Regime shift triggered by an extreme climatic event in an oligotrophic mountain lake

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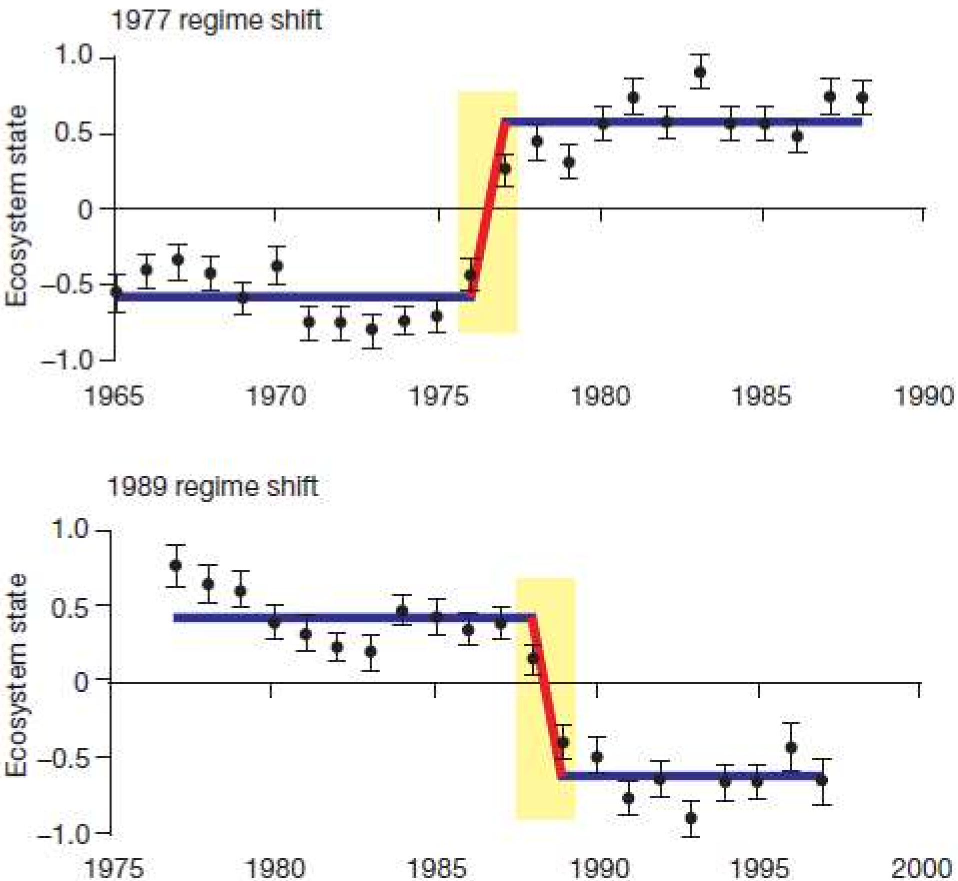
Ecological regime shifts

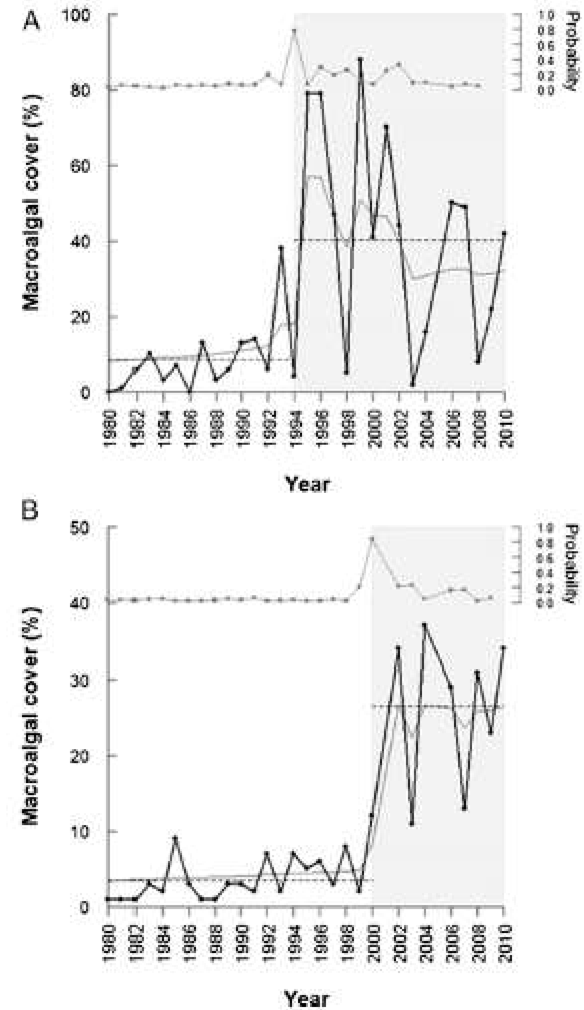
Sudden changes in ecosystem status caused by passing a threshold where core ecosystem functions, structures and processes are fundamentally changed (Andersen et al., 2009 TREE).

North Pacific Ocean



Scheffer et al., 2001 Nature
(mod. from Hare & Mantua, 2000, Prog. Oceanogr.)

Svalbard fjords



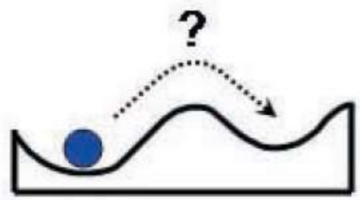
Kortsch et al., 2013 PNAS

Climate-induced regime shifts

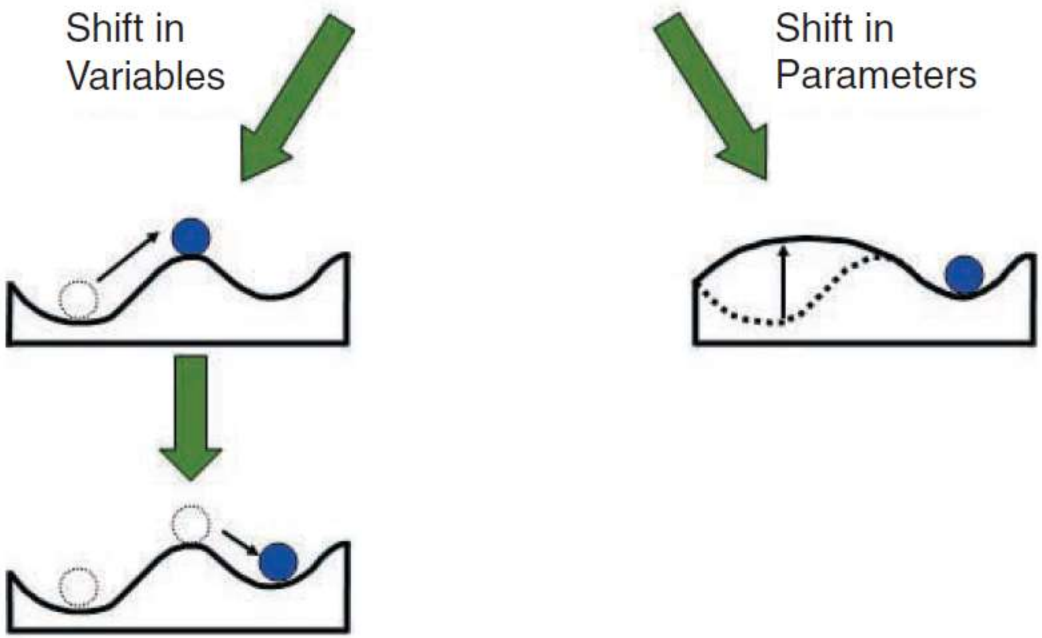
Climate change

Heatwaves
Droughts
Floods
.....

Extreme climatic events



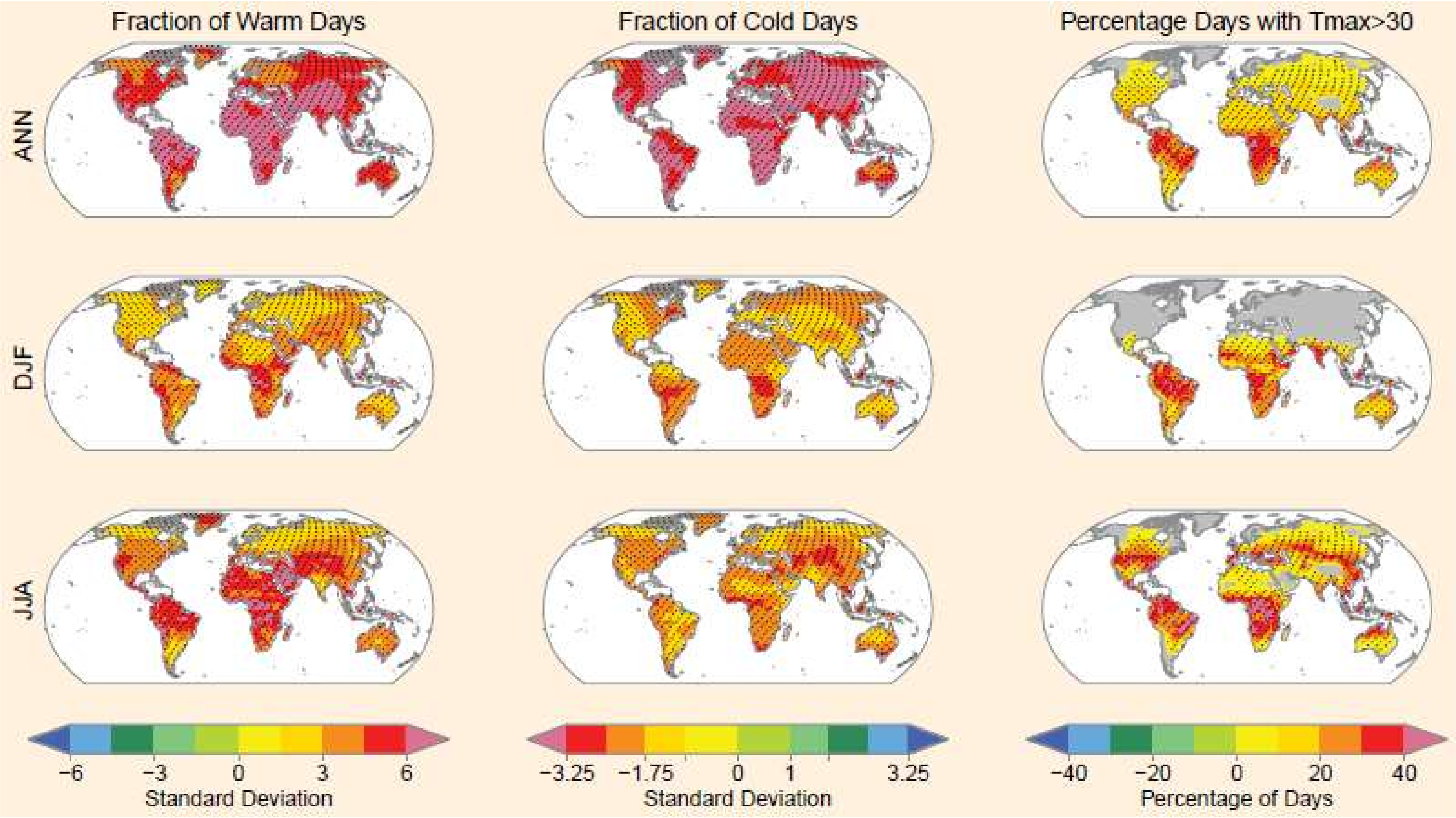
Average climatic conditions



Beisner et al., 2003 Front. Ecol. Environ.

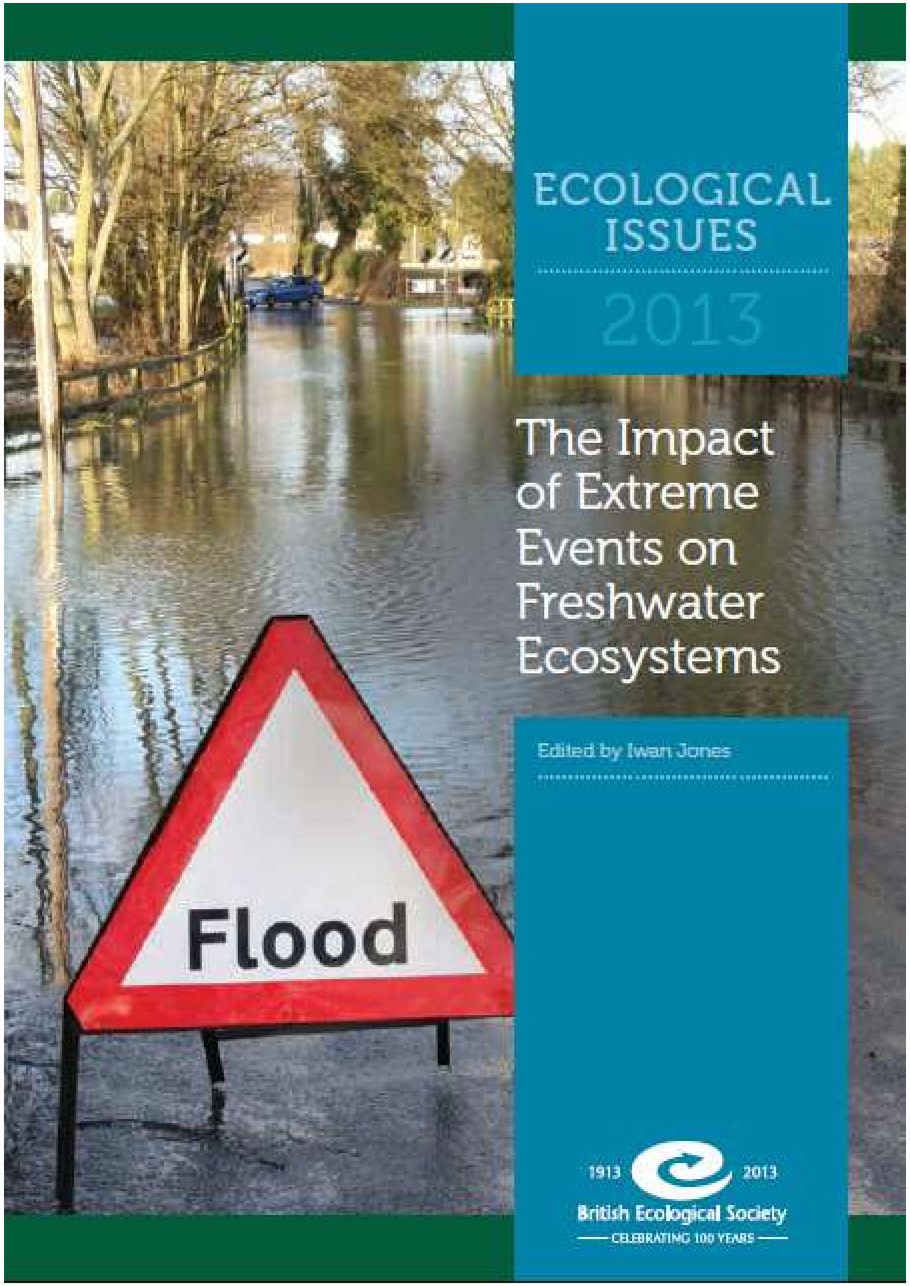
Climatic extremes - projections

2081-2100



Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. IPCC 2012

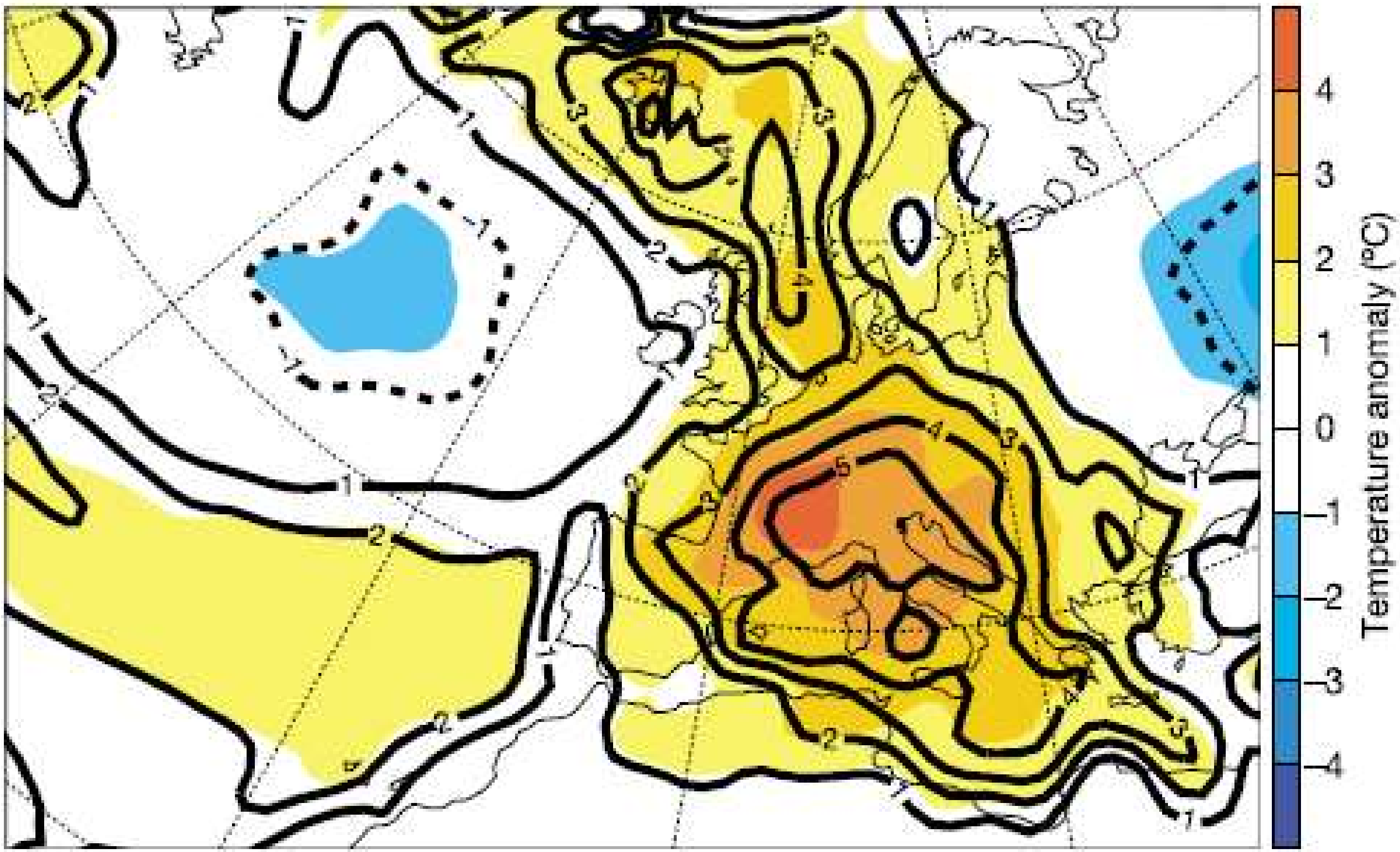
Impacts of climatic extremes on freshwater ecosystems



- Water temperature/ Heat balance
- Duration/stability of thermal stratification
- Water level
- Ice phenology
- Length of the growing season
- …

The 2003 European summer heatwave

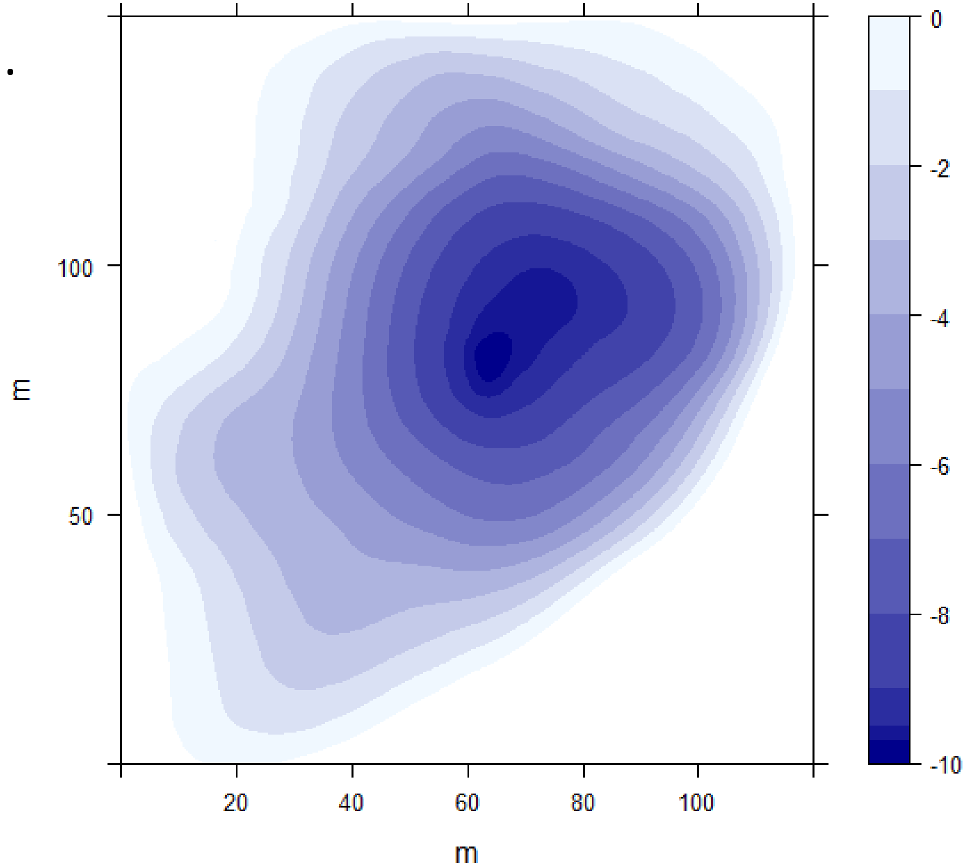
2003 summer T anomaly with respect to the 1961-1990 mean



Schär et al., 2004 Nature

Lake Scuro Parmense

- Altitude: 1527 m a.s.l.
- Surface: 1.2 ha
- Zmax: 9.4 m
- Volume: 44058 m^3
- Watershed area: 17 ha
- Naturally fishless, sporadic trout introduction



- Lithology: sandstone
- Vegetation: beech
- Dimictic lake
- Ice-covered from Nov to May
- Oligotrophic

Surveys: 1986, 1989, 1990-1994, 1998, 2003, 2007-2009, 2012

Long-term data

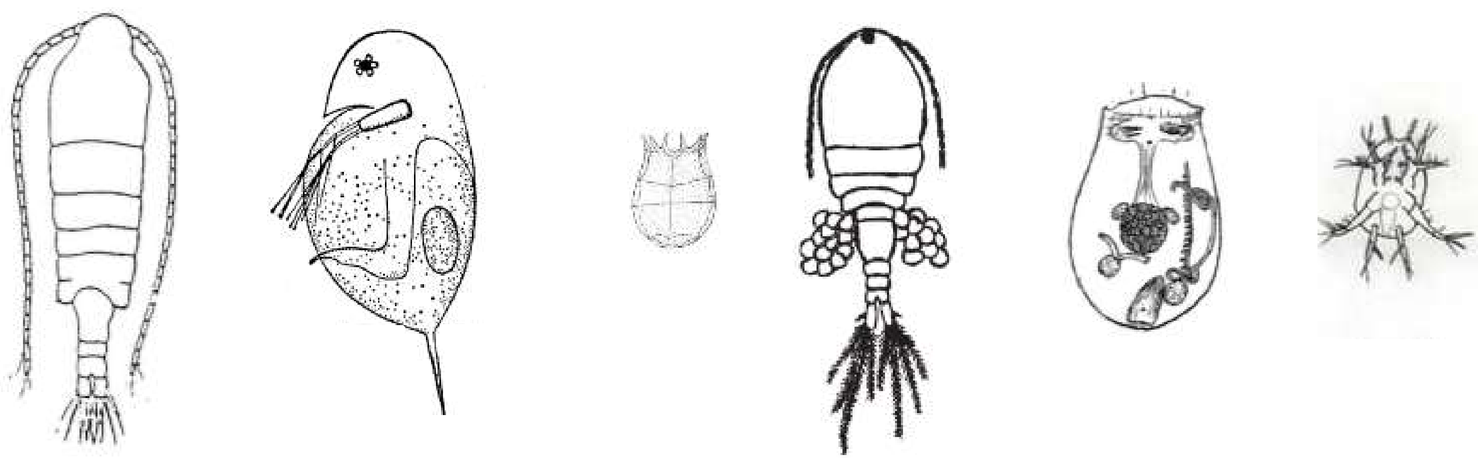
Hydrochemistry

Zmax, SDT, Water T at 1-m intervals, pH, EC, TA, DO, SRP, DRSi, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Chl-*a*

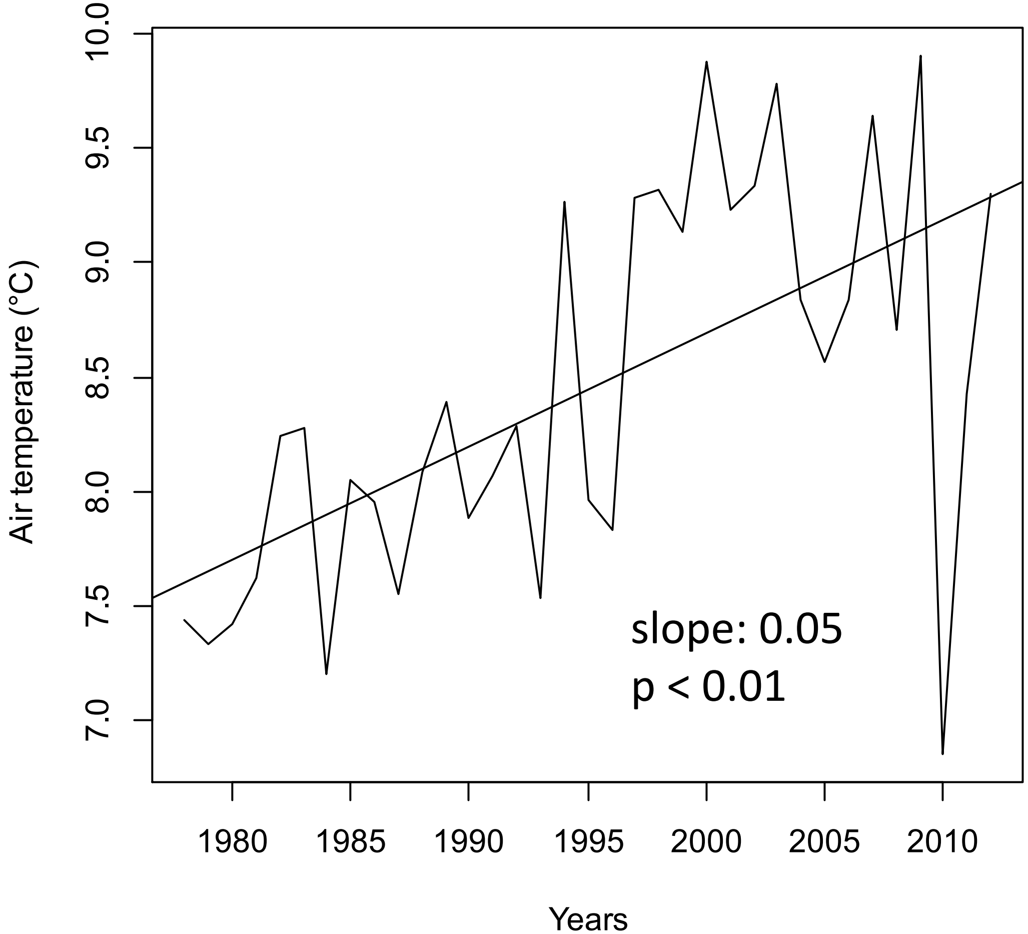
Zooplankton

Zooplankton density and composition – mostly species level

Life-history traits (body size, egg type and number, life stages, sex ratio) for selected crustacean species



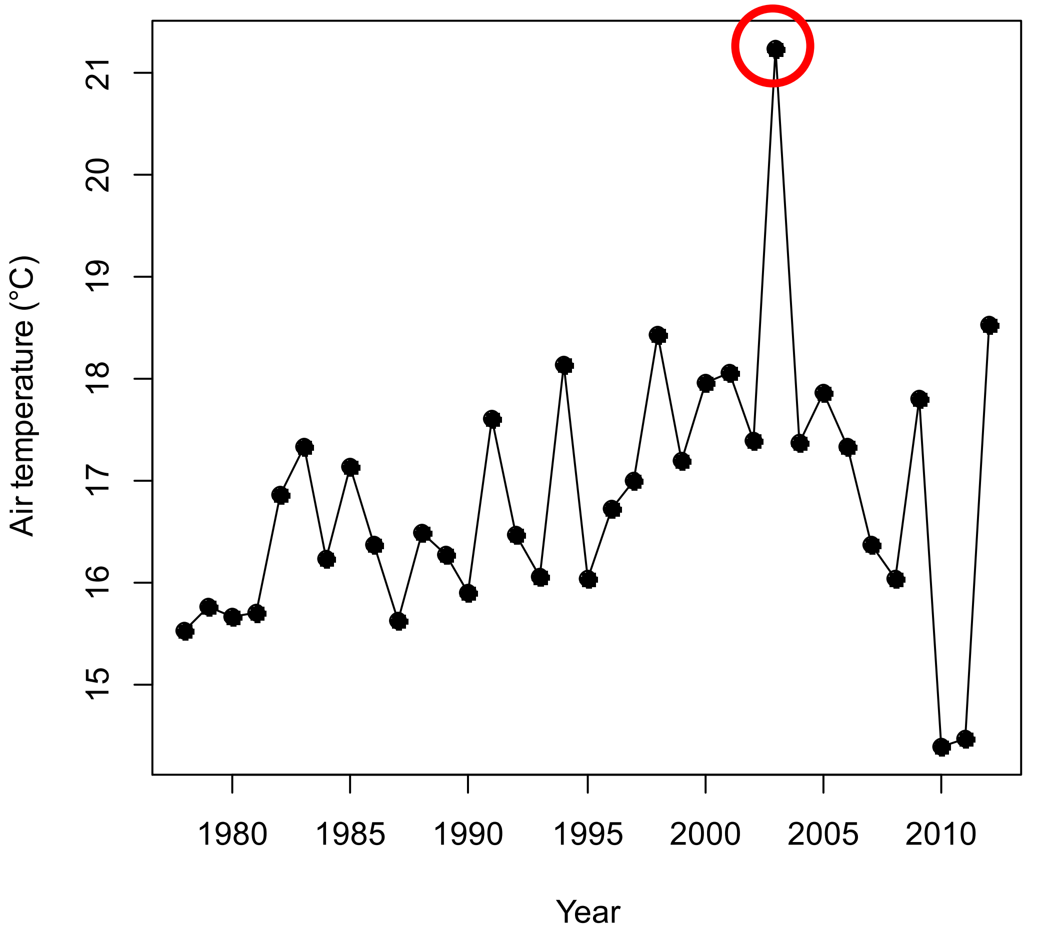
Annual Mean Air Temperature 1978 – 2012



Weather station: Passo della Cisa (1040 m a.s.l., ~ 30 km from site)

Source: NOAA website

Summer Mean Air Temperature 1978 – 2012



Weather station: Passo della Cisa (1040 m a.s.l., ~ 30 km from site)

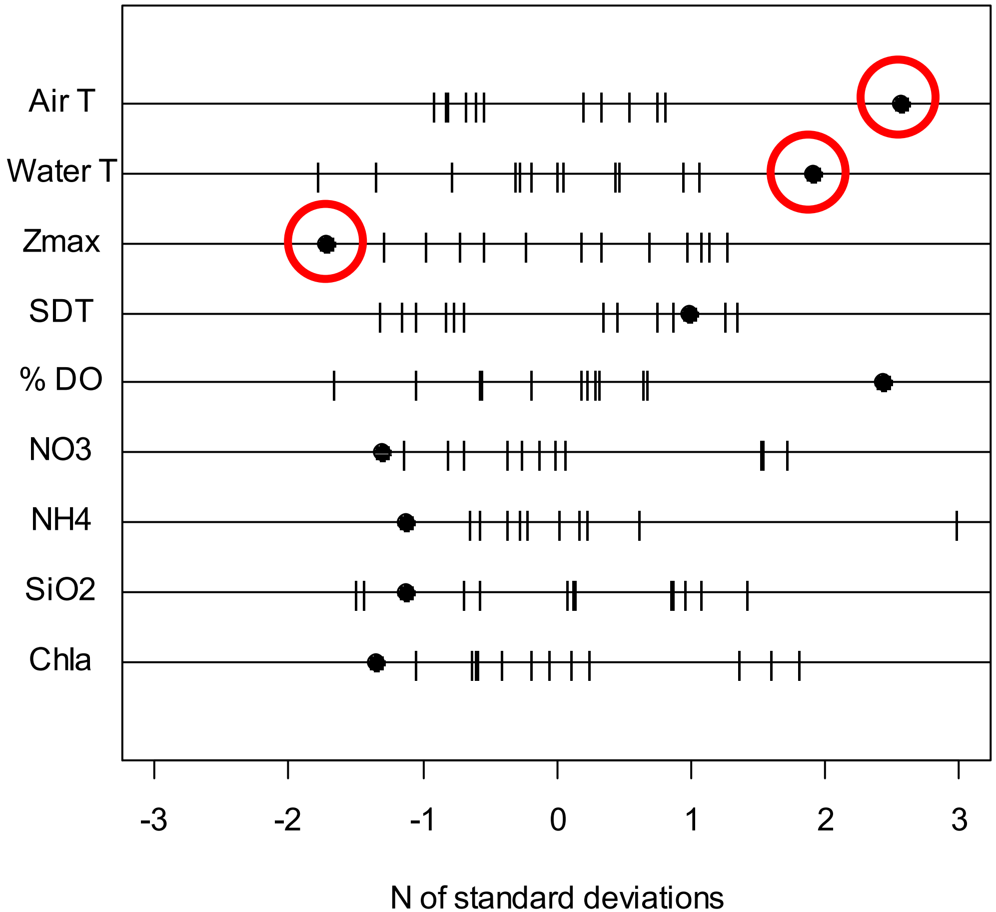
Source: NOAA website

Summer 2003 at Lake Scuro Parmense

Lake bottom completely covered by a charophyte (*Nitella gracilis*)

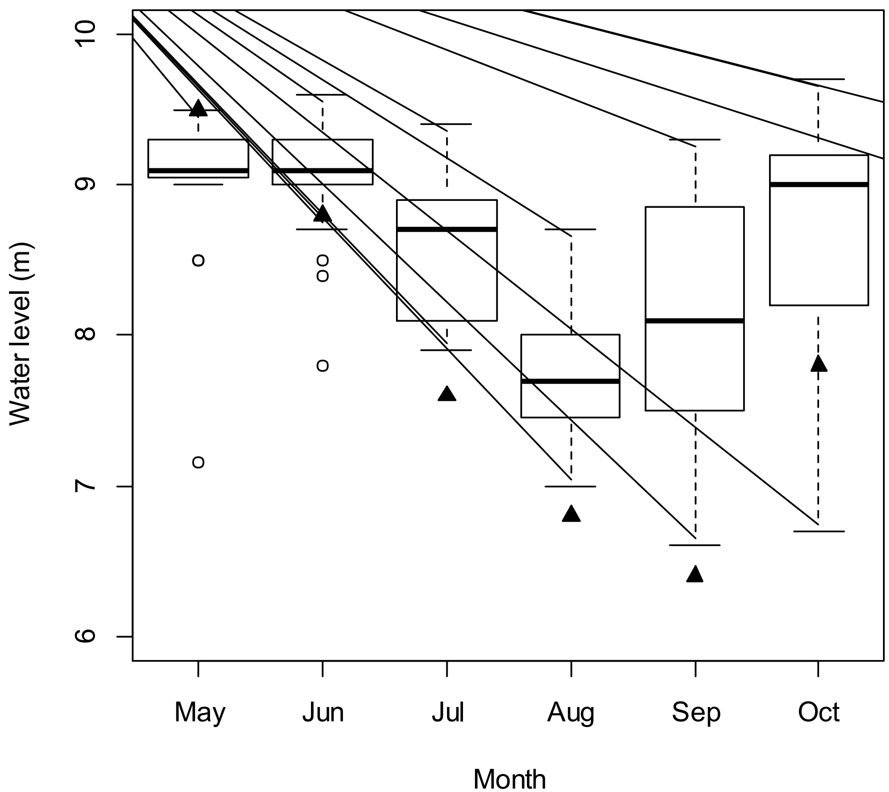
Heatwave impact on physical lake characteristics

Standardized summer means

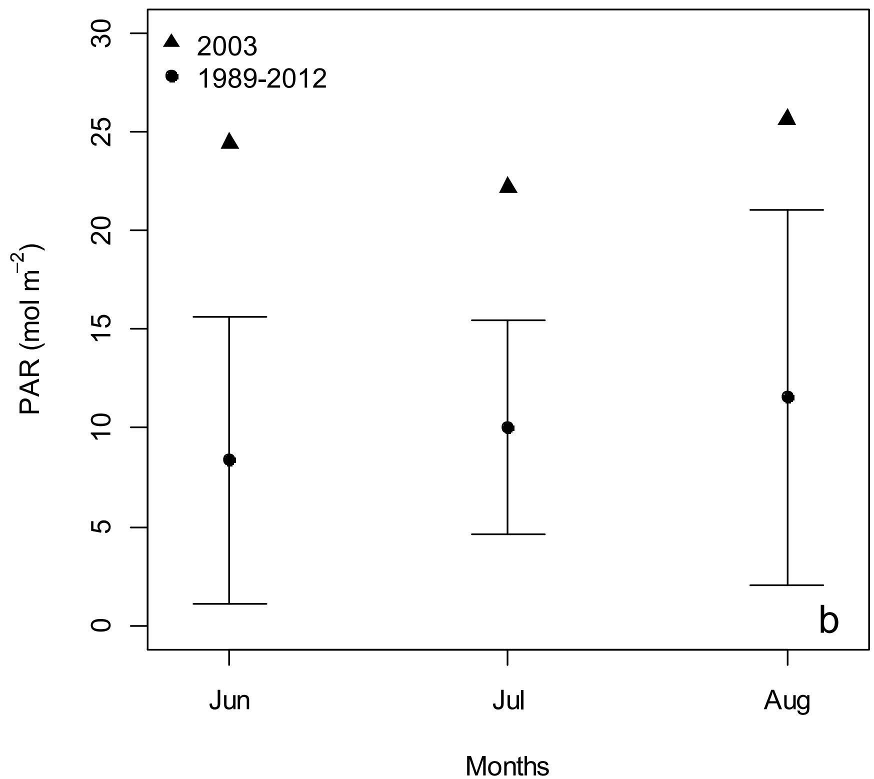


Heatwave impact on physical lake characteristics

Water level

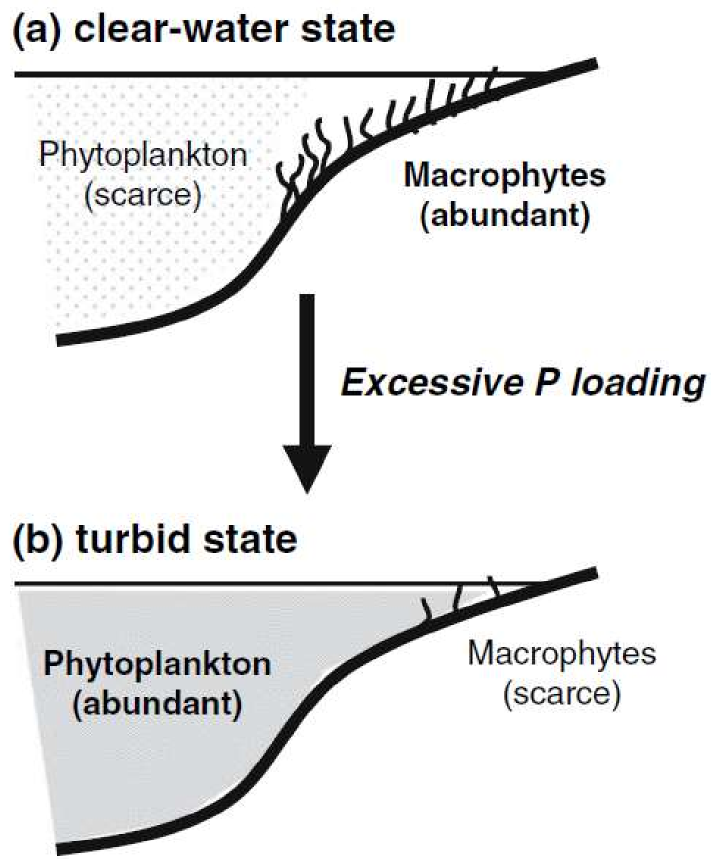


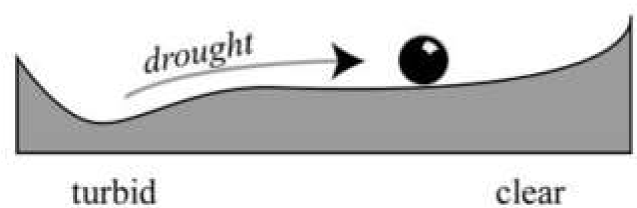
PAR at lake bottom



Modelling vegetation response to changes in water level

Regime shifts in shallow lakes





Scheffer & Jeppesen, 2007 Ecosystems

Modelling vegetation response to changes in water level

$$V = \frac{h_E^p}{E^p + h_E^p}$$

$$E = E_0 \times \frac{h_v}{h_v + V}$$

E_0: vertical light attenuation with no macrophytes

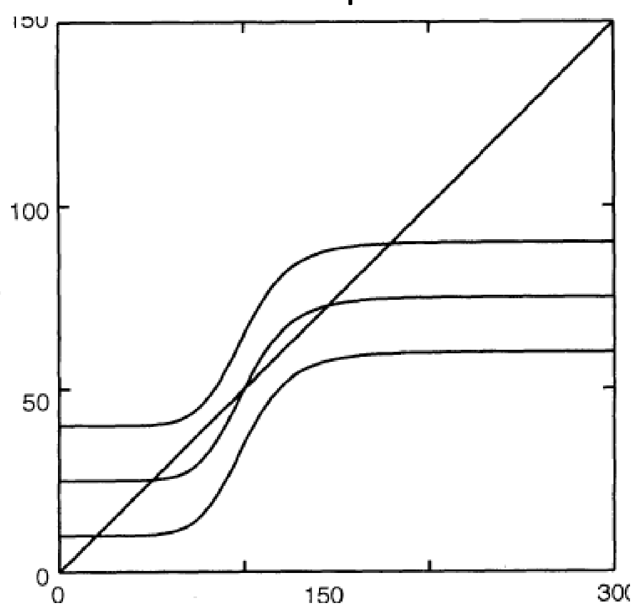
h_V: vegetation % cover causing a 50% decrease in light attenuation

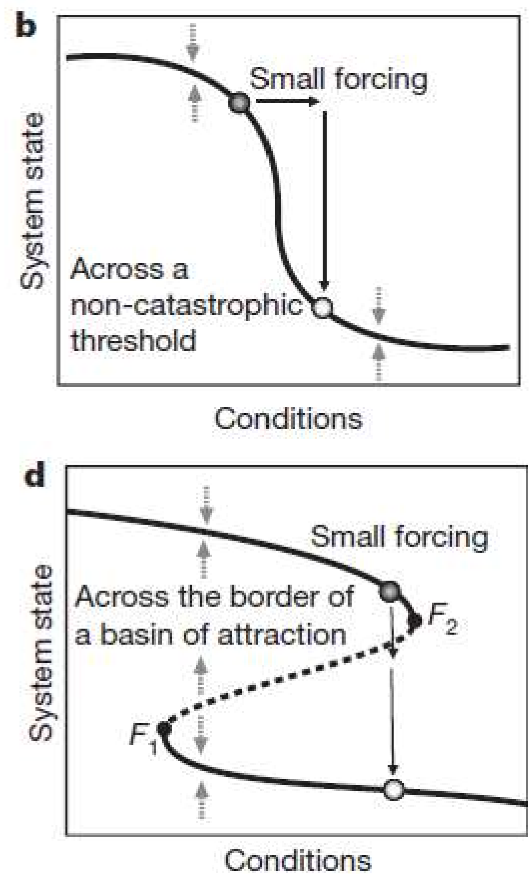
h_E: light attenuation at which vegetation colonizes half lake bottom

p: shape of vegetation response to changes in turbidity/water level

Scheffer, 1998

Phase-plane





Scheffer et al., 2009 Nature

Modelling vegetation response to changes in water level

$$V = \frac{h_E^p}{E^p + h_E^p}$$

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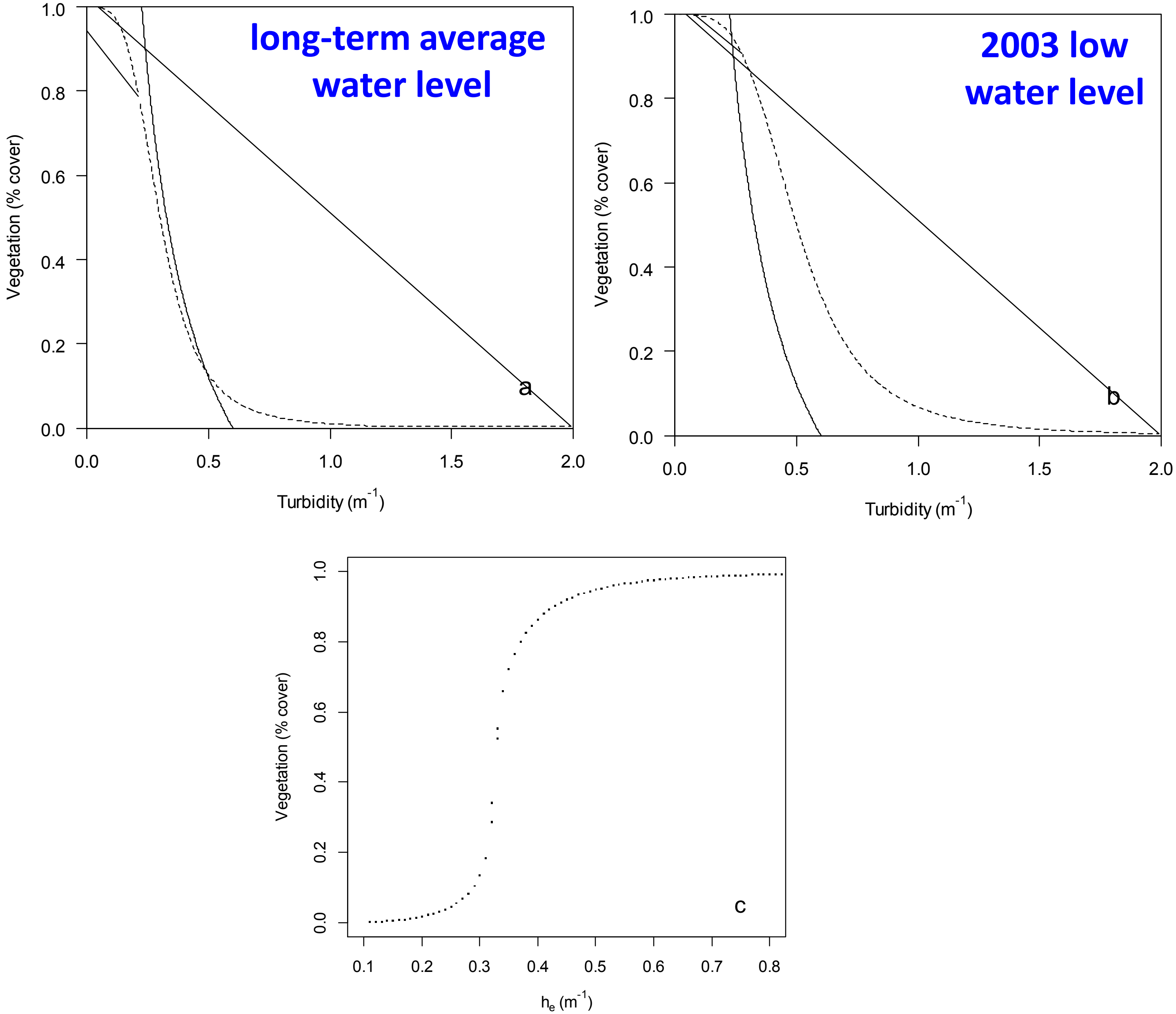
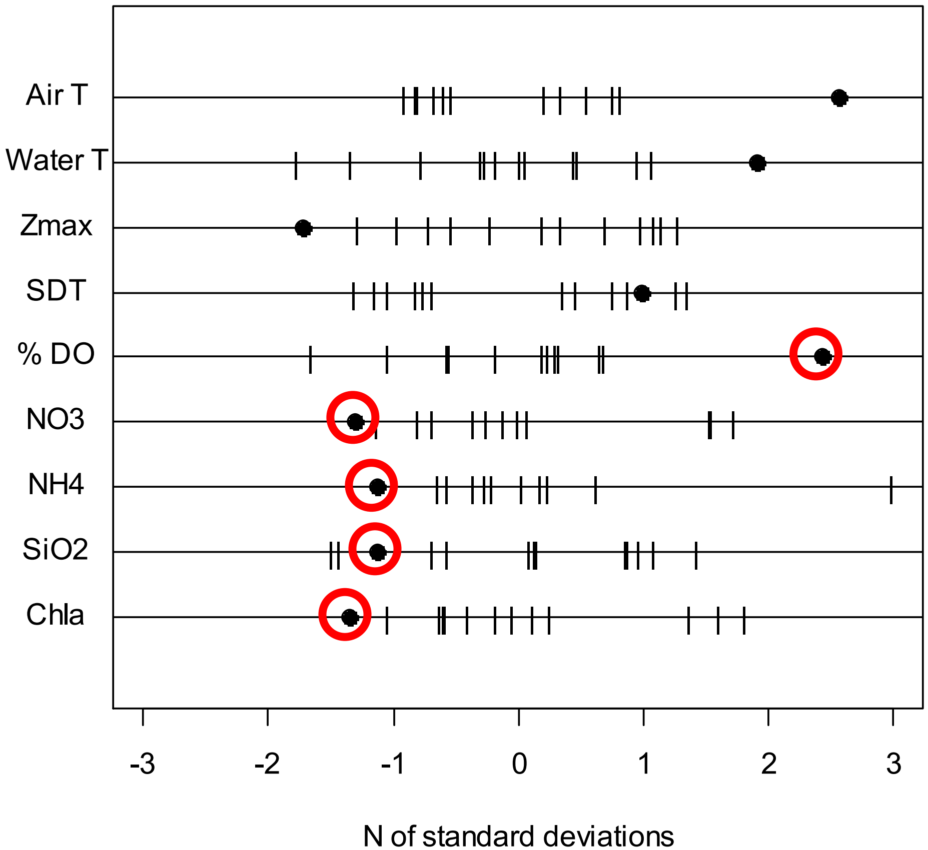
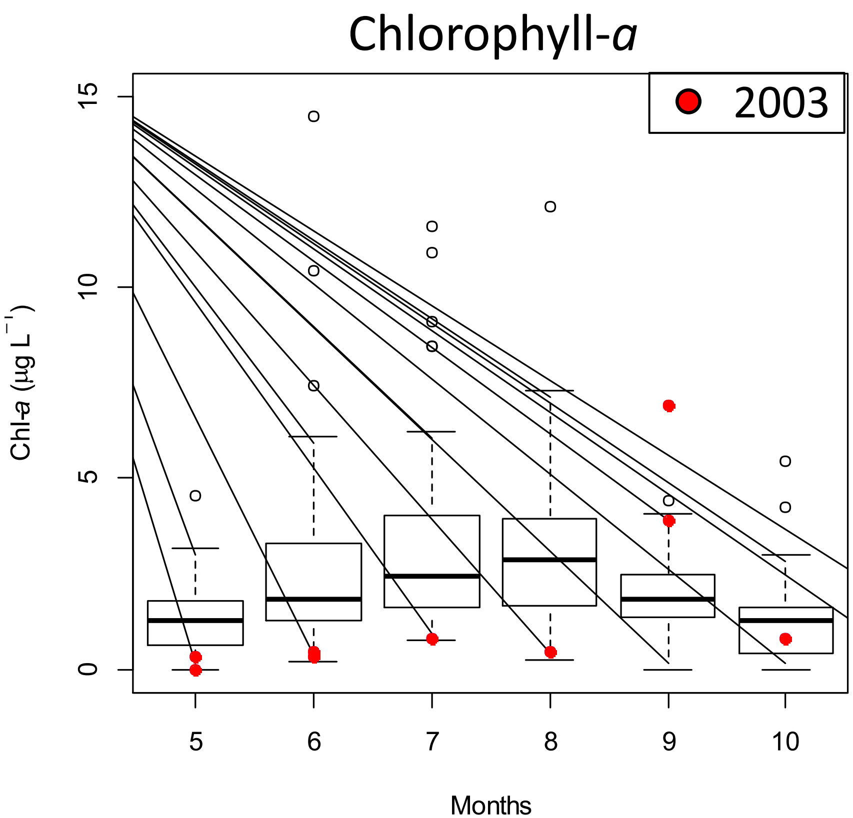
Scheffer model nullclines



Implications of macrophyte take-over





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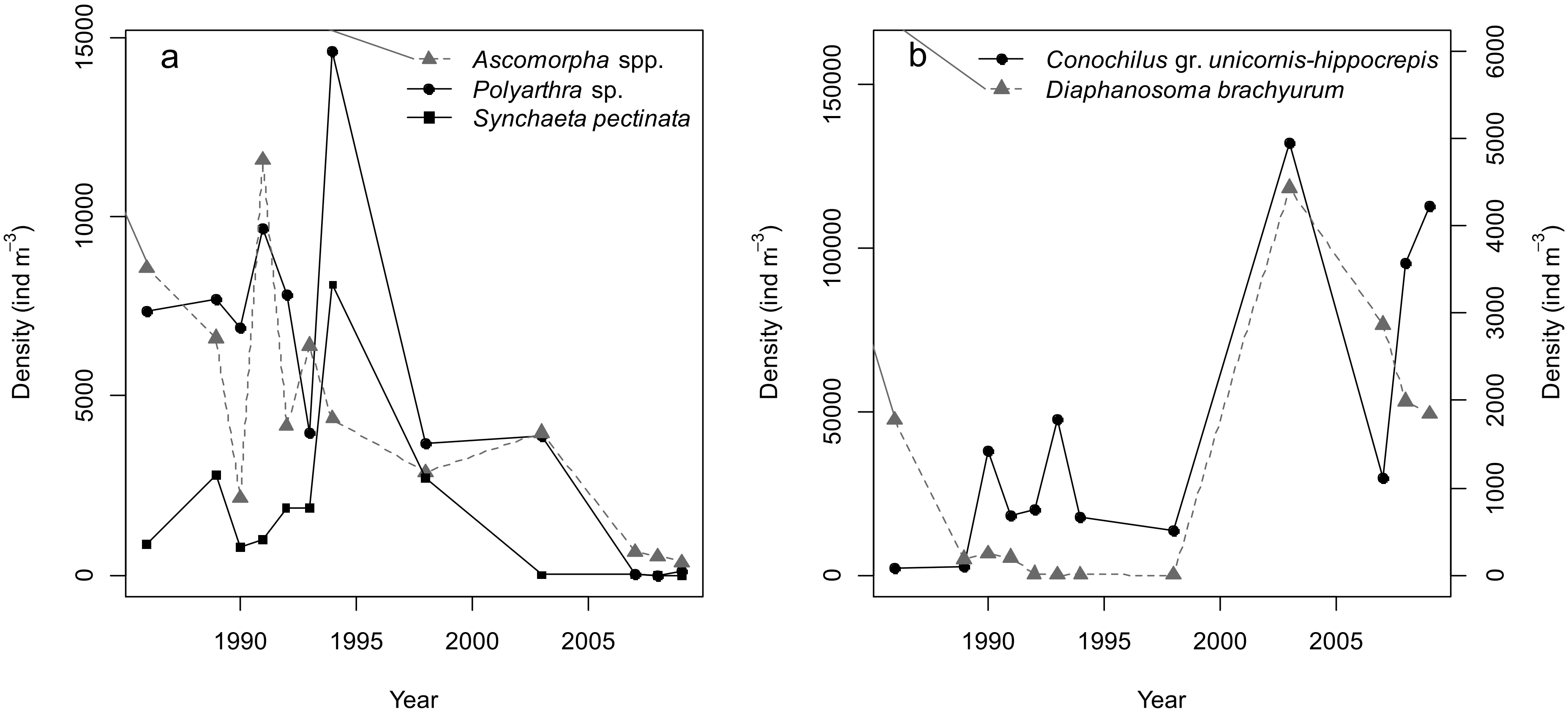
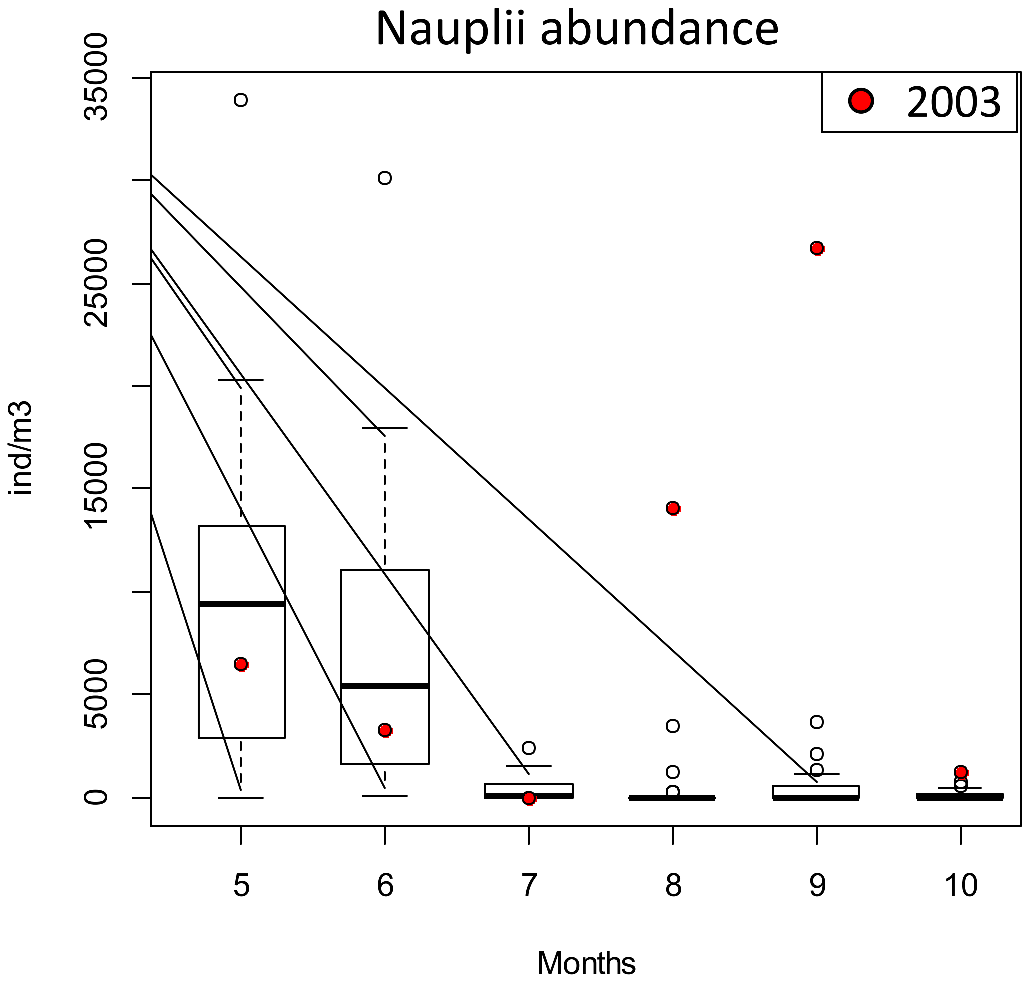


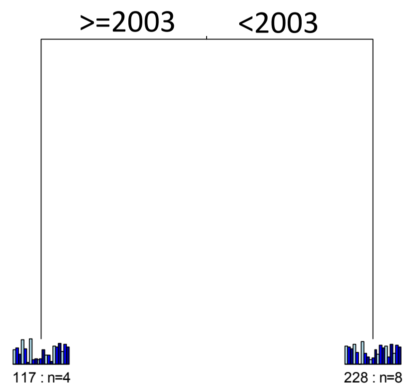
Eudiaptomus intermedius

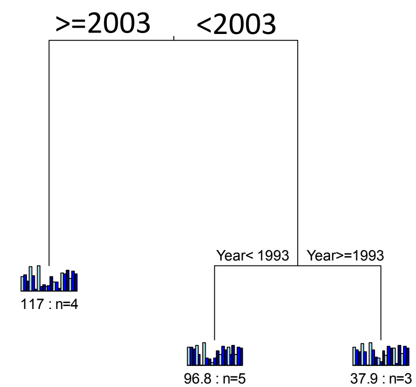


Two generations in 2003

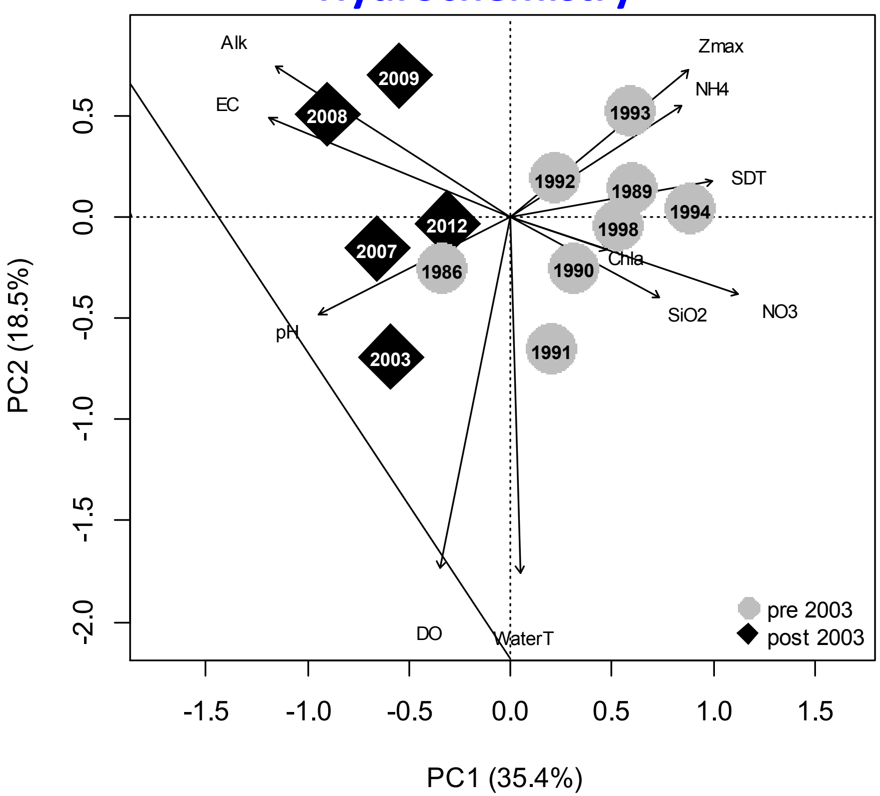
Implications of macrophyte take-over

Chronological clustering (via MRT) of hydrochemical and zooplankton time-series

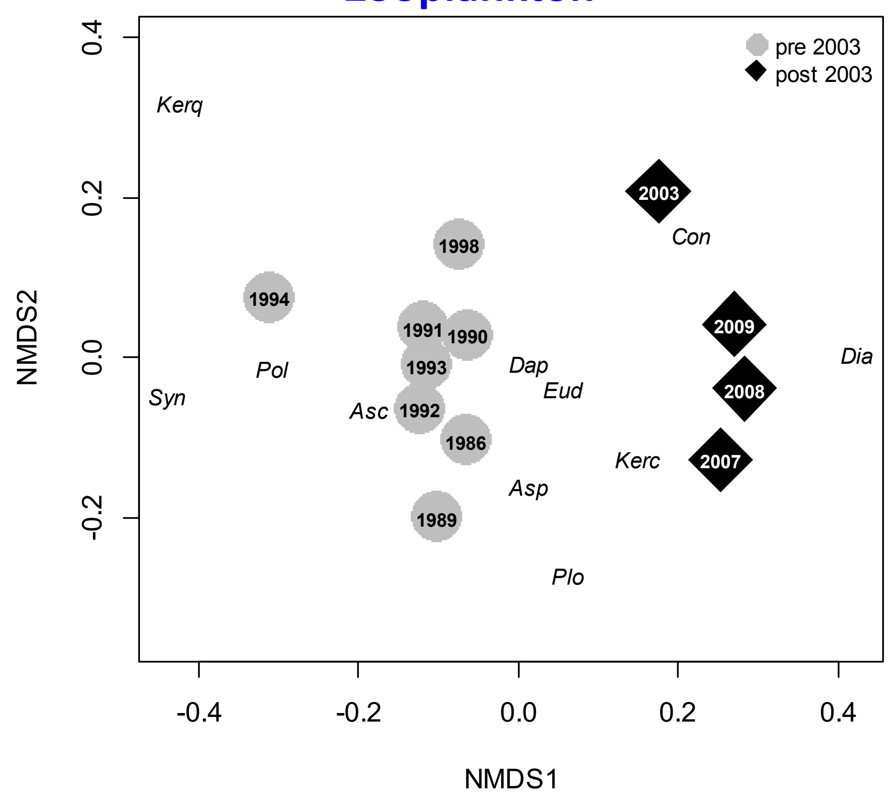




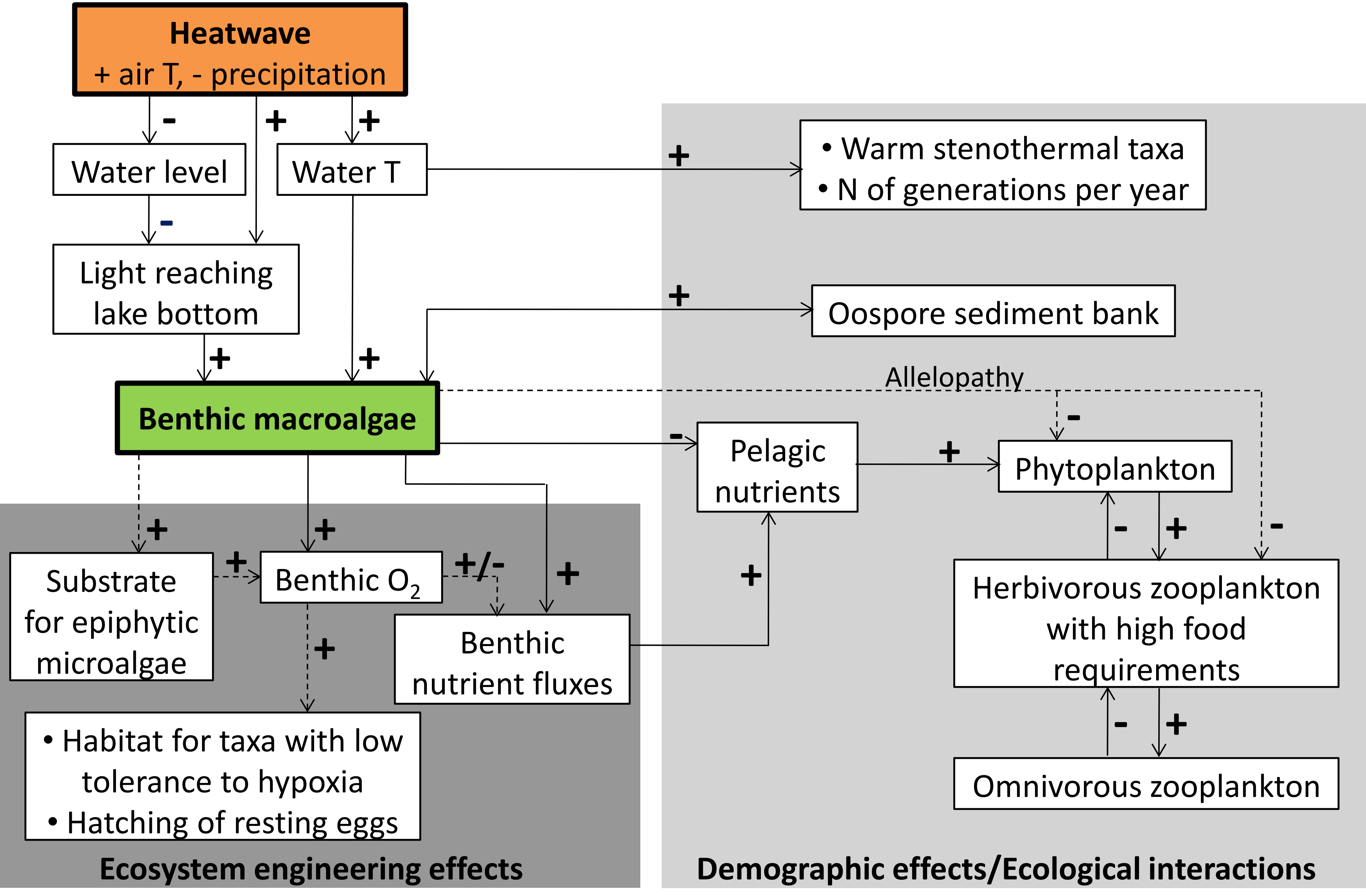
Hydrochemistry



Zooplankton

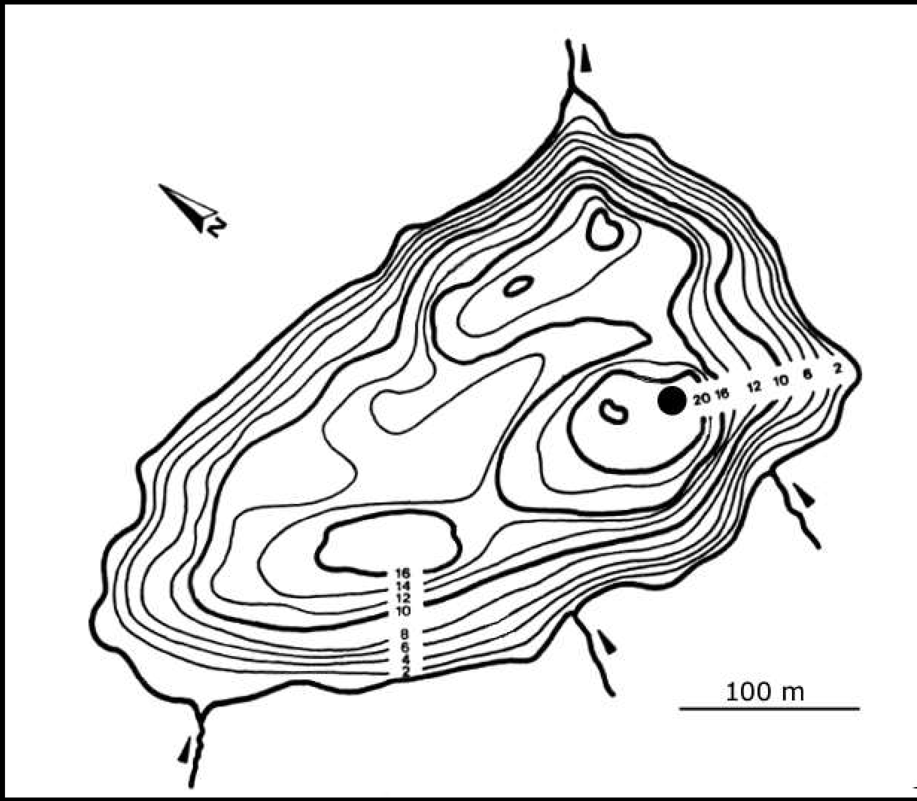


Extreme climatic events may trigger regime shifts in lakes that propagate across multiple trophic levels



Lago Santo Parmense

Altitudine 1507 m s.l.m.
Z_{max} 22.5 m



Ecosystems (2006) 9: 1–56
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ECOSYSTEMS

Detecting Stress at the Whole-Ecosystem Level: The Case of a Mountain Lake (Lake Santo, Italy)

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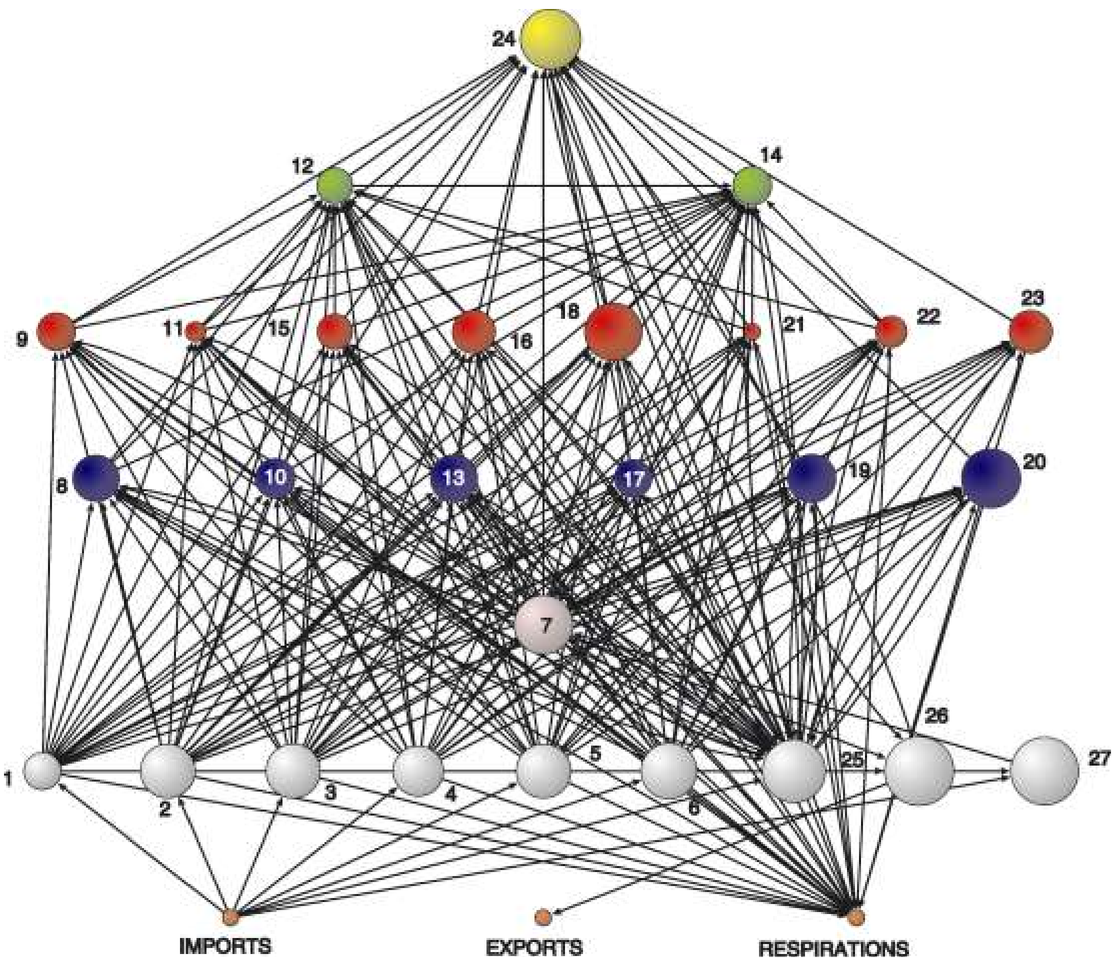
Abstract

Detecting the early signs of stress is imperative for the conservation of natural ecosystems. They may, however, go unrecognized because ecosystems, when disturbed, may act as sinks that absorb the external impact without showing any evident changes. This seems to be the case for Lake Santo, a small water body located in a mountainous area of northern Italy. Tourism activity in this area began to develop in the early 1970s and grew continuously over the following 20 years. This activity caused a continually increasing nutrient load into the waters, but surprisingly the lake has remained oligo-mesotrophic, as it was before human pressure became a stressor to the lake. To anticipate possible severe damage to the ecosystem, we searched for early signs of stress by carrying out a retrospective analysis based on a whole-ecosystem approach using trophic flow networks. Ecosystem properties of the lake as calculated from network analysis for the disturbed (year 1991) and unimpacted (year 1973) configurations were compared, with the support of sensitivity analysis and statistical tests. We found evidence that in the period 1970–90 nutrient enrichment did change the course of normal development as the observed increase in system throughput was accompanied by a drop in the level of mutual organization of flows, which instead would be expected to increase during the natural progression of the ecosystem. The scenario that emerged from the comparison of system-level indices, cycling activity, trophic structure, and trophic efficiency indicates that the ecosystem has been subjected to stress. In particular, the type of disturbance corresponds to a quantitative definition of eutrophication.

Key words: ecosystem development; lake ecosystem; network analysis; nutrient cycling; stressed ecosystem; system-level trends; trophic analysis.

Network analysis
Lago Santo Parmense, summer 1991



1 *Flagellatae*; 2 *Clorophyceae*; 3 *Crisophyceae*; 4 *Dinophyceae*; 5 *Criptophyceae*; 6 *Diatomeae-Cianophyceae*; 7 Living POC; 8 *Keratella quadrata*; 9 *Keratella cochlearis*; 10 *Kellicottia longispina*; 11 *Ascomorpha ecaudis*; 12 *Synchaeta* sp.+*Ploesoma* sp., 13 *Polyarthra* spp.;14 *Asplanchna priodonta*, 15 *Filinia terminalis*, 16 *Conochilus* spp., 17 Other Rotifers, 18 *Daphnia longispina*, 19 *Bosmina longirostris*, 20 *Eudiaptomus intermedius*, 21 Nauplii, 22 Copepodites, 23 Other Copepods, 24 Fish, 25 WPOC, 26 BPOC, 27 DOC.