The briefest introduction into phytoplankton ecology

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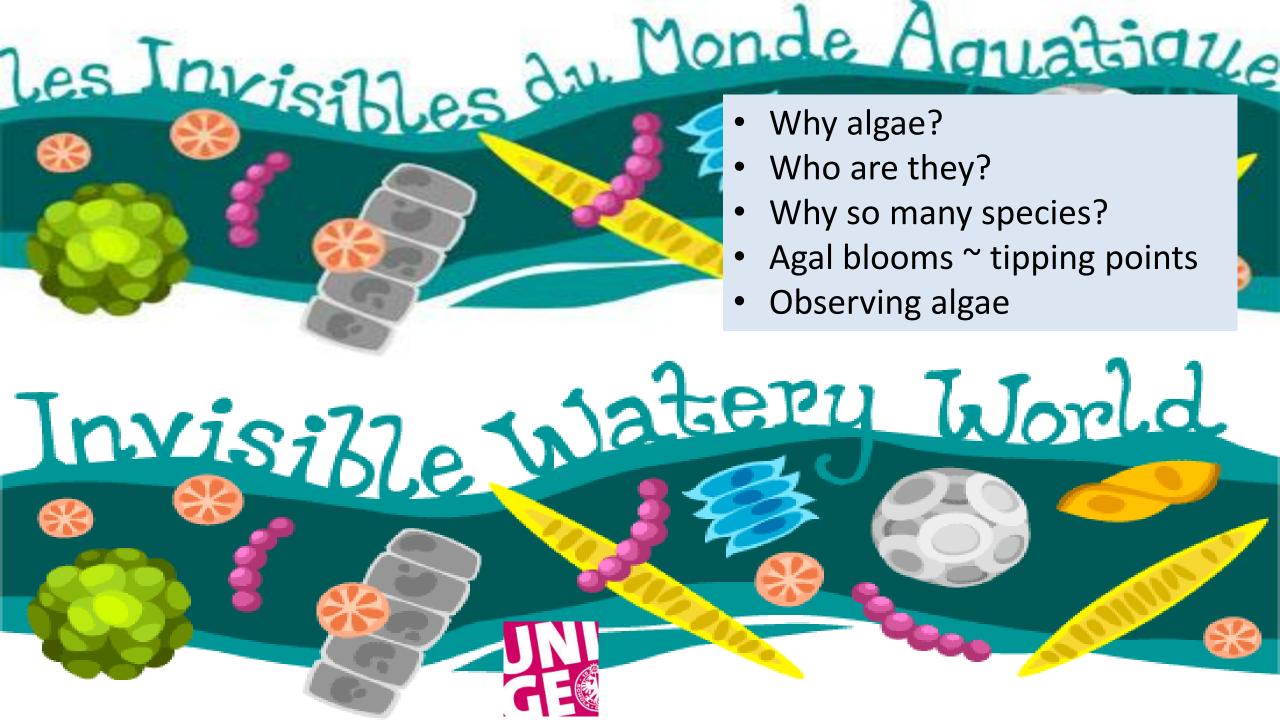
MANTEL ITN Workshop

Tartu, Estonia, September 2017

- Why algae?
- Who are they?
- Why so many species?
- Agal blooms ~ tipping points
- Observing algae

Why algae?

Life
Under
the
Sun

1 μm

2 mm

1 mm

100 m
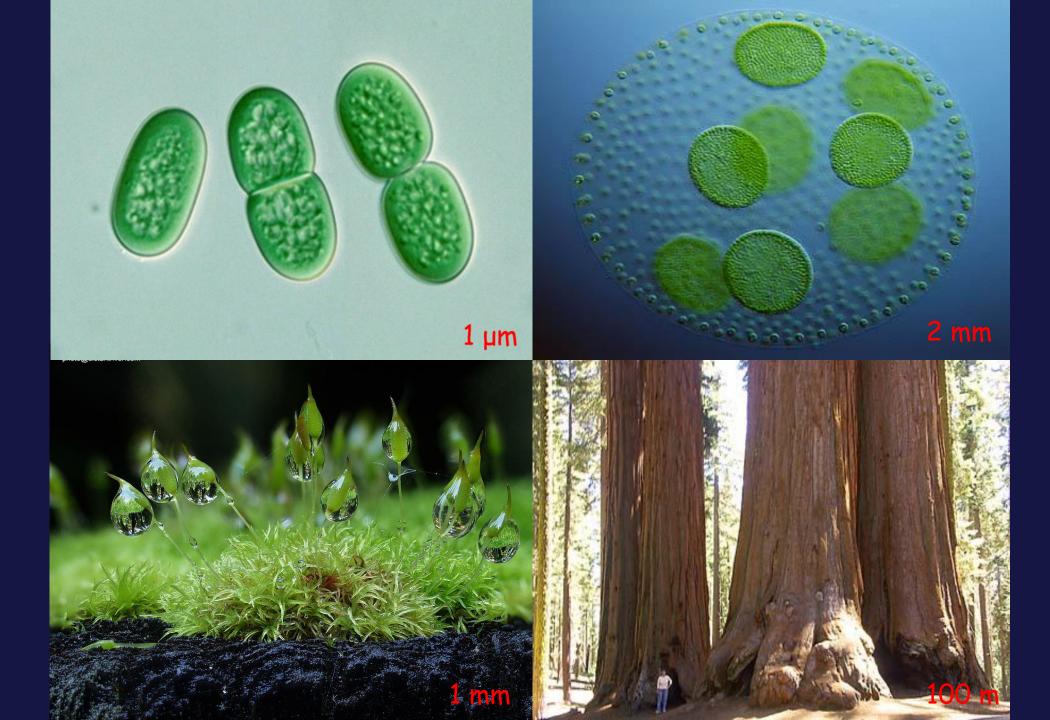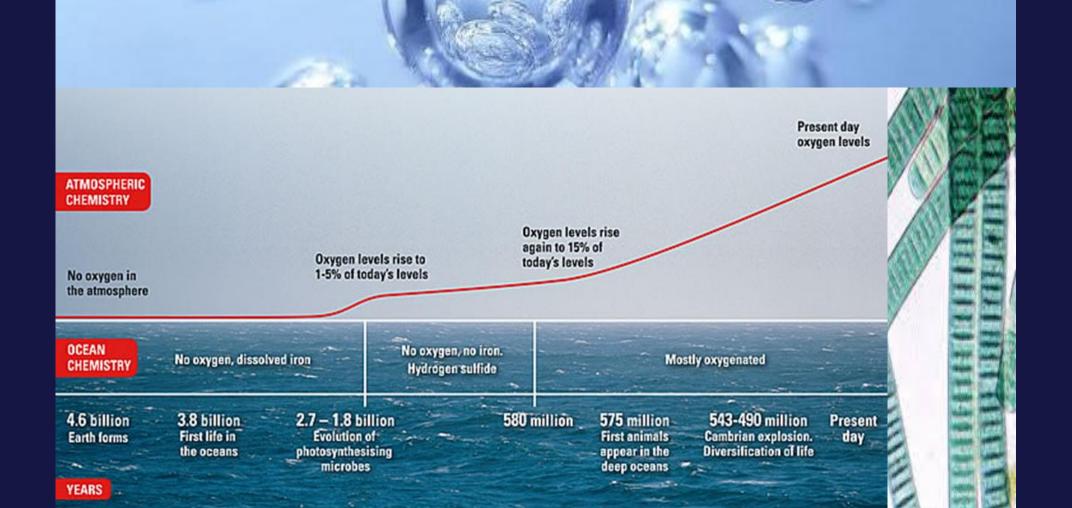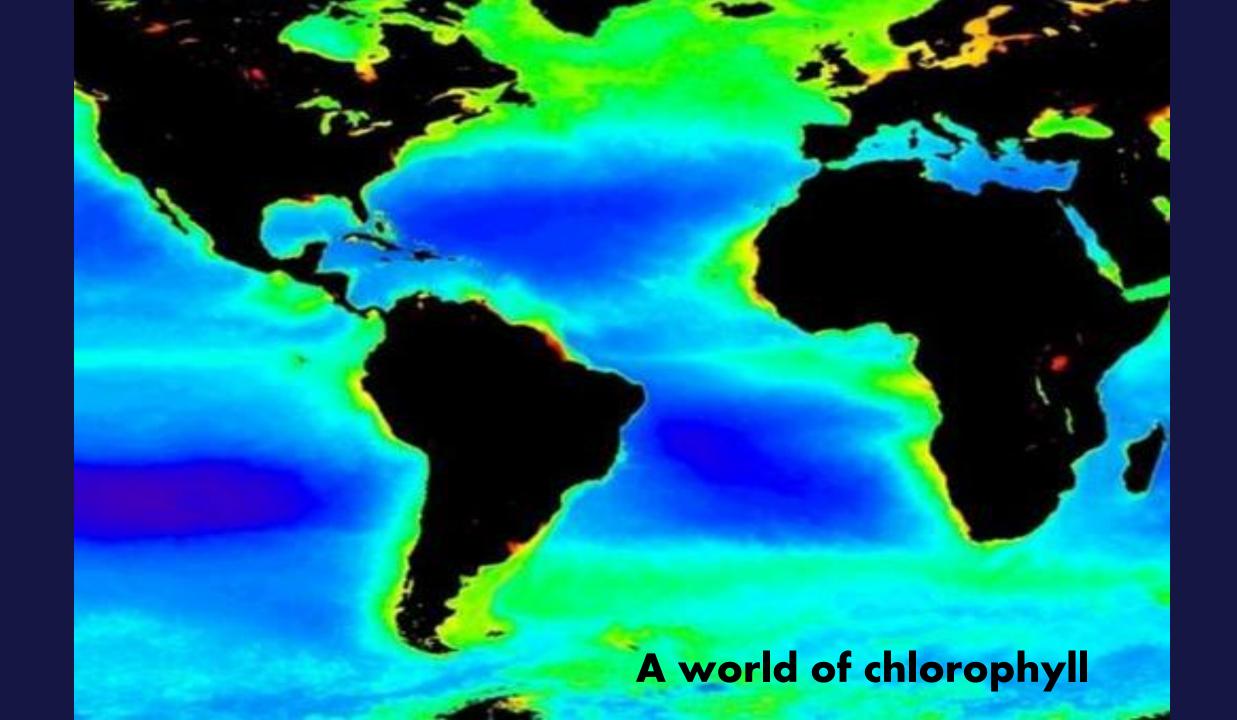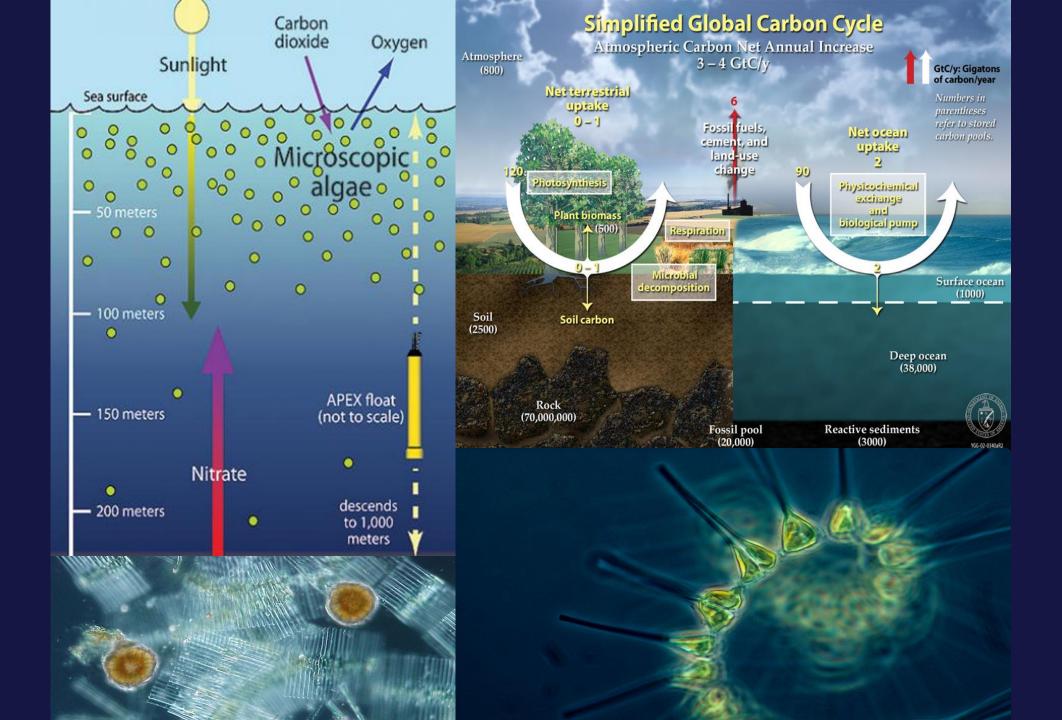
The evolution of photosynthesis led to what is called
the great oxygenation event

ATMOSPHERIC CHEMISTRY

Present day oxygen levels

Oxygen levels rise again to 15% of today's levels

Oxygen levels rise to 1-5% of today's levels

No oxygen in the atmosphere

OCEAN CHEMISTRY

No oxygen, dissolved iron

No oxygen, no iron. Hydrogen sulfide

Mostly oxygenated

YEARS

4.6 billion Earth forms

3.8 billion First life in the oceans

2.7 – 1.8 billion Evolution of photosynthesising microbes

580 million

575 million First animals appear in the deep oceans

543-490 million Cambrian explosion. Diversification of life

Present day

A world of chlorophyll

Simplified Global Carbon Cycle
Atmospheric Carbon Net Annual Increase
3 – 4 GtC/y

Assessing the Dynamics of Organic Aerosols over the North Atlantic Ocean

Jérôme Kasparian[1], Christel Hassler[2,3], Bas Ibelings[2,3], Nicolas Berti[1], Sébastien Bigorre[4], Violeta Djambazova[2], Elena Gascon-Diez[2], Grégory Giuliani[2], Raphaël Houlmann[1], Denis Kiselev[1], Pierric de Laborie[2], Anh-Dao Le[2,3], Thibaud Magouroux[1], Tristan Neri[2], Daniel Palomino[2,3], Stéfanie Pfändler[2], Nicolas Ray[2], Gustavo Sousa[1], Davide Staedler[1,5], Federico Tettamanti[5], Jean-Pierre Wolf[1] & Martin Beniston[1,2,3]

▲ Possible trajectory of "PlanetSolar"
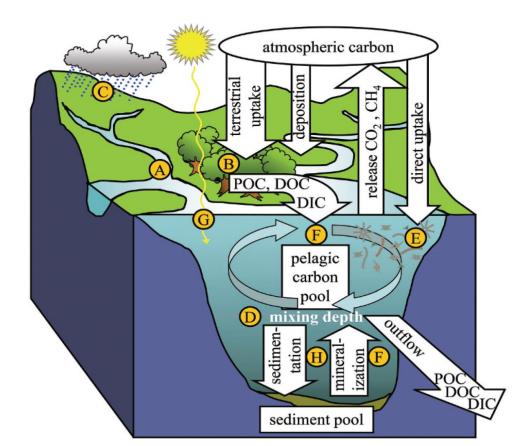
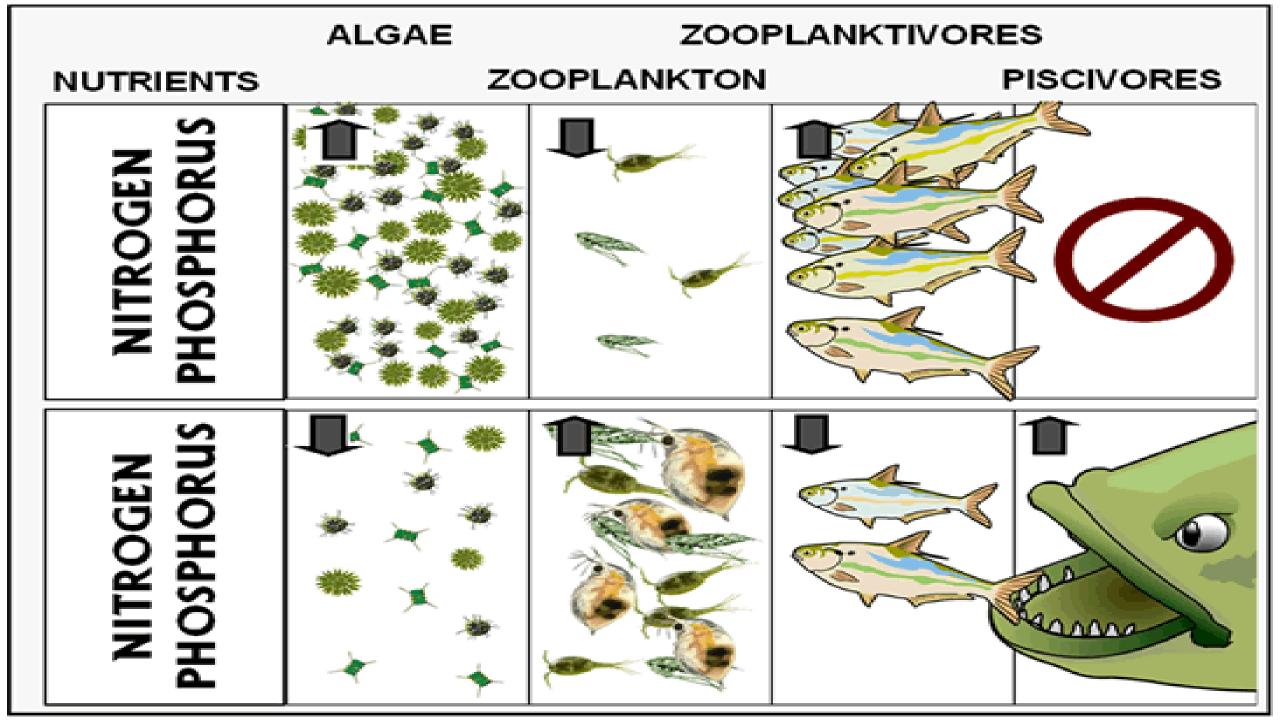▲ A view of the upper deck of "Planet Solar" with

Lakes and reservoirs as regulators of carbon cycling and climate

Lars J. Tranvik,[a,*] John A. Downing,[b] James B. Cotner,[c] Steven A. Loiselle,[d] Robert G. Striegl,[e] Thomas J. Ballatore,[f] Peter Dillon,[g] Kerri Finlay,[h] Kenneth Fortino,[i] Lesley B. Knoll,[j] Pirkko L. Kortelainen,[k] Tiit Kutser,[l] Soren Larsen,[m] Isabelle Laurion,[n] Dina M. Leech,[o] S. Leigh McCallister,[p] Diane M. McKnight,[q] John M. Melack,[r] Erin Overholt,[j] Jason A. Porter,[s] Yves Prairie,[t] William H. Renwick,[u] Fabio Roland,[v] Bradford S. Sherman,[w] David W. Schindler,[x] Sebastian Sobek,[y] Alain Tremblay,[z] Michael J. Vanni,[j] Antonie M. Verschoor,[aa] Eddie von Wachenfeldt,[a] and Gesa A. Weyhenmeyer[a]

- Inland waters constitute a significant part of global C-cycle
- Their contribution to the cycle has increased in response to climate change, and will continue to do so

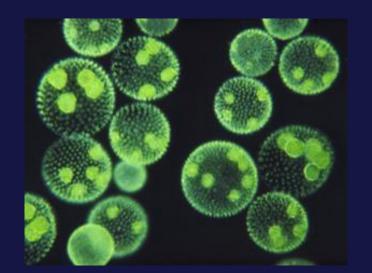NUTRIENTS | ALGAE | ZOOPLANKTON | ZOOPLANKTIVORES | PISCIVORES

Who are they?

Phytoplankton

- Plankton originates from '$\pi\lambda\alpha\gamma\kappa\tau o\nu$'
- This means 'wandering stuff ', i.e. plankton are 'passively' transported through the water
- *Bacterioplankton* = bacteria
- *Phytoplankton* = 'plants'
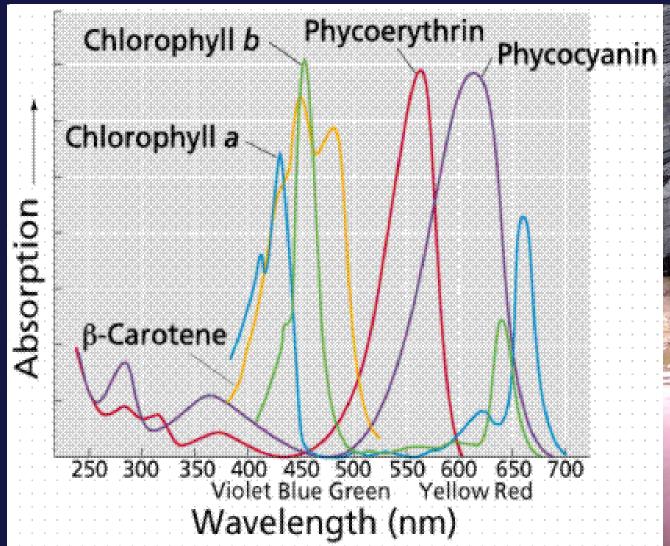- *Zooplankton* = 'animals'

Phytoplankton classes

Table 9.3 Characteristics of Major Groups of Freshwater Algae					
Group (Common Name)	**Dominant Pigments**	**Cell Wall**	**Habitats**	**Approximate # of Species (% Freshwater)**	**Ecological Importance**
Cyanobacteria	Chl *a*, phycobilins	Peptidoglycan	Oligotrophic to eutrophic, benign to harsh environments	1,200–5,000 (50%)	Some fix nitrogen, some toxic, floating blooms characteristic of nutrient-rich lakes
Rhodophyceae (red algae)	Chl *a*, phycobilins	Cellulose	Freshwater species in streams	1,500–5,000 (5%)	Rare in freshwaters except *Batrachospermum* in streams
Chrysophyceae	Chl *a*, chl *c*, carotenoids	Chrysolaminarin	Freshwater, temperate, plankton	300–1,000 (80%)	*Dinobryon*, a common dominant in phytoplankton
Bacillariophyceae (diatoms)	Chl *a*, chl *c*, carotenoids	Silica frustule	Plankton and benthos	5,000–12,000 (20%)	An essential primary producer, both in freshwaters and globally
Dynophyceae	Chl *a*, chl *c*, carotenoids	Cellulose	Primarily planktonic	230–1,200 (7%)	Some toxic, some phagotrophic, involved in many symbiotic interactions
Euglenophyceae	Chl *a*, chl *b*	Protein	Commonly in eutrophic waters, associated with sediments	400–1,000	Can be phagorophic, indicative of eutrophic conditions
Chlorophyceae (green algae)	Chl *a*, chl *b*	Naked, cellulose, or calcified	Oligotrophic to eutrophic, planktonic to benthic	6,500–20,000 (87%)	Very variable morphology, very important primary producers. Filamentous types in streams, unicellular in plankton
Charophyceae	Chl *a*, chl *b*,	Cellulose, many calcified	Benthic, still to slowly flowing water	315 (95%)	Often calcareous deposits

(After South and Whittick, 1987, and Vymazal, 1995)
See Figures 9.4–9.6 and 9.8 and 9.9 for representative genera and some morphological characteristics.

Different phytoplankton groups have different pigments
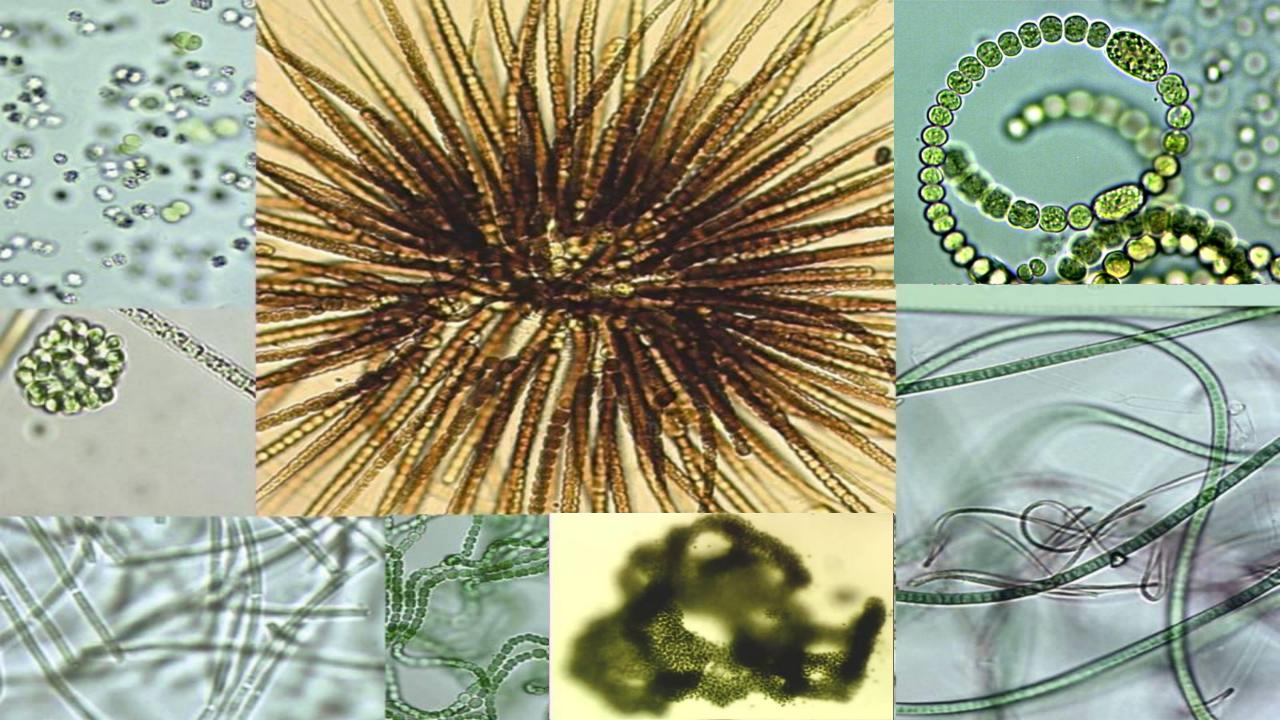
Emiliania huxleyi an armour-plated, photosynthesizing single-celled dino

Foam-algae

CYANOBACTERIA:
Good-Bad
ALGAE

REVIEW AND SYNTHESIS

Biodiversity in a complex world: consolidation and progress in functional biodiversity research
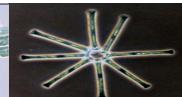
Trait-Based Community Ecology of Phytoplankton

Elena Litchman[1] and Christopher A. Klausmeier[2]

Kellogg Biological Station, [1]Department of Zoology, and [2]Department of Plant Biology, Michigan State University, Hickory Corners, Michigan 49060; email: litchman@msu.edu, klausme1@msu.edu

DARWIN'S FINCHES

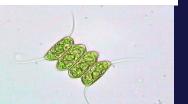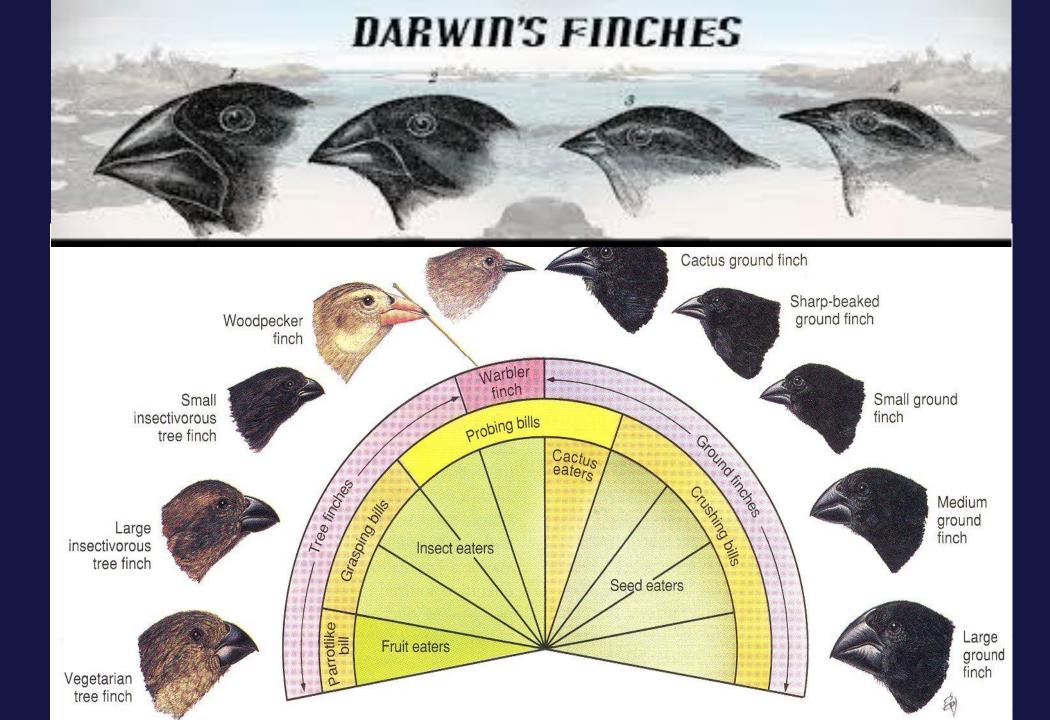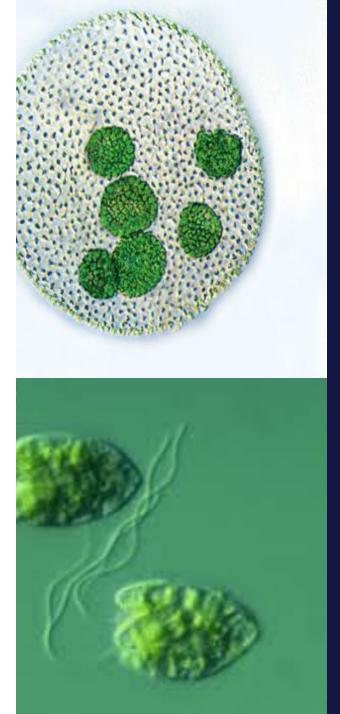|	Ecological function		
Trait type	**Reproduction**	**Resource acquisition**	**Predator avoidance**
Morphological	Cell size		
		Cell shape	
		Coloniality	
Physiological		Photosynthesis	
		Nutrient uptake, requirements	
	Protein synthesis		Toxin production
		Nitrogen fixation	
		Mixotrophy	
Behavioral		Motility	
Life history	Sexual/asexual reproduction		
	Resting stages		

Taxonomic group	Description phenotype	Representative sp
Chlorococcales, Chroococcales Oscillatoriales, Xanthophyceae Ultotrichiales	Small organisms with high SA/V	
Chrysophycea	Small flagellated organisms with siliceous exoskeletal structures	
Nostocales Oscillatoriales	Large filaments with gas-vacuoles	
Chroococcales, Oscillatoriales Xanthophyceae, Zygnematophyceae	Organisms of medium size lacking specialized features	
Cryptophyceae, Dinophyceae Euglenophyceae, Volvocales Chlorococcales	Unicellular flagellates of medium to large size	
Bacillariophyceae	Non-flaggelated organisms with siliceous skeletons	
Chlorococcales Chroococcales Oscillatoriales	Large mucilaginous colony forming organisms	

Understanding the key ecological traits of cyanobacteria as a basis for their management and control in changing lakes

Evanthia Mantzouki · Petra M. Visser ·
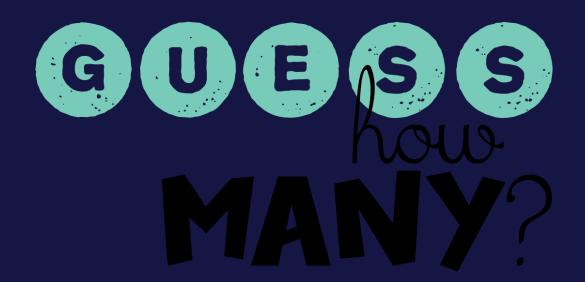Myriam Bormans · Bas W. Ibelings

25 μ

Table 1 Different cyanobacterial functional groups, with their preferable habitats, typical representatives, tolerances, key traits, sensitivities and the possible management actions, are displayed

| Group	Habitat	Typical representatives	Tolerances	Key traits	Sensitivities/management action
S_1/S_2 (non-N_2-fixing filaments)	Deep/shallow Turbid mixed layers	***Planktothrix agardhii*** *Arthrospira*	Light deficiency	Efficient light harvesting	Short residence time/ flushing
S_N (filaments)	Warm mixed layers	***Cylindrospermopsis raciborskii*** *Anabaena minutissima*	Light, N deficiency	N_2 fixation Optimal growth rate at elevated temperatures Resting cells	Short residence time/ flushing
H_1/H_2 (filaments)	Small/large Mesotrophic lakes	***Dolichospermum flos-aquae*** *Gleotrichia echinulata*	N, C deficiency	N_2 fixation Buoyancy Resting cells	Light deficiency/artifical mixing P deficiency/control of phosphorus loading
L_O/L_M (colony)	Mesotrophic/ eutrophic Summer epilimnia	*Woronichinia* ***Microcystis***	C deficiency Stratification	Buoyancy	Light deficiency/artificial mixing
R (non-N_2-fixing filaments)	Metalimnia of mesotrophic stratified	***Planktothrix rubescens*** *P.mougeotii*	Light deficiency Strong segregation of light and nutrients	Buoyancy Efficient light harvesting	Physical instability/artificial mixing, stringent nutrient control

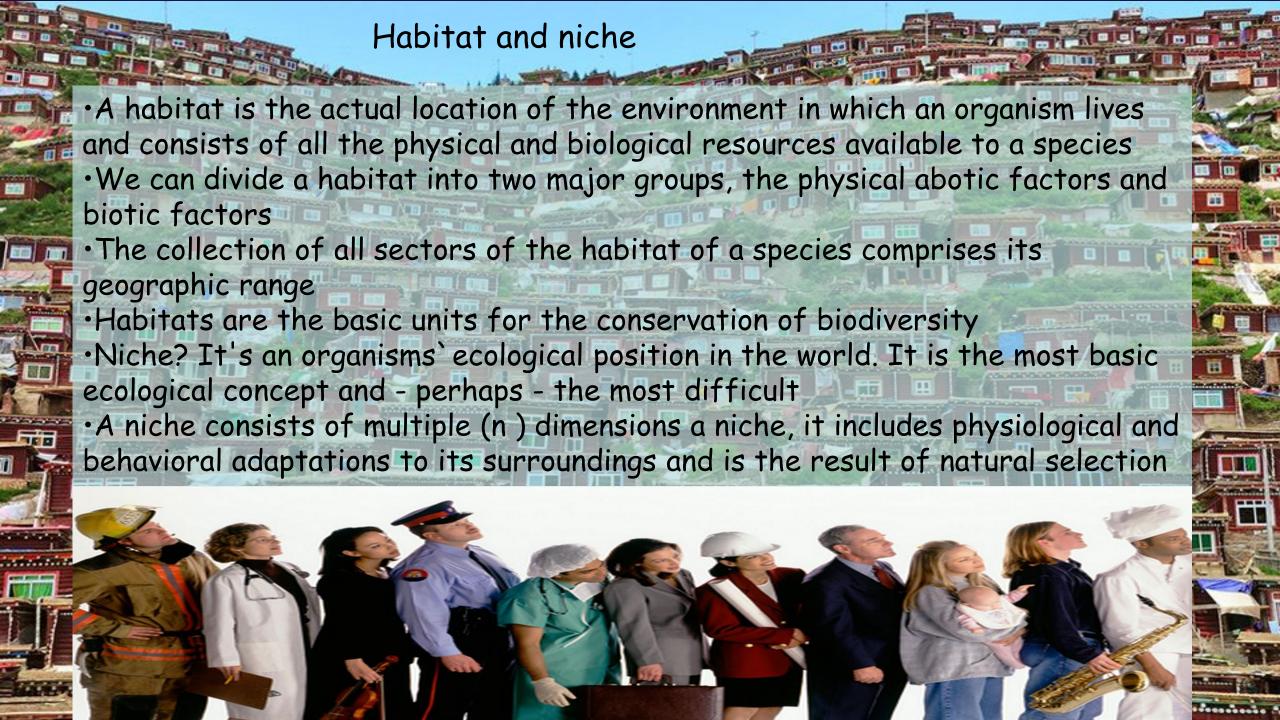# Why so many phytoplankton species?
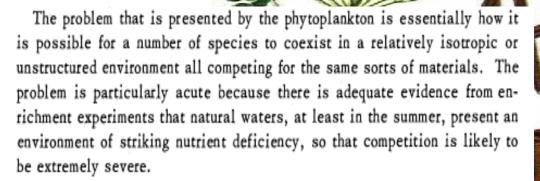
THE PARADOX OF THE PLANKTON*

G. E. HUTCHINSON

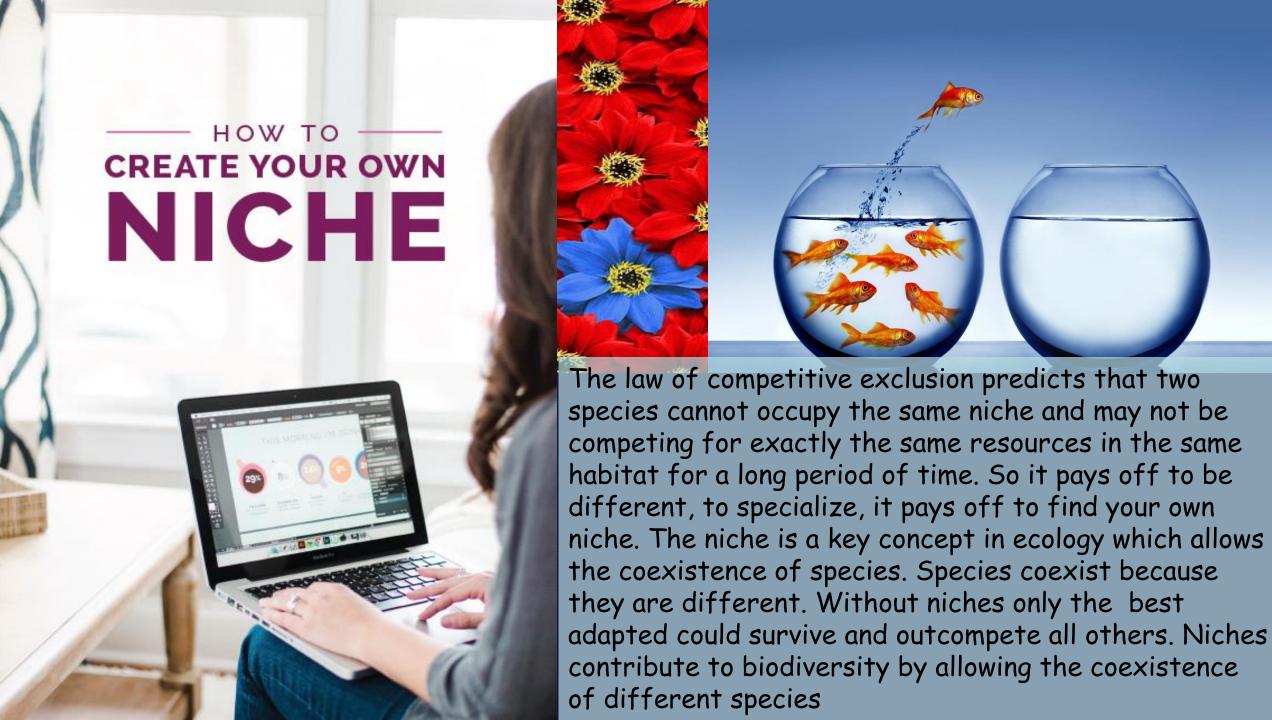Osborn Zoological Laboratory, New Haven, Connecticut

The problem that is presented by the phytoplankton is essentially how it is possible for a number of species to coexist in a relatively isotropic or unstructured environment all competing for the same sorts of materials. The problem is particularly acute because there is adequate evidence from enrichment experiments that natural waters, at least in the summer, present an environment of striking nutrient deficiency, so that competition is likely to be extremely severe.

According to the principle of *competitive exclusion* (Hardin, 1960) known by many names and developed over a long period of time by many investigators (see Rand, 1952; Udvardy, 1959; and Hardin, 1960, for historic reviews), we should expect that one species alone would outcompete all the others so that in a final equilibrium situation the assemblage would reduce to a population of a single species.

Twenty years ago in a Naturalists' Symposium, I put (Hutchinson, 1941) forward the idea that the diversity of the phytoplankton was explicable primarily by a permanent failure to achieve equilibrium as the relevant external factors changed. I later pointed out that equilibrium would never be ex-

Habitat and niche

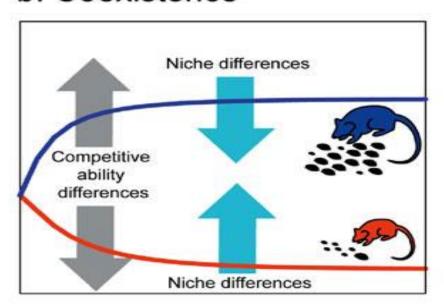•A habitat is the actual location of the environment in which an organism lives and consists of all the physical and biological resources available to a species
•We can divide a habitat into two major groups, the physical abotic factors and biotic factors
•The collection of all sectors of the habitat of a species comprises its geographic range
•Habitats are the basic units for the conservation of biodiversity
•Niche? It's an organisms` ecological position in the world. It is the most basic ecological concept and - perhaps - the most difficult
•A niche consists of multiple (n) dimensions a niche, it includes physiological and behavioral adaptations to its surroundings and is the result of natural selection

HOW TO CREATE YOUR OWN NICHE

The law of competitive exclusion predicts that two species cannot occupy the same niche and may not be competing for exactly the same resources in the same habitat for a long period of time. So it pays off to be different, to specialize, it pays off to find your own niche. The niche is a key concept in ecology which allows the coexistence of species. Species coexist because they are different. Without niches only the best adapted could survive and outcompete all others. Niches contribute to biodiversity by allowing the coexistence of different species
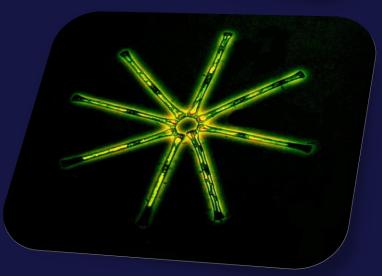
a. Competitive exclusion

b. Coexistence

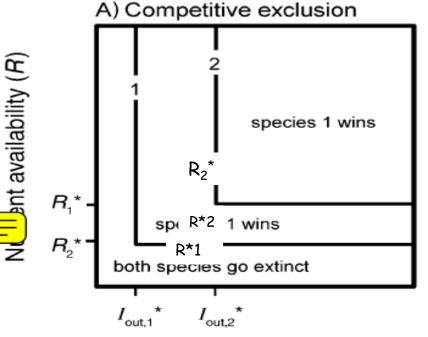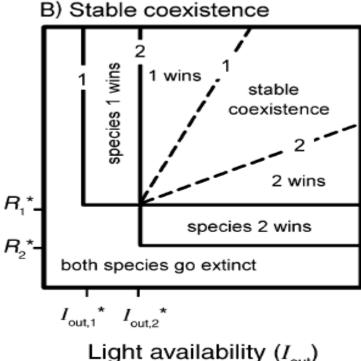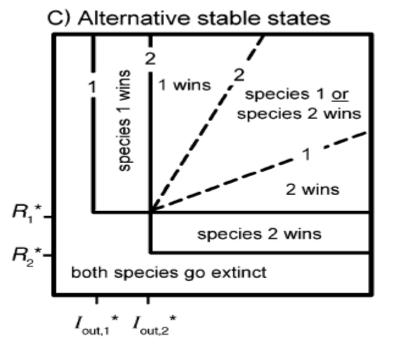# Competitive exclusion

Coexistence

Tilman's resource ratio hypothesis

The species with the lowest "critical resource" (R *) will outcompete all others and win the competition. The number of species that is able to coexist in equilibrium cannot exceed the number of limiting resources

A) Competitive exclusion

B) Stable coexistence
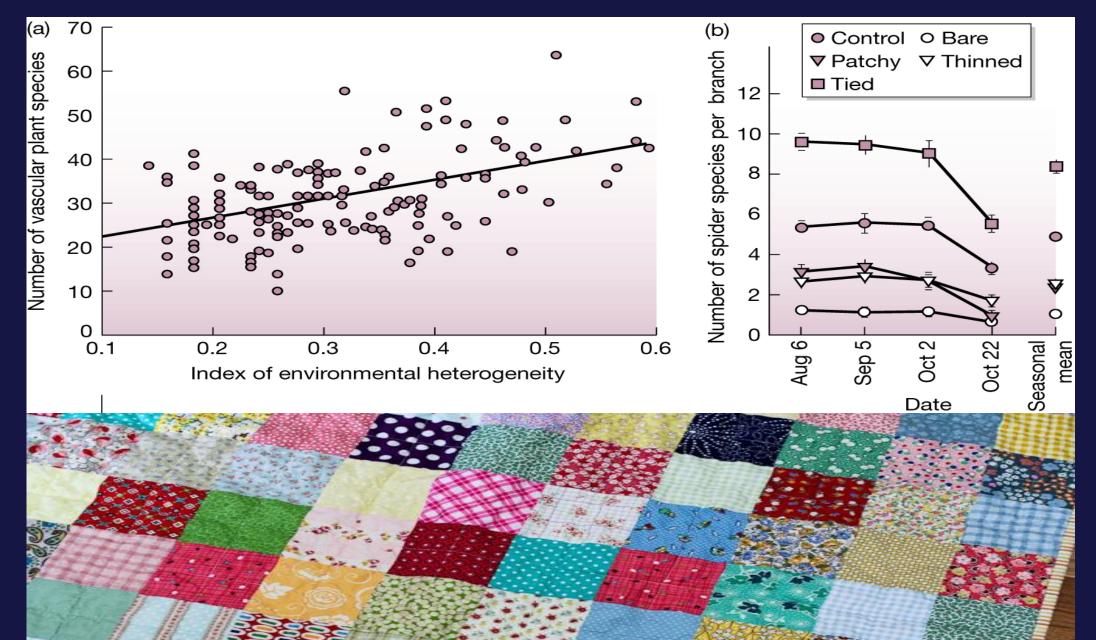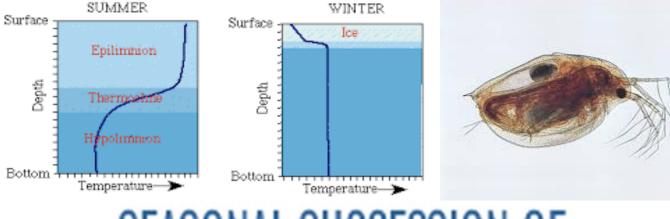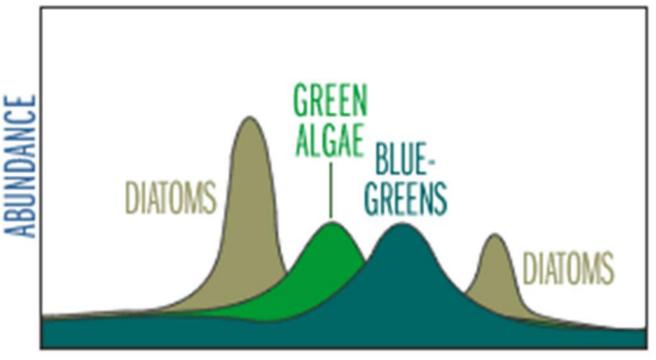
C) Alternative stable states

Nutrient availability (R)

Light availability (I_{out})

- Spatial heterogeneity of a habitat is an important factor controlling species richness in the landscape
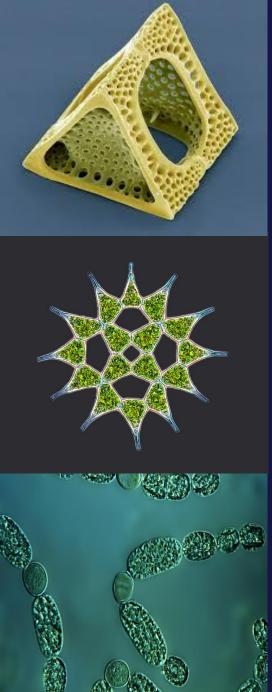- The diversity of microhabitats include differences in the availability of resources, microclimate etc
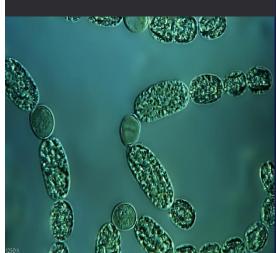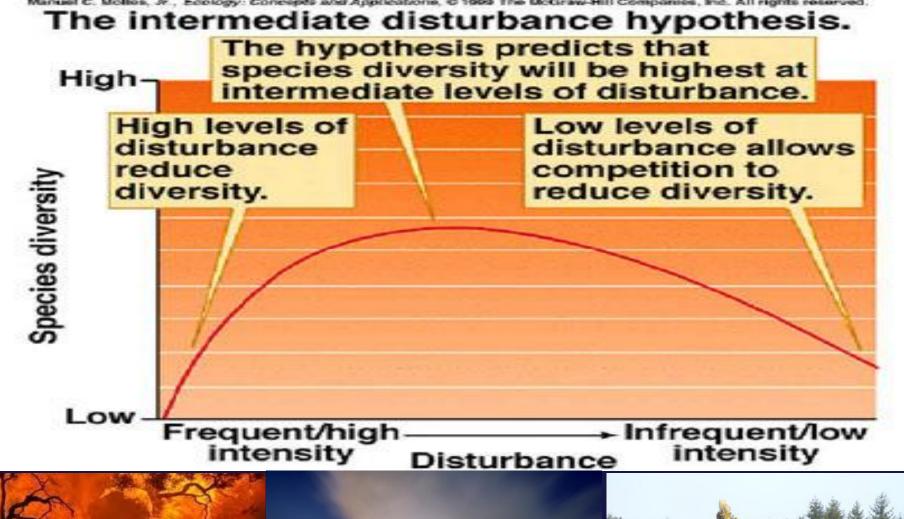
SEASONAL SUCCESSION OF PHYTOPLANKTON POPULATIONS

The intermediate disturbance hypothesis.

The hypothesis predicts that species diversity will be highest at intermediate levels of disturbance.

High levels of disturbance reduce diversity.

Low levels of disturbance allows competition to reduce diversity.

Species diversity

High

Low

Frequent/high intensity ← Disturbance → Infrequent/low intensity
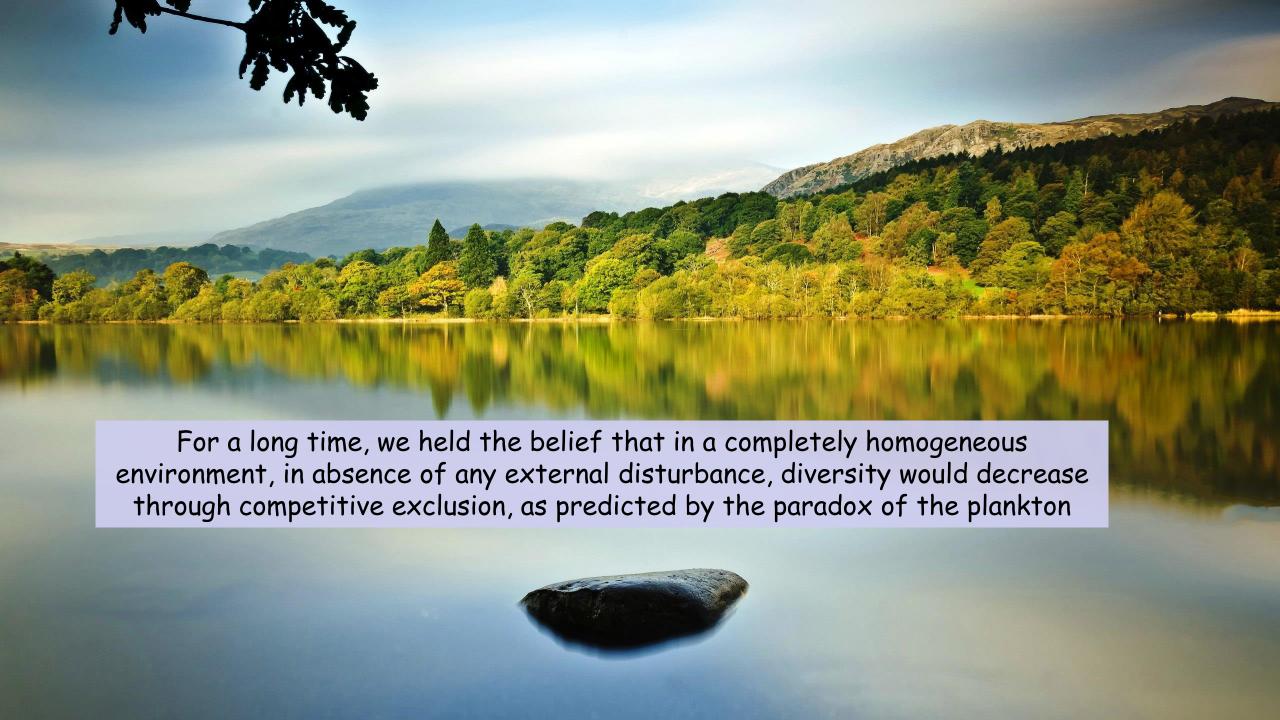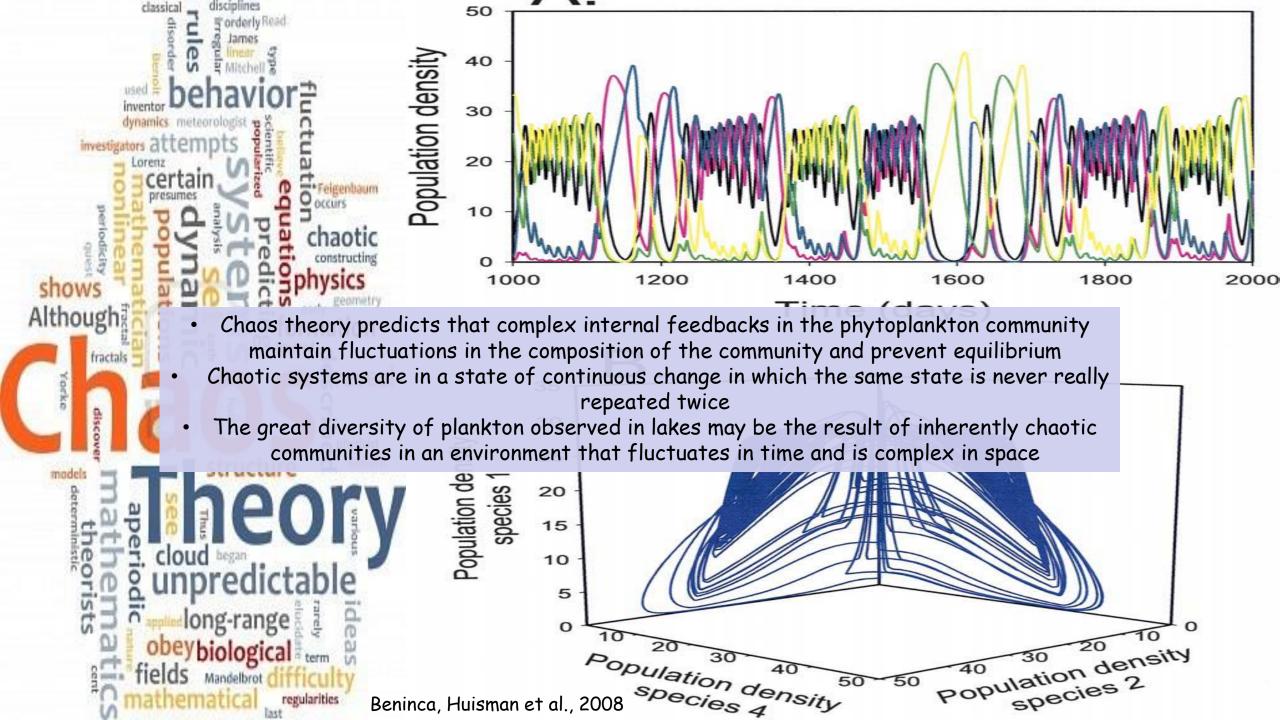
The intermediate disturbance hypothesis: ecosystems often are often highly dynamic, there is no time for the best adapted species to outcompete the others, the process of competitive will not run to completion since the conditions will have been disturbed, for example, by a storm or bush fire, and the advantage shifts to another set of species. Diversity is maximum when the frequency / intensity of the disturbance is intermediate in nature

For a long time, we held the belief that in a completely homogeneous environment, in absence of any external disturbance, diversity would decrease through competitive exclusion, as predicted by the paradox of the plankton

- Chaos theory predicts that complex internal feedbacks in the phytoplankton community maintain fluctuations in the composition of the community and prevent equilibrium
- Chaotic systems are in a state of continuous change in which the same state is never really repeated twice
- The great diversity of plankton observed in lakes may be the result of inherently chaotic communities in an environment that fluctuates in time and is complex in space

Beninca, Huisman et al., 2008

news feature

Neutrality versus the niche

'be different...'

Niche:

- les espèces sont différentes
- elles coexistent parce qu'elles sont assez différents en évitant une concurrence intense.
- les niches permettent la co-existence
- les interactions entre les espèces et entre espèces et leur environnement abiotique déterminent quelles espèces sont présentes dans une collectivité locale

Neutre:

- la théorie neutre les espèces au sein d'un niveau trophique ne sont pas différentes, elles sont interchangeables
- Aucune espèce unique ne peut dominer toutes les autres espèces.
- La dispersion – arriver tôt - et les processus aléatoires déterminent quelles espèces sont présentes dans une collectivité locale

Algal bloooms ~ tipping points

"The greatest threat to water quality worldwide is nutrient pollution. Cultural eutrophication by nutrients in sewage, fertilizers, and detergents is feeding massive algal blooms, choking out aquatic life and outpacing heavy metals, oil spills, and other toxins (climate change?) in the devastation wrought upon the world's fresh waters" (David Schindler)
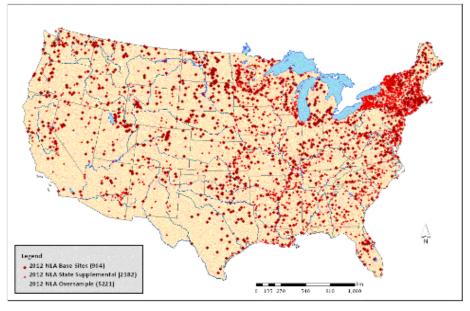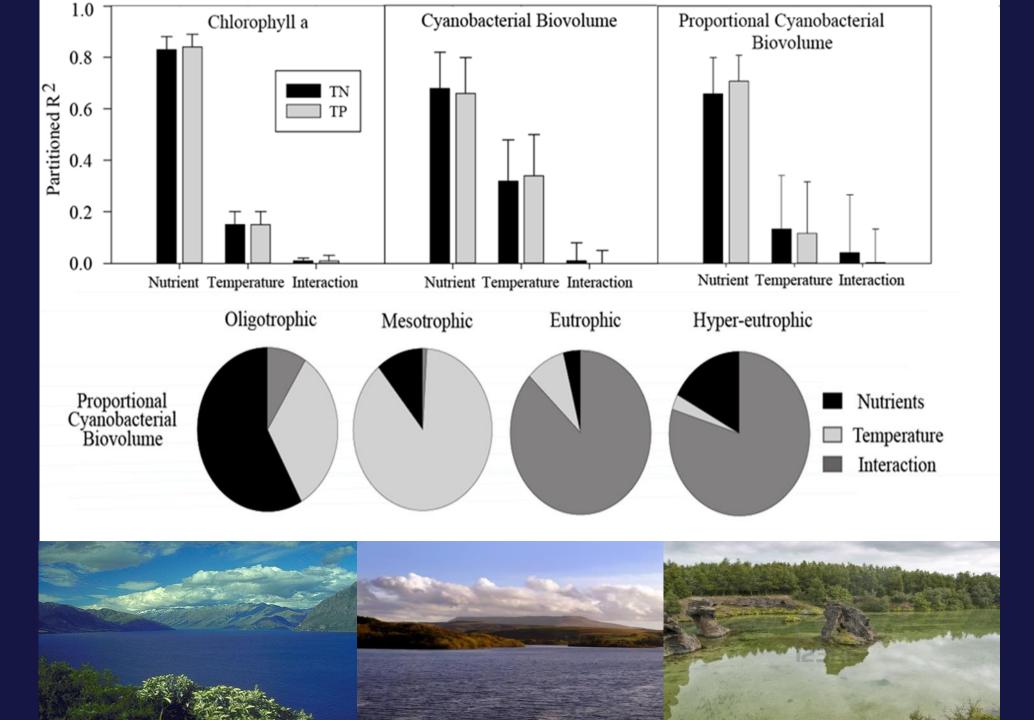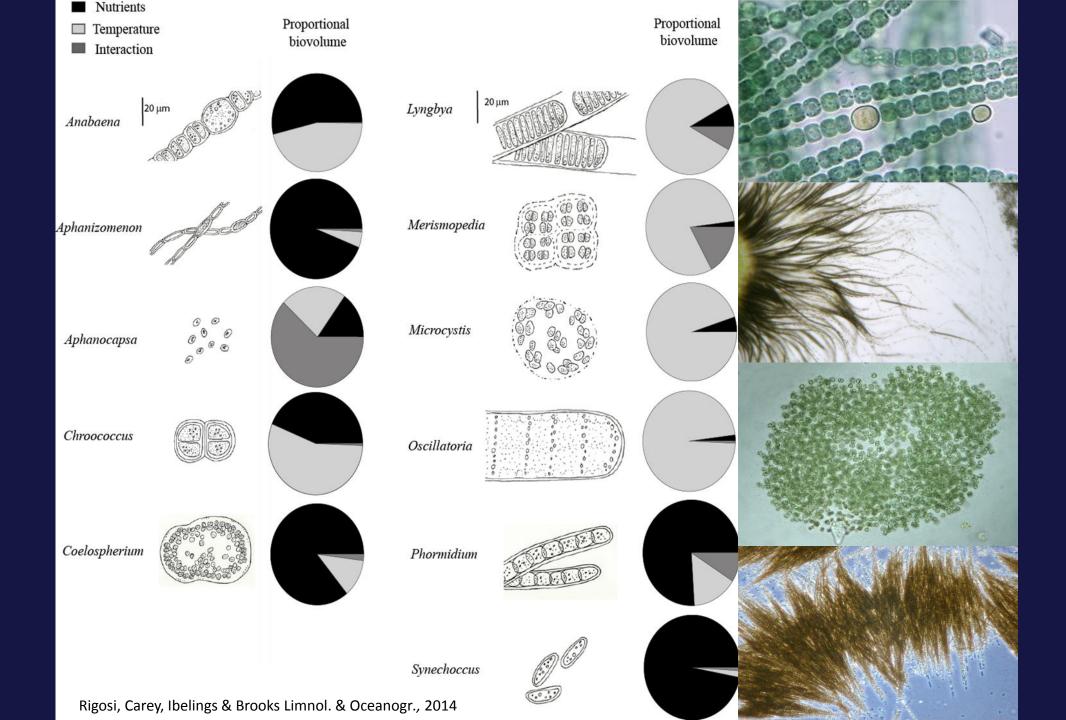
SYNERGY
1+1=3

LE CHANGEMENT CLIMATIQUE AGGRAVE LA CRISE DE L'EAU.
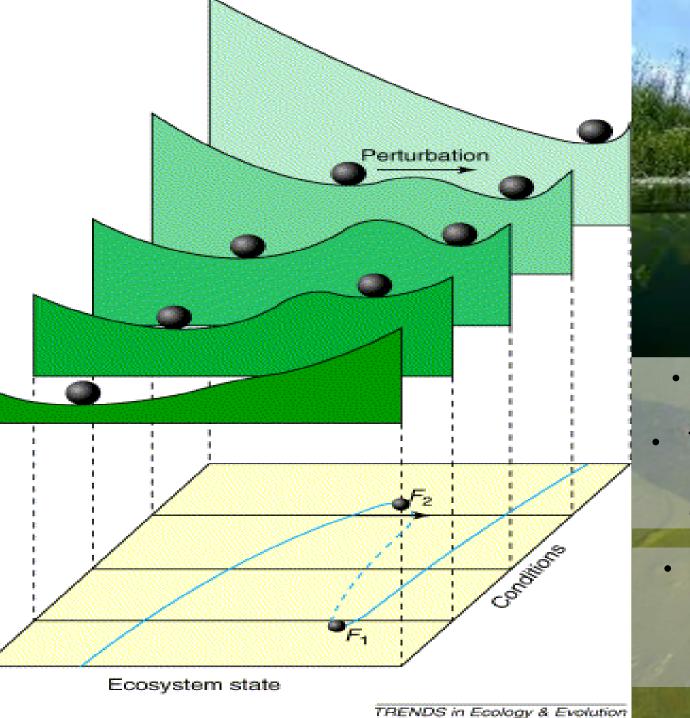
National Lakes Assessment
A Collaborative Survey of the Nation's Lakes

Design Sites for the
2012 National Lakes Assessment

Legend
• 2012 NLA Base Sites (904)
• 2012 NLA State Supplemental (2182)
   2012 NLA Oversample (5221)

Rigosi, Carey, Ibelings & Brooks Limnol. & Oceanogr., 2014

TRENDS in Ecology & Evolution

- In shallow lakdes there are two alternative stable states, clear and turbid
- The transition between these clear and turbid state - as evidenced by the thin blue line - is known as a fold bifurcation or state transition

- Once the clear state is lost and macrophytes are missing, also the turbid state shows resilience against change, hindering lake restoration

Tipping points are points of no return, when a series of small changes is important enough to cause a bigger change
The moment where a 'system' that has changed slowly and predictably will suddenly moved to another state, which is no longer predictable
is known as a regime change

The
TIPPING POINT
How Little Things Can
Make a Big Difference

- For a long time - putting straw after straw on a camel`s back - does not do anything, until you reach a critical point, a tipping point, and then it`s the final straw that brakes the camel`s back
- Can we predict this tipping point? Can we know this moment beforehand, before the vase overflows with the final drop?
- Can we act to prevent the regime shifts?

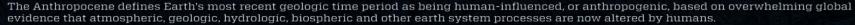C'est la goutte d'eau qui fait déborder le vase

Literal meaning
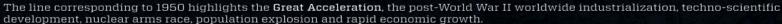It's the drop of water that made the vase overflow

English expression
It's the straw that broke the camel's back

french words

THE **ANTHROPOCENE**

The Anthropocene defines Earth's most recent geologic time period as being human-influenced, or anthropogenic, based on overwhelming global evidence that atmospheric, geologic, hydrologic, biospheric and other earth system processes are now altered by humans.

The line corresponding to 1950 highlights the **Great Acceleration**, the post-World War II worldwide industrialization, techno-scientific development, nuclear arms race, population explosion and rapid economic growth.
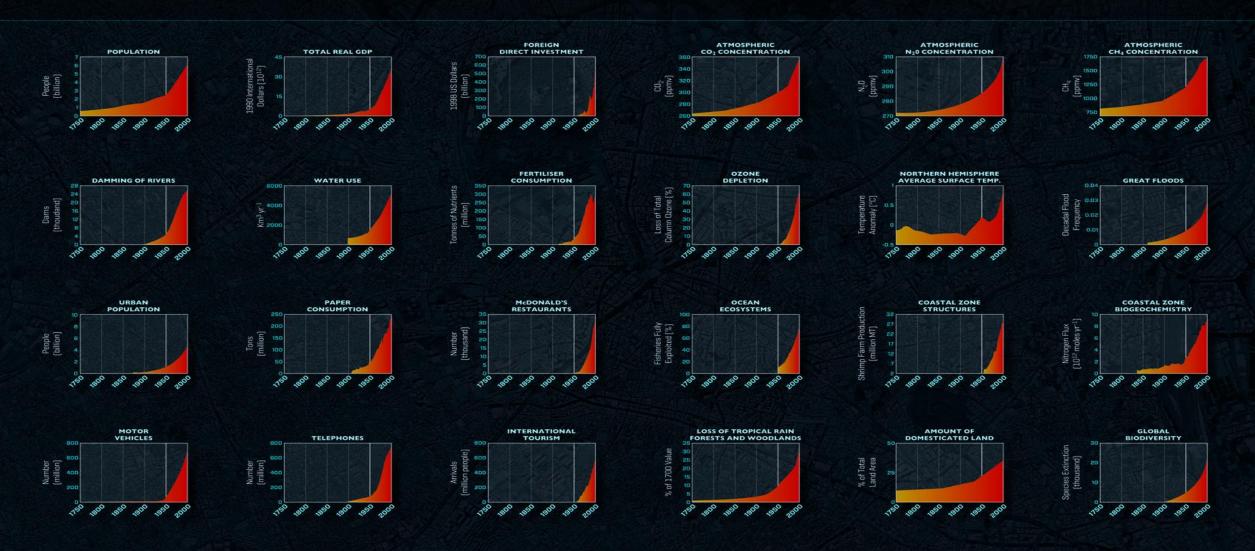
These graphs were compiled in a publication of the **International Geosphere-Biosphere Programme** (IGBP).

POPULATION

TOTAL REAL GDP

FOREIGN DIRECT INVESTMENT

ATMOSPHERIC CO₂ CONCENTRATION

ATMOSPHERIC N₂0 CONCENTRATION

ATMOSPHERIC CH₄ CONCENTRATION

DAMMING OF RIVERS

WATER USE

FERTILISER CONSUMPTION

OZONE DEPLETION

NORTHERN HEMISPHERE AVERAGE SURFACE TEMP.

GREAT FLOODS

URBAN POPULATION

PAPER CONSUMPTION

McDONALD'S RESTAURANTS

OCEAN ECOSYSTEMS

COASTAL ZONE STRUCTURES

COASTAL ZONE BIOGEOCHEMISTRY

MOTOR VEHICLES

TELEPHONES

INTERNATIONAL TOURISM

LOSS OF TROPICAL RAIN FORESTS AND WOODLANDS
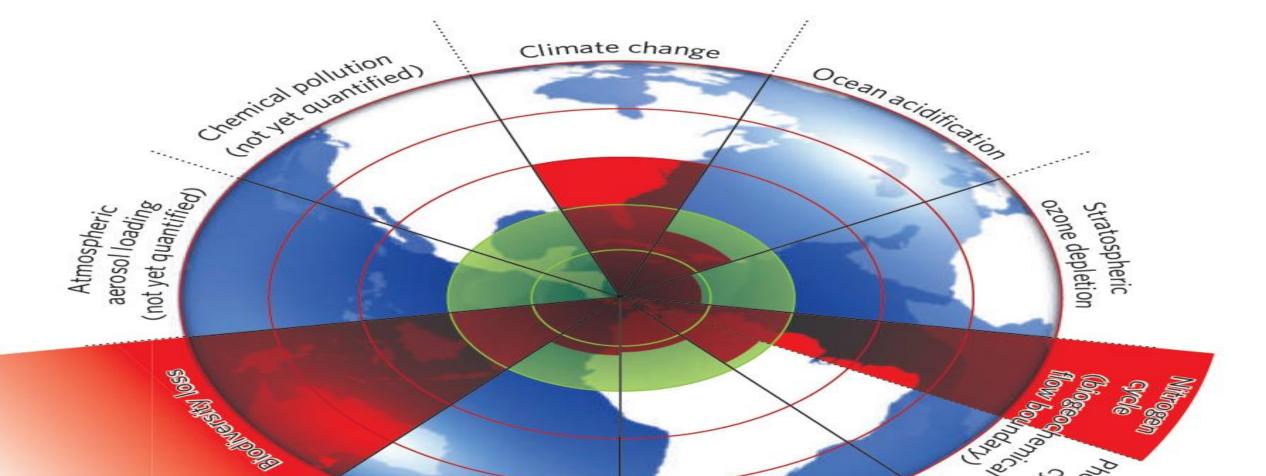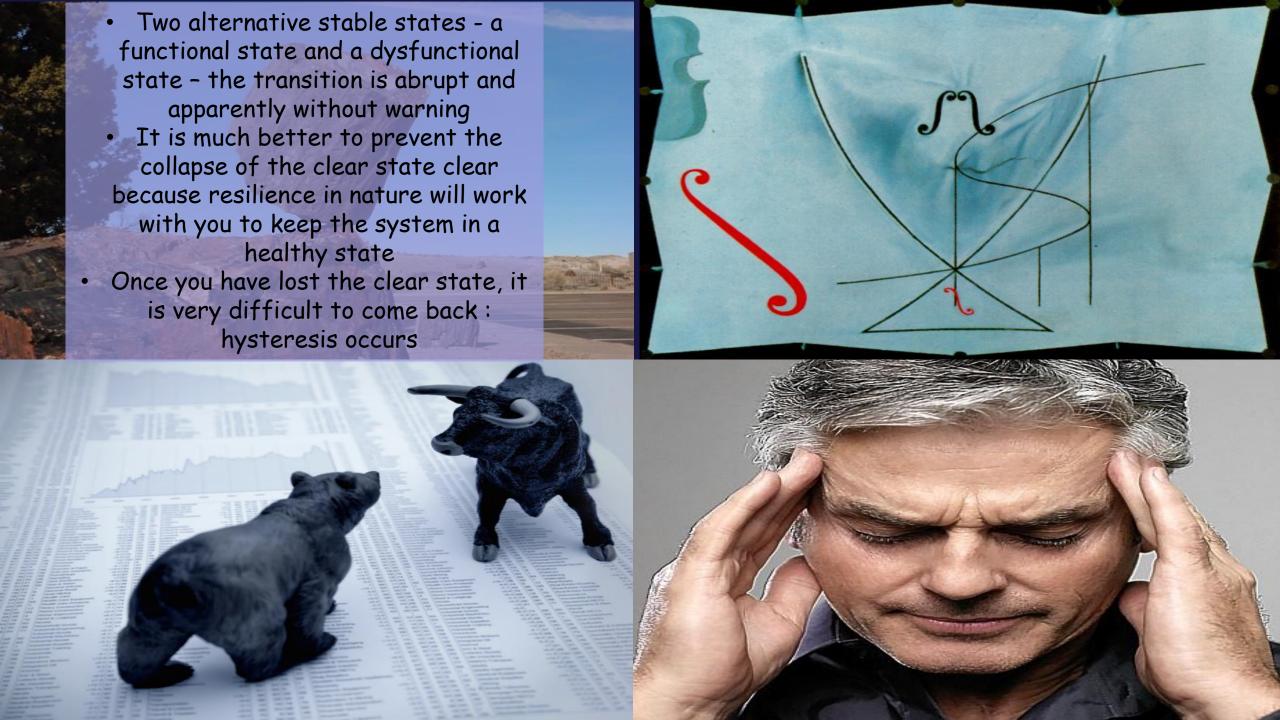
AMOUNT OF DOMESTICATED LAND
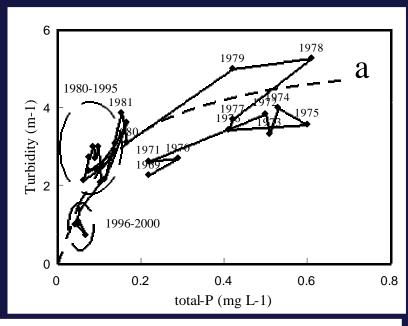
GLOBAL BIODIVERSITY
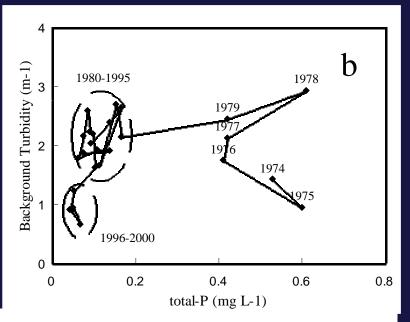
A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

- Two alternative stable states - a functional state and a dysfunctional state – the transition is abrupt and apparently without warning
- It is much better to prevent the collapse of the clear state clear because resilience in nature will work with you to keep the system in a healthy state
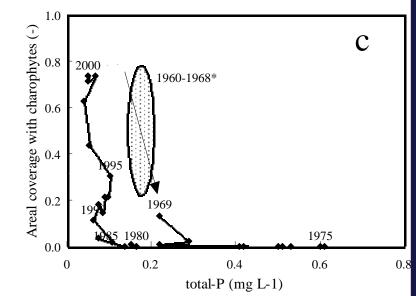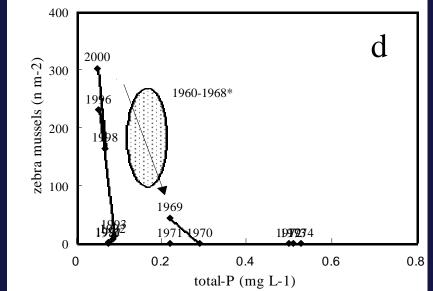- Once you have lost the clear state, it is very difficult to come back : hysteresis occurs

Hysteresis Lake Veluwe (NL)

Critical slowing down

Although the regime changes seem to occur without warning there are generic early warning signals in all systems. One of the early warning signals is known as critical slowing down. A system near a tipping point will return much more slowly to the state of origin – after disturbance - than a healthier system

small changes
no surprises

a

small changes
small surprises

b

small changes
big surprises

F1

F2

c

conditions

system state

high resilience   low resilience   b

basin of attraction   basin of attraction

critical slowing down

http://www.early-warning-signals.org/home/
http://www.vasilisdakos.info/

far from the transition

a

basin of attraction

'saddle'

high recovery rate

disturbances

close to the transition

b

basin of attraction

'saddle'

low recovery rate

disturbances

a1 recovery time

system state

time

a2 autocorrelation

system state, t+1

system state, t

b1 recovery time

system state

time

b2 autocorrelation

system state, t+1

system state, t

a3 variance

system state

time

a4 skewness

occurrence

system state

b3 variance

system state

time

b4 skewness

occurrence

system state

recovery time after a temporal perturbation

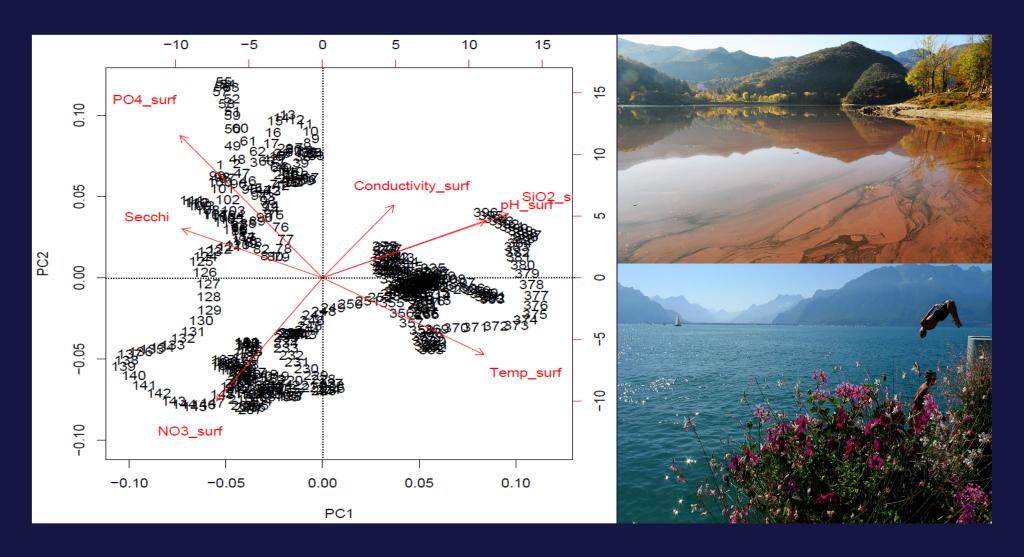underexploited

overexploited

Observing algae
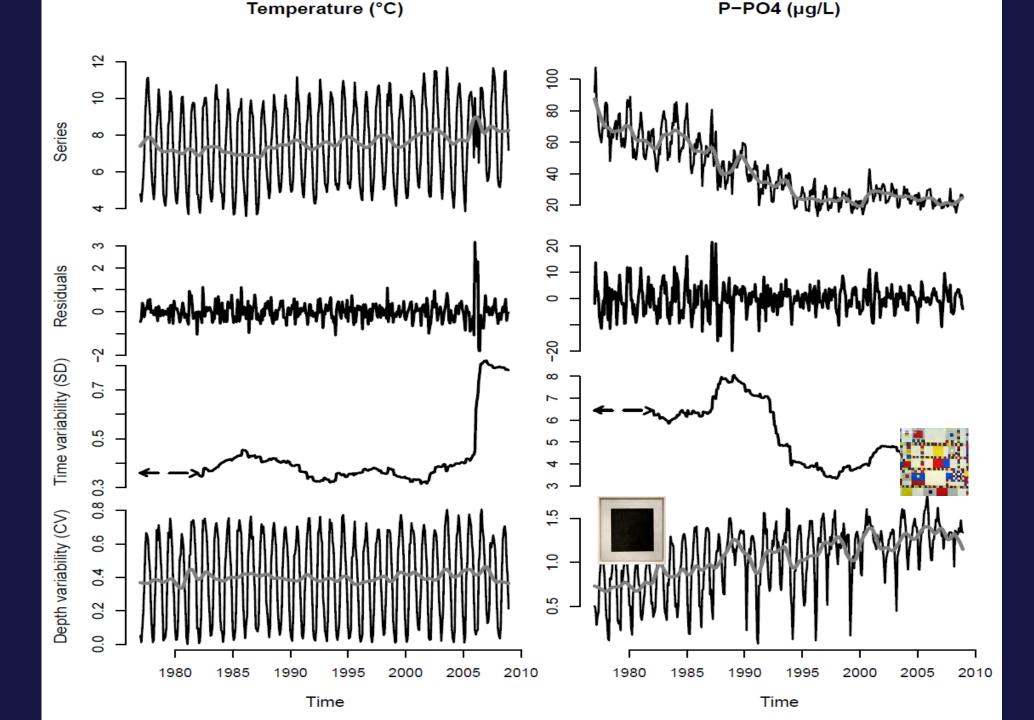
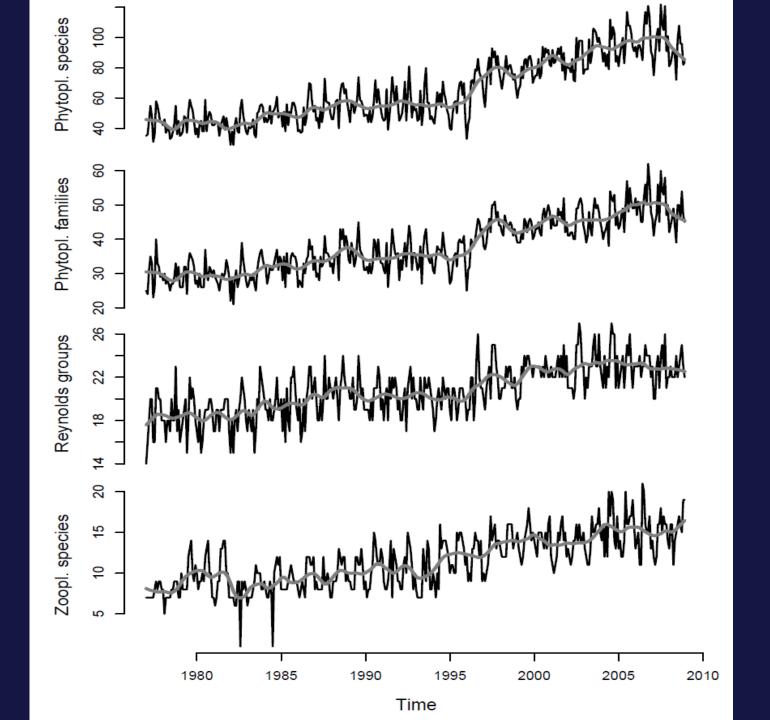# Dr Zürisee het d'Form vonerä Bananä

Our study is concerned with unravelling the long term consequences of environmental change (here eutrophication / re-oligotrophication and climate warming)on the biodiversity and functioning of lake ecosystems
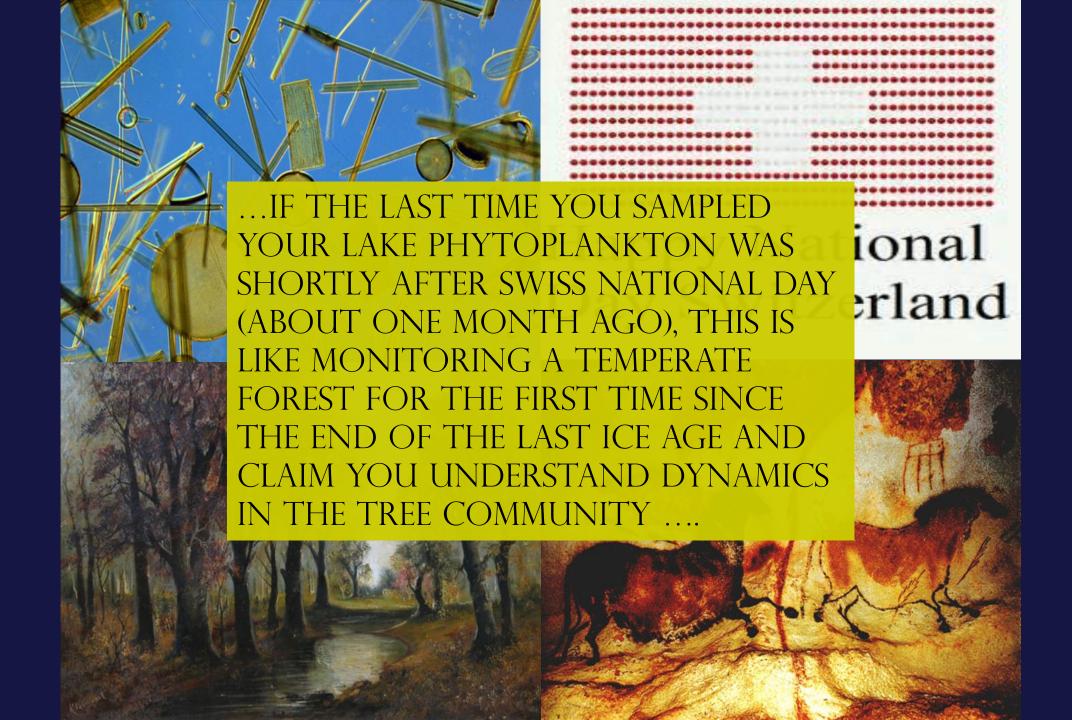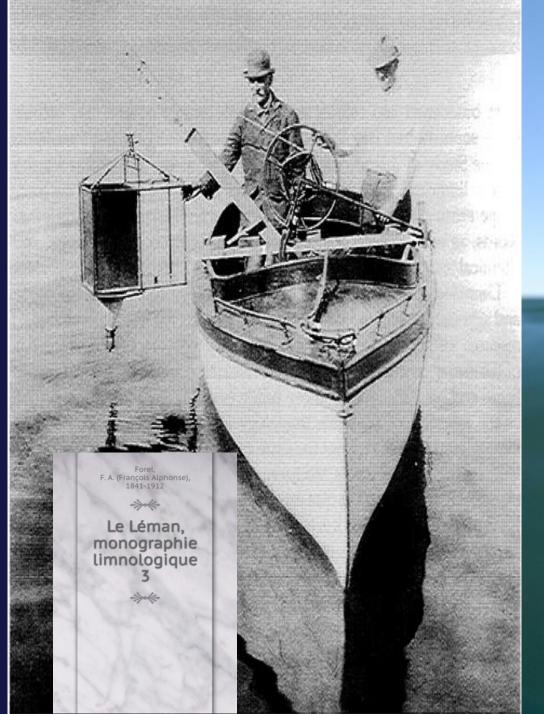
PCA of decomposed time series

Pomati, Matthews, Ibelings, Oikos 2012

…IF THE LAST TIME YOU SAMPLED YOUR LAKE PHYTOPLANKTON WAS SHORTLY AFTER SWISS NATIONAL DAY (ABOUT ONE MONTH AGO), THIS IS LIKE MONITORING A TEMPERATE FOREST FOR THE FIRST TIME SINCE THE END OF THE LAST ICE AGE AND CLAIM YOU UNDERSTAND DYNAMICS IN THE TREE COMMUNITY ….

Forel,
F. A. (François Alphonse),
1841-1912

Le Léman,
monographie
limnologique
3

Lakes in a changing world: **we are facing 21st century environmental challenges** *using 19th century techniques to collect our information*
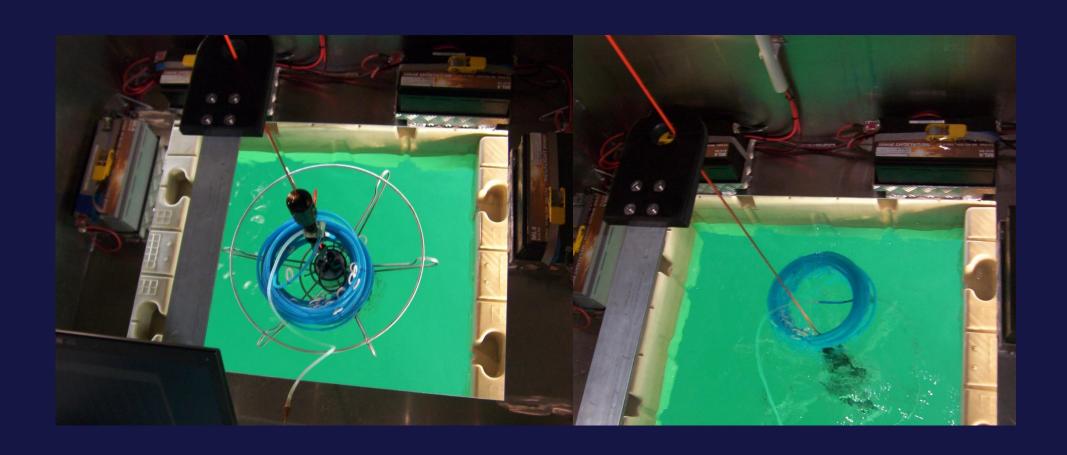
automated vertical profiling in operation

Monitoring the environment
multiparameter probe

Prsofiling sensors:
Pressure
Temperature
Conductivity
Oxygen
pH
NO_3
Chl-a
Phycocyanin
Phycoerithrin
PAR
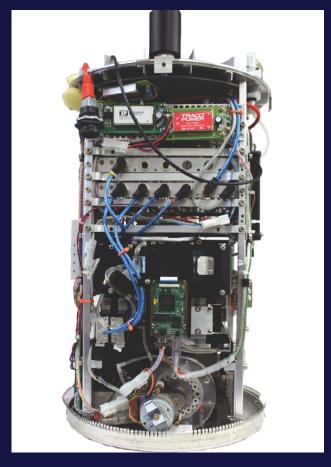
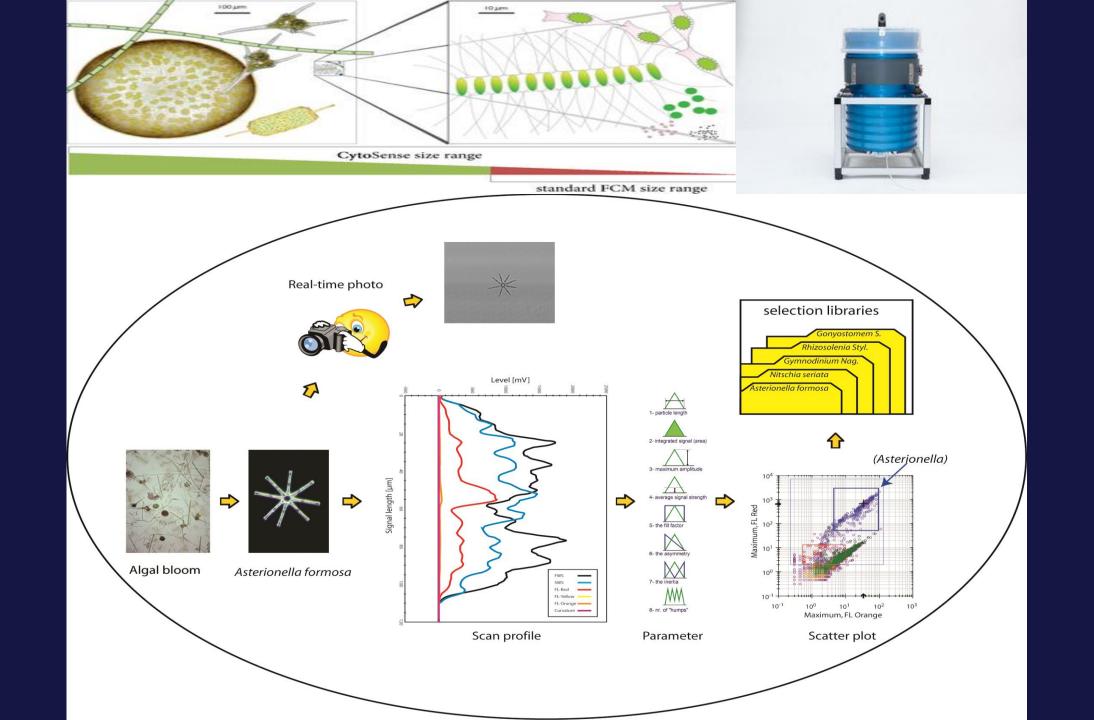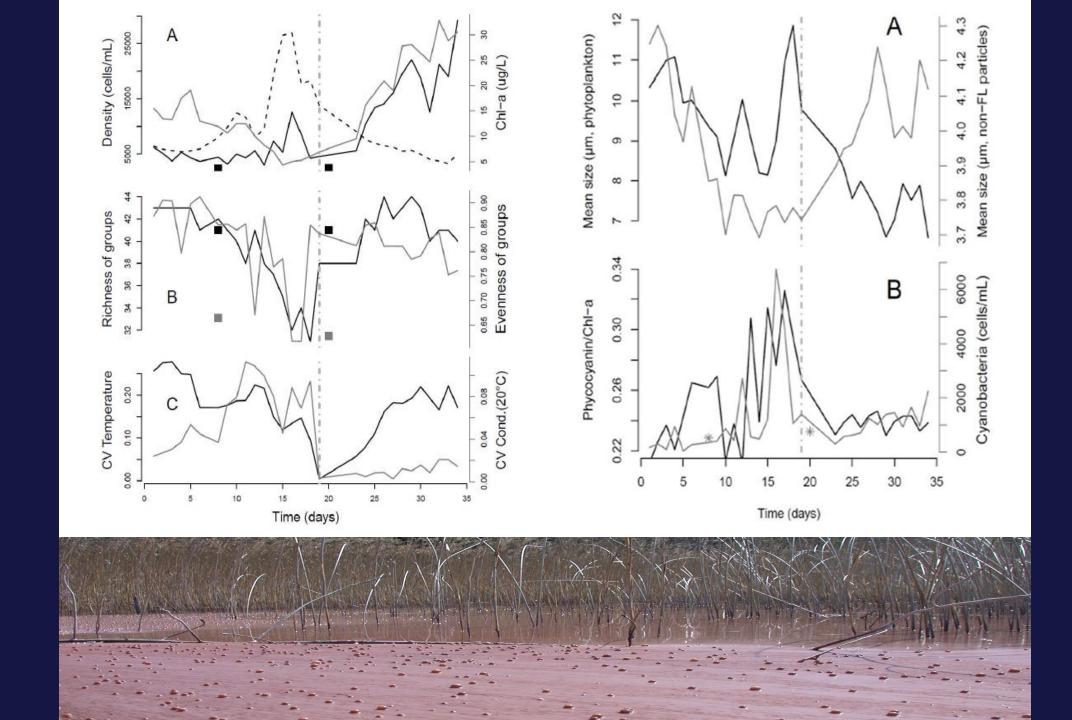Surface
data logger:
PAR
UV
Meteo station
WISP

IDRONAUT OCEAN SEVEN 316Plus CTD PROBE
20Hz SAMPLING RATE - REAL-TIME AND SELF-RECORDING CAPABILITY

Scanning flowcytometry to quantify – functional - phytoplankton diversity

standard FCM size range

CytoSense size range

Real-time photo

selection libraries

Gonyostomem S.
Rhizosolenia Styl.
Gymnodinium Nag.
Nitschia seriata
Asterionella formosa

Level [mV]

1- particle length

2- integrated signal (area)

3- maximum amplitude

4- average signal strength

5- the fill factor

6- the asymmetry

7- the inertia

8- nr. of "humps"

(Asterionella)

Algal bloom

Asterionella formosa

Signal length [μm]

FWS
SWS
FL-Red
FL-Yellow
FL-Orange
Curvature

Maximum, FL Red

Maximum, FL Orange

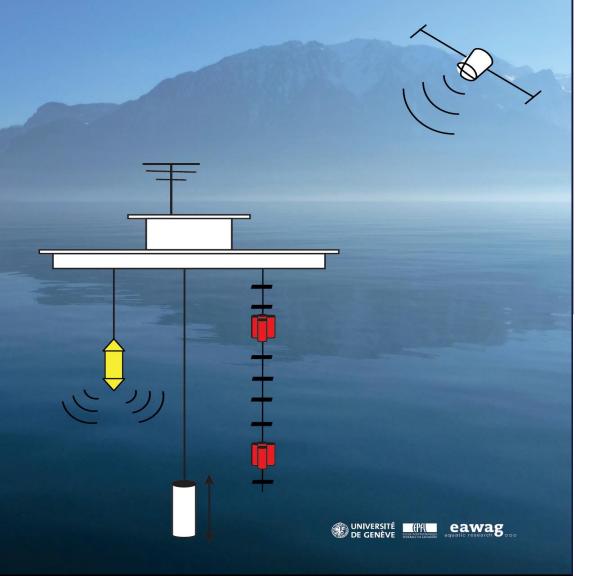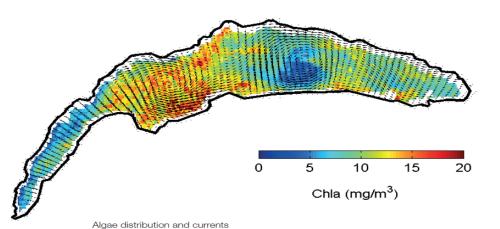Scan profile

Parameter

Scatter plot

LéXPLORE

The platform to investigate the impacts of environmental changes in Lake Geneva

LÉXPLORE
(Lac Léman Exploration)

LéXPLORE is a common project between EPFL, University of Geneva and Eawag and their internationally leading research groups in lake ecology under the coordination of the EPFL Limnology Center.
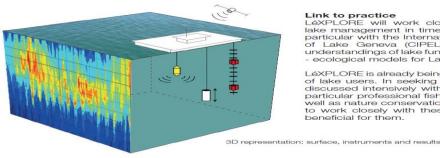
The LéXPLORE experimental platform will be installed on Lake Geneva for a period of 10 years near Pully, where the water depth is 110 m. The platform will be equipped with cutting-edge instrumentation to investigate lake processes as well as interactions between water and atmosphere. A suite of state-of-the-art instruments will allow unprecedented simultaneous observations of coupled physico-biological processes. This in-situ deployment of sensitive profiling instruments will allow measurements at high temporal and spatial resolutions and enable observations of unparalleled frequency, long-term duration, continuity and reliability. At the same time, the platform will offer information from across the lake, by integrating in-situ data from the platform with remote sensing observations and data from automatic underwater vehicles.

Chla (mg/m^3)

Algae distribution and currents

BENEFICIARIES

Sciences
The platform will create a dynamic, interdisciplinary and cutting edge research on Lake Geneva by:

- Supporting local scientists from the institutions around Lake Geneva and in Switzerland (EPFL, UNIL, UNIGE, Eawag, Hepia, INRA-Thonons-les-Bains);
- Attracting leading researchers worldwide through incorporation in the global GLEON network (www.gleon.org);
- Developing innovative technological applications;
- Facilitating working conditions for scientists;
- Promoting education for students from secondary school and universities

Link to practice
LéXPLORE will work closely with stakeholders to optimise lake management in times of rapid environmental change, in particular with the International Commission for the Protection of Lake Geneva (CIPEL, www.cipel.org). We expect new understandings of lake functioning and improved hydrodynamic - ecological models for Lake Geneva.

LéXPLORE is already being embedded in the local communities of lake users. In seeking a location for the platform we have discussed intensively with the main users of lake services, in particular professional fishermen, navigation, marine police, as well as nature conservation agencies. LéXPLORE will continue to work closely with these users, so that the outcomes are beneficial for them.

3D representation: surface, instruments and results

UNIVERSITÉ DE GENÈVE   EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE   eawag aquatic research

Total suspended solids [mg/l]   Green field reedbeds [mg/l]

low   high   low   high