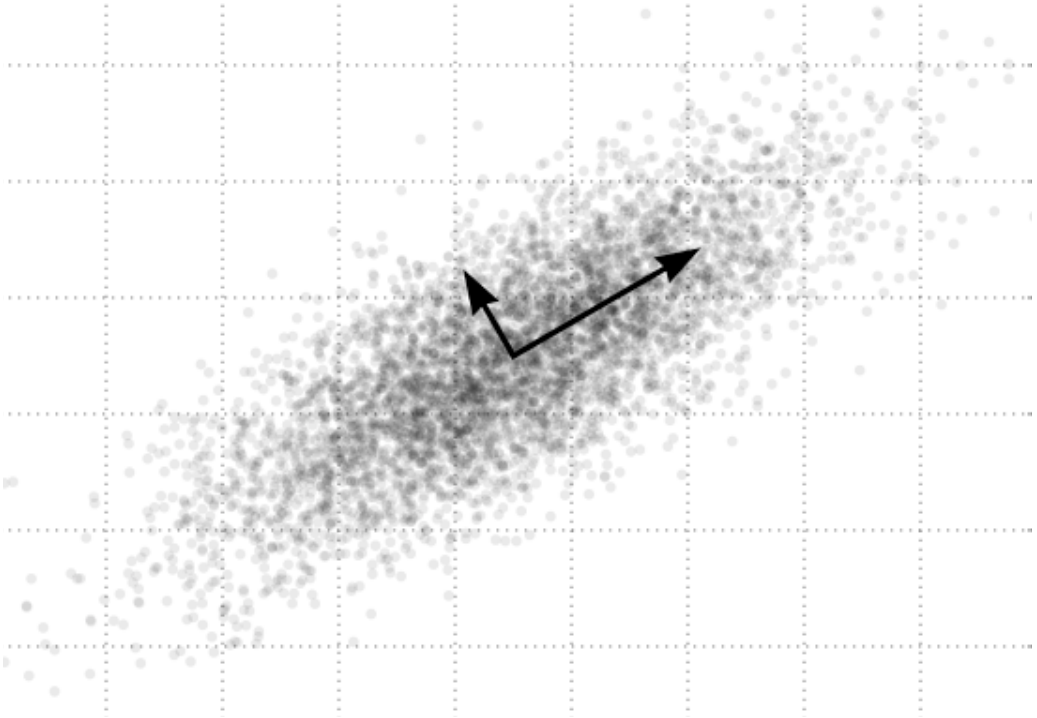
QUANTIFYING RESILIENCE

Vasilakopoulos & Marshall (2015) applied this method to Barents Sea cod population. By interpolating the annual resilience values, a folded stability landscape was fit.



INTEGRATED RESILIENCE ASSESSMENT

1) Reduce complexity through multivariate analysis (PCAs)



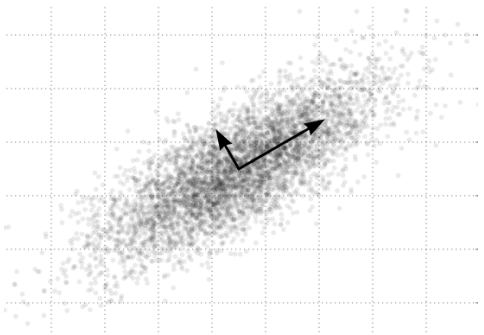
Vasilakopoulos *et al.* (2017) *Scientific Reports*

INTEGRATED RESILIENCE ASSESSMENT

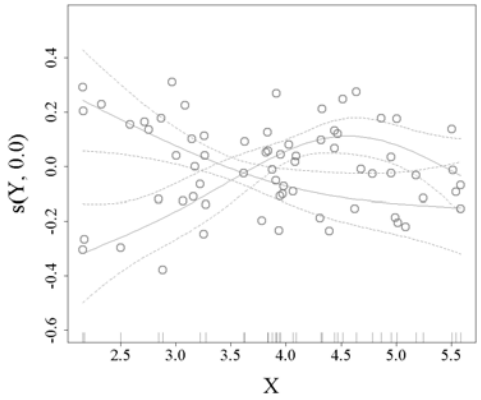
1) Reduce complexity through multivariate analysis (PCAs)

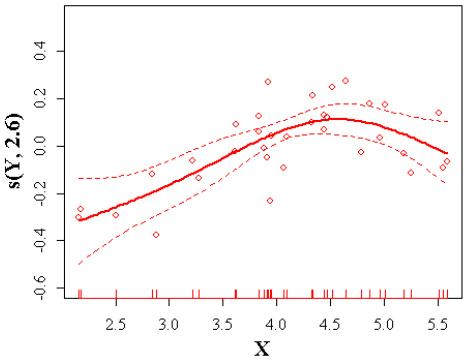
2) Non-additive modelling to investigate possible nonlinear system-stressor relationships (e.g. tGAMs)

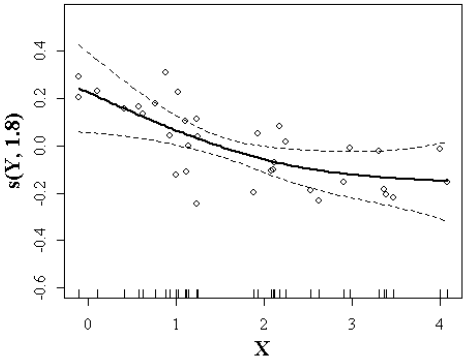
1)



2)







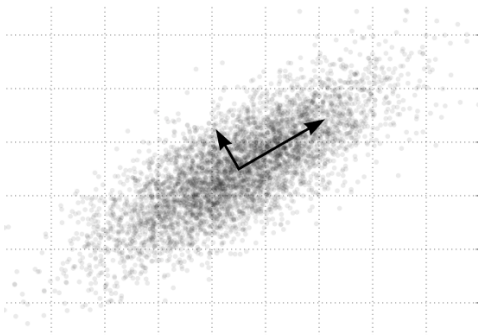
INTEGRATED RESILIENCE ASSESSMENT

1) Reduce complexity through multivariate analysis (PCAs)

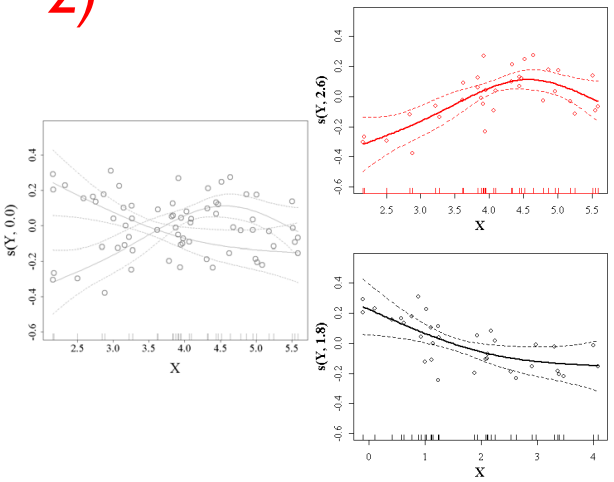
2) Non-additive modelling to investigate possible nonlinear system-stressor relationships (e.g. tGAMs)

3) Resilience assessment to build a folded stability landscape

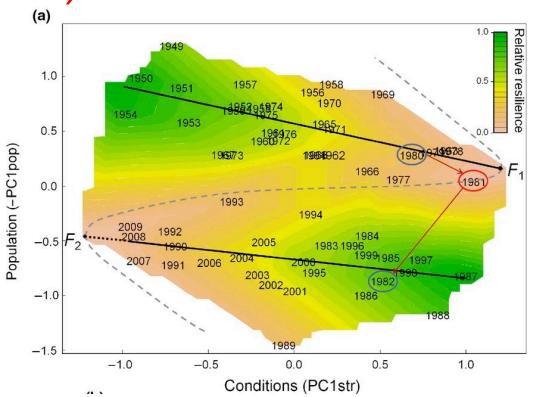
1)



2)



3)

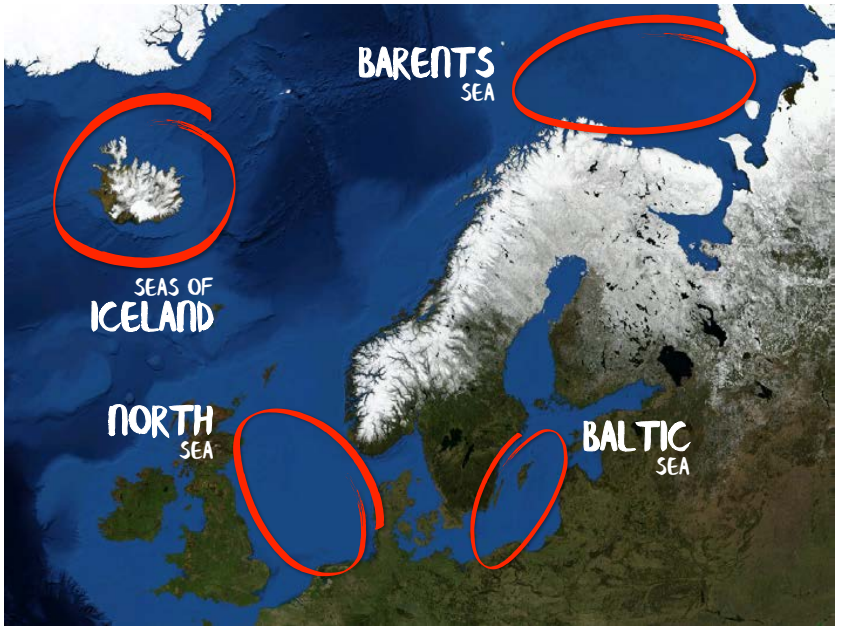


Vasilakopoulos *et al.* (2017) *Scientific Reports*

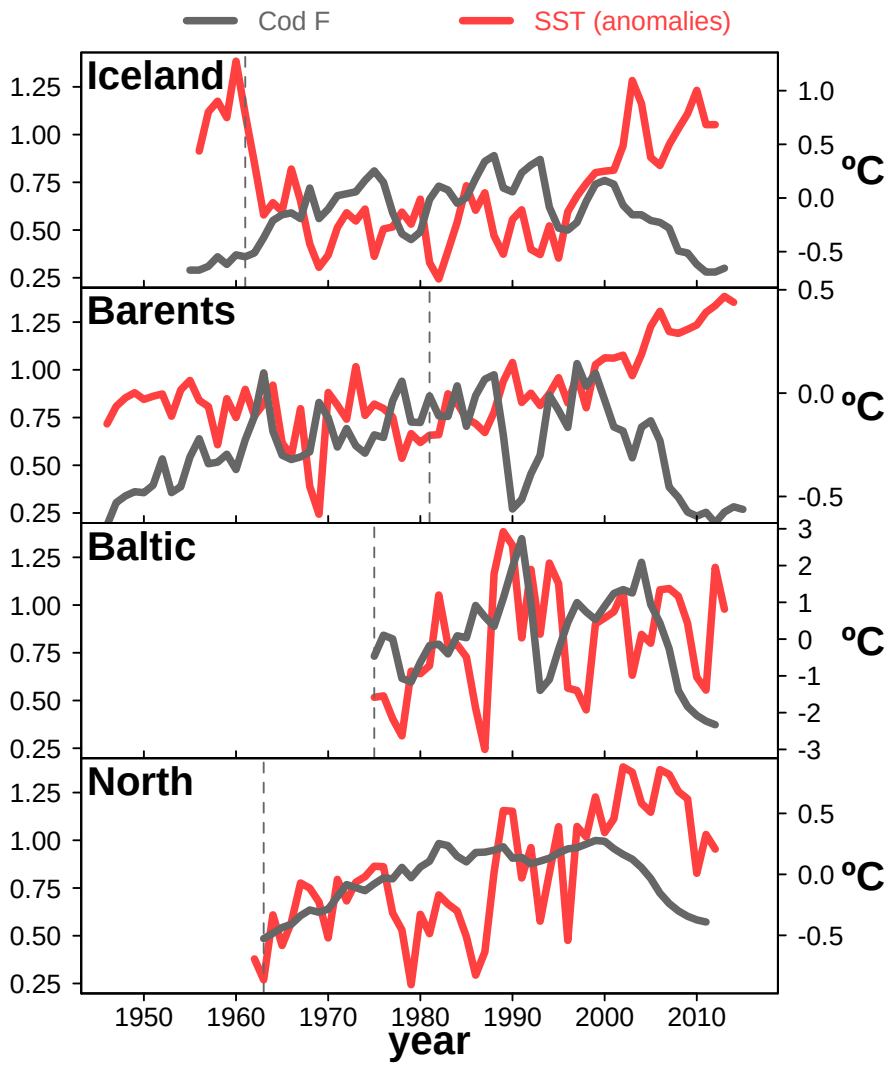
study area | NORTHEAST ATLANTIC

stressors | warming
heavy fishing
(eutrophication)

gradients | temperature
connectivity
diversity
(salinity)

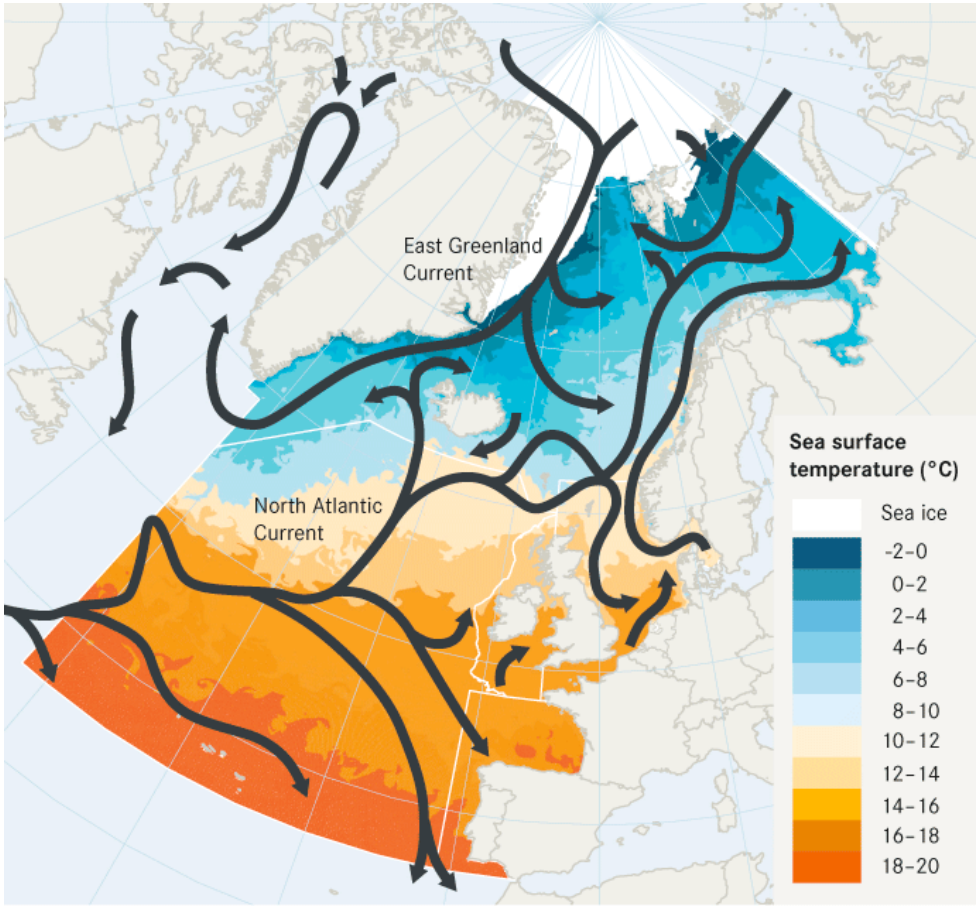


study area | STRESSORS



study area | GRADIENTS

Overall south-north temperature gradient (except Baltic Sea) and different degree of isolation from the almost enclosed Baltic Sea, partly enclosed North Sea to the open systems of Barents and Iceland Seas.



OSPAR commission

study area | DATA

STATE

fish

different
trophic levels

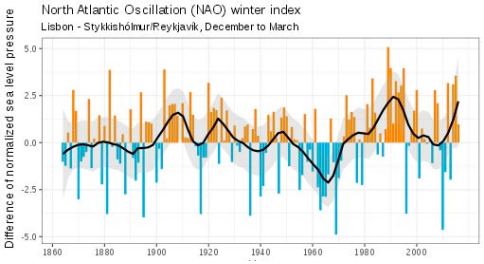
plankton

phytoplankton
zooplankton

STRESSORS

abiotic


fishing pressure
temperature
climatic indices
(nutrients)

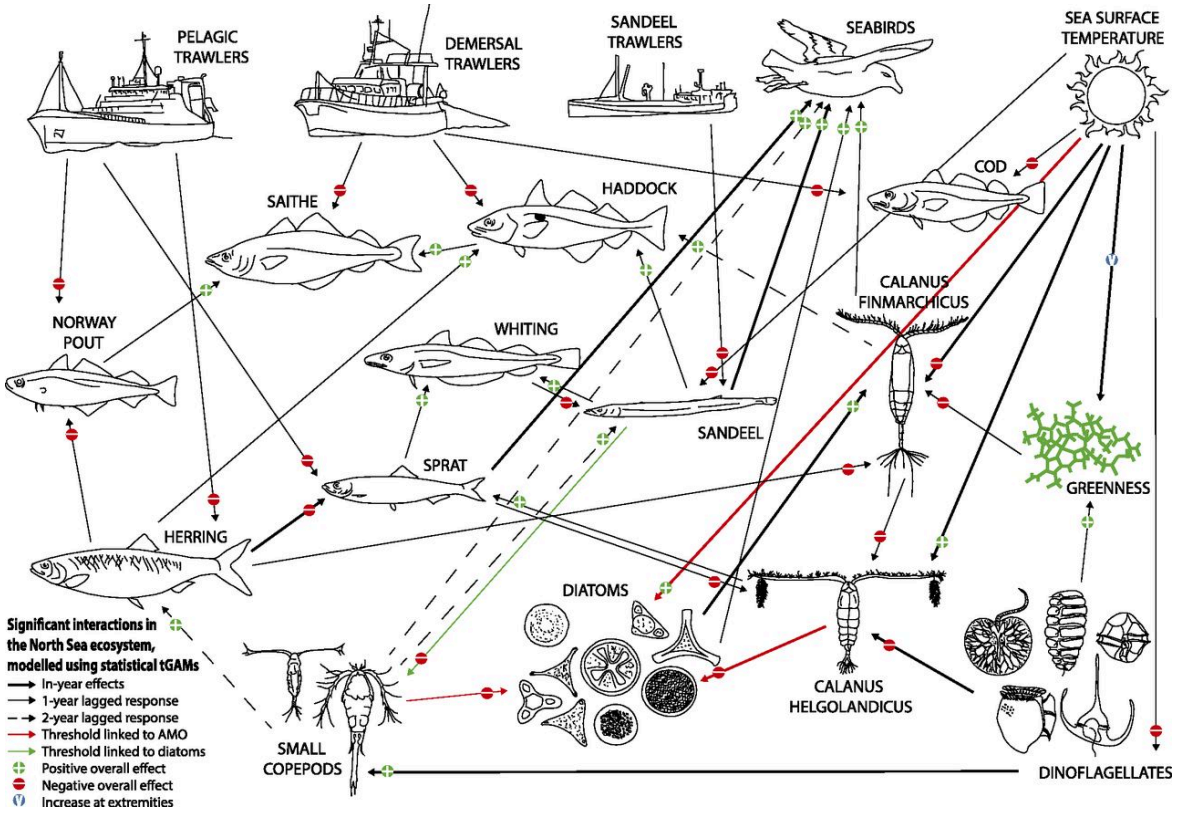


resolution

> 30 years
annual

OBJECTIVE

The aim is to provide a first holistic assessment of ecosystem resilience, including as many trophic levels and stressors as many (and relevant) as possible



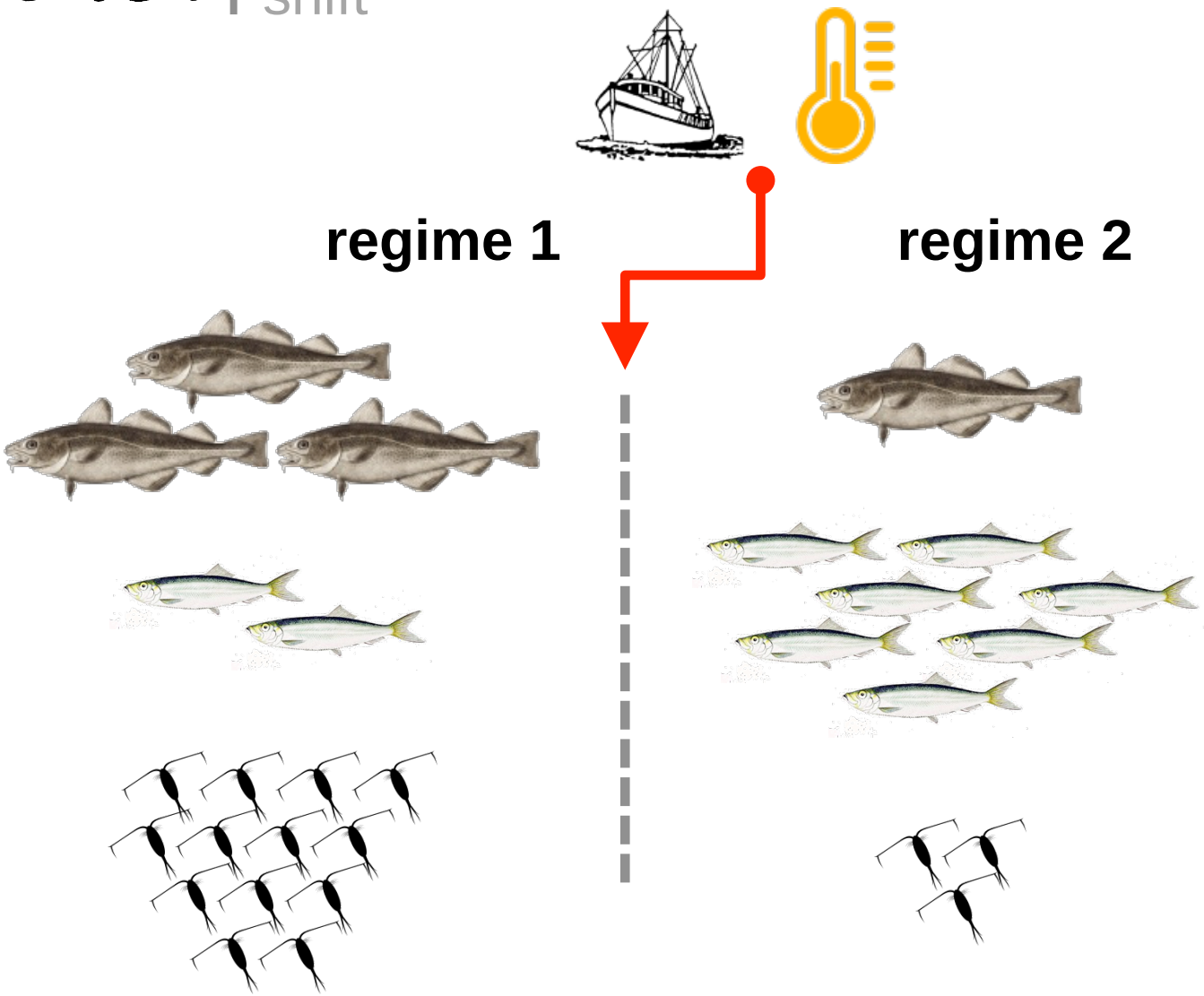
North Sea interaction web

Lynam, Llope *et al* (2017) *PNAS*

WHAT DO WE KNOW?

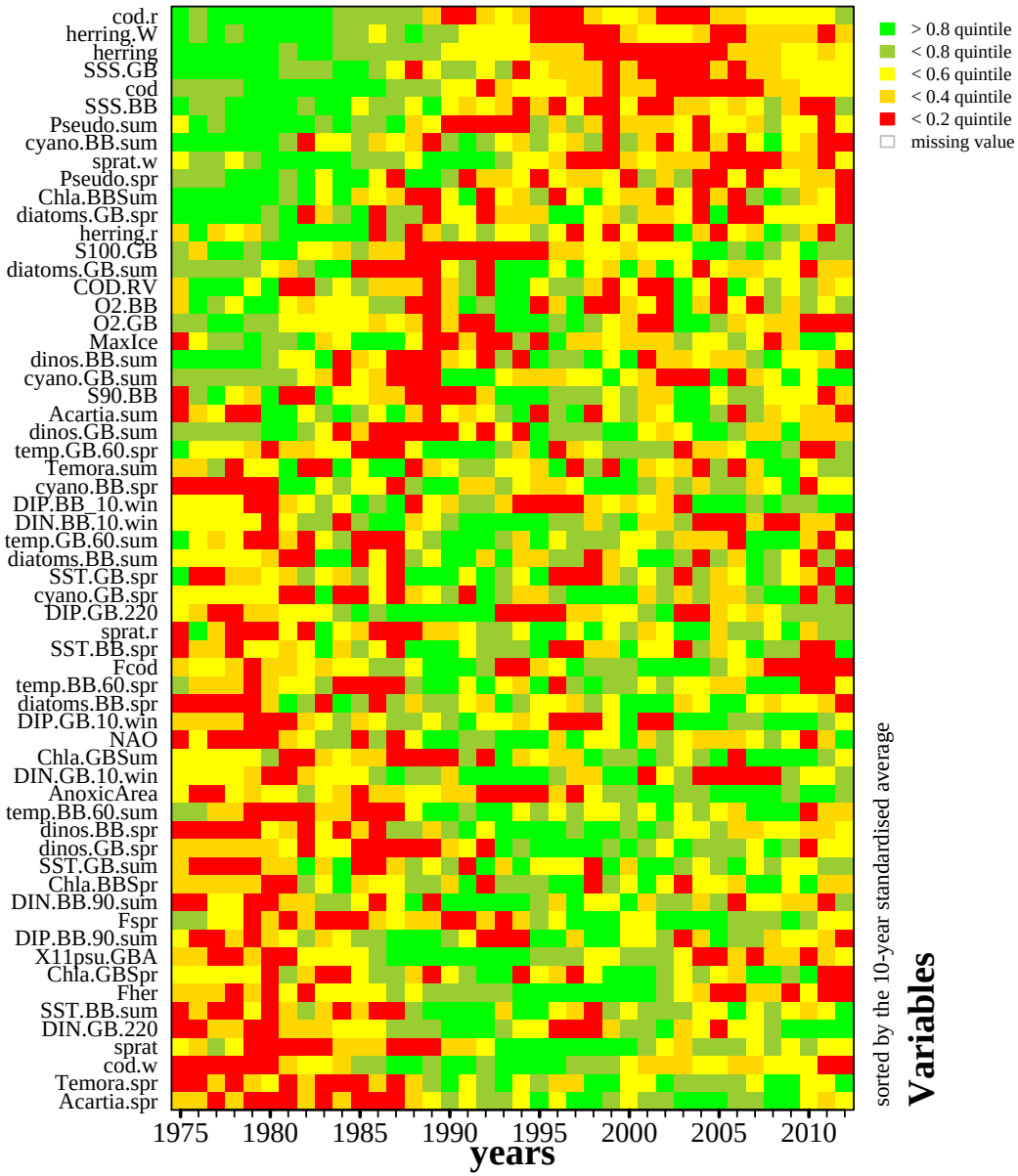

BALTIC
SEA

BALTIC SEA | regime shift

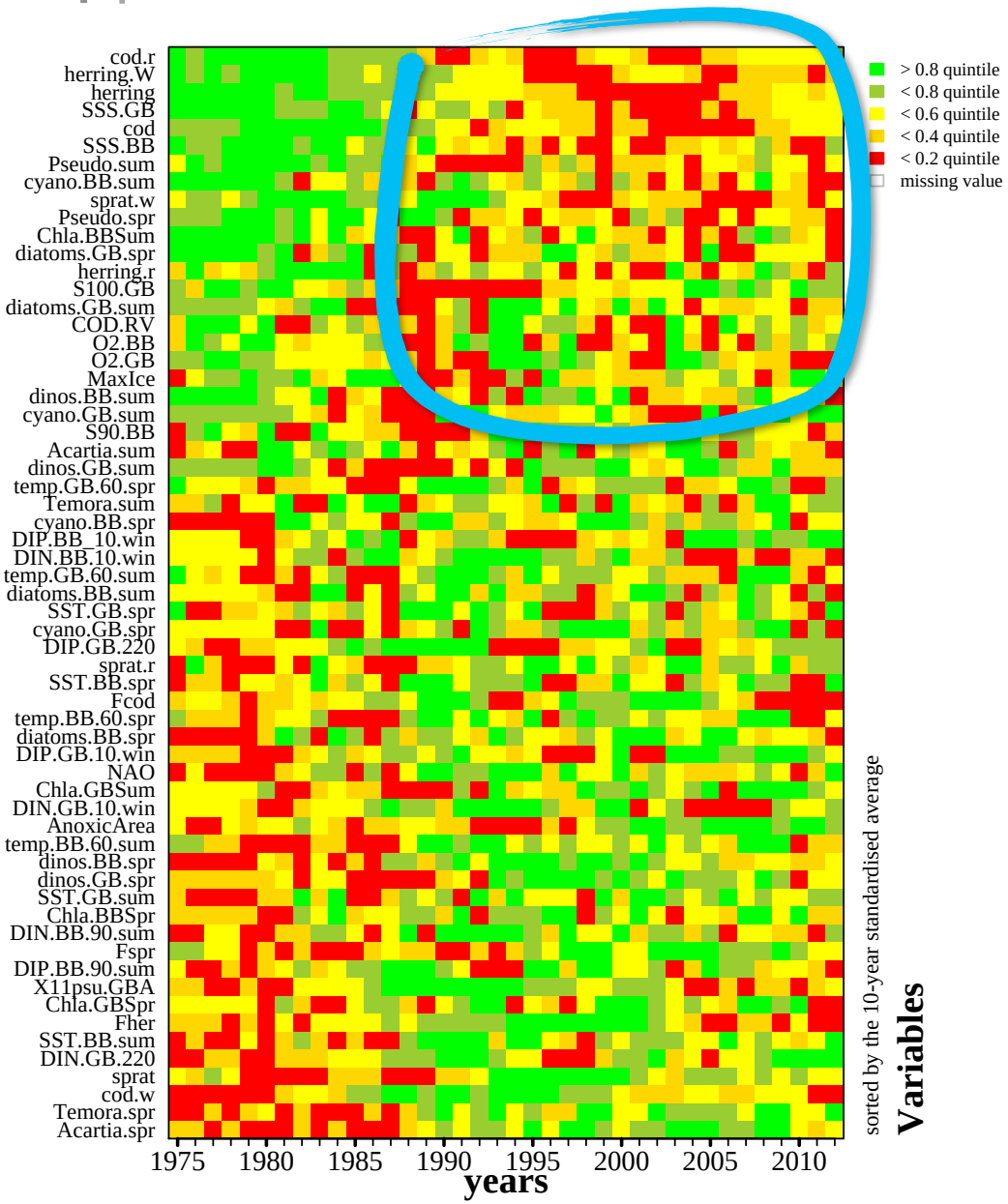


Möllmann *et al* (2009) *Global Change Biol*
Blenckner, Llope *et al* (2015) *Proc Royal Soc B*

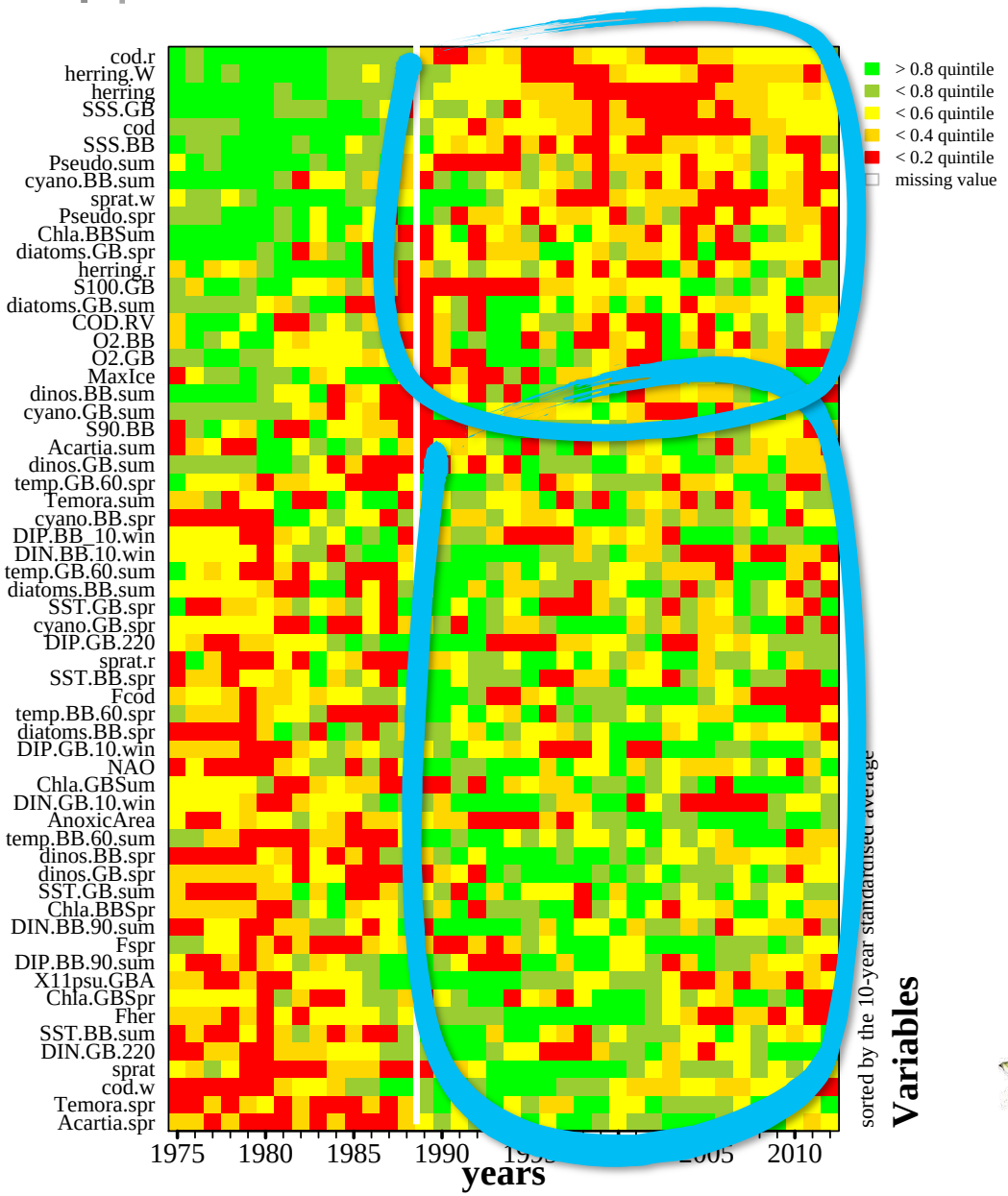
BALTIC SEA | trafficlight plots

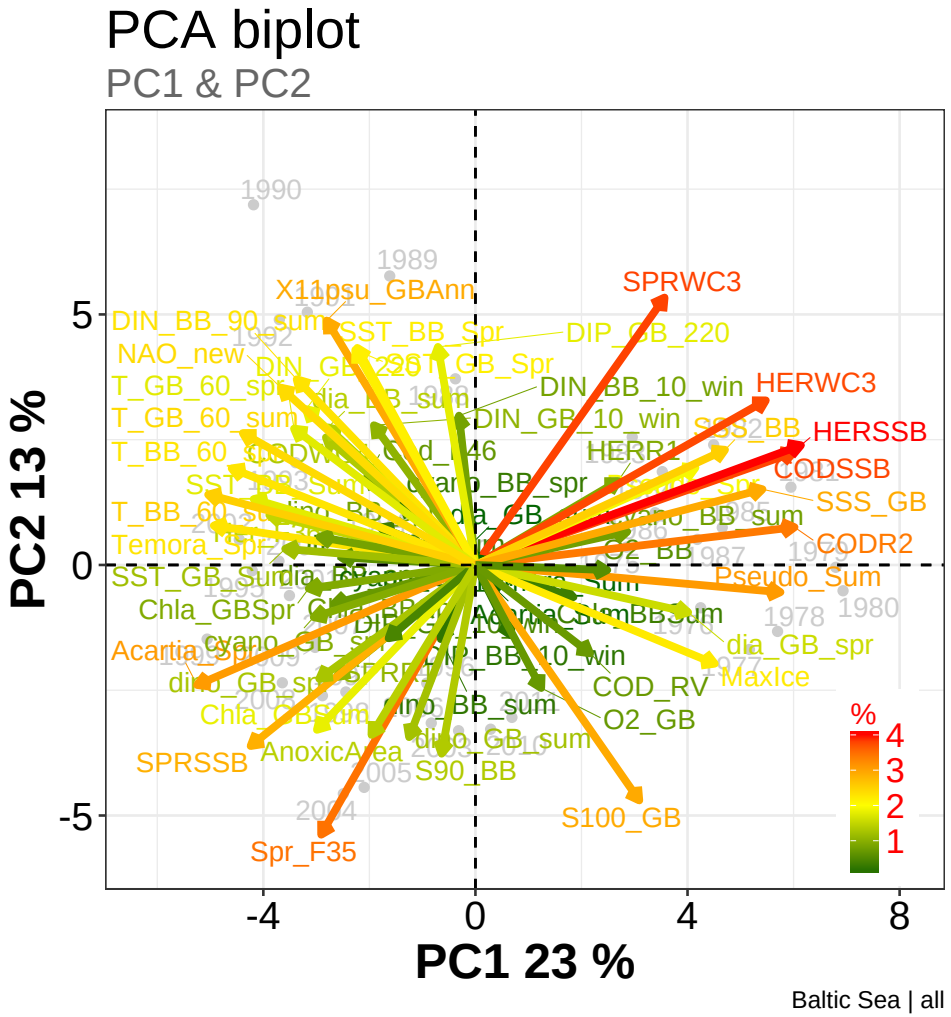


BALTIC SEA | trafficlight plots



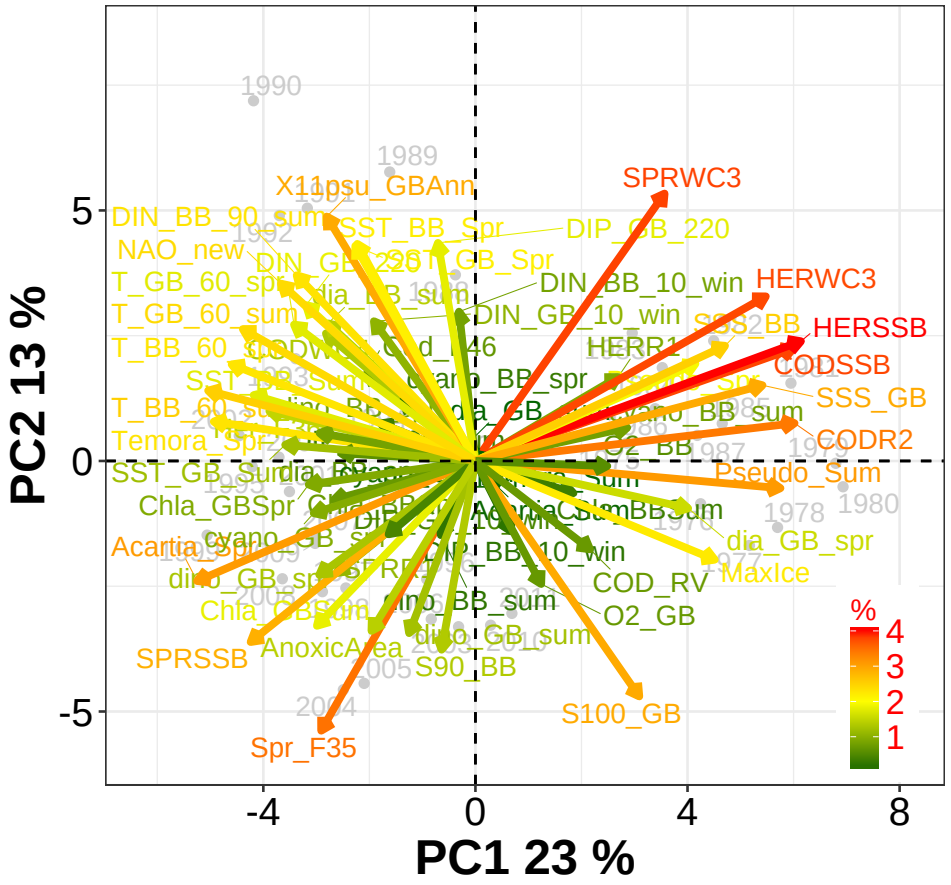
BALTIC SEA | trafficlight plot





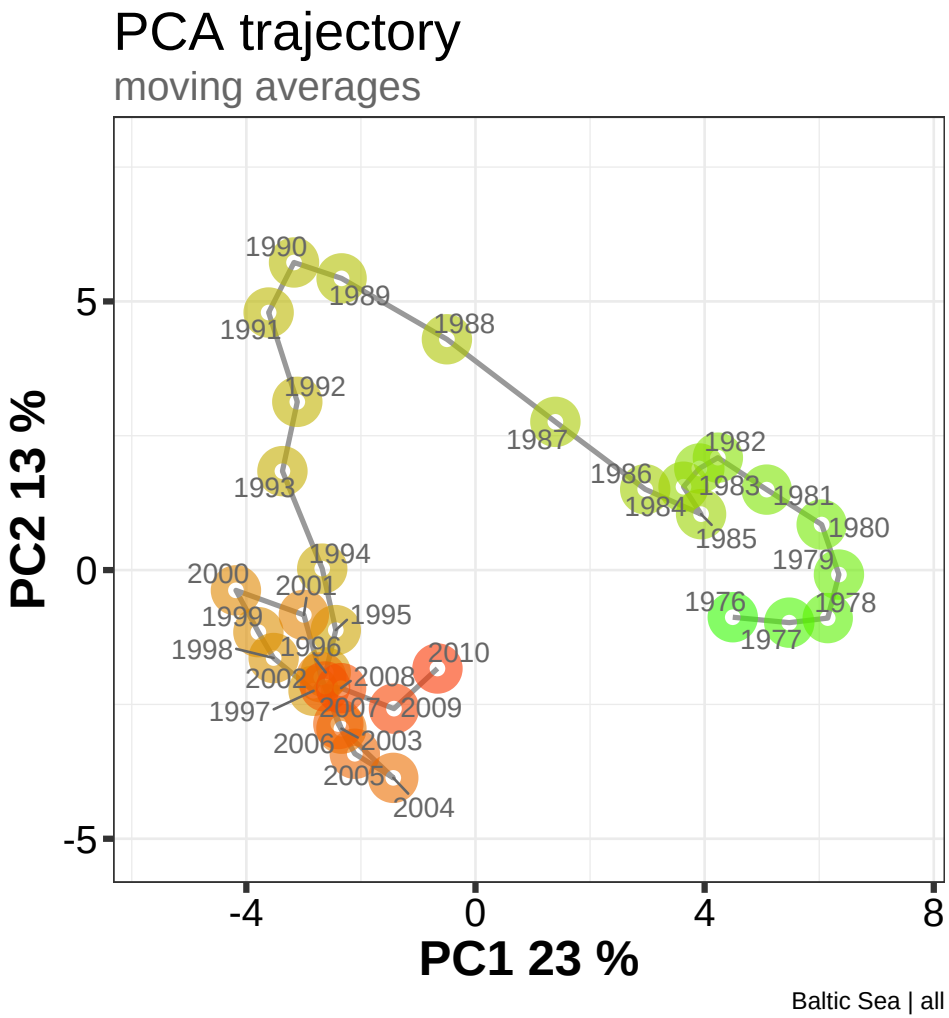
Baltic Sea | all

BALTIC SEA | PCA biplot | whole dataset

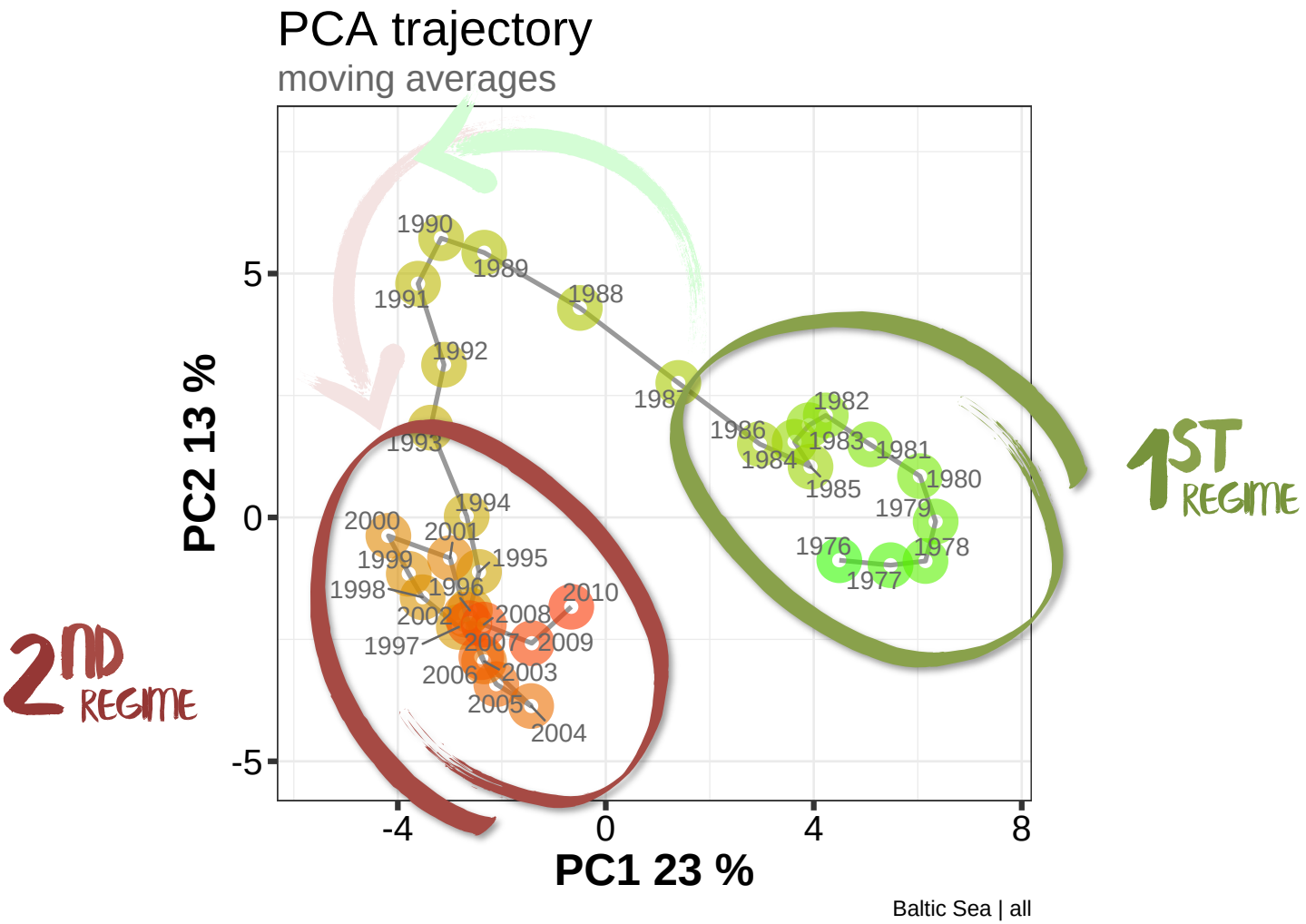


Baltic Sea | all

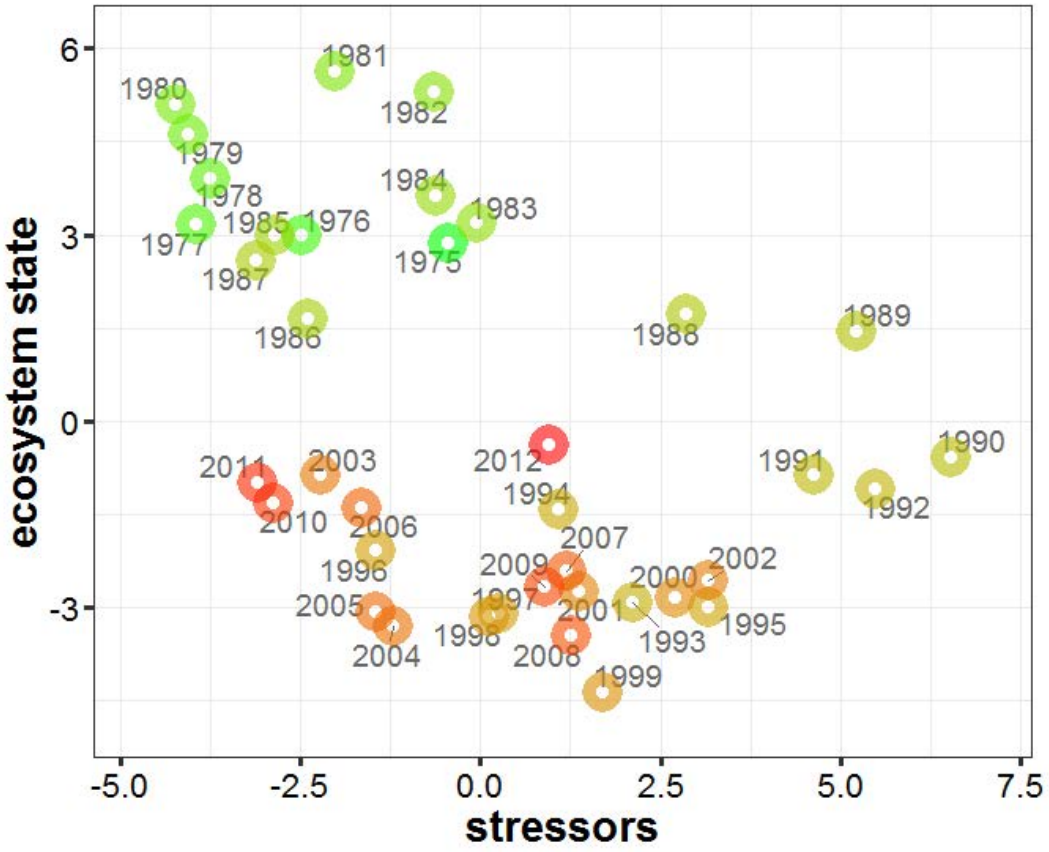
BALTIC SEA | PC analysis | whole dataset



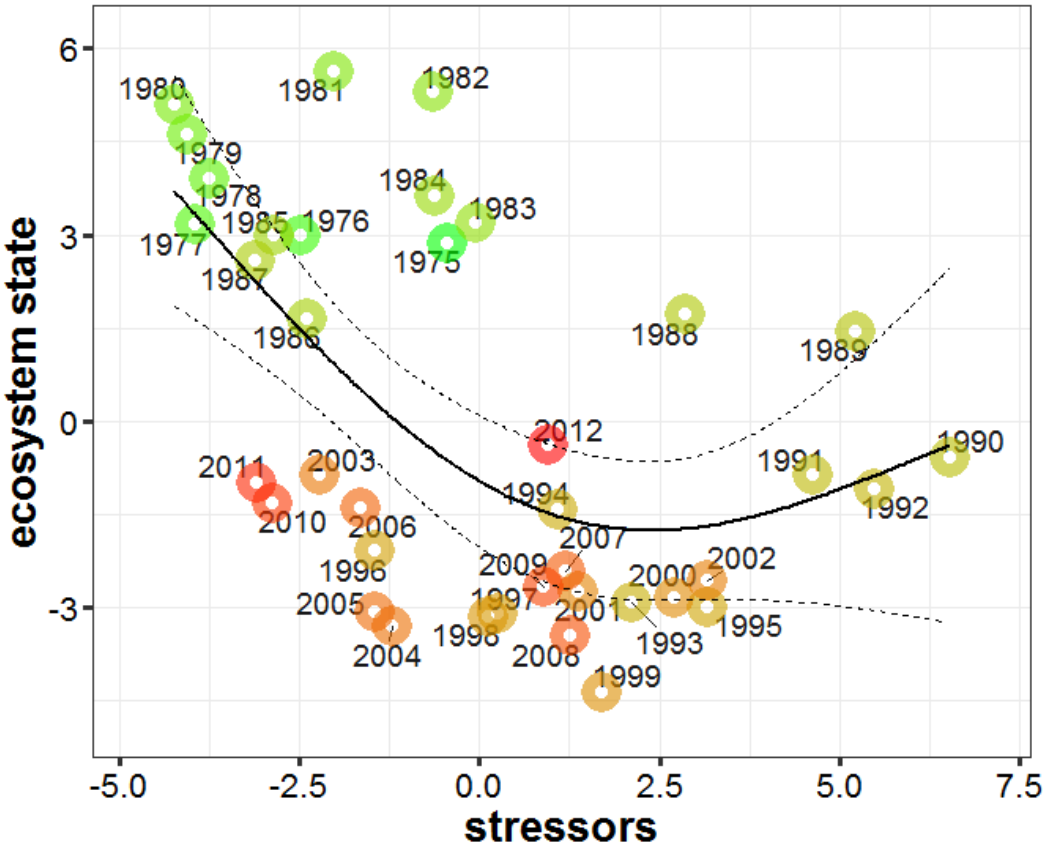
BALTIC SEA | PC analysis | whole dataset



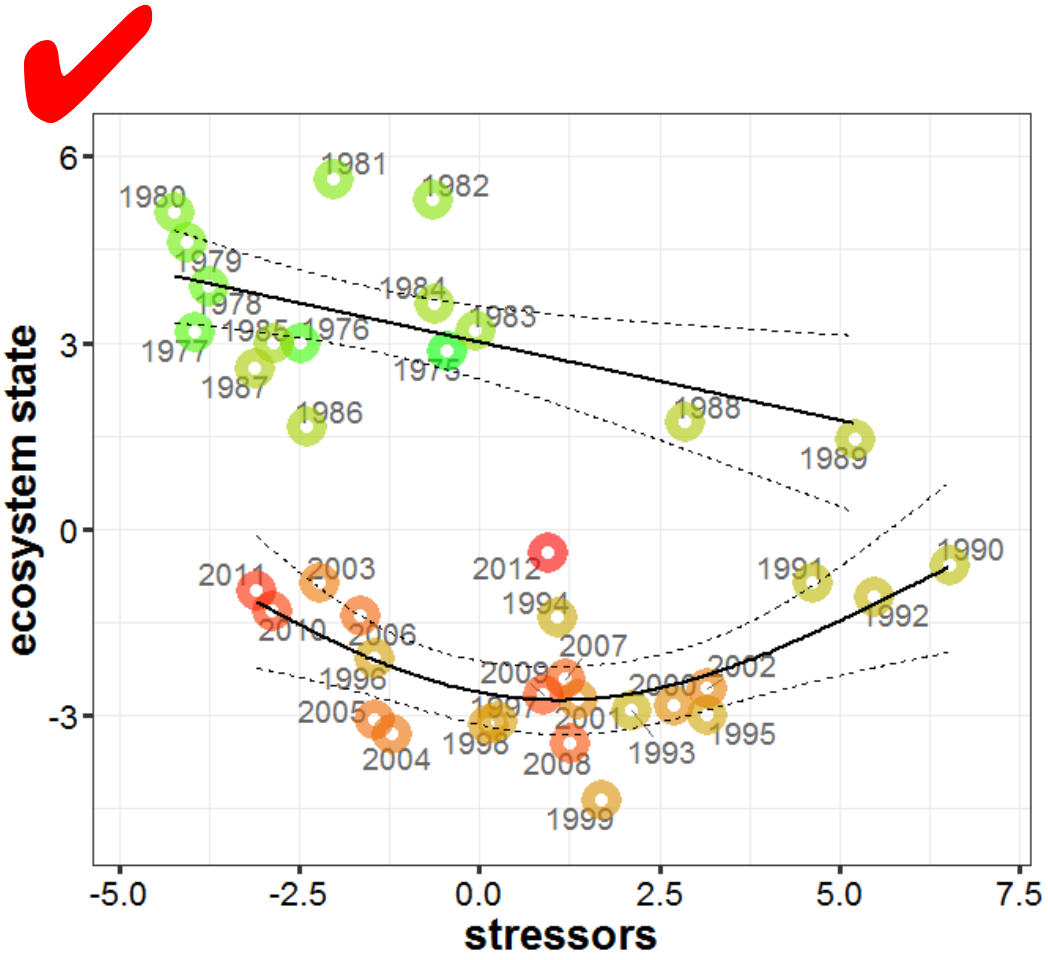
BALTIC SEA | PC analysis | state *vs.* stressors



BALTIC SEA | GAM additive modelling | state *vs.* stressors



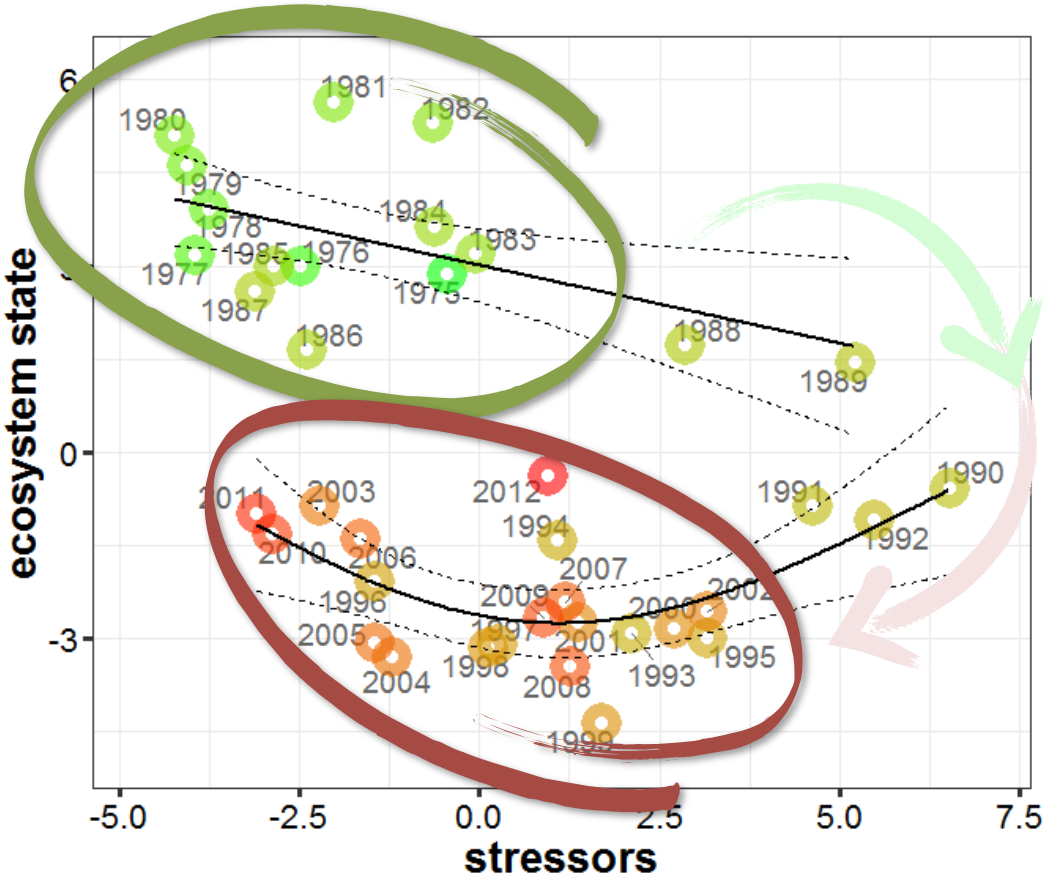
BALTIC SEA | tGAM non-additive modelling | state *vs.* stressors



BALTIC SEA | PC analysis | state *vs.* stressors

1ST REGIME

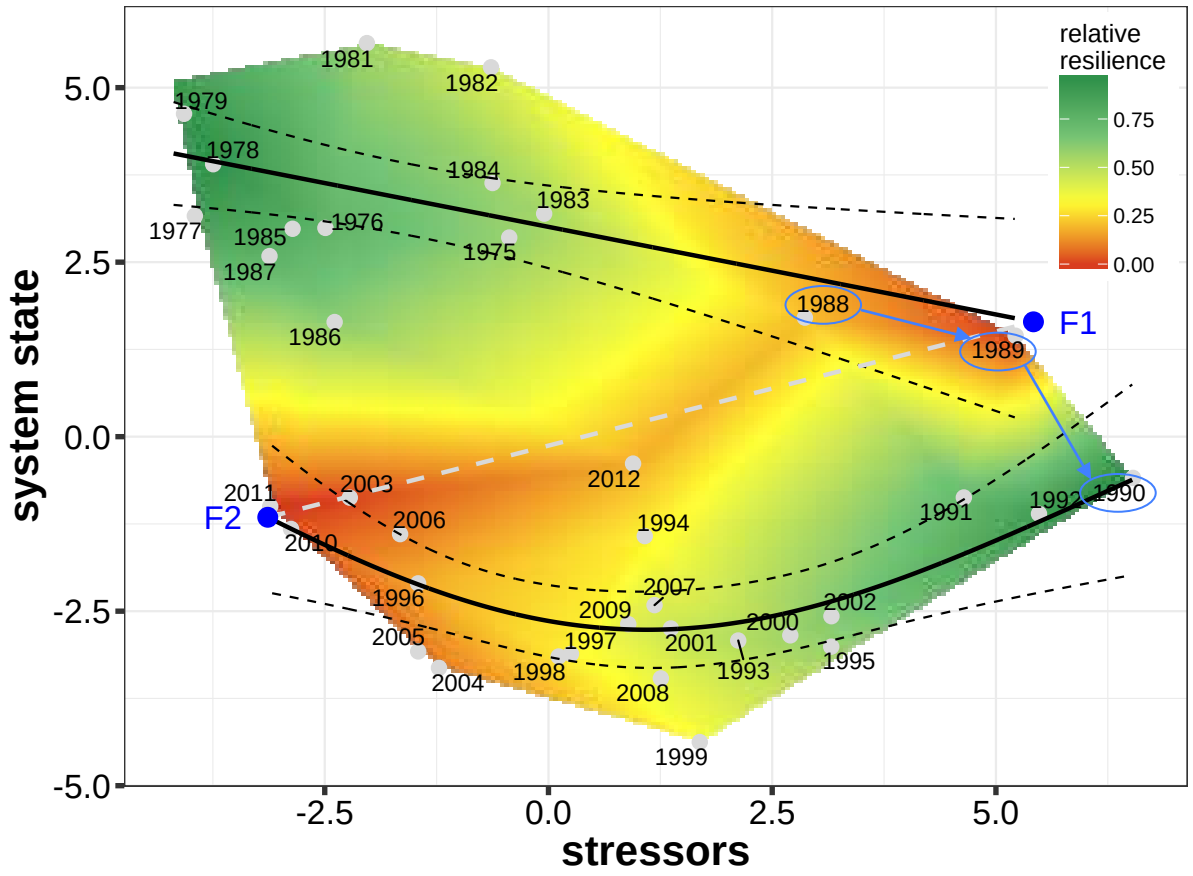
2ND REGIME



BALTIC SEA | stability landscape

1ST REGIME

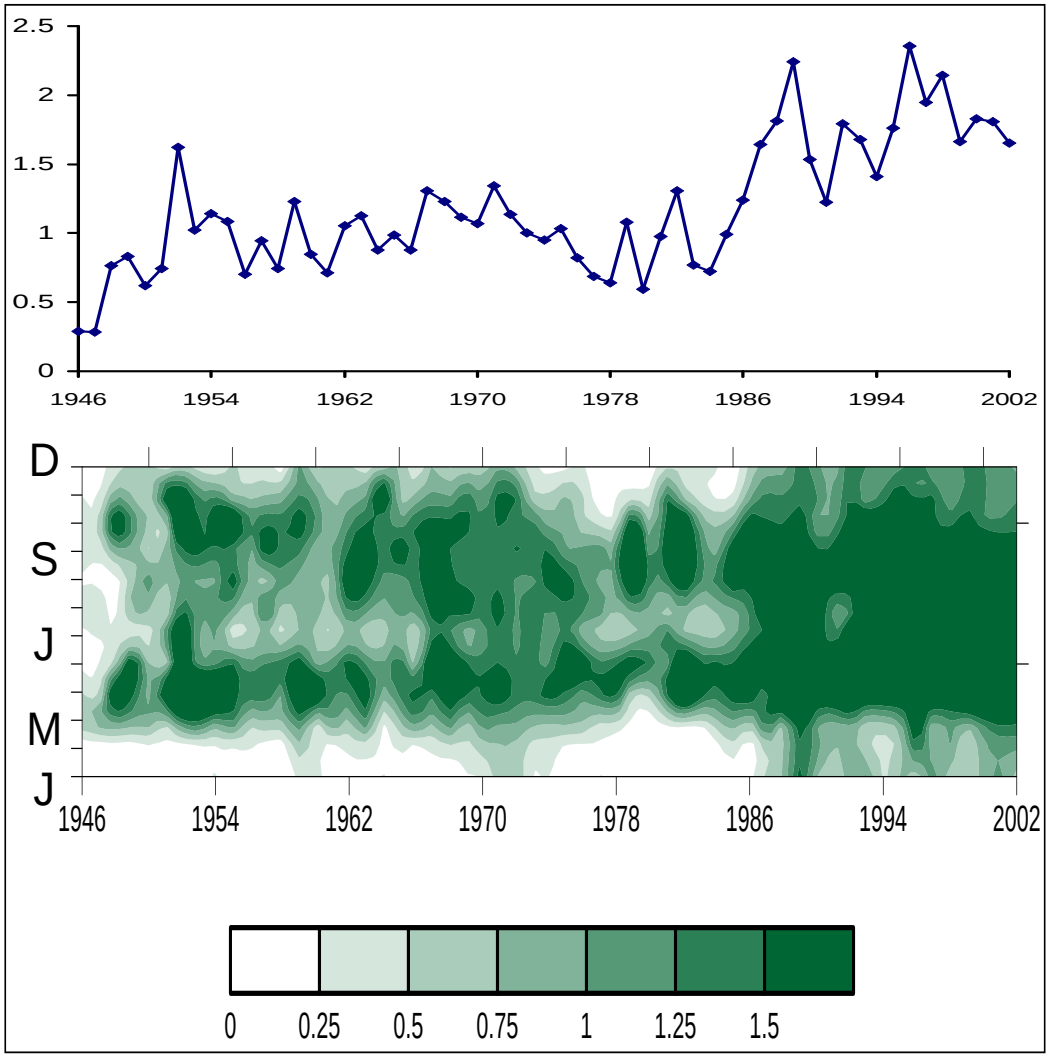
2ND REGIME




NORTH
SEA

NORTH SEA | regime shift

PHYTOPLANKTON COLOUR INDEX

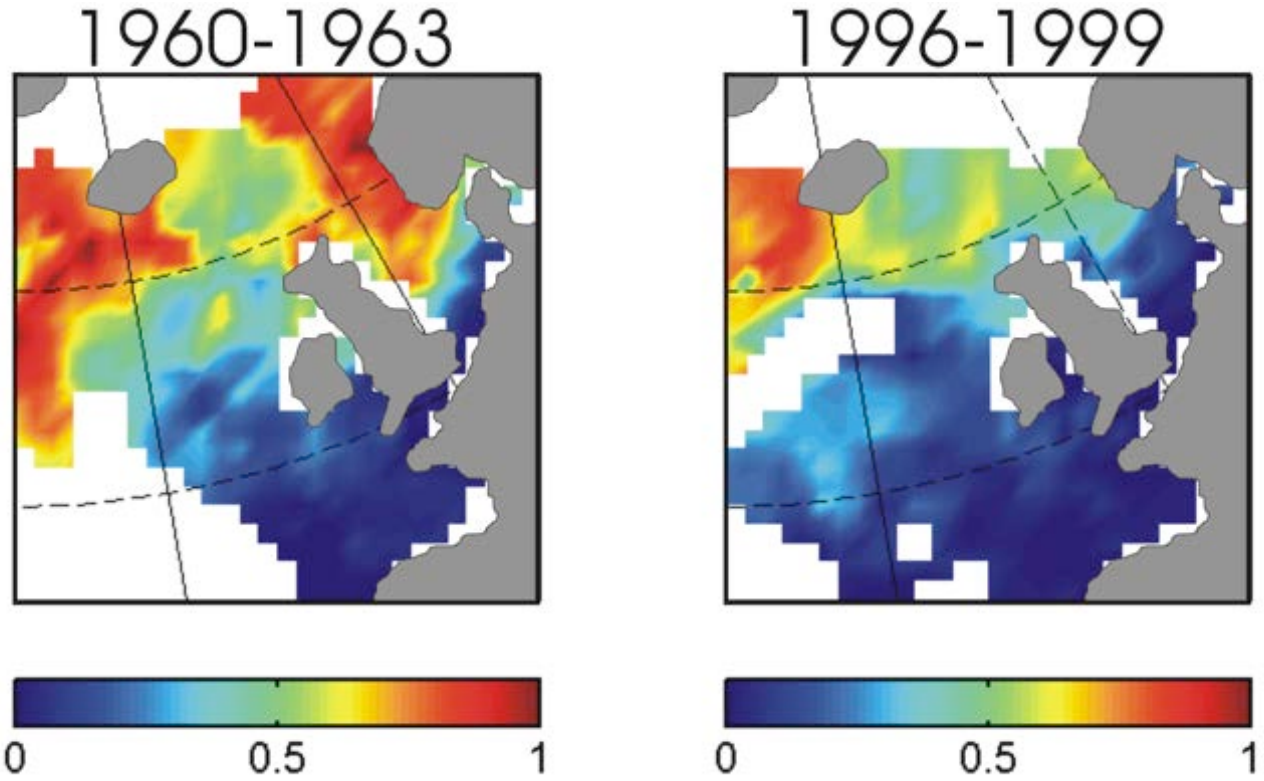


continuous plankton recorder - Reid *et al* (1998) Nature

NORTH SEA | regime shift

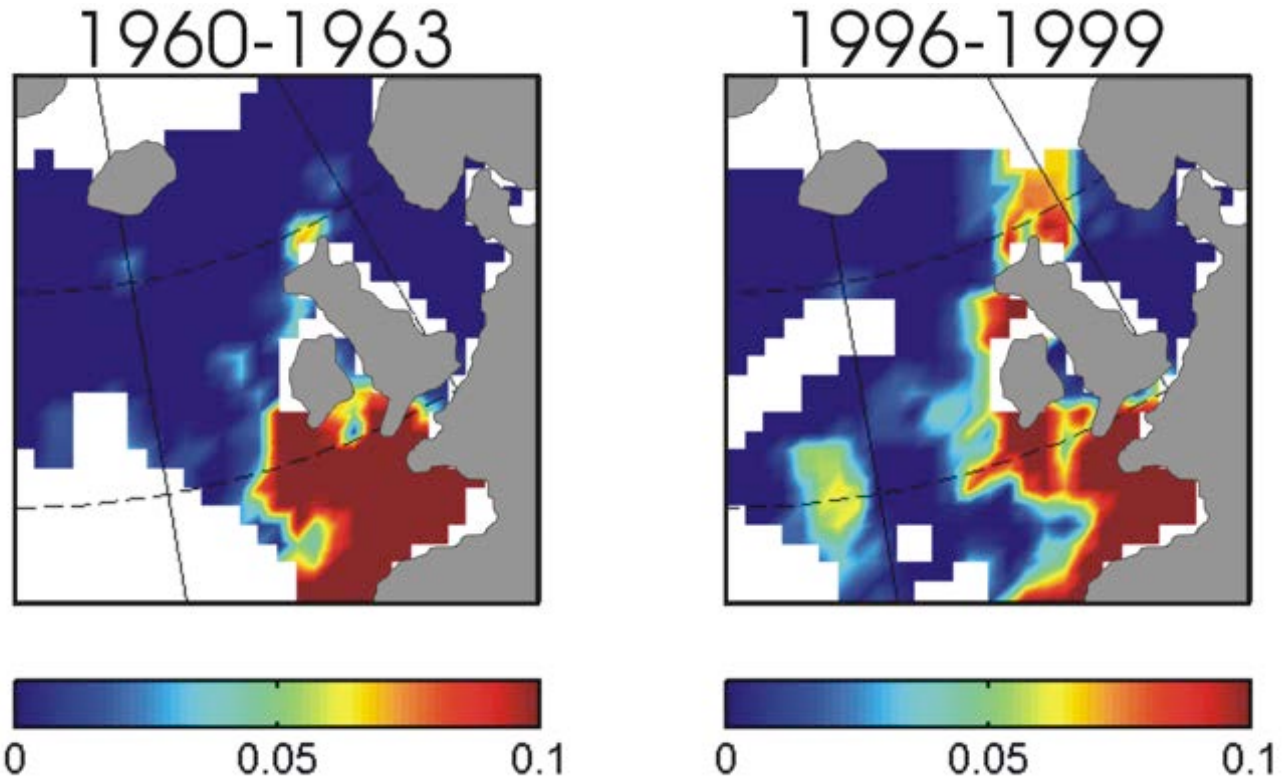
ZOOPLANKTON

Subarctic species



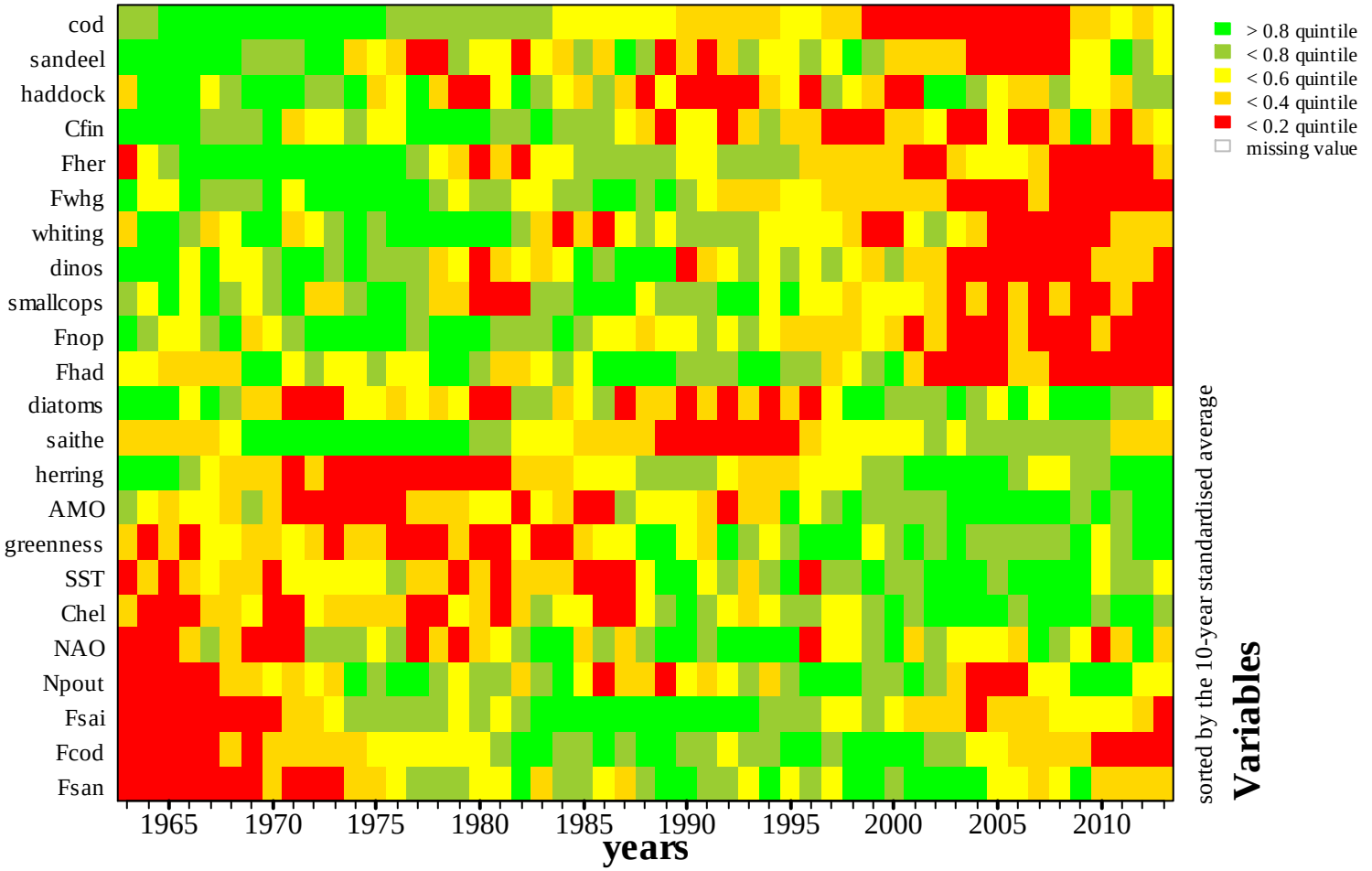
continuous plankton recorder - Beaugrand *et al* (2002) Science

Warm-temperature species

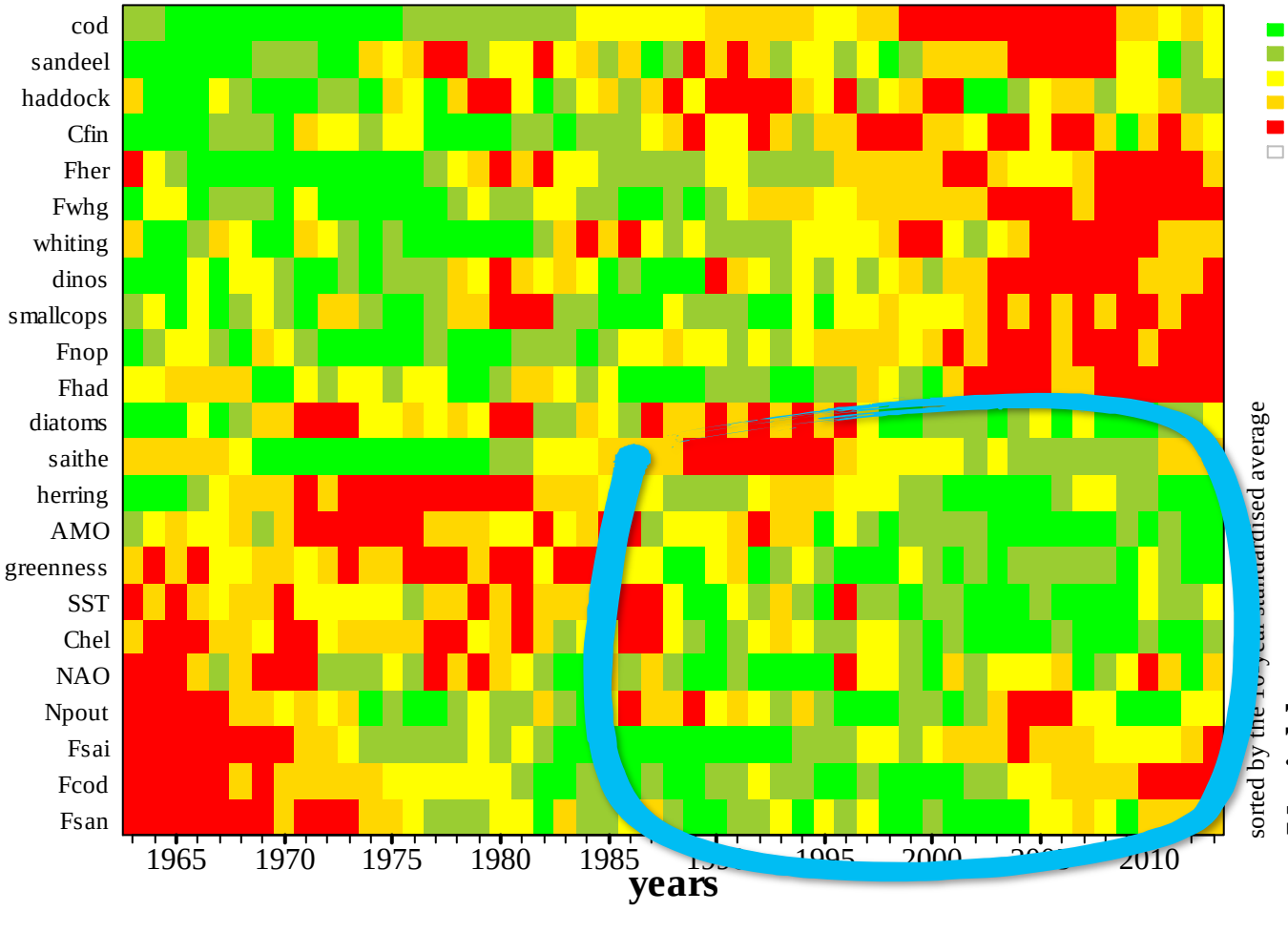


continuous plankton recorder - Beaugrand *et al* (2002) Science

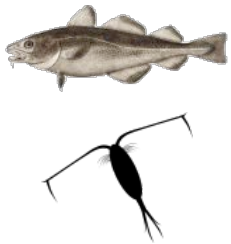
NORTH SEA | trafficlight plot

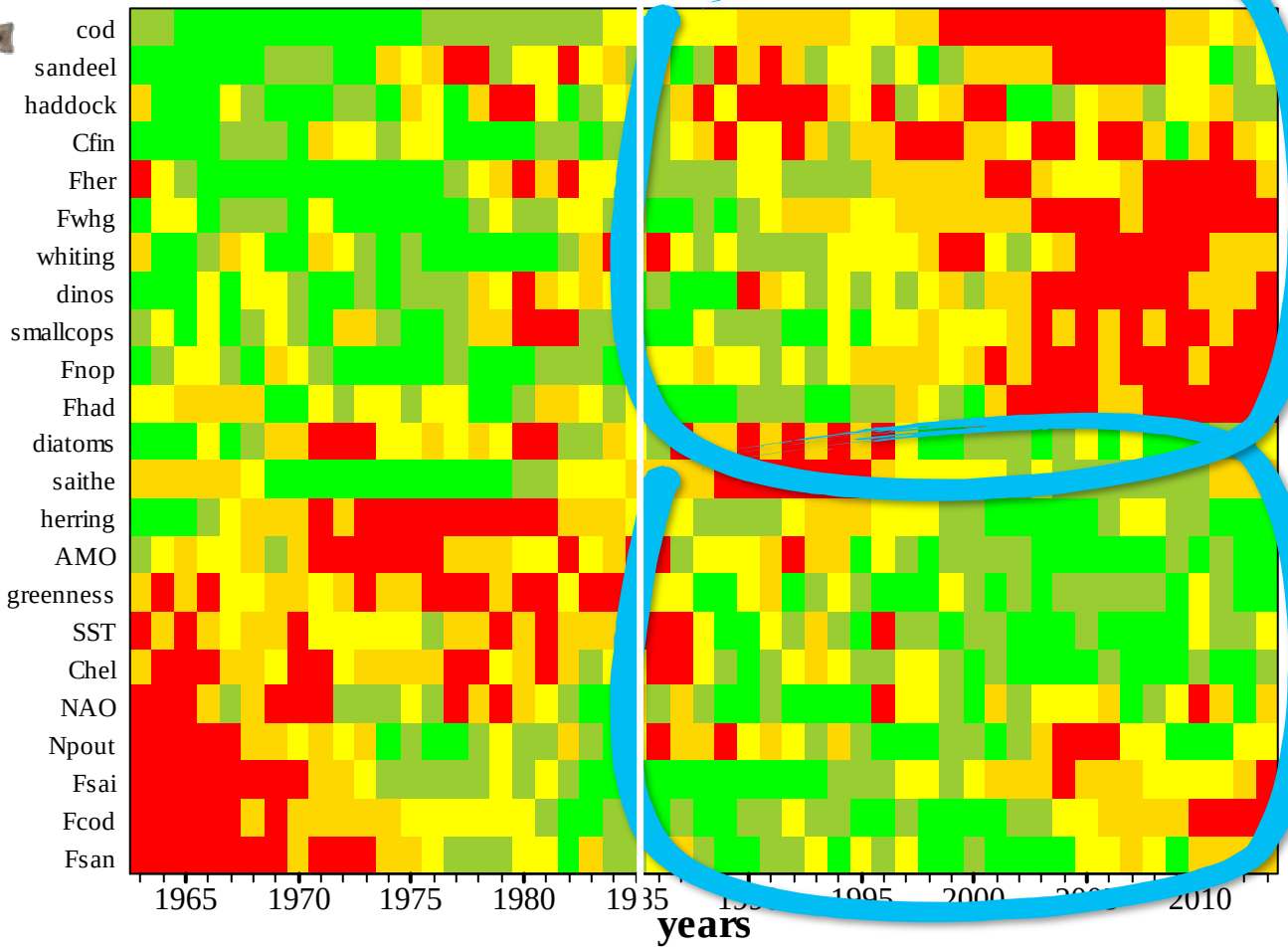


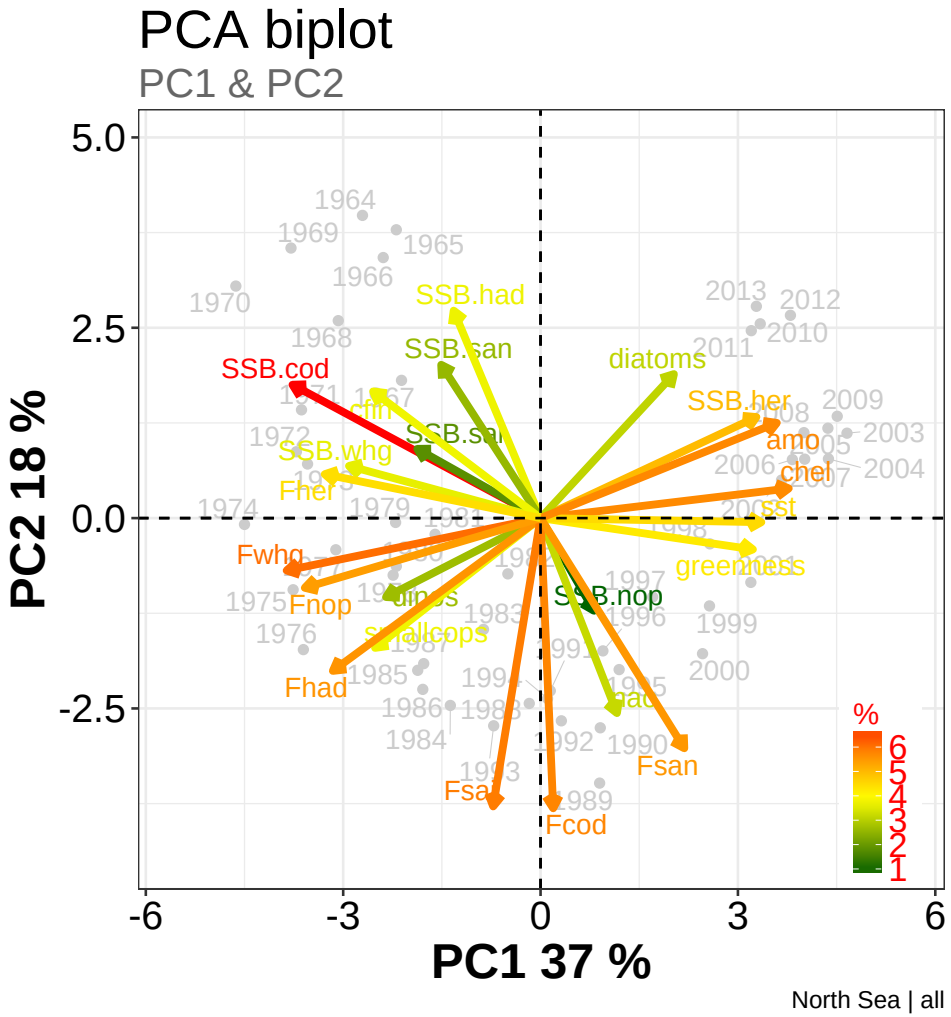
NORTH SEA | trafficlight plot



NORTH SEA | trafficlight plot






PCA biplot
PC1 & PC2
PC2 18 %
PC1 37 %
5.0
2.5
0.0
-2.5
-6
-3
0
3
6
SSB.had
SSB.san
SSB.cod
SSB.sai
SSB.whg
Fher
Fwhg
Fnop
Fhad
Fsai
Fcod
Fsan
diatoms
SSB.her
amo
chel
sst
greenness
SSB.nop
%
6
5
4
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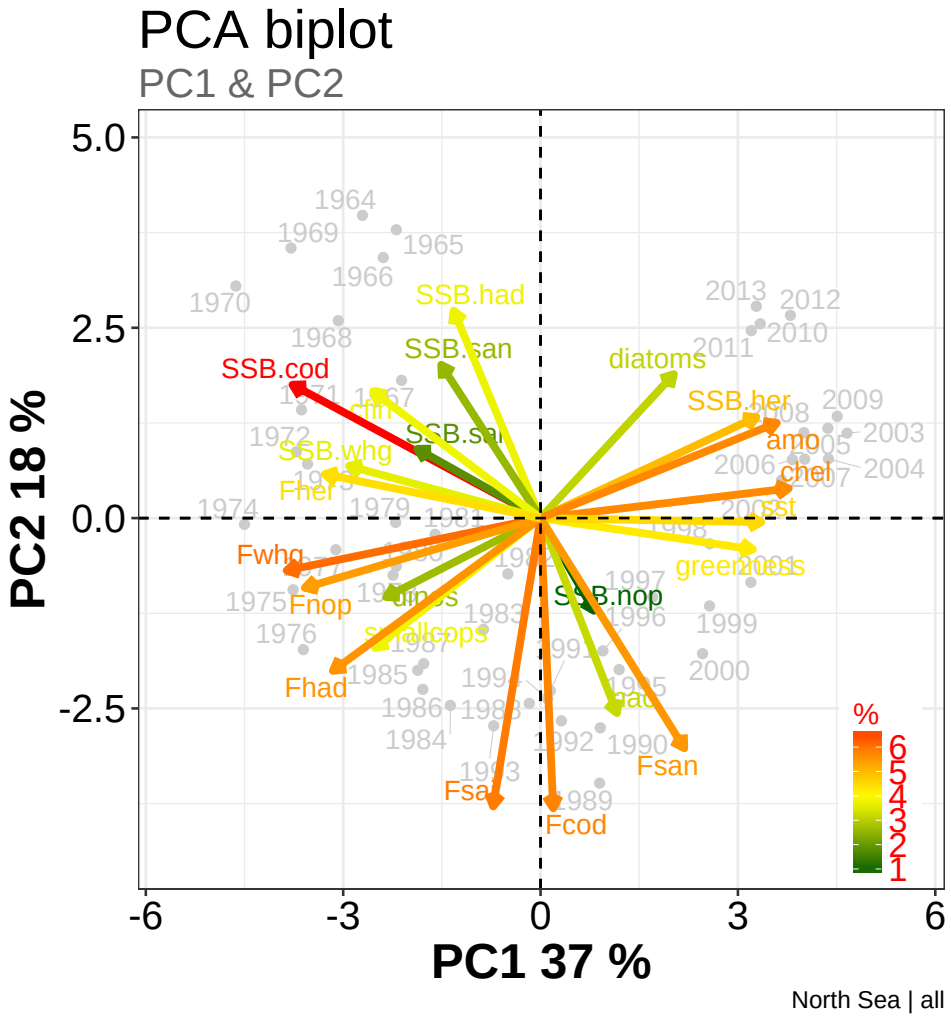
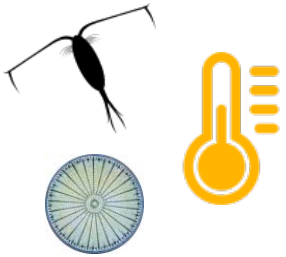
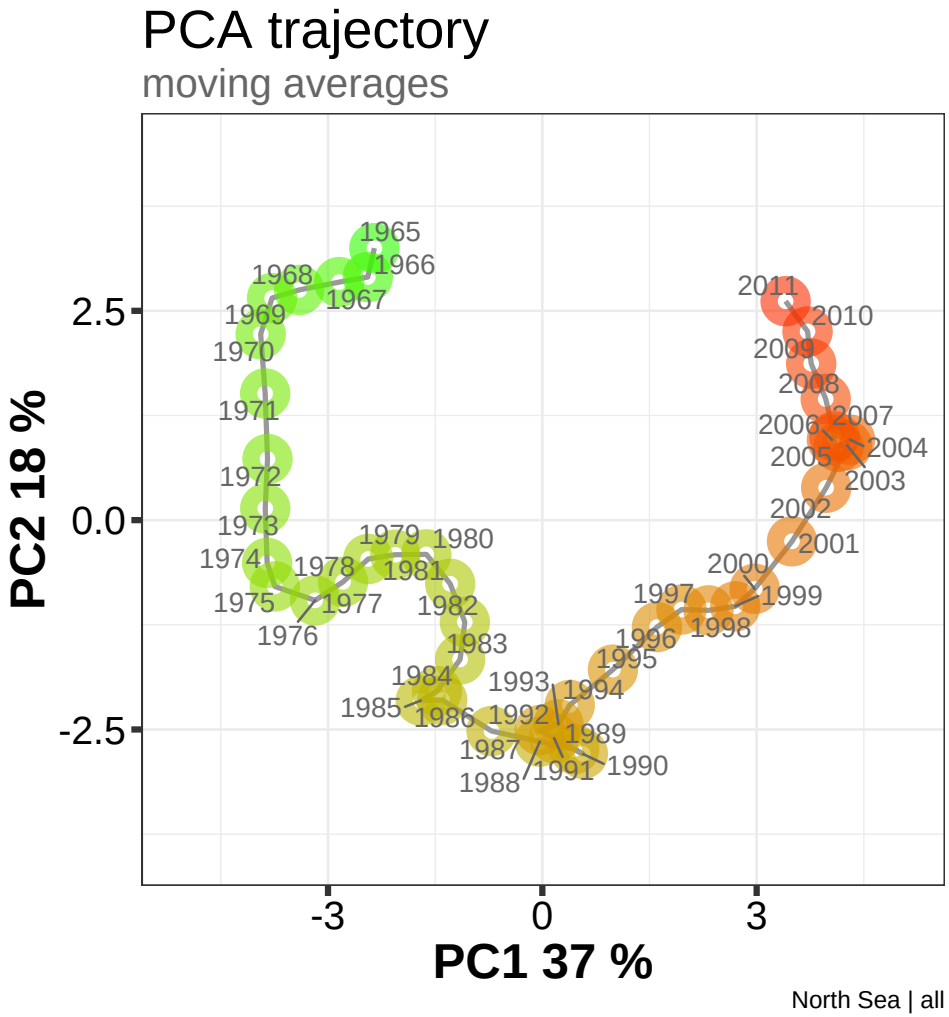
2000
North Sea | all

NORTH SEA | PC analysis | whole dataset



North Sea | all




PCA trajectory
moving averages
PC2 18 %
PC1 37 %
2.5
0.0
-2.5
-3
0
3
1965
1966
1967
1968
1969
1970
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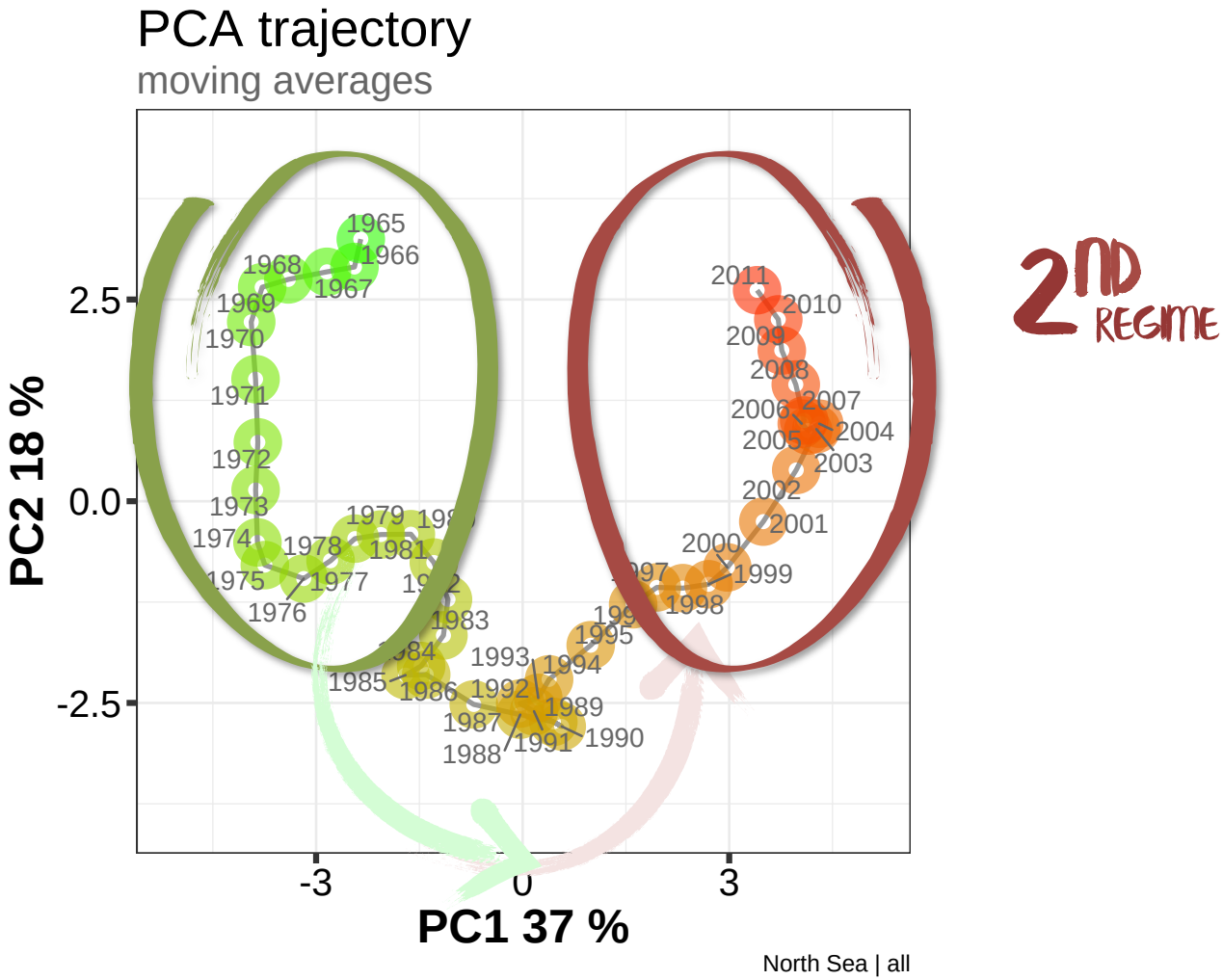
2008
2009
2010
2011
North Sea | all

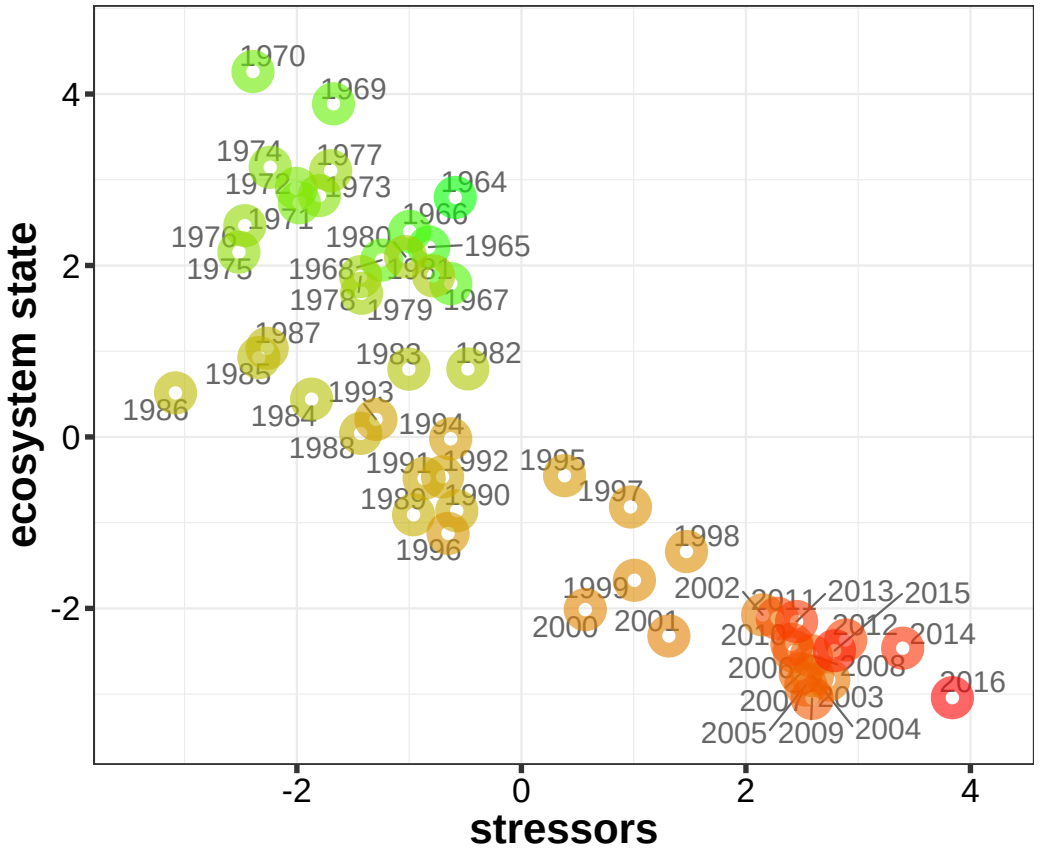
NORTH SEA | PC analysis | whole dataset

1ST REGIME

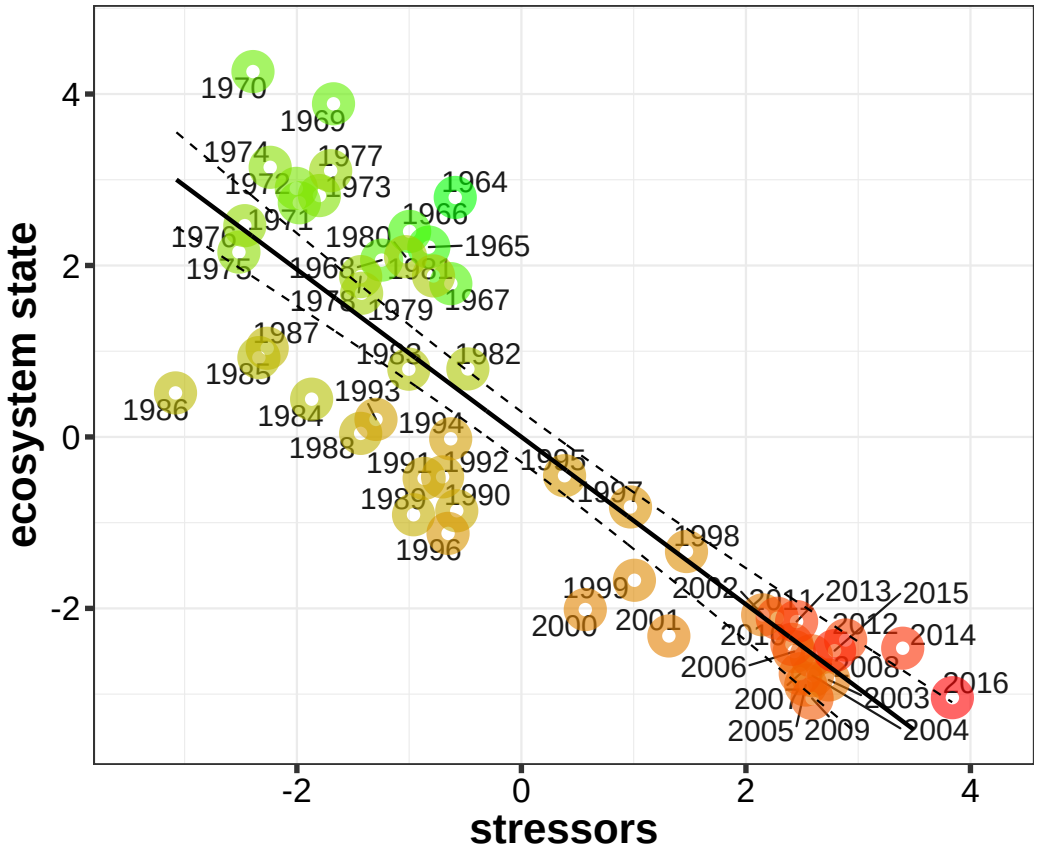
2ND REGIME



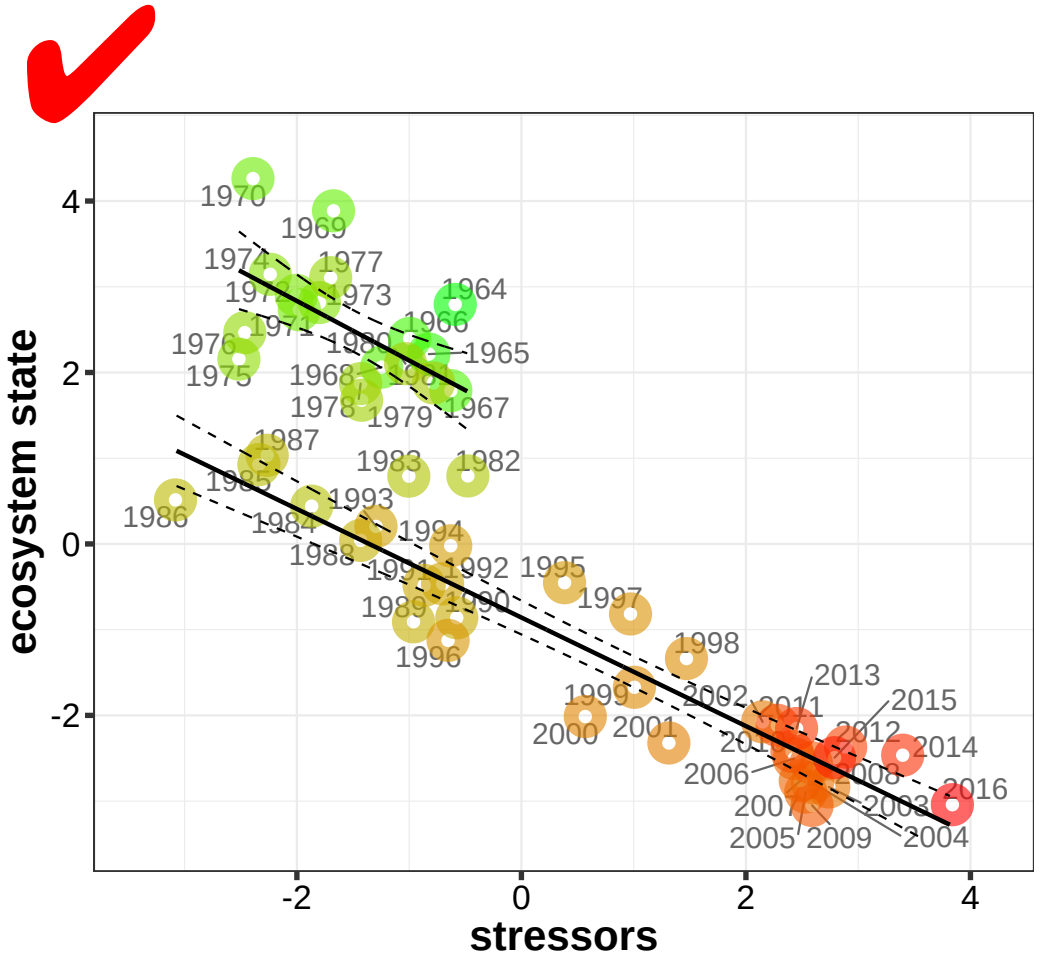
NORTH SEA | PC analysis | state *vs.* stressors



NORTH SEA | GAM additive modelling | state *vs.* stressors



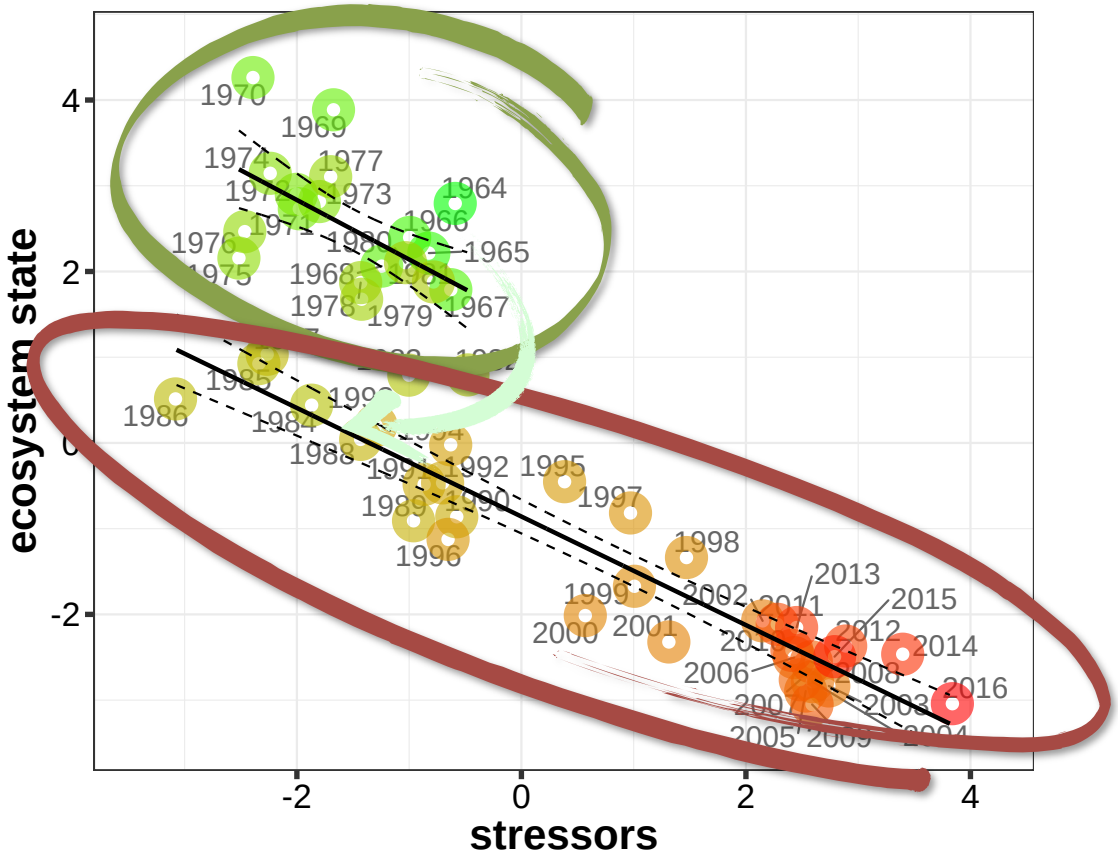
NORTH SEA | tGAM non-additive modelling | state *vs.* stressors



NORTH SEA | PC analysis | state *vs.* stressors

1ST REGIME

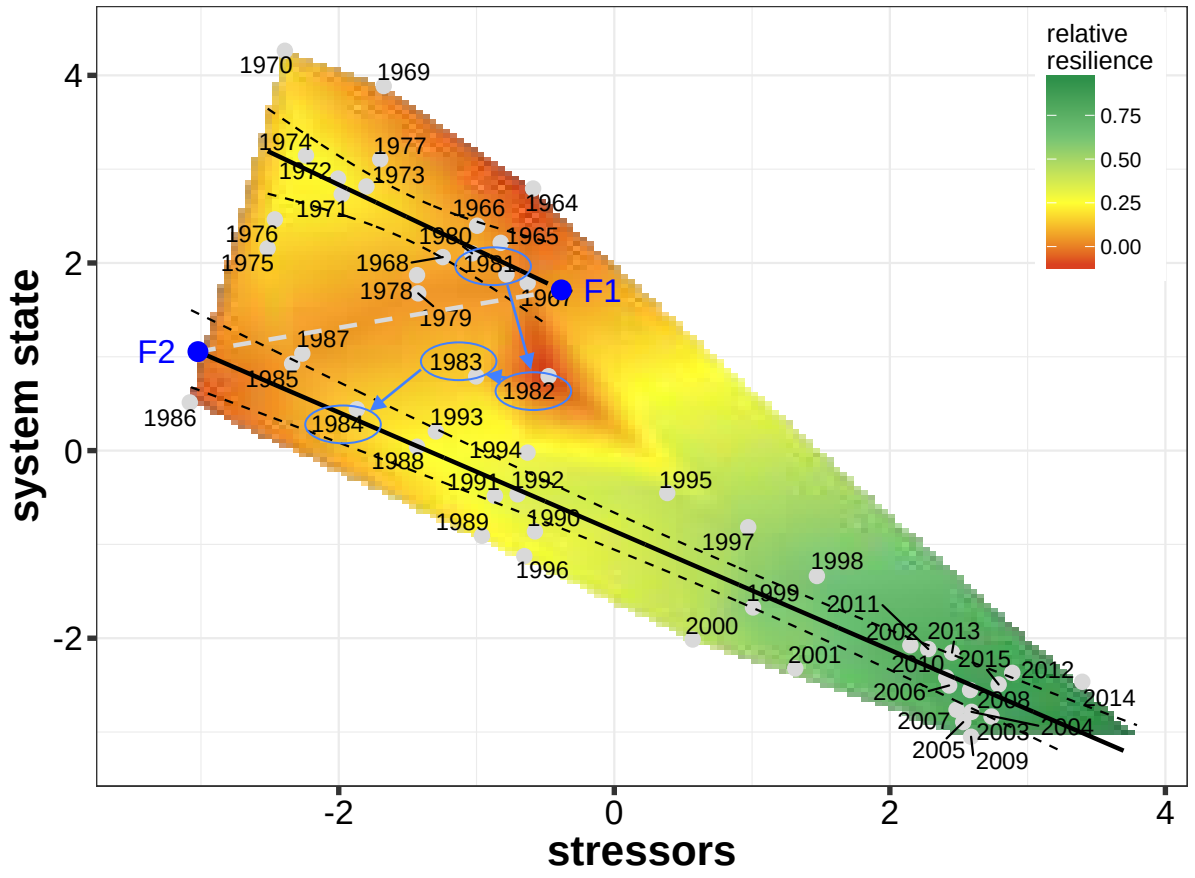
2ND REGIME

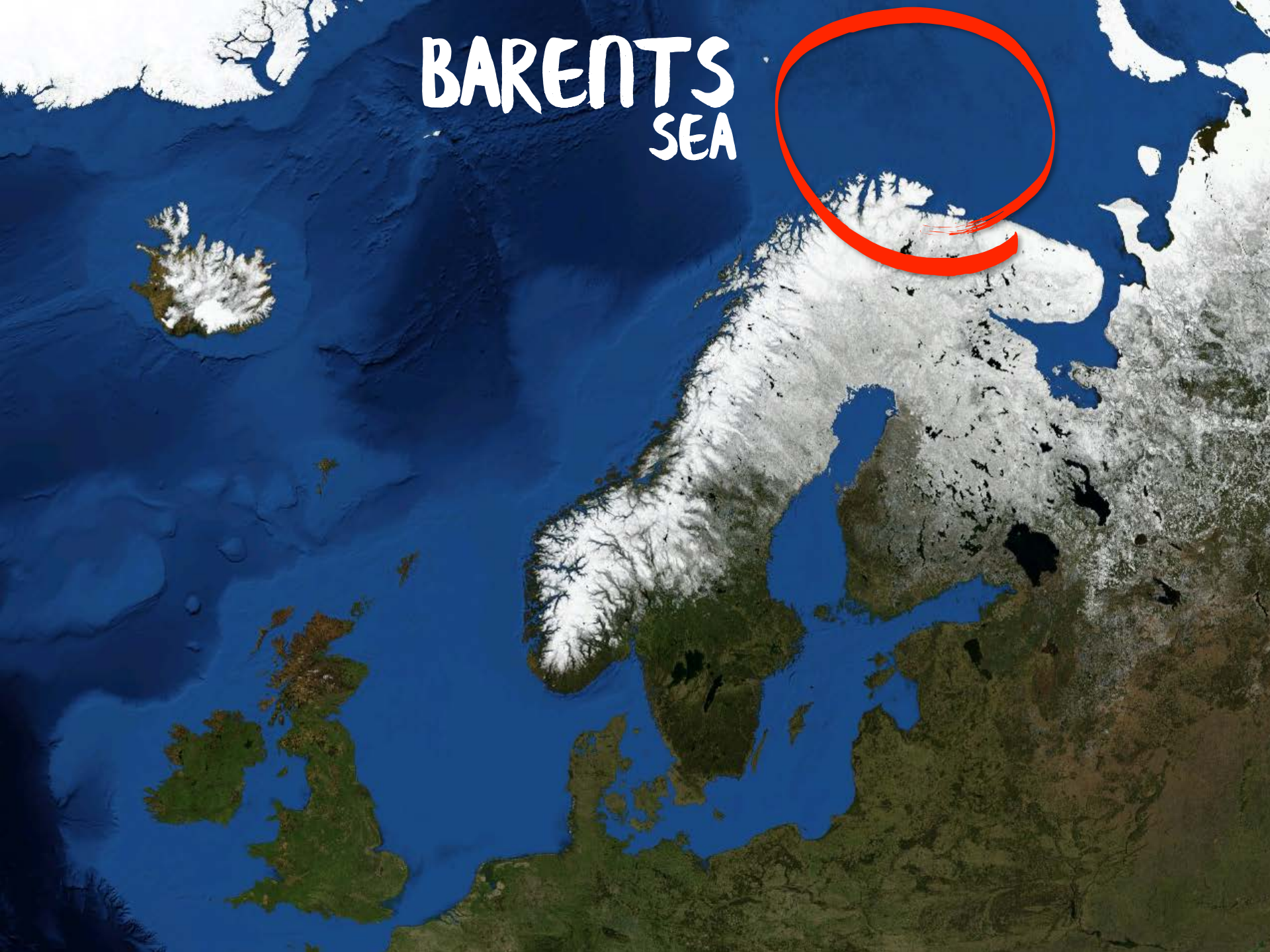


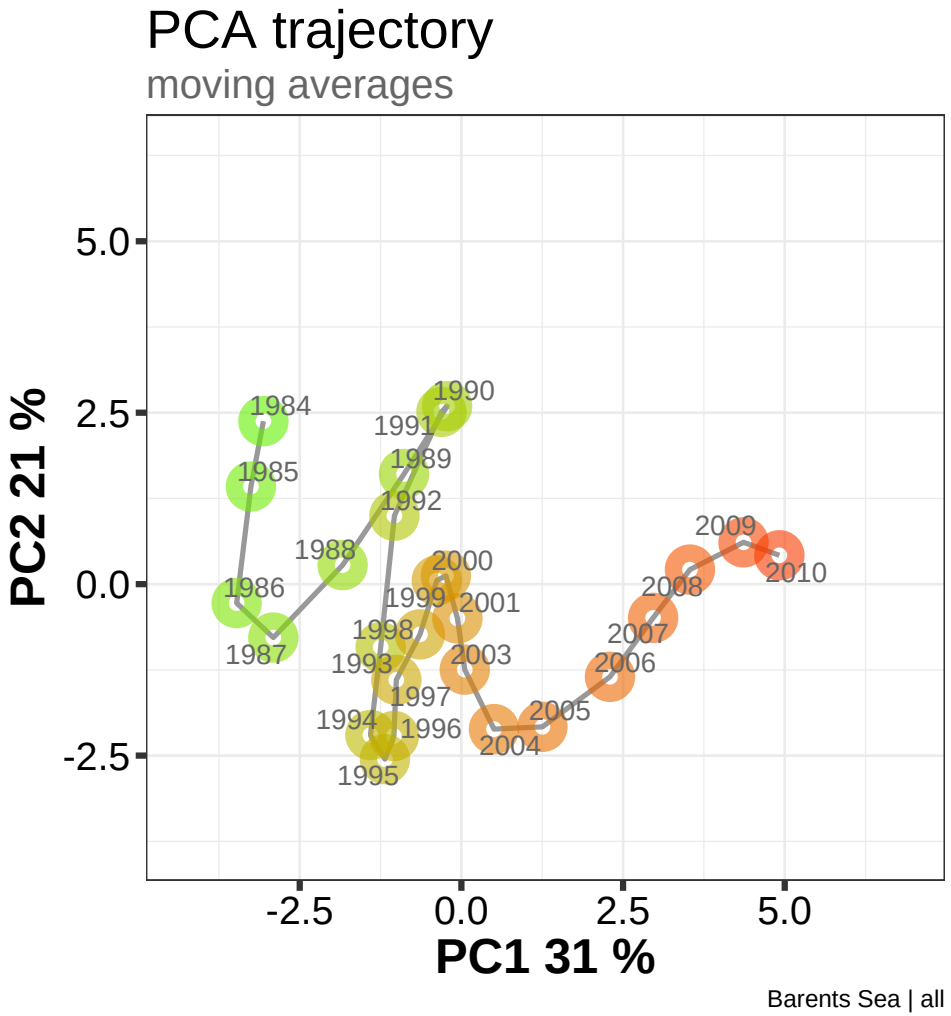
NORTH SEA | stability landscape

1ST REGIME

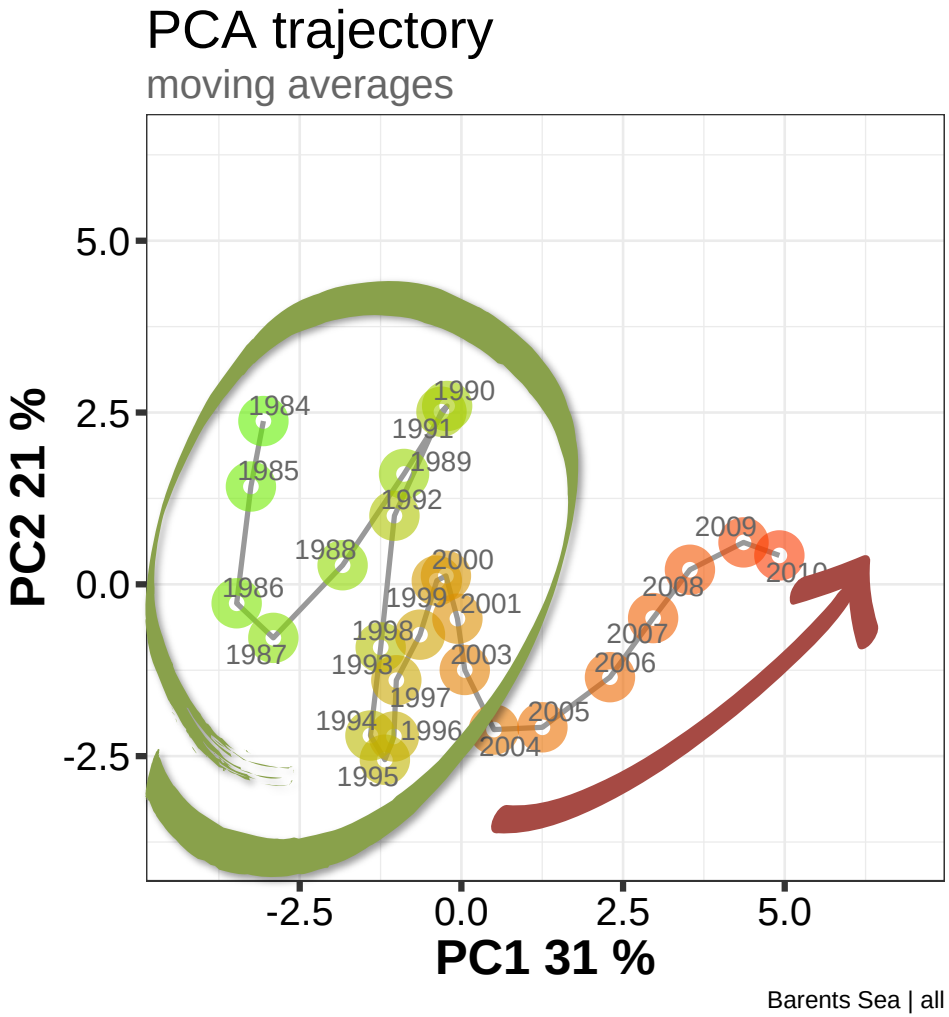
2ND REGIME



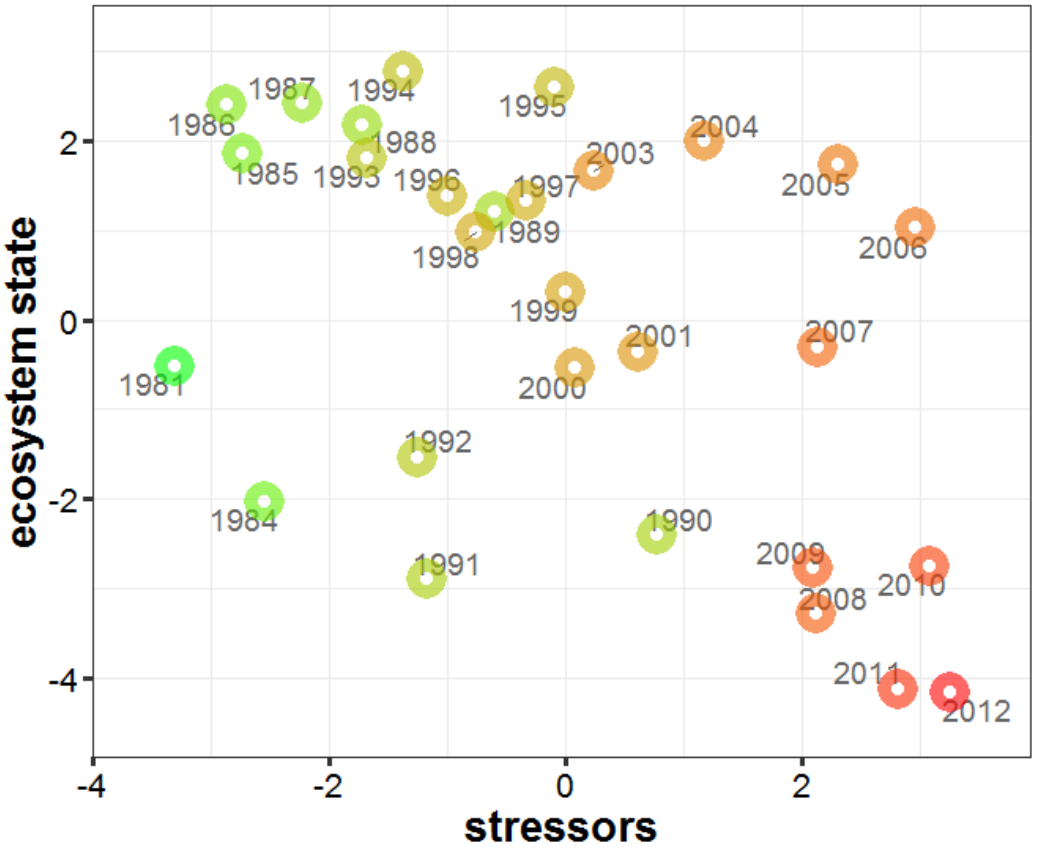

BARENTS
SEA


PCA trajectory
moving averages
PC2 21 %
PC1 31 %
5.0
2.5
0.0
-2.5
-2.5
0.0
2.5
5.0
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2003
2004
2005
2006
2007
2008
2009
2010
Barents Sea | all

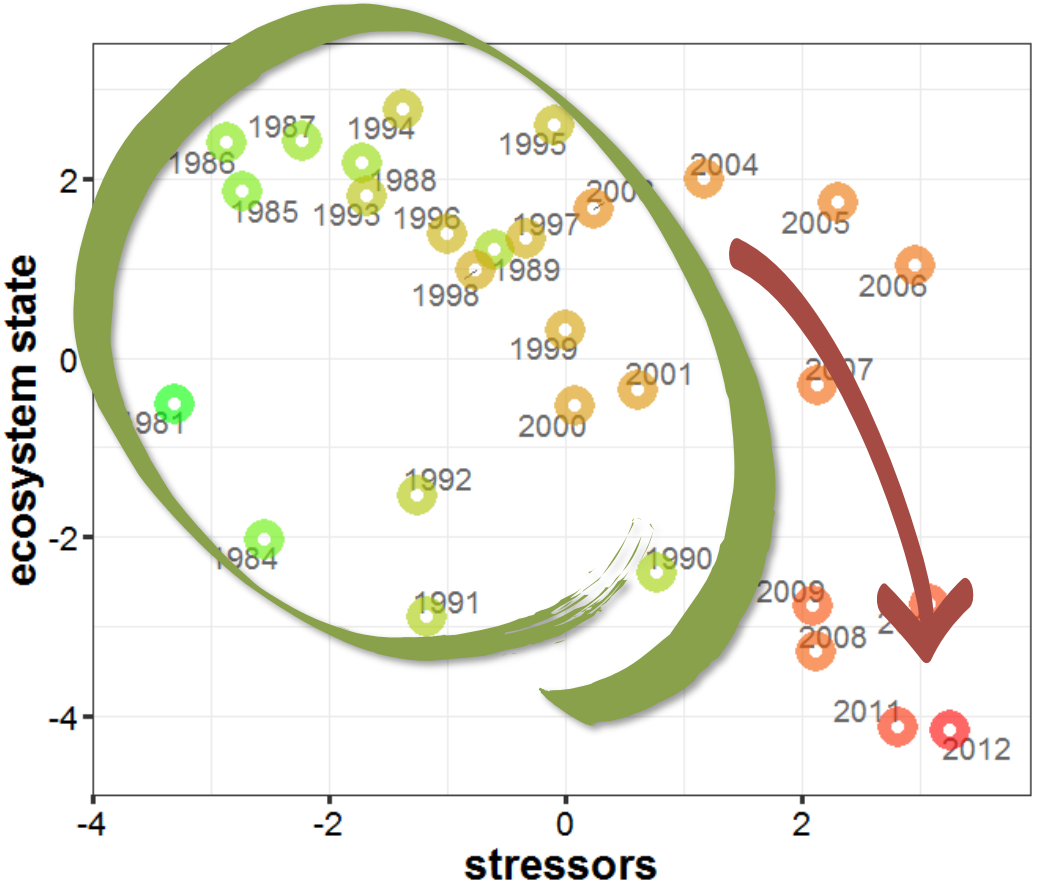
BARENTS SEA | PC analysis | whole dataset



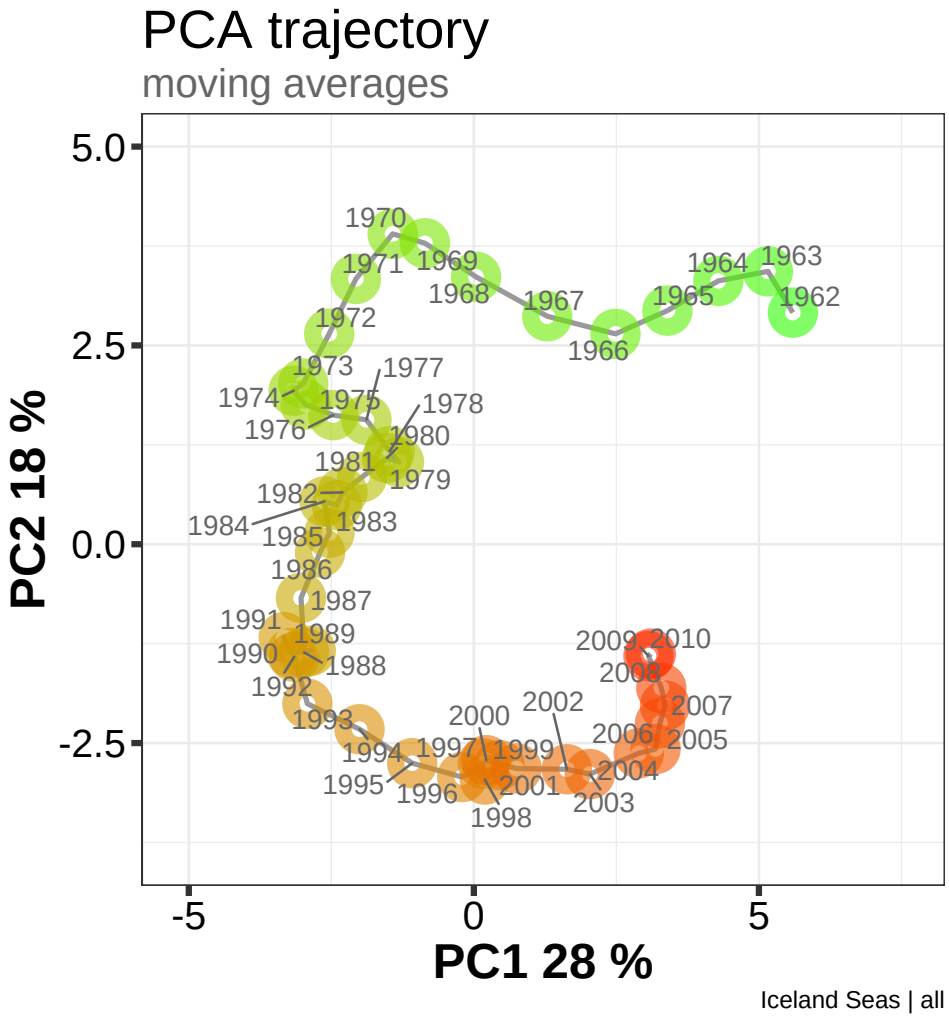
BARENTS SEA | PC analysis | state *vs.* stressors



BARENTS SEA | PC analysis | state *vs.* stressors




SEAS OF
ICELAND


PCA trajectory
moving averages
5.0
2.5
0.0
-2.5
PC2 18 %
-5
0
5
PC1 28 %
1970
1971
1969
1968
1967
1966
1965
1964
1963
1962
1972
1973
1977
1974
1975
1978
1976
1980
1981
1979
1982
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2010
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2001
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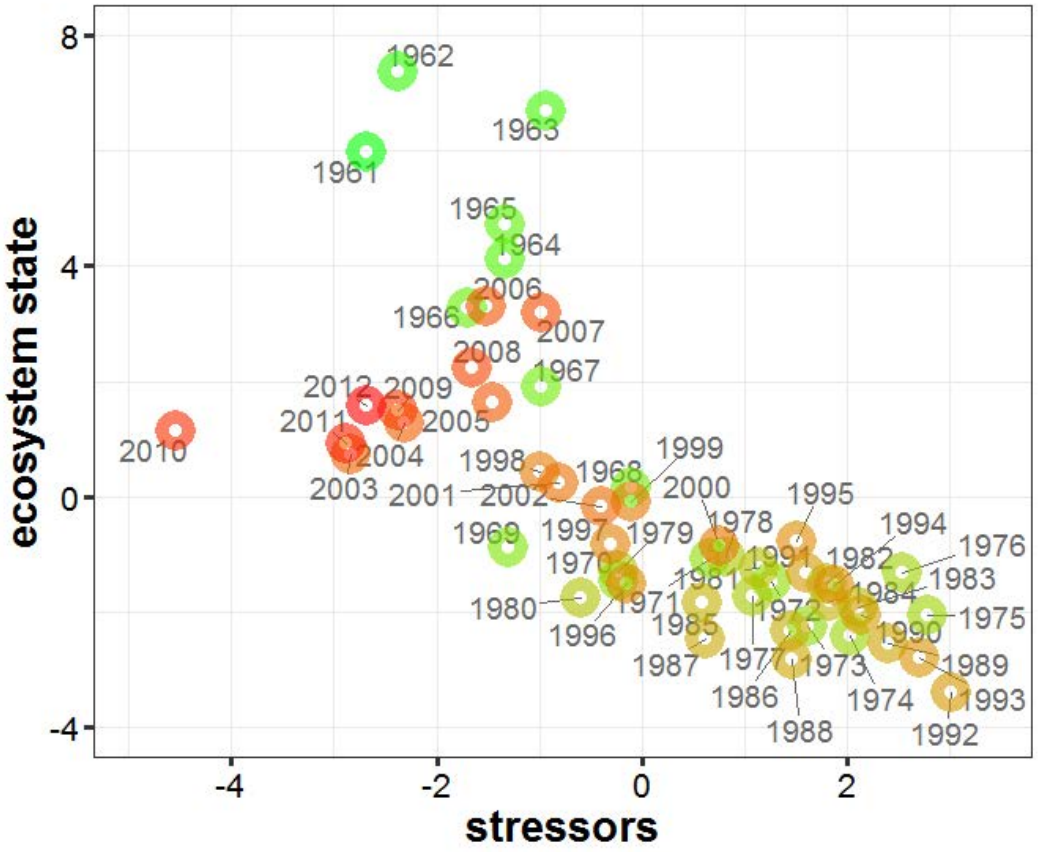
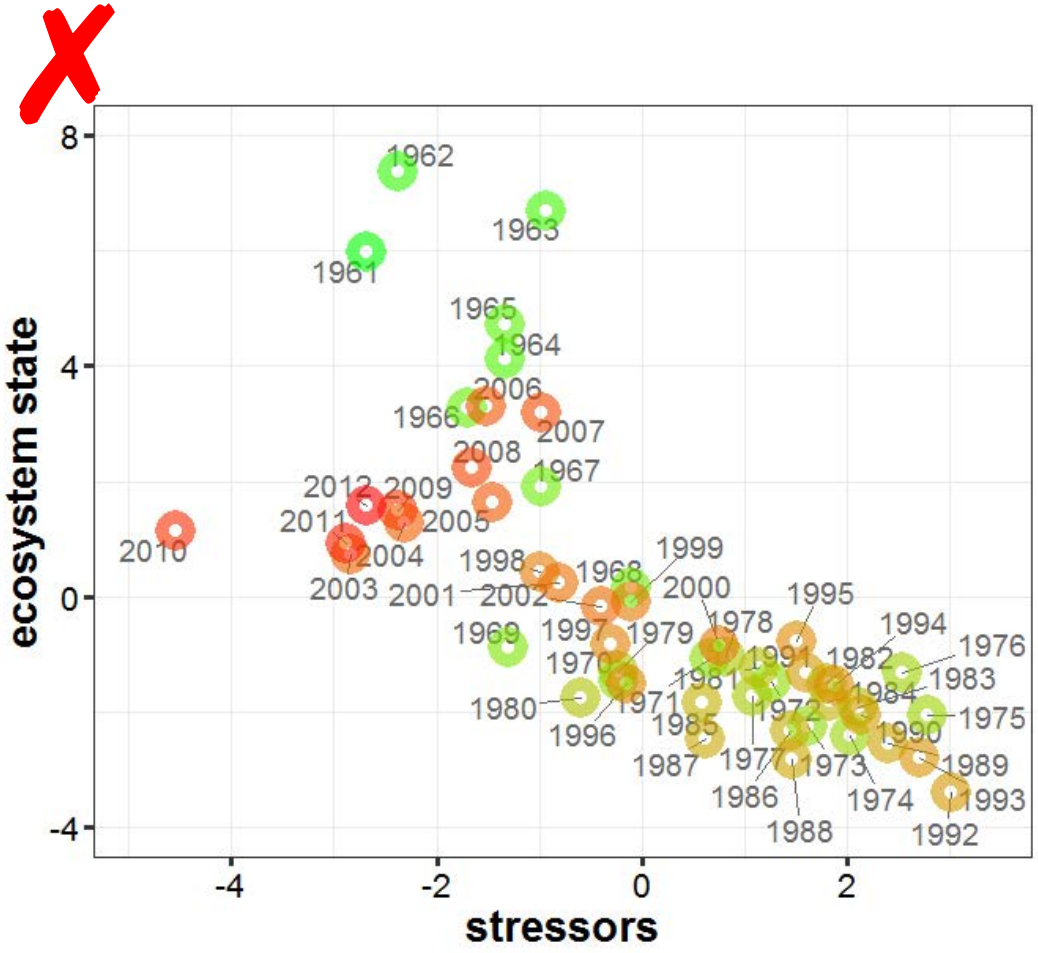
1998
Iceland Seas | all

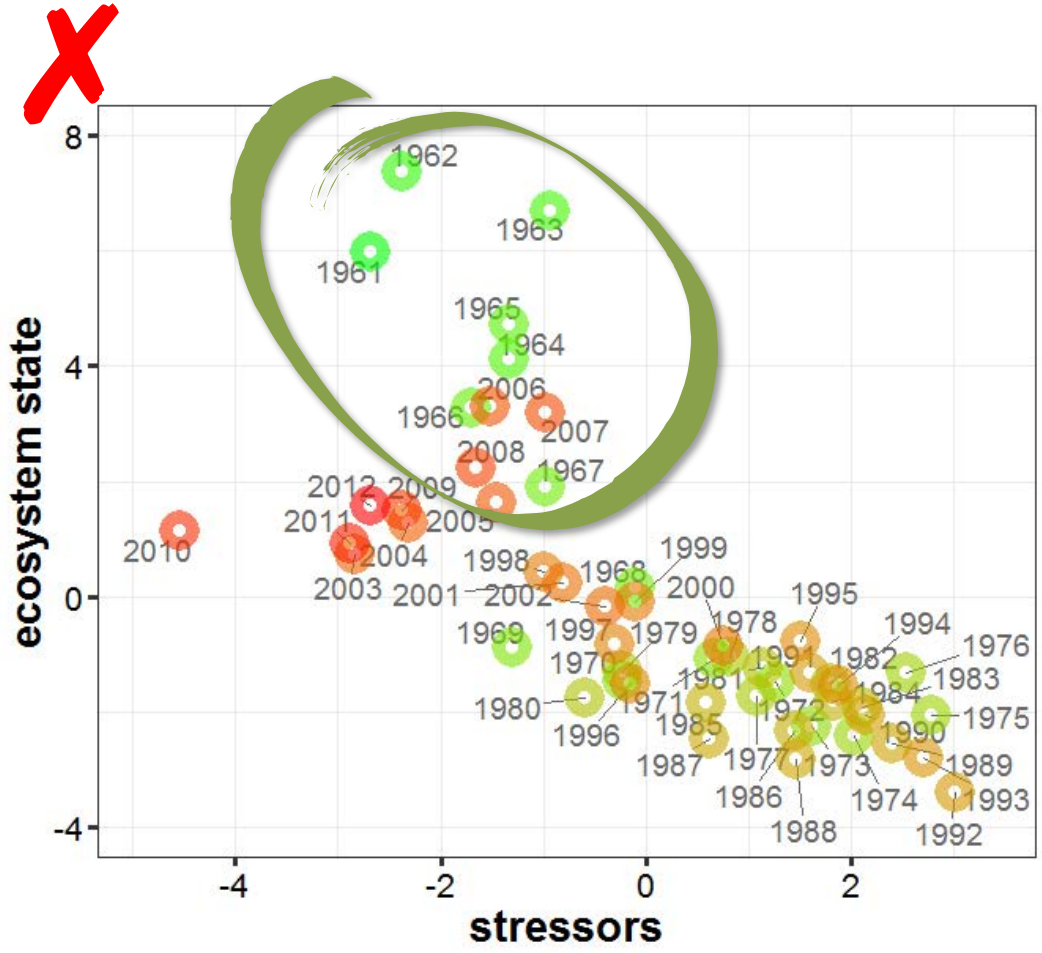
ICELAND SEAS | PC analysis | state vs. stressors



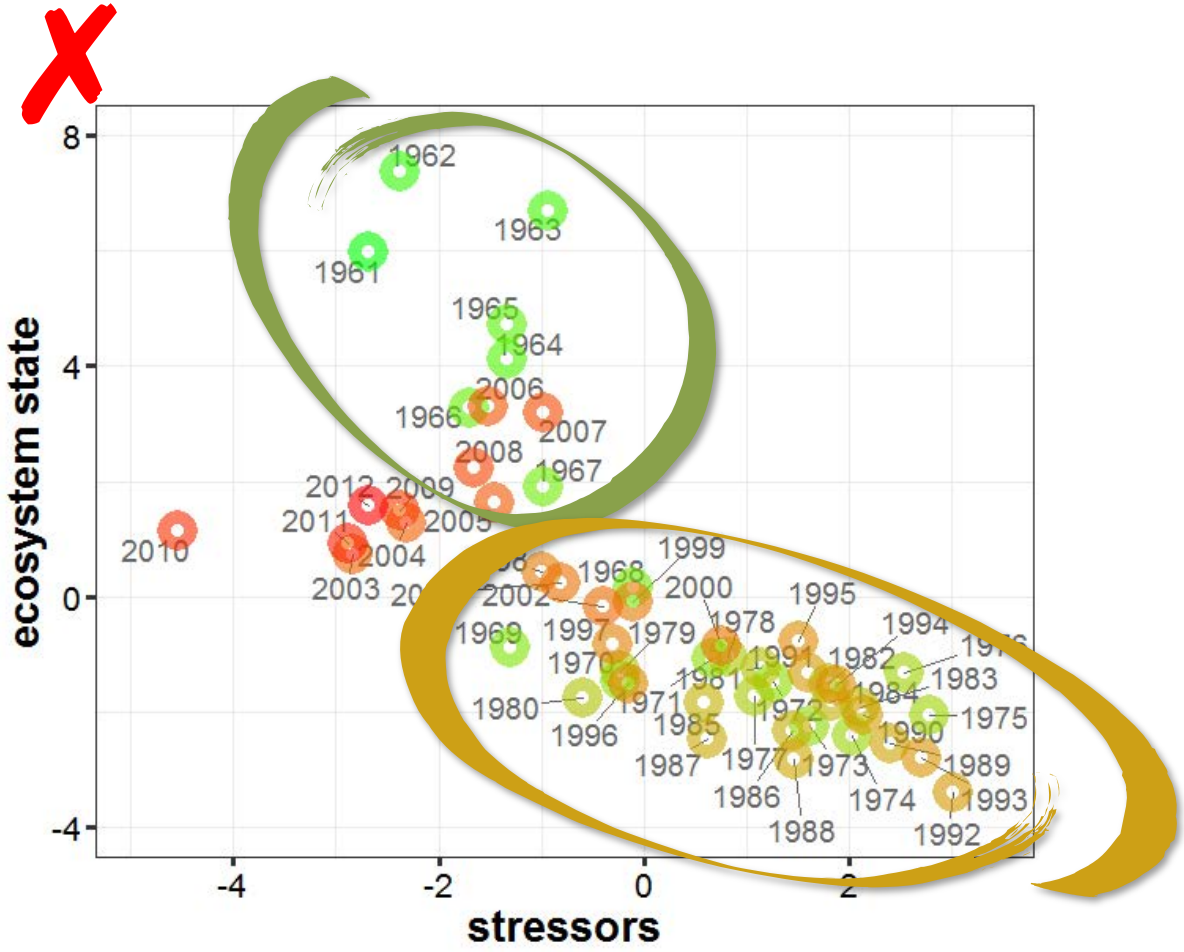
ICELAND SEAS | PC analysis | state vs. stressors



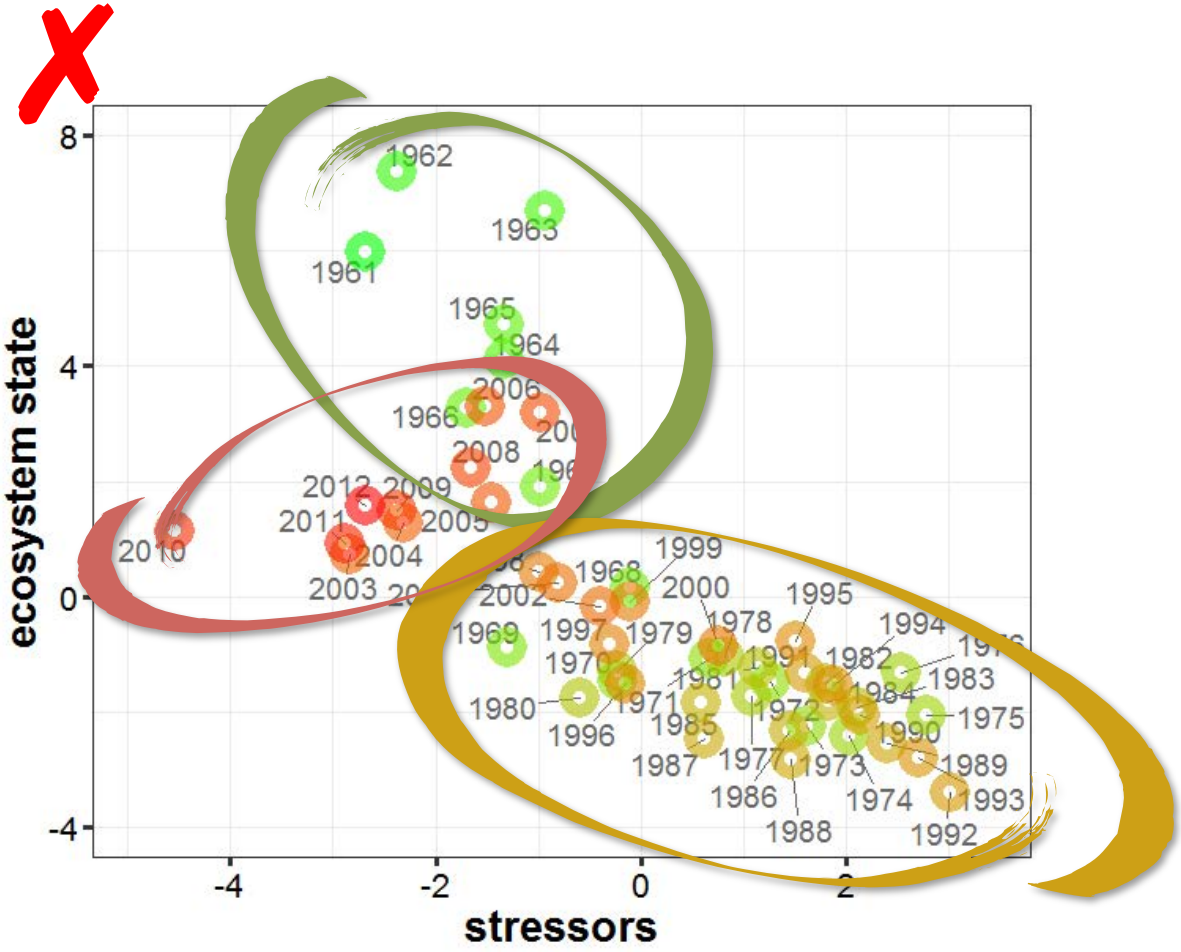
ICELAND SEAS | PC analysis | state vs. stressors



ICELAND SEAS | PC analysis | state vs. stressors



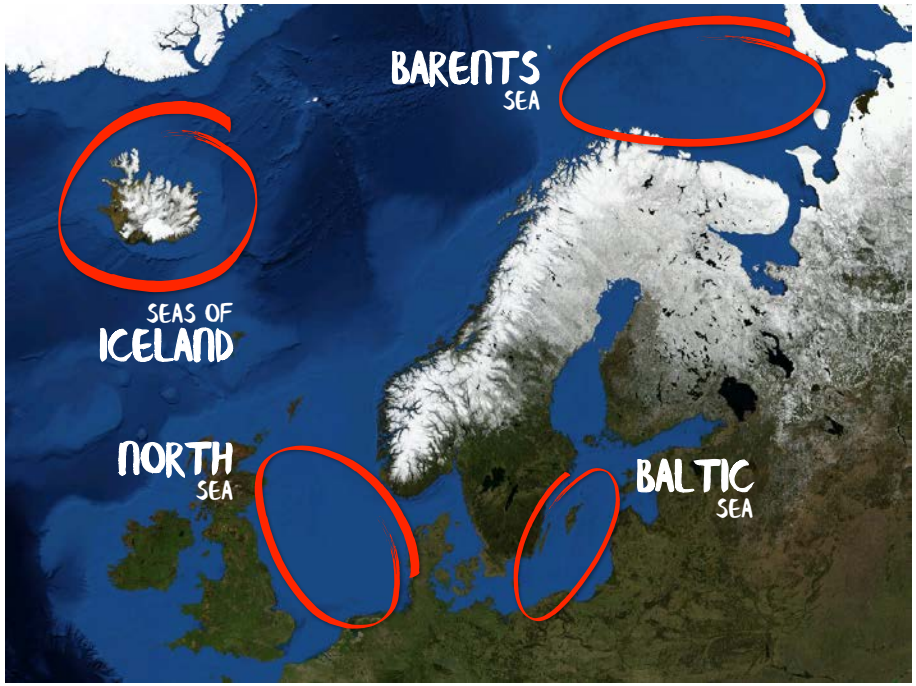
ICELAND SEAS | PC analysis | state vs. stressors



CONCLUSIONS | preliminary

✗ **ICELAND SEAS**
BARENTS SEA
no clear
stability landscape

✔ **NORTH SEA**
BALTIC SEAS
indication of
stability landscapes

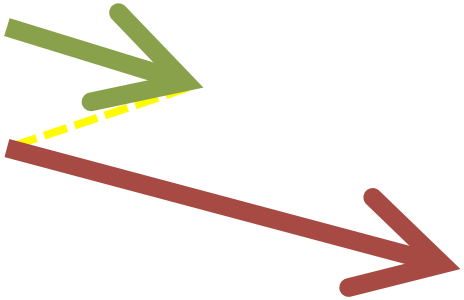


CONCLUSIONS | preliminary

1ST REGIME

2ND REGIME

NORTH SEA



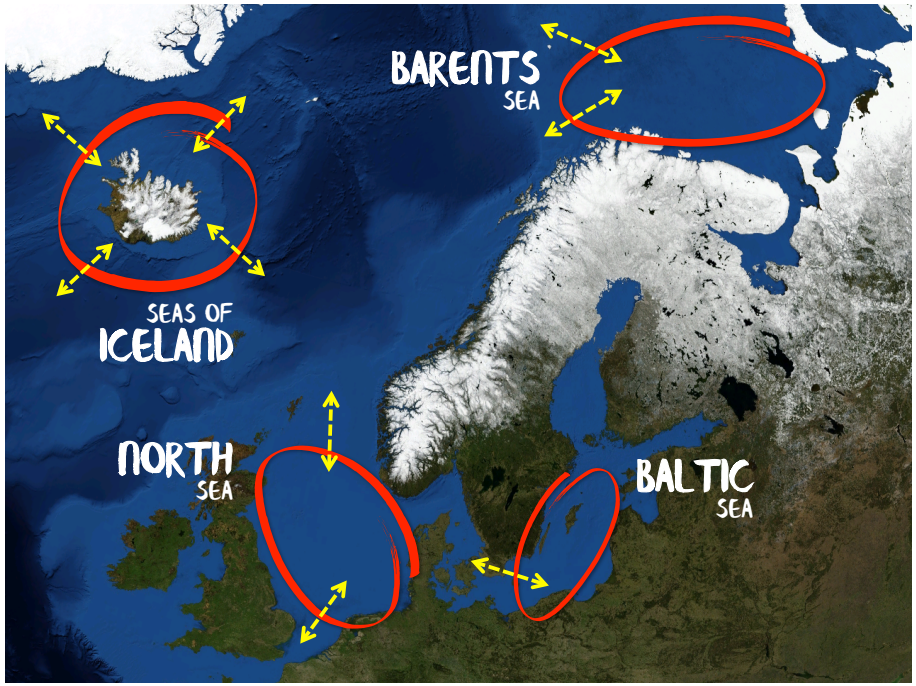
the system entered into a new stressors domain (not previously seen) and seems to have reached high resilience within its present regime

BALTIC SEA

stressors seem to have moved back towards the 70s but this is only part of the story (PC1). Anoxia and eutrophication still important (PC2)

CONCLUSIONS | and questions ?

To what extent diversity (highest in the North Sea) and/or level of isolation (Barents Sea and Iceland Sea are open ecosystems, while North and Baltic are semi-enclosed) could be responsible for this gradient in responses to similar stressors?



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GreenMAR
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NordForsk

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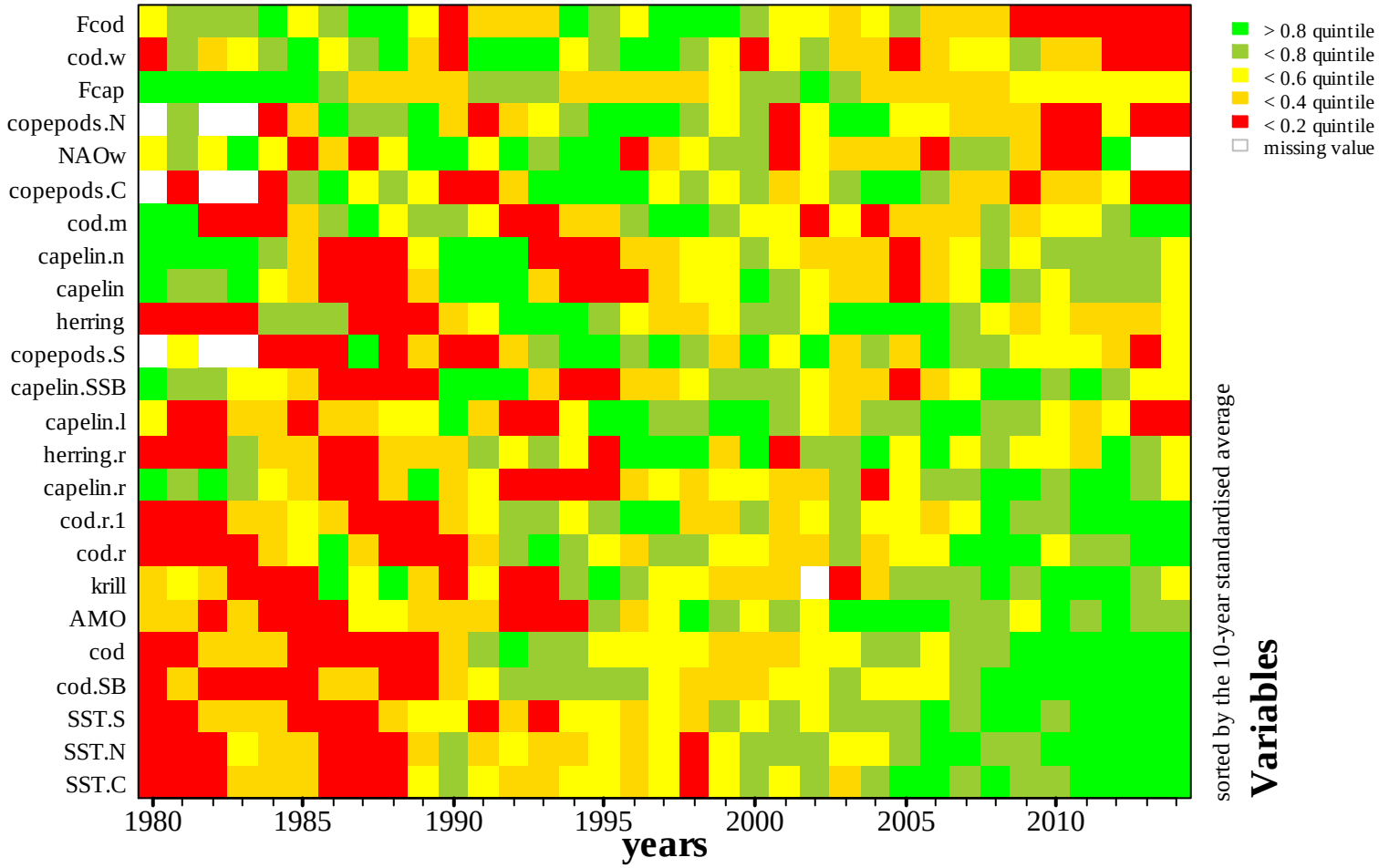
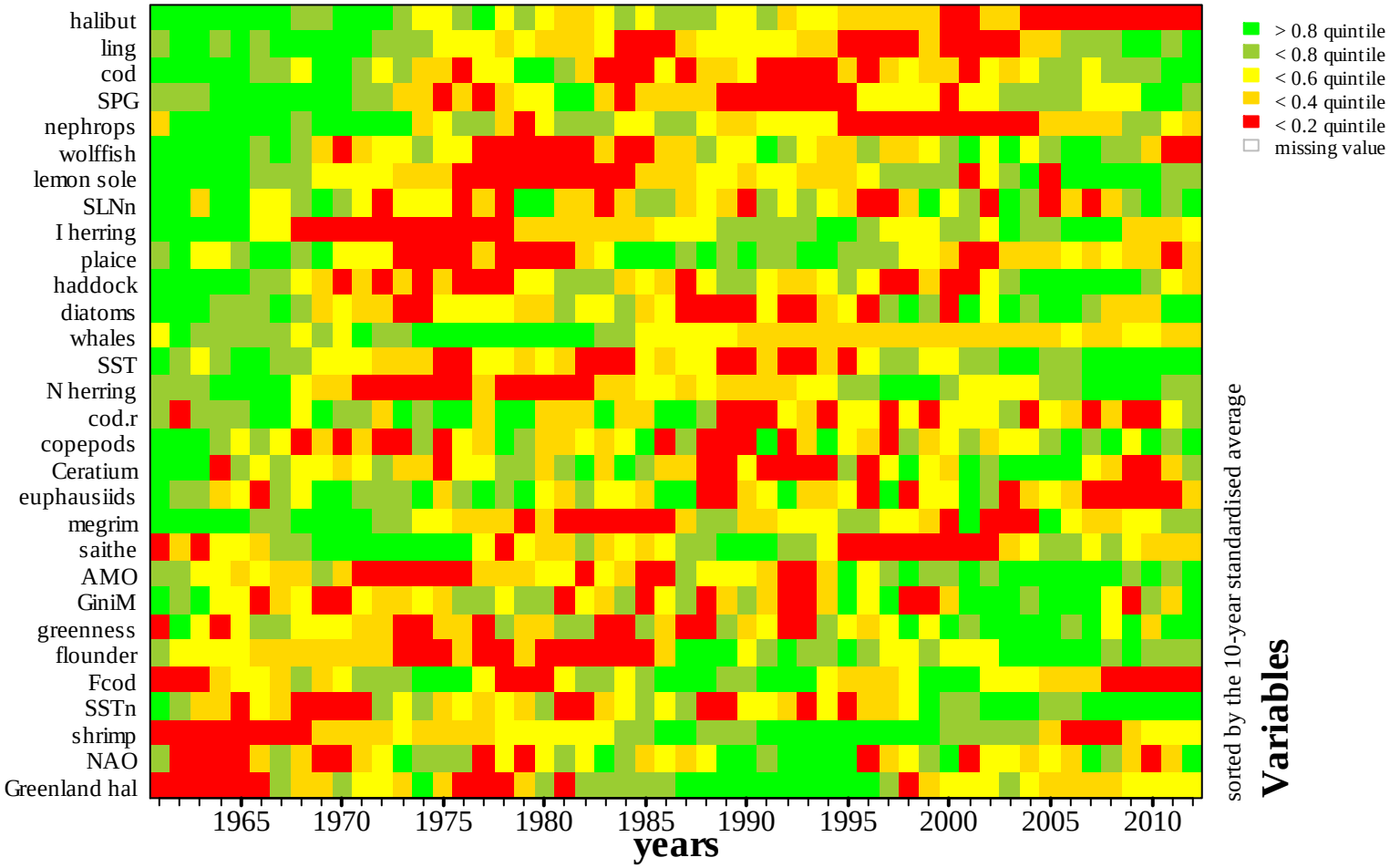
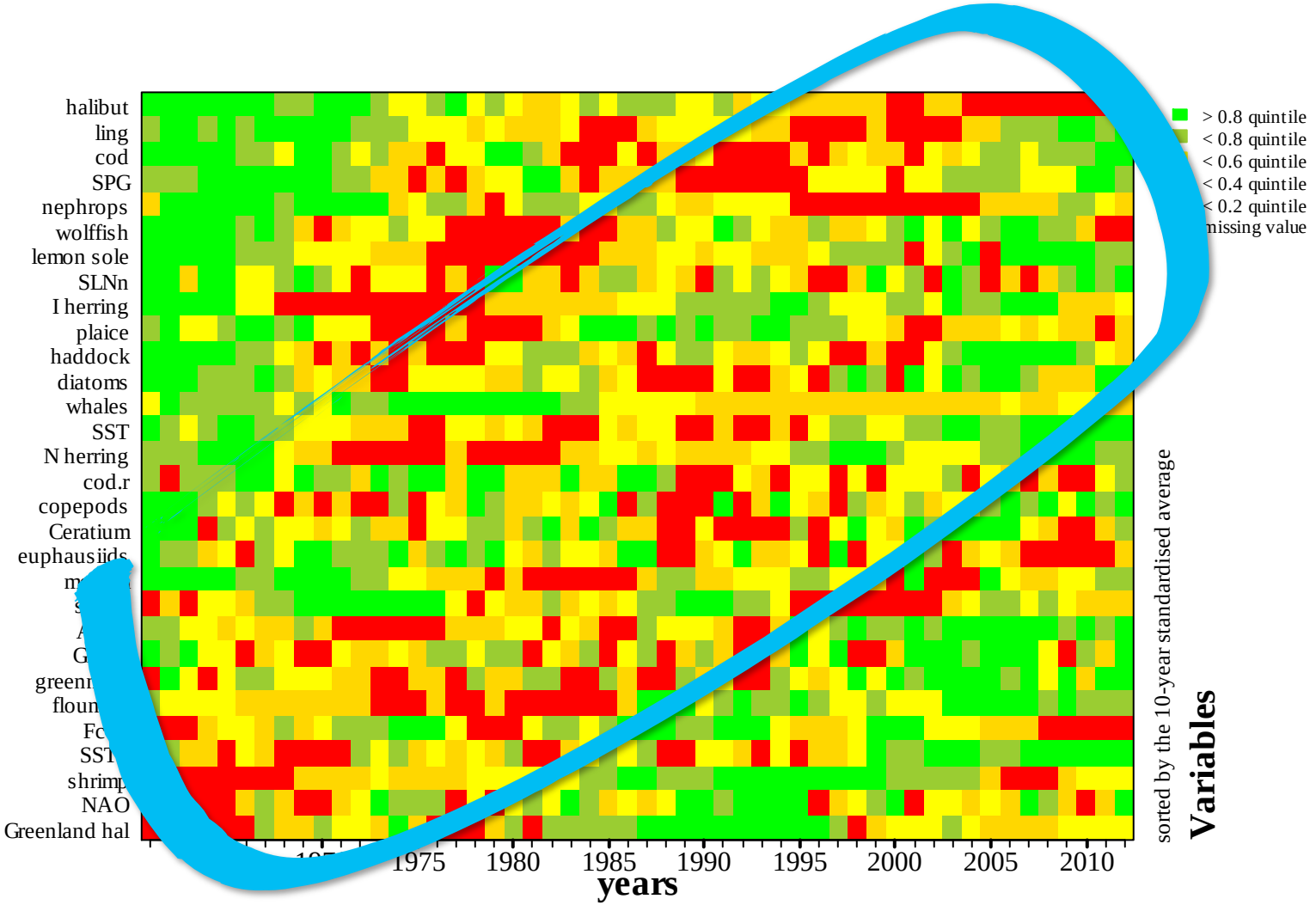
BARENTS SEA | trafficlight plot

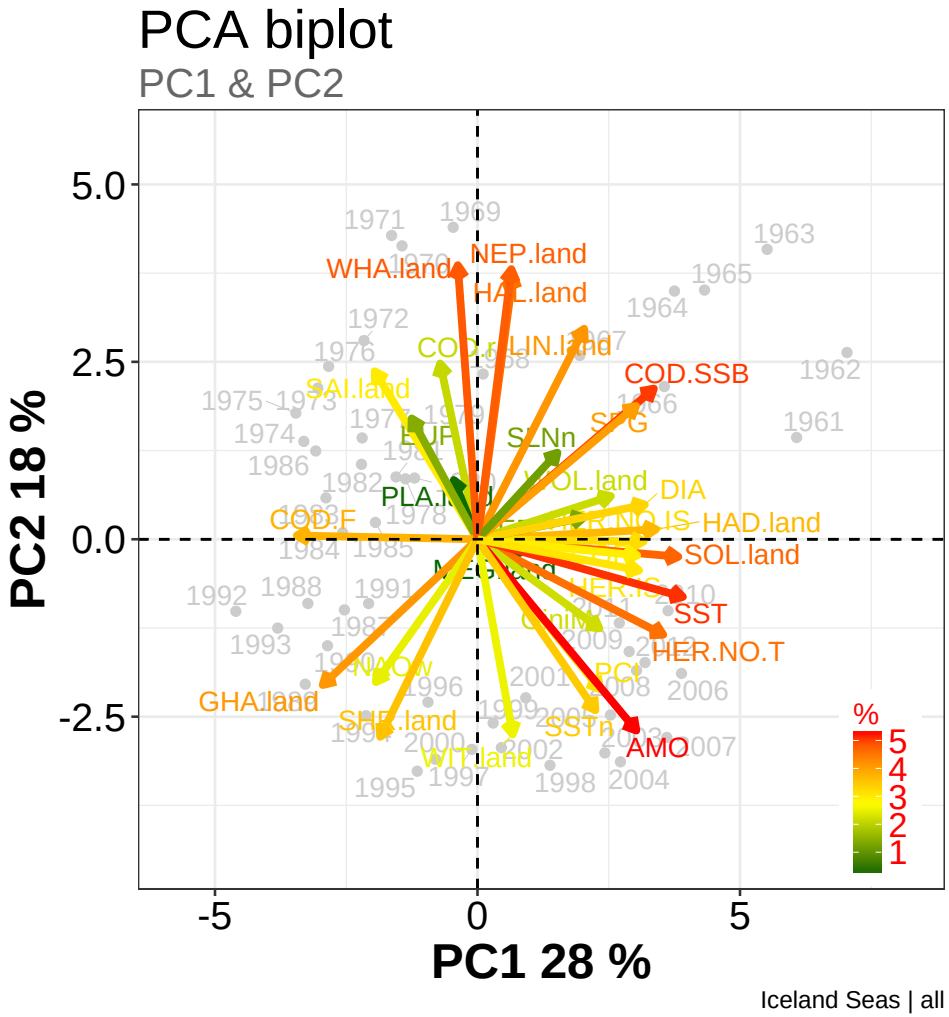


ICELAND SEAS | trafficlight plot



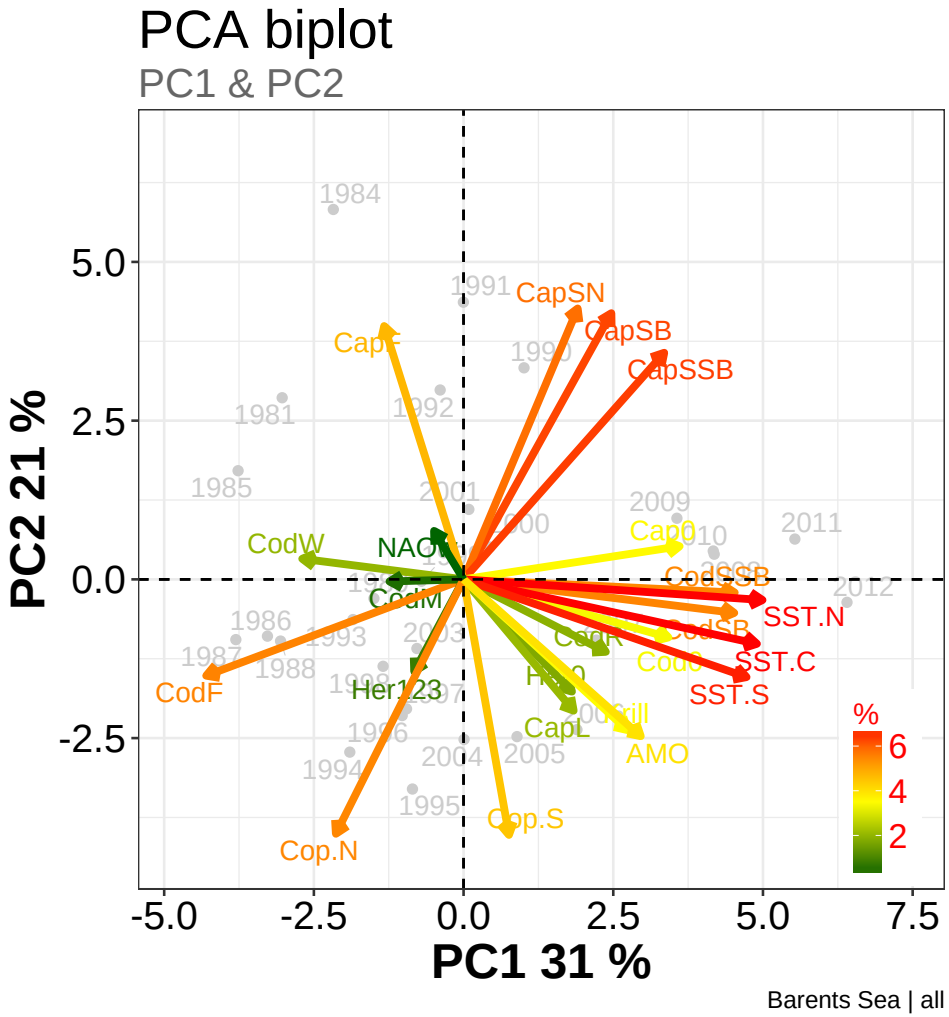
ICELAND SEAS | trafficlight plot





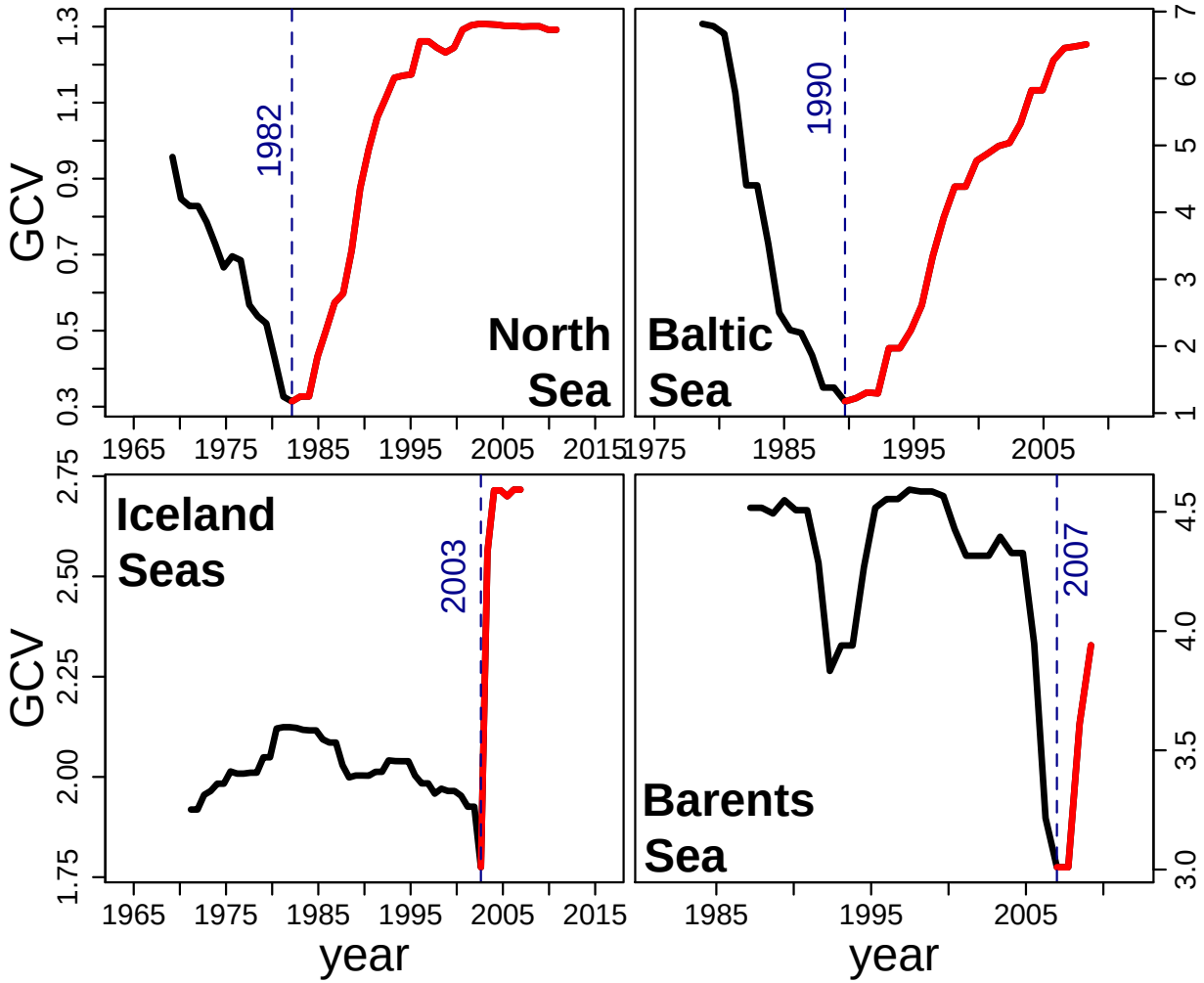
Iceland Seas | all

BARENTS SEA | PC analysis

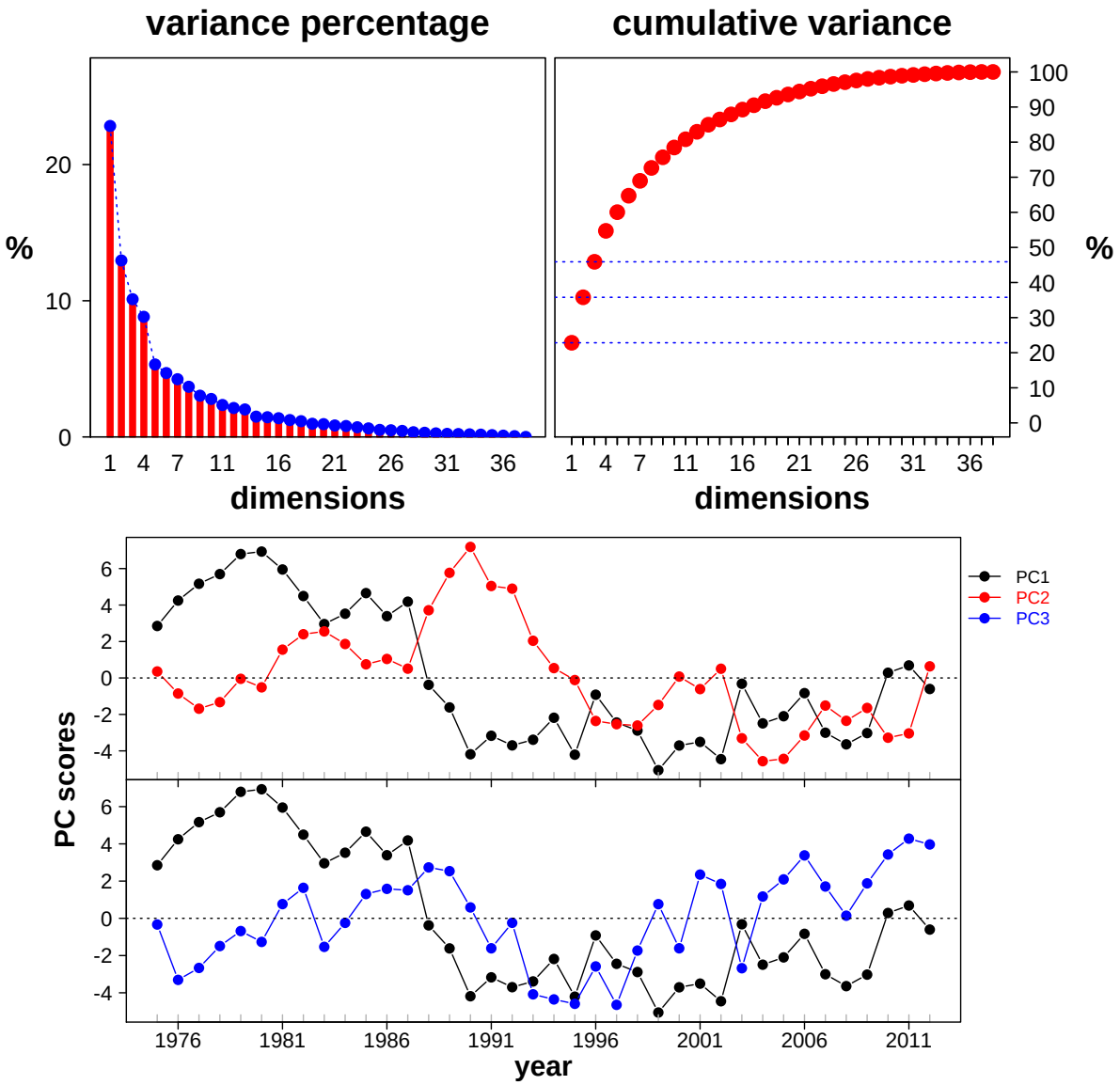


Barents Sea | all

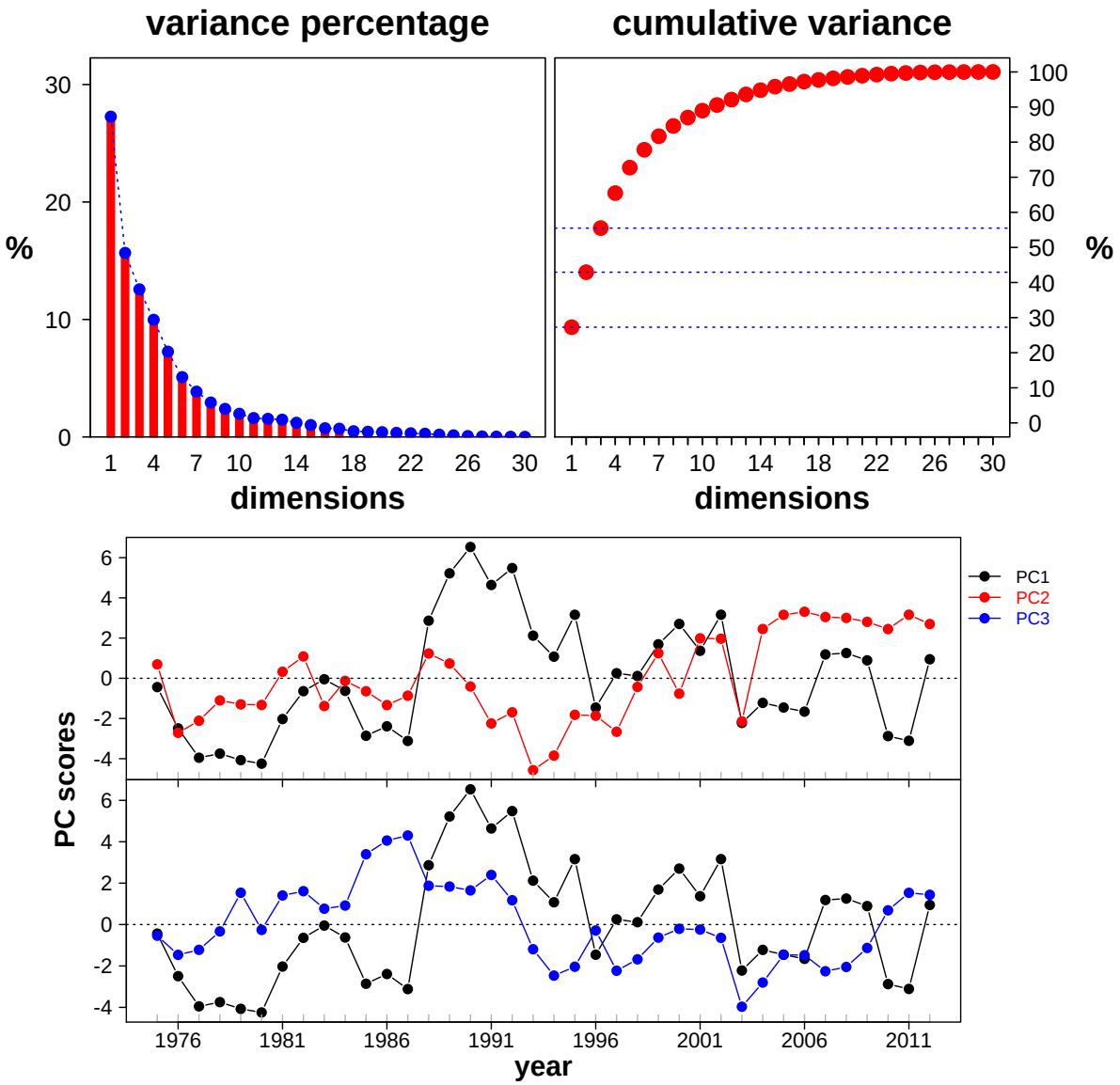
THRESHOLD | estimation tGAM



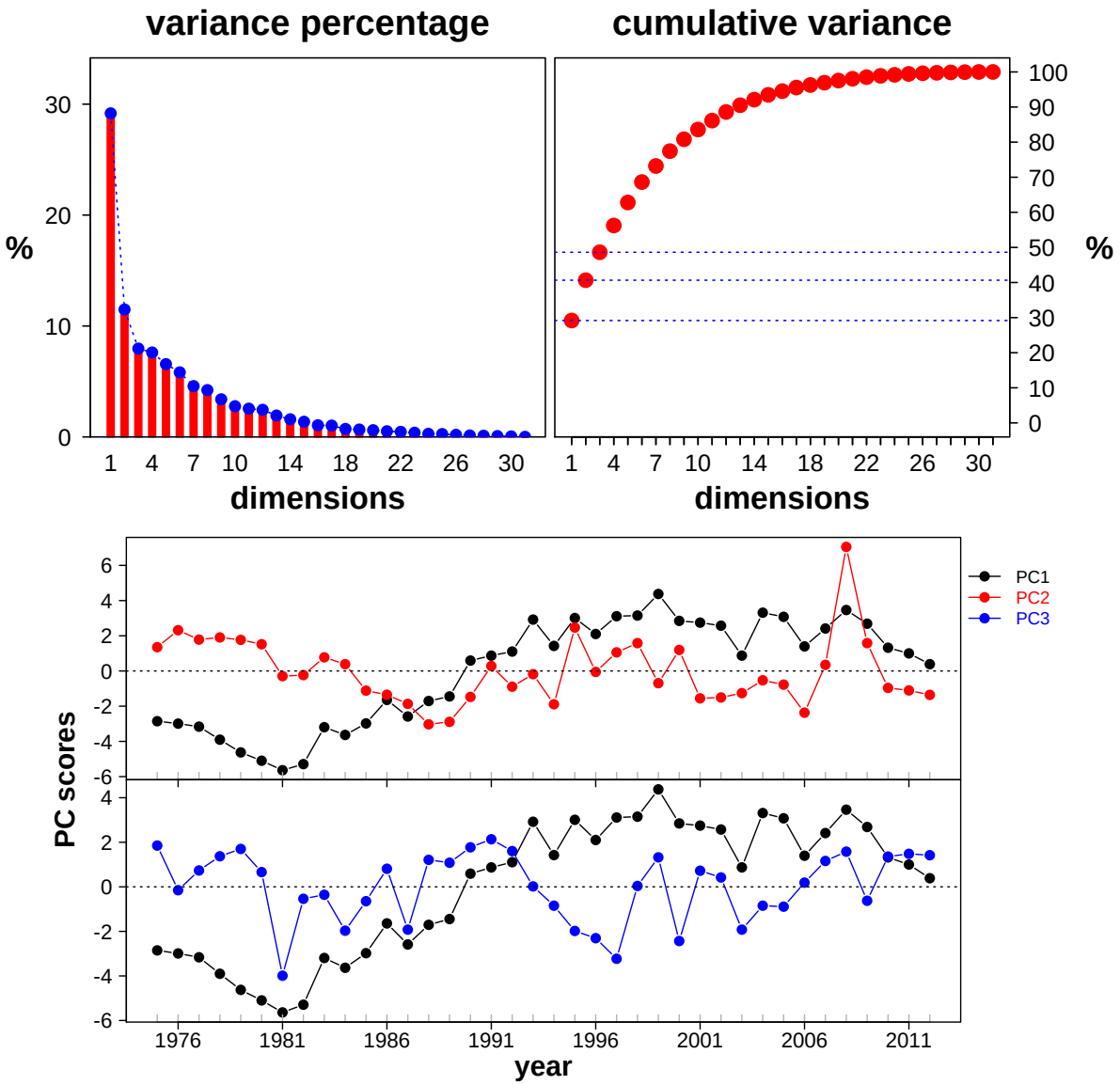
BALTIC SEA | PC analysis | whole dataset



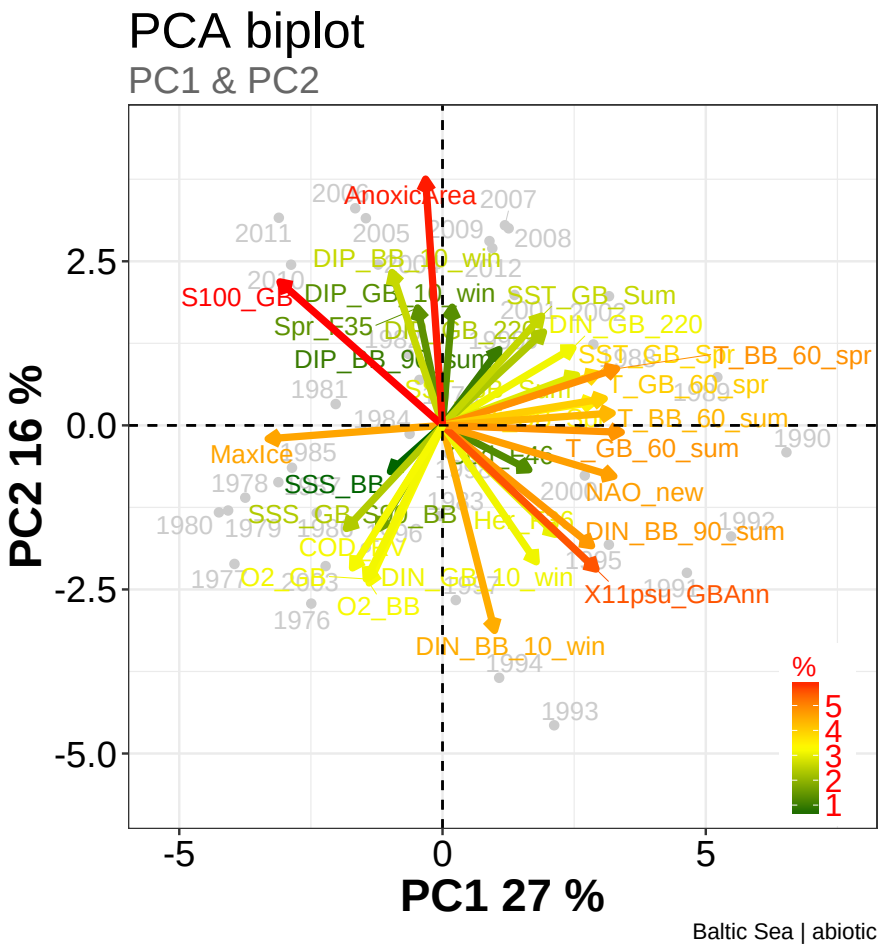
BALTIC SEA | PC analysis | abiotic



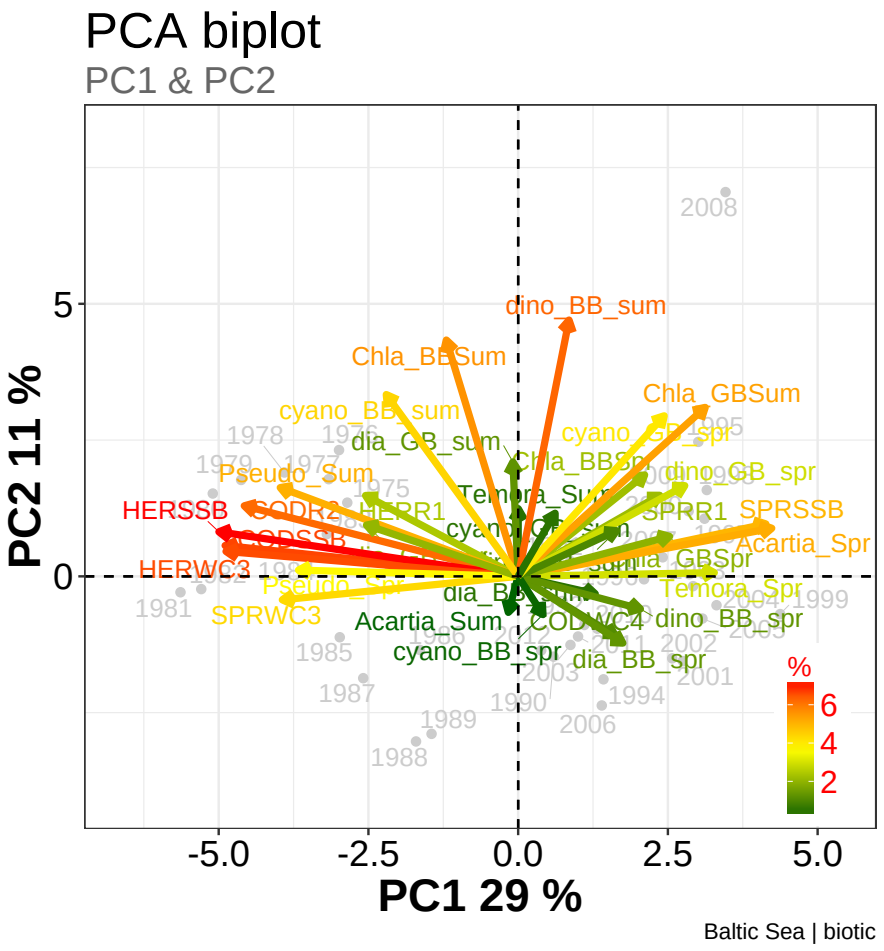
BALTIC SEA | PC analysis | biotic



BALTIC SEA | PCA biplot

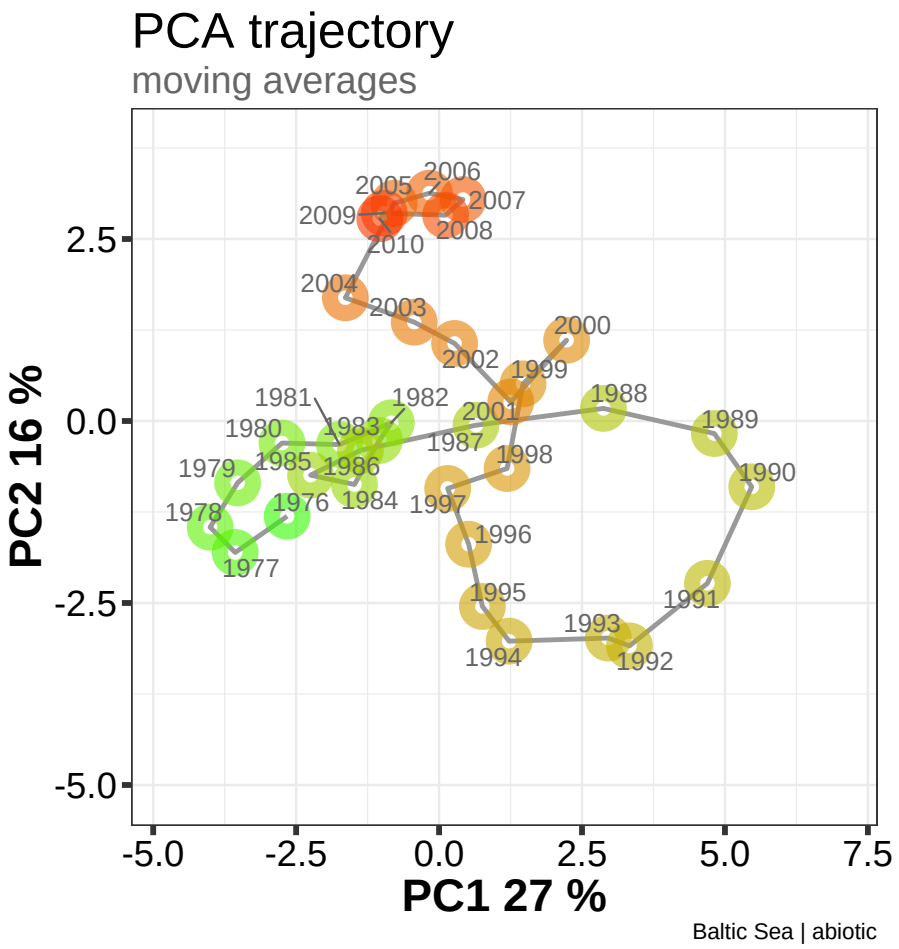


ABIOTIC

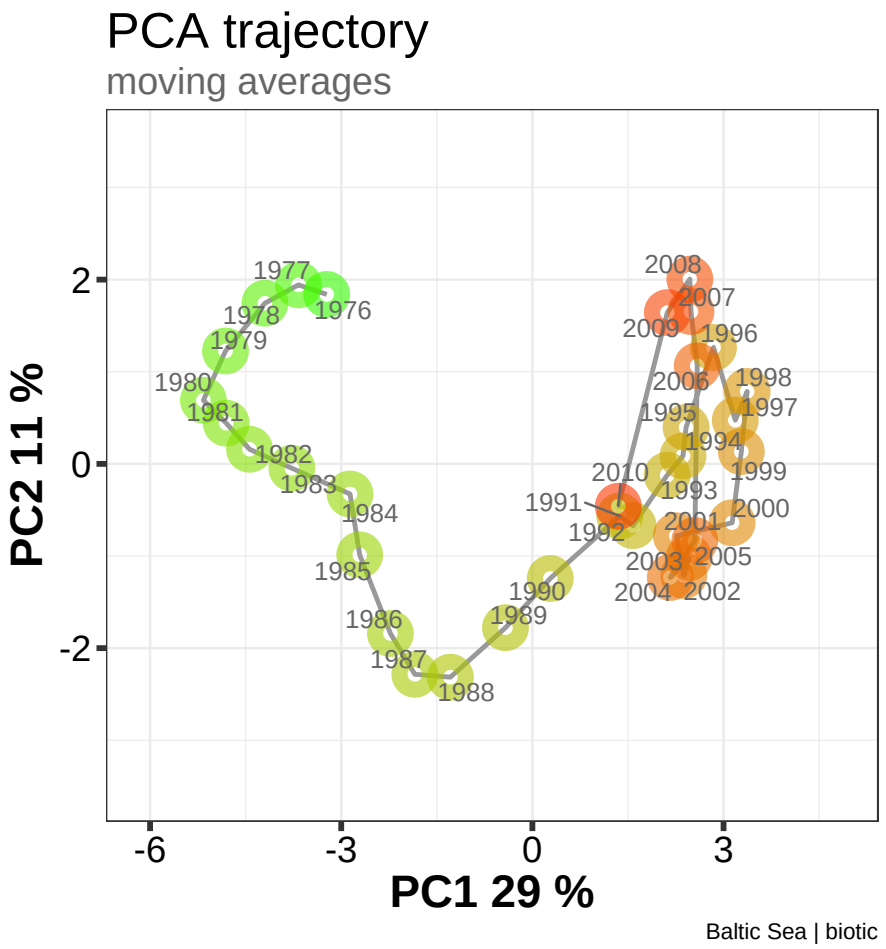


BIOTIC

BALTIC SEA | PCA trajectories

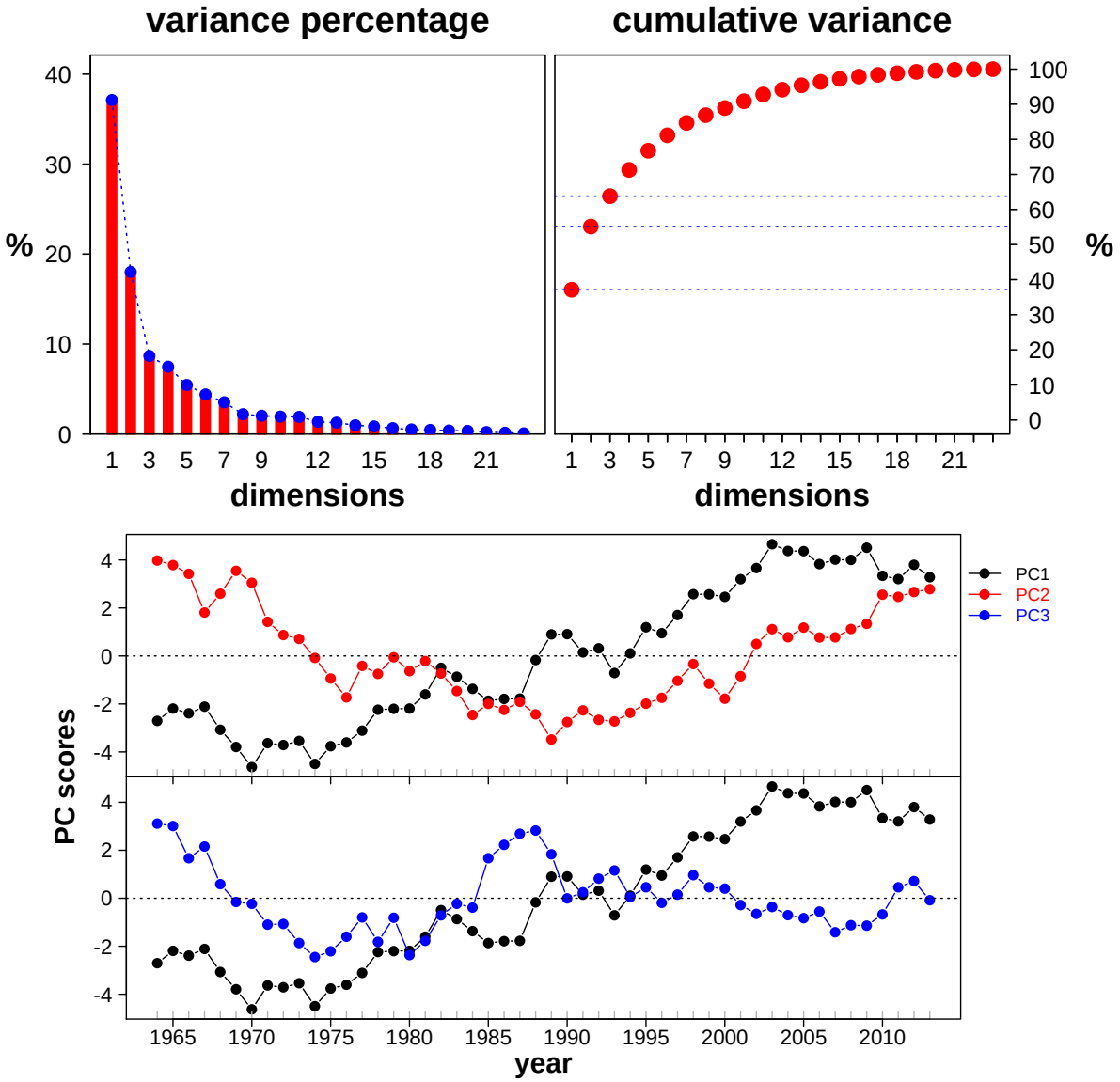


ABIOTIC

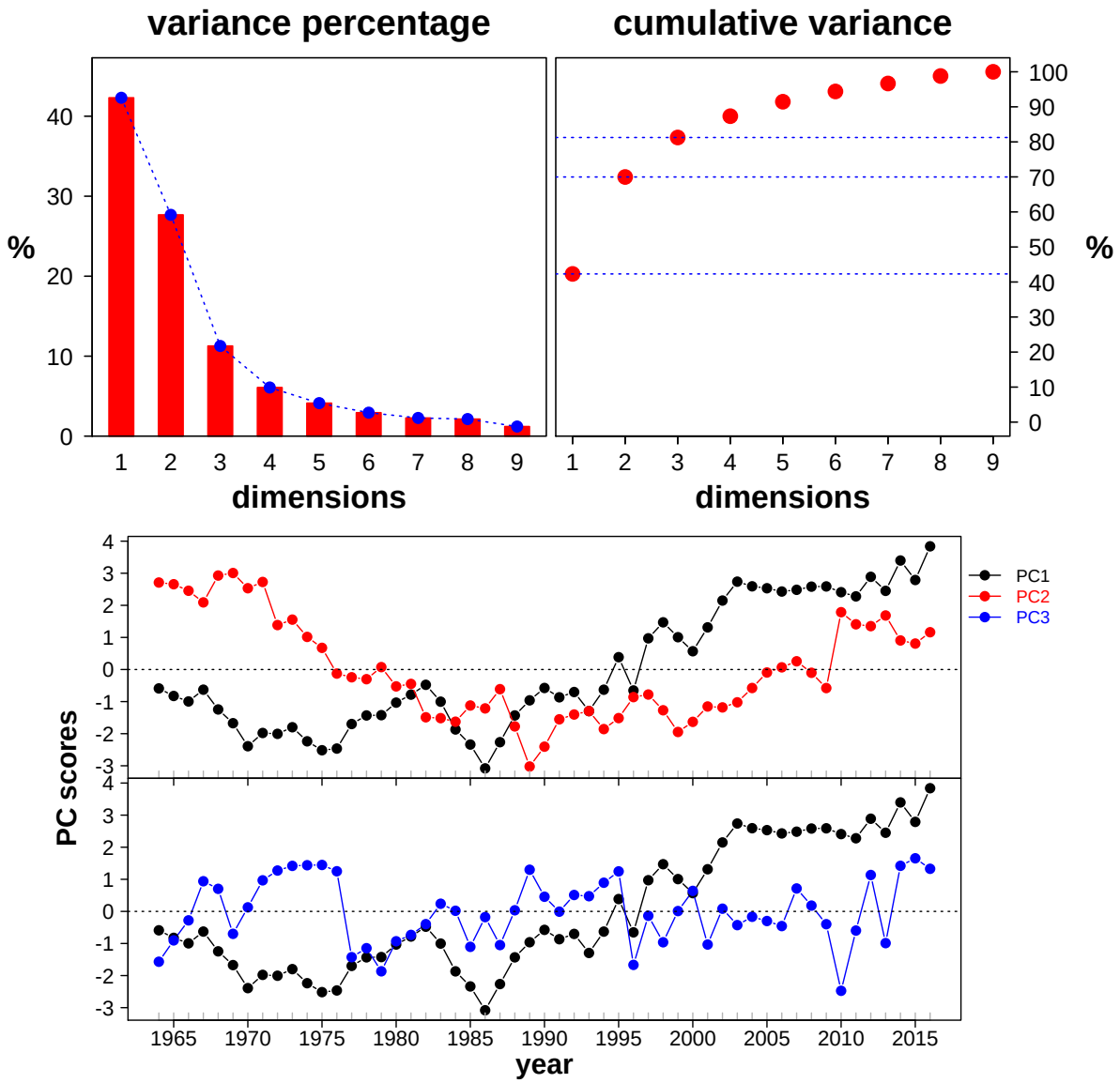


BIOTIC

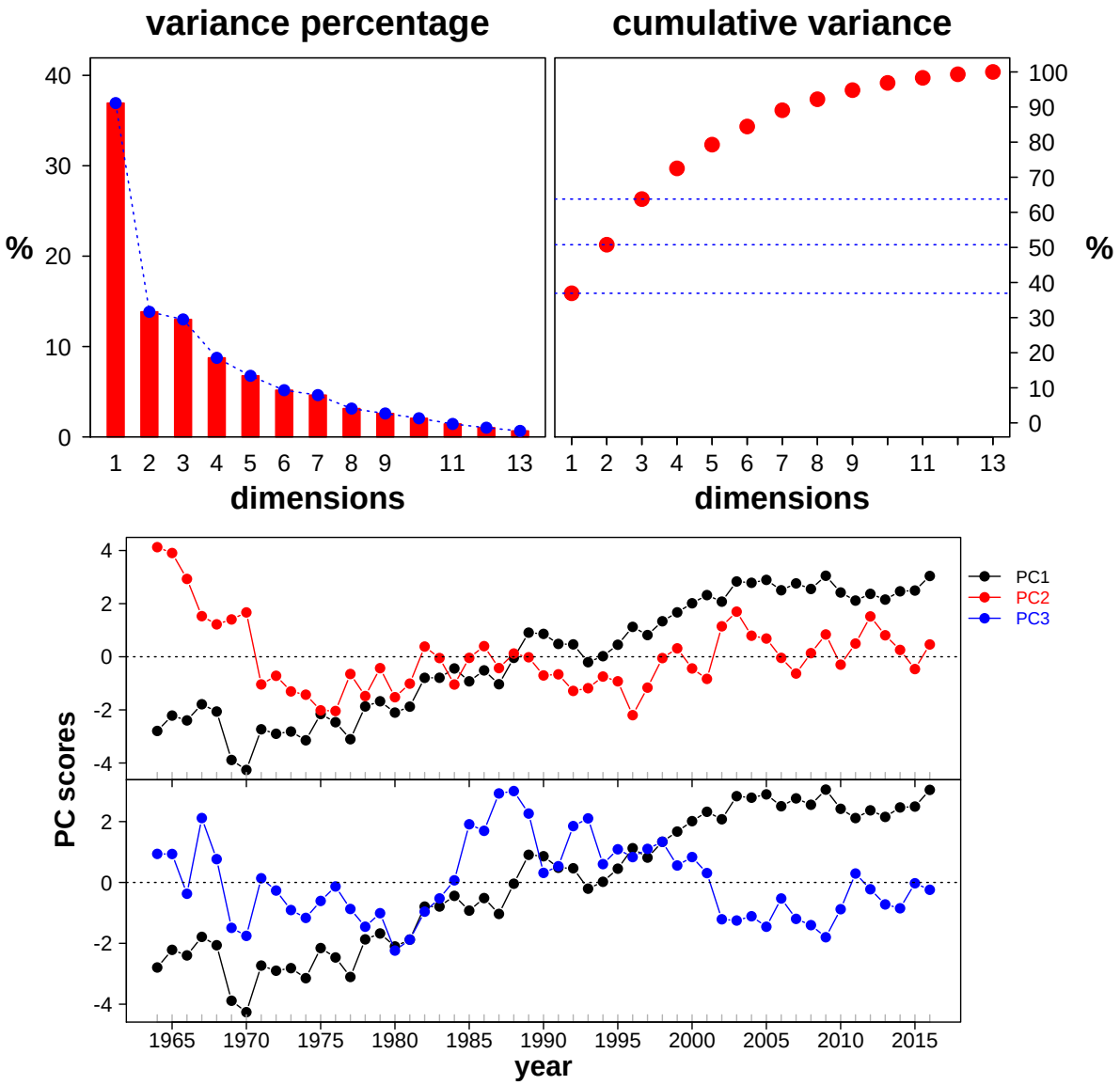
NORTH SEA | PC analysis | whole dataset



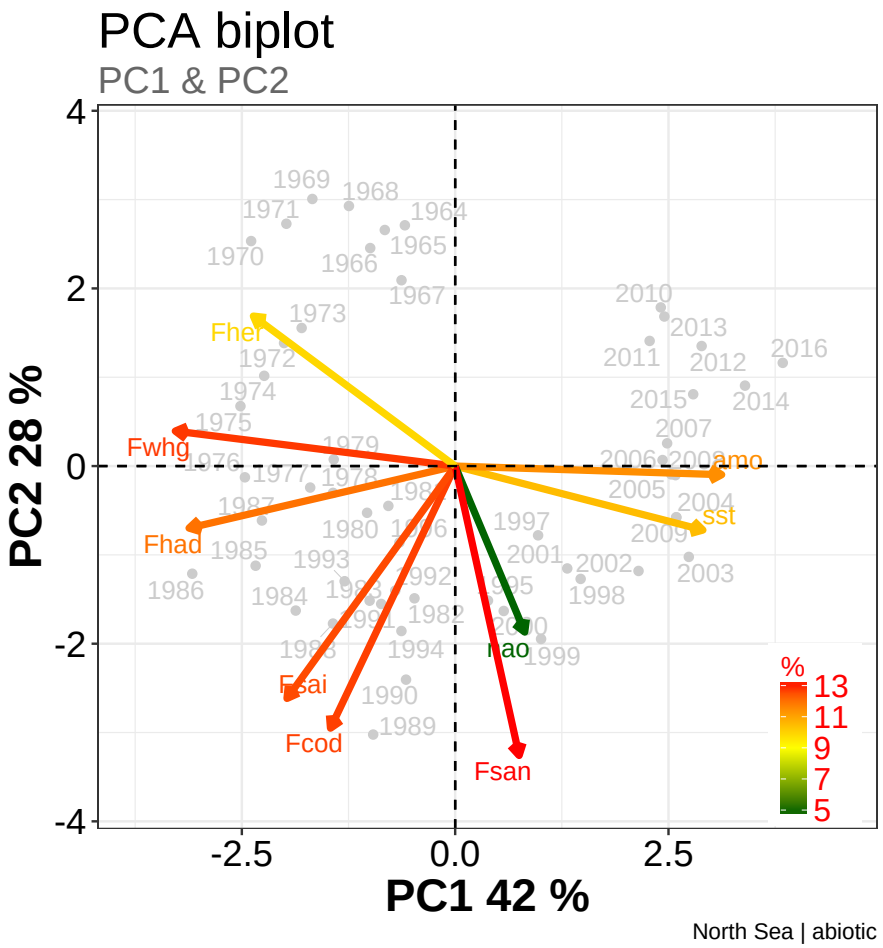
NORTH SEA | PC analysis | abiotic

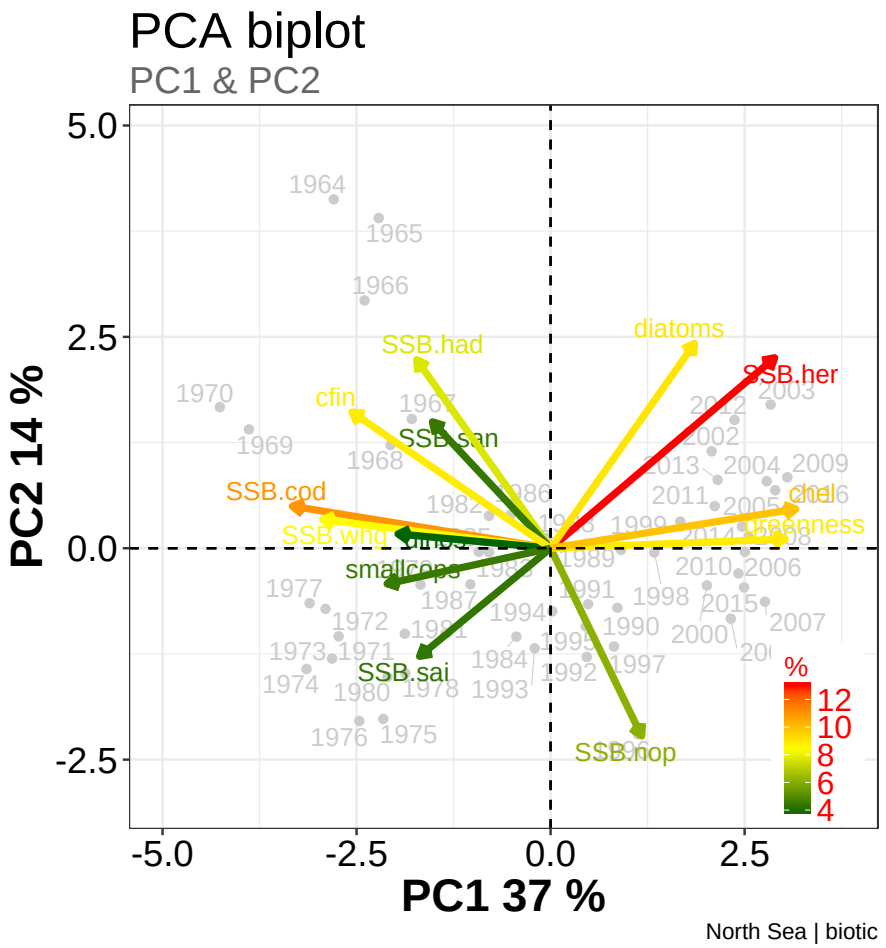


NORTH SEA | PC analysis | biotic



NORTH SEA | PCA biplot

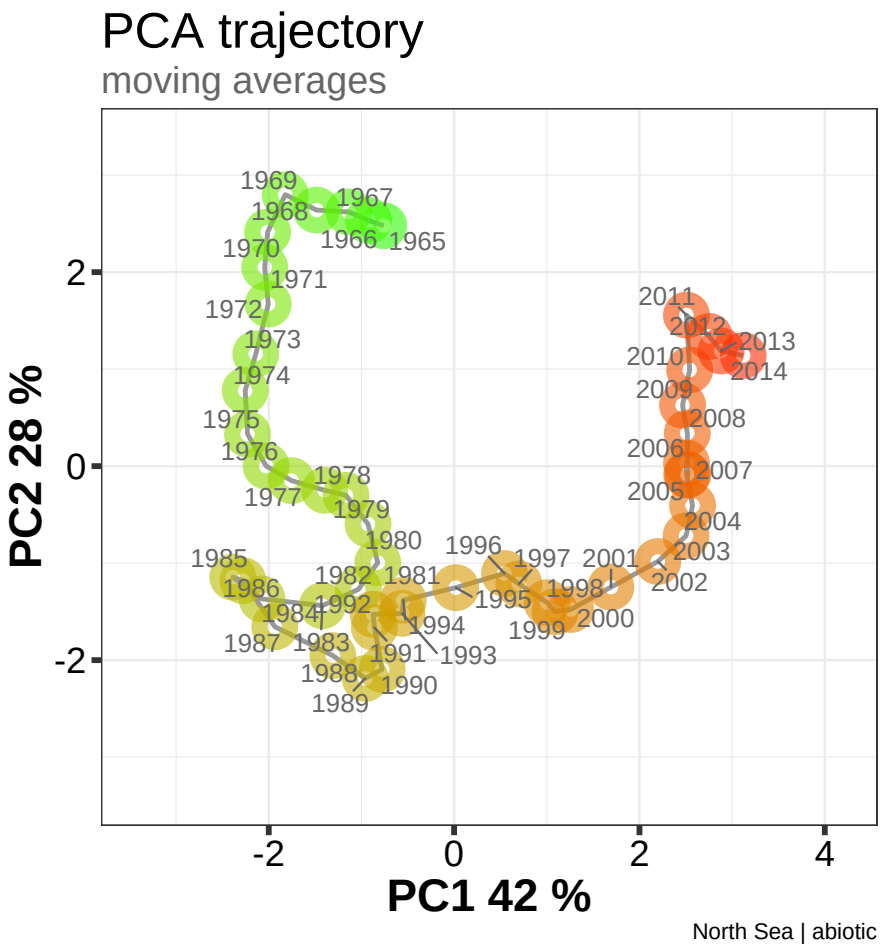




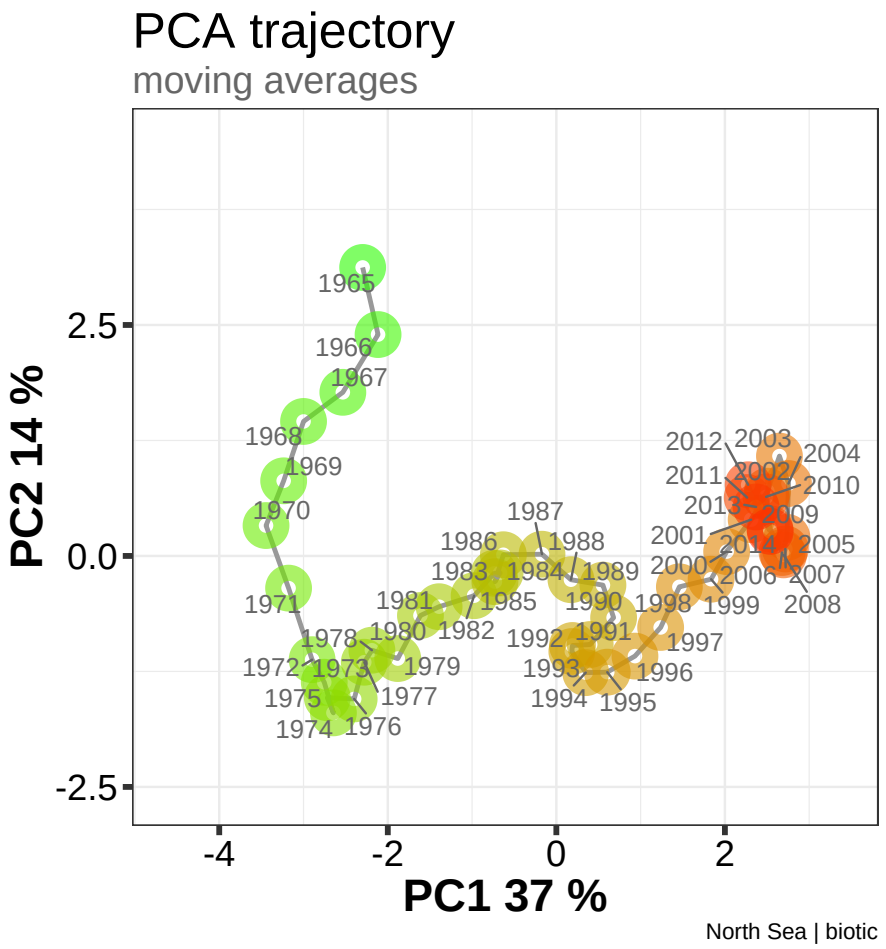
ABIOTIC

BIOTIC

NORTH SEA | PCA trajectories

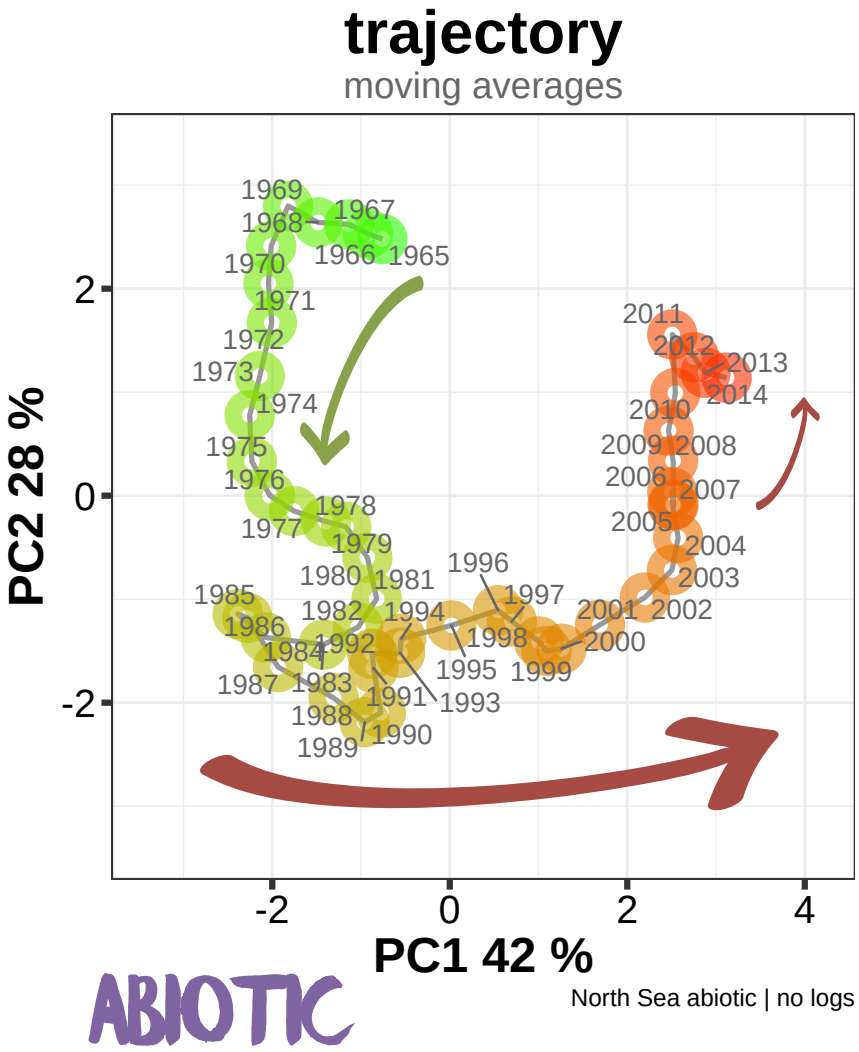


ABIOTIC



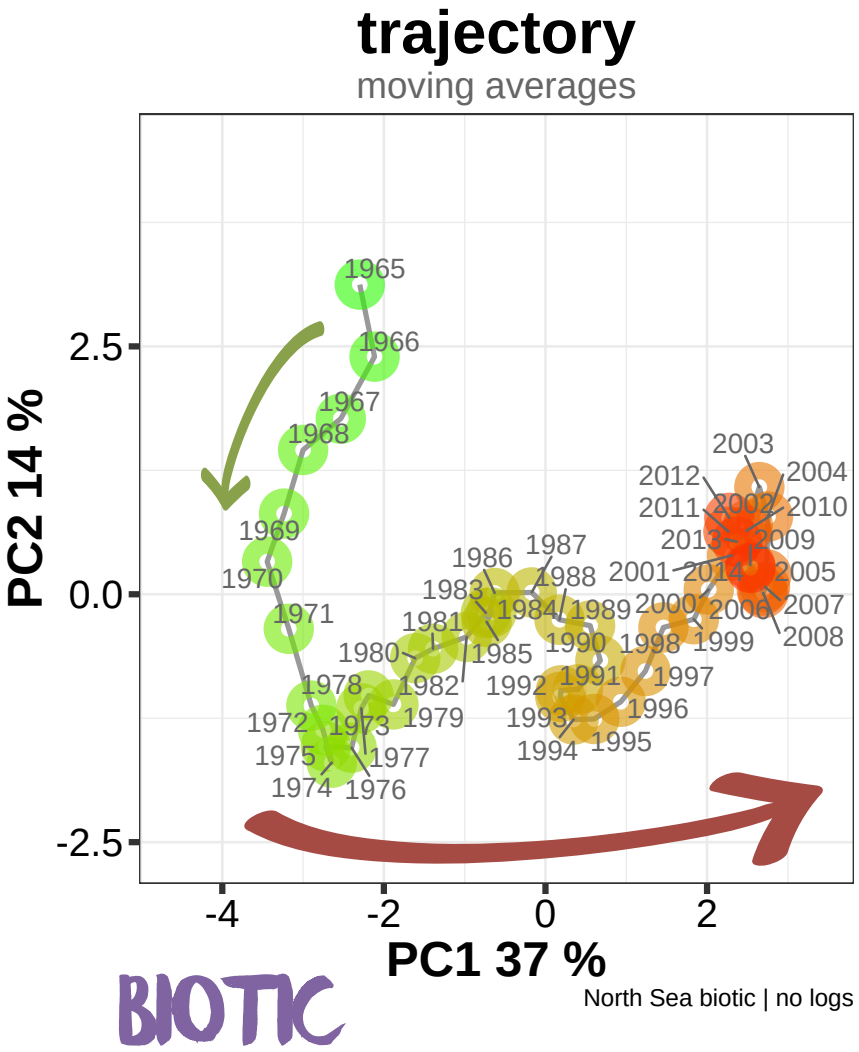
BIOTIC

NORTH SEA | PC analysis



ABIOTIC

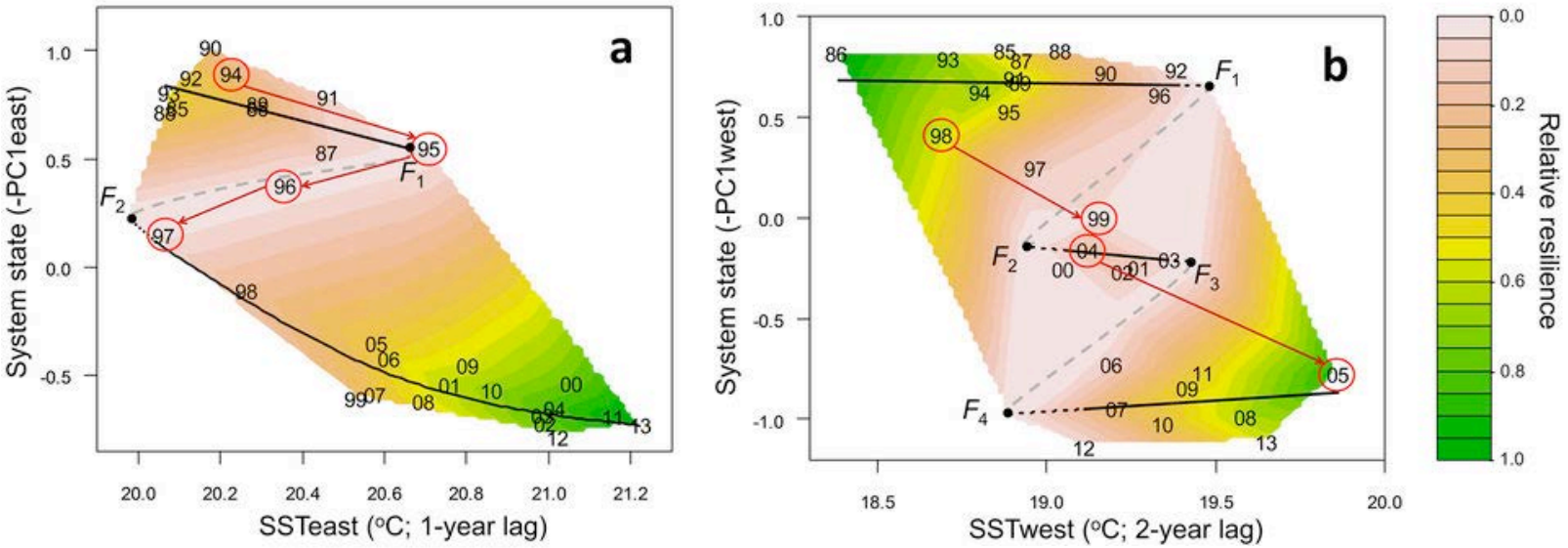
North Sea abiotic | no logs



BIOTIC

North Sea biotic | no logs

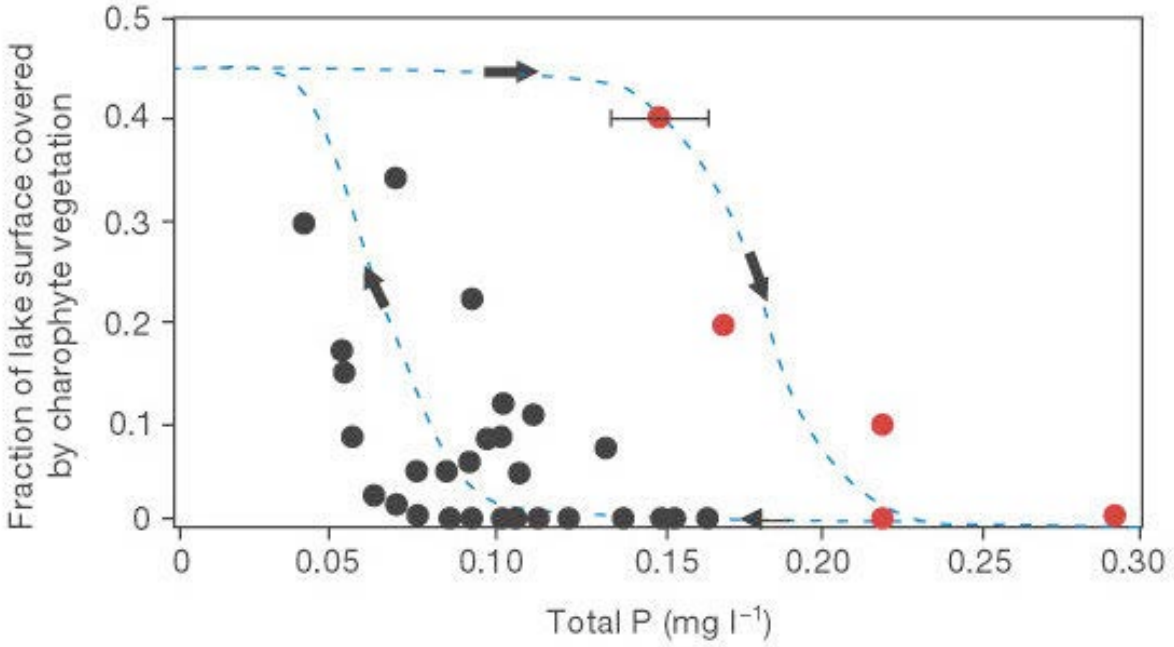
QUANTIFYING RESILIENCE



and later on Mediterranean fish in what was coined 'integrated resilience assessment'

Vasilakopoulos *et al.* (2017) *Scientific Reports*

PREVIOUS STUDIES



Hysteresis have been seen in lakes

Scheffer *et al.* (2001) *Nature*


BARENTS
SEA
SEAS OF
ICELAND
NORTH
SEA
BALTIC
SEA

2 data | cod
differences