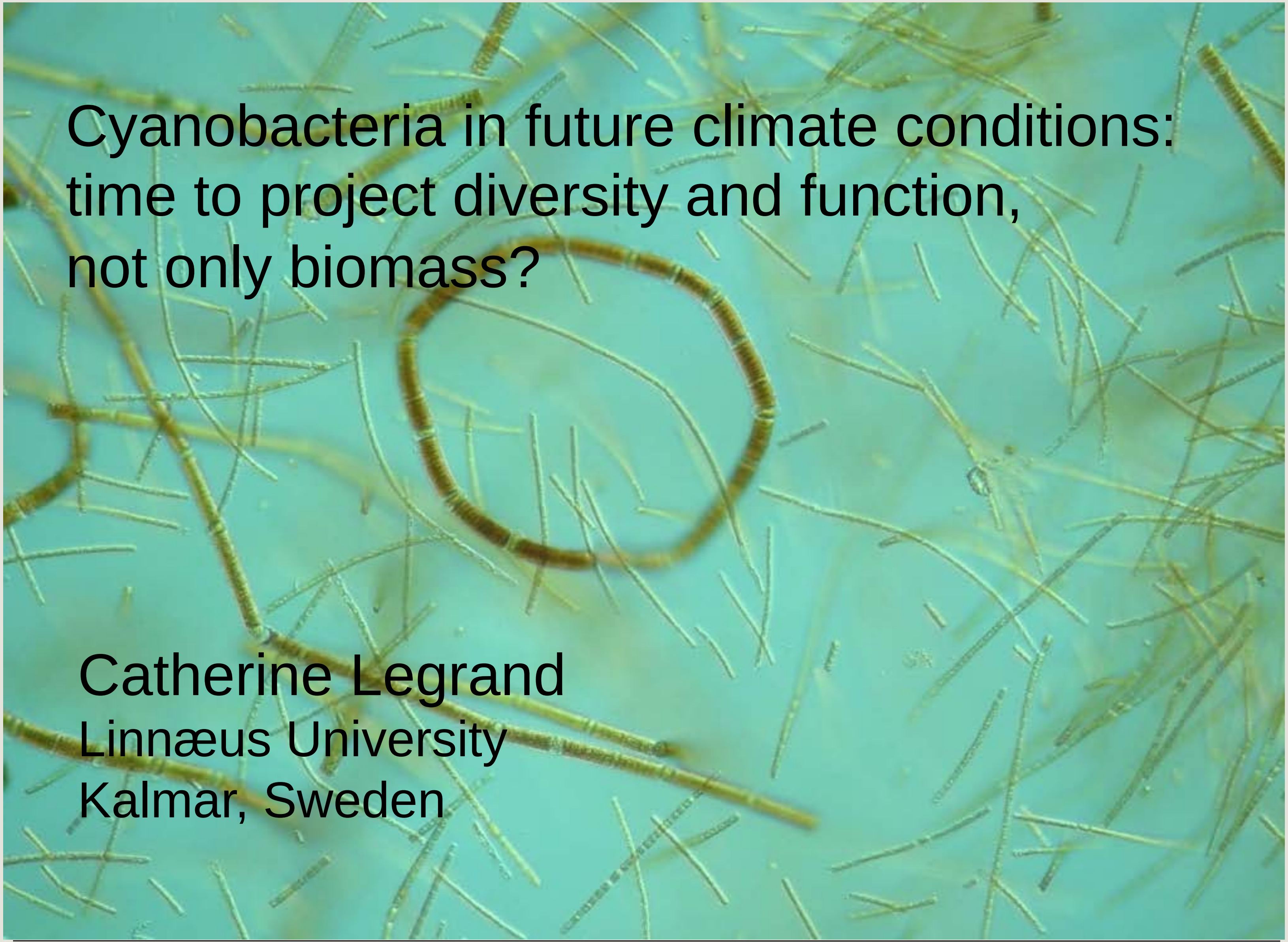


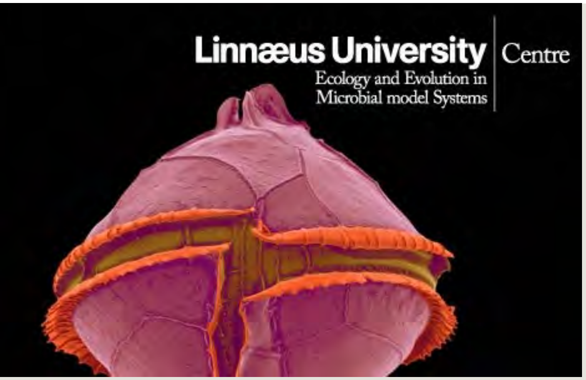
Cyanobacteria in future climate conditions: time to project diversity and function, not only biomass?

Catherine Legrand
Linnæus University
Kalmar, Sweden

Linnæus University | Centre
Ecology and Evolution in Microbial model Systems

www.lnu.se/eemis
www.umf.umu.se/english/ecochange/

ECOCHANGE.



UMEÅ UNIVERSITET

SLU

SciLifeLab

Kristofer Bergström
Frida Eriksson
Hanna Farnelid
Emil Fridolfsson
Franziska Klotz
Ivan Ivanov
Elin Lindehoff
Markus V. Lindh
Anders Månsson
Emmelie Nilsson
Martin Olofsson

formas
The Swedish Research Council Formas
Committed to excellence in research for sustainable development

Michele Casini
Hanna Mazur-Marzec
Per Larsson
Agneta Andersson
Jarone Pinhassi
Catherine Legrand

Linnæus University Centre
Ecology and Evolution in
Microbial model Systems

www.lnu.se/eemis
www.umf.umu.se/english/ecochange/

What do CYANO-models need?

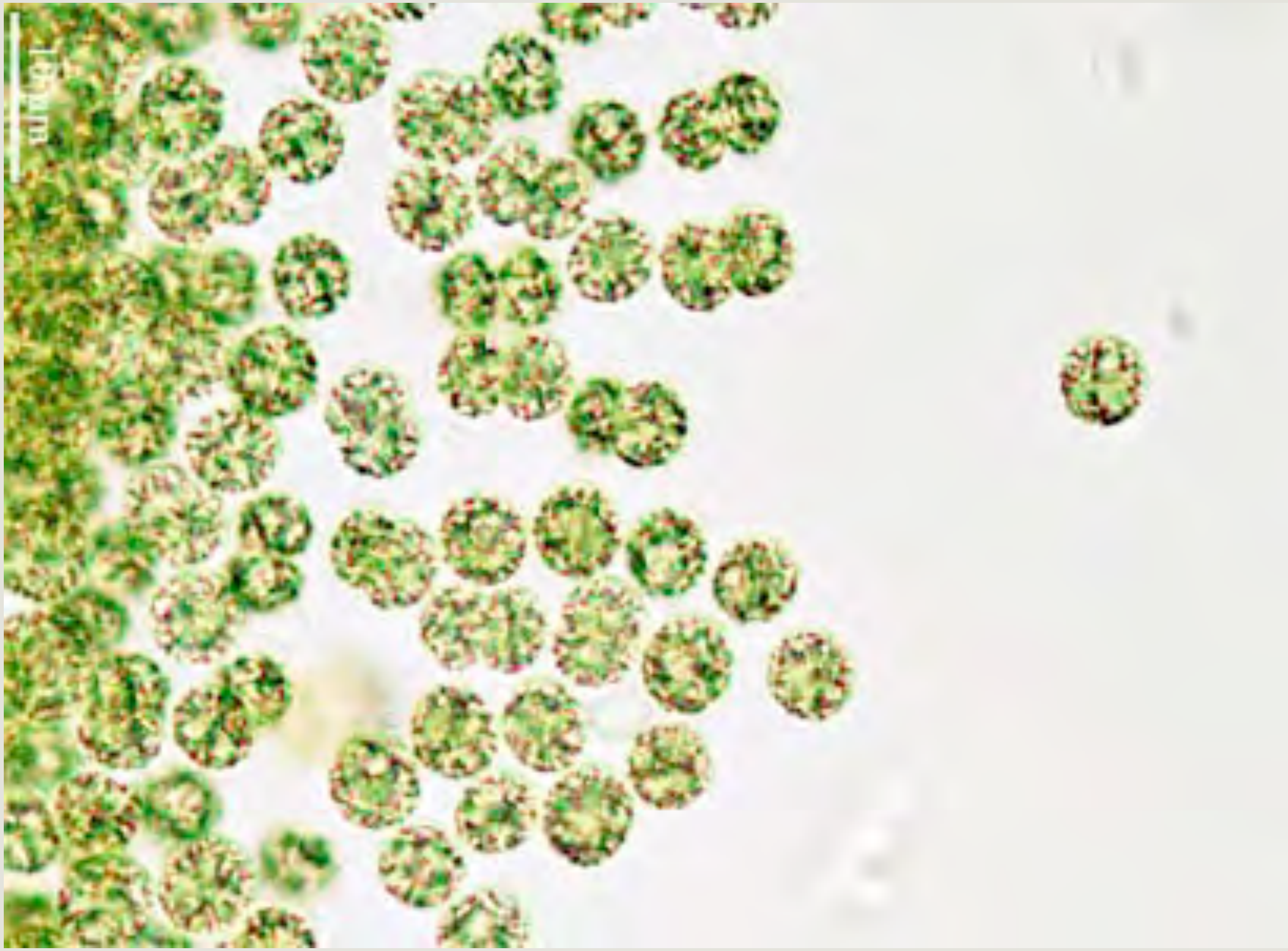
1- Response of HAB to future CC
(physiology, life cycle, adaptation???)

2- Temporal and spatial dynamics
(Who is there, how much, where and when?)

3-Trophic interactions
(grazer-prey-competitor incl. heterotrophic bacteria)

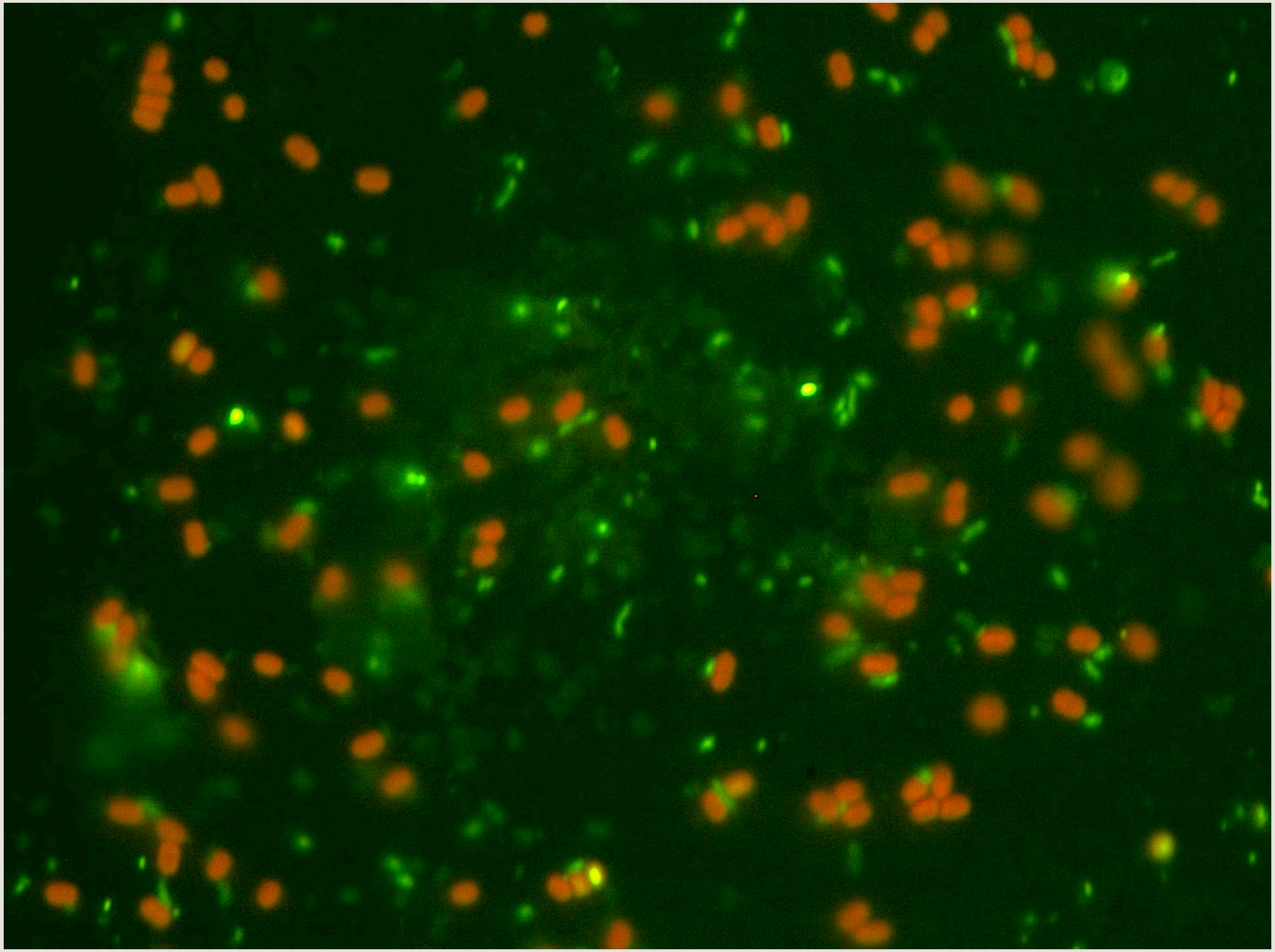
4-Biotic/chemical interactions
(bioactive compounds)

Colonial cyanobacteria

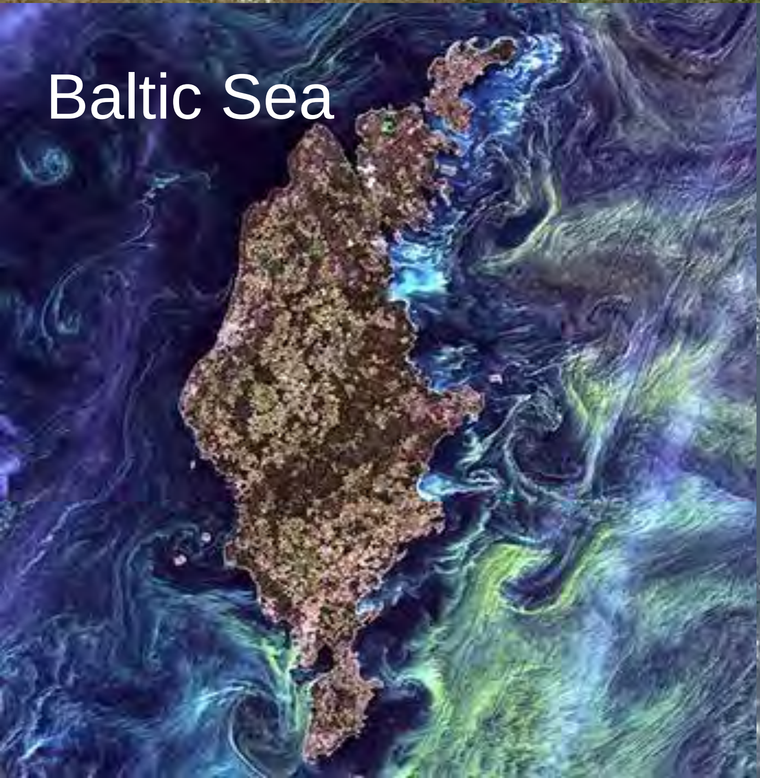


Filamentous cyanobacteria (N_2-fixers)

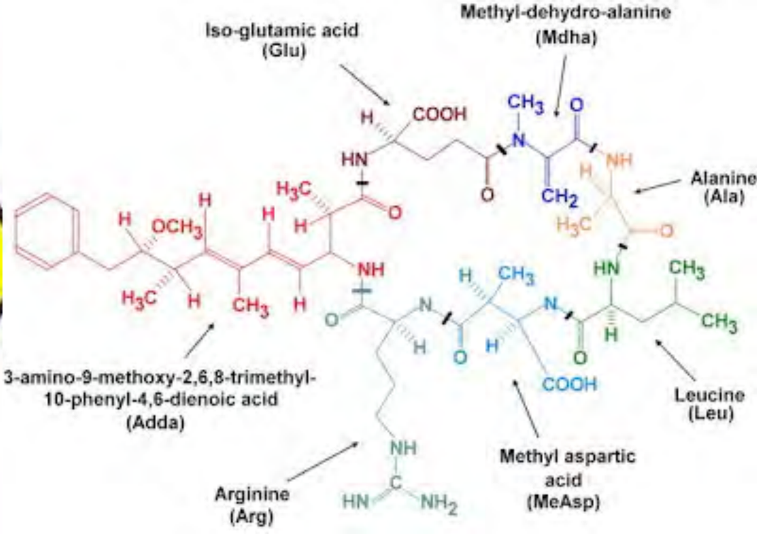
Picocyanobacteria




Lake Erié


Baltic Sea


SW Pacific Ocean
Tanna
Trichodesmium bloom
Lifou
20 km



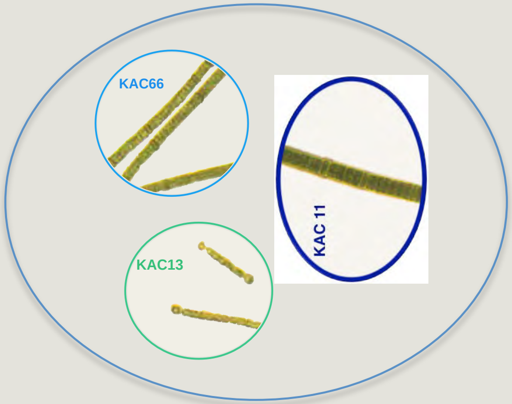
- Peptide Hepatotoxins (Microcystins and Nodularin)
- Neurotoxins
- Cylindrospermopsin
- β-N-methylamino-L-alanine (BMAA)
- Lipopolysaccharide Endotoxins

- Other NR peptides (spumigins, aeruginosins, anabaenopeptids, unknown)

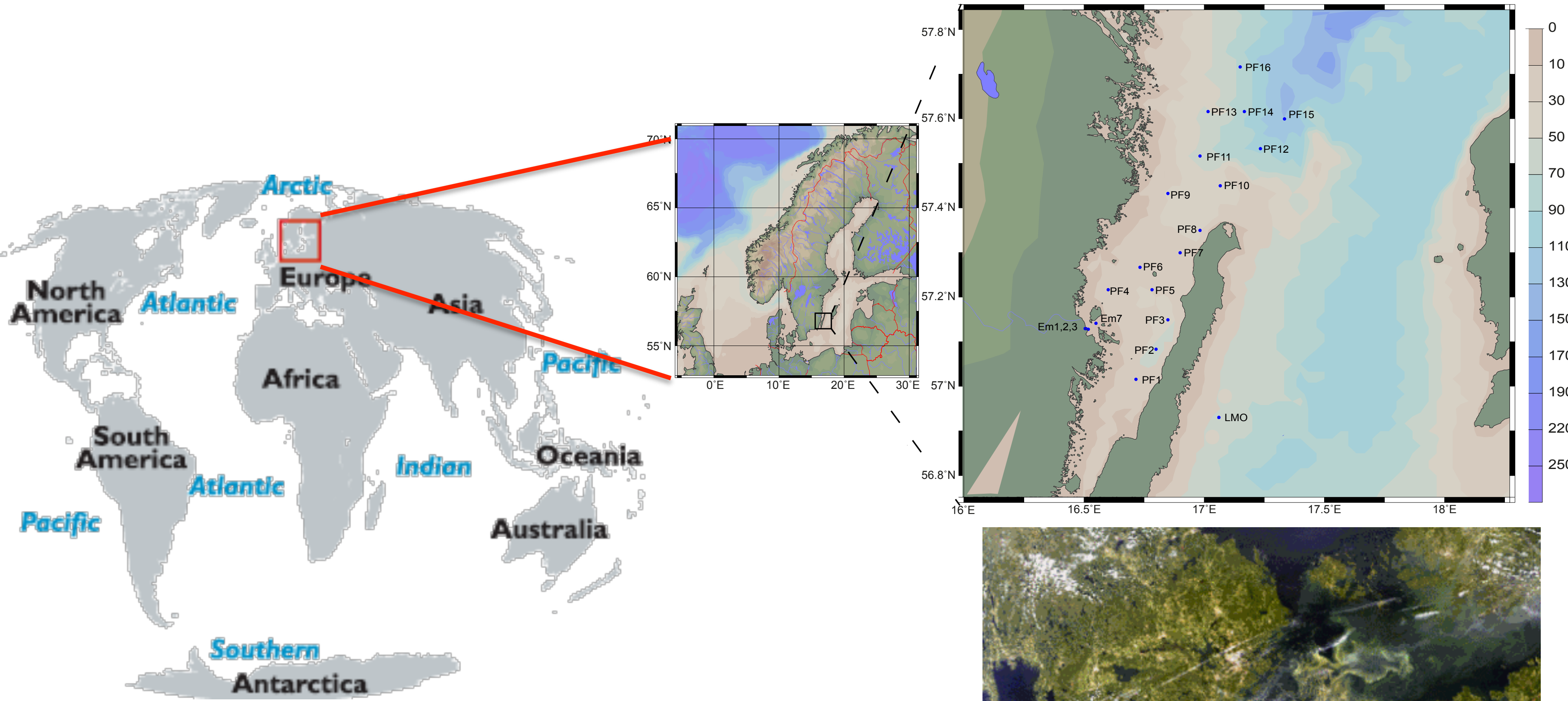
Linnæus University | Centre
Ecology and Evolution in
Microbial model Systems

Nodularin and other NR-peptides

m/z	Oligopeptide structure	KAC13	KAC66	KAC11
Spumigins				
641	(Hpla+42)+Hty+Pro+Argol			•
639	(Hpla+42)+Hty+Pro+Argal			•
627	Hpla+Hty+MePro+Arg		•	
613	Hpla+Hty+MePro+Argol	•	•	
613	Hpla+Hty+Pro+Arg	•	•	•
611	Hpla+Hty+MePro+Argal	•	•	•
599	Hpla+Hty+Pro+Argol	•	•	•
597	Hpla+Hty+Pro+Argal	•	•	•
583	Hpla+Tyr+Pro+Argal		•	
457	Hpla+Hty+Pro+OH		•	•
Aeruginosins				
603	?+Tyr+Choi+Arg		•	•
589	?+Tyr+Choi+Argol		•	•
587	?+Tyr+Choi+Agm		•	•
Nodularins				
825	Cyclo[MeAsp+Arg+Adda+Glu+Mdhb]	•	•	•
811	Cyclo[Asp+Arg+Adda+Glu+Mdhb]	•	•	•
Anabaenopeptins (Nodulapeptins)				
934	Phe+CO+[Lys+Val+Hty+MeHty+MetO]		•	
918	Phe+CO+[Lys+Val+Hph+MeHty+MetO]		•	
916	Phe+CO+[Lys+Val+Hty+MeHty+AcSer]		•	
902	Phe+CO+[Lys+Val+Hph+MeHty+Met]		•	
900	Phe+CO+[Lys+Val+Hph+MeHty+AcSer]		•	
884	Phe+CO+[Lys+Val+Hph+MeHph+AcSer]		•	
842	Phe+CO+[Lys+Ile+Hty+MeAla+Phe]			•
829	Unknown		•	
828	Phe+CO+[Lys+Val+Hty+MeAla+Phe]			•
808	Ile+CO+[Lys+Ile+Hty+MeAla+Phe]			•
Unknown peptides				
824	Unknown			•
810	Unknown			•



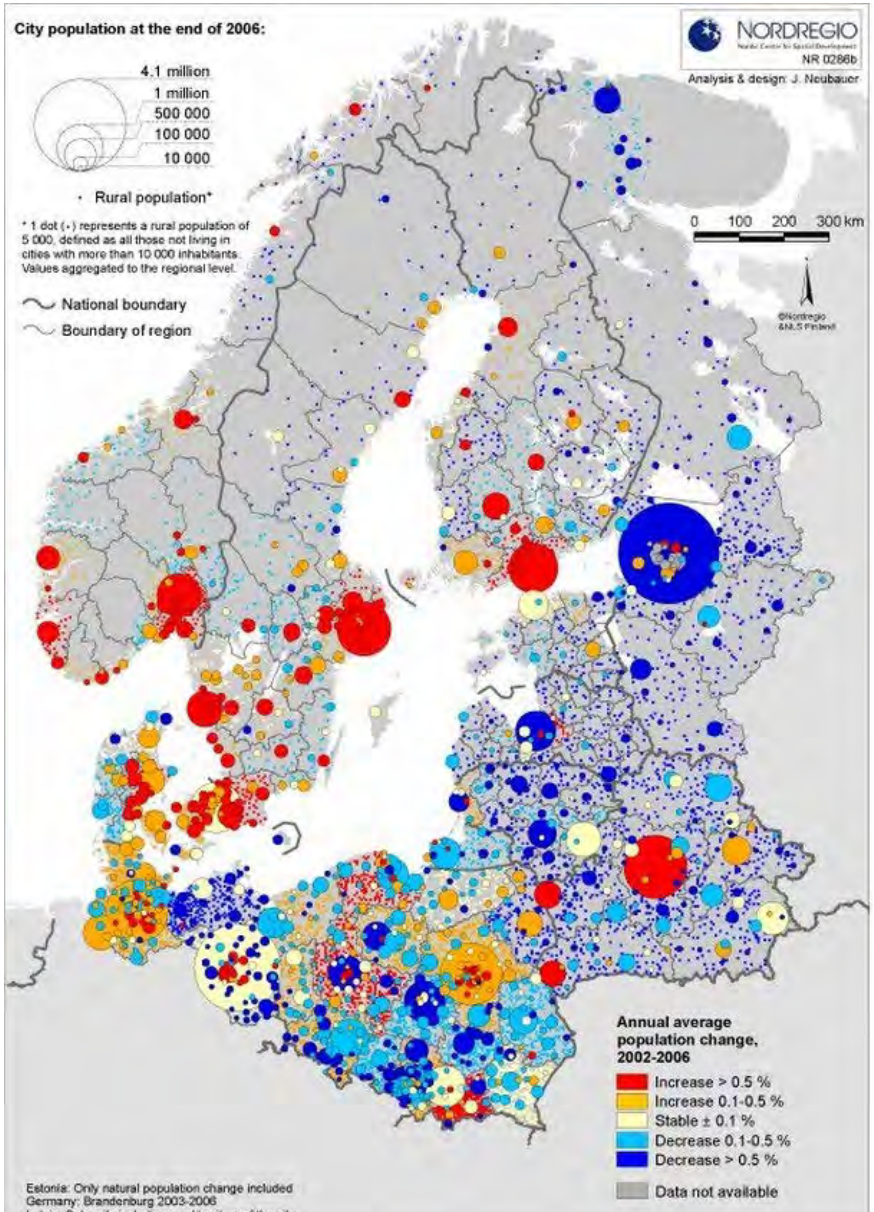
The Baltic Sea

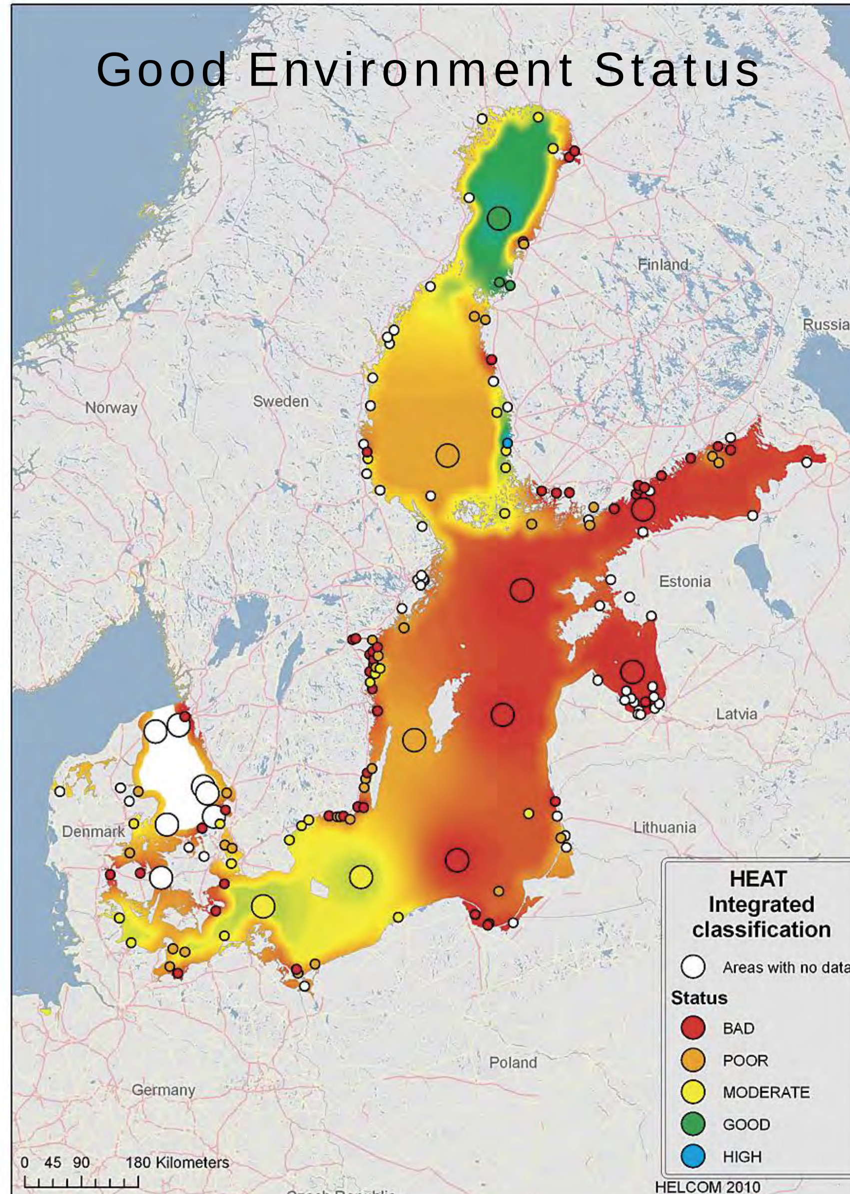


Linnæus University Centre
Ecology and Evolution in Microbial model Systems

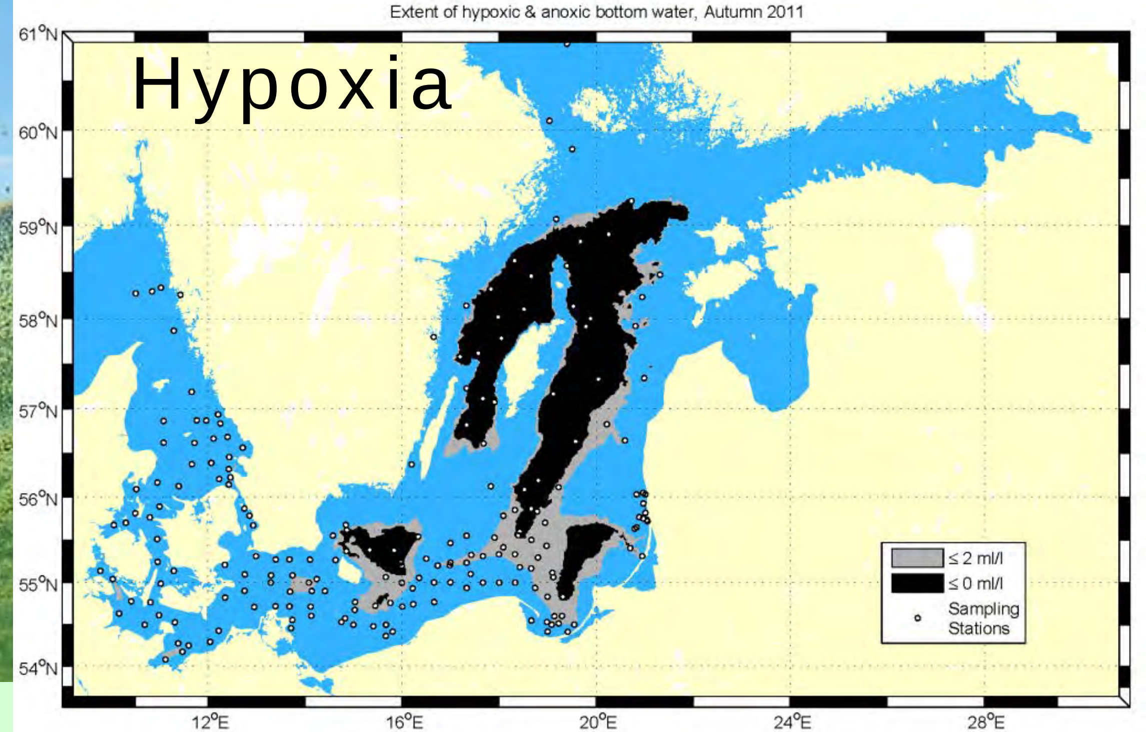
EcoChange

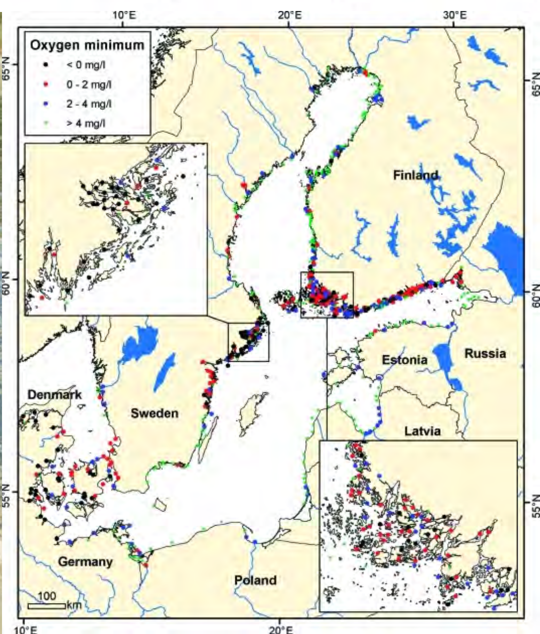
Baltic Sea Region





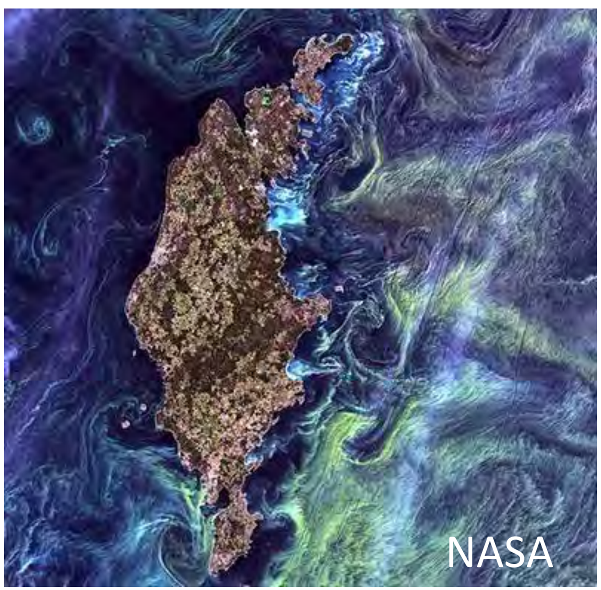
Eutrophication



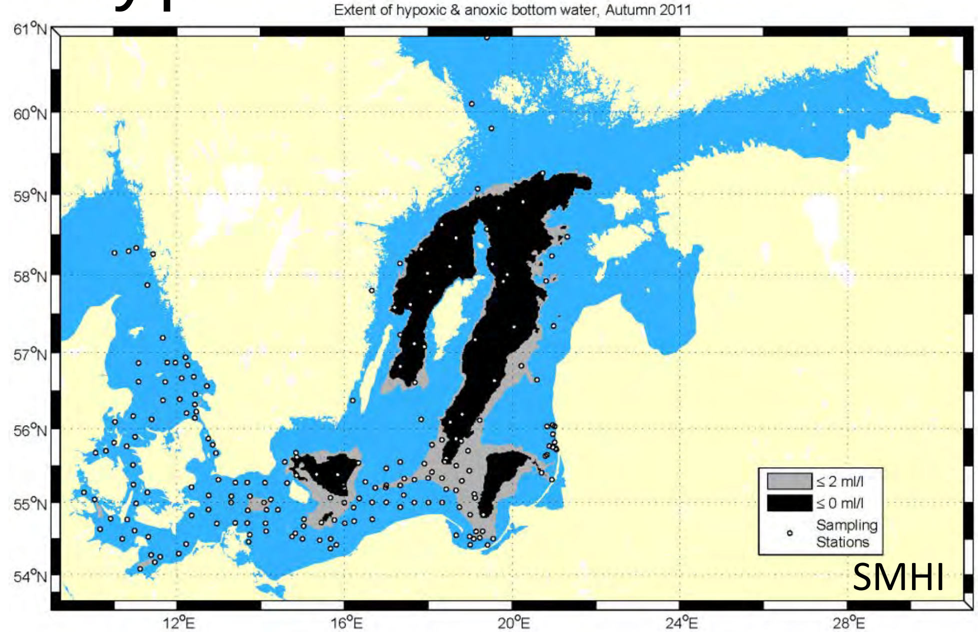


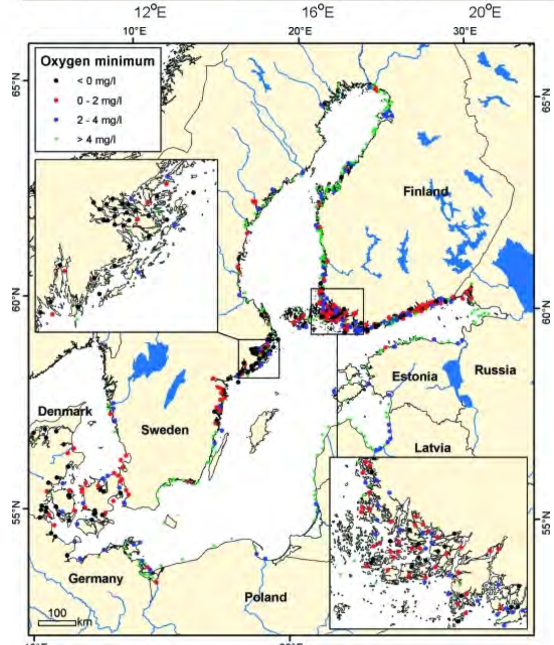
Conley et al. 2011

Eutrophication



Hypoxia

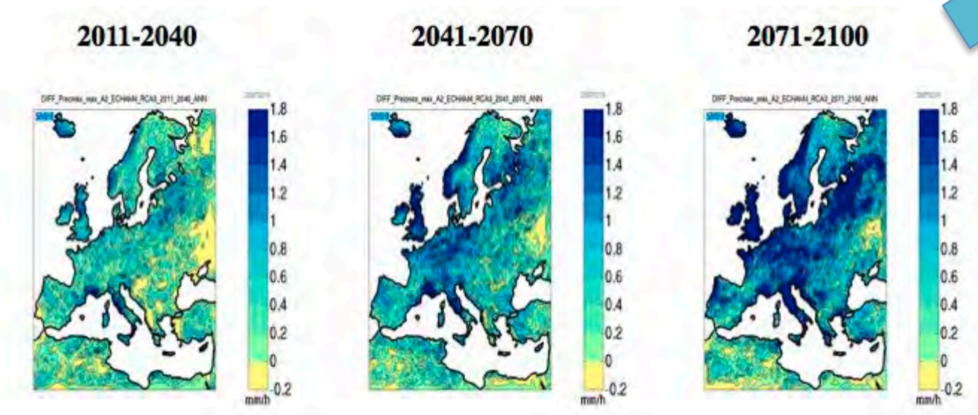




Conley et al. 2011

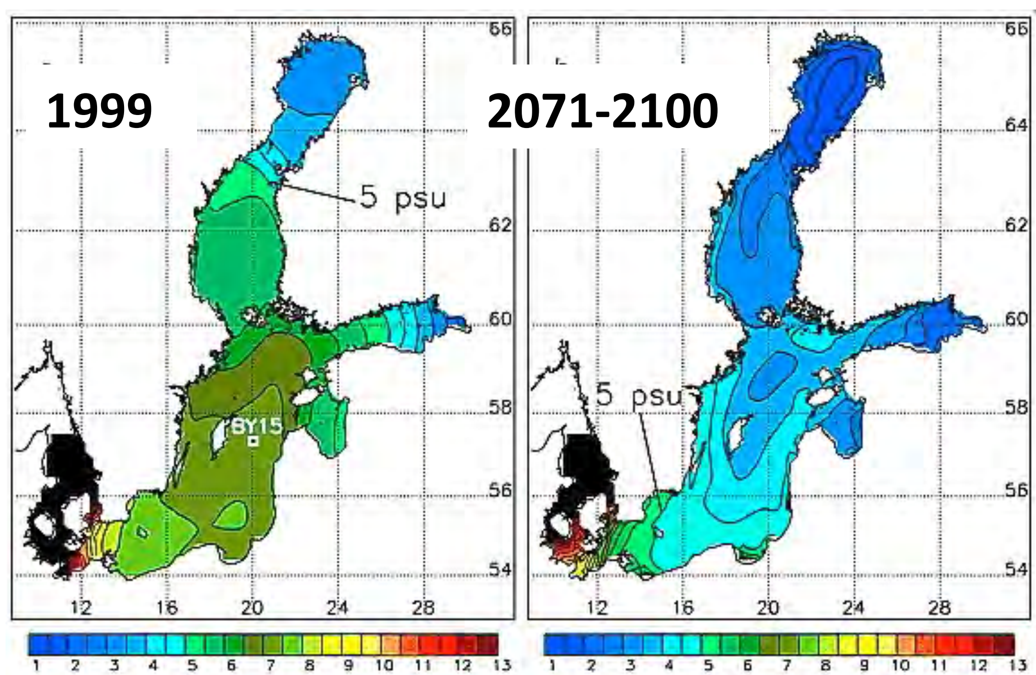
Climate change

Precipitations



Smhi.se

Salinity



Meier et al. 2006

The Baltic Sea is warming faster than other seas

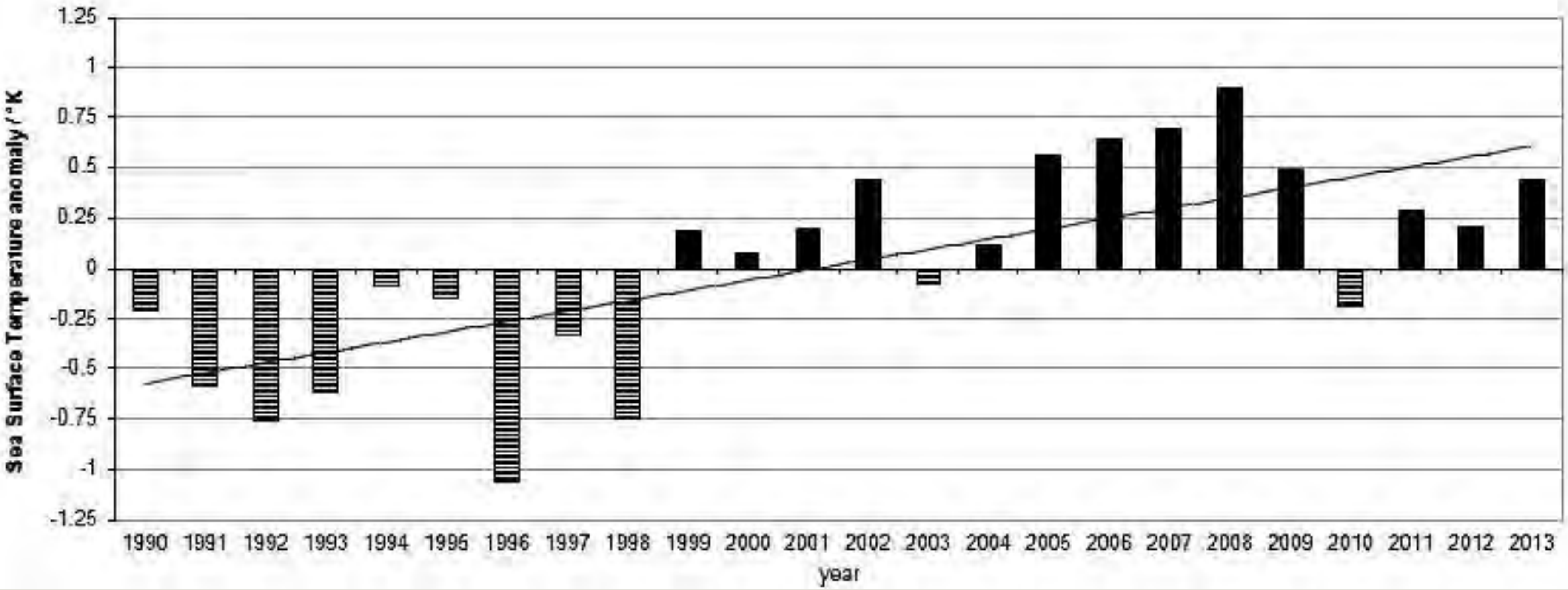
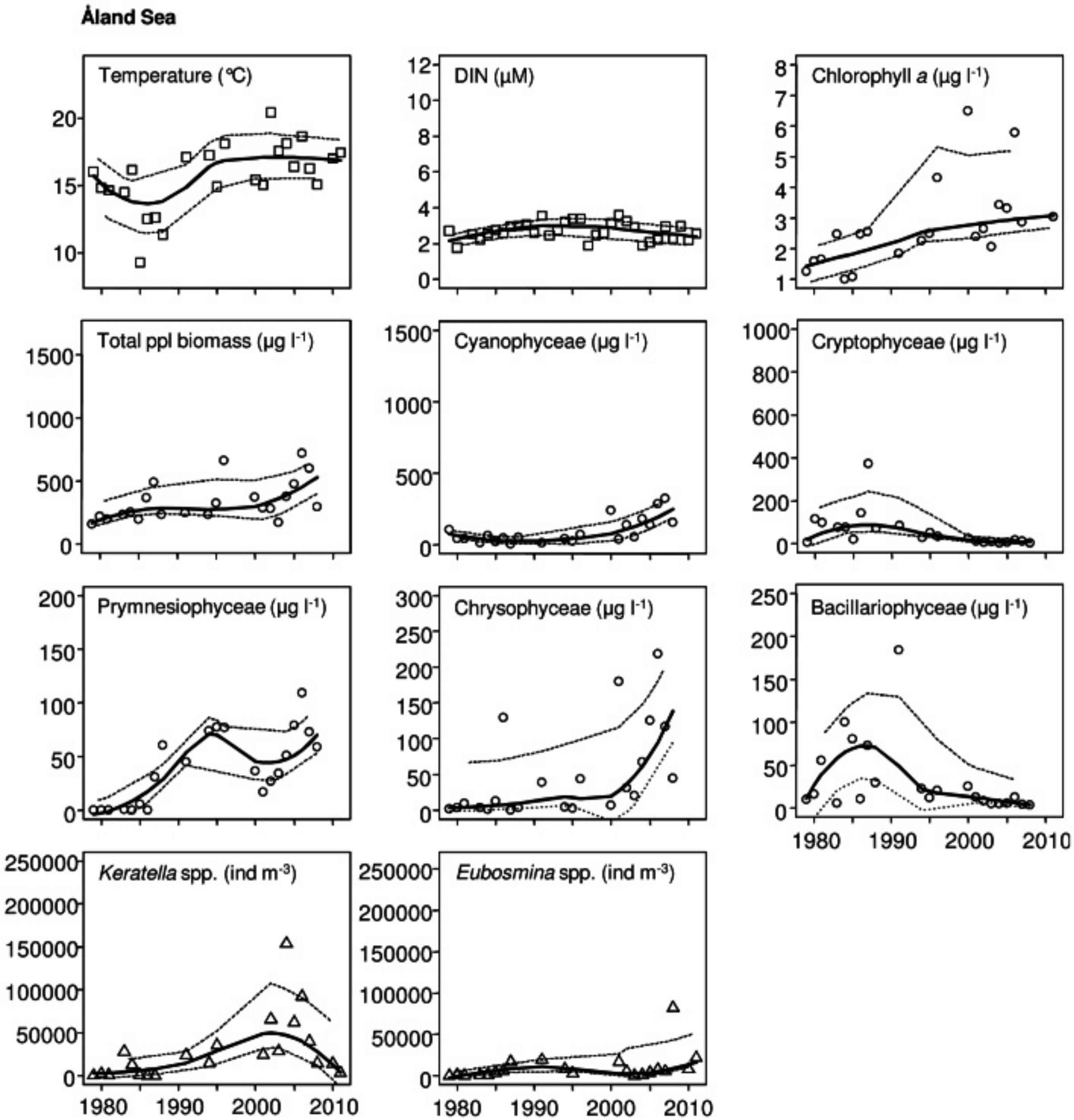


Figure 7. Trend of SST- Anomalies of the annual averages of the Baltic referring to the long-term means 1990 – 2012.

Siegel & Gerth 2014



Phytoplankton increased in the Åland Sea from 1979 to 2008

Significant trends ($p<0.05$) in environmental (squares) and zooplankton parameters (triangles) in the Åland Sea from 1979 to 2011, and in phytoplankton (circles) from 1979 to 2008.

Suikkanen et al. 2013

Chlorophyll a

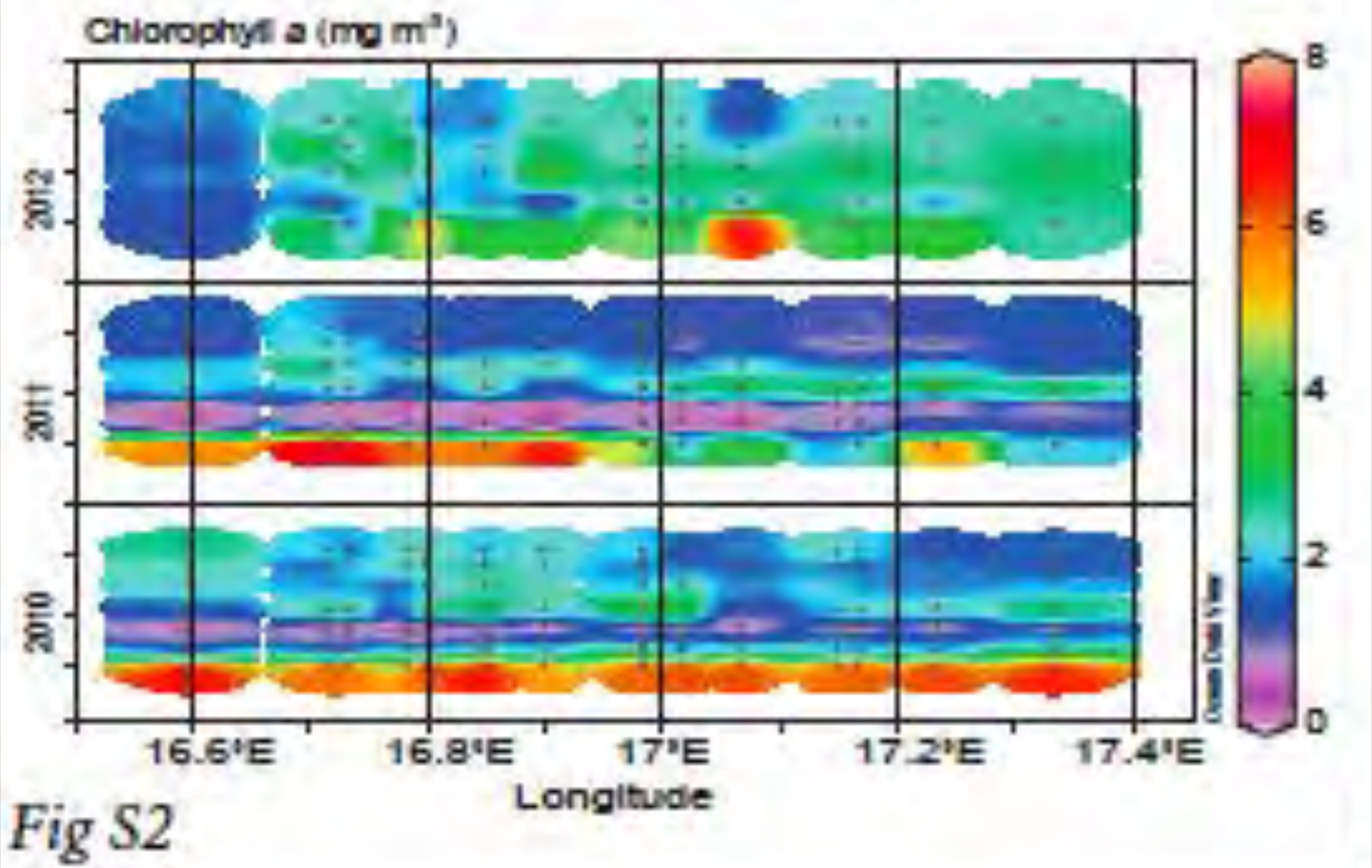
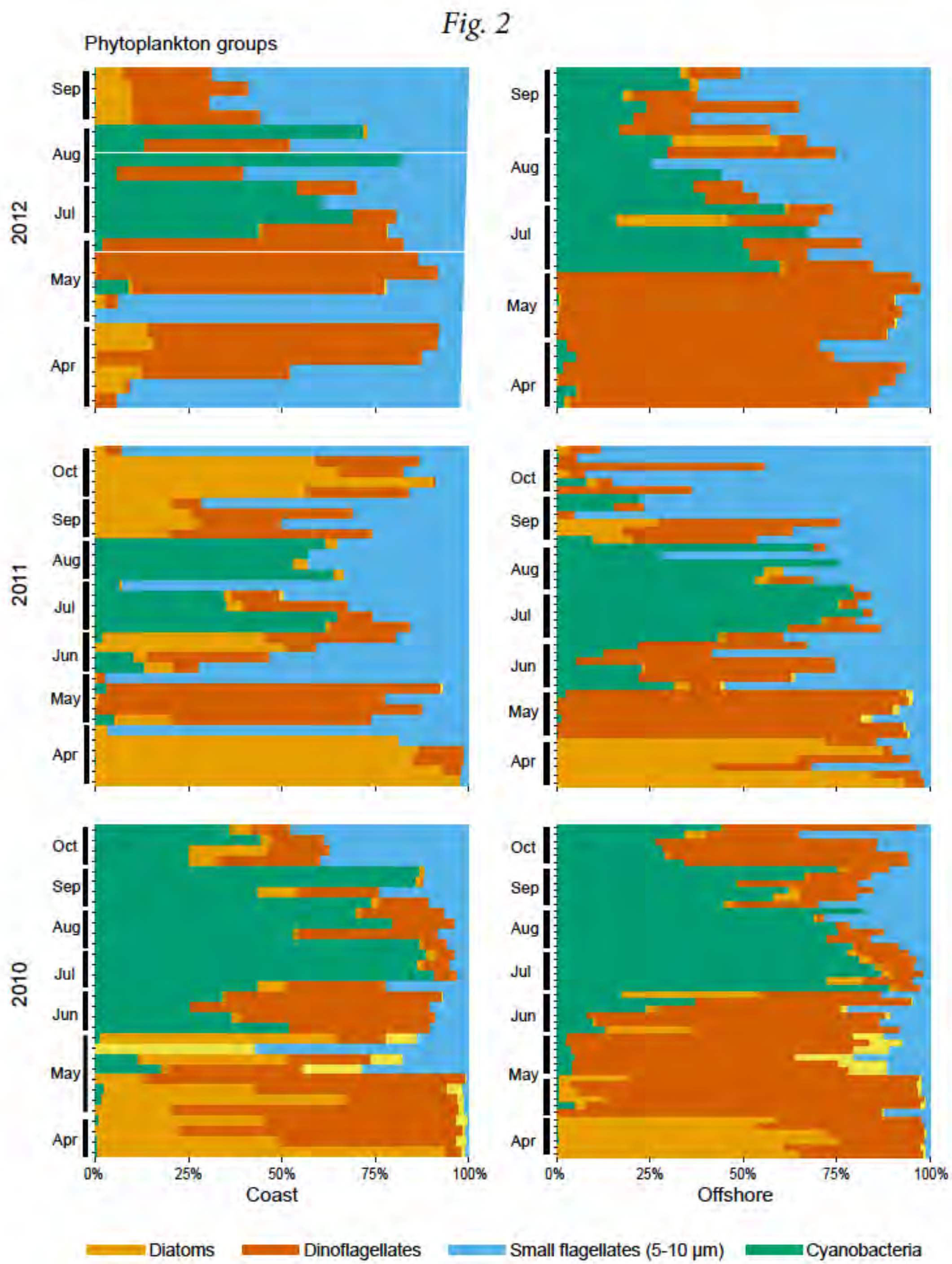


Fig S2

Linnæus University Centre
Ecology and Evolution in Microbial model Systems

Legrand et al. 2015



Phytoplankton

Mild winter favours dinoflagellates over diatoms in spring

Legrand et al. 2015

CLIMATE

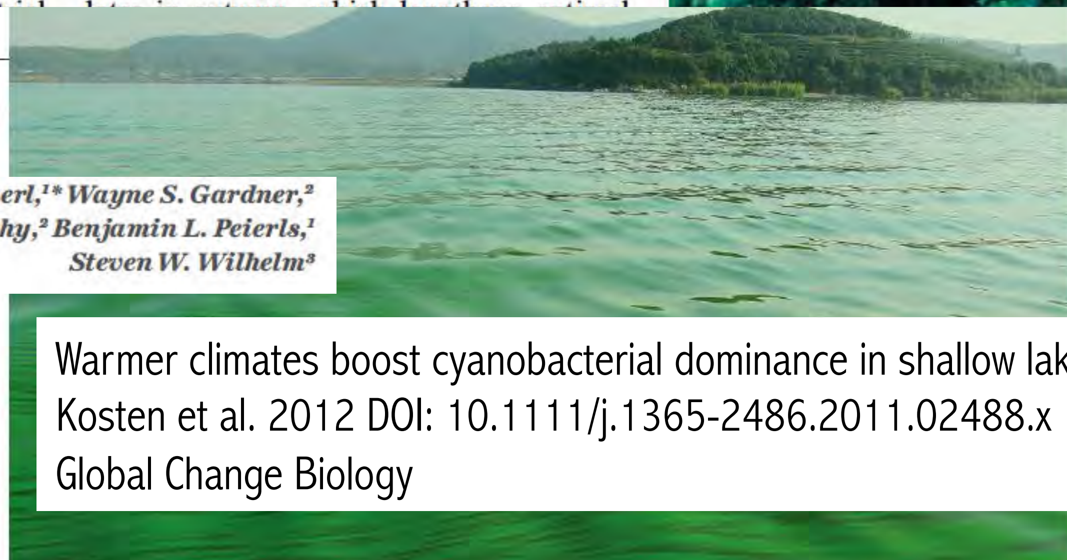
Blooms Like It Hot

Hans W. Paerl[1] and Jef Huisman[2] Science 2008

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

Nutrient overenrichment of waters by

lakes to stratify earlier in spring and destratify



LETTERS

Edited by Jennifer Sills

Algal blooms: Noteworthy nitrogen

Hans W. Paerl,[1] Wayne S. Gardner,[2] Mark J. McCarthy,[2] Benjamin L. Peierls,[1] Steven W. Wilhelm[3]*

NUTRIENT OVER-ENRICHMENT in lakes drives water-quality deterioration. The August 2014 water supply shutdown from Lake Erie to over 500,000 residents in Toledo, Ohio (*1*), highlights this problem, which has been historically addressed by controlling phosphorus (P) inputs. Management and research are based on the premise that P is the limiting factor in freshwater productivity and harmful algal bloom (HAB) formation (*2*, *3*). However, reducing P is no longer adequate for many lakes. Recent studies indicate algal proliferation in response to combined nitrogen (N) and P additions, or in some cases, the addition of only N (*4*–*8*). This shift in the

Warmer climates boost cyanobacterial dominance in shallow lakes

Kosten et al. 2012 DOI: 10.1111/j.1365-2486.2011.02488.x

Global Change Biology

Algal blooms: Proactive strategy

CYANOBACTERIAL HARMFUL algal blooms (CHABs) are increasing in severity on a worldwide basis. Combining nutrient-source control with post-bloom control is currently considered the best strategy for dealing with CHABs (*1*). However, huge

Proactive CHAB control requires appropriate technical expertise aimed at inhibiting algal growth during the spring season, when cyanobacteria is vulnerable to foraging species. This would involve developing new tools to trace pre-bloom algal distribution so that proactive treatments only need to be implemented within algae concentrated areas and in a cost-effective manner. Continuous monitoring and assessment of water bodies would maximize treatment efficacy.

*Mingzhi Qu,[1] Daniel D. Lefebvre,[1] Yuxiang Wang,[1] Yunfang Qu,[2] Donglin Zhu,[3] Wenwei Ren[4]**

Linnæus University
Ecology and Evolution in Microbial model Systems

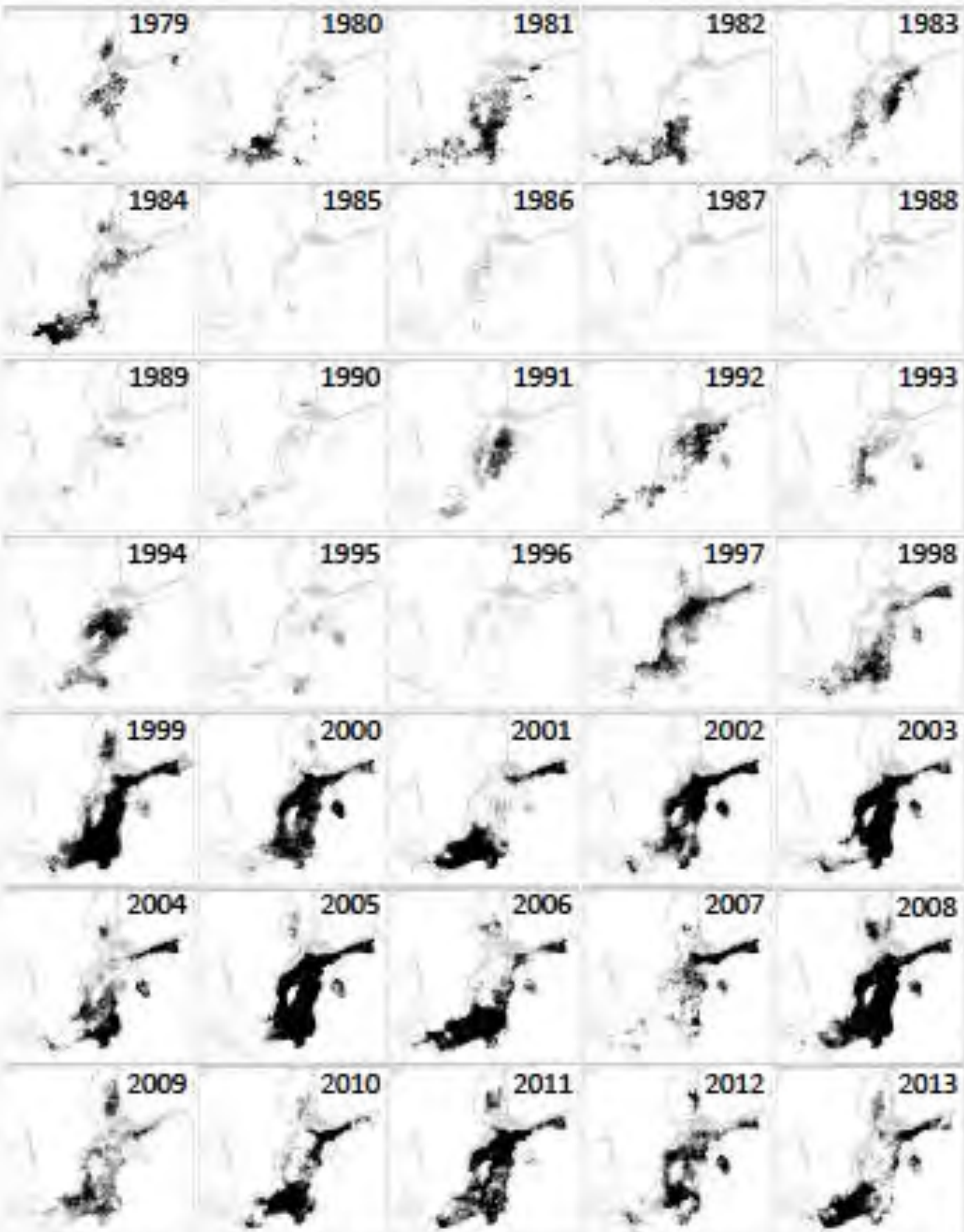


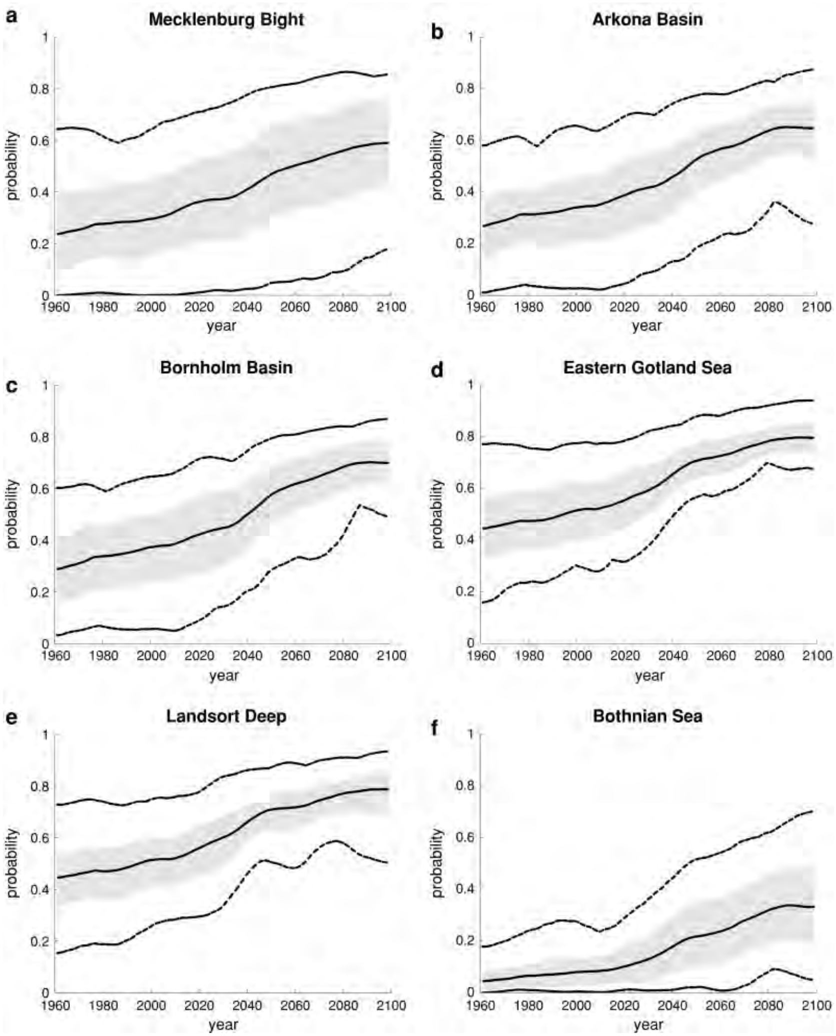
Figure 13. Maps of the mean July–August FCA in the Baltic Sea, 1979–2013. Gray-scale from light to dark corresponds to increasing FCA.

Nodularia spumigena

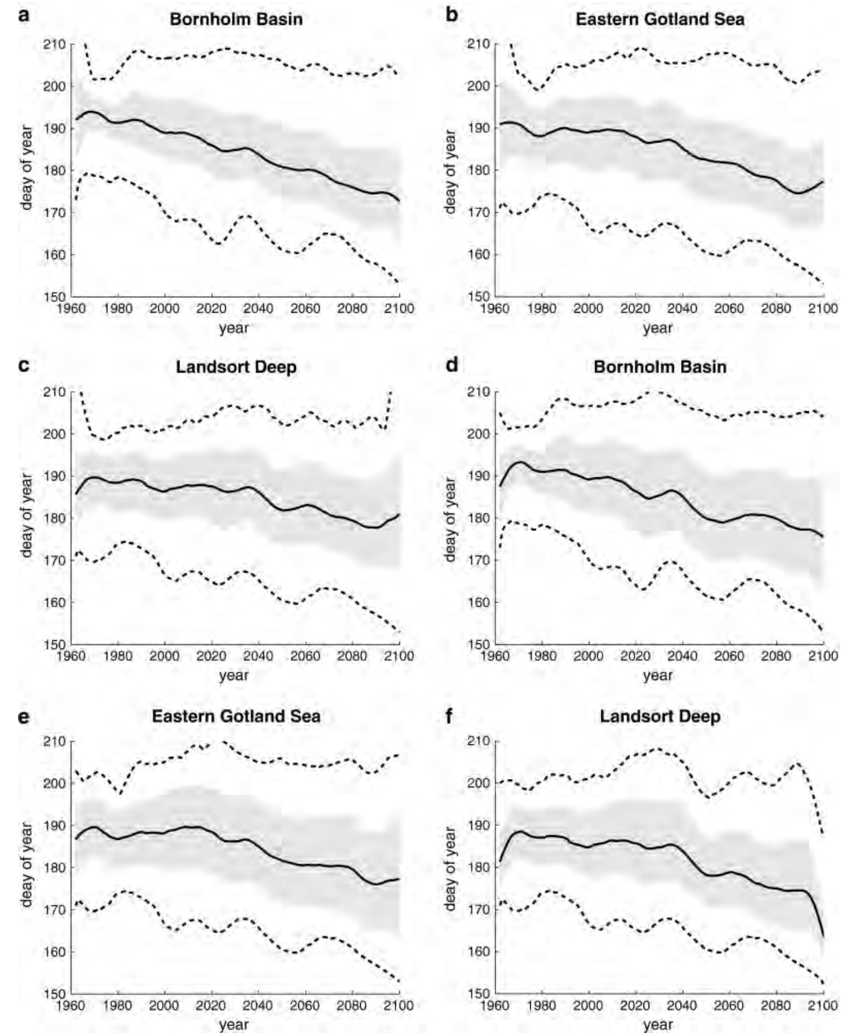
surface accumulation

Kahru and Elmgren 2014

Probability that SST will exceed 18°C in summer



Day of 1st occurrence of Cyano bloom



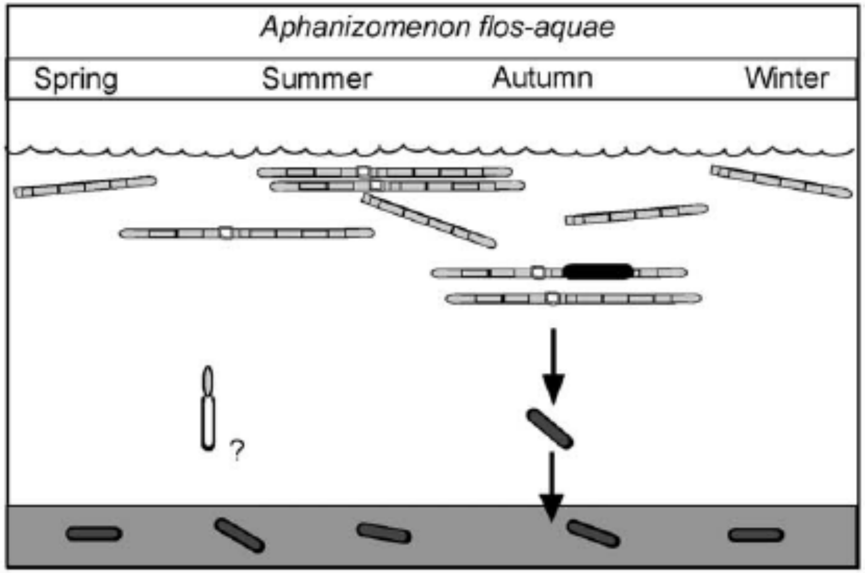
+ 20-30%

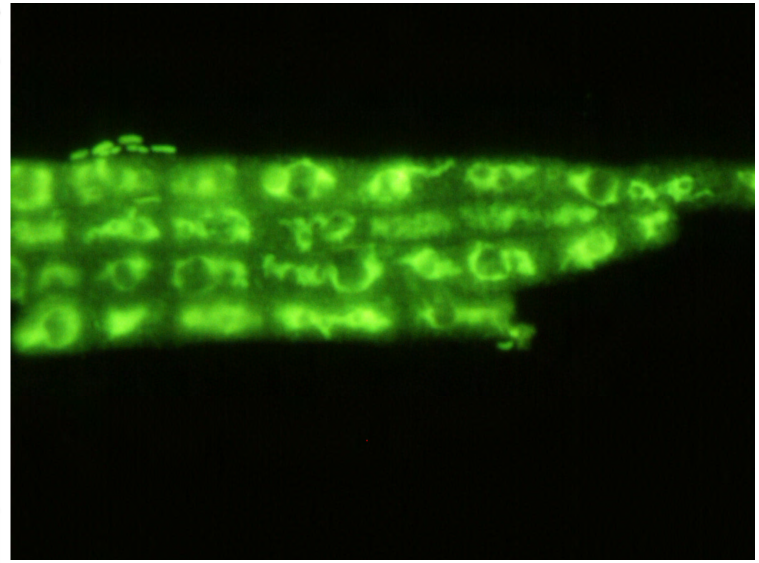
+ 10-15 days

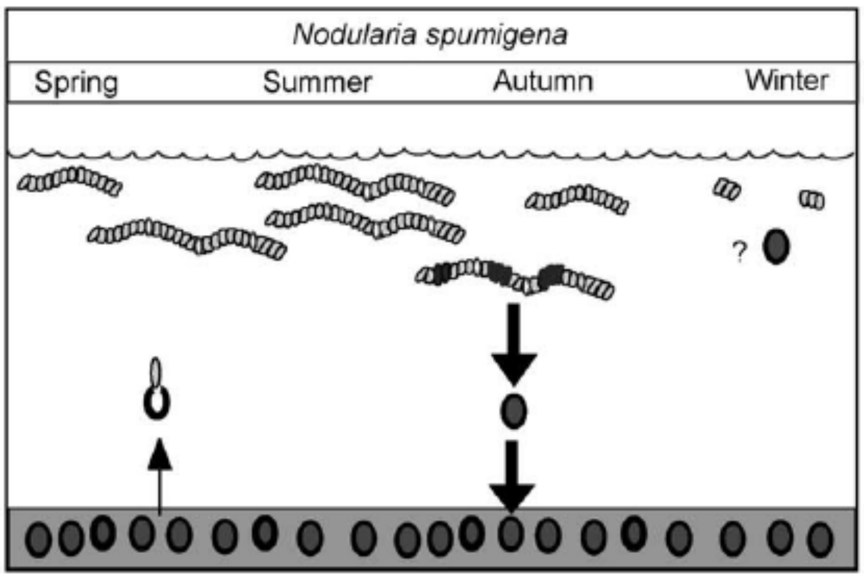
Linnæus University | Centre
Ecology and Evolution in Microbial model Systems

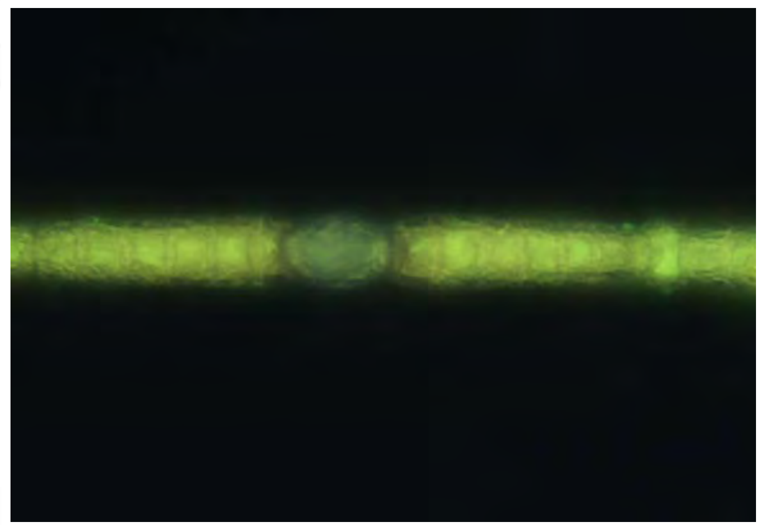
Neumann et al. 2012

Life cycle strategies in cyanobacteria



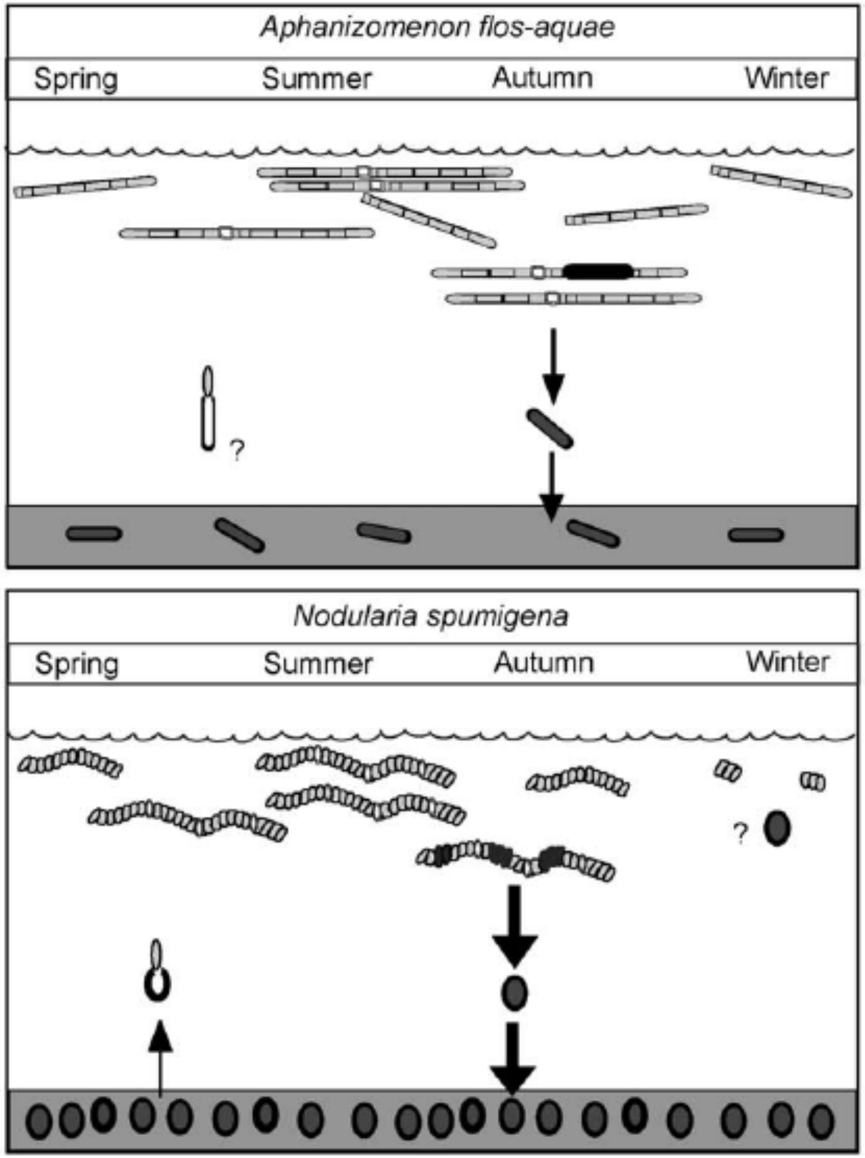






Suikkanen et al. 2011

Life cycle strategies in cyanobacteria



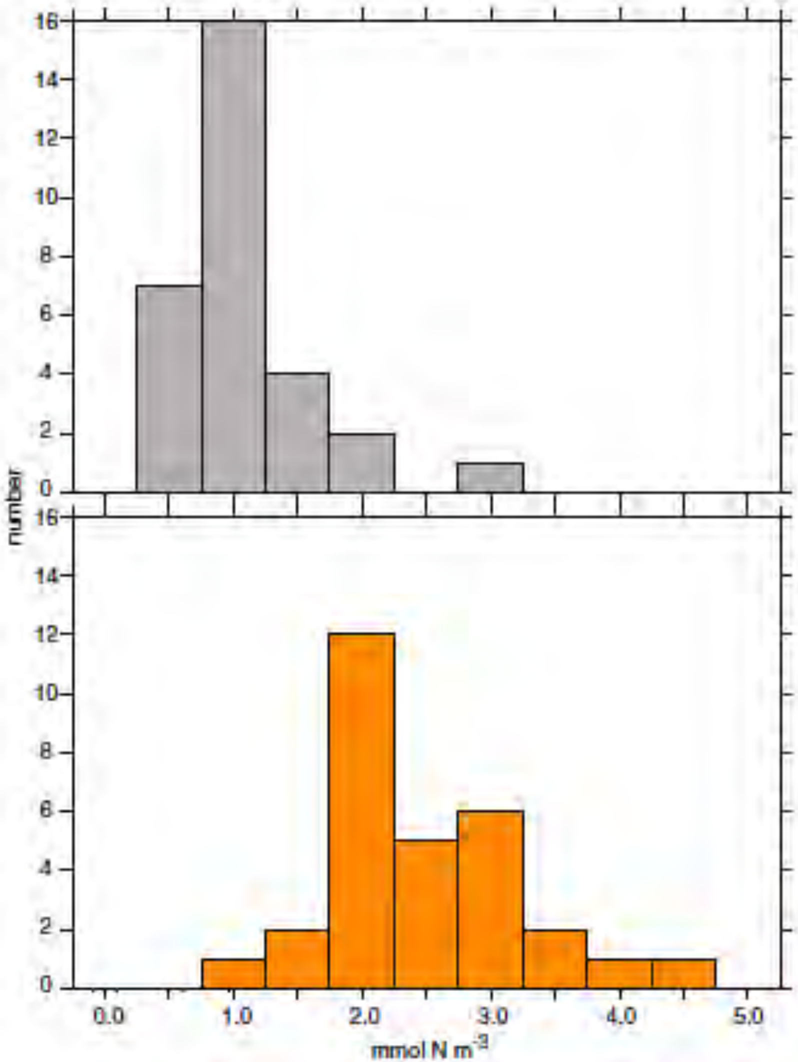
Including LC stages in models:
Better temporal variability

Hense and Burchard 2101

Hense et al. 2013

Suikkanen et al. 2011

Increase in cyanobacteria in the future



Including LC stages in models:
Better temporal variability
Hense and Burchard 2010
Hense et al. 2013

Hense et al. 2013

Climate extremes impacts on cyanobacteria

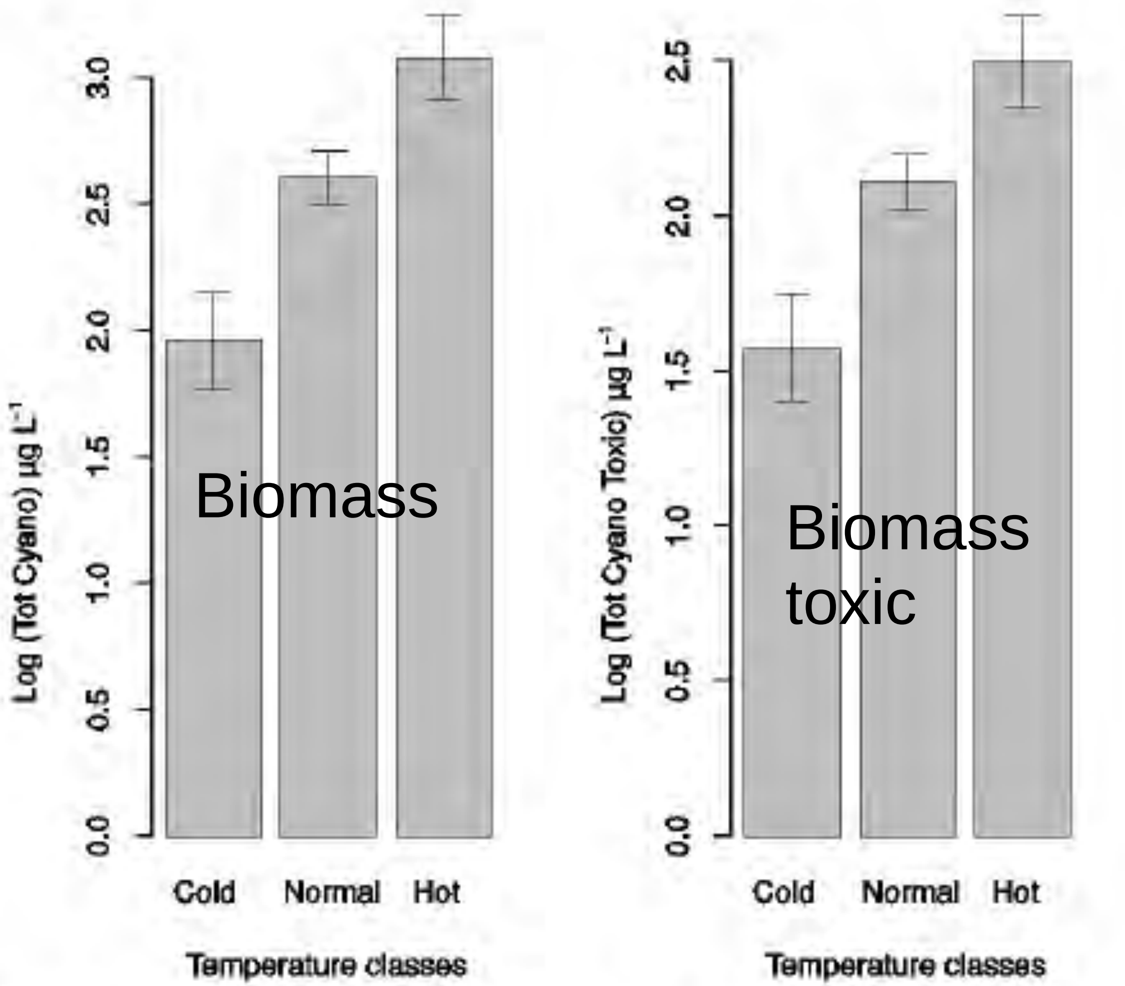
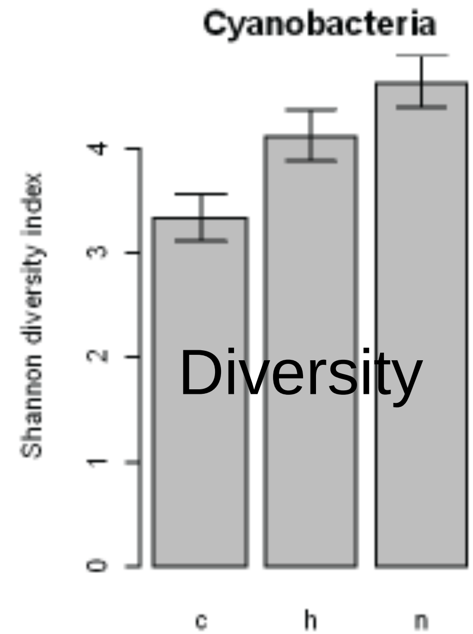


Fig. 2. Mean and standard error for each ET-Class derived from **A**) the log-transformed total cyanobacteria biomass [Log (TotCyano)] and **B**) the log-transformed total toxic cyanobacteria biomass [Log (TotCyanoToxic)].



Gallina et al. 2011

Climate extremes impacts on cyanobacteria

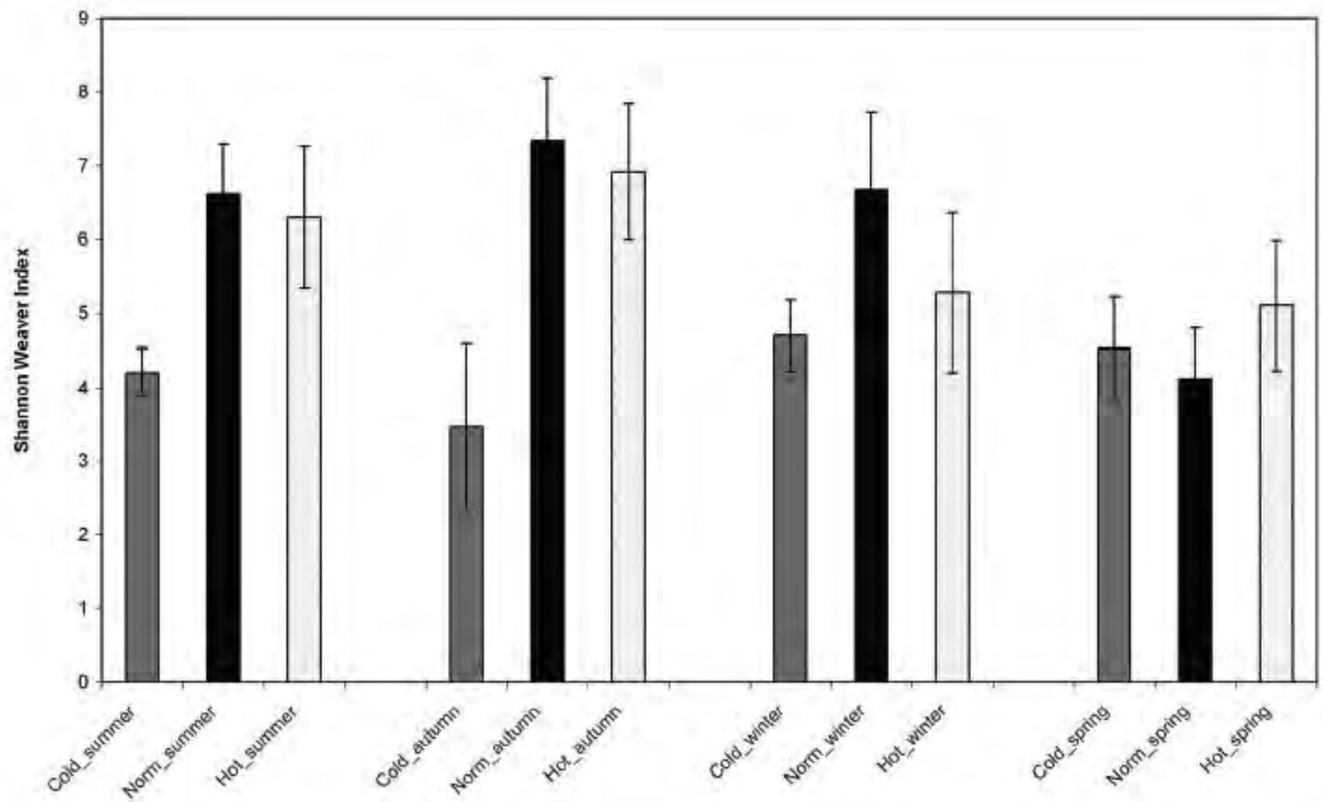
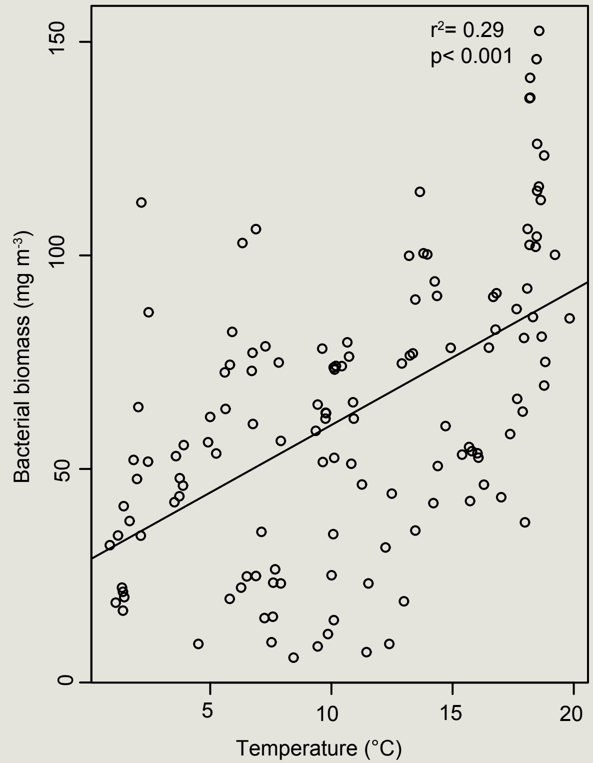
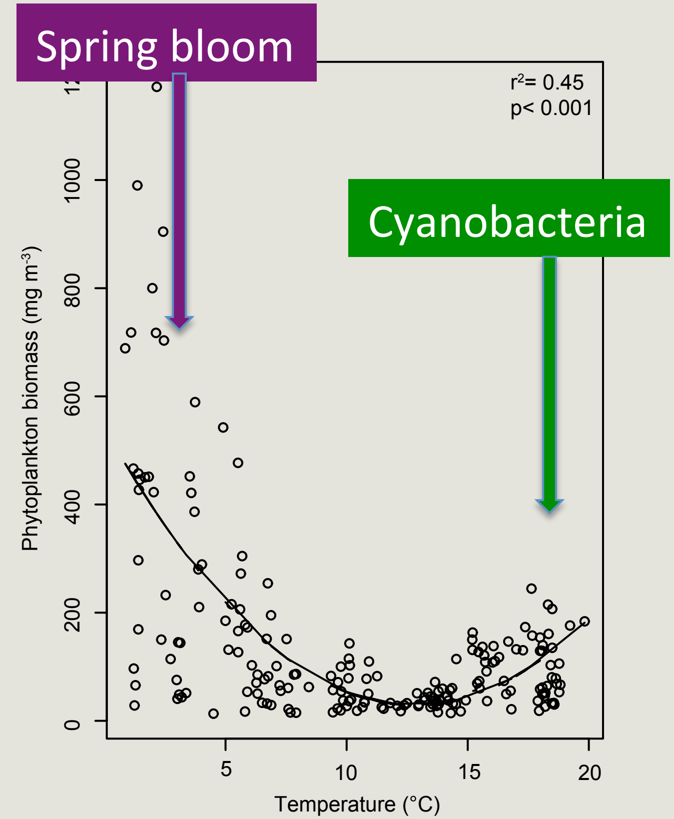


Fig. 6. Yearly and seasonal averages of the cyanobacteria diversity derived from monthly values represented by the different ET-Classes. The bars represent the standard deviations.

Gallina et al. 2011

A standard view is that increased temperature (+4 C) in the photic zone will boost summer phytoplankton (cyanos) blooms in the Baltic proper

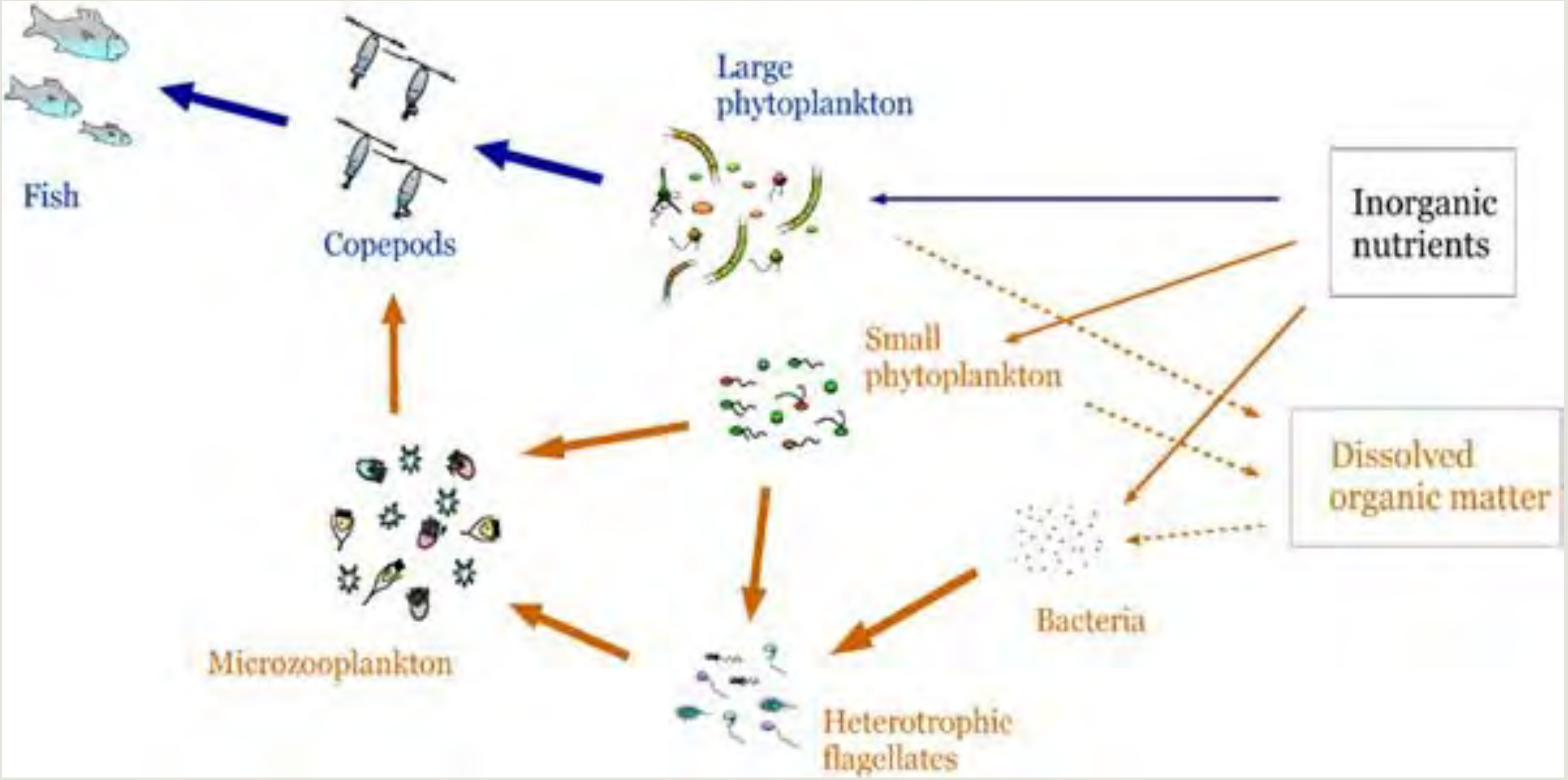




Linnæus University Centre
Ecology and Evolution in Microbial model Systems

Legrand et al. AMBIO 2015

Main trophic pathways in planktonic food webs



CSIC webpage)

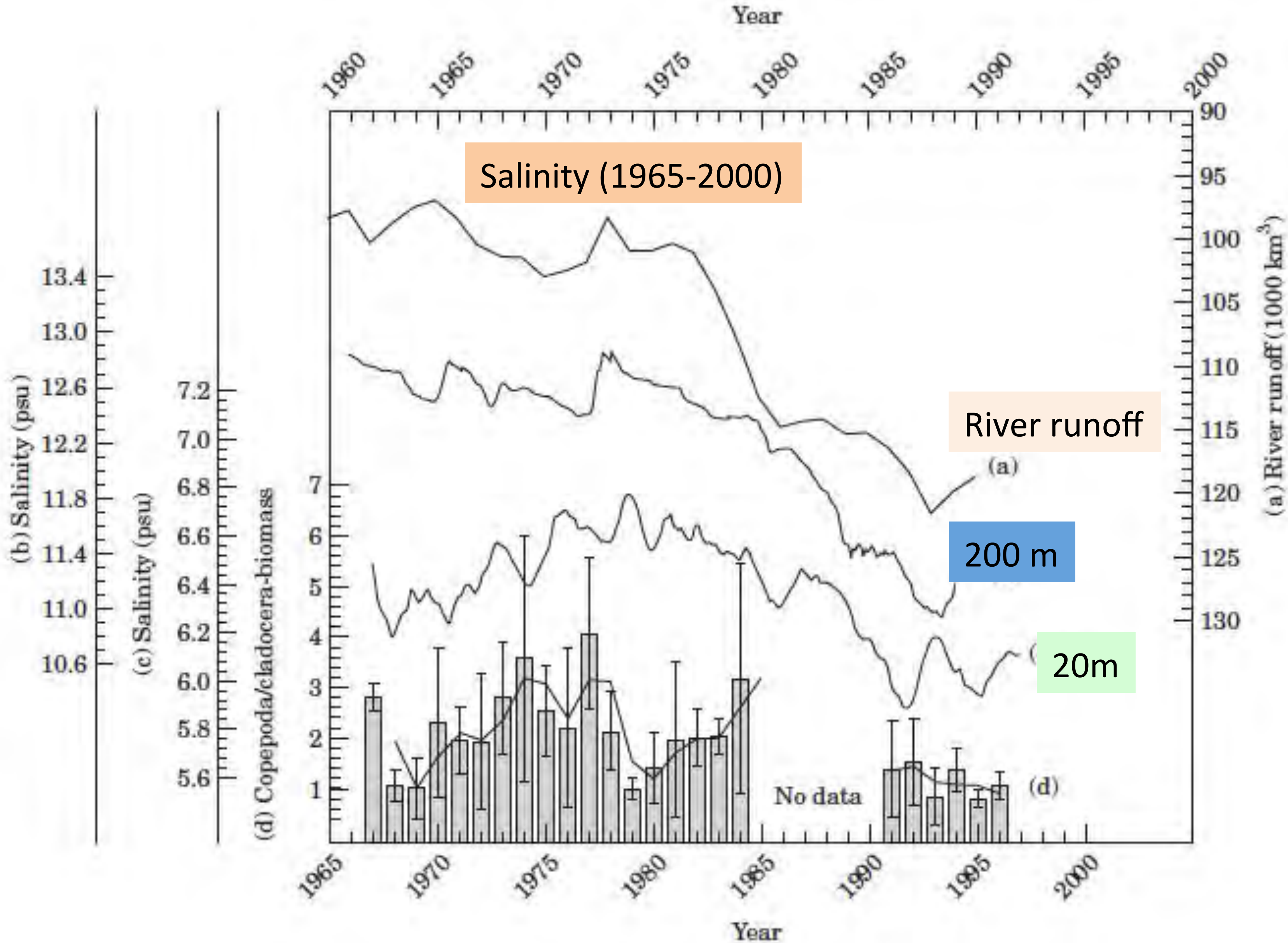
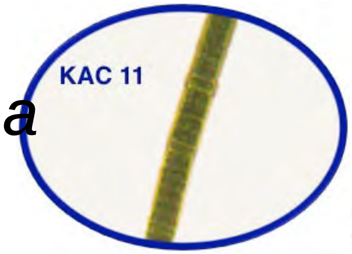


Figure 2. Time series of: (a) 15-year moving average of river run-off (km^3) to the Baltic Proper (y-axis inverted; x-axis shifted by 5 years); (b) 6-month moving average for salinity at 200 m depth at station II; (c) 12-month moving average for salinity at 20 m depth at station I; (d) average copepoda/cladocera biomass ratio for May–September (error bars: standard error) and 2-year moving average (line).

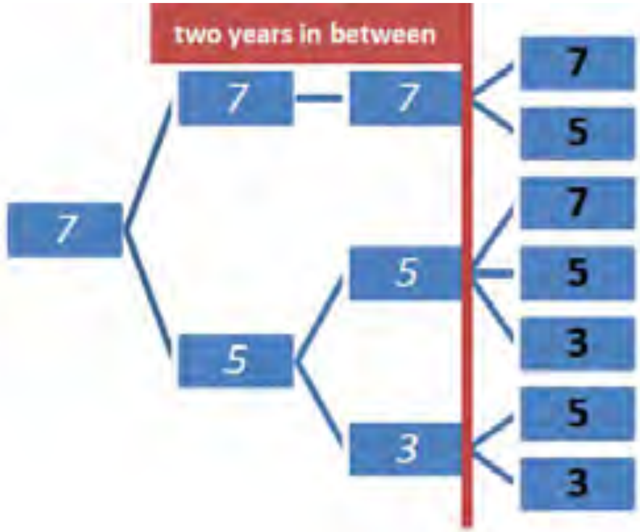
Vuorinen et al. 1998

Facing salinity changes: Adaptation?

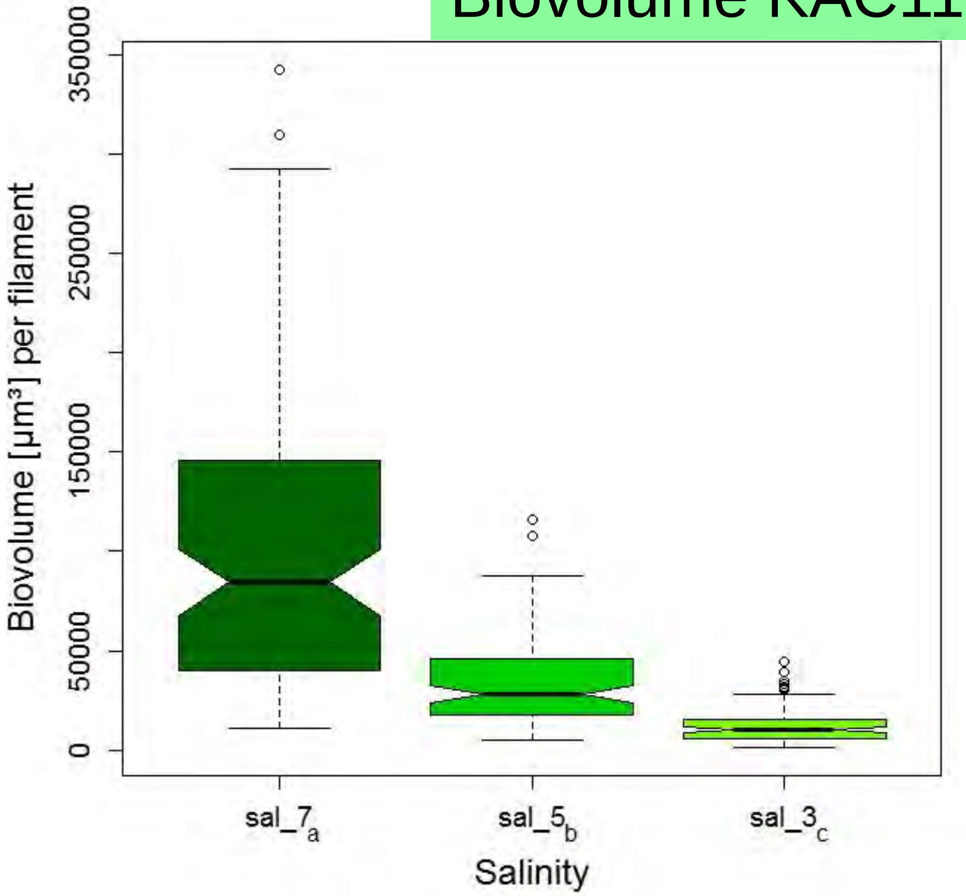
Nodularia spumigena



Salinity

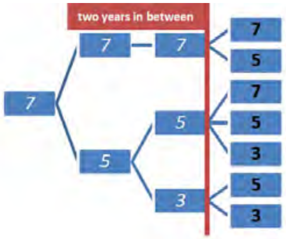


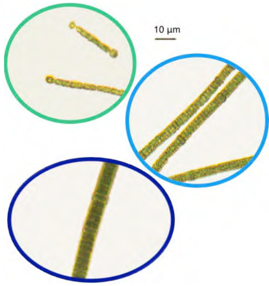
Biovolume KAC11



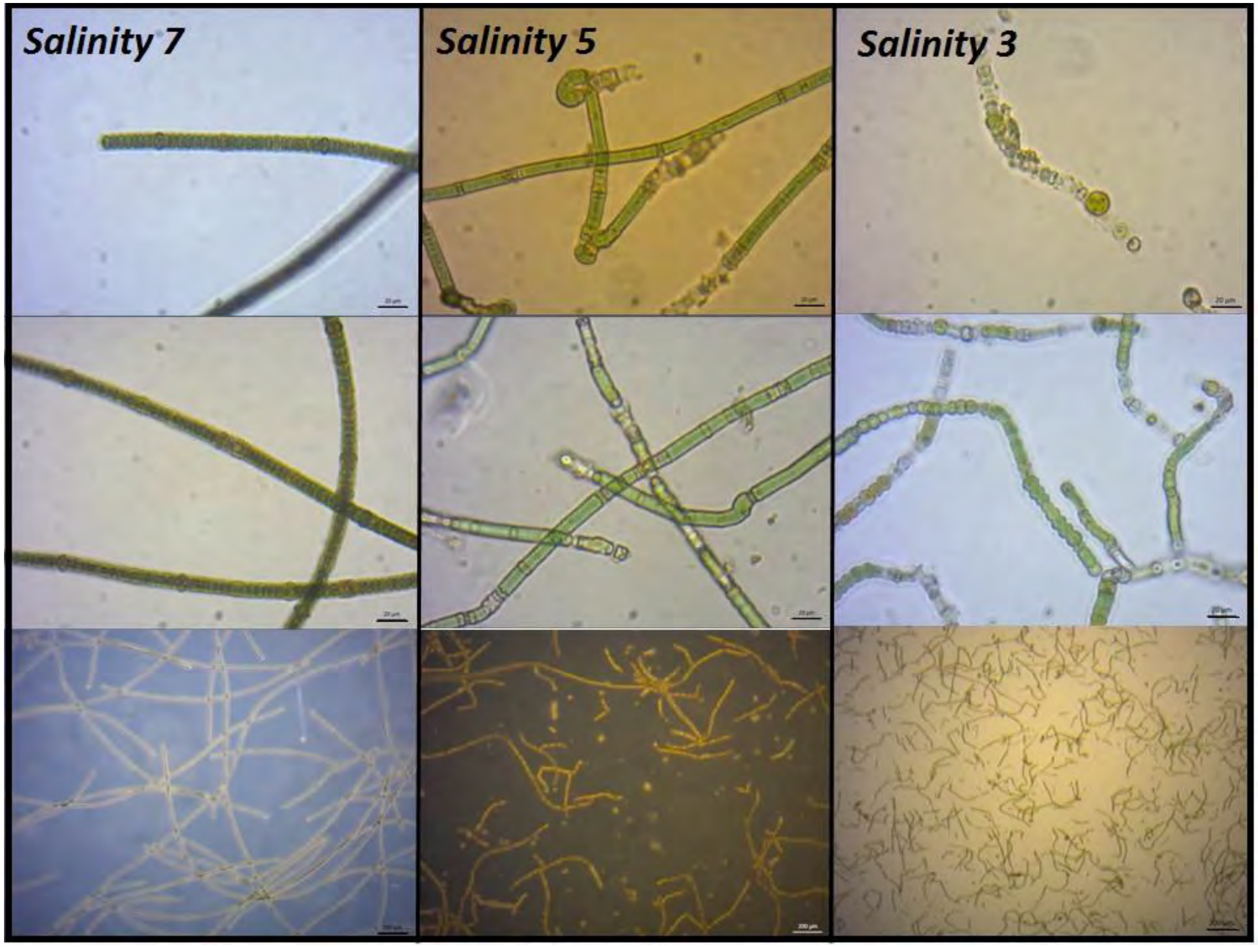
Klotz et al. 2014

Shock, Adaptation, Recovery?





Morphotypes KAC11

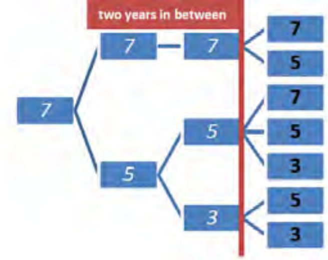


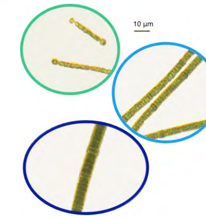
Akinetes

Biovolume

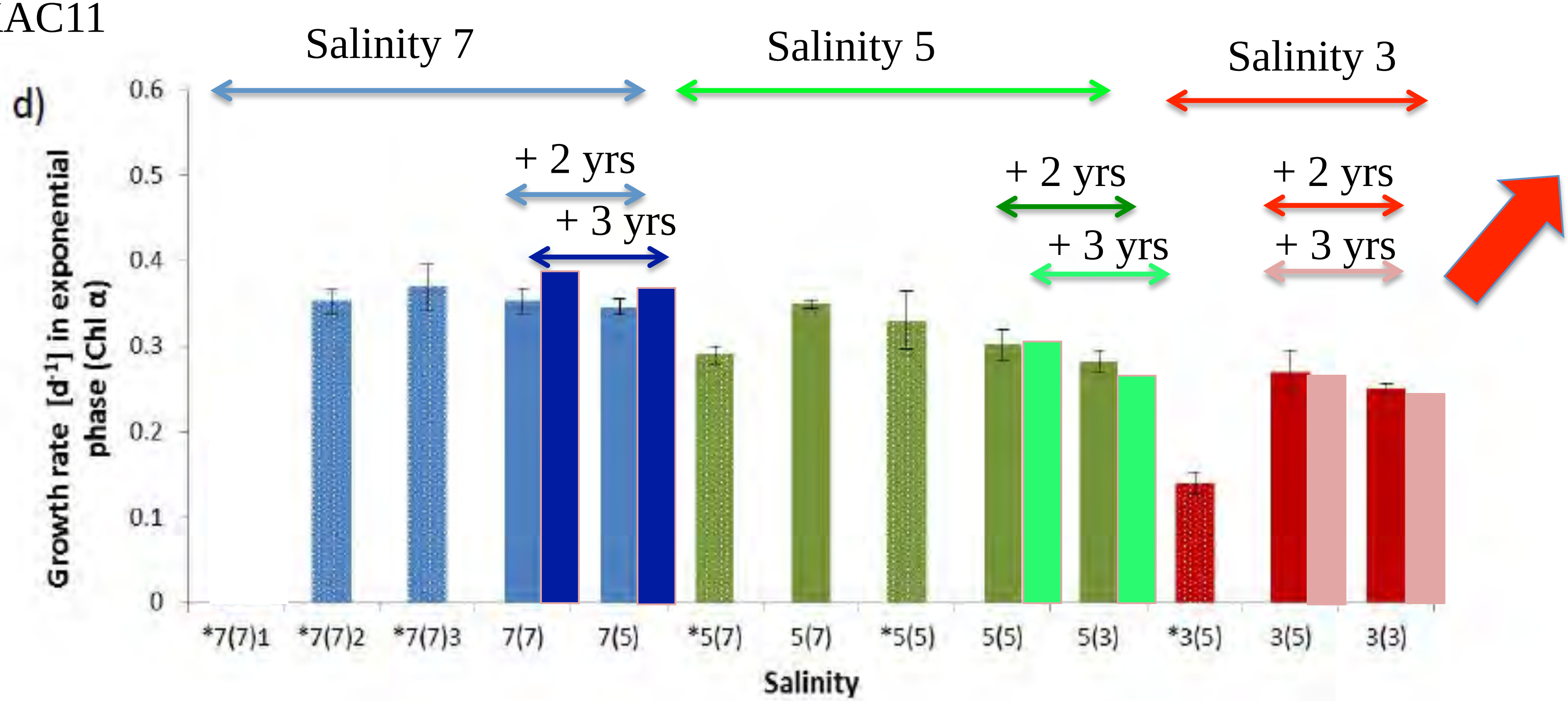
Klotz et al. 2014

Shock, Adaptation, Recovery?





KAC11



Linnæus University Centre
Ecology and Evolution in Microbial model Systems

Klotz et al. 2014
Bertos Fortis et al. in review

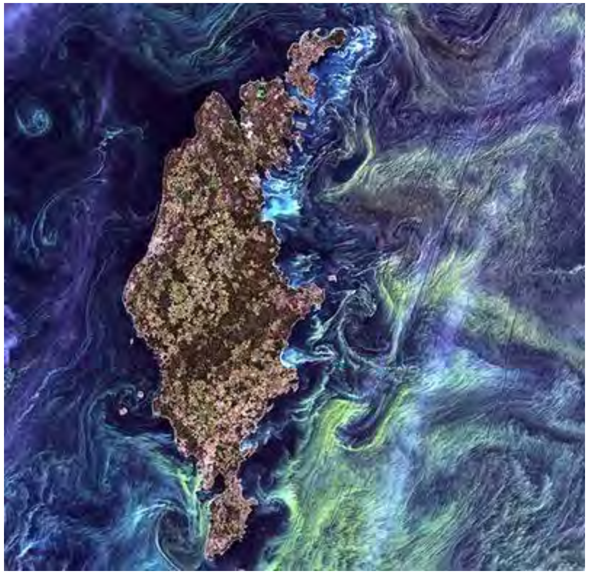
Perspectives

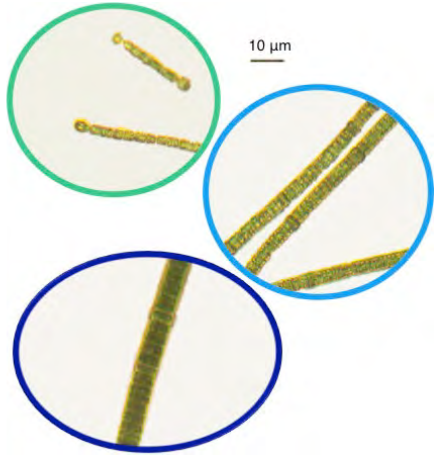
Towards reduced salinity

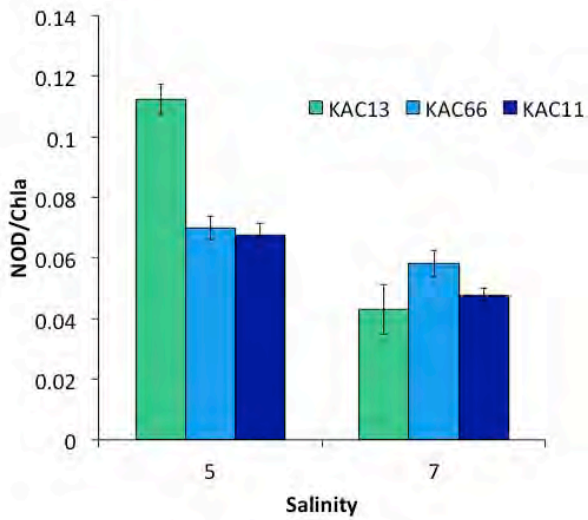
- Natural selection and rapid adaptation drive cyanobacterial dynamics.
- Reduced growth, biovolume and buoyancy
- Shorter filaments => increased grazing pressure
- No impact on toxin content (nodularin)
- Restricted peptide profile => high tolerance to lower salinity and a strong competitive ability against co-occurrent strains

Lower salinity could favour *N. spumigena* genotypes that will alter food web efficiency in response to temperature and eutrophication

Toxicity and shift in salinity in the Baltic Sea?







Bertos Fortis et al. 2013

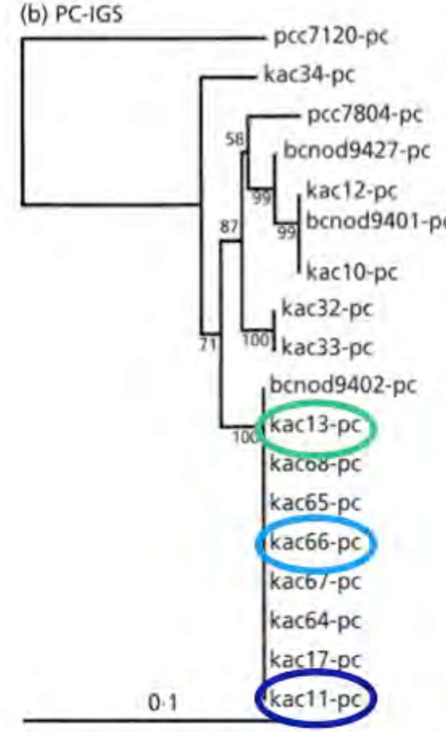
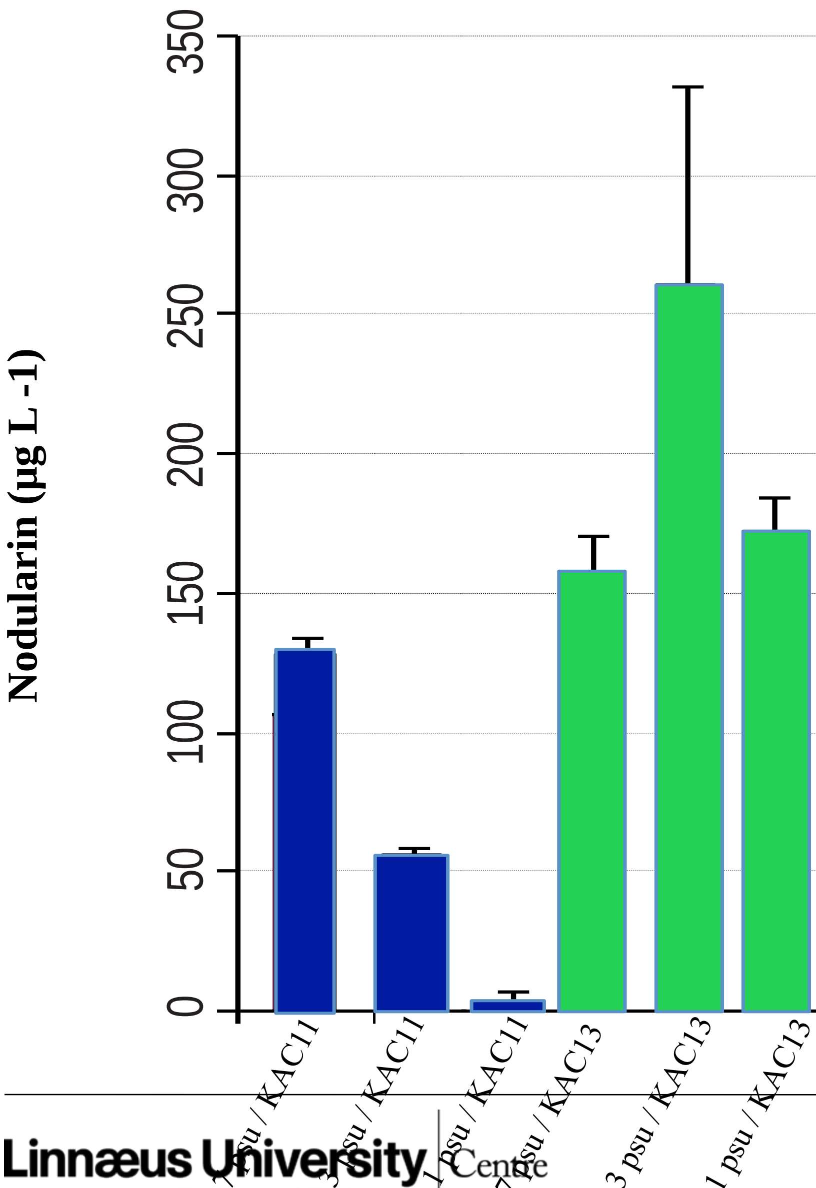
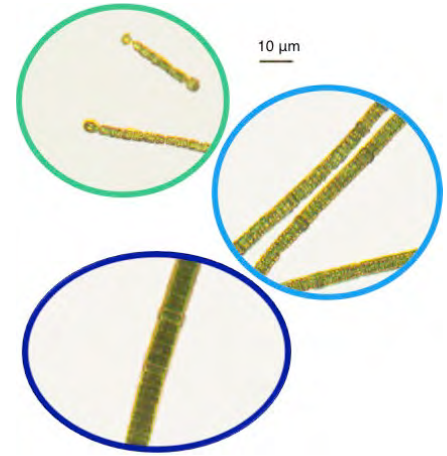


Figure 1 in Janson and Granéli 2002

Some do better than others…





Nodularin
Competitive advantage
Or extreme cost?

Olofsson 2011

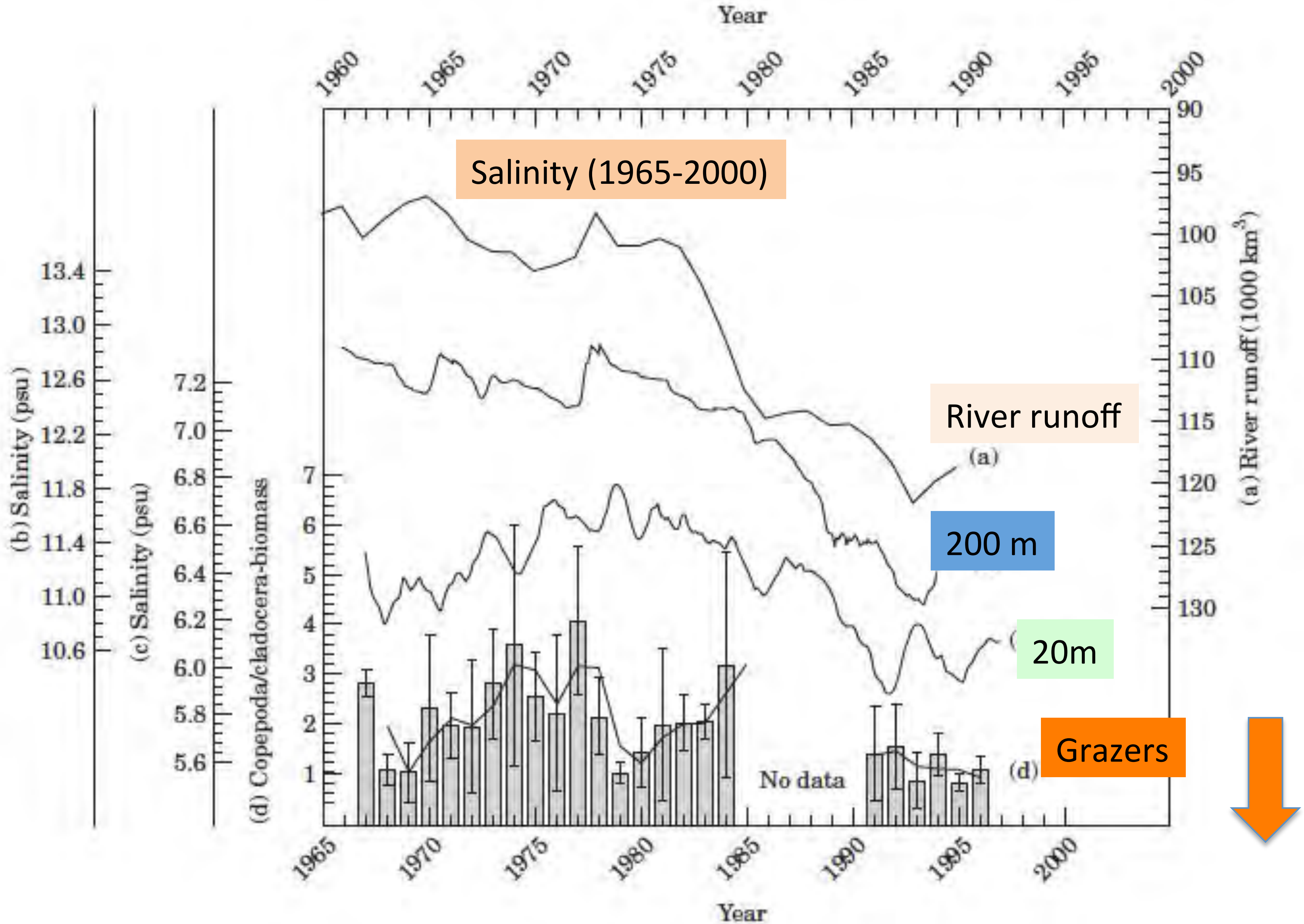
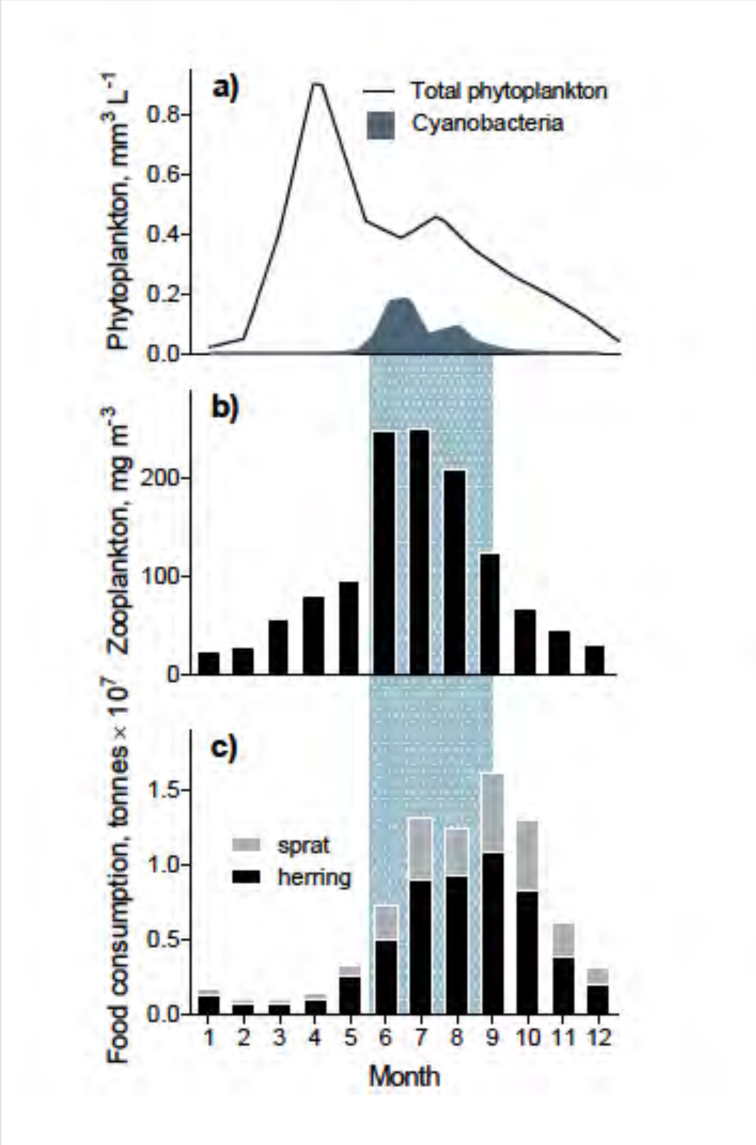


Figure 2. Time series of: (a) 15-year moving average of river run-off (km^3) to the Baltic Proper (y-axis inverted; x-axis shifted by 5 years); (b) 6-month moving average for salinity at 200 m depth at station II; (c) 12-month moving average for salinity at 20 m depth at station I; (d) average copepoda/cladocera biomass ratio for May–September (error bars: standard error) and 2-year moving average (line).

Seasonal development in the Northern Baltic Sea



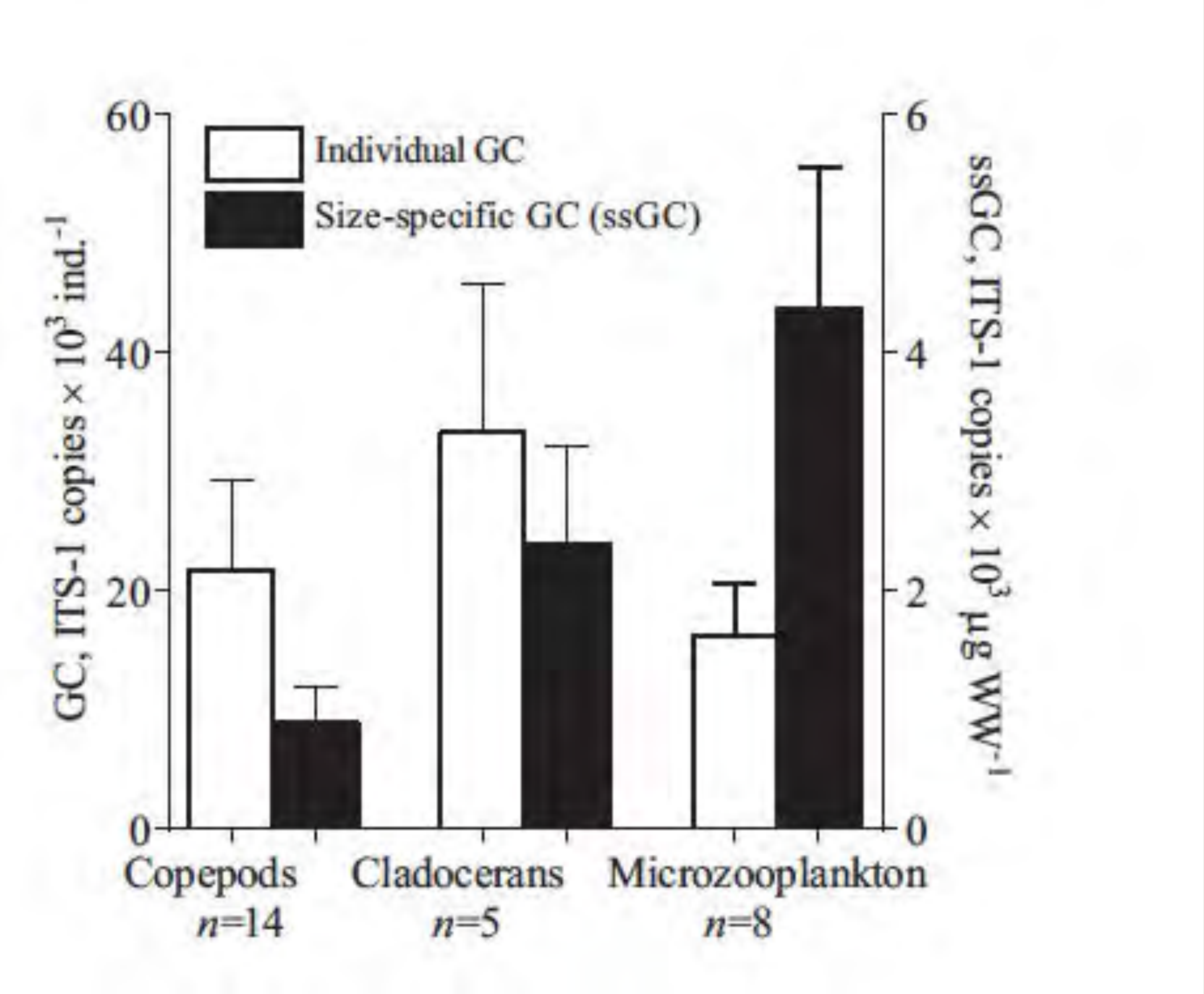
Phytoplankton
Cyanobacteria
(1992-2011)

Zooplankton
(1992-2011)

Food consumption
Planktivorous fish
(Arrhenius & Hansson 1993)

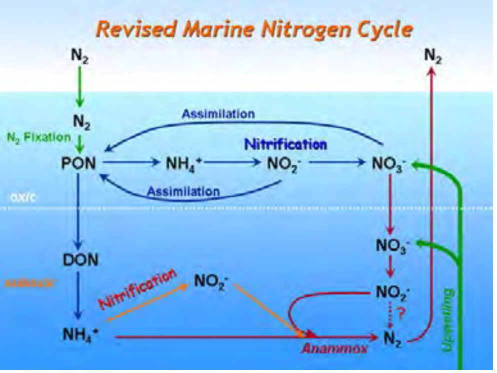
Karlson et al. 2015

Occurrence of *Synechococcus* in Zooplankton

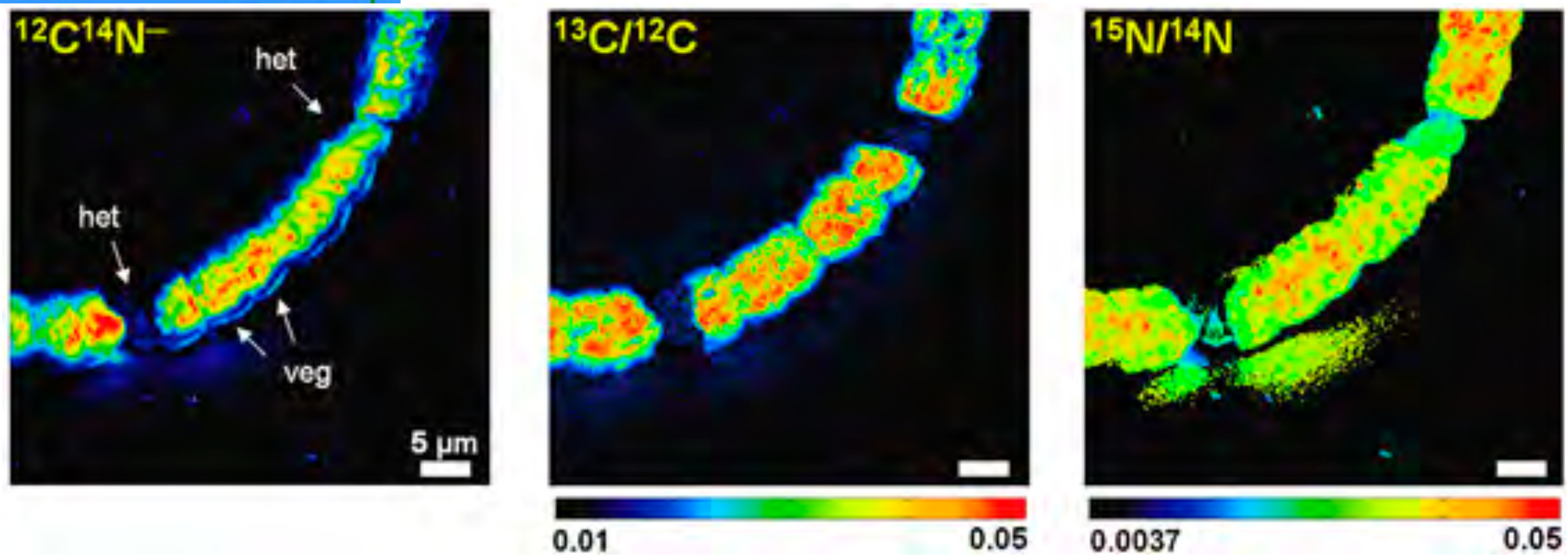


Field-collected zooplankton
GC: Gut Content
ssGC: size specific Gut Content

Motwani & Gorokhova 2013



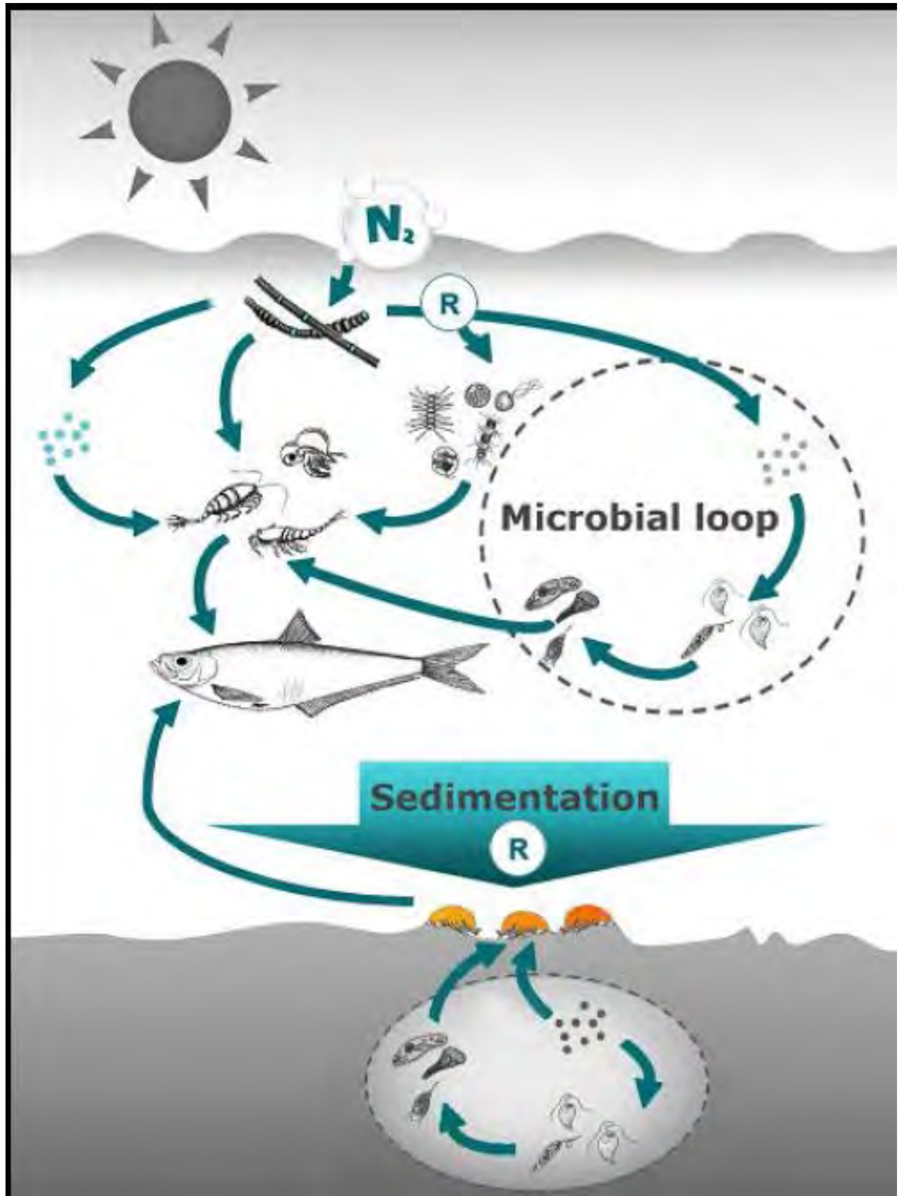
N_2-fixation in live cells



Distribution of $^{12}C^{14}N^-$, $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in single *Nodularia* cells as measured by nanoSIMS after 6 h incubations with ^{13}C and $^{15}N_2$.

Ploug et al. 2011 ISME

N_2-fixing Cyanobacteria stimulate secondary production in the Baltic Sea



Karlson et al. 2015

Value of N:P ratios for predicting cyanobacterial blooms

PNAS

Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment

David W. Schindler*†, R. E. Hecky‡, D. L. Findlay§, M. P. Stainton§, B. R. Parker*, M. J. Paterson§, K. G. Beaty§, M. Lyng§, and S. E. M. Kasian§

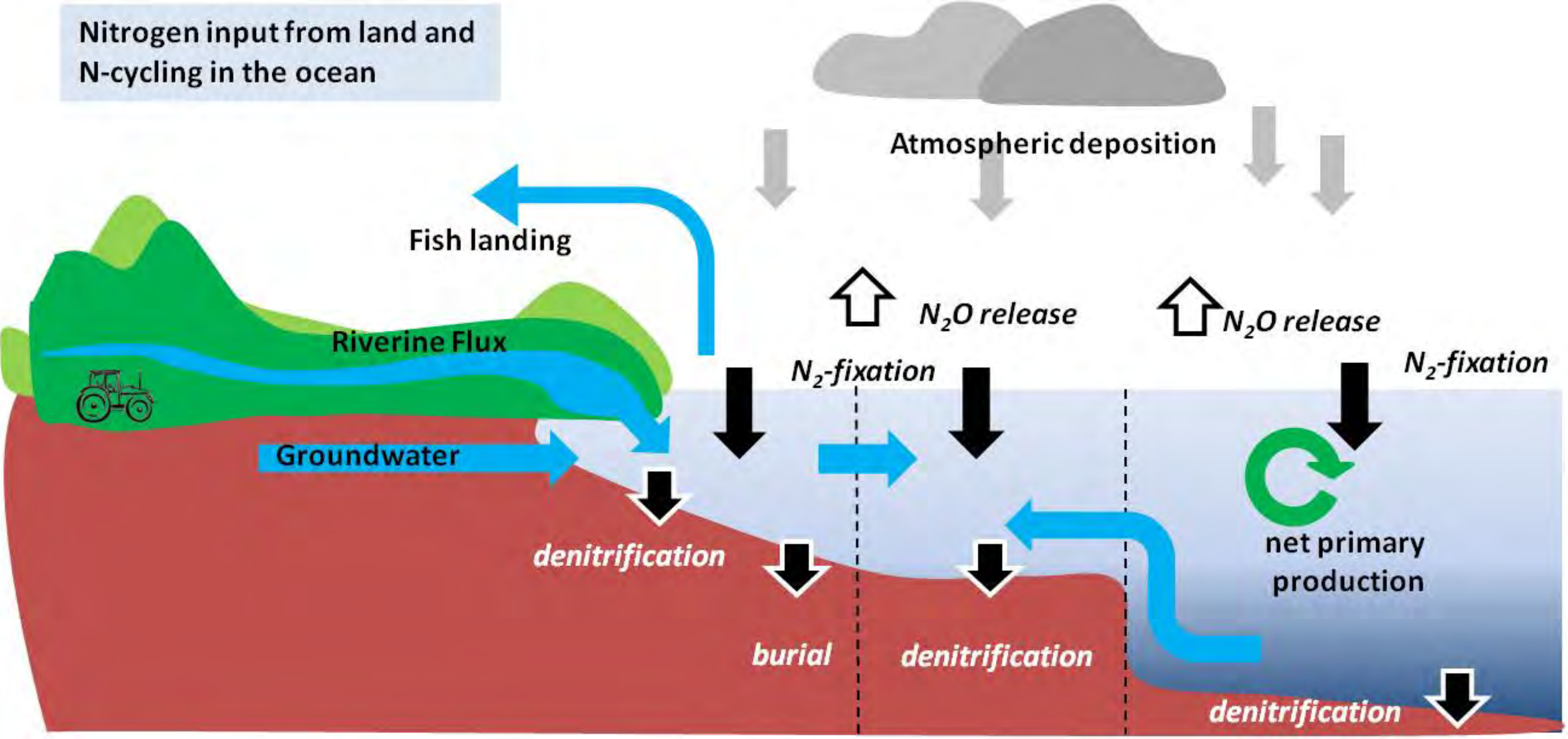
*Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9; ‡Department of Biology, University of Minnesota, Duluth, MN 55812; and §Freshwater Institute, Canadian Department of Fisheries and Oceans, Winnipeg, MB, Canada R3T 2N6

ECOLOGY

Controlling Eutrophication: Nitrogen and Phosphorus

Improvements in the water quality of many freshwater and most coastal marine ecosystems requires reductions in both nitrogen and phosphorus inputs.

Daniel J. Conley,[1]* Hans W. Paerl,[2] Robert W. Howarth,[3] Donald F. Boesch,[4] Sybil P. Seitzinger,[5] Karl E. Havens,[6] Christiane Lancelot,[7] Gene E. Likens[8]



- How much N is fixed by cyanobacteria?
- Role of environmental factors?
- Transfer to higher trophic level?
- Can the losses of combined nitrogen by denitrification counteract eutrophication?

IOW 2012