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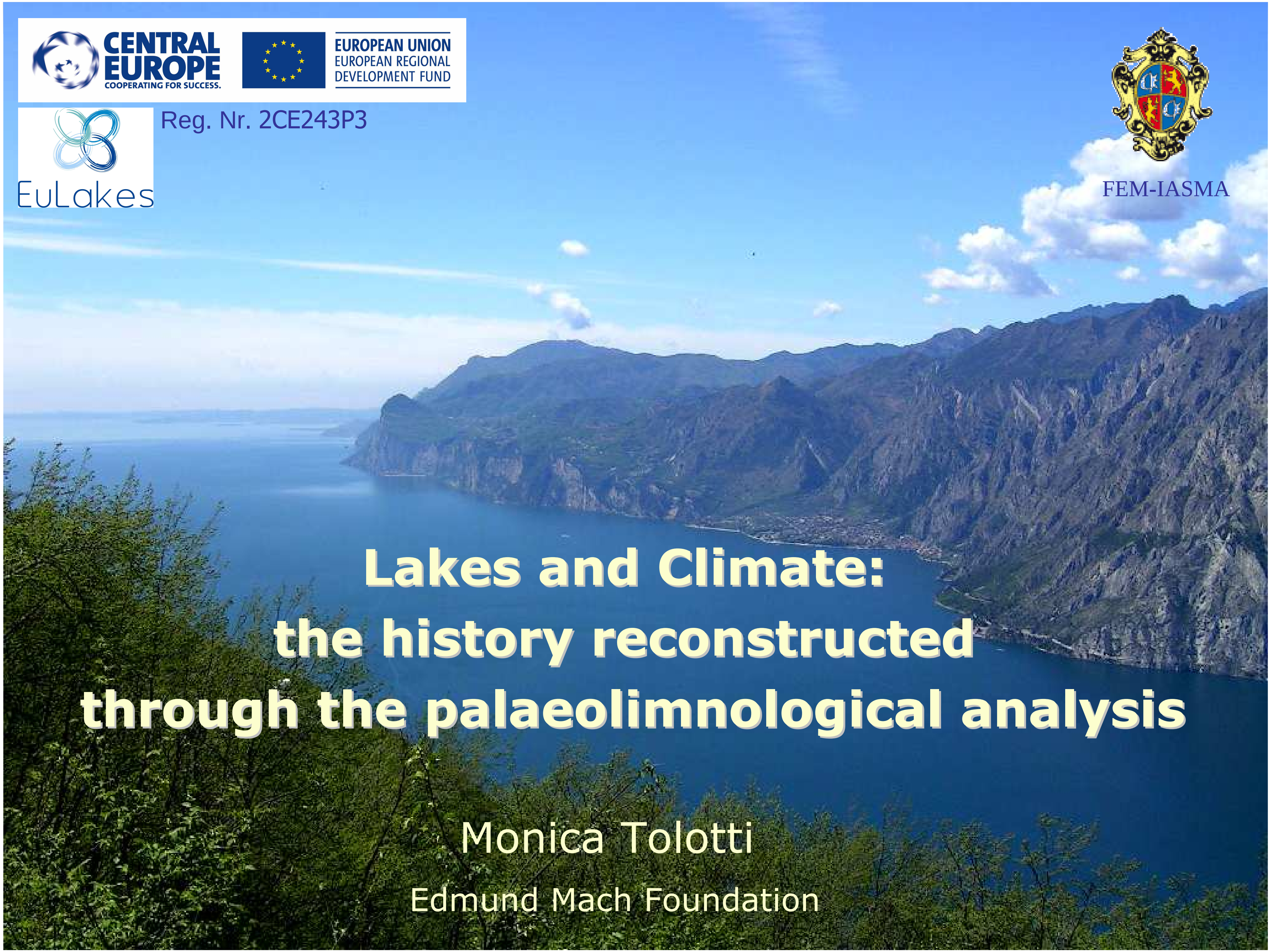


Lakes and Climate: the history reconstructed through the palaeolimnological analysis

Monica Tolotti

Edmund Mach Foundation

Summary

- Climate: a brief overview
- Palaeolimnology: definition and background
- Methods
- Palaeolimnology for reconstruction of climate driven changes in lakes (some examples)

- Contribution of palaeolimnology to the EuLakes Project

A changing environment constantly alternating cold and warm periods

<u>Glacial periods</u>: low temperature and land ice expanding

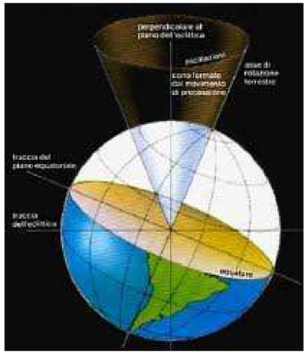
- dominating conditions for the planet in the last 2.5 Mil y
- <u>highly variable</u>: quasi cyclical abrupt warming (1.5 Ky, **interstadial**) and harsh cooling (7 Ky)
- <u>Würm glaciation:</u> last maximum ice expansion in the Alps: ca 20-11 Ky BP

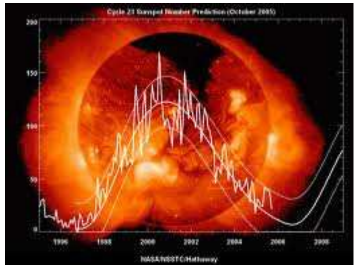
<u>Interglacial periods</u>: temperature increase and recession of land ice

Holocene:
- last ca. 11.5 Ky BP, rapid temperature increase, adjustment of the hearth system
- last ca. 8 Ky BP in <u>stable conditions</u> similar to present day
- last ca. 5 Ky, human colonization of the boreal hemisphere, agriculture, industry

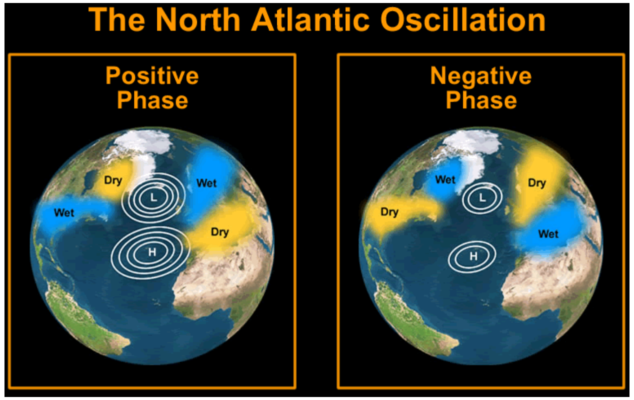
Natural climate variability

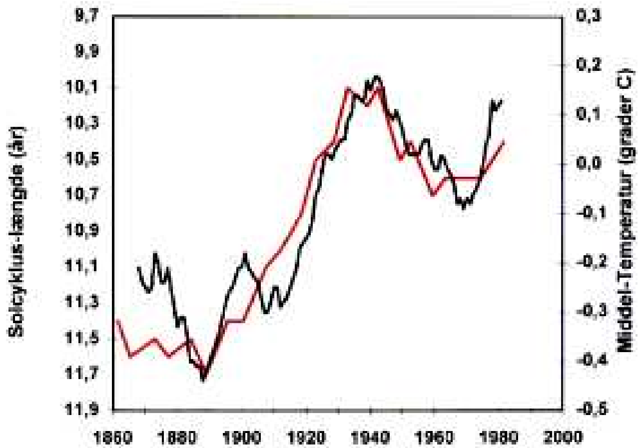
- changes in the terrestrial rotation axis (equinox precession)
- cyclical variation in solar activity (11 y periodicity)
- volcanic activity (scattering and absorption of incoming solar radiation)





- Internal dynamics of climate system, such as differences in atmospheric pressure over the oceans leading to North Atlantic Oscillation (NAO), South Ocean Oscillation (ENSO) etc…





<u>Millennial scale changes:</u>

- Warmer early Holocene (ca. 2°C)
- Desertification (Sahara, Arabia, India, China)
- Medieval cooling culminating in the Little Ice Age (ca. 1750-1850)

<u>Secular scale changes:</u>

- ca. 200 y cycles of slightly warmer and colder periods

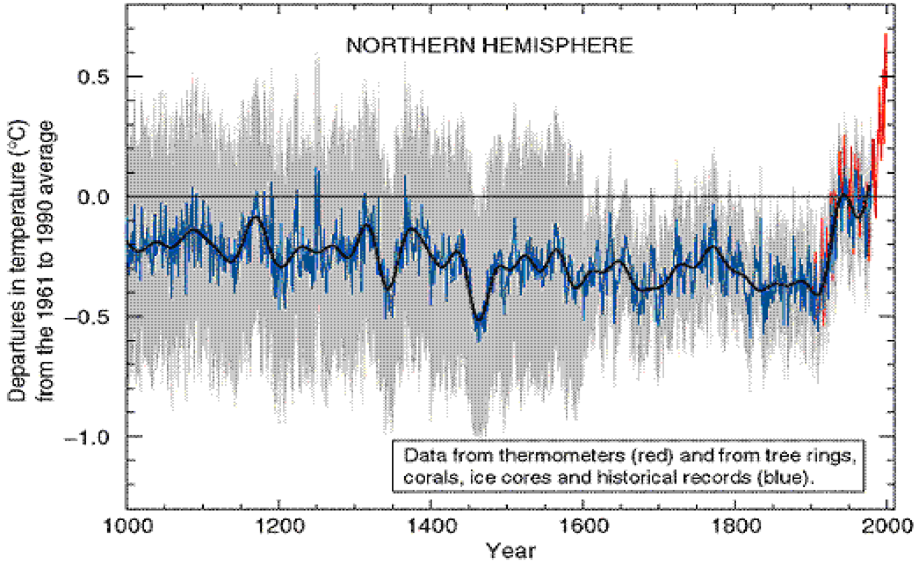
Climate reconstruction

Long term reconstruction of past climate (air temperature, precipitation) through:

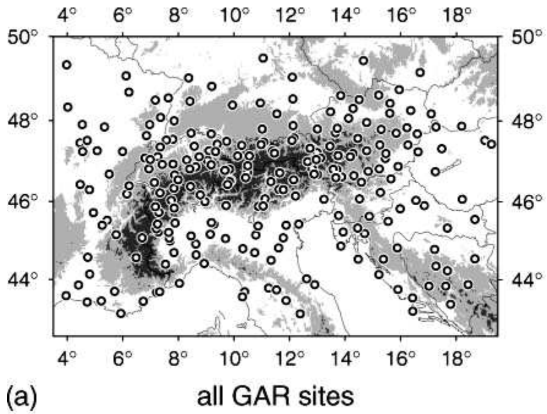
- ✓ instrumental records from meteorological stations (max. last ca. 250 years)

+

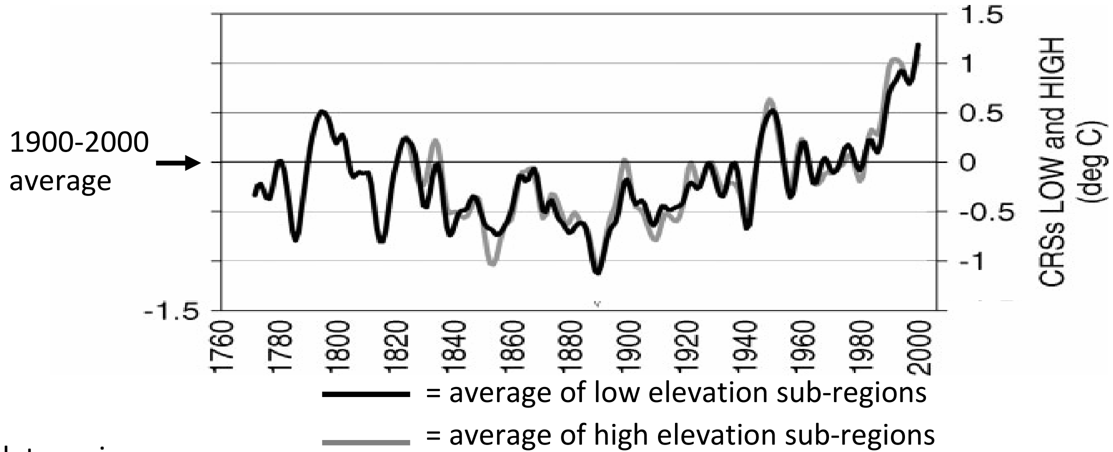
- ✓ Ice cores (Arctic, Antarctic, Greenland)
- ✓ Ice-rafted debris from marine cores
- ✓ Calcite depositions in caves
- ✓ Pollen in peat bogs
- ✓ Tree-rings



HISTALP: Historical Instrumental Climatological Surface Time Series of the Greater Alpine Region (Auer et al., 2007)



GAR = Greater Alpine Region:
(4–19 °E, 43–49 °N, 0–3500 m a.s.l.), 557 data series

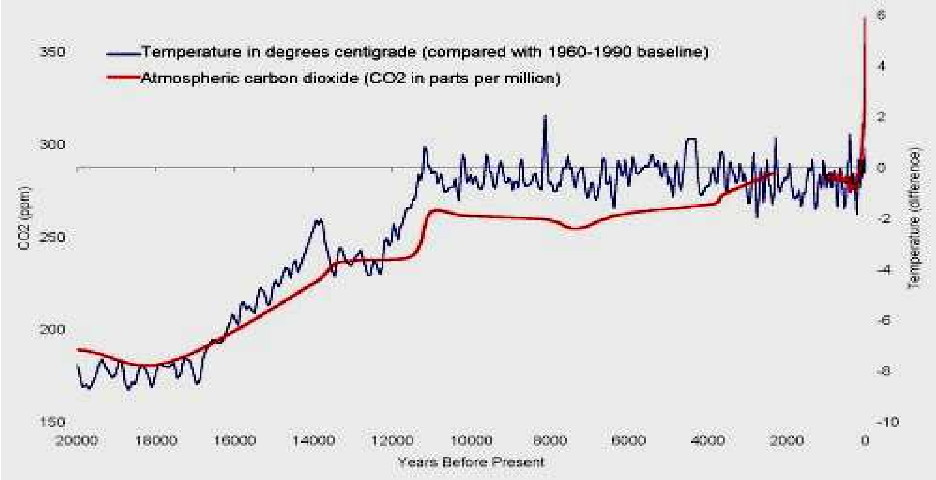


Human driven climate variability

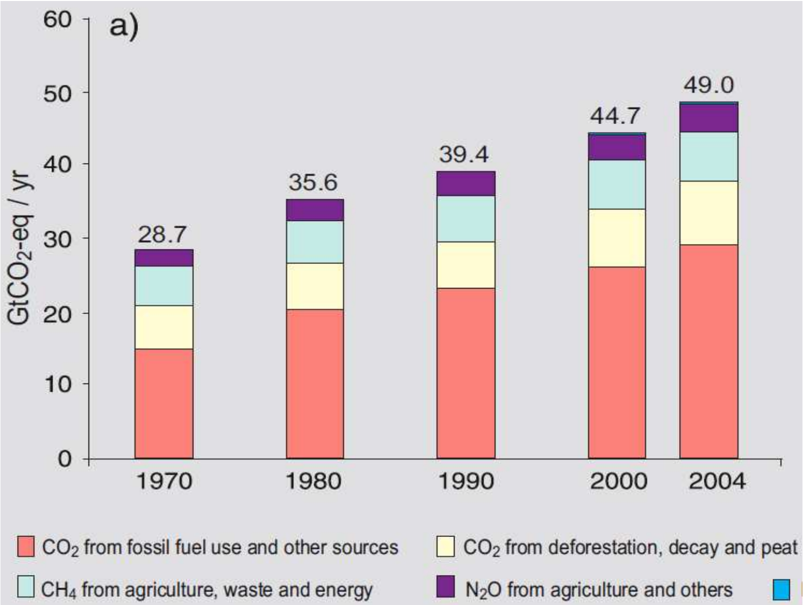
Pronounced and rapid increase in global temperature during the last ca. 150 years

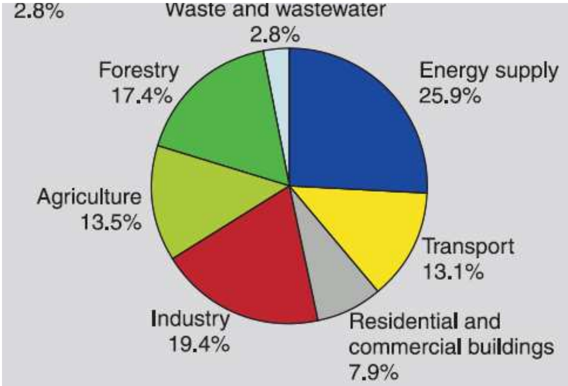
It has become increasingly clear that there is a strong human contribution to global warming, related to the emission of greenhouse gases (CO_2, NH_4, NO_x)

Largely accepted by scientific community



- Greenhouse gas concentrations are higher than at any time in the last 750 Ky
- Temperature in the N hemisphere are higher than in the last 10,000 y

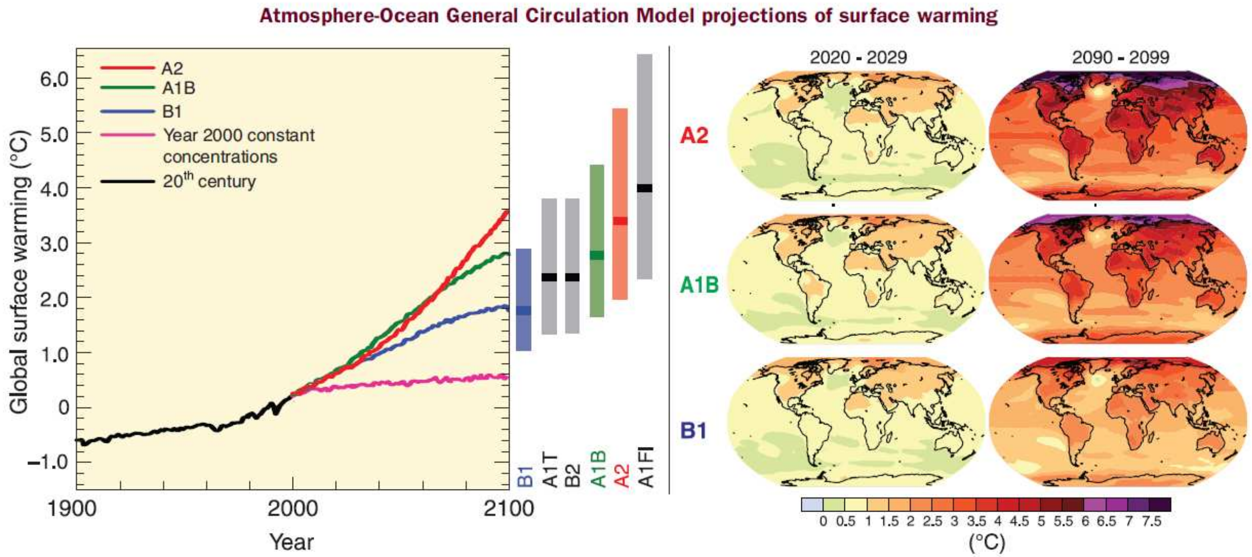




(modified from IPCC report, 2007)

Scenarios and questions

Different climate scenarios in relation to different previsions of future atmospheric emissions



(modified from IPCC report, 2007)

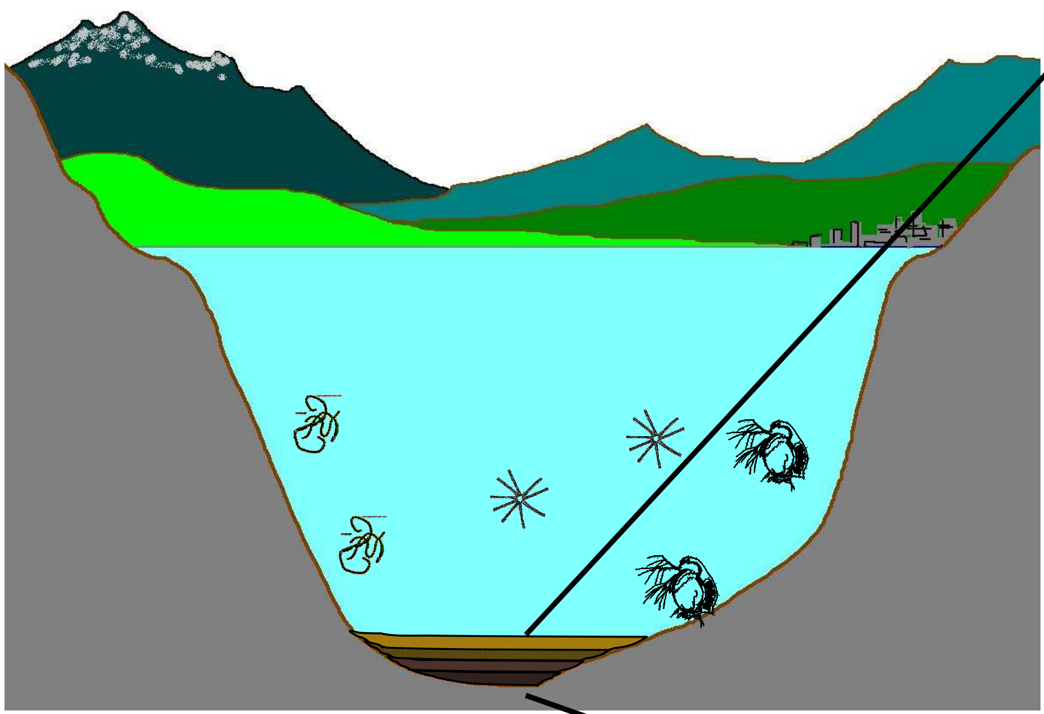
- Questions regarding magnitude and effects of global climate changes have elicited vivid discussion, as **all aspects of human life can be directly or indirectly affected** (agriculture, forestry, industry, transports, migrations, city development, tourism, etc…)

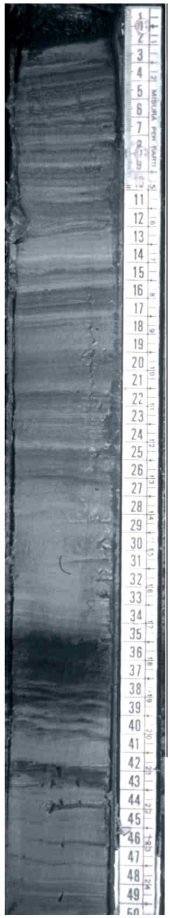
- **Effects of climate change on aquatic ecosystems are more difficult to be predicted** due to:
  - interactions between climate and catchment/lake processes
  - similarity between climate effects and nutrient-driven effects
  - necessity of long-term monitoring data (decennial scale)

Palaeolimnology represents a powerful tool to cope with some of these critical aspects

What is palaeolimnology?

Study of lake sediments for the reconstruction of past lake evolution



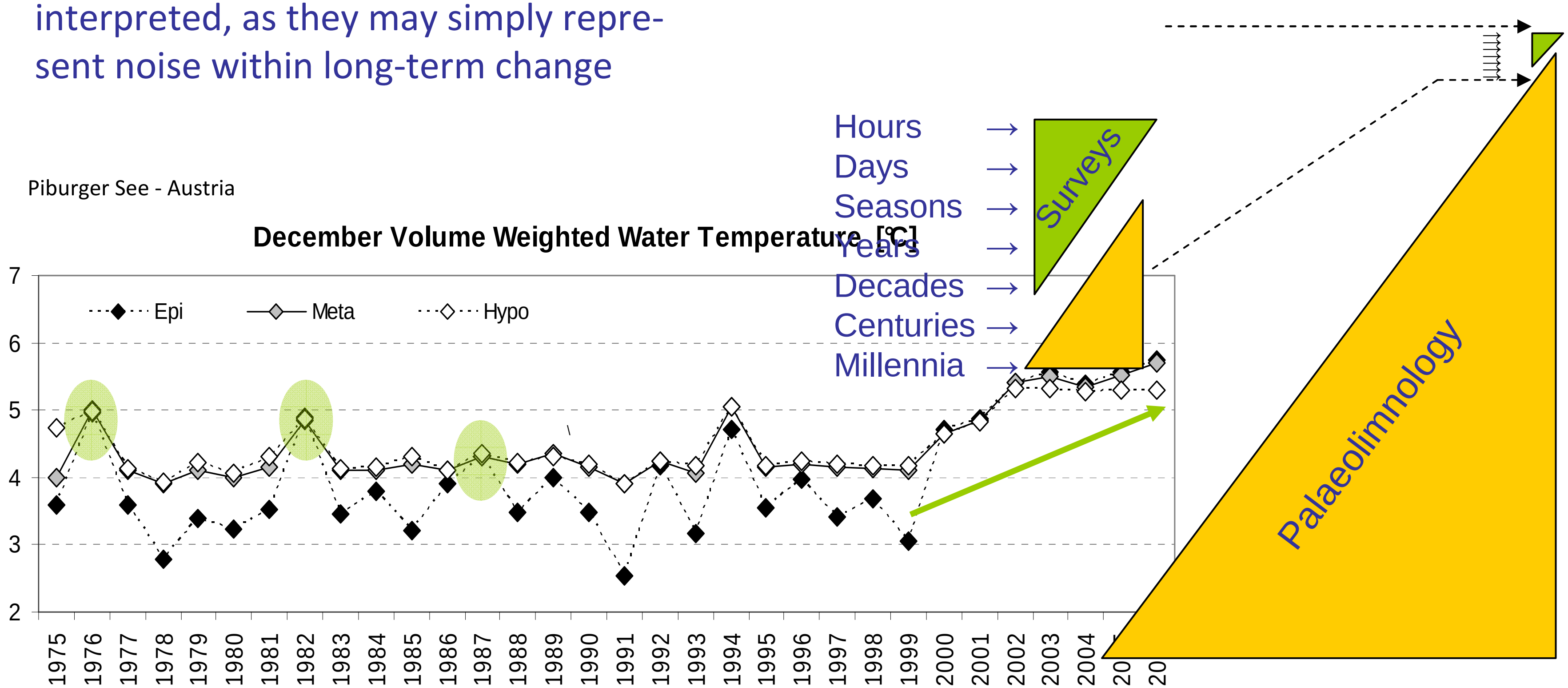


Physical, chemical and biological events occurring in the lake leave back remains and signs, which sink toward lake bottom day after day, thus slowing forming the lake sediments

Studying lake sediments means to get access to the lake historical archive

A matter of time scale

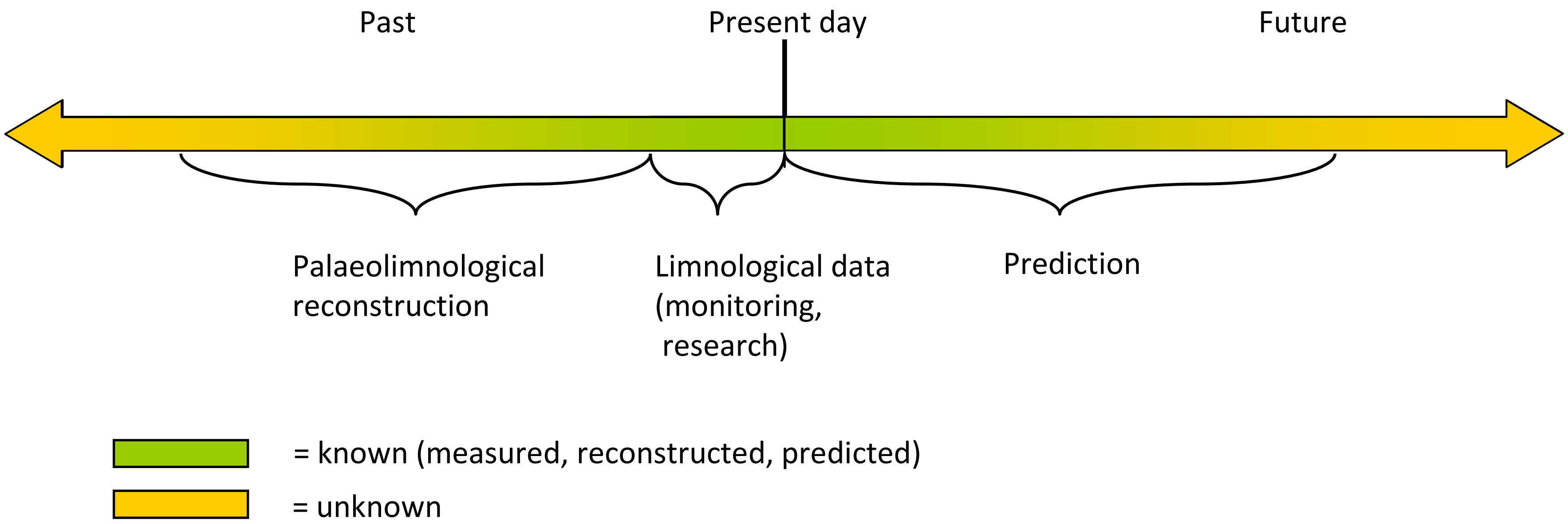
- 70% of ecological surveys based on observation of 1 year's duration or less (Smol, 2008).
- Instrumental climatic records cover the last max 200 years (often much less)
- Short-term changes are often mis-interpreted, as they may simply repre-sent noise within long-term change
- <u>Limnological</u> studies can cover a time span up to decades [even at LTER sites]
- <u>Palaeoecological</u> studies can cover millennia, i.e. up to the entire history of EU temperate lakes



What is palaeolimnology for?

It is not (only) an academic exercise able to satisfy curiosity about the past lakes history …

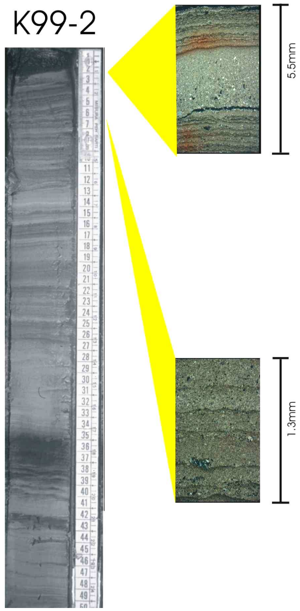
<u>**General objective**</u> = to **expand backwards** the knowledge on long term evolution of lakes in relation to local and global changes, and to use these information to **forecast** future development



The farther backward you can look, the further forward you are likely to see

W. Churchill (1874-1965)

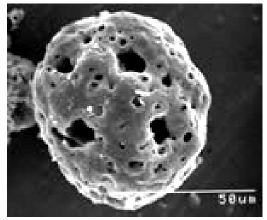
A multidisciplinar approach - I

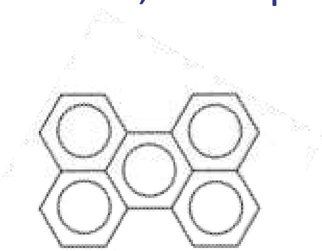


A multidisciplinar approach based on the study of numerous **proxies**, i.e. synthetic indicators of limnological conditions and processes

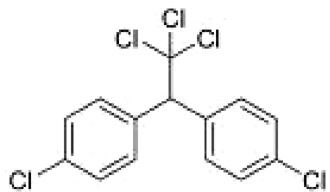
Geochemical proxies

- Visual aspect and granulometry = changes in lake hydrology
- H_2O, organic matter, S, N, P = chemical and trophic evolution
- Radionuclides (^{210}Pb, ^{137}Cs, ^{226}Ra, ^{241}Am, ^{14}C) = sediment age
- SCPs (Spheroidal Carbonaceous Particles) = atmospheric contamination
- heavy metals, POPs (e.g. PCBs, PAHs) = human driven pollution
- S, C, N isotopes = acidification, eutrophication, trophic nets





Perylene



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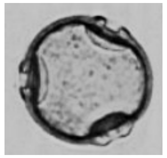
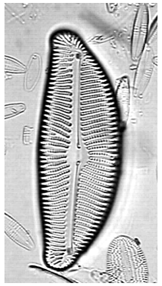
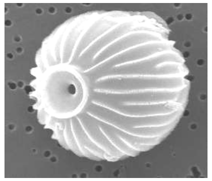
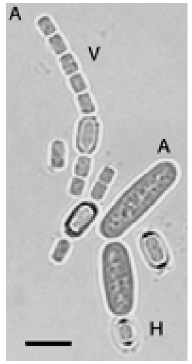
A multidisciplinar approach - II





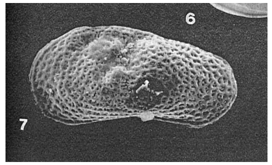




Biological proxies

Sub-fossil remains:

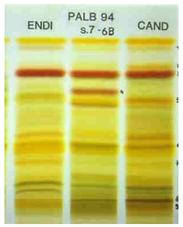
- plants: pollens, diatoms, chrysophytes and cyanobacterial cysts

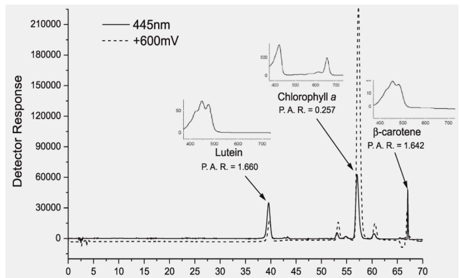


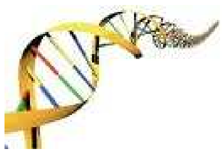
- animals: cladocera, ostracoda, insects, mollusca, etc...

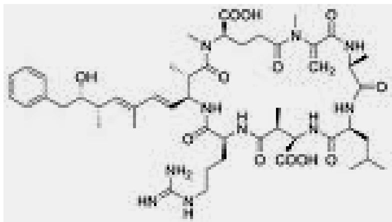
Biochemical remains:

- algal and bacterial pigments = algal populations
- lipids, organic compounds = changes in biodiveristy
- DNA = changes in biodiversity (genetic composition, microevolution, physiological phenotypes)









Classical application

Reconstruction of past changes in lake trophic status (nutrients)

- ✓ to set **restoration targets** (quality objective) based on **reference conditions** (i.e. undisturbed) – WFD EU/60 2000
- ✓ to assess lake **vulnerability** in relation to future nutrient inputs (scenarios)
- ✓ to contribute to the development of **mitigation** and **adaptation** strategies aimed at maintain ecological functionality and human use (research + management)

The majority of European temperate lakes experienced nutrient enrichment after WWII, especially in 1960s-1970s (Schindler et al., 2006)

- domestic and productive (food industry, cattle) sewage
- P-rich detergents
- fertilizers in agriculture

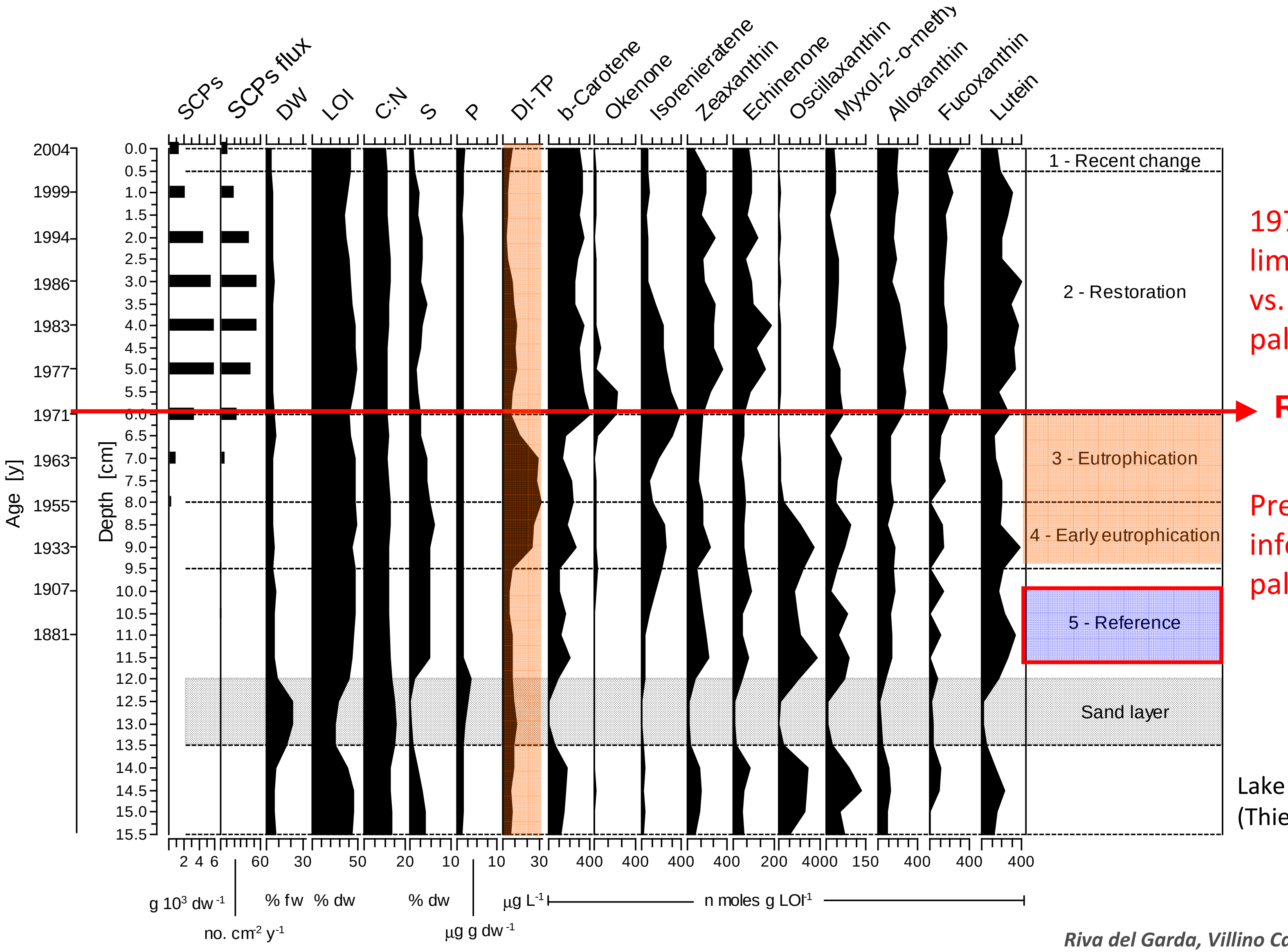
Major effects:

- increase in lake productivity (higher algal biomass)
- algal (toxic) blooms and scums
- decrease in lake transparency (tourism)
- oxygen depletion (decomposition of algal biomass)
- fish killing, biodiversity loss

Reconstruction of lake trophic conditions

Regular monitoring often started during or after acute cultural eutrophication

Palaeolimnology provides a **post-hoc evaluation** of eutrophication mechanisms and restoration



1970-2004: limno- vs. palaeolimnolgical

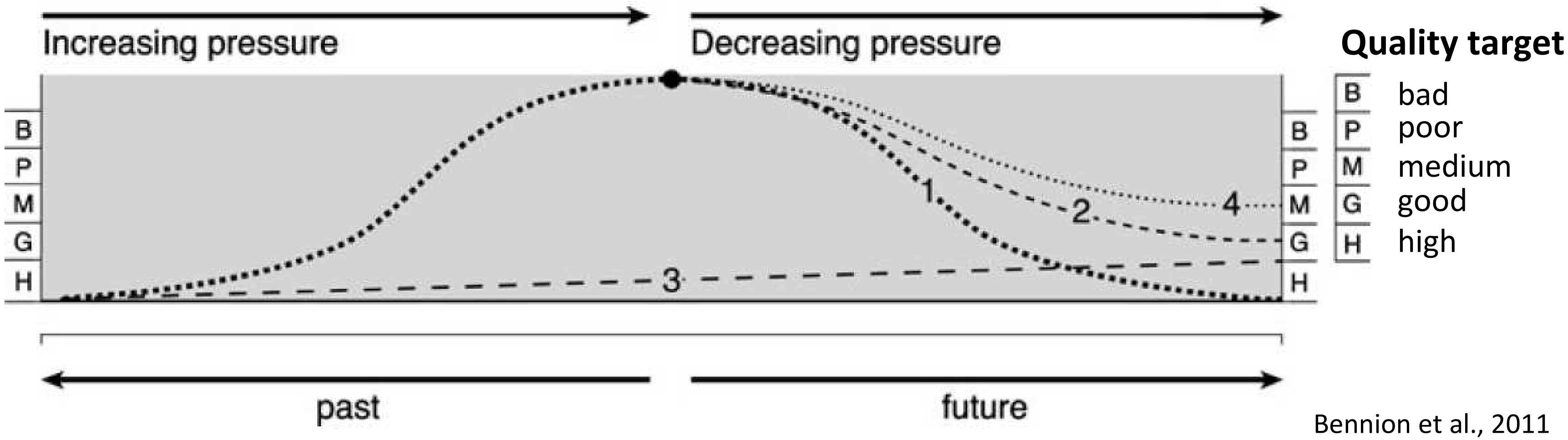
Pre-1970: inferred from palaeo.

Lake Piburger, Austria (Thies, Tolotti et al. 2011)

Climate driven shift in the quality base-line

As a consequence of the climate change, the base line (i.e. reference conditions) may

1. not been reached any more by restored lakes
2. change even in pristine lakes



Bennion et al., 2011

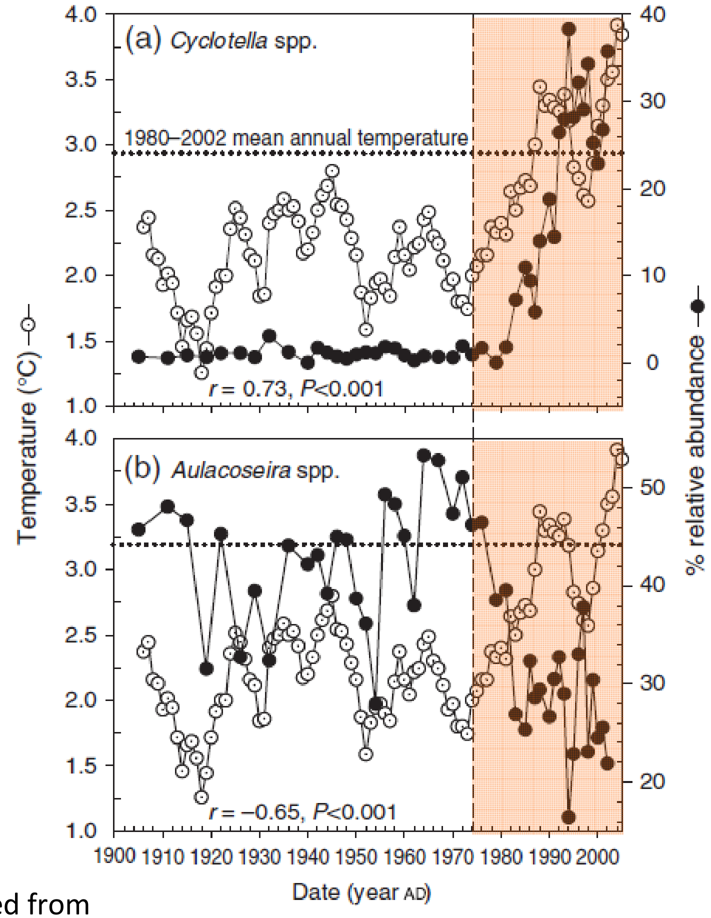
1 = recovering process without climate change
2-4 = recovering scenarios under different climate changes
3 = base line (reference conditions)

To understand the effects on climate change on lake ecological processes is of key importance for management purposes

Evidence of climate driven effects on lakes - algae

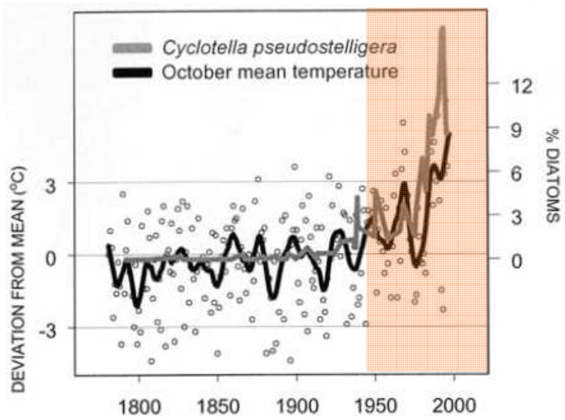
- **High latitude** and **high altitude** lakes = optimal study sites, as human impact is often negligible

Canada, Ontario, Experimental Lake Area,



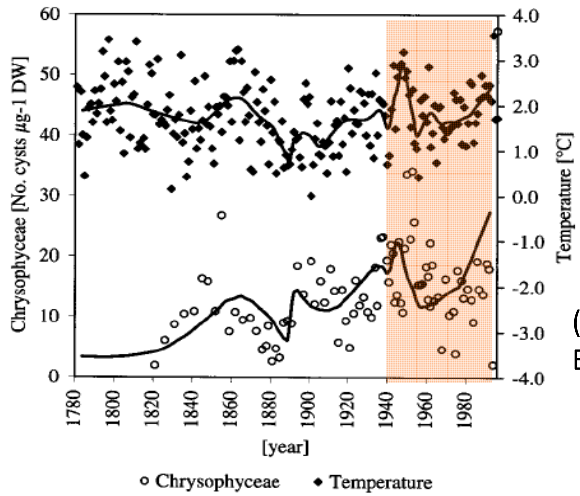
(modified from
Rühland et al., 2008)

Spain, Pyrenees, L. Redò, 2240 m a.s.l.



(modified from
Catalan et al., 2002

Slovenia, Jezero v Ledvici, 1830 m a.s.l.



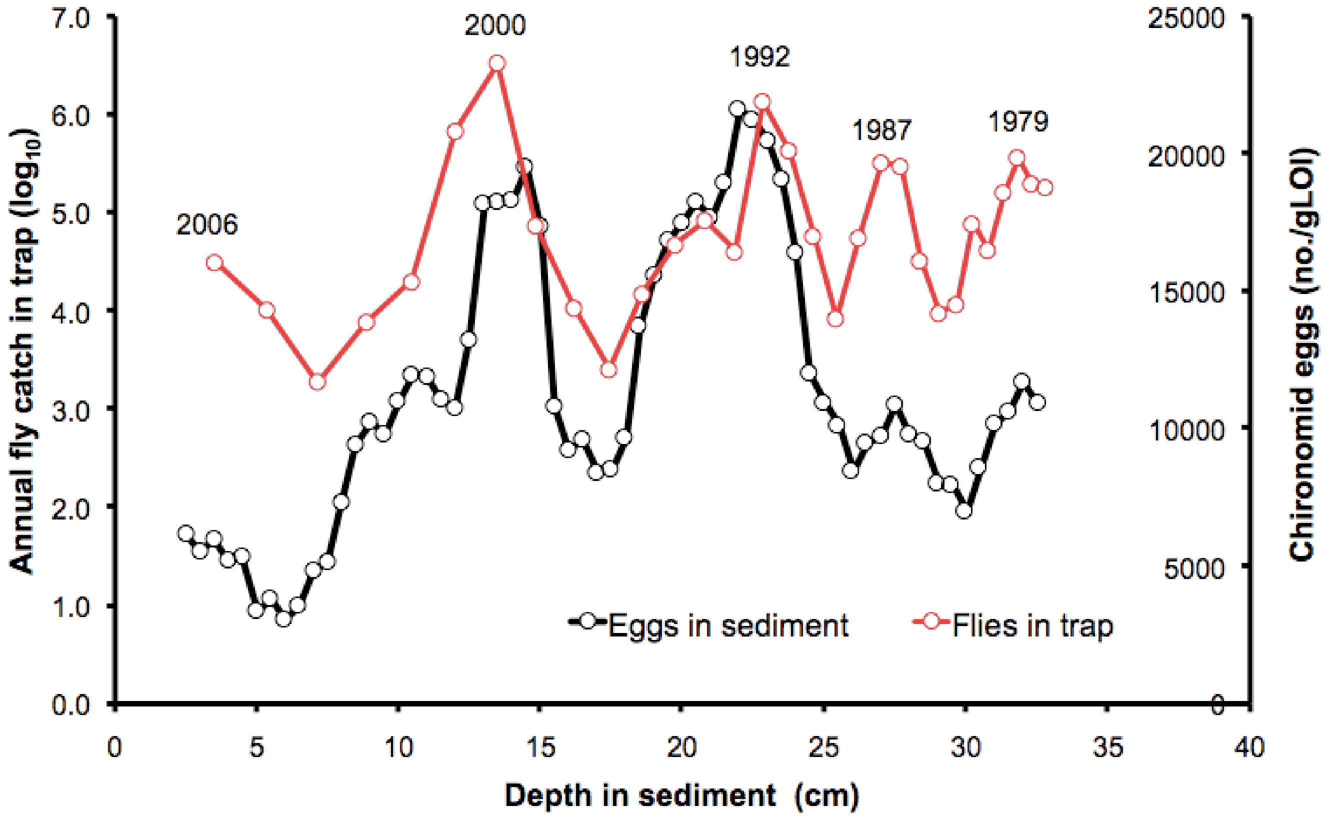
(modified from
Brancelj et al., 2002

Evidence of climate driven effects on lakes - insects

Density of insects (chironomids) *egg shells* in a sediment core compared with the annual catch of *adult chironomids* in a nearby flytrap.

(modified from Hauptfleisch et al., 2010)

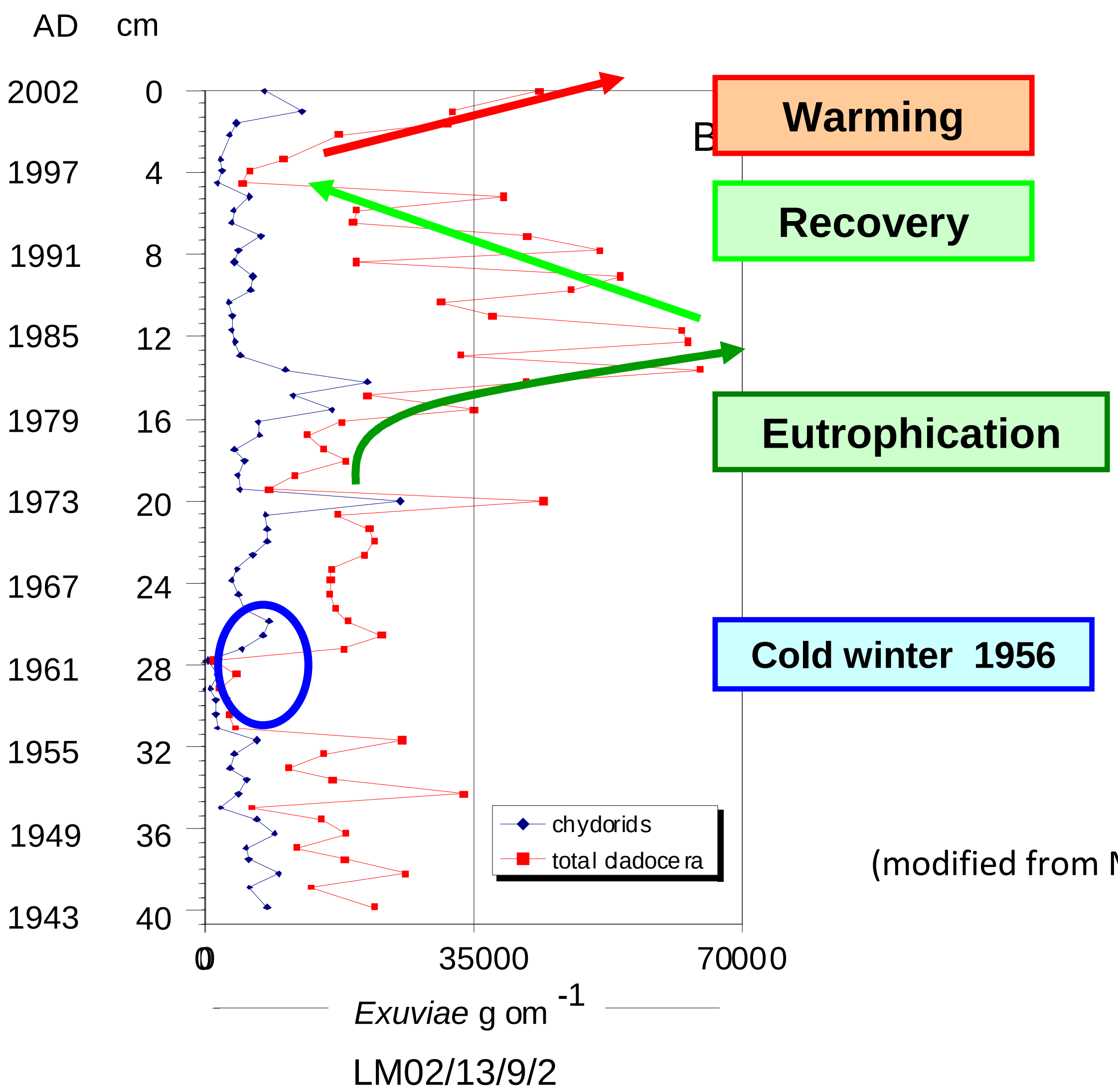
Lake Myvatn, Iceland



The trend of the biological proxy in sediment record matches direct observations, which correspond to colder/warmer years

Distinguishing effects of eutrophication and climate change - I

- **Low** to **mid altitude** lakes at **temperate latitudes** are typically subjected to **multiple stressors** (nutrients, pollutants), that can interfere, mask or override the climate signal (Smol, 2008)



Lake Maggiore: nutrient variability during the 20th and superimposed climate variability

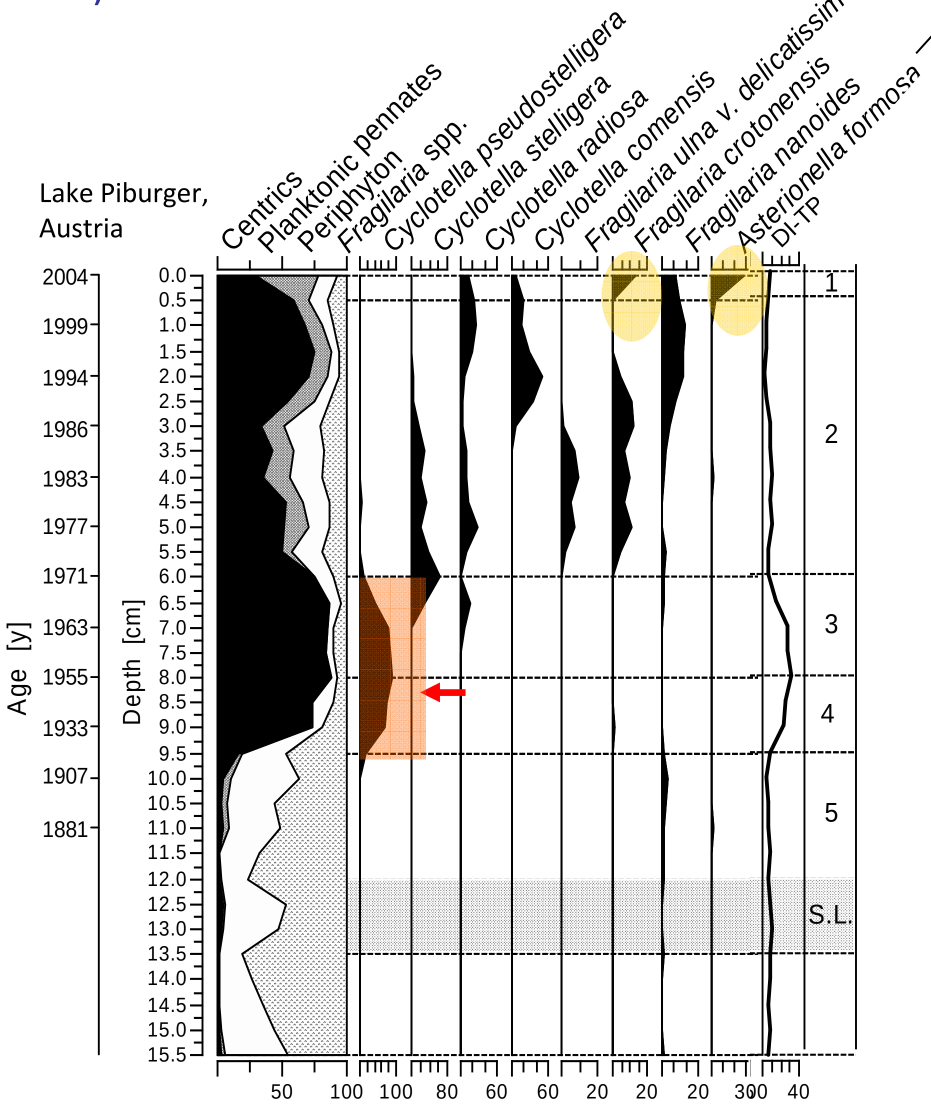
Lake warming often slows down lake recovery after restoration measures, or superimposes **counteracting effects**

(modified from Manca et al., 2007)

Distinguishing effects of eutrophication and climate change - II

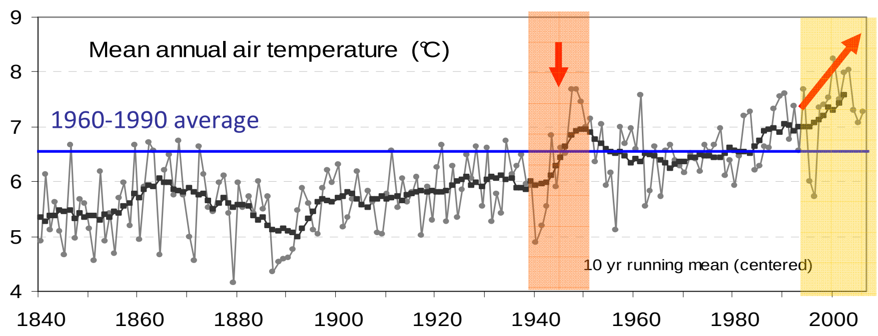
Effects of climate and nutrients may be extremely difficult to be discriminated, due to:

1) to synergic / opposite, mimicking effects ...
2) simultaneous action



Intensive statistical analyses can help disentangling the simultaneous effects

- temperature increase in the 1940s superimposed to nutrient increase started in the early 1900s
- recent changes due to nitrogen and water temperature increase

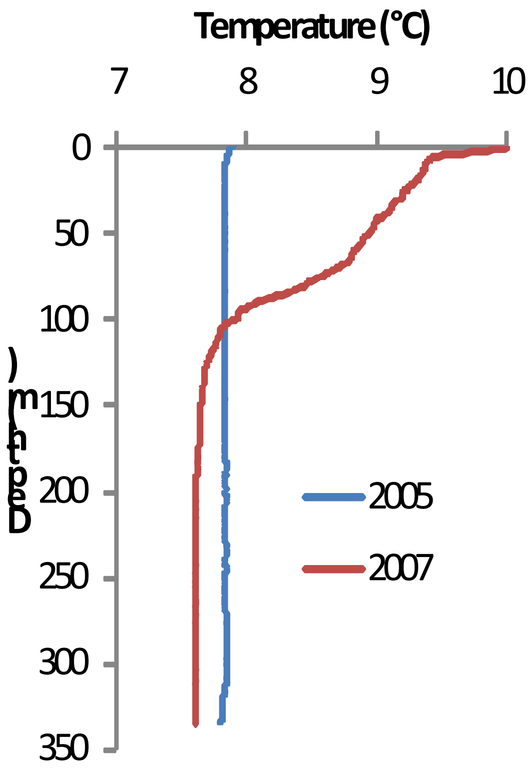


Modified from Thies, Tolotti et al. 2011

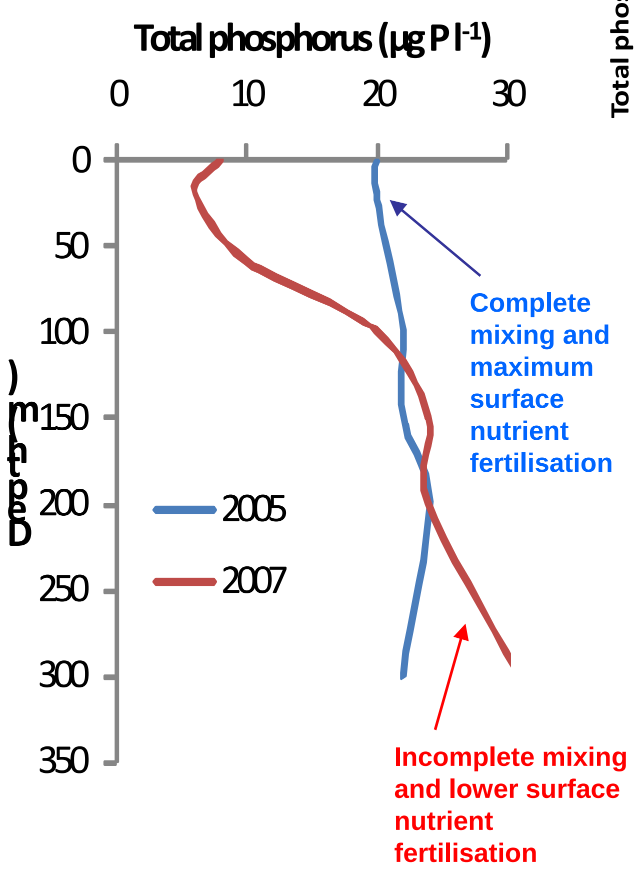
A paradigm of complexity in disentangling eutrophication and climate

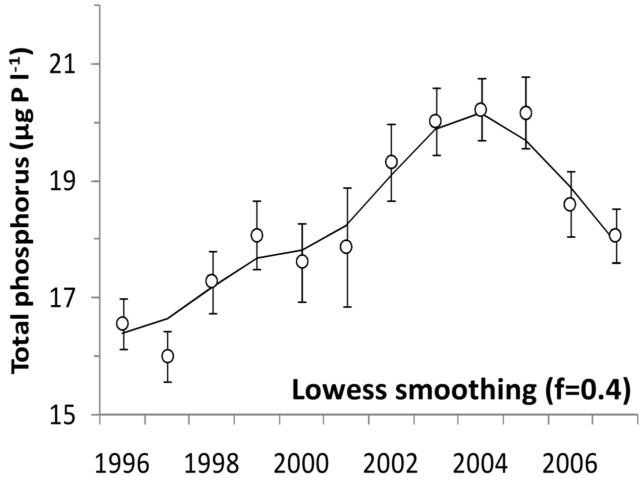
Lake Garda is classified as a **warm monomictic** lake (mixing in late winter), but owing to its great depth, complete mixing occurs only during cold winters (oligomixis)

Lake warming hinder nutrient replenishment (oligotrophication?), but may lead to deep anoxia (nutrient release and eutrophication?)



Modified from Salmaso, 2009





Modified from Salmaso, 2010

Studying **older** lake **sediments** we can reach the situation when climate change was the dominant driver, and try to understand past lake response and forecast future development

Project EULAKES

WP 3.1. - *Lake ecological history characterisation*

Study of chemical and biological proxies stratified in lake sediments for the reconstruction of lake evolution during the max. last 200 years.

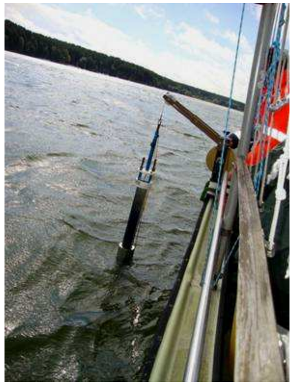
Objectives:

- definition of **lake reference conditions** and **restoration targets**
- reconstruction of long term colonisation dynamics by potentially **toxic cyanobacteria** (WP 5)
- assessment of lake **vulnerability** in relation to **climate change** and other **human impacts** (i.e. eutrophication, land use, increasing resource exploitation).

⇓

Results combined with data from regional monitoring programmes and other project WPs to support the development of mitigation and adaptation strategies for the four CE lakes in collaboration with local stakeholders.

Work programme



Short cores retrieved from the 4 project lakes
(dated sections = 100 -160 y)

- **Radiometric dating**

- Geochemical proxies:

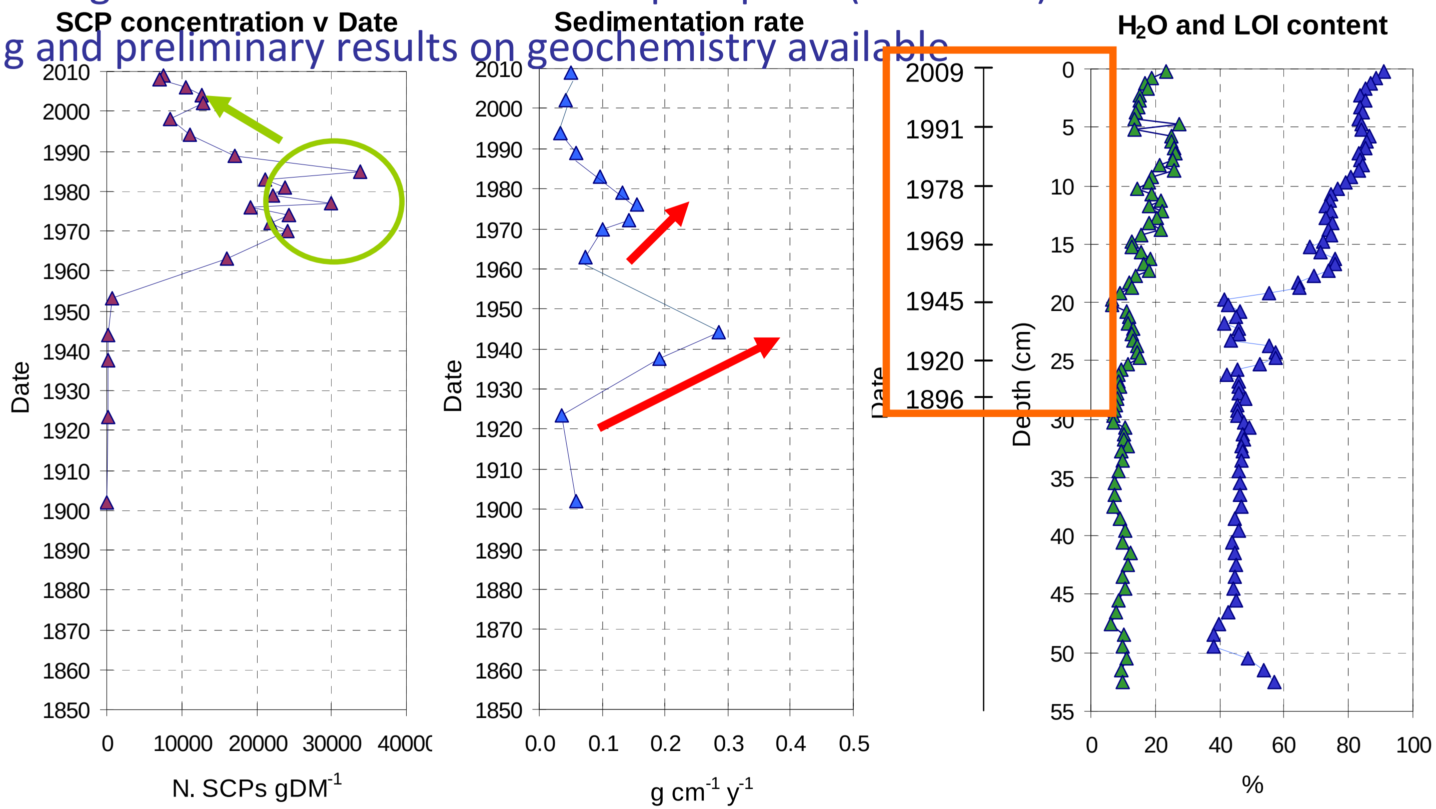
  1) **water** and **organic content** (LOI),
  2) Spheroidal Carbonaceous Particles (**SCPs**)

- Biological proxies:

  1) **sub-fossil pigments** of major algal groups
  2) **diatoms**: species diversity, diatom-based reconstruction of past lake properties
  3) **cyanobacteria akynetes**: species diversity, hatching experiments, genetic and molecular diversity

Lake Garda – preliminary results

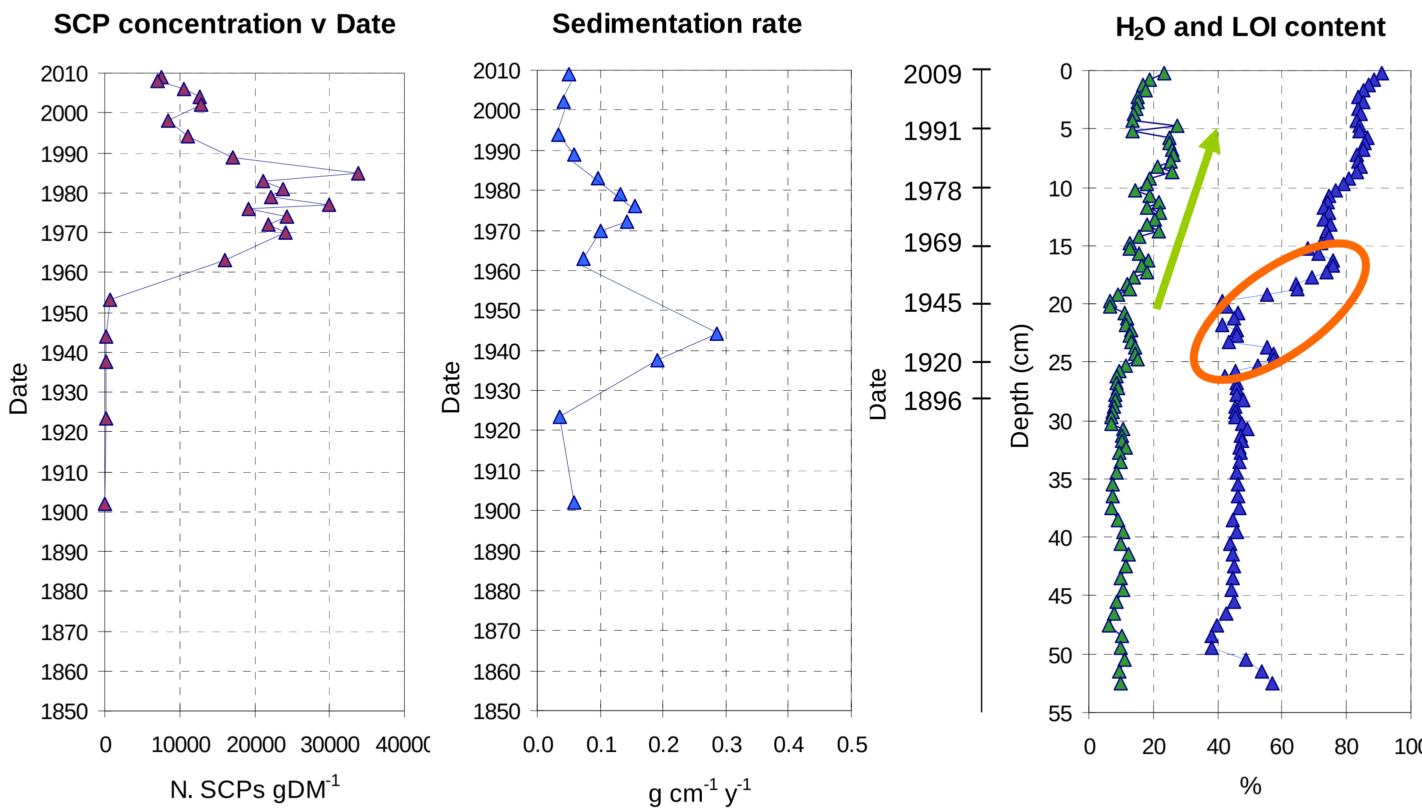
- ✓ **56 cm** long cores collected from the deepest point (Brenzone)
- ✓ dating and preliminary results on geochemistry available



- upper 27 cm of the core corresponding to the last ca. 110 years
- max. SCPs concentration in mid 1980s, followed by a decrease till present (typical for EU lakes)
- increase in sedimentation rate between 1920s and 1940s (building of power plants within the basin of the main inlet?) and secondly between 1960 and mid 1970s (eutrophication)

Riva del Garda, Villino Campi, 8th September 2011

Lake Garda – preliminary results



- very rapid (ca. 20 years) and pronounced increase in water content since the mid 1940s (possibly related to reduced solid transport by the major inlet since the beginning of the intensive hydroelectric exploitation within the river basin).

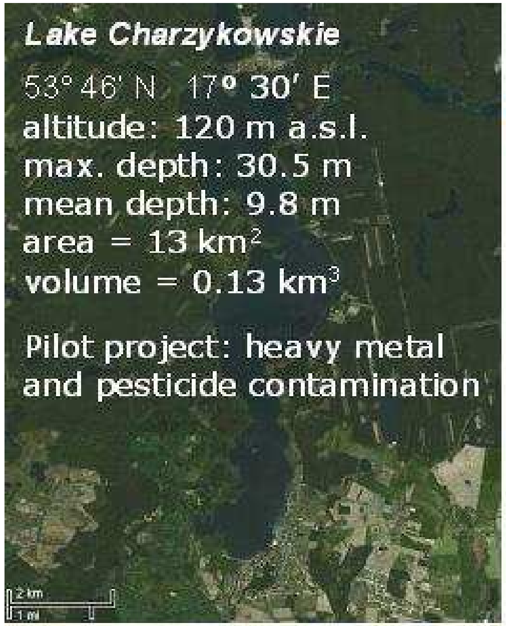
- increasing organic content from mid 1940s to early 1990s (up to 25%)

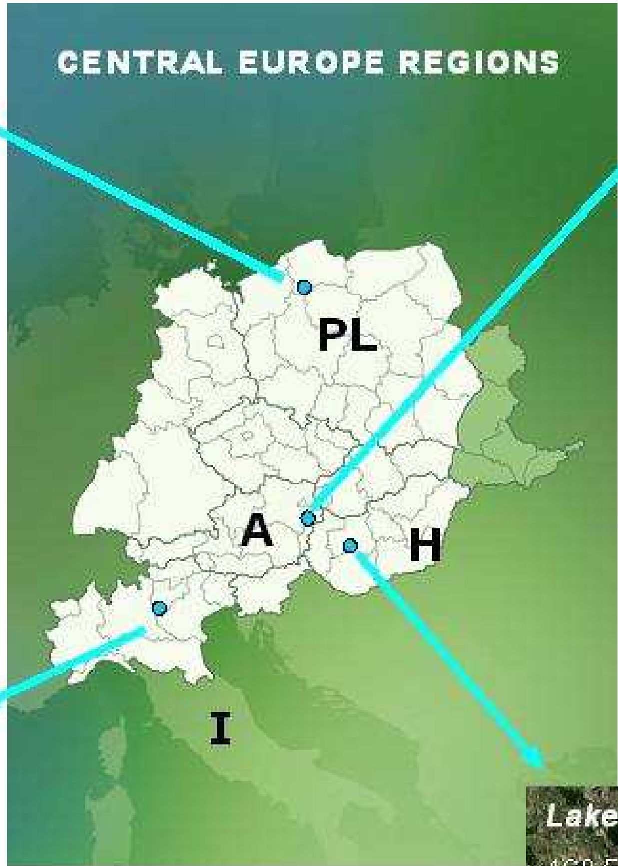
Acknowledgements:

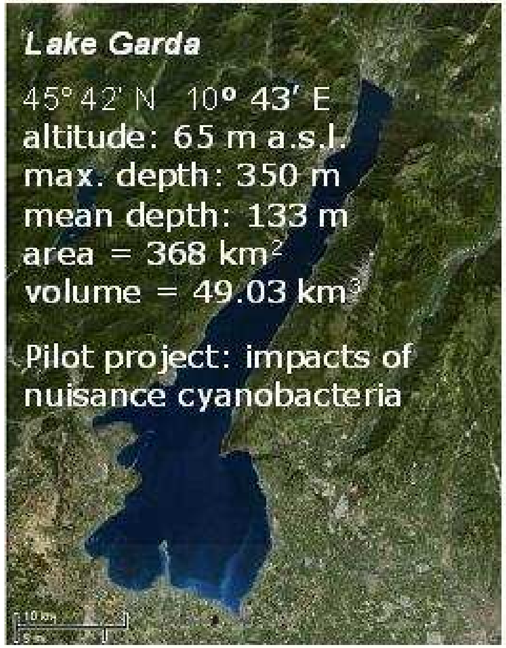
- dr. Neil Rose and dr. Handong Yang, University College London, UK, for radiometric dating and SCPs analyses of Lake Gardamaster core
- Prof. A. Herzig and Mr. R. Haider of Biological Station Illmitz for logistic support and advices during the field work at Lake Neusiedl
- Barbara Novicka and collaborators (IMWM) for logistical support during the field work at Lake Charzykowskie
- András Ács (University of Pannonia) and Janos Korponai (West-Transdanubian District Environmental and Water Authority, Dept. Kis-Balaton, Hungary) for logistical support during the field and lab work at Lake Balaton

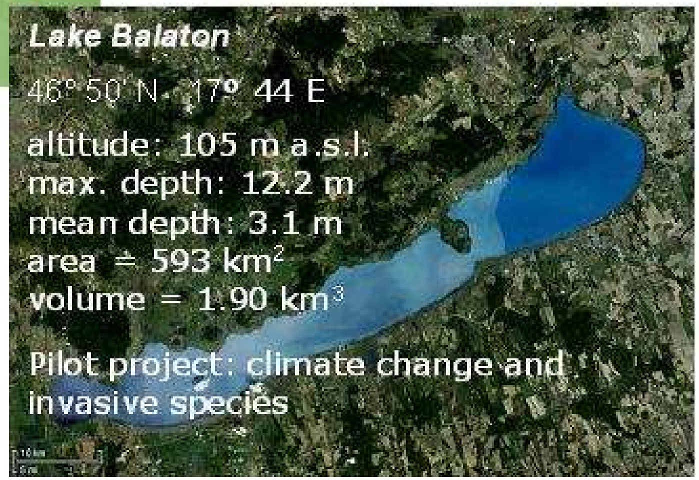
Thank you for the kind attention

The study sites







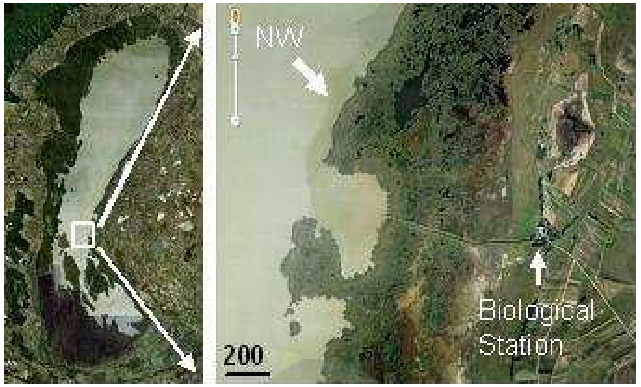


Work in progress

- Short cores retrieved from all the four lakes

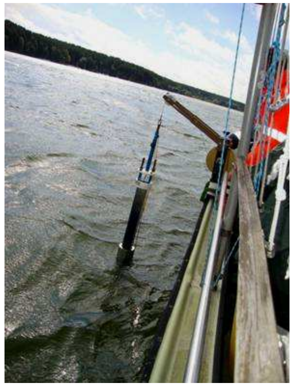
Lake Neusiedl (A)
Master core = 68 cm

68 cm = ca. 140 y



Lake Charzykowskie (PL)
m.c. = 87 cm

81 cm = ca. 160 y



Lake Balaton (HU)
m. c. = 64 cm

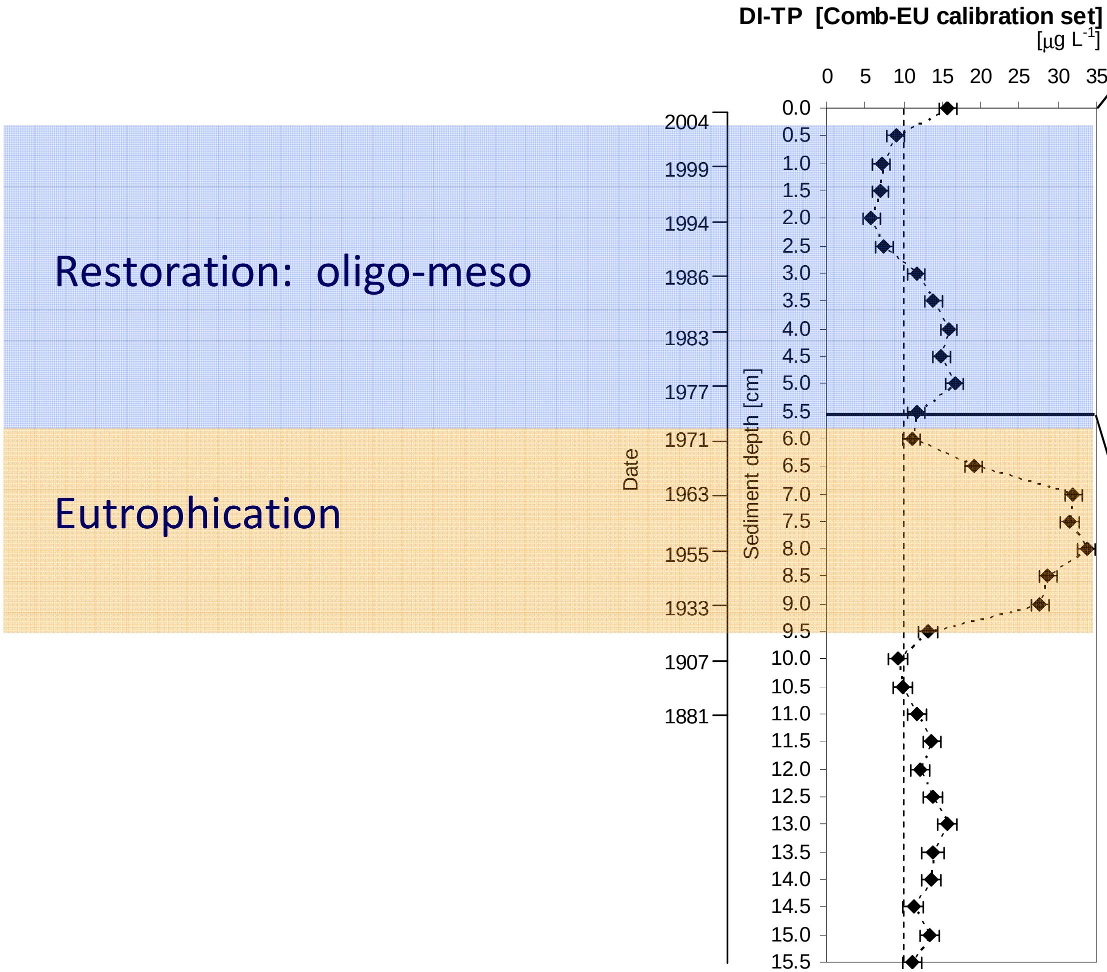
11 cm = ca. 90y

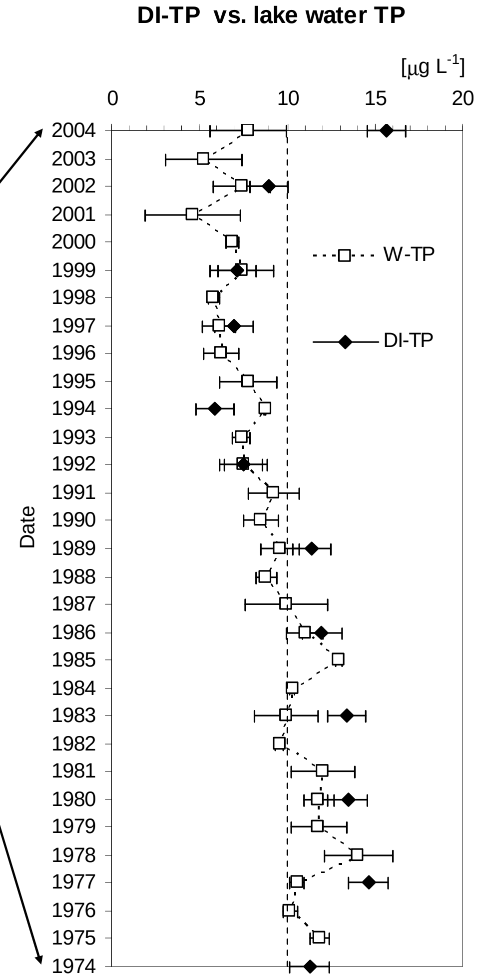


Validation of reconstruction

Despite past-oriented, palaeolimnology strongly depends on the knowledge of **present relationships** between environment and organisms, which is necessary both

- to infer past ecological conditions
- to validate environmental reconstruction





$R^2 = 0.5$ $p<0.05$