Climate-related decadal dynamics in Baltic Sea zooplankton: Interactive and additive effects of bottom-up and top-down controls

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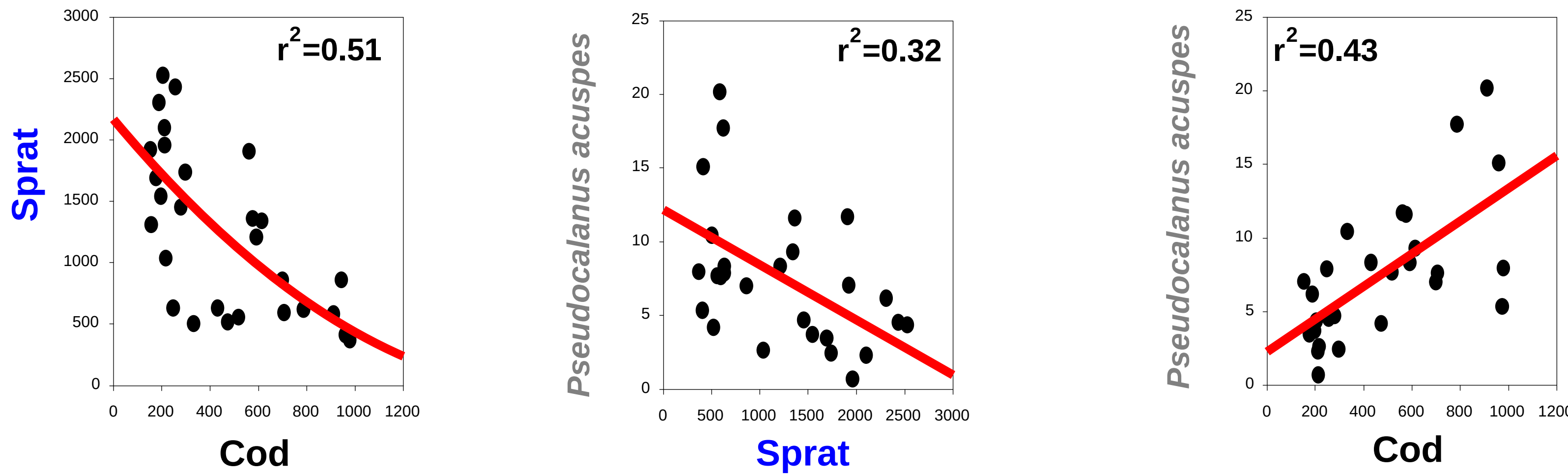
Introduction

- **Central Baltic ecosystem has experienced pronounced changes in structure and function („Regime Shift“) on all trophic levels in late 80s**
- **Intiated by climate-induced changes in the abiotic environment**
- **Stabilized by high fishing mortality on top predator cod (*Gadus morhua*) and top-down cascading effects:**



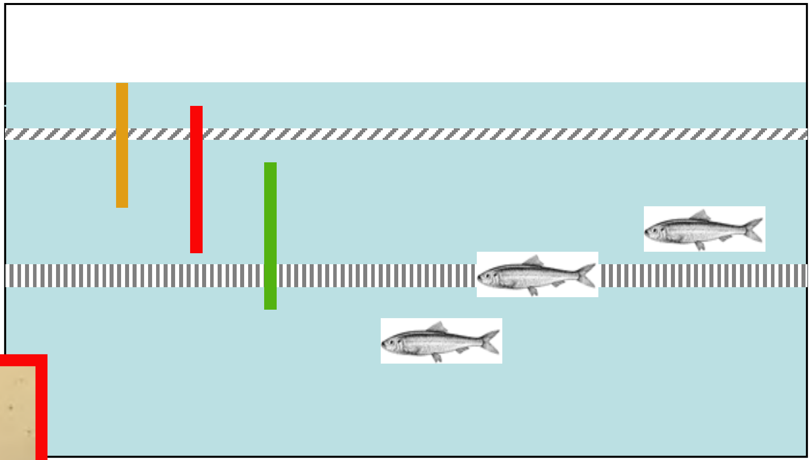
- **Zooplankton was a major player in these changes**

Introduction – Species Characteristics

- **ACARTIA**
- mainly *A. bifilosa* / *A. longiremis*
- brackish-water species
- thermophilic

PSEUDOCALANUS

- *P. acuspes*
- arctic relict species
- inhabits halocline region
- dominant species in winter
- main prey species for planktivorous fish



TEMORA (*T. longicornis*)

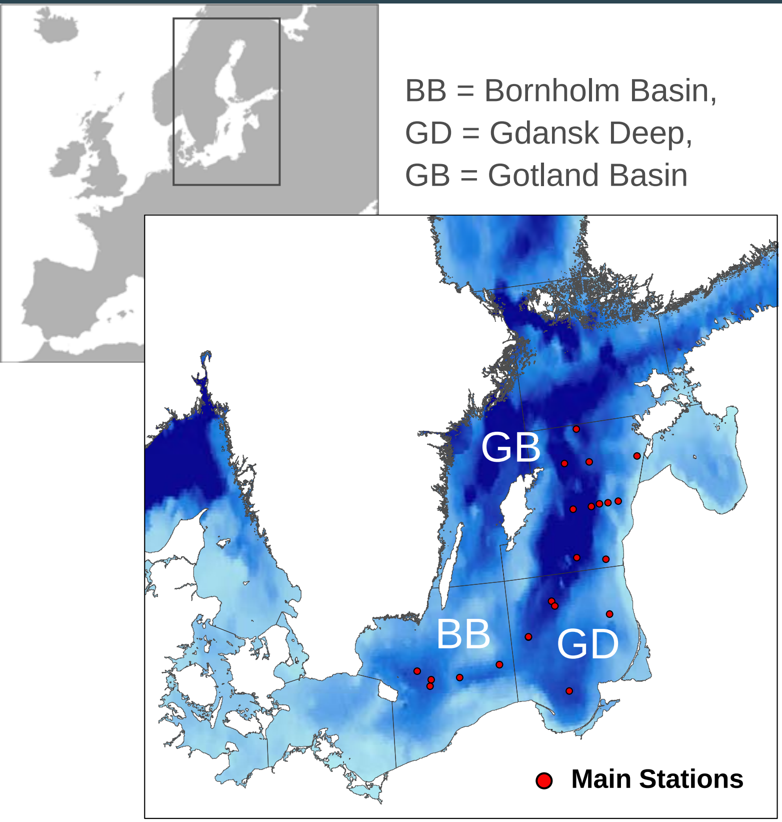
- euryhaline, neritic species
- thermophilic
- lives in colder, more saline waters than *Acartia* (mainly in or below thermocline)
- prey species for planktivorous fish

Fotos: www.eol.org

Aim of the study

- *Analyse* inter-annual dynamics of main zooplankton species using
  - a long data set (1960 – 2008)
  - a more spatially resolved data set covering all three sub- regions of the Central Baltic Sea (Bornholm Basin, Gdansk Deep and Gotland Basin)
- *Identify* additive and interactive effects of climate and foodweb effects (i.e. bottom-up and top-down controls) using
  - Generalized Additive Models (GAMs)
  - Threshold Generalized Additive Models (TGAMs)

Study Area & Combinations of Time Series



BB = Bornholm Basin,
GD = Gdansk Deep,
GB = Gotland Basin

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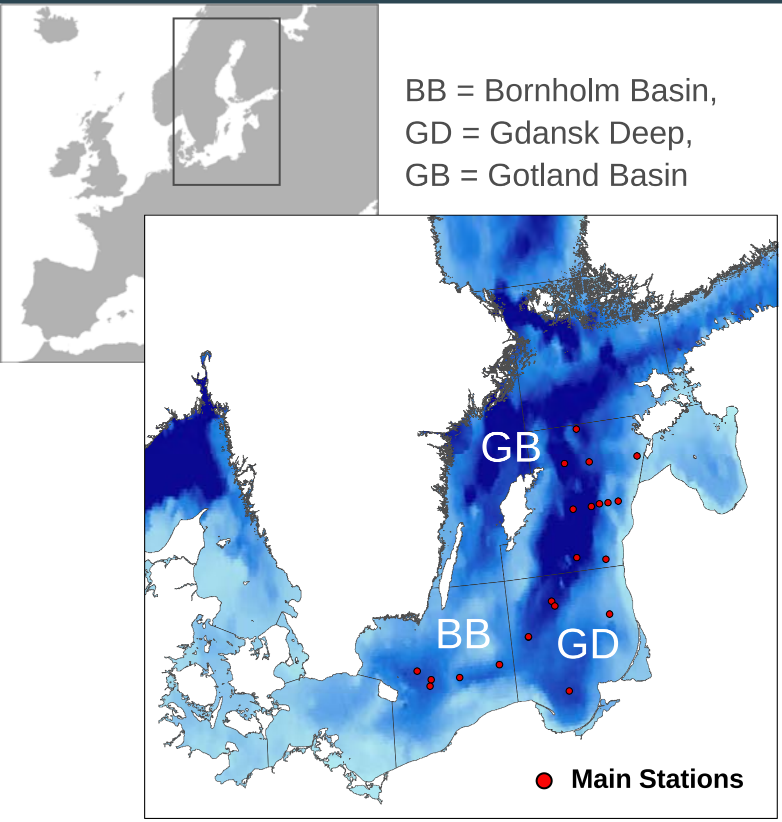

Latvian dataset (BIOR)	German dataset (IOW)
1960-2008 Juday net (mesh size 160 µm) 1 sampling / season 1-10 stations per basin	1979-2008 WP-2 (mesh size 100 µm) 1-6 samplings / season 1 station (Bornholm basin)

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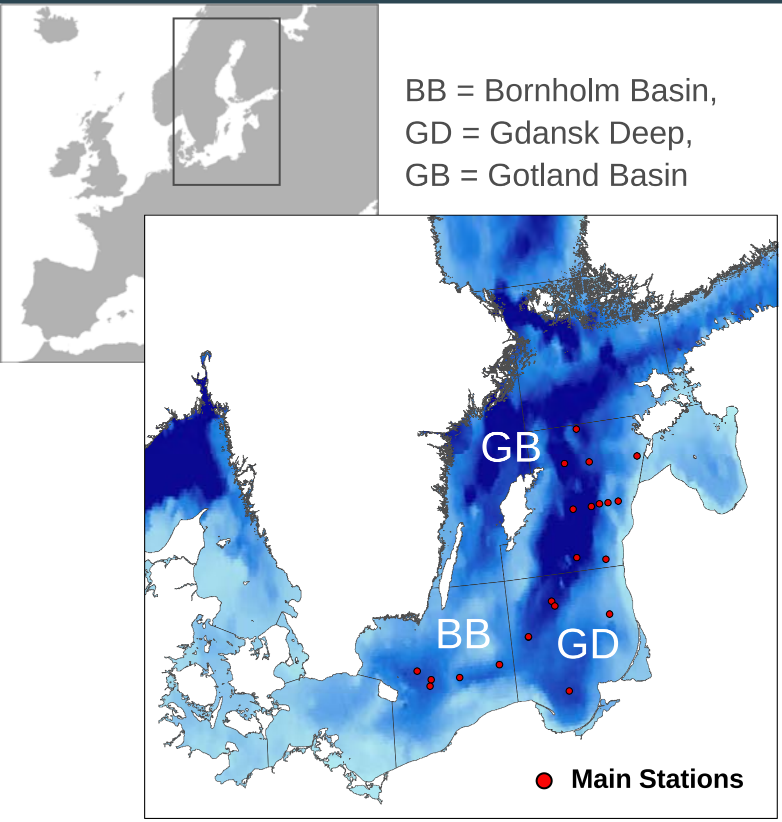

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- Average of species abundances (N* m^{-3} of C1-C6) per basin / season / year
- Overlapping years → calculation of weighted annual means from log10(x+1) transformed annual mean abundances of each time series and back-transformation to original abundances
- Modelled variable: log-transformed anomalies (Mackas & Beaugrand, 2010)

  $A'(t) = \log[A(t)] - \log[\bar{A}] = \log[A(t) / \bar{A}]$

Variable Selection

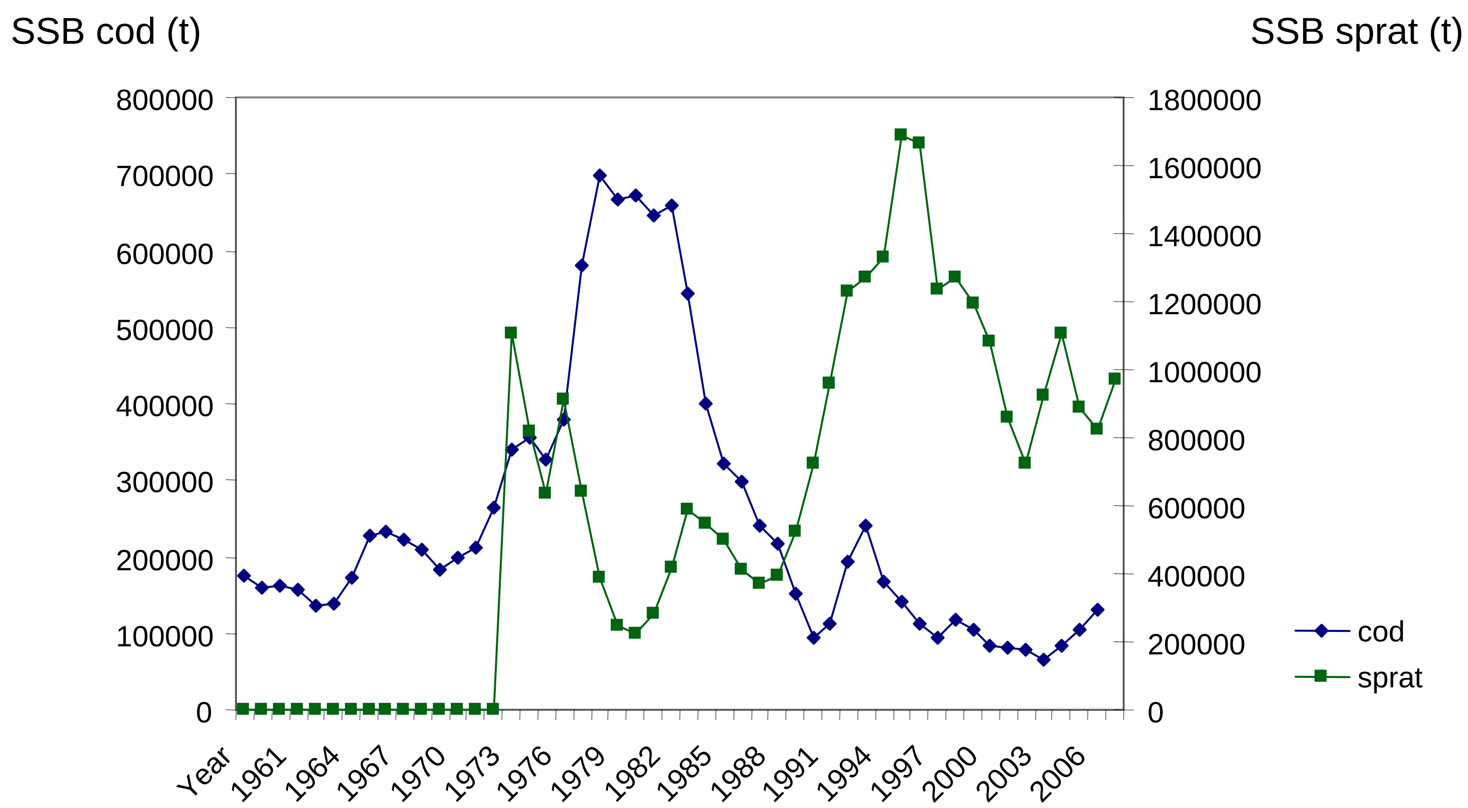
Based on prior knowledge and an explorative correlation analysis seasons and abiotic / biotic predictor variables were identified:

A = *Acartia* spp., **T** = *Temora longicornis*, **P** = *Pseudocalanus acuspes*

Spring: A, T **Winter**: P

- Local climate index: **Baltic Sea Index** (**BSI**) (Dec-March mean) (A, T, P)
- **Temperature**: seasonal mean value per basin and depth stratum (A, T)
- **Salinity**: seasonal mean value per basin and depth stratum (T, P)
- **Predation Index (PI):** based on annual mean of cod spawning stock biomass as an indirect index of predation pressure (T, P)

Variable Selection



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Statistical Models

Generalized Additive Models (GAM)

- cope with **non-linear patterns**
- **smoothing function** links response and explanatory variable
- correlation structures included when models indicated **auto-correlation**

$$P.a._{by}^{s} = \alpha + Ba\sin_{y} + f_{b}(BSI_{y}) + g_{b}(S_{y}^{s}) + j_{b}(PI_{y}) + \varepsilon_{by}^{s}$$

Indices: s=season, b=basin, y=year
f, *g*, and *j* : individual smoother

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Threshold GAM (TGAM)

- modified GAM formulation
- allows for **2 different effects below / above threshold** of predation
- threshold is **estimated from the data**
- see also Ciannelli et al. (2004)

$$P.a._y^s = \left\{ \alpha + \frac{f_1(BSI_y) + g_1(S_y^s) + j_1(PI_y) + \varepsilon_y^s}{f_2(BSI_y) + g_2(S_y^s) + j_2(PI_y) + \varepsilon_y^s} \right. \begin{array}{l} PI < r \\ \text{otherwise} \end{array}$$

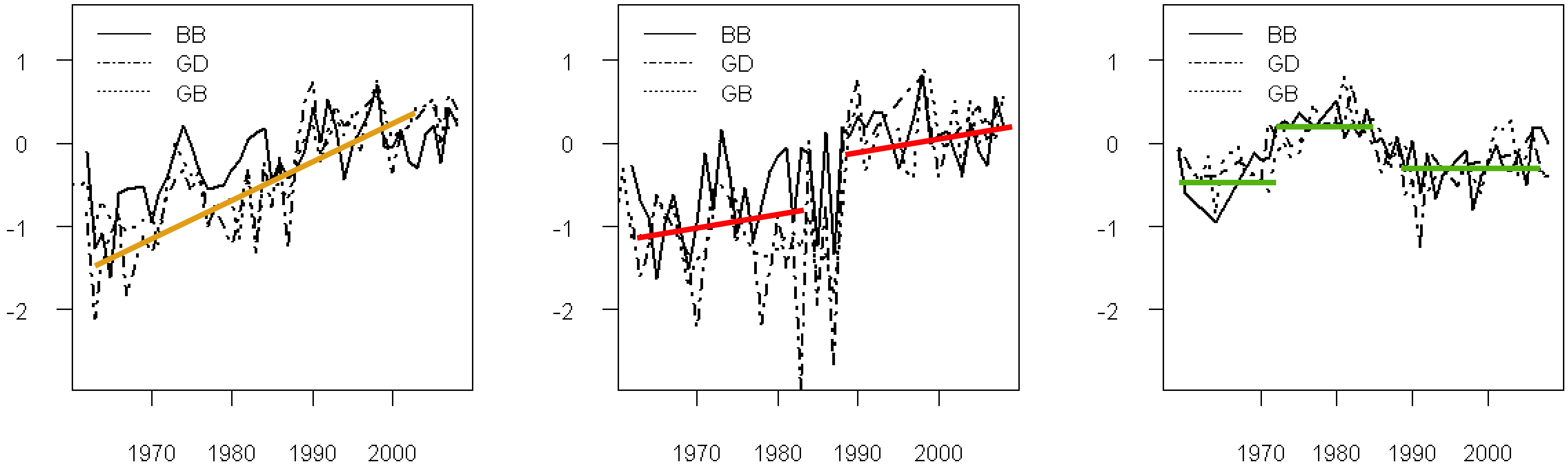
f_1, f_2, g_1, g_2, j_1 *and* j_2 : individual smoother in each PI state

Results – Long-term Trends

Acartia spp.

Temora longicornis

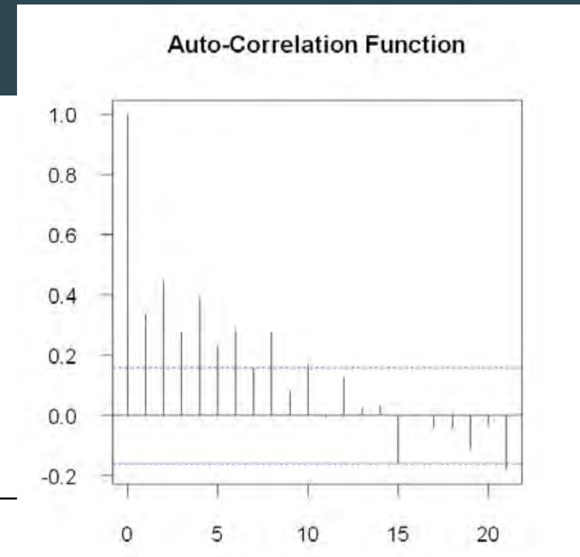
Pseudocalanus acuspes

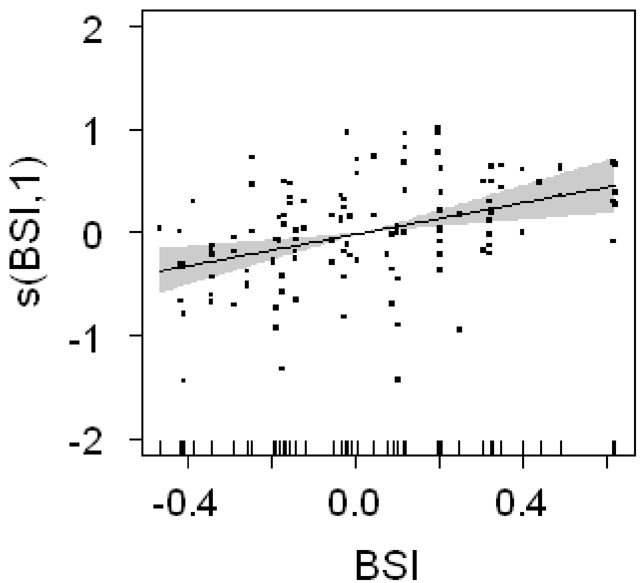


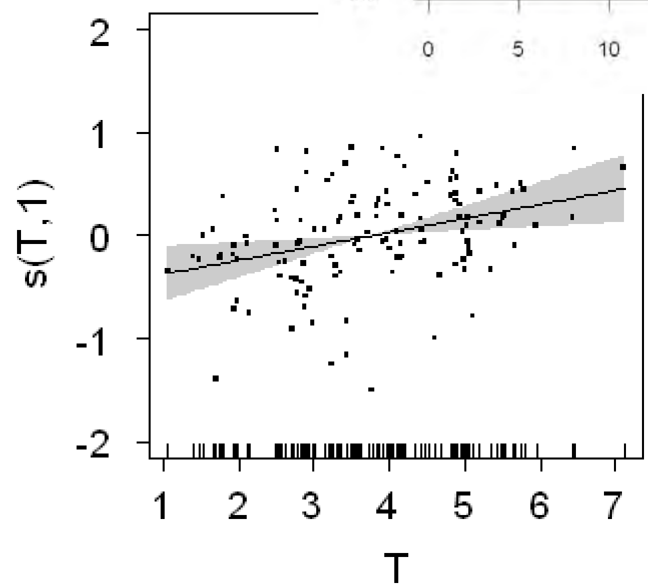
No significant BASIN effect!

Model Results – *Acartia* spp.

Species	Model	Predictors	explained dev. (%)	GCV	gCV
A. spp.	GAM	BSI + T	37.3	0.219	
	GAMM	BSI + T	29.5		







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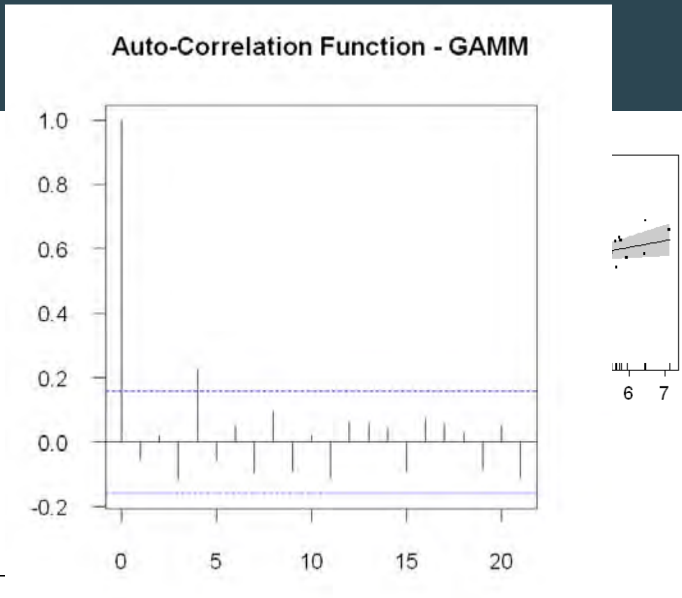
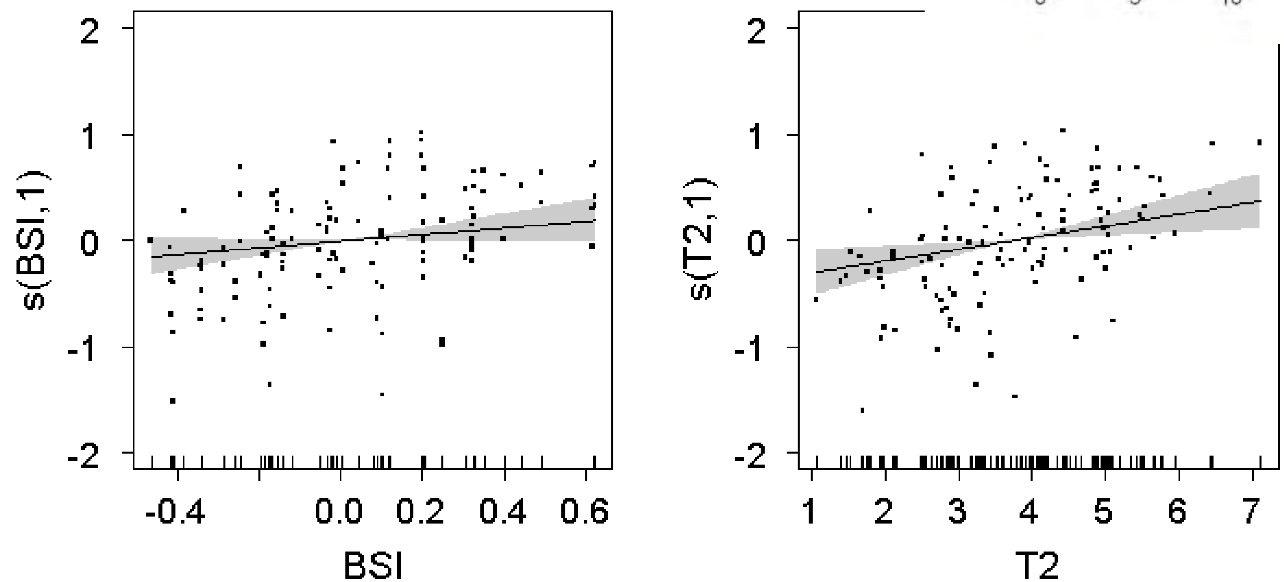
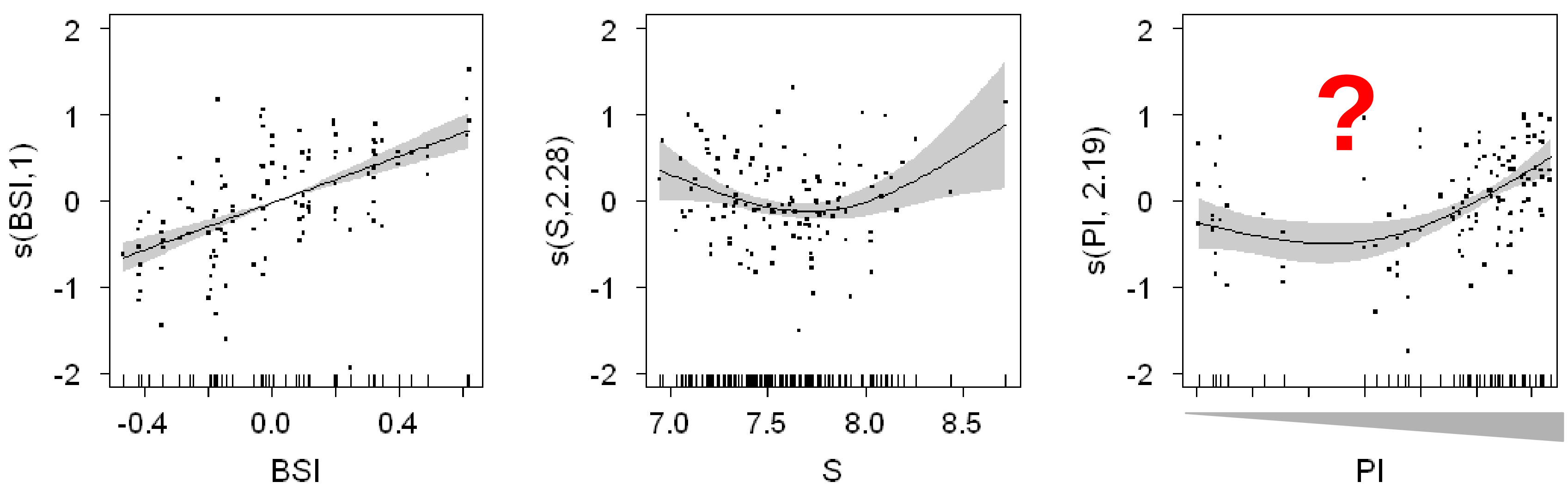




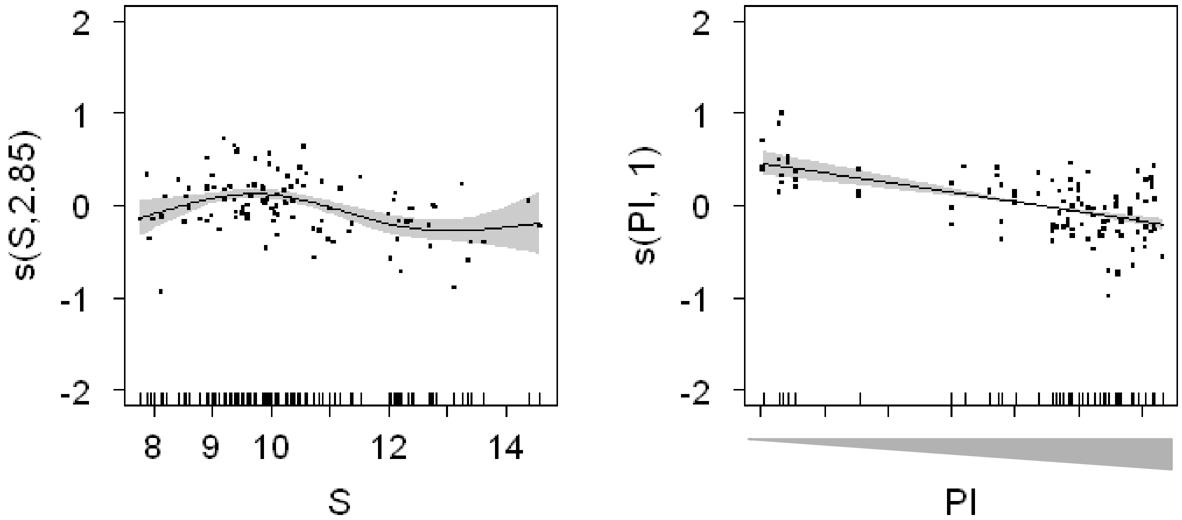
Model Results – *Temora longicornis*

Species	Model	Predictors	explained dev. (%)	GCV	gCV
T. longicornis	**GAM**	BSI + S + PI	55.7	0.291	0.5613
	TGAM	BSI + S + PI	65.7	0.234	0.647



Model Results – *Pseudocalanus acuspes*

Species	Model	Predictors	explained dev. (%)	GCV	gCV
P. acuspes	GAM	S + PI	44.8	0.084	0.319
	TGAM	BSI + S + PI	53.8	0.074	0.296



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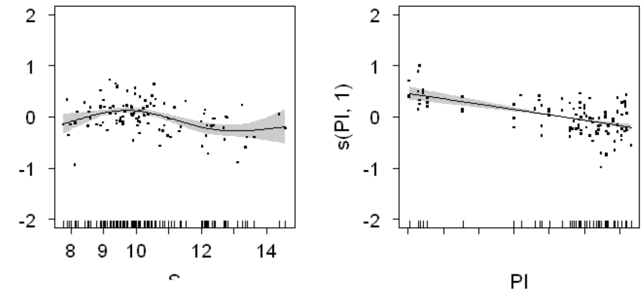
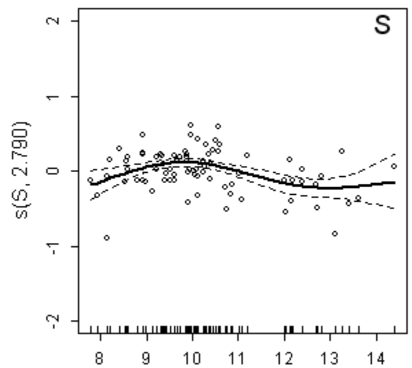
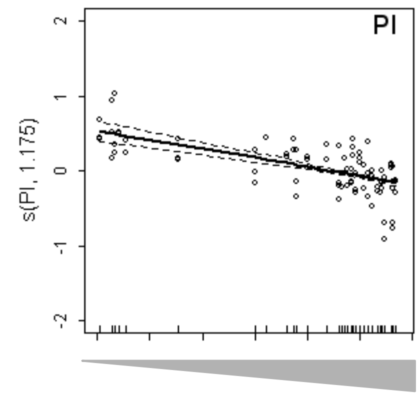


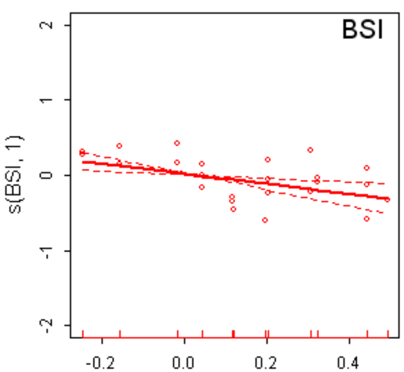
LOW
predation
pressure

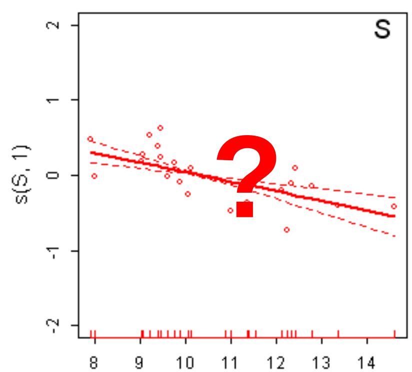
BSI - Low
no effect





HIGH
predation
pressure

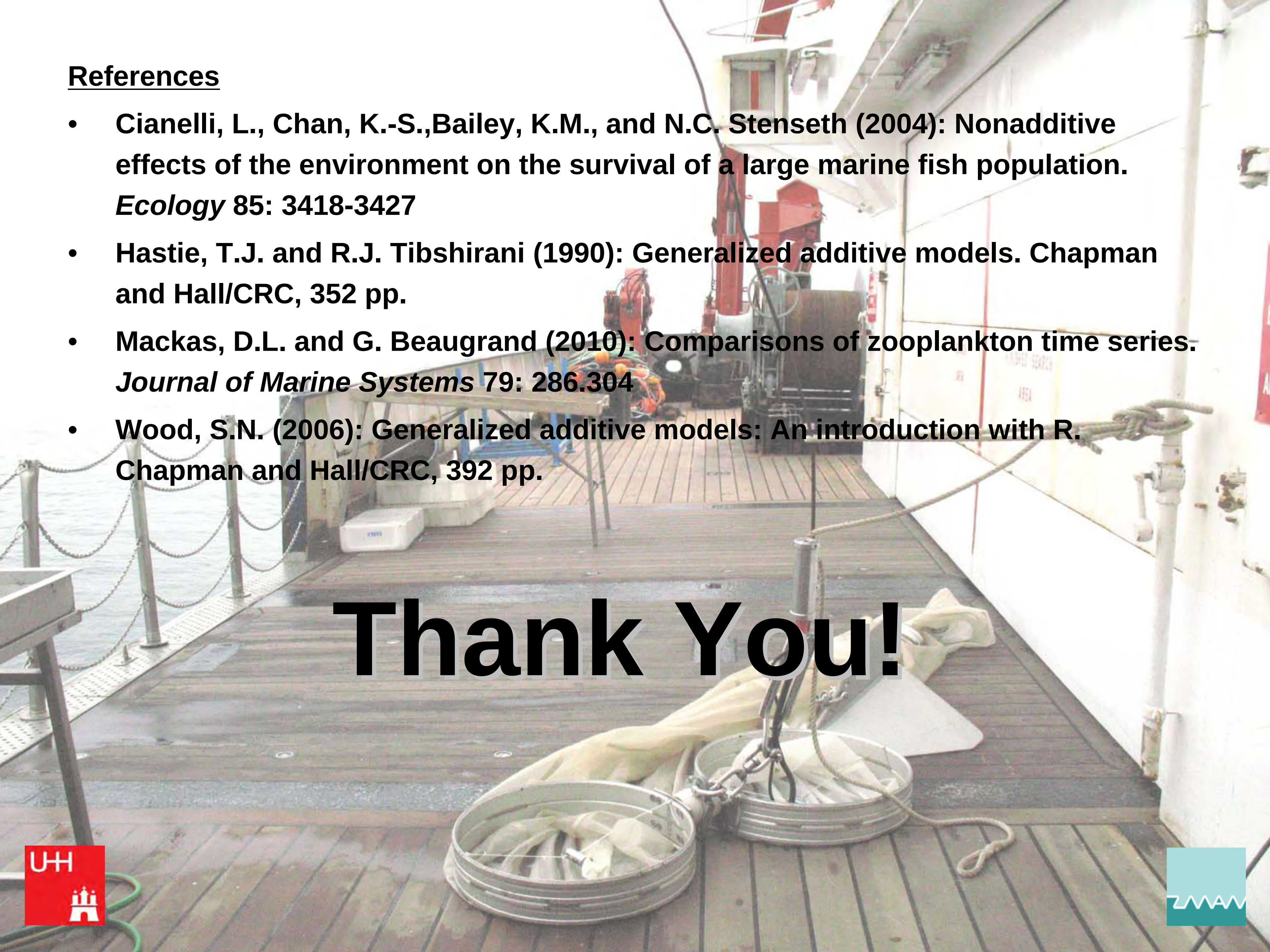




PI - High
no effect

Summary

- **no „basin-effect“ – spatially homogenuous trends**
  - combination of two datasets increased sample size
- **strong stratification/vertical habitat segregation causes species-specific responses to the environment**
  - „climate effect“ through temperature important near surface (A)
  - „climate effect“ through salinity important deeper in the water column (T,P)
  - importance of „cascade (predation) effect“ depends on vertical overlap with planktivorous fish (P)
- **climate and predation effect interact – relative importance of bottom-up and top-down control can change**



References

- Cianelli, L., Chan, K.-S.,Bailey, K.M., and N.C. Stenseth (2004): Nonadditive effects of the environment on the survival of a large marine fish population. *Ecology* 85: 3418-3427
- Hastie, T.J. and R.J. Tibshirani (1990): Generalized additive models. Chapman and Hall/CRC, 352 pp.
- Mackas, D.L. and G. Beaugrand (2010): Comparisons of zooplankton time series. *Journal of Marine Systems* 79: 286.304
- Wood, S.N. (2006): Generalized additive models: An introduction with R. Chapman and Hall/CRC, 392 pp.

Thank You!