Modelling eutrophication of lake ecosystems

Brigitte Vinçon-Leite
Leesu/Ecole des Ponts ParisTech
Université Paris-Est

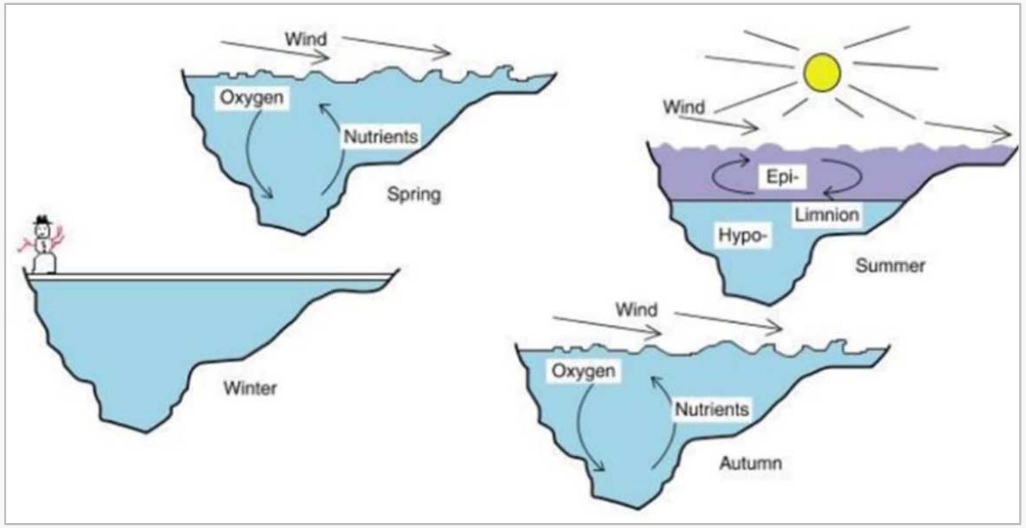
20/04/2017

Outline

- Context of lake eutrophication modelling
- Modelling phytoplankton dynamics
  - Cyanobacteria
- Models as prospective tools
  - Assessing the impact of global change
  - Supporting decision-making
  - Forecasting systems
- Perspectives and conclusion

Lake specific patterns

- High residence time of water
- Slow current velocities
- Thermal stratification
- Integrative response to pressures from the catchment and the atmosphere



(From Boehrer and Schultze, 2009)

Lake eutrophication

- Historical awareness in the 1950's
  - *e.g.* Lake Washington (Edmonson *et al.*, 1956); Lake Zürich (Thomas, 1965)
- Paleolimnology
  - Early symptoms of eutrophication of the perialpine lakes in the 1930s (*e.g.* Jenny et al., 2013)
- OECD report (Vollenweider, 1968)

ORGANISATION DE COOPERATION
ET DE DEVELOPPEMENT ECONOMIQUES

DIFFUSION GENERALE

Paris, le 30 septembre 1970

LES BASES SCIENTIFIQUES DE L'EUTROPHISATION

DES LACS ET DES EAUX COURANTES

SOUS L'ASPECT PARTICULIER DU PHOSPHORE ET DE L'AZOTE

COMME FACTEURS D'EUTROPHISATION

Ce rapport, paru originellement le 17 septembre 1968, a été préparé par le Dr. Richard A. Vollenweider à la demande du Comité de la Coopération dans la Recherche de l'O.C.D.E. pour l'aider à établir son programme de travail sur l'eau. En raison de l'intérêt immédiat qu'il souleva à l'époque, le rapport fut largement disbribué dans les milieux scientifiques. Le Conseil de l'O.C.D.E. lui a maintenant attribué une distribution générale.

La liste des travaux consultés est disponible sous forme d'annexe bibliographique.

Study sites

- Historically the large lakes, Great Lakes in the USA and Canada, peri-alpine lakes in Europe… and the large reservoirs
- Since the early 2000s
  – Chinese lakes (*e.g.* Lake Taihu)
  – Increasing number of modelling studies of reservoirs
  – Urban lakes

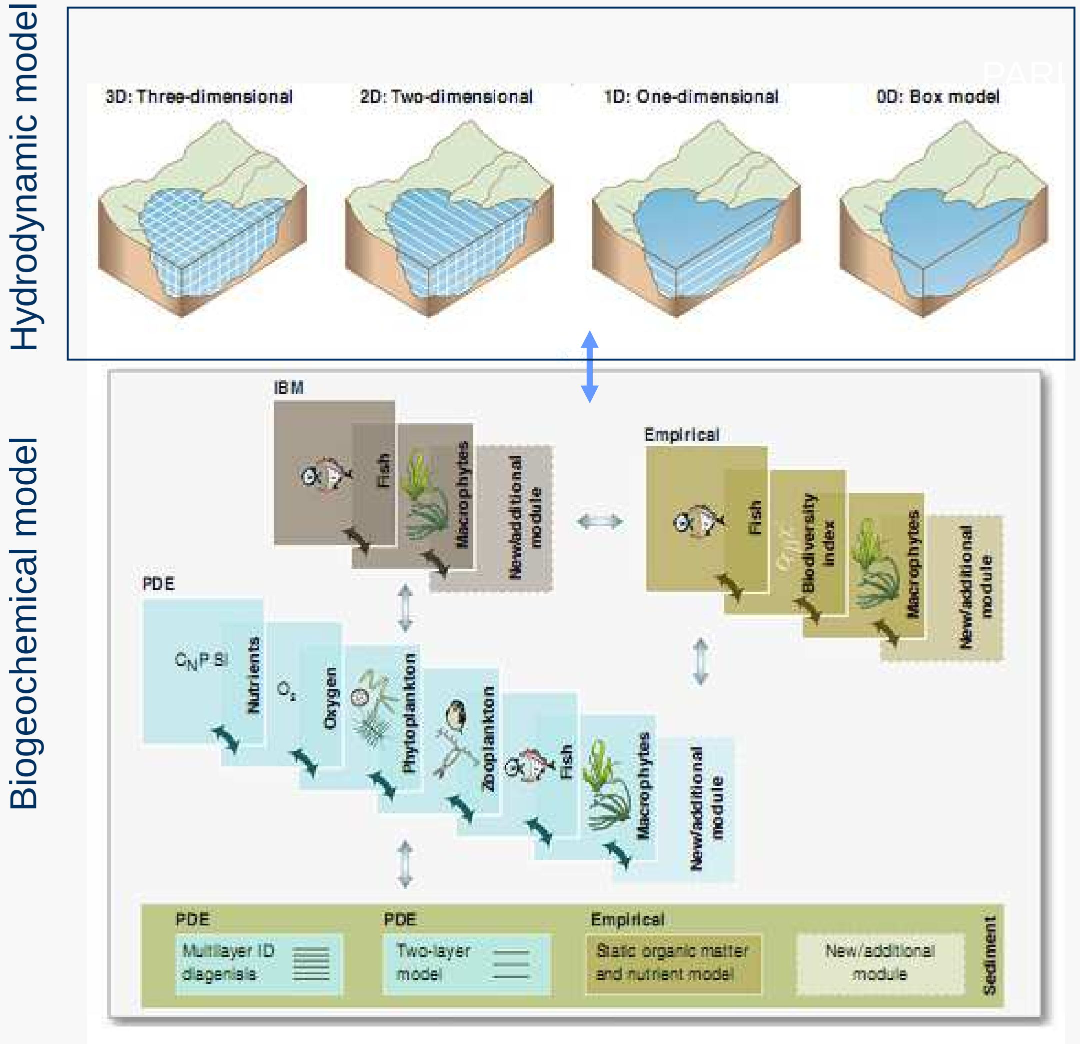
Modelling objectives

- Relationship between nutrient loading and the variables depicting eutrophication: nutrients, chlorophyll, oxygen…
- Long-term response of the ecosystem to global change scenarios (climate change, watershed management …)
- Short-term forecast of algal blooms, including cyanobacteria, depending on the use of the lake (drinking water uptake, bathing, recreation..)

- And also
  - Regulatory objectives, for example the European Water Framework Directive
  - Prediction of the functioning and impact of a planned reservoir

Deterministic models

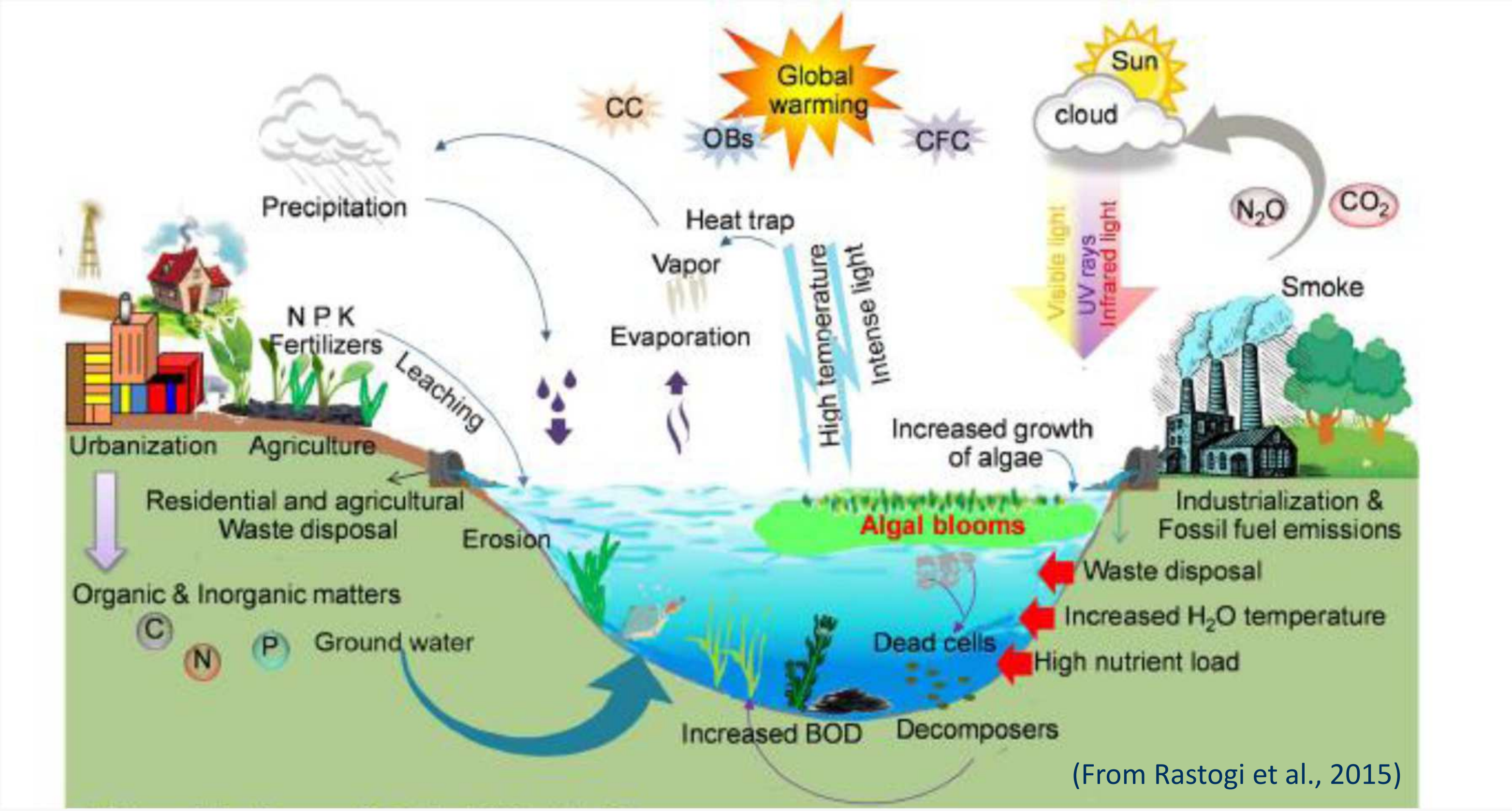
- Coupling hydrodynamics and biogeochemistry
- 0 to 3D
- Variable complexity of the biogeochemical/ ecological model
- Sediment modelling



(From Trolle et al., 2012)

Lake eutrophication modelling

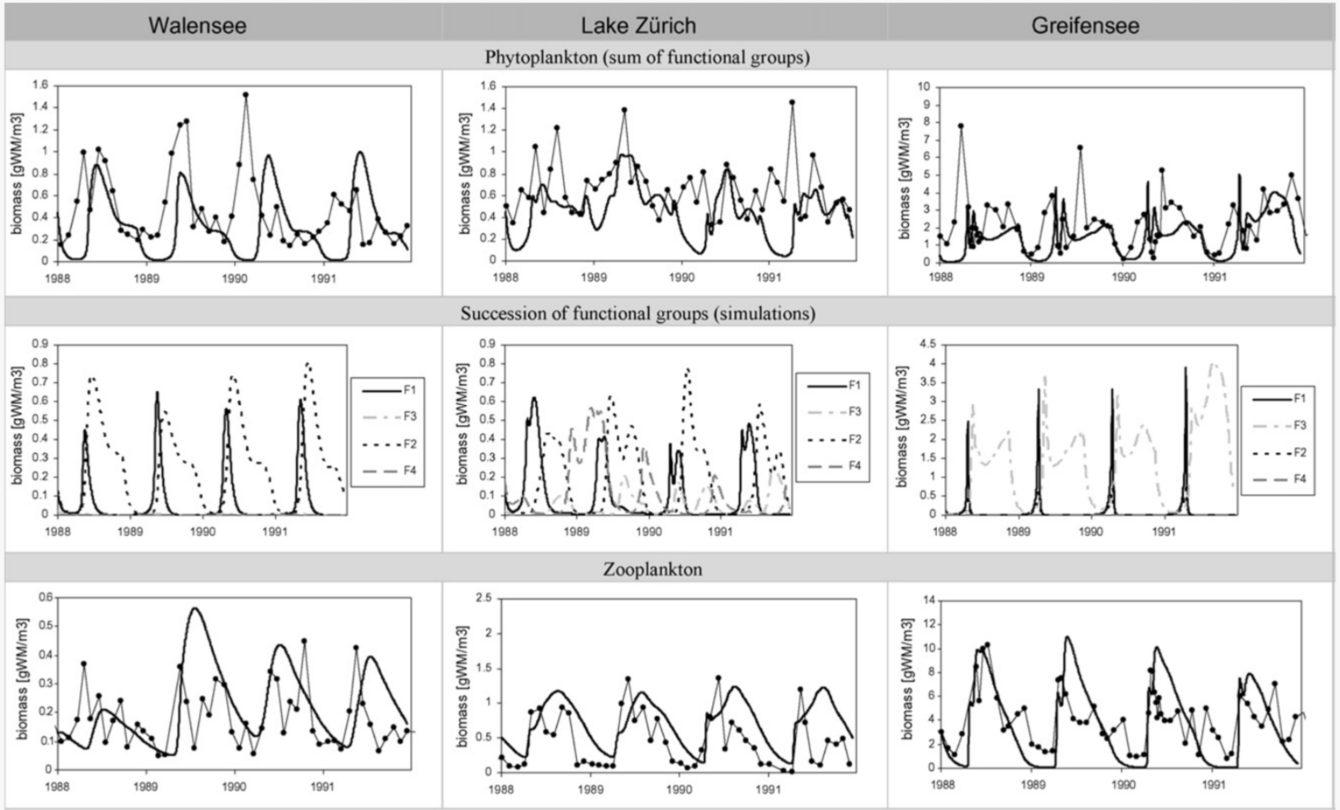
- Phytoplankton
- Interplay of the driving factors



(From Rastogi et al., 2015)

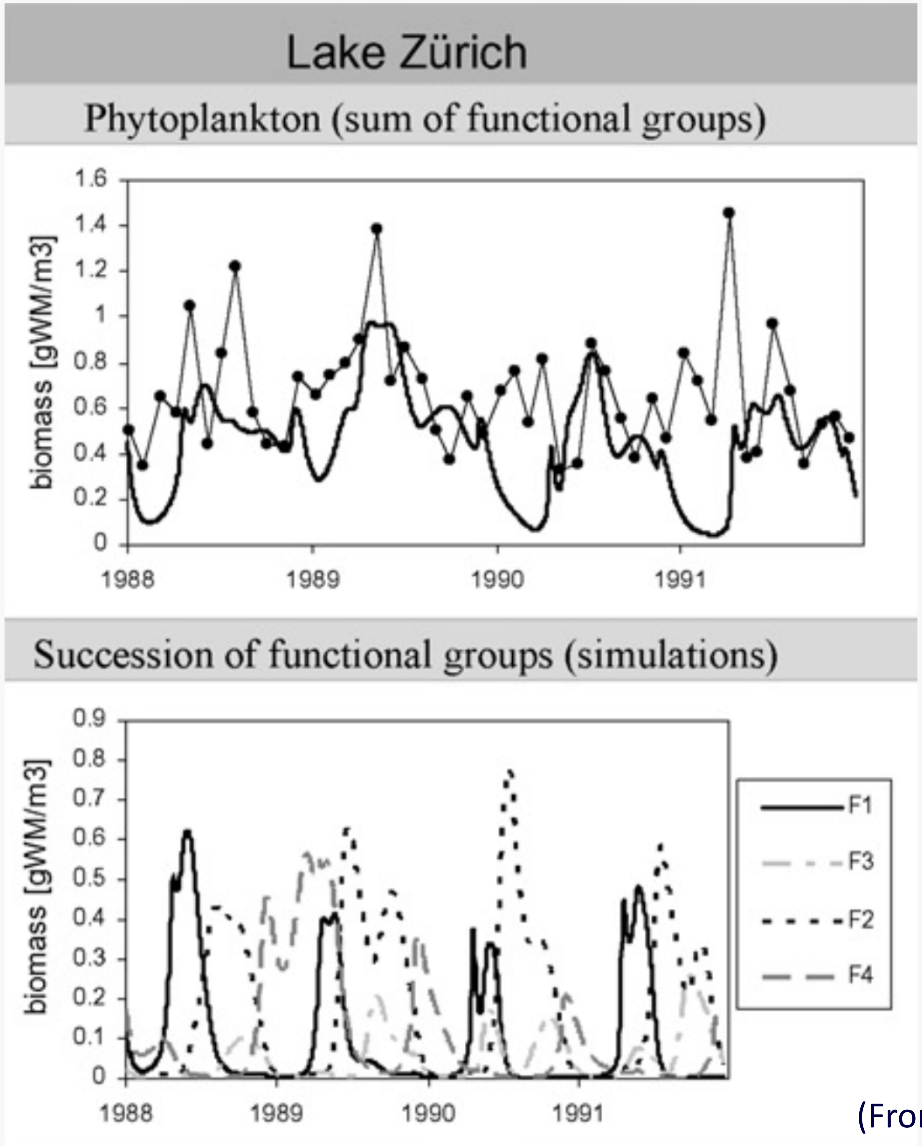
Understanding the phytoplankton dynamics

- Multiannual scale
- Phytoplankton groups based on functional traits



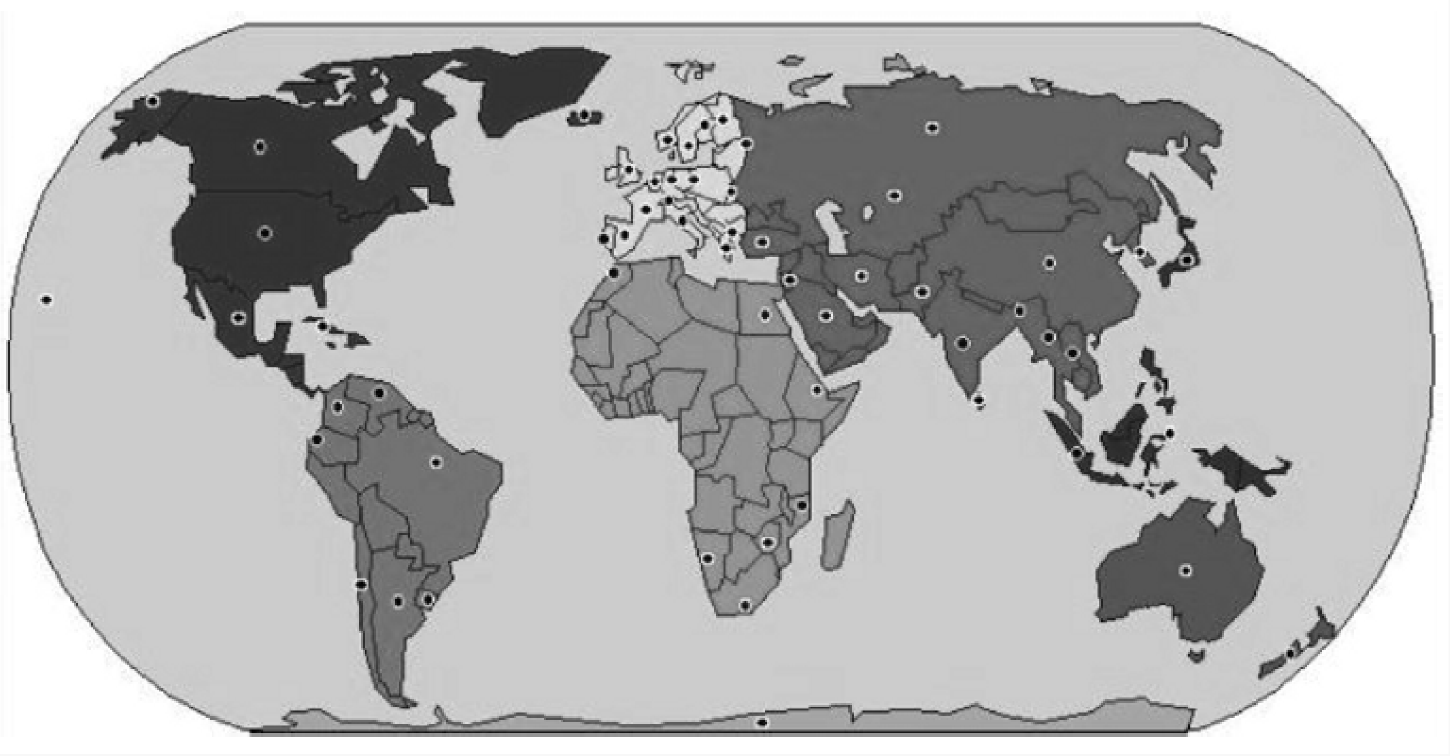
(Mieleitner et al., 2008)

Understanding the phytoplankton dynamics



(From Mieleitner et al., 2008)

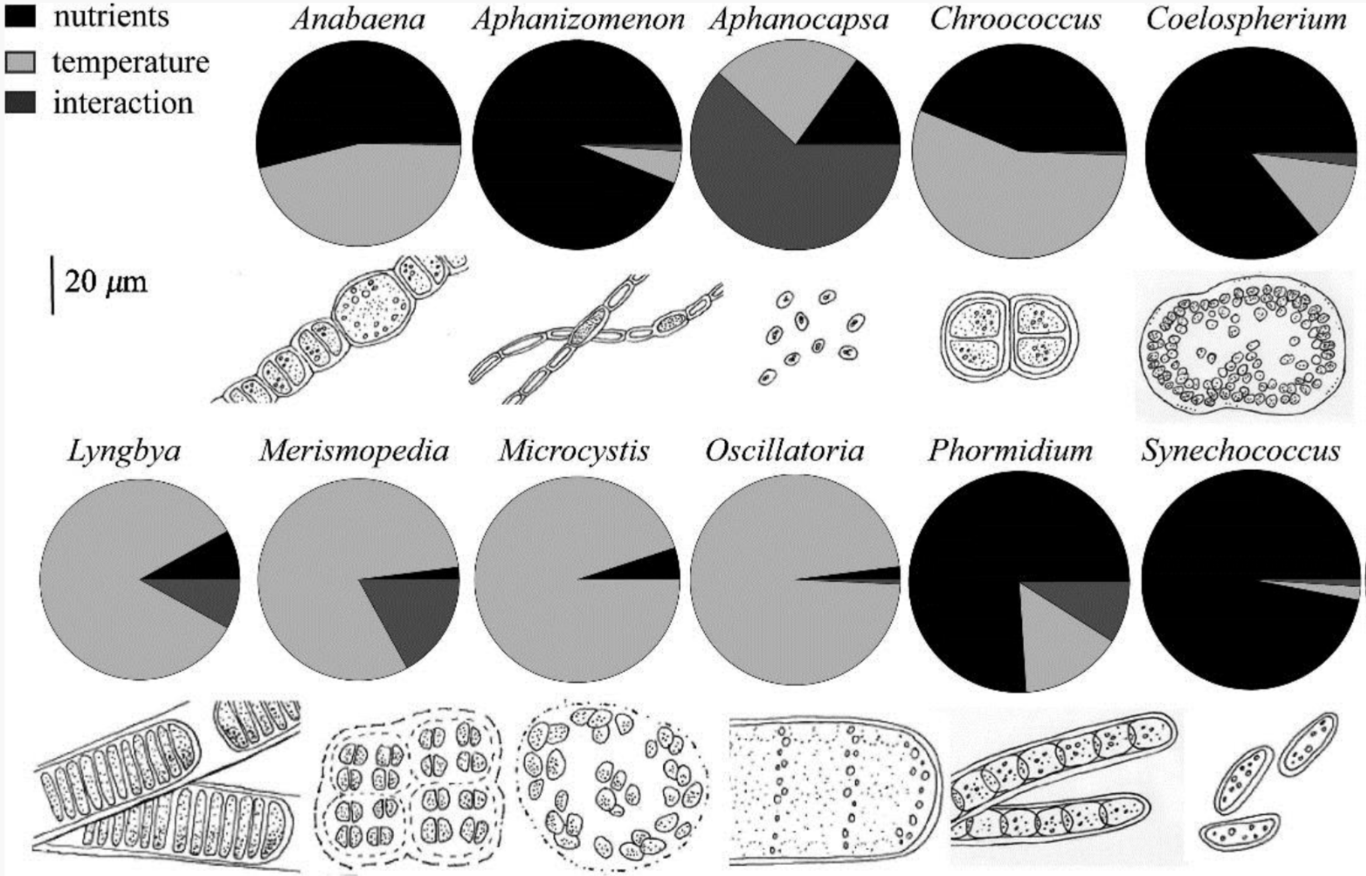
Cyanobacteria



(Carmichael, 2006 unpublished data in Hudnell 2008)

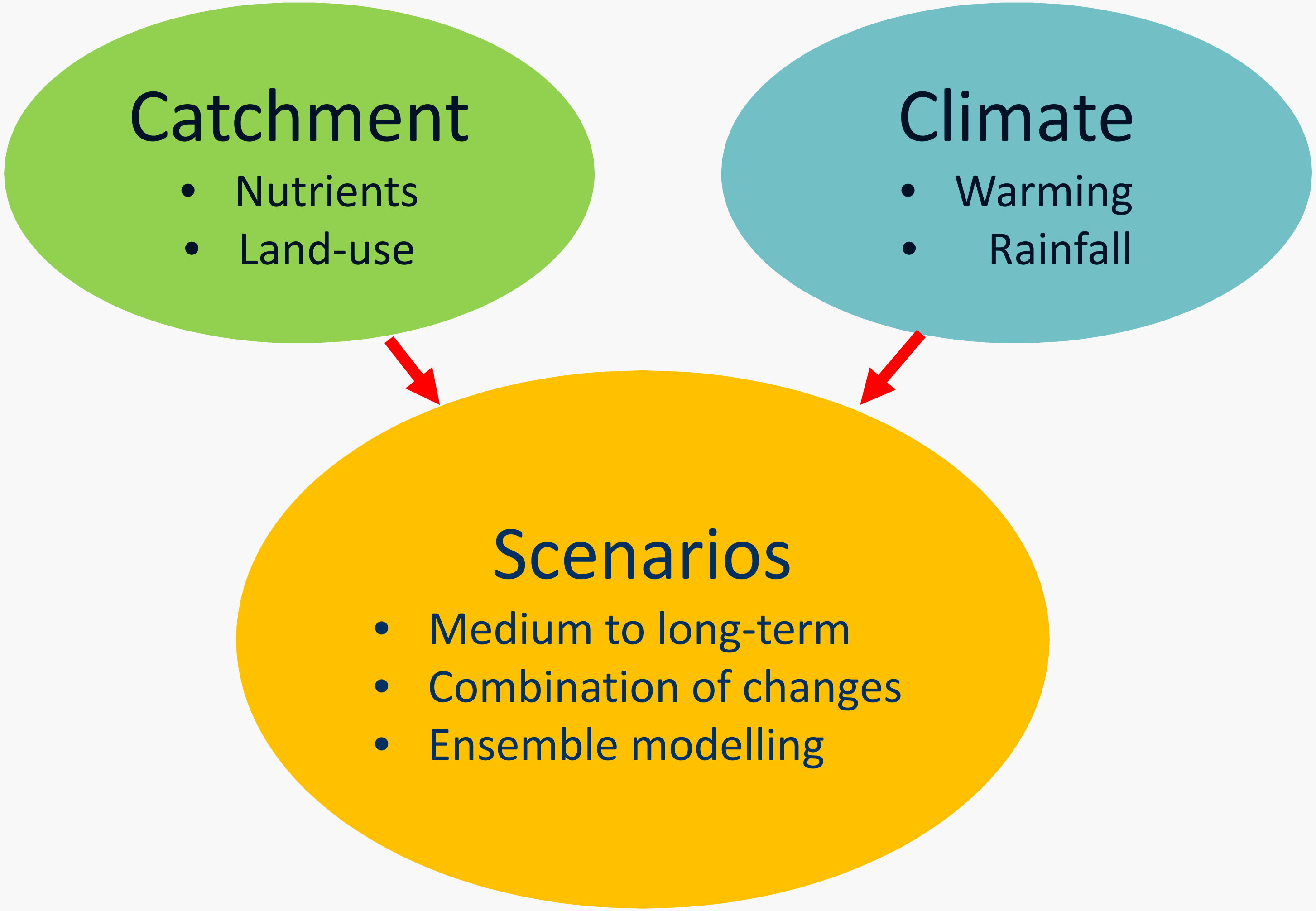
Cyanobacteria dynamics

- Different species
- Functional and morphological traits



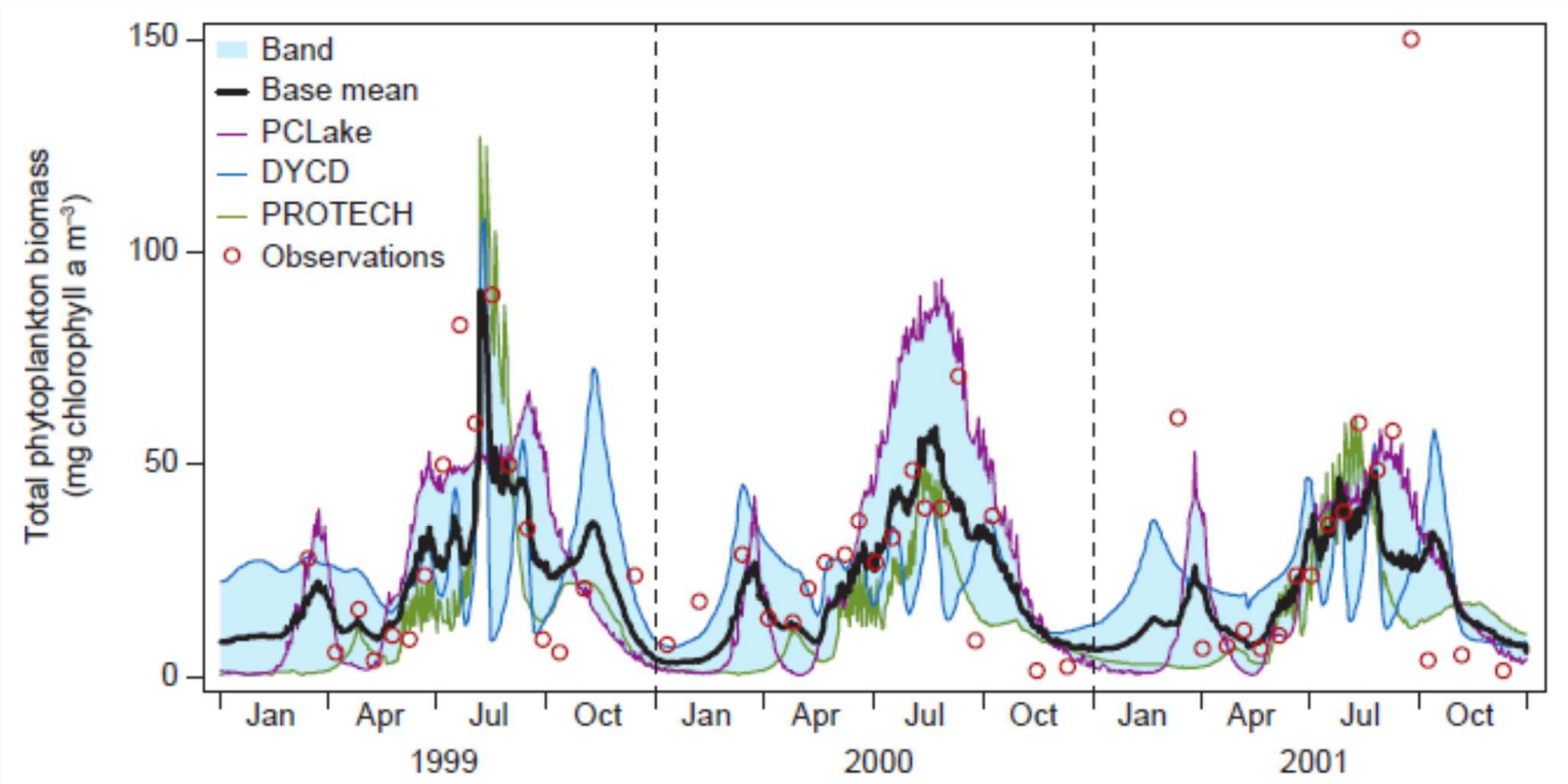
(From Rigosi et al., 2014)

Assessing the impact of global change



Assessing the impact of global change

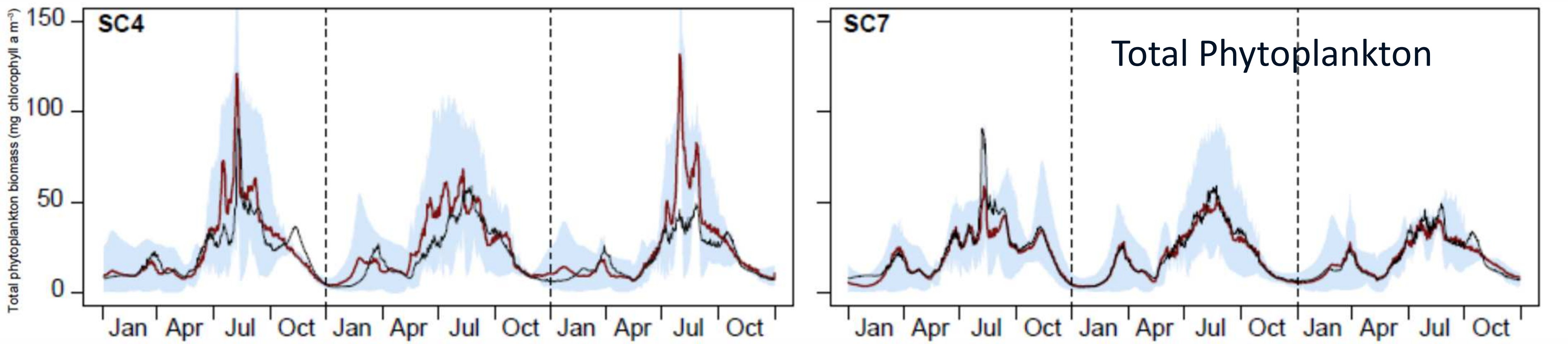
- Climate and nutrient loading



(Trolle et al., 2014)

Assessing the impact of global change

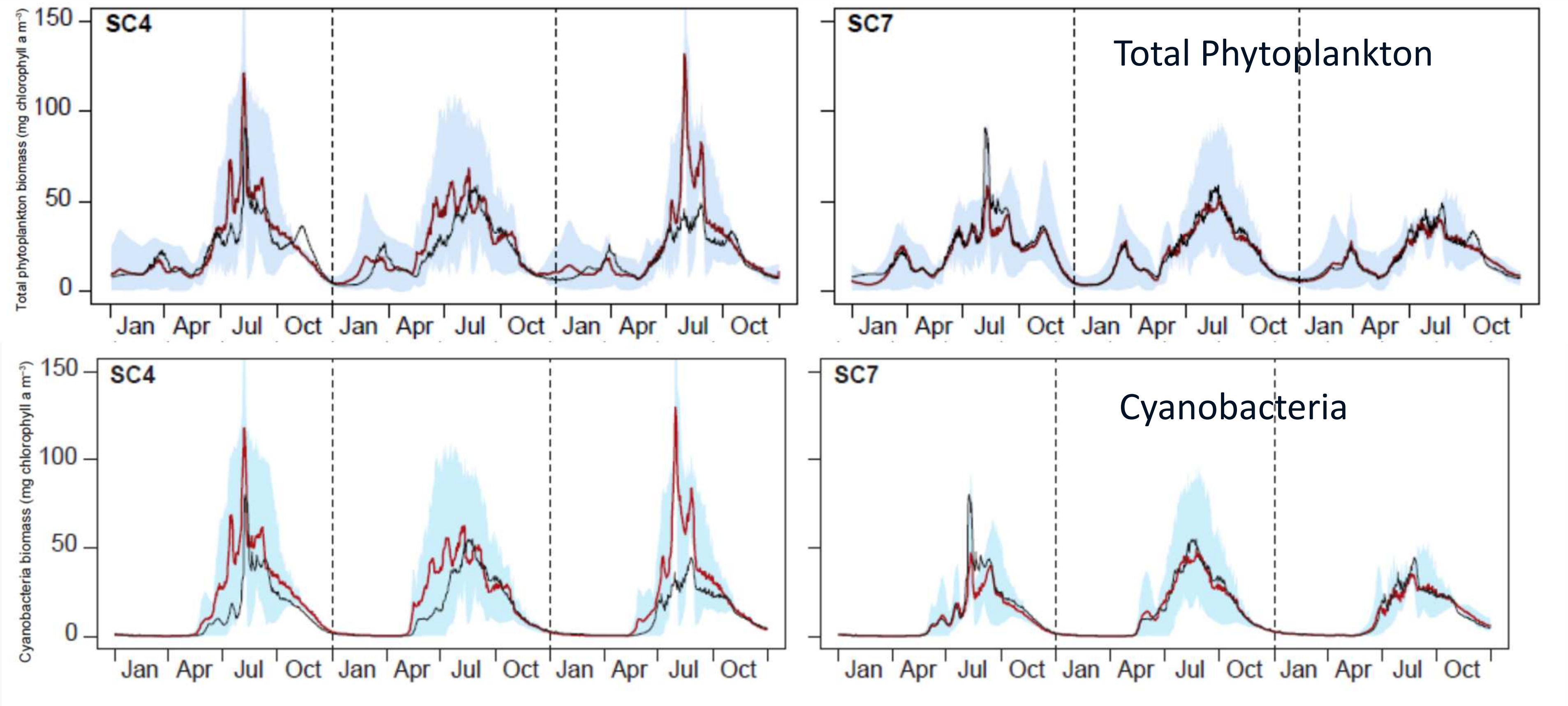
- Warming and nutrient loading
- Total phytoplankton biomass
-



(Trolle et al., 2014)

Assessing the impact of global change

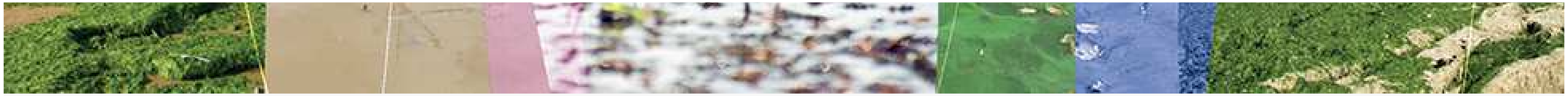
- Warming and nutrient loading
- Total phytoplankton biomass
- Cyanobacteria biomass



(Trolle et al., 2014)

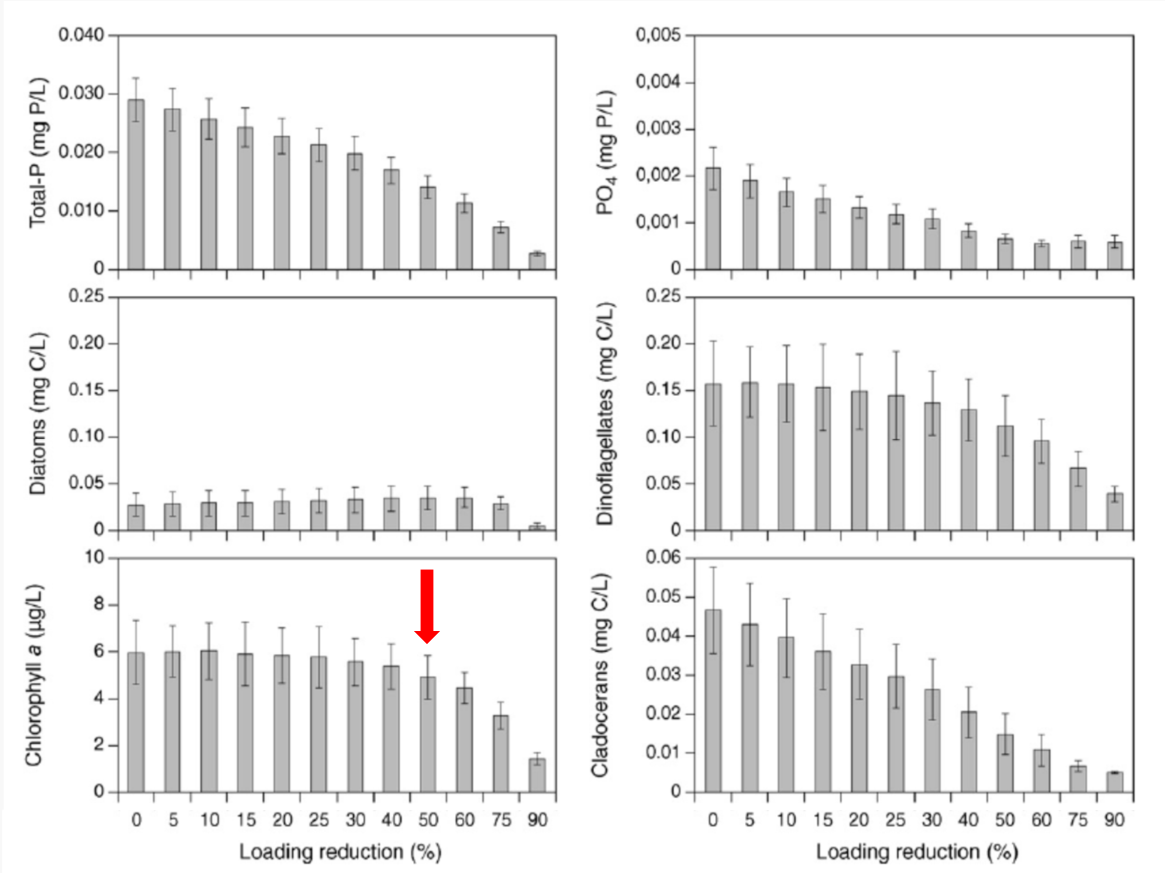
Modelling for management support

- Water Framework Directive
  - Lake Ravn Denmark (Trolle et al., 2008)
- Catchment management
  - Land-use and sanitation (Rodriguez-Reartes *et al.*, 2016)
  - Modelling chain: catchment and lake (Markensten *et al.*, 2016)



WFD requirements

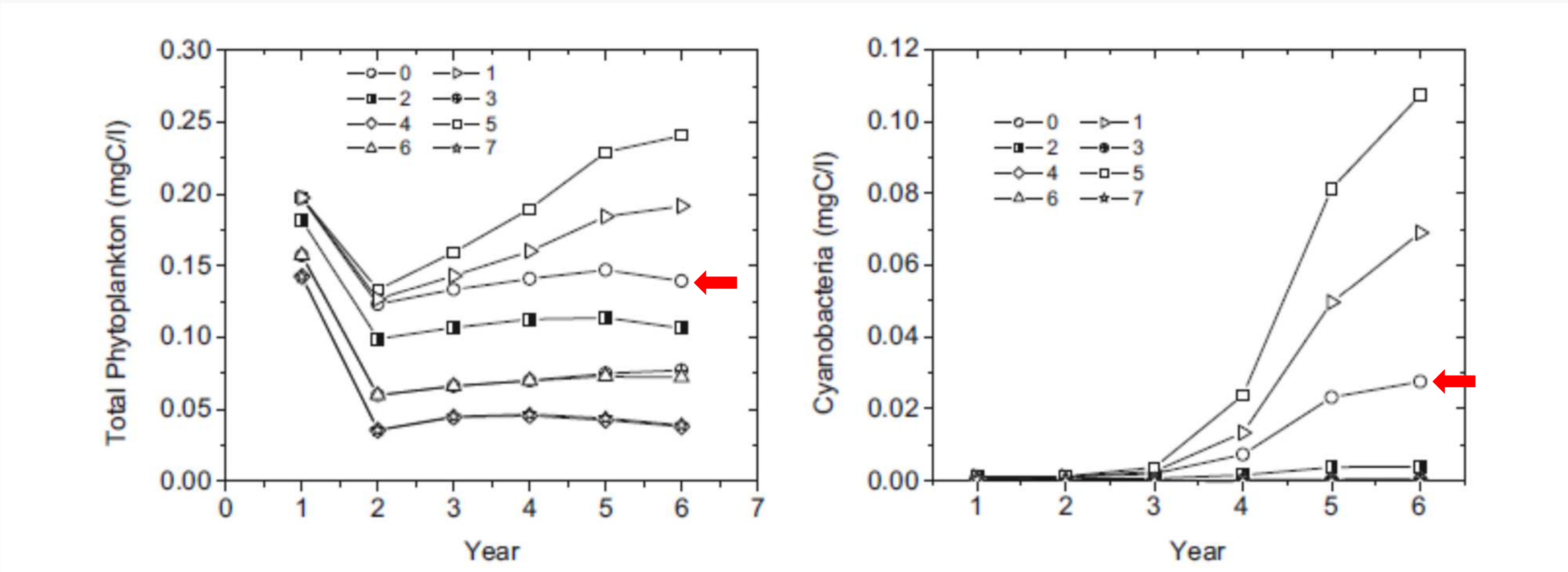
- Good ecological status of Lake Ravn (Denmark)
- Dyresm-Caedym to estimate P loading reduction
- Reduction of 50%



(Trolle et al. 2008)

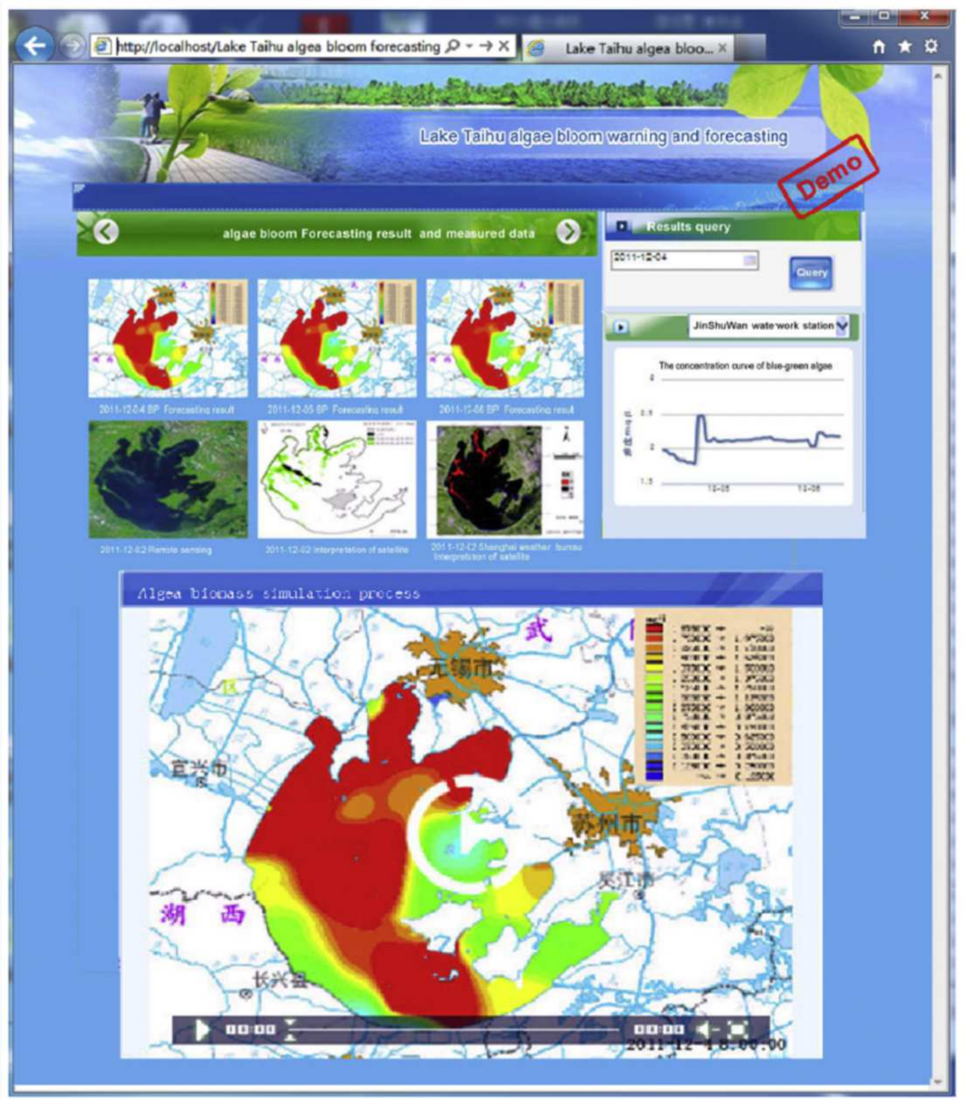
Catchment management

- Reservoir in Argentina (Rodriguez-Reartes *et al.*, 2016)
- 7 nutrient loading scenarios
  - Livestock
  - Sanitation
  - Combination
- 6 year simulations



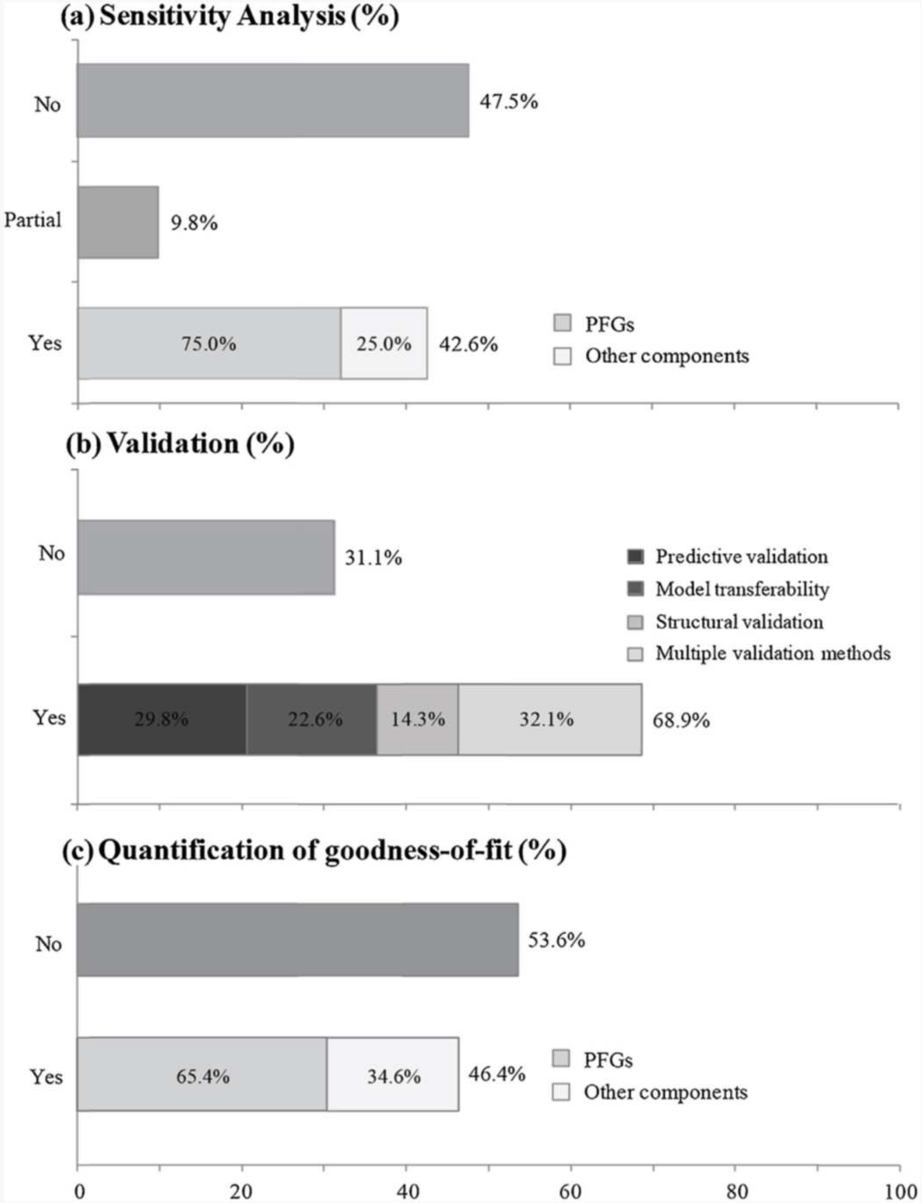
Short-term forecasting of cyanobacteria blooms

- Lake Taihu, China (Zhang *et al.*, 2014)
- 3-day forecast
- 3D hydrodynamic-biological model



Validation and uncertainty assessment

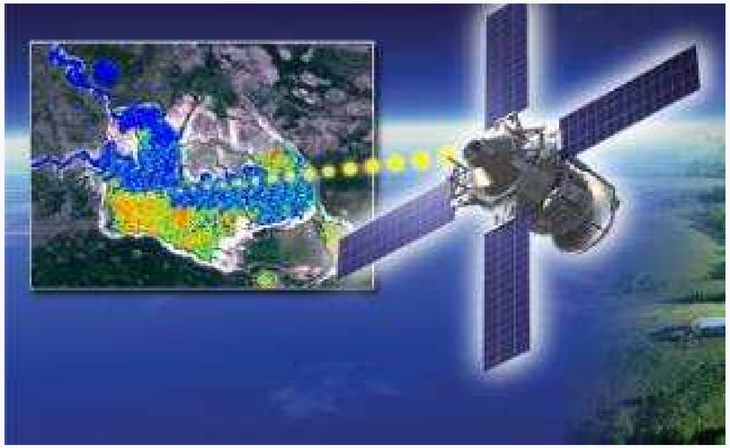
- Validation
  - Qualitative assessment
  - Performance indicators : RMSE, MAE, Nash, Taylor diagrams
- Sensitivity analysis of the parameters
- Uncertainty analysis



(Shimoda and Arhonditsis, 2016)

Data collection

- Online sensors
- High-frequency measurements
- High-resolution satellite data



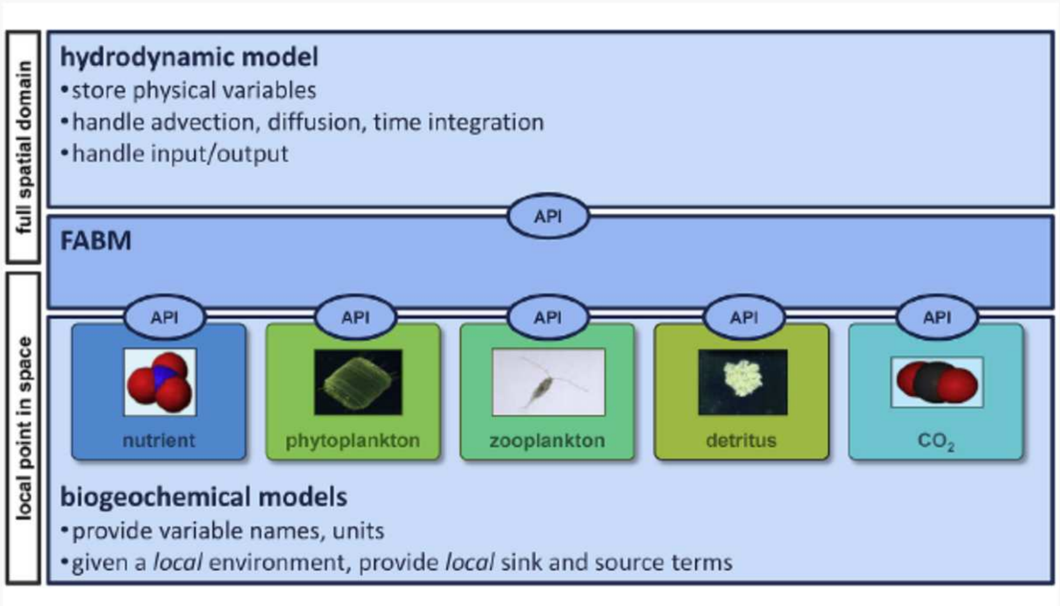
Modelling platforms

- Open-sources models
- Benchmark of models

Environmental Modelling & Software 61 (2014) 249–265
Contents lists available at ScienceDirect
Environmental Modelling & Software
journal homepage: www.elsevier.com/locate/envsoft

A general framework for aquatic biogeochemical models☆

Jorn Bruggeman[a,b,*], Karsten Bolding[a]



(Bruggeman and Bolding, 2014)

Environmental Modelling & Software 61 (2014) 266–273
Contents lists available at ScienceDirect
Environmental Modelling & Software
journal homepage: www.elsevier.com/locate/envsoft

Serving many at once: How a database approach can create unity in dynamical ecosystem modelling☆

Wolf M. Mooij[a,b,*], Robert J. Brederveld[c], Jeroen J.M. de Klein[b], Don L. DeAngelis[d], Andrea S. Downing[e], Michiel Faber[c], Daan J. Gerla[f,p], Matthew R. Hipsey[g], Jochem 't Hoen[b], Jan H. Janse[h], Annette B.G. Janssen[a,b], Michel Jeuken[i], Bob W. Kooi[j], Betty Lischke[k], Thomas Petzoldt[l], Leo Postma[h], Sebastiaan A. Schep[c], Huub Scholten[m], Sven Teurlincx[a], Christophe Thiange[h], Dennis Trolle[n], Anne A. van Dam[o], Luuk P.A. van Gerven[a,b], Egbert H. van Nes[b], Jan J. Kuiper[a,b]

Hydrobiologia (2012) 683:25–34
DOI 10.1007/s10750-011-0957-0

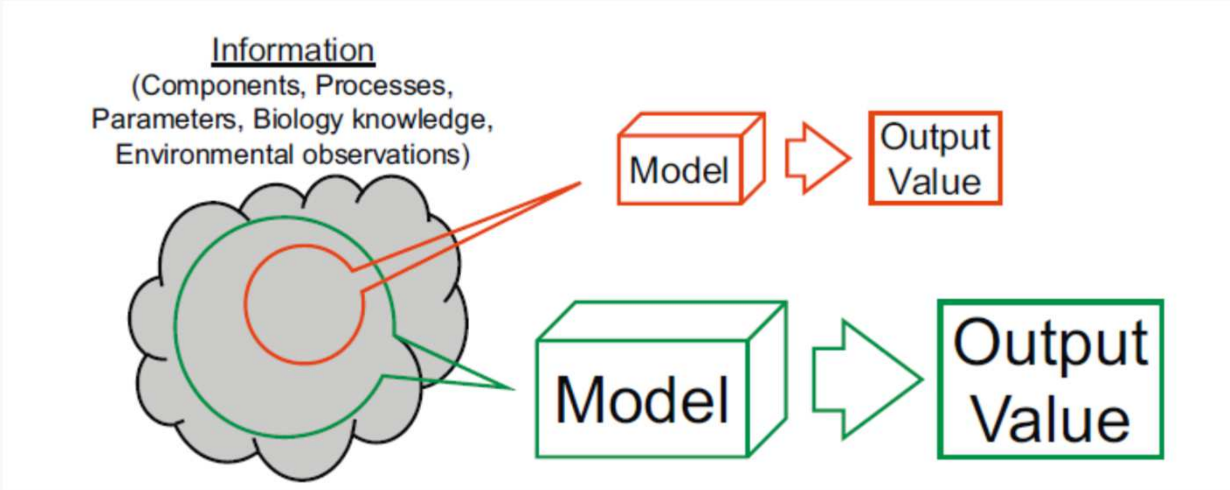
OPINION PAPER

A community-based framework for aquatic ecosystem models

Dennis Trolle · David P. Hamilton · Matthew R. Hipsey · Karsten Bolding · Jorn Bruggeman · Wolf M. Mooij · Jan H. Janse · Anders Nielsen · Erik Jeppesen · J. Alex Elliott · Vardit Makler-Pick · Thomas Petzoldt · Karsten Rinke · Mogens R. Flindt · George B. Arhonditsis · Gideon Gal · Rikke Bjerring · Koji Tominaga · Jochem't Hoen · Andrea S. Downing · David M. Marques · Carlos R. Fragoso Jr. · Martin Søndergaard · Paul C. Hanson

Increasing the complexity of ecosystem models?

“There is a lot of knowledge we are not using”



(Hellweger, 2017)

J. Plankton Res. (2014) 36(3): 613–620. First published online February 17, 2014 doi:10.1093/plankt/fbu011

HORIZONS

Leaving misleading legacies behind in plankton ecosystem modelling

S. LAN SMITH[1,2,3*], AGOSTINO MERICO[4,5], KAI W. WIRTZ[6] AND MARKUS PAHLOW[7]
[1]RESEARCH INSTITUTE FOR GLOBAL CHANGE, JAMSTEC (JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY), YOKOHAMA, JAPAN, [2]CREST (CORE RESEARCH FOR EVOLUTIONAL SCIENCE AND TECHNOLOGY), JAPAN SCIENCE AND TECHNOLOGY AGENCY, TOKYO, JAPAN, [3]YOKOHAMA INSTITUTE FOR EARTH SCIENCES, JAMSTEC, 3173-25 SHOWA-MACHI, KANAZAWA-KU, YOKOHAMA 236-0001 JAPAN, [4]SYSTEMS ECOLOGY, ZMT (LEIBNIZ CENTER FOR TROPICAL MARINE ECOLOGY), BREMEN, GERMANY, [5]SCHOOL OF ENGINEERING AND SCIENCE, JACOBS UNIVERSITY, BREMEN, GERMANY, [6]HZG (HELMHOLTZ CENTER FOR MATERIALS AND COASTAL RESEARCH), GEESTHACHT, GERMANY AND [7]GEOMAR (HELMHOLTZ CENTER FOR OCEAN RESEARCH, KIEL), KIEL, GERMANY

Ecological Modelling 221 (2010) 428–432
Contents lists available at ScienceDirect
Ecological Modelling
ELSEVIER
journal homepage: www.elsevier.com/locate/ecolmodel

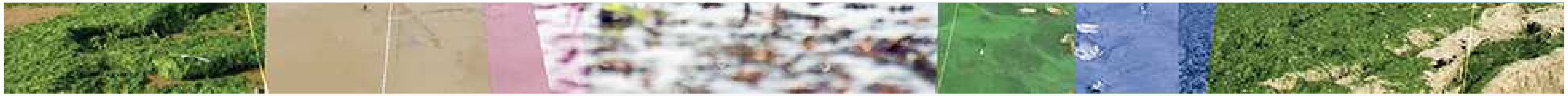
Short communication

Using a model selection criterion to identify appropriate complexity in aquatic biogeochemical models

Cory P. McDonald *, Noel R. Urban
Department of Civil and Environmental Engineering, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931, USA

Main outcomes

- Hydrodynamics: good results ☺
- Phytoplankton dynamics
  - Rather good results of the global biomass at the seasonal time scale 😐
  - Rather limited results for functional groups ☹
- Prospective
  - Rather good short-term prevision 😐
  - Long-term predictions: generally no *a posteriori* validation ☹



Summarising

- How to improve the predictive power of models in an *unpredictable world?*
  - Better representation of the ***biological processes***
  - Functional and morphological traits of the phytoplankton species
  - Complexity, cascading effects (Trolle et al. 2008; Hellweger et al., 2017)
- Model assessment
  - Validation in different forcing configurations
  - Long-term scenarios in pristine and future conditions
- Data
  - High-frequency sensors
  - Satellite high-resolution images
  - Paleolimnology data ….
- Improvement of the model performance
  - ***modelling platforms,*** open-source models
  - ***multidisciplinary*** research: physics, biology, hydrology, applied mathematics …
  - ***collaborative*** research: benchmark of the models, sharing the data sets


Thank you!