Cyanobacteria and their toxins: ecological and health risks

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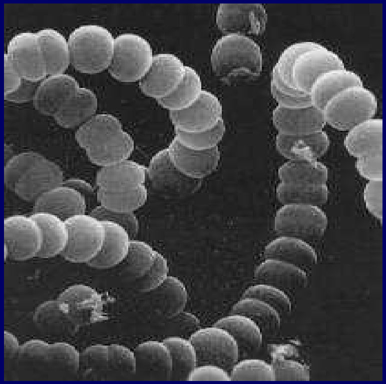
www.cyanobacteria.net

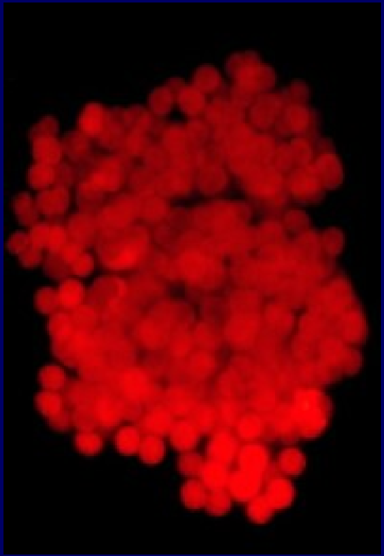
Research centre for toxic compounds in the environment

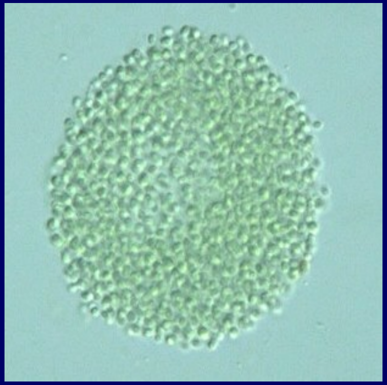
Blue green algae
(CYANOBACTERIA, CYANOPHYTA)

- photosynthetic prokaryota
  - live at various biotops (**water**, soil, ice, rocks, lichens …)

- cca 3 x 10^9 years old
- formation of the oxygen atmosphere







Cyanobacteria - current problem

HUMAN ACTIVITIES
(agriculture, waste waters...)

→

EU/TROPHICATION
(=increased concentration of **nutrients**)

↓

CYANOBACTERIAL MASS DEVELOPMENT




Cyanobacterial water blooms – global problem

Upper Saranac River, USA

Bedetti Lake, Argentina

Neuse River, USA

Baltic sea, Europe

Nové Mlýny, Czech Rep.

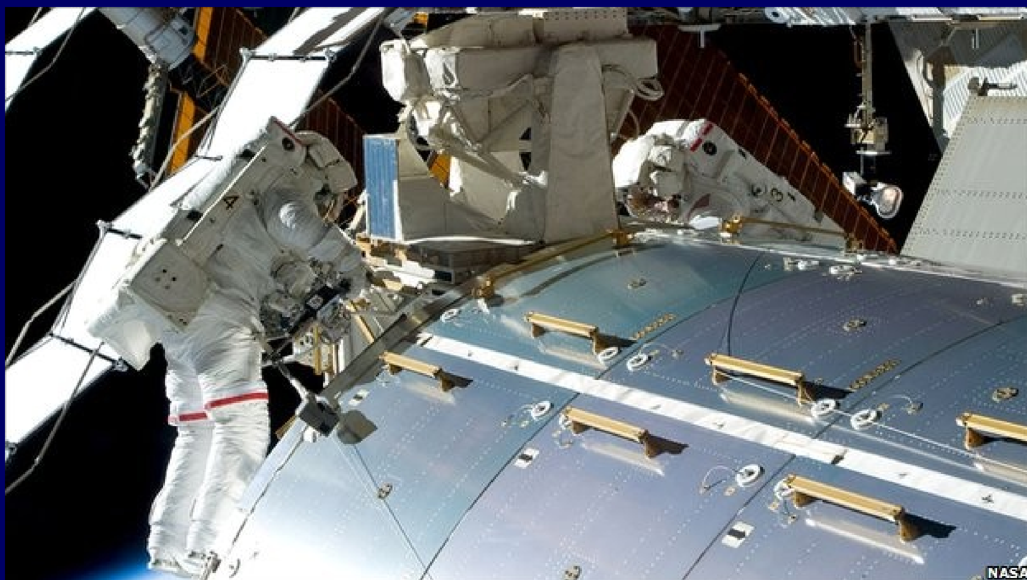
Yellow sea, China

Lake Mokoan, Australia

South Africa

Cyanos in space

Space colonization, oxygen, fuel and biomass production, nutrient acquisition, and feedstock provisions.

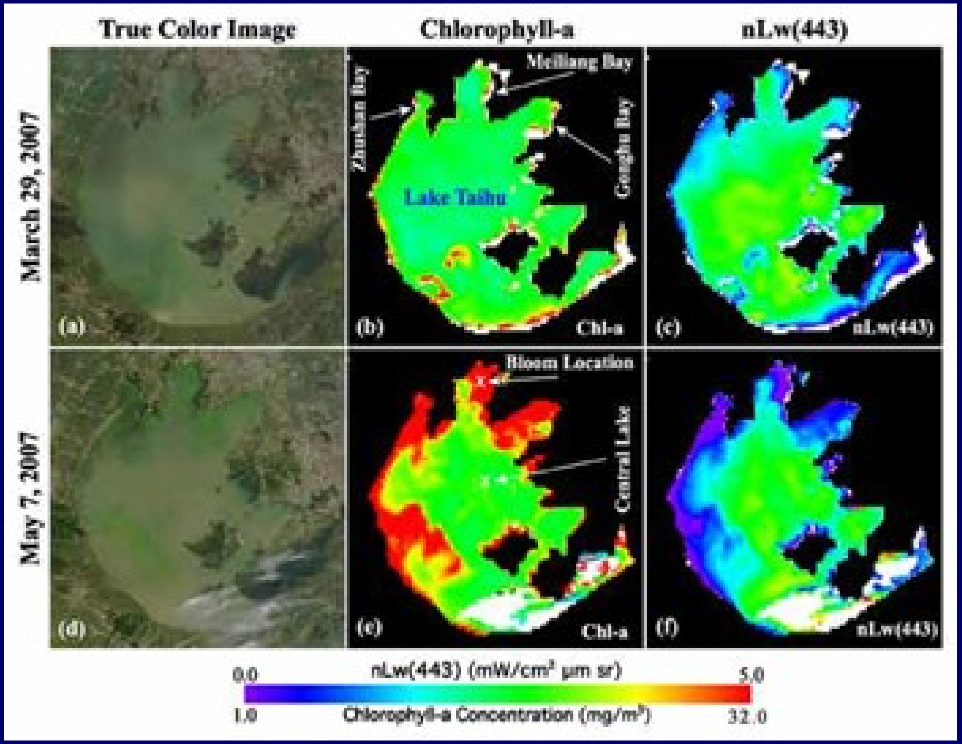


Astronauts retrieve cyanobacteria samples from the outside of the ISS

Chamber used for simulating conditions on the martian surface.

Cyanos from space

Cyanobacterial bloom in Lake Erie (satellite image, Sept. 27 2011)

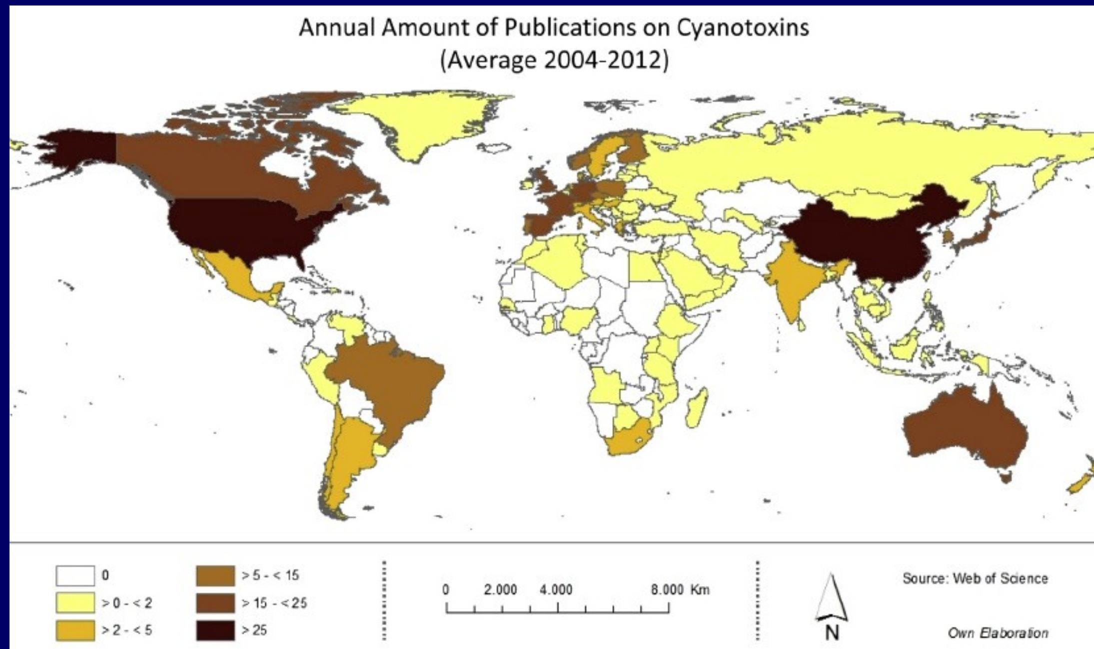


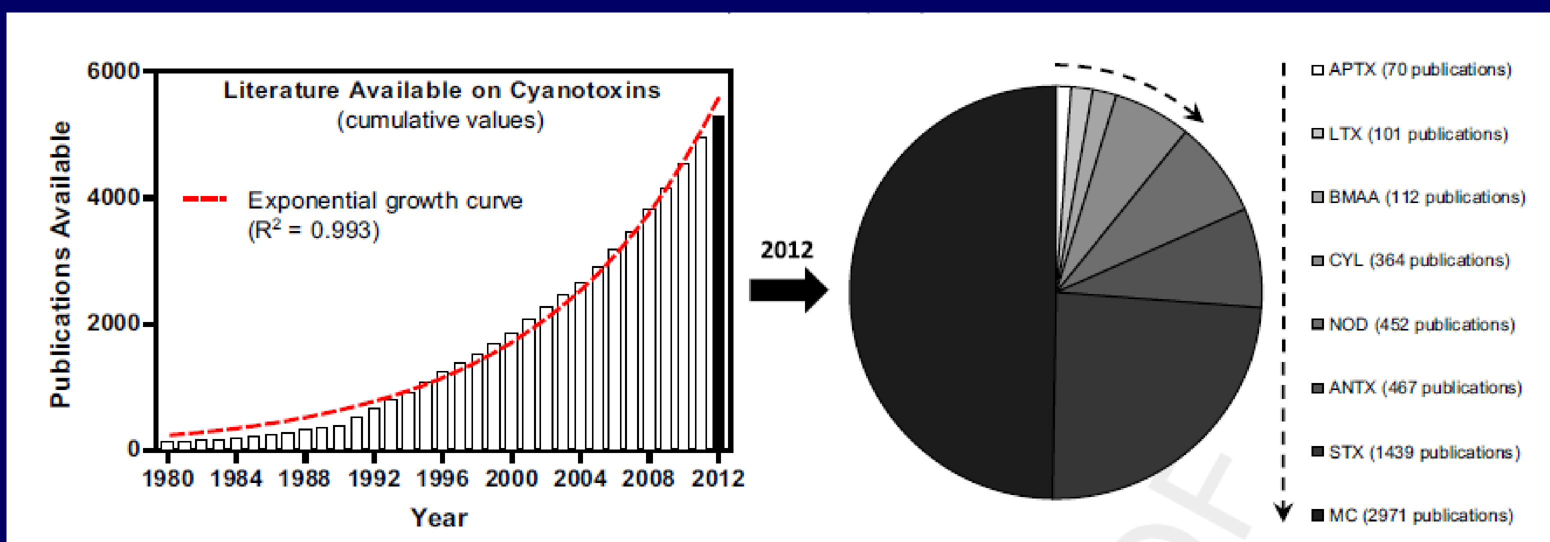
Satellite sensing of harmful algal blooms in Lake Taihu, China.

The Great Lakes over Europe

Research on cyanotoxins

Merel et.al (2013) *Toxicon* 76, 118-131

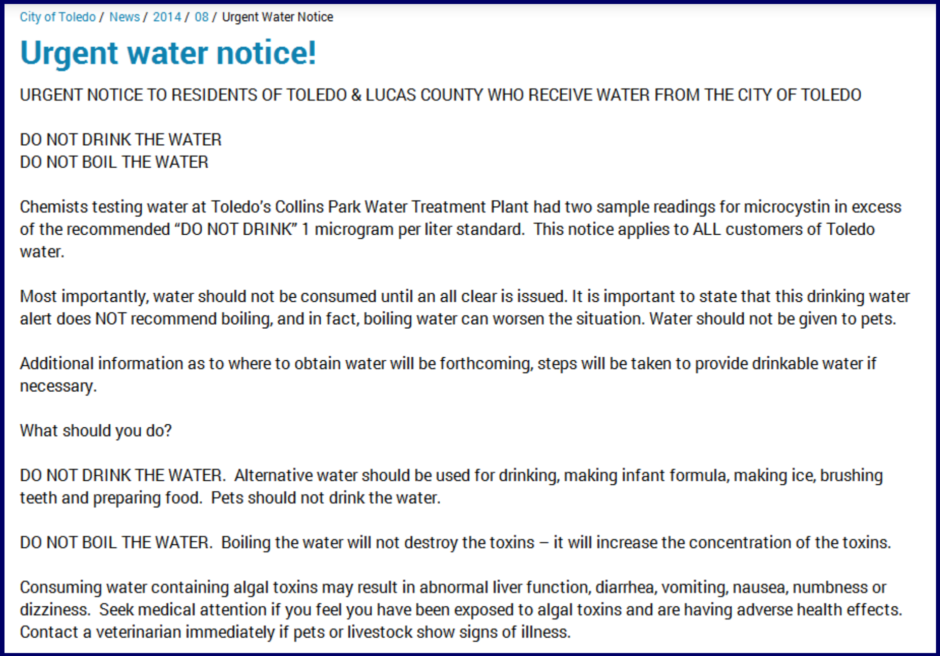




USA: The Toledo water crisis

- On August 2, 2014, the City of Toledo, Ohio, issued a "Do Not Drink – Do Not Boil" water notice, due to the presence of **microcystins**.
- The notice affected more than 400.000 people.
- Toledo water utilities abstract water from lake Erie, which suffers from cyanobacterial blooms.

Cyanobacterial bloom in Lake Erie (satellite image, Sept. 27 2011)



City of Toledo / News / 2014 / 08 / Urgent Water Notice

Urgent water notice!

URGENT NOTICE TO RESIDENTS OF TOLEDO & LUCAS COUNTY WHO RECEIVE WATER FROM THE CITY OF TOLEDO

DO NOT DRINK THE WATER
DO NOT BOIL THE WATER

Chemists testing water at Toledo's Collins Park Water Treatment Plant had two sample readings for microcystin in excess of the recommended "DO NOT DRINK" 1 microgram per liter standard. This notice applies to ALL customers of Toledo water.

Most importantly, water should not be consumed until an all clear is issued. It is important to state that this drinking water alert does NOT recommend boiling, and in fact, boiling water can worsen the situation. Water should not be given to pets.

Additional information as to where to obtain water will be forthcoming, steps will be taken to provide drinkable water if necessary.

What should you do?

DO NOT DRINK THE WATER. Alternative water should be used for drinking, making infant formula, making ice, brushing teeth and preparing food. Pets should not drink the water.

DO NOT BOIL THE WATER. Boiling the water will not destroy the toxins – it will increase the concentration of the toxins.

Consuming water containing algal toxins may result in abnormal liver function, diarrhea, vomiting, nausea, numbness or dizziness. Seek medical attention if you feel you have been exposed to algal toxins and are having adverse health effects. Contact a veterinarian immediately if pets or livestock show signs of illness.

The water notice issued by the City of Toledo

USA TODAY
A GANNETT COMPANY

NEWS SPORTS LIFE MONEY TECH TRAVEL OPINION 79° CROSSWORDS YOUR TAKE

Ohio's 4th largest city has no drinking water

Rick Jervis, USA TODAY 1:50 a.m. EDT August 3, 2014

(Photo: John Seewer, AP)

Residents of a large swath of northwestern Ohio are still without drinkable water after a dangerous toxin was discovered late Friday in an area water treatment plant.

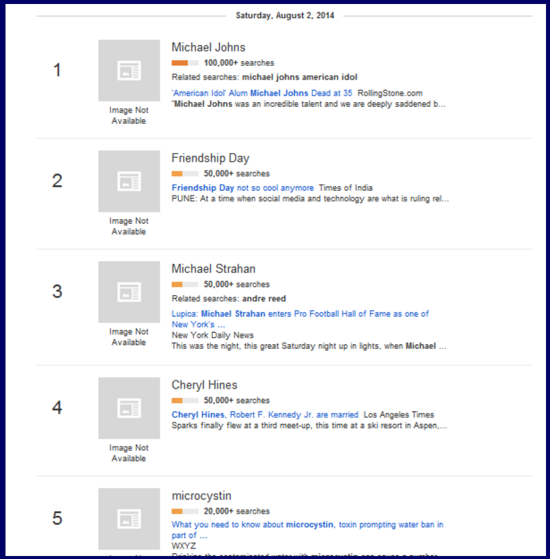
Hours after news of the contamination surfaced, Gov. John Kasich declared a state of emergency for Lucas, Wood and Fulton counties and deployed the National Guard to get water to the area. He pledged that state agencies were working to bring water and other supplies to areas around Toledo while also assisting hospitals and other businesses impacted. The state also was making plans to make more deliveries if the water problem lingered, he said.

"What's more important than water? Water's about life," Kasich said. "We know it's difficult. We know it's frustrating."

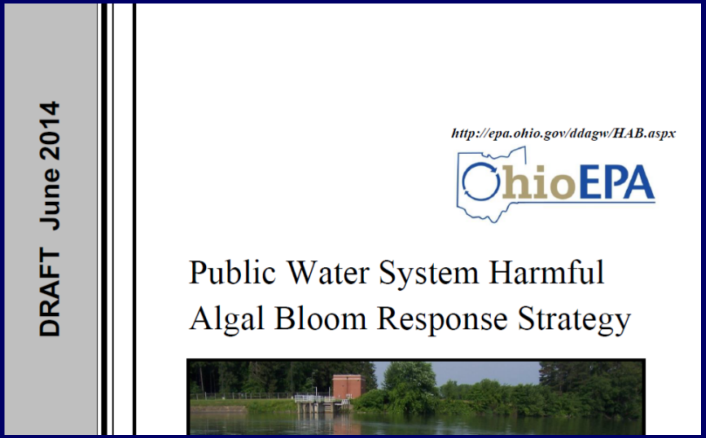
USA: Response to Toledo water crisis

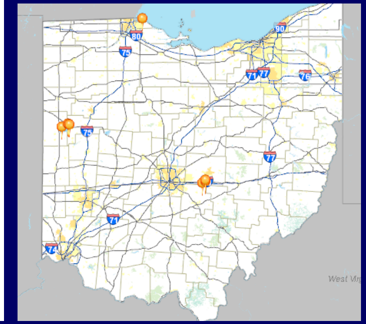
Date	Time	Date Ohio EPA Notified	Location	Sample Water Type	Methodology	Results by Testing	
						Toledo	Ohio EPA
2/8/2014	12:20 μμ	8/3/2014 - 10:28 PM	1474 Detroit, F.D.	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:45 μμ	8/3/2014 - 10:28 PM	2566 Cass	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:25 μμ	8/3/2014 - 10:28 PM	2616 Heatherdown	Distribution System	ELISA - Unlysed Quenched		0.31 ug/L
2/8/2014	12:50 μμ	8/3/2014 - 10:28 PM	3332 St. Lawrence	Distribution System	ELISA - Unlysed Quenched		0.54 ug/L
2/8/2014	12:46 μμ	8/3/2014 - 10:28 PM	4251 S. Clark TFD	Distribution System	ELISA - Unlysed Quenched		0.57 ug/L
2/8/2014	1:10 μμ	8/3/2014 - 10:28 PM	4710 Detroit	Distribution System	ELISA - Unlysed Quenched		0.53 ug/L
2/8/2014	12:56 μμ	8/3/2014 - 10:28 PM	6230 Summit	Distribution System	ELISA - Unlysed Quenched		0.34 ug/L
2/8/2014	1:10 μμ	8/3/2014 - 10:28 PM	6268 Edgewater	Distribution System	ELISA - Unlysed Quenched		0.68 ug/L
2/8/2014	12:19 μμ	8/3/2014 - 10:28 PM	8 ft	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:38 μμ	8/3/2014 - 10:28 PM	Bahiamar and Suder	Distribution System	ELISA - Unlysed Quenched		0.53 ug/L
2/8/2014	1:05 μμ	8/3/2014 - 10:28 PM	BK/Secor	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:40 μμ	8/3/2014 - 10:28 PM	Bob Evans Restaurant Reynolds	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:31 μμ	8/3/2014 - 10:28 PM	BP	Distribution System	ELISA - Unlysed Quenched		<0.30 ug/L
2/8/2014	12:23 μμ	8/3/2014 - 10:28 PM	BP Detroit/Alexis	Distribution System	ELISA - Unlysed Quenched		0.44 ug/L
2/8/2014	12:25 μμ	8/3/2014 - 10:28 PM	Bull Sheffieldd and Florence	Distribution System	ELISA - Unlysed Quenched		0.48 ug/L
2/8/2014	2:37 μμ	8/3/2014 - 10:28 PM	Bull Tracy and Andrus	Distribution System	ELISA - Unlysed Quenched		0.44 ug/L
2/8/2014	1:15 μμ	8/3/2014 - 10:28 PM	Bull Wakes Rd Pump and Hyd	Distribution System	ELISA - Unlysed Quenched		0.6 ug/L
2/8/2014	12:15 μμ	8/3/2014 - 10:28 PM	Burger King	Distribution System	ELISA - Unlysed Quenched		0.36 ug/L

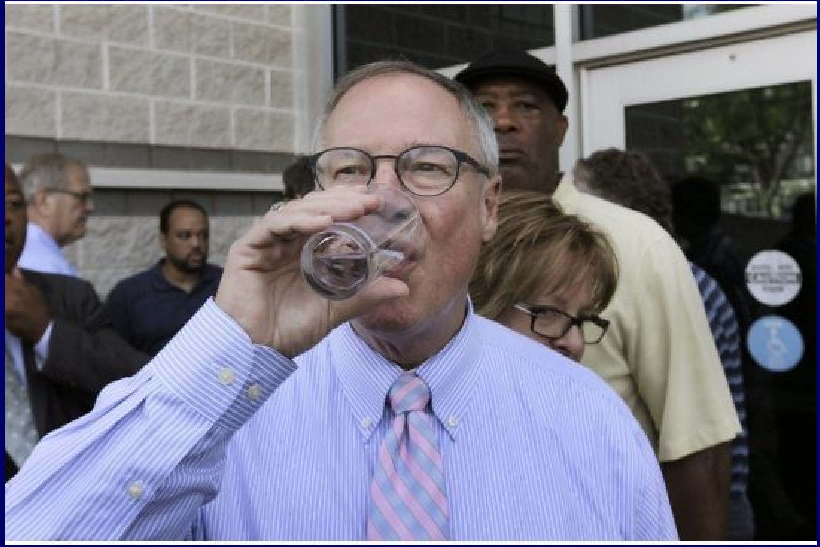
Open data for monitoring of lakes and drinking water supplies (US EPA)



Google "Hot Searches", August 2, 2014





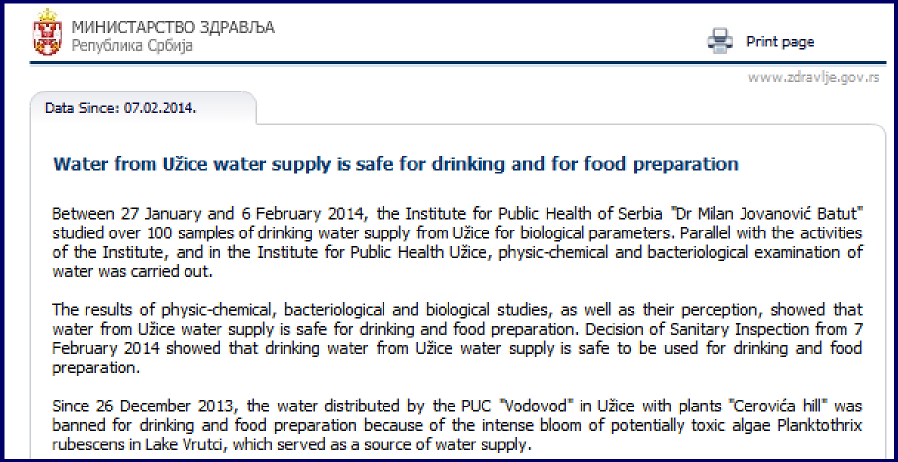


Toledo mayor, Dr. Michael Collins on August 4, when the water ban was lifted PAUL SANCYA / THE ASSOCIATED PRESS thestar.com

- **Short – term measures:** Continuous monitoring of water supplies for toxins
- **Long –term strategies**: limit nutrient runoffs in lake Erie (mainly phosphorus)

Serbia: The Uzice case

- In December 2013 there was a widespread bloom of *Planktothrix rubescens* in lake Vruci which is an artificial water reservoir serving the city of Uzice (ppl. 70.000).
- The use of water for drinking and preparation of food was forbidden.
- The WTP switched to an alternative source of water (groundwater).
- Data regarding the presence of cyanotoxins in water during the episode were not publicized.



МИНИСТАРСТВО ЗДРАВЉА
Република Србија

Print page

www.zdravlje.gov.rs

Data Since: 07.02.2014.

Water from Užice water supply is safe for drinking and for food preparation

Between 27 January and 6 February 2014, the Institute for Public Health of Serbia "Dr Milan Jovanović Batut" studied over 100 samples of drinking water supply from Užice for biological parameters. Parallel with the activities of the Institute, and in the Institute for Public Health Užice, physic-chemical and bacteriological examination of water was carried out.

The results of physic-chemical, bacteriological and biological studies, as well as their perception, showed that water from Užice water supply is safe for drinking and food preparation. Decision of Sanitary Inspection from 7 February 2014 showed that drinking water from Užice water supply is safe to be used for drinking and food preparation.

Since 26 December 2013, the water distributed by the PUC "Vodovod" in Užice with plants "Cerovića hill" was banned for drinking and food preparation because of the intense bloom of potentially toxic algae Planktothrix rubescens in Lake Vrutci, which served as a source of water supply.

Water tank in Užice. Photo: Milos Cvetkovic

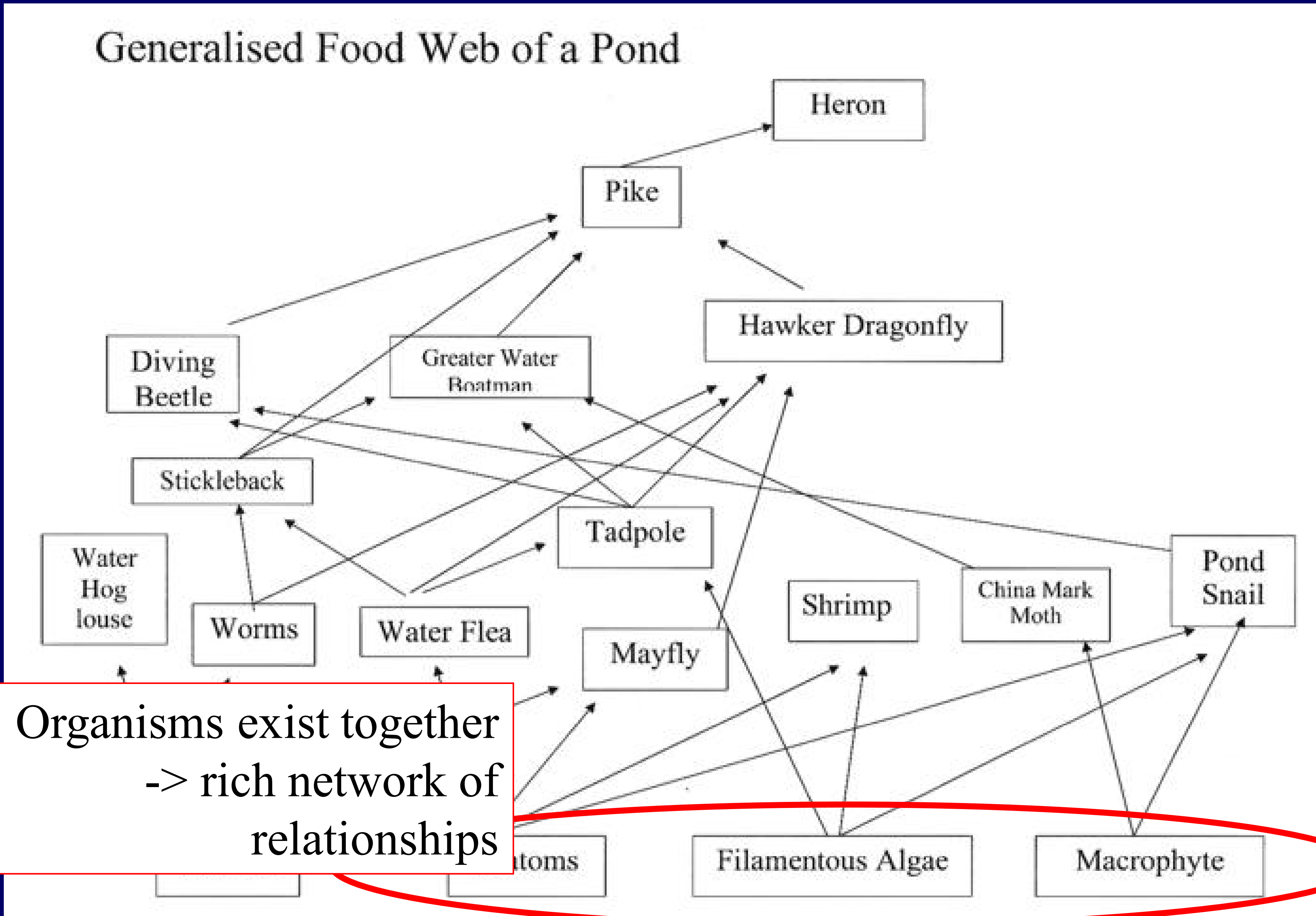
Talking about „risks" of cyanobacteria

- **RISK = probability of the occurrence of HAZARDOUS event**
  - **„Hazardous events" resulting from eu/trophication of the environment**
    - **Primary** damage to structure and functioning of ecosystems
    - **Secondary** signs -> ecotoxicity and toxicity

Ecological „stability“

- **Stable and functioning ecosystem**
    - Complex and complicated structure (diversity)
    - Many links (food networks) among organisms = ecosystem functioning
        - *Including „ecosystem services*" *to humans:*
          supplies, regulations, cultural / aesthetic, supporting

Complex ecosystem



Organisms exist together
-> rich network of
relationships

CYANOBACTERIAL BLOOMS: RISKS

BLOOM →

↓

ECOLOGICAL RISKS

TOXINS →

↓

HUMAN
health risks

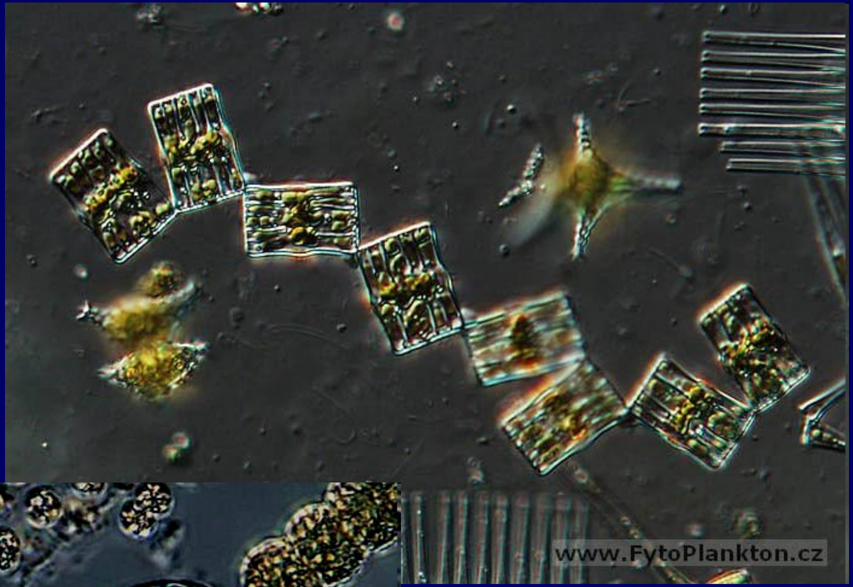
Ecological risk 1: Loss of phytoplankton biodiversity

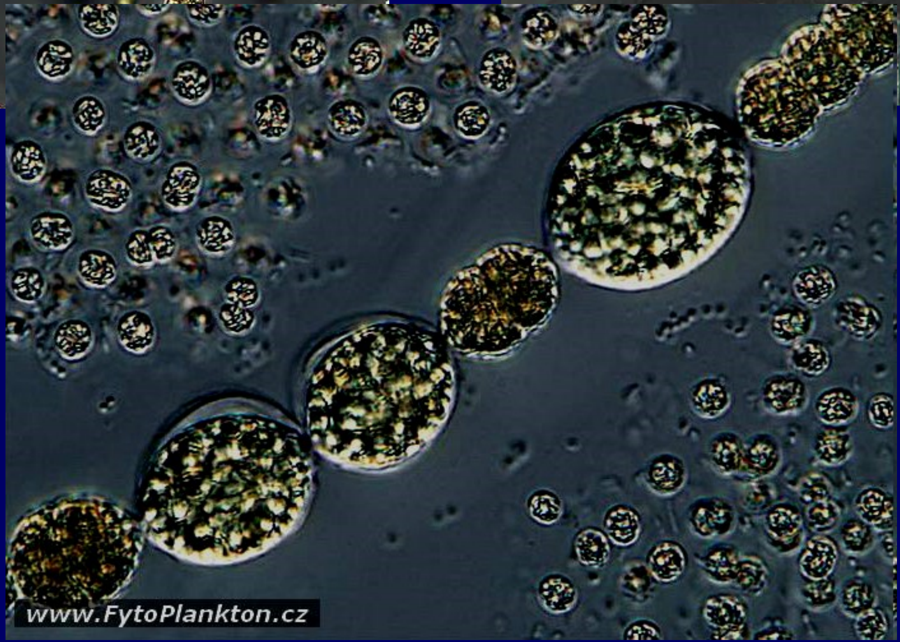
- Anthropogenic changes in the environment (more nutrients - P,N)
  -> advantage for „some" phytoplankton organisms

- Complex communities replaced with „monoculture" (often *Microcystis aeruginosa, Planktothrix sp.*)

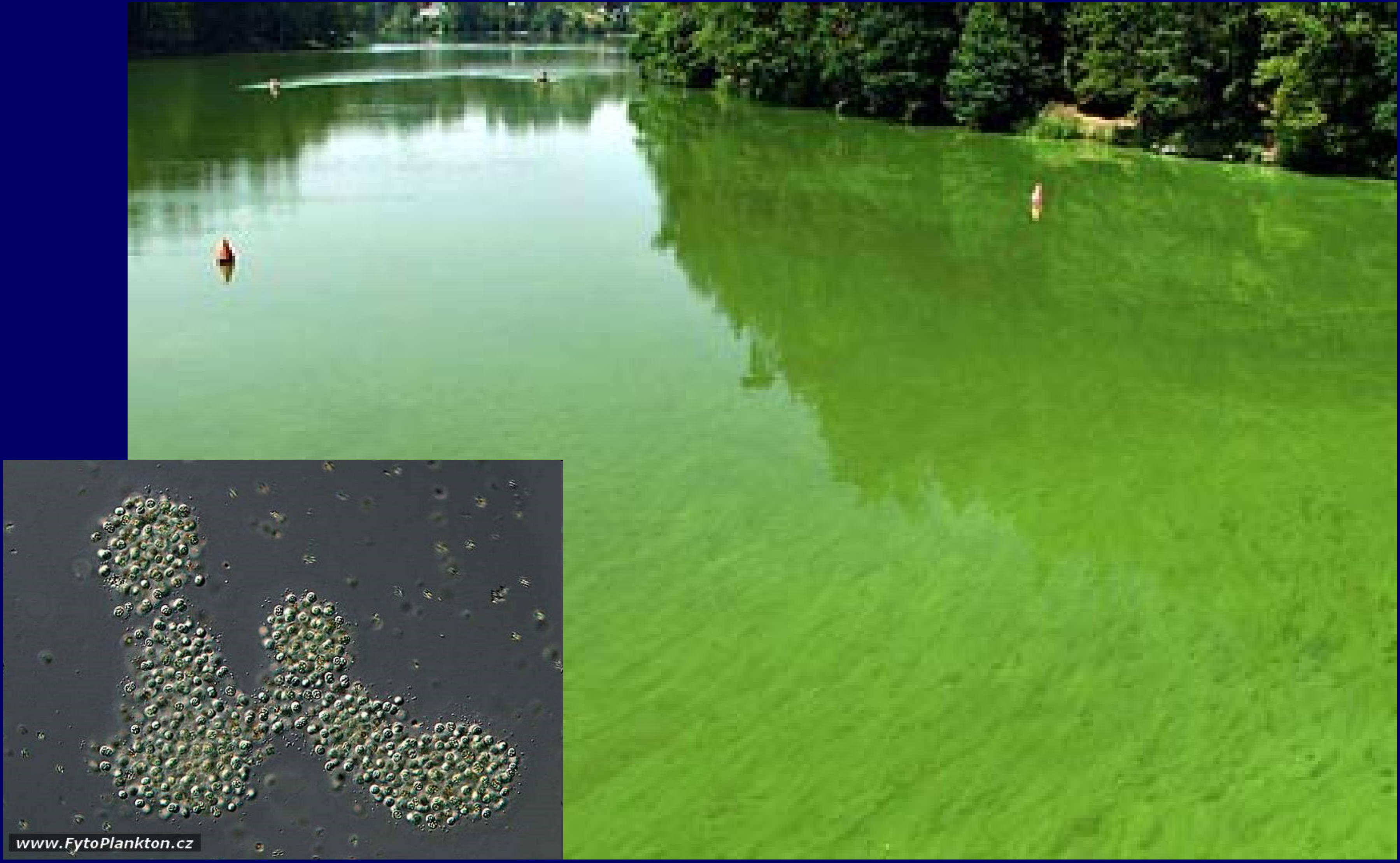
- „Monocultures" **have secondary effects**
  -> changes in hydrochemistry (higher pH, transparency)
  -> further indirect impacts on other organisms

Ecological risk 1: Loss of phytoplankton biodiversity





Ecological risk 1: Loss of phytoplankton biodiversity



Ecological risk 2: Further ecosystem changes

- **Phytoplankton -> changes in the whole network**
  - Reported examples …
    - Changes in the consumers communites
      zooplankton -> fish -> …
    - Makrophyte disappearance (reed)
      (shading -> no germination …)

      -> macrophytes
      = substrate for other organisms …

- **New „expansive“ species**
  - cyanobacterium *Cylindrospermopsis raciborskii (?)*
- **Water blooms** = substrate for „associated bacteria“

Ecological risk 3: Ecosystem catastrophes

- Sudden disappearance of the producers „monoculture“ (*rapid environmental changes, „infections*" *by viruses/phages*) -> **Ecosystem collapse**

- Seasonal changes
  - Cyanobacterial biomass lysis -> bacterial decay -> loss of O_2 -> **anaerobic conditions - collapse**
  - Deaths of aquatic organisms (fish ...)
  - Pathogens (anaerobic Clostridium botulinum)

CYANOBACTERIAL BLOOMS: RISKS

BLOOM →

↓

ECOLOGICAL RISKS

TOXINS →

↓

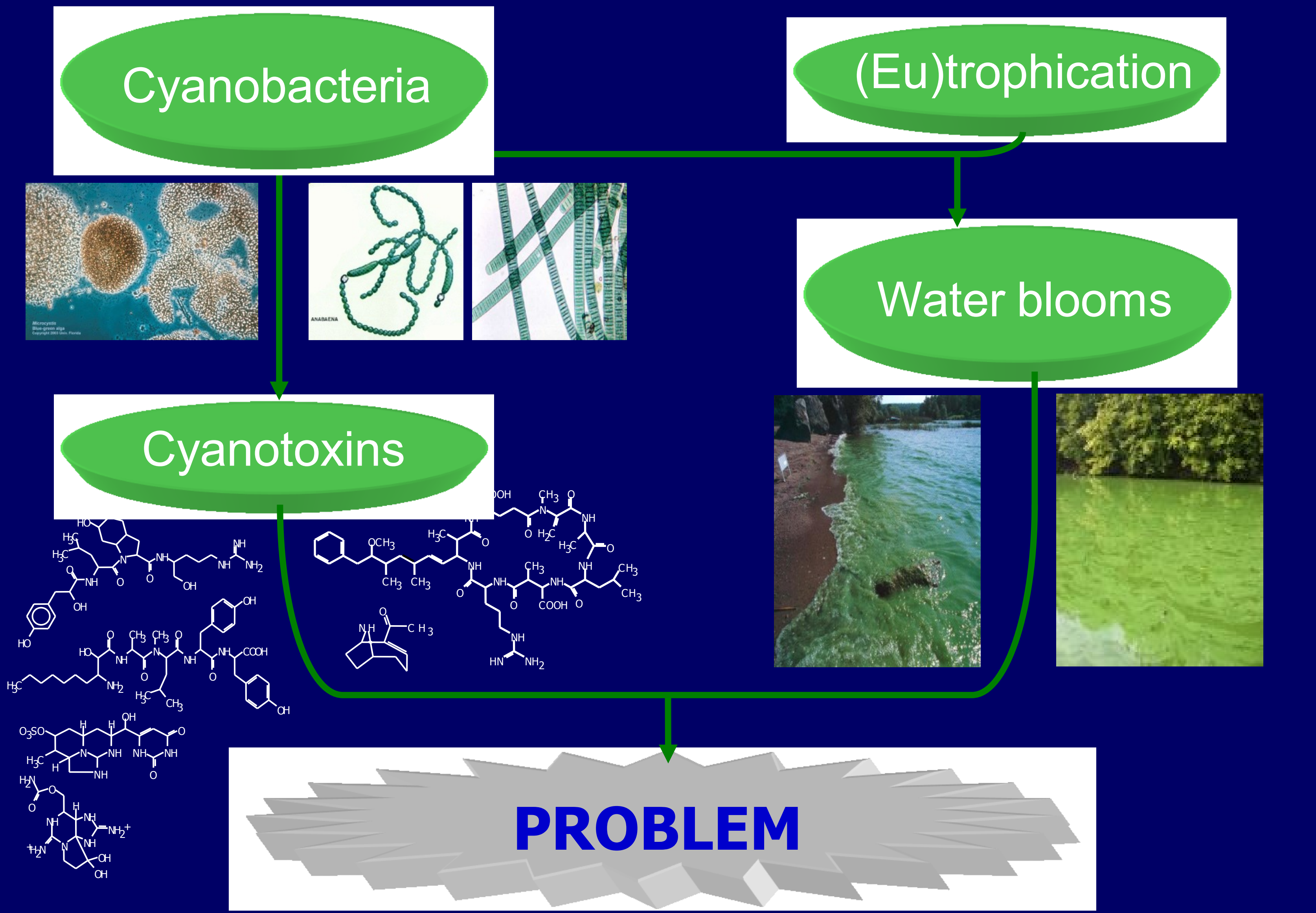
HUMAN
health risks

Ecological risk 4: Cyanobacterial **toxins**

- **Cyanobacteria** - evolutionary old and important organisms (atmospheric oxygen)

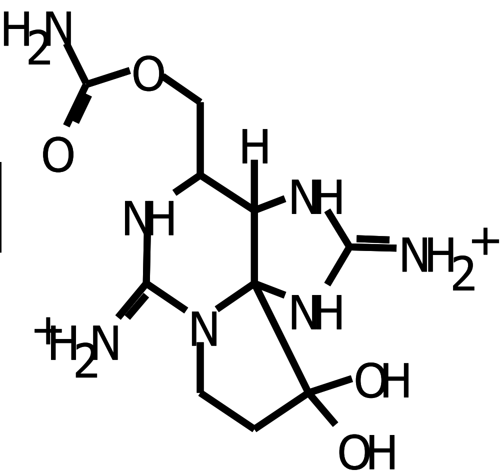
- **G- bacteria** (10 mil. Cells / mL)
  - G- : cell walls contain lipopolysaccharides (LPS, *similar to E. coli, Salmonella sp…)*

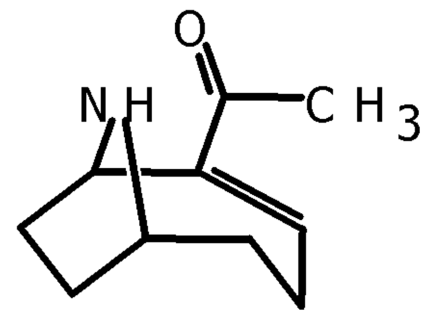
- **Water blooms**
  - several complex problems (see previous slides…)
  - just one of the problems = **toxin production**


Cyanobacteria
(Eu)trophication
Water blooms
Cyanotoxins
PROBLEM

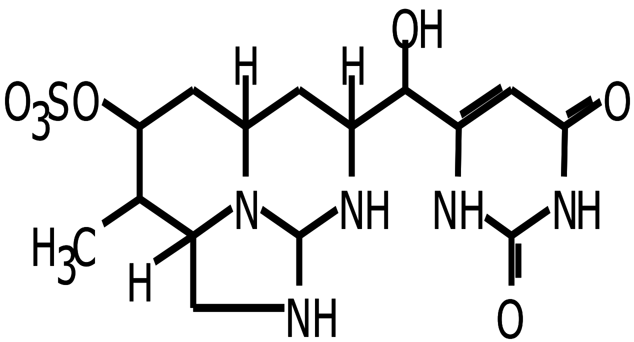
Selected „known“ cyanotoxins

Saxitoxin



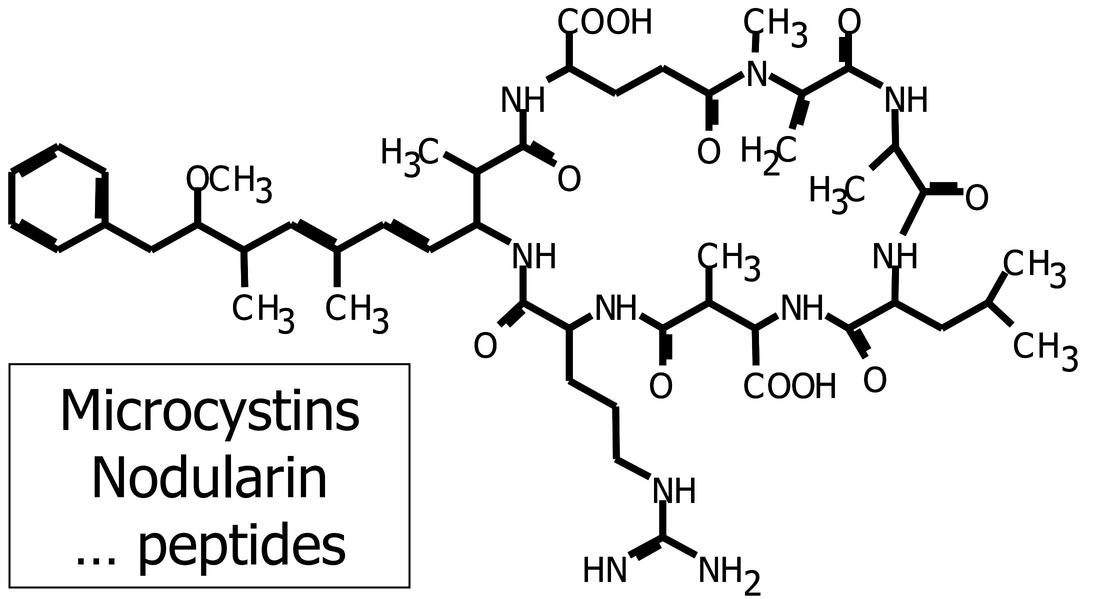


Anatoxin-a



Cylindrospermopsin

Microcystins
Nodularin
… peptides



Categorization of cyanotoxins

1. **According to the chemical structure**
   - cyclic and linear peptids
   - alkaloids
   - lipopolysaccharides

2. **According to biological activity**

   mechanisms of toxicity

   - hepatotoxicity, neurotoxicity, cytotoxicity, irritating, immunotoxicity, genotoxicity ...

TOXIN	STRUCTURE	STRUCTURE VARIATION	LD50* ($\mu g.kg^{-1}$)	TOXICITY
Microcystin	cyclic heptapeptide	>60	50-1200	hepatotoxicity, tumor promotion, induction of oxidative stress
Nodularin	cyclic pentapeptide	7	50-2000	hepatotoxicity, tumor promotion
Anatoxin	alkaloide	2	200-250	neurotoxicity
Anatoxin-a(S)	methylphospho-ester N-hydroxy-guanine	1	20	neurotoxicity
Saxitoxin	carbamat alkaloid	19	10	neurotoxicity
Cylindrospermopsin	guanidin alkaloid	2	200**	cytotoxicity, target organs: liver and kidney
Aplysiatoxin		2		dermatotoxicity, tumor promotion
Lyngbyatoxin	modified cyclic dipeptide	1		dermatotoxicity, tumor promotion
Lipopolysaccharide				irritate effect

Cyanobacteria	Toxins produced
Anabaena	Anatoxins, Microcystins, Saxitoxins, LPS's
Anabaenopsis	Microcystins, LPS's
Anacystis	LPS's
Aphanizomenon	Saxitoxins, Cylindrospermopsins, LPS's
Cylindrospermopsis	Cylindrospermopsins, Saxitoxins, LPS's
Hapalosiphon	Microcystins, LPS's
Lyngbia	Aplysiatoxins, Lyngbiatoxin-a, LPS's
Microcystis	Microcystins, LPS's
Nodularia	Nodularin, LPS's
Nostoc	Microcystins, LPS's
Phormidium (*Oscillatoria*)	Anatoxin, LPS's
Planktothrix (*Oscillatoria*)	Anatoxins, Aplysiatoxins, Microcystins, Saxitoxins, LPS's
Schizothrix	Aplysiatoxins, LPS's
Trichodesmium	yet to be identified
Umezakia	Cylindrospermopsin, LPS's

THE COMPARIOSON OF TOXICITY OF THE NATURAL TOXINS
(i.p. injection, acute rat test, **LD50 in μg/kg)**
Bacteria-cyanobacteria- animals- fungi- plants

Amatoxin	Amanita phalloides	fungus	500
Muscarin	Amanita muscaria	fungus	1100
Aphanotoxin	*Aphanizomenon flos-aquae*	cyano	10
Anatoxin -A	*Anabaena flos-aquae*	cyano	20
microcystin LR	*Microcystis aeruginosa*	cyano	43
nodularin	*Nodularia spumigena*	cyano	50
botulin	*Clostridium botulinum*	bacteria	0,00003
tetan	*Clostridium tetani*	bacteria	0,0001
kobra	*Naja naja*	snake	20
kurare	*Chondrodendron tomentosum*	plant	500
strychnine	*Strychnos nux-vomica*	plant	2 000




Cyanobacterial EKOtoxicity ?

- **Isolated microcystins** - many toxicological studies
- HOWEVER: **Water blooms are more than microcystins**

  - complex mixtures of many compounds (toxins, lipopolysaccharides, non-toxic components…)

  - ? accumulated toxicants (metals, POPs ???)

Many studies:

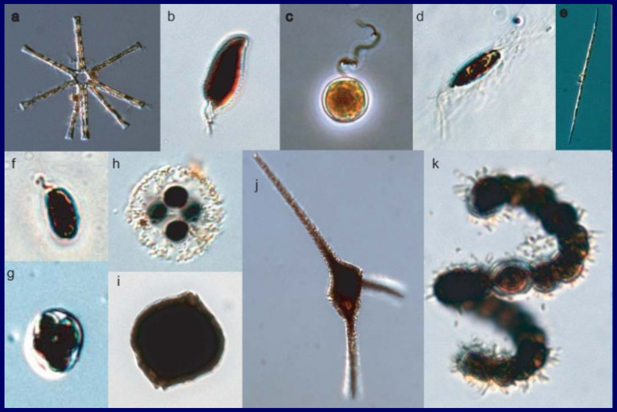
tested complex water blooms BUT interpreted as „MCs"

Ecotoxicity of WATER BLOOMS to **bacterioplankton**

- highly relevant question (MCs are evolutionary old … as well as bacteria)
- only few studies - in general **low toxicity** observed

Ecotoxicity of <u>WATER BLOOMS</u> to **algae (phytoplankton)**

- **<u>Algae = competitors to cyanobacteria</u>**
  - limited data
  - **weak direct toxicity** only at high (nonrelevant) concentrations
  - some studies indicate allelopathy between cyanobacteria & algae (*inhibition of growth, specific effects on dormant stages)*



Ecotoxicity of WATER BLOOMS to **zooplankton**

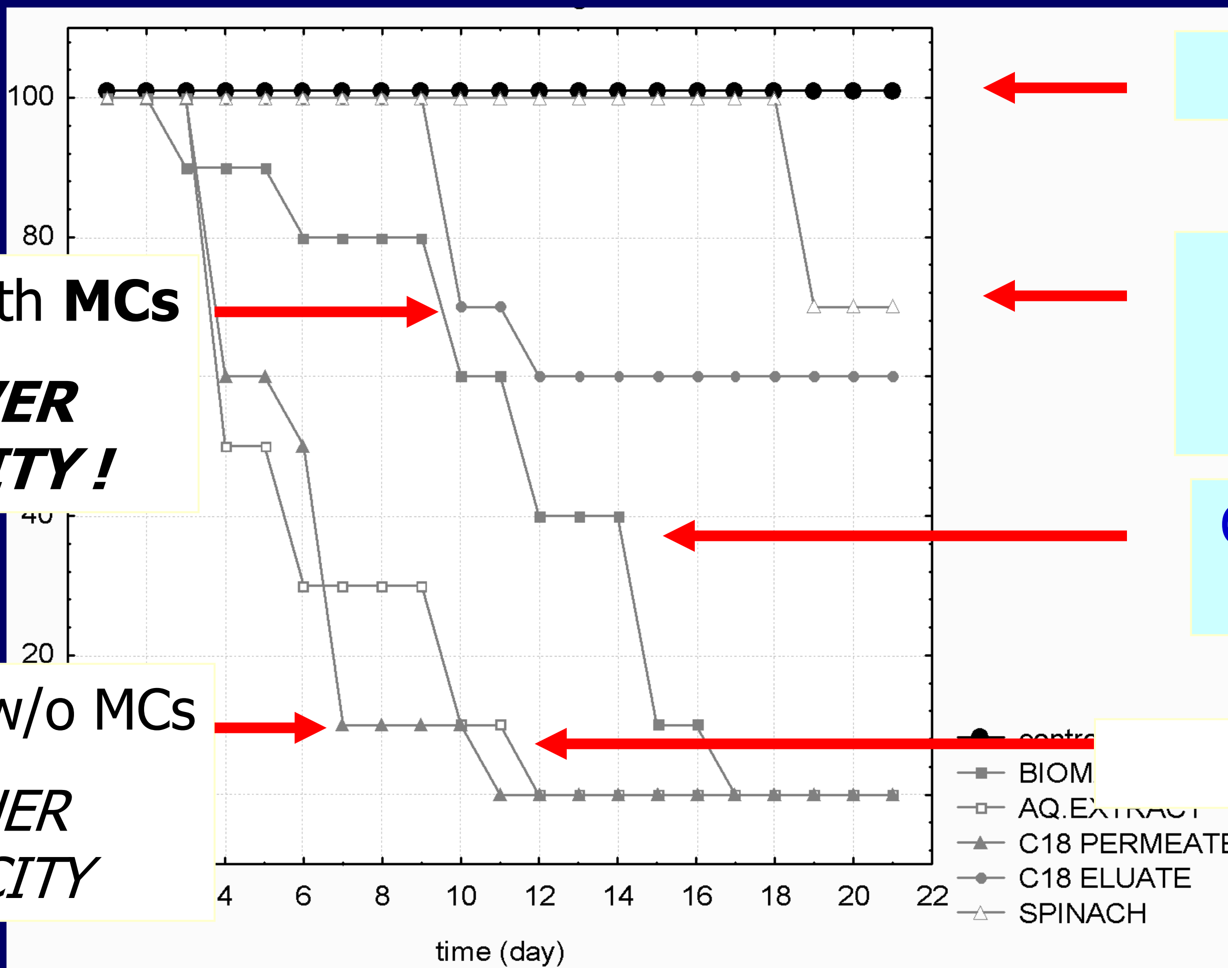
- invertebrates - **lower sensitivity** than vertebrates
- variable sensitivity of different (even closely related) invertebrate species

- one of the first hypotheses: „MCs are against predators“ (not confirmed - several contras…)

  BUT: zooplankton prefers nontoxic strains during feeding
  (? -> indirect effects on development of toxic blooms ?)

Ecotoxicity of cyanobacteria

Reproduction



Controls

Nontoxic biomass (spinach)

Complex water bloom

Extract

Fraction with **MCs**

! LOWER TOXICITY !

Fraction w/o MCs

HIGHER TOXICITY

Ecotoxicity of WATER BLOOMS to **fish and amphibians**

- Many studies … toxin accumulations
  + several effects observed (histhology, biochemistry…)

! Indirect effects (pH changes, oxygen content) more important in toxicology !

Ecotoxicity of WATER BLOOMS to **birds**

- deaths documented (with toxins in bird tissues)
- limited number of controlled experiments
    - low direct toxicity to model birds

! Water blooms stimulate effects of other agents

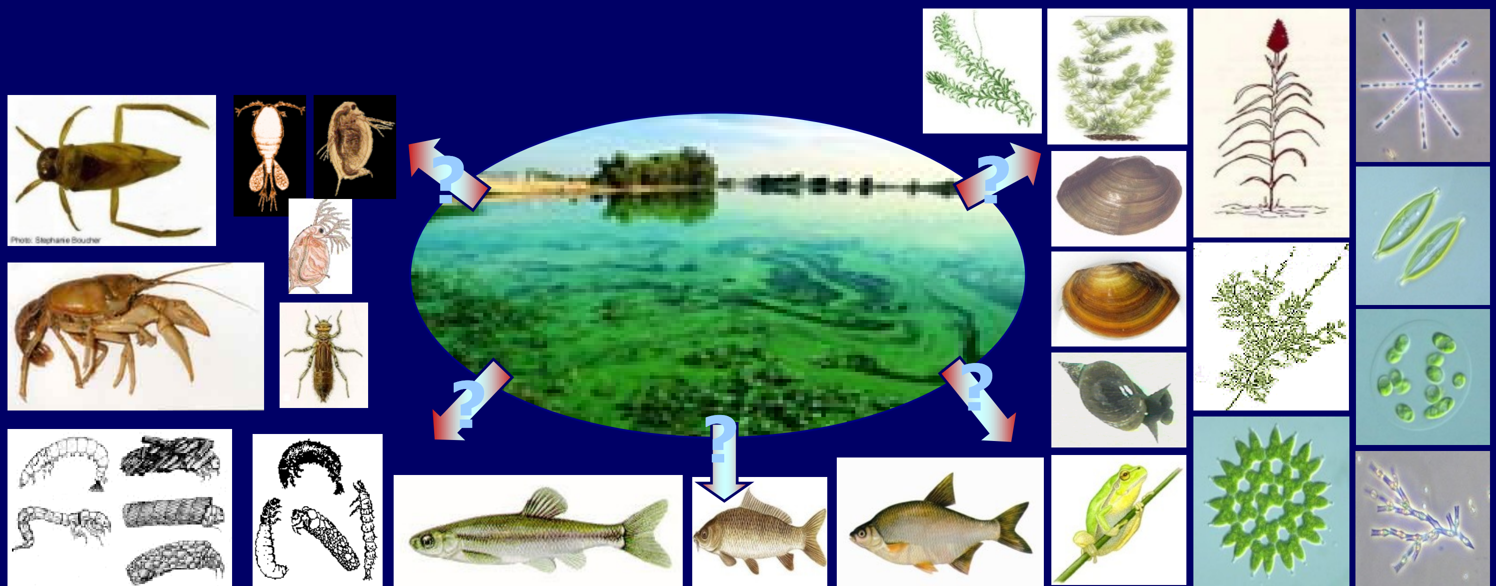
(lead toxicity, immunosupressions)

Summary
Ecotoxicological risks

- **Only MCs studied** *(… results disputable …)*

- **In general: Lower importance of „known" isolated toxins (such as MCs)**

! Complex bloom effects are more important !



CYANOBACTERIAL BLOOMS: RISKS

BLOOM → ECOLOGICAL RISKS

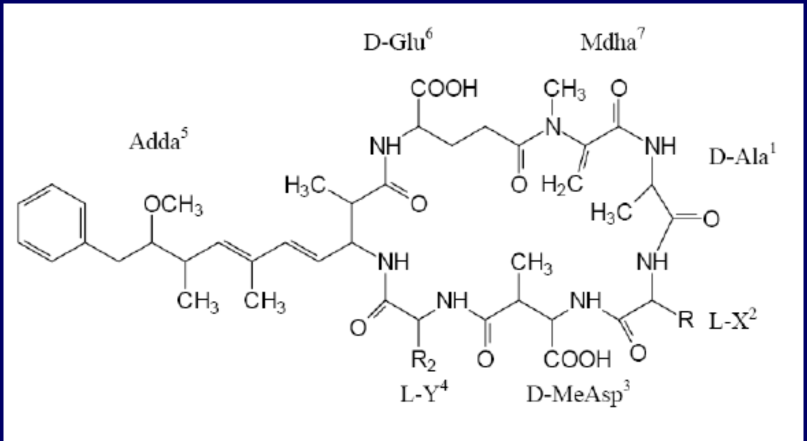
↓

TOXINS →

↓

HUMAN
health risks

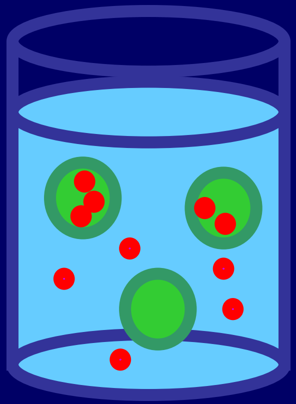
MICROCYSTINS



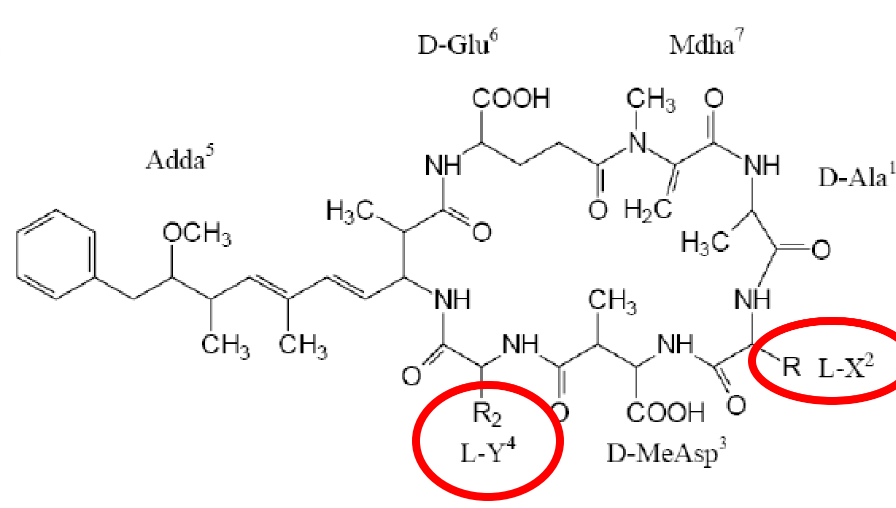
- **The most studied and most important**

- Produced and present inside cells:
  - **Intracellular**:
    - up to 10 mg/g d.w. of biomass

      1% dw -> tons / reservoir
  - **Extracellular** (dissolved): up to 10 ug/L
- Stable in water column, bioaccumulative (?)



MICROCYSTINS



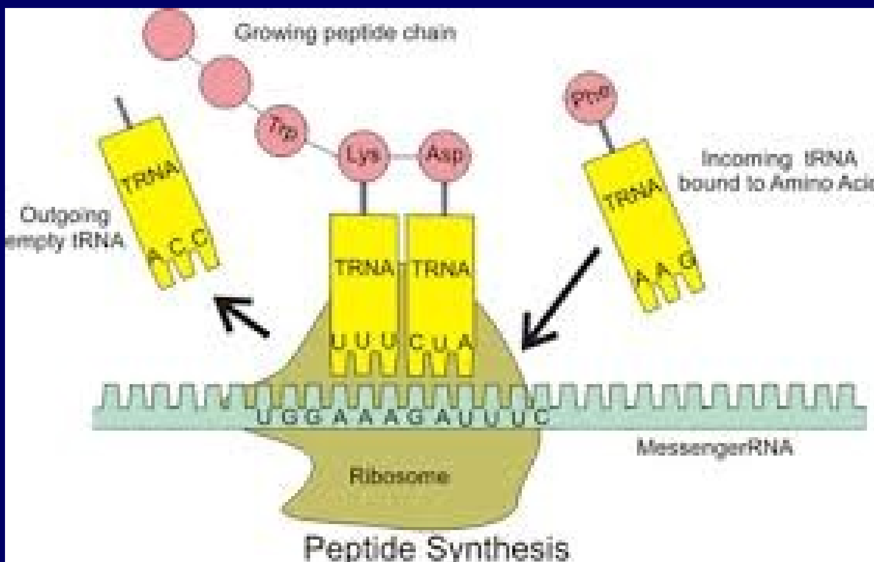
- Inhibit regulatory protein phosphatases
  - -> tumor promoter
  - -> hepatotoxic

- **70 variants**: MC-LR only considered by WHO
  - chronic TDI: 0.04 ug/kg b.w./day
  - drinking water guidline recommendation: 1 ug/L

- **Highly toxic to mammals** and humans
- Ecotoxicology ? Natural function ?

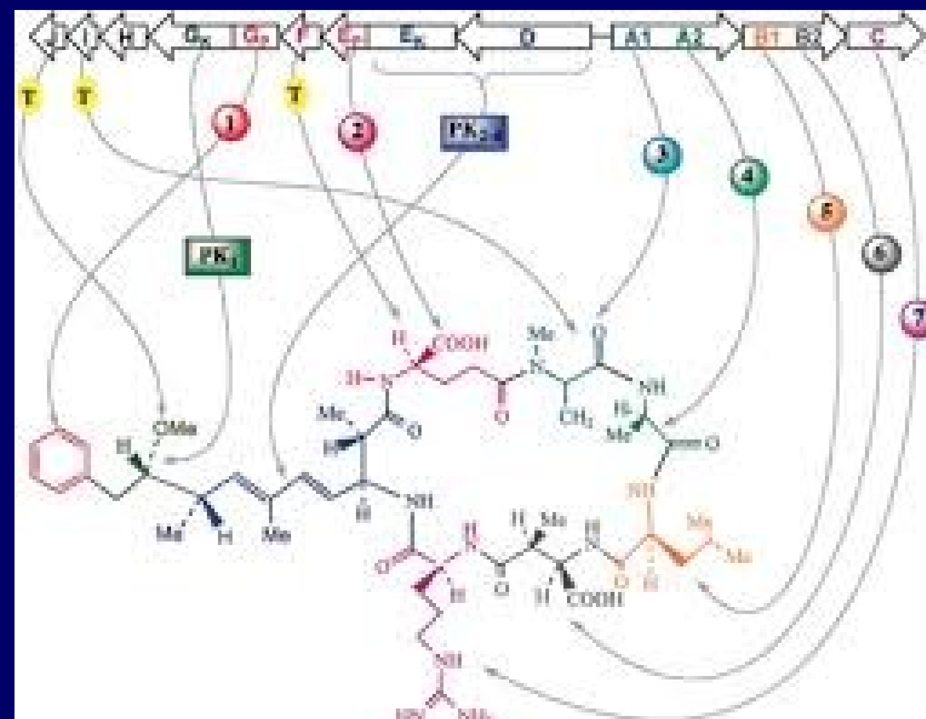
Microcystin synthesis

- **Non-ribozomal polyketide synthetases**



7 genes: 7 enzymes

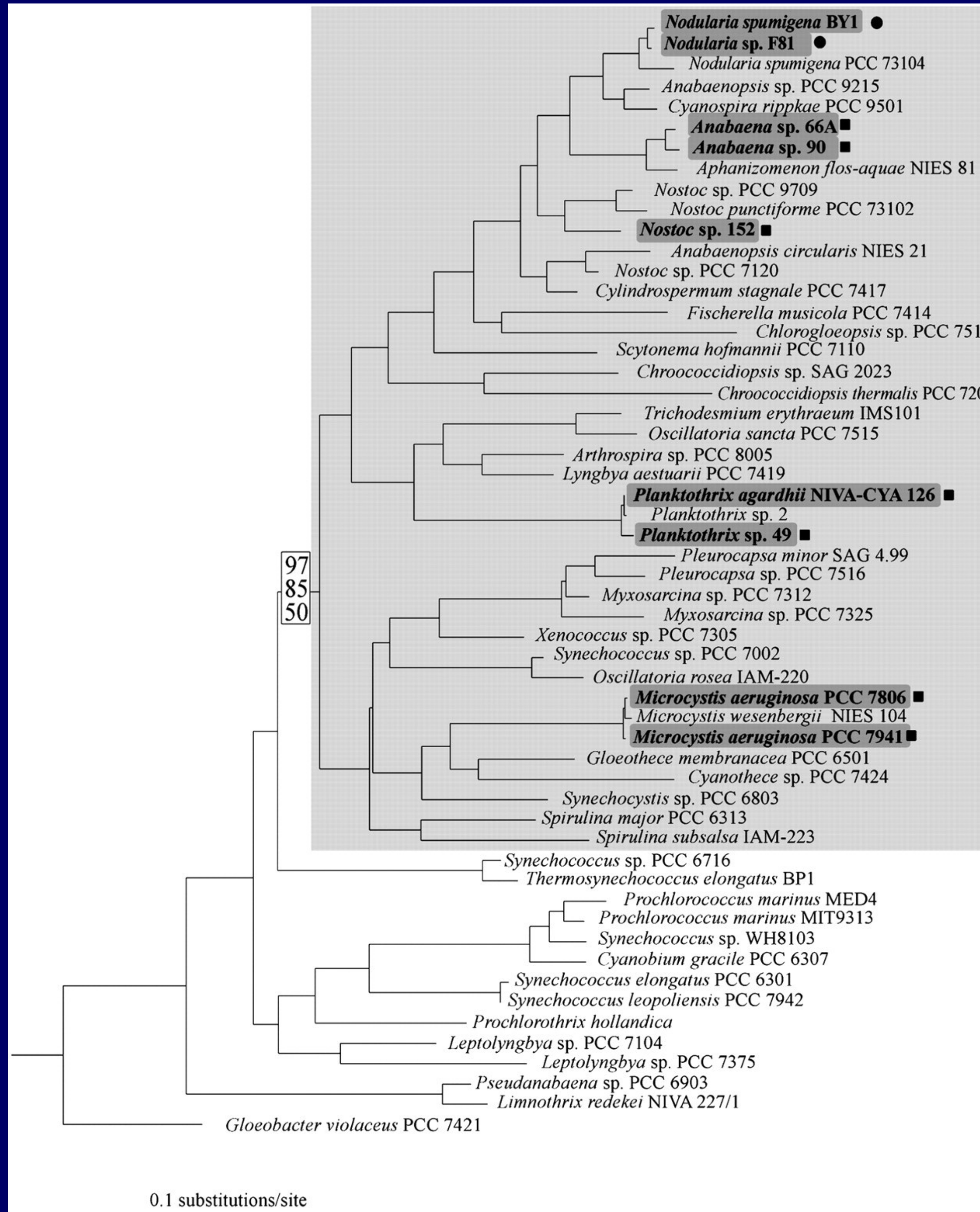
Enzymatic
complex catalyzing
binding of aminoacids
(!!! Very high ATP demand)



Microcystin synthesis

- **Evolution of non-ribozomal polyketide synthetases**

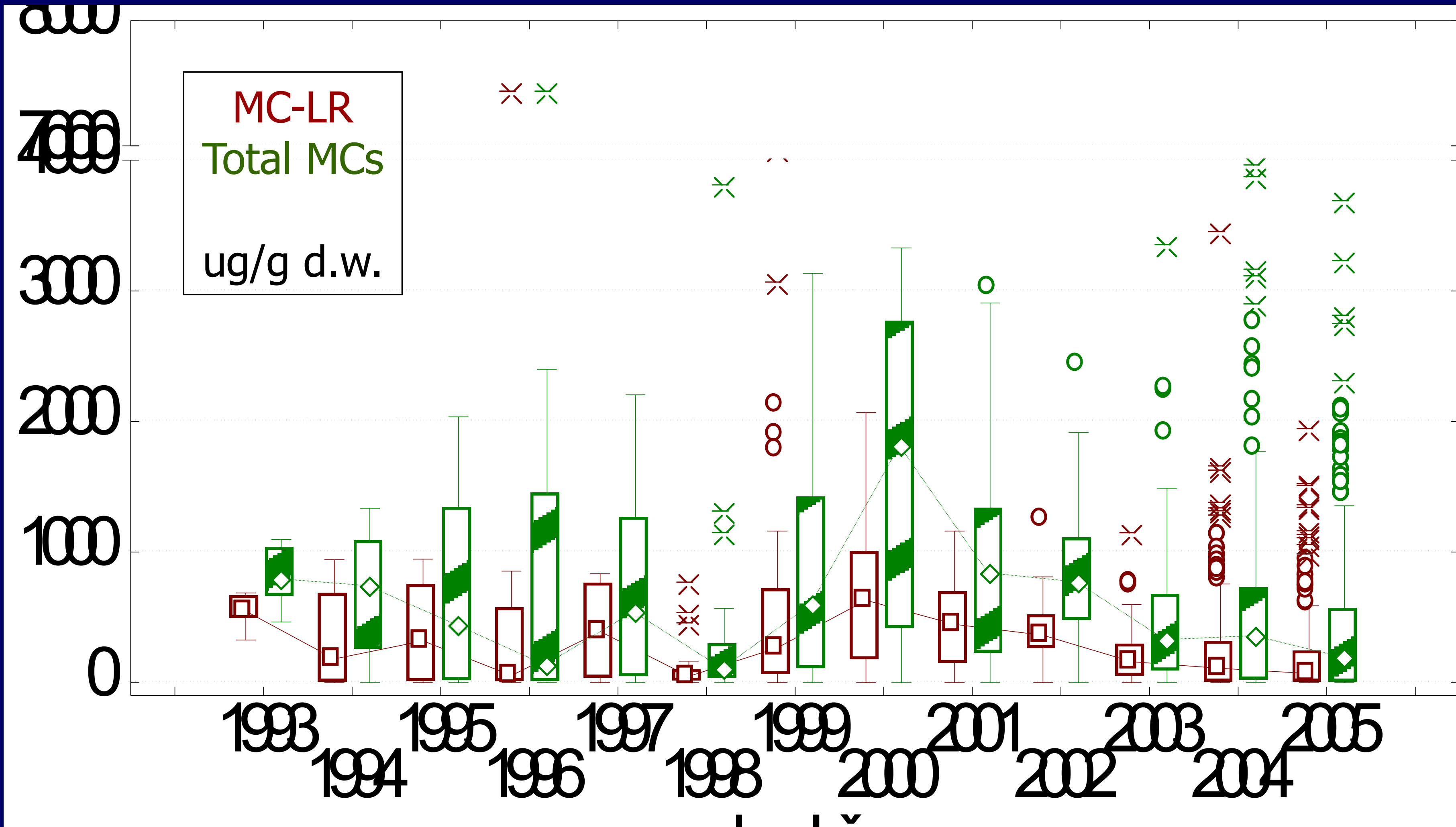
- **Evolutionary old genes**
  - ***Why remained?***



Rantala et al. (2004) PNAS 101:568

Microcystins in the Czech Rep.

(Water bloom biomass concentrations
… up to several mg/g dry weight)

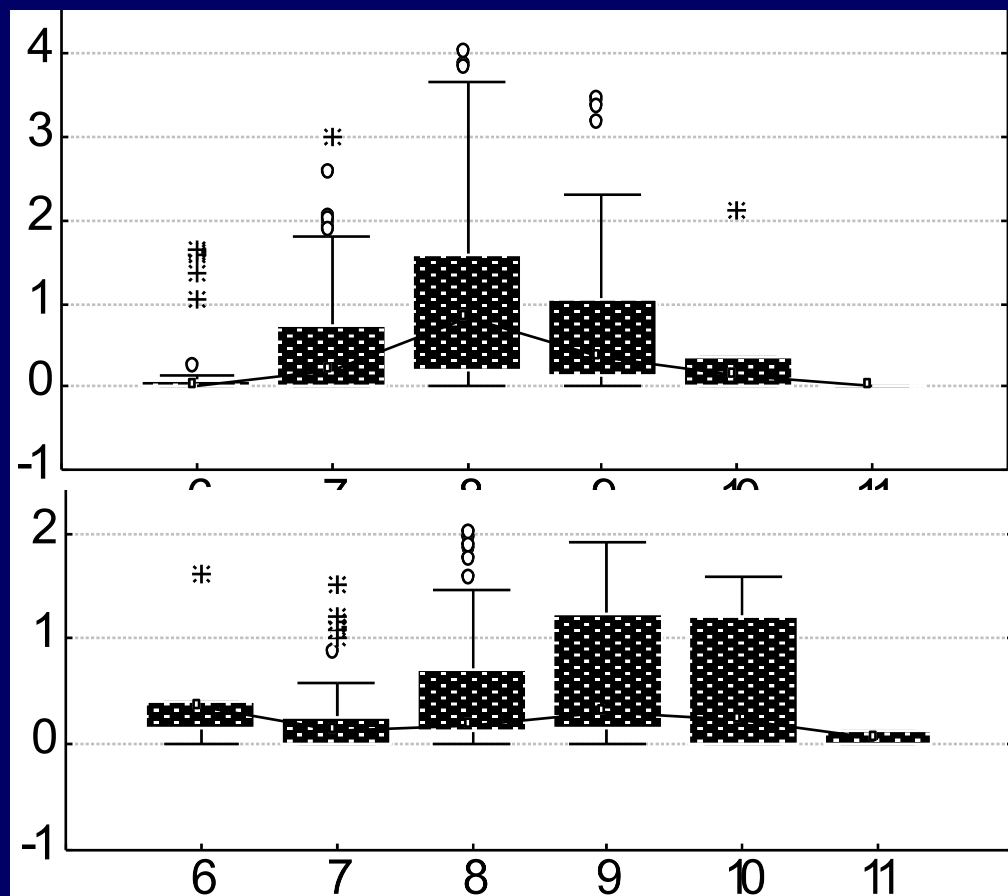


Seasonal variability

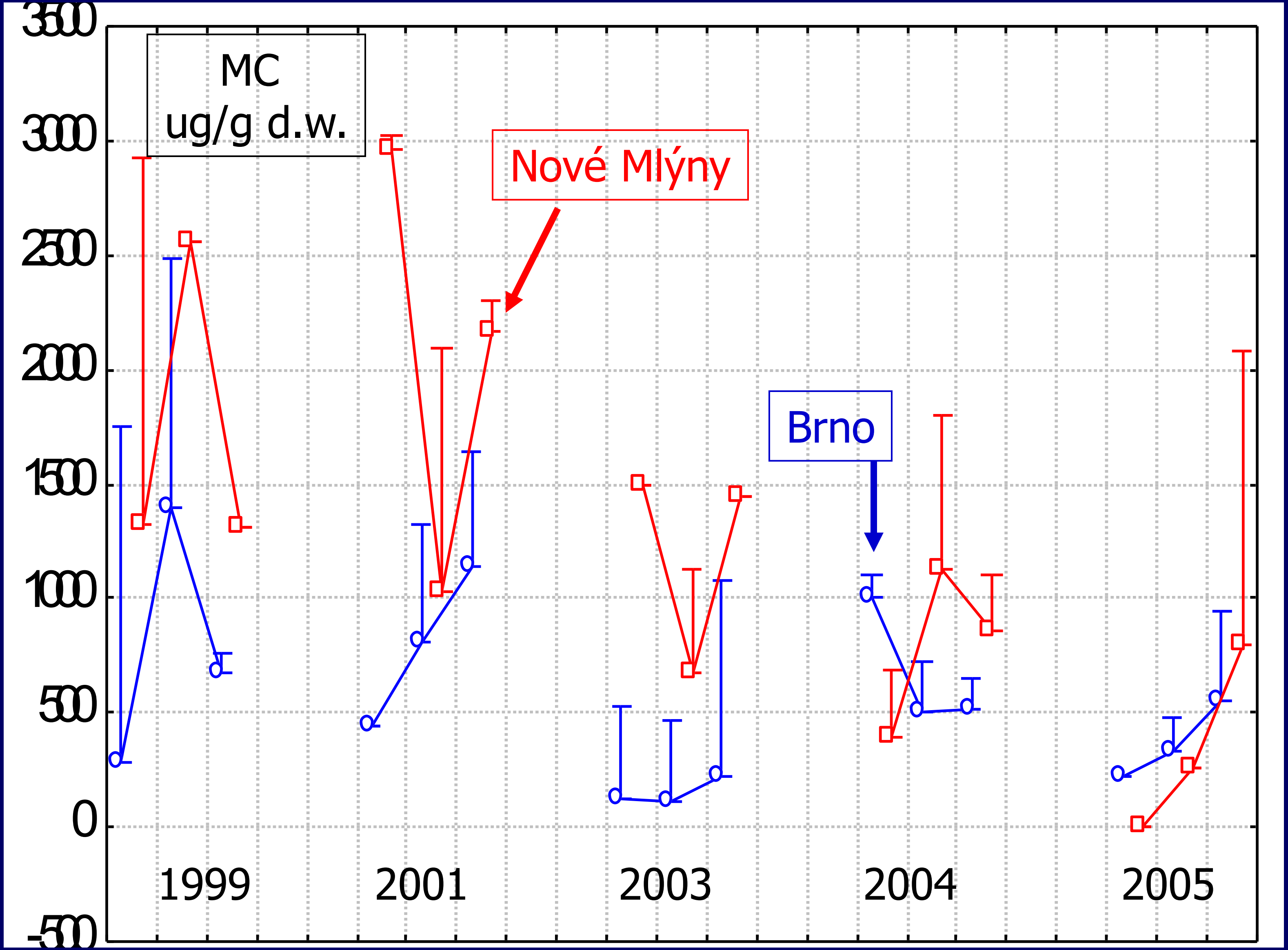
- **dissolved** microcystins in the C.R. (water concentrations)

2004

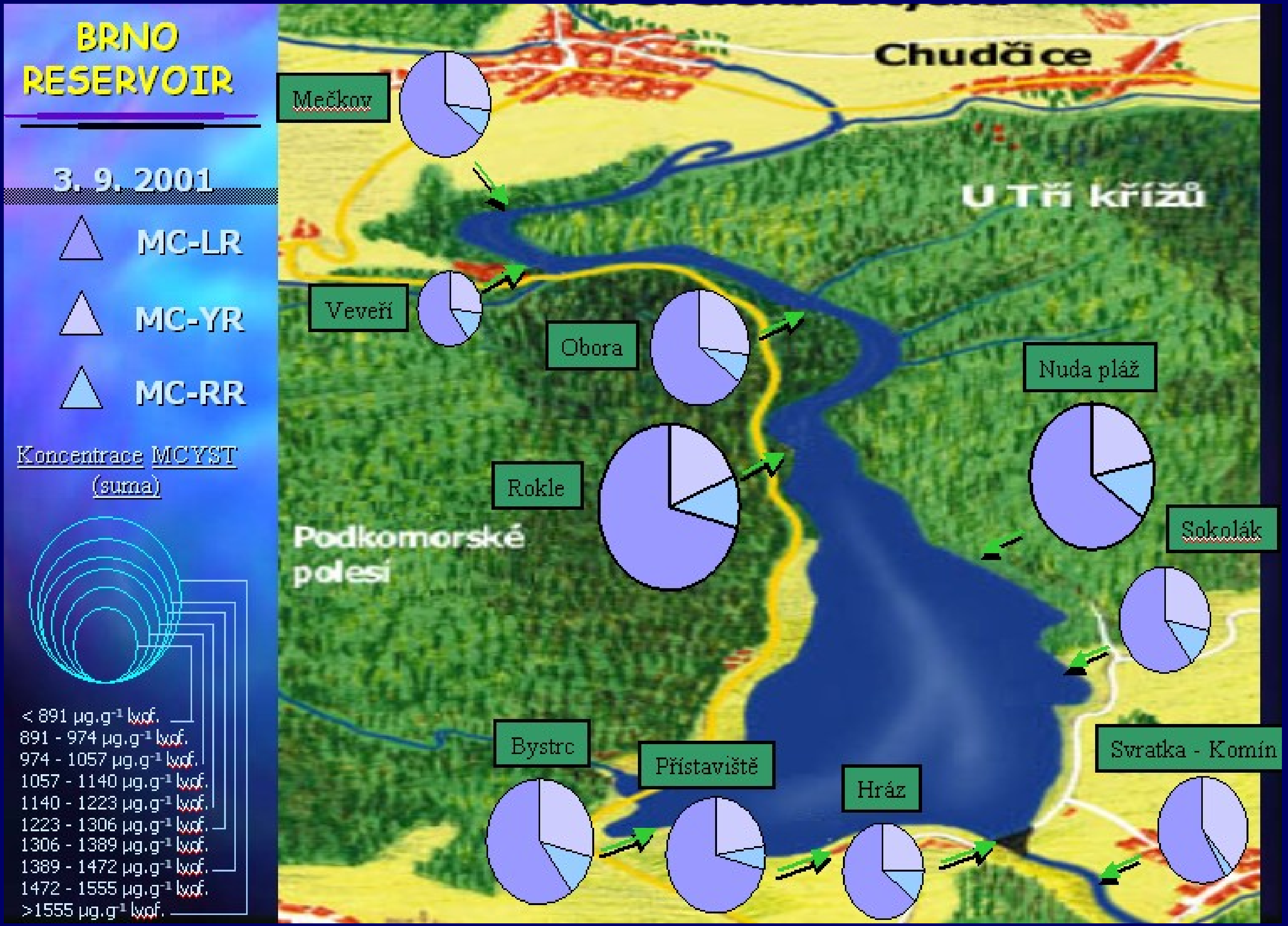
2005



Reservoir seasonal data



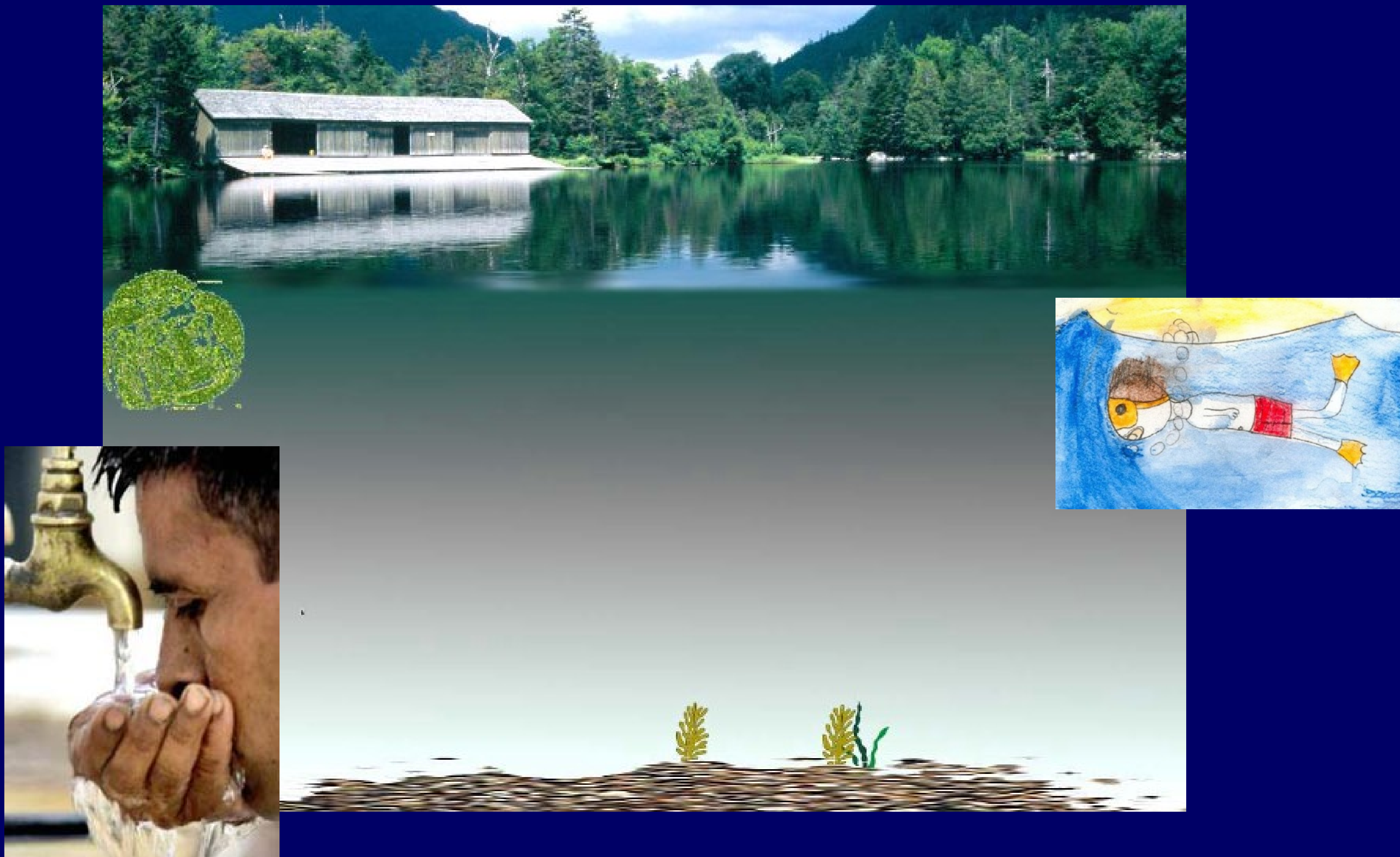
Reservoir spatial variability



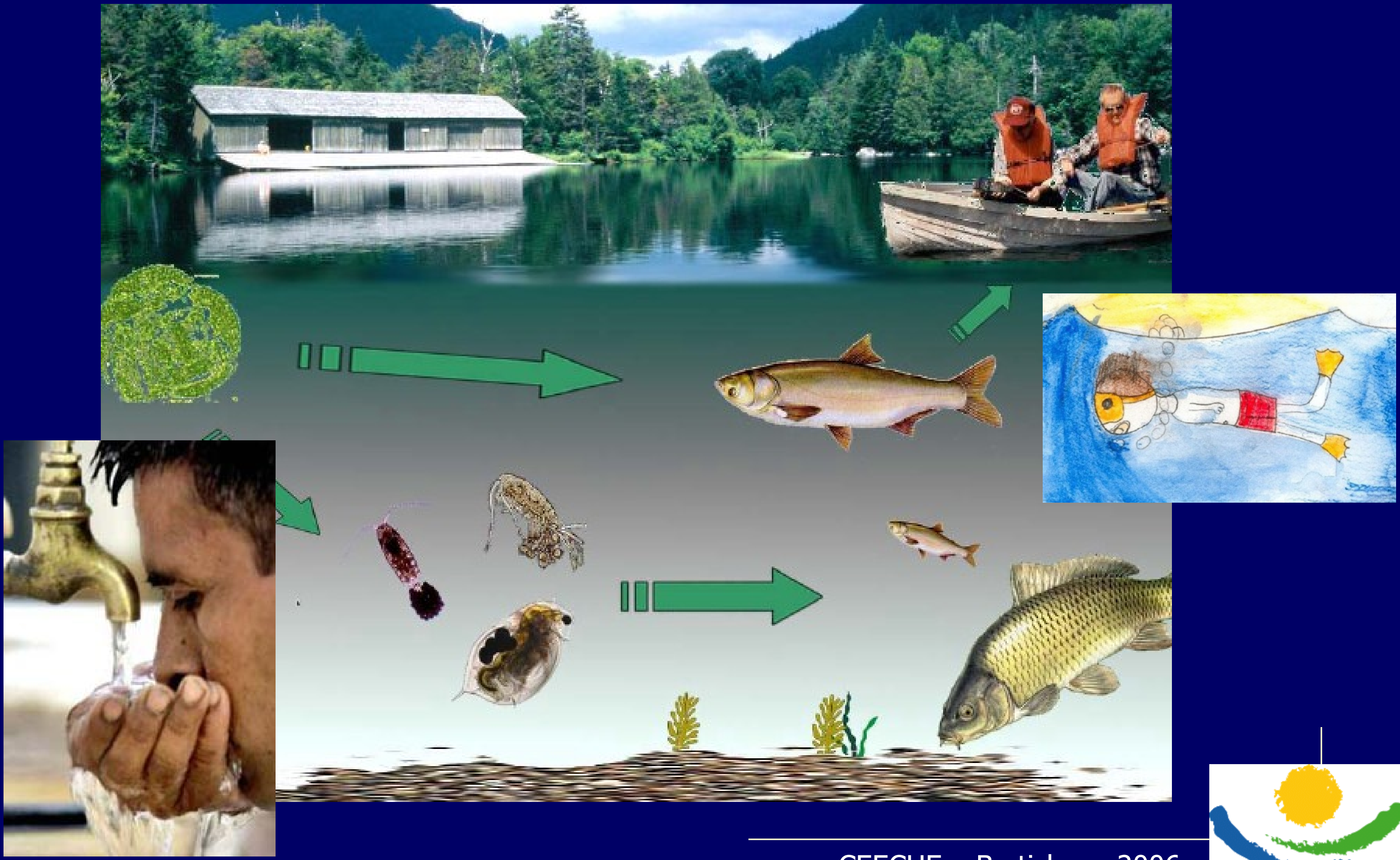
Microcystins

HUMAN HEALTH RISKS

EXPOSURE ROUTES

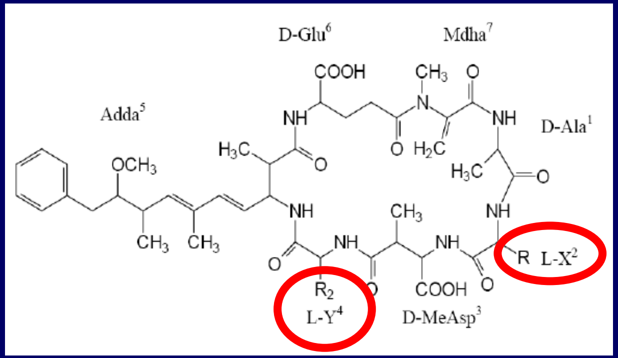


EXPOSURE ROUTES



MICROCYSTINS

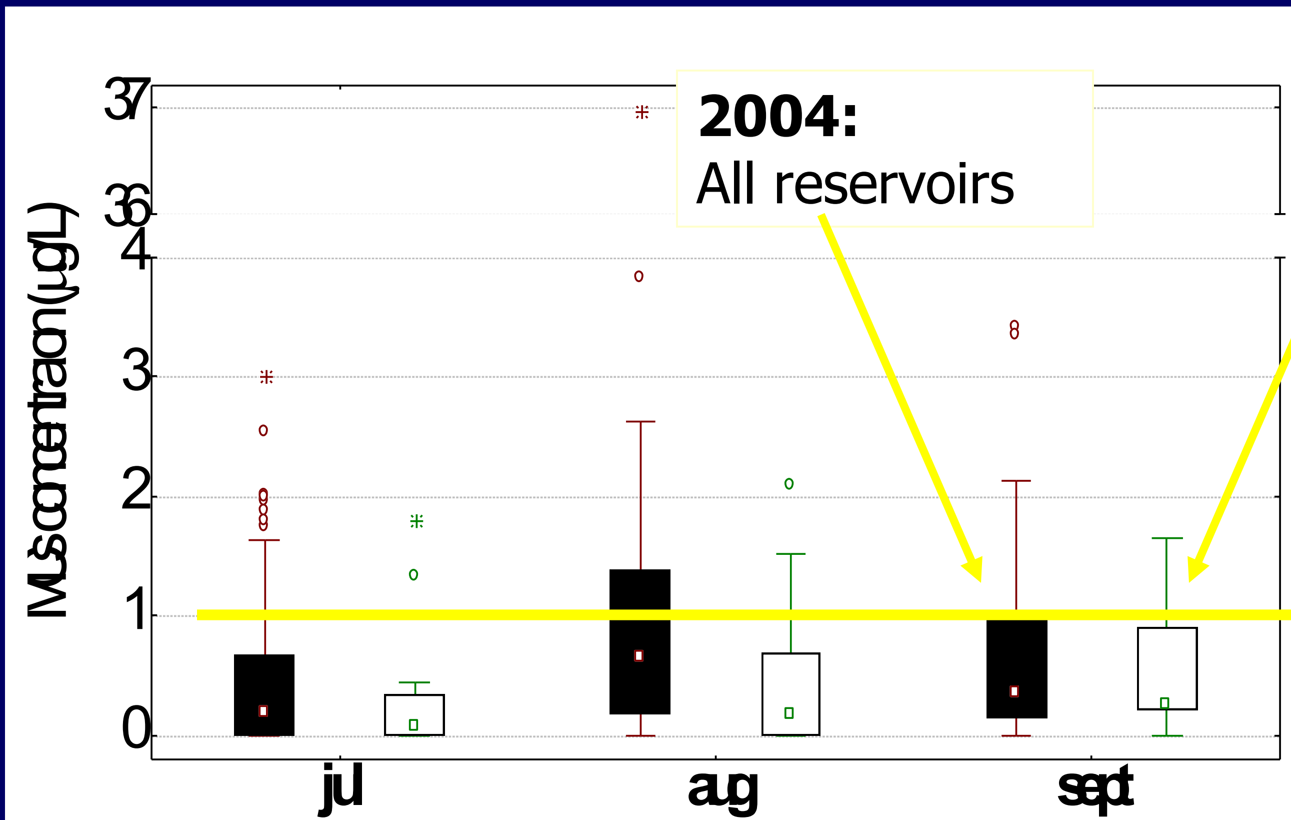
… brief reminder …



- **70 structural variants**:
  MC-LR only (about 30-50% of MCs) considered by WHO
- Human chronic TDI: **0.04 ug/kg b.w. daily**
  - drinking water guideline recommendation: **1 ug/L**
    (usually accepted in national laws worldwide, incl. Czech Rep.)

- **High toxicity** - safety risks: **manipulation regulated**
  United Nations - Bacteriological and Toxin Weapons Convention
  Czech Rep. - Law no. 281/2002 Sb. and 474/2002 Sb.

MCs in drinking water reservoirs



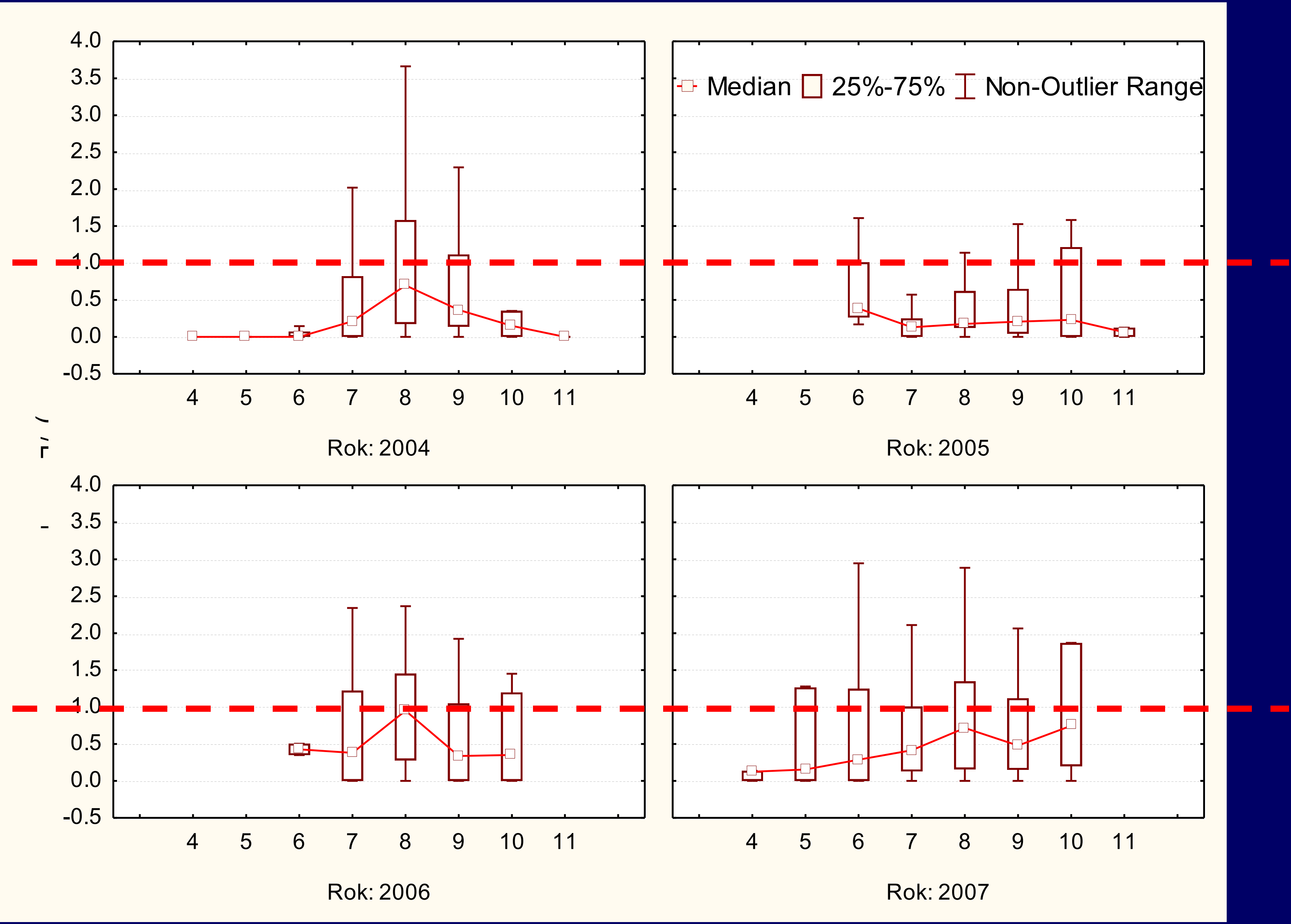
2004:
27 DW reservoirs

WHO recom.
for tap waters
1 ug/L

- **Tap waters up to 8 ug/L (1999)**

  Bláha & Maršálek (2003) Arch Hydrobiol

MCs in drinking water reservoirs



"TOP" MCs **in waters** (Czech Rep. 2004-7)

Lokalita	**Datum odběru**	**MC [ug/L]**
Velké Žernoseky (pískovna)	1.8.2004	37.0
Nechranice	31.7.2004	19.0
Dubice, Česká Lípa	8.9.2004	15.1
Prostřední, Lednice	6.9.2005	18.7
Lučina	19.7.2005	17.3
České údolí VN	8.8.2005	9.3
Plumlov	15.8.2006	24.8
Dalešice	14.7.2006	16.3
Hracholusky	21.8.2006	16.3
Nechranice	26.7.2007	29.8
Skalka	22.8.2007	19.9
Novoveský	2.10.2007	16.3

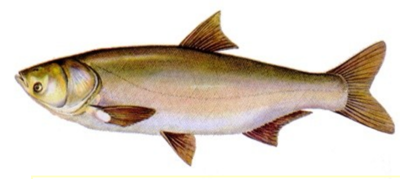
Bláhová et al. (2007). CLEAN - Soil, Air, Water 35(4), 348-354.

Risks of MCs in drinking water supplies

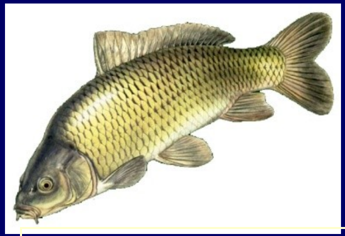
concentration of dissolved MC	20% daily intake from sources of drink.w.		100% daily intake from sources of drink.w.	
	child (25kg)	adult (70kg)	child (25kg)	adult (70kg)
	dose MC($\mu g.kg^{-1}$ live wt. day $^{-1}$) **HI**	dose MC($\mu g.kg^{-1}$ live wt. day $^{-1}$) **HI**	dose MC($\mu g.kg^{-1}$ live wt. day $^{-1}$) **HI**	dose MC($\mu g.kg^{-1}$ live wt. day $^{-1}$) **HI**
median **0.205** µg/L	0.0015 **0.038**	0.0005 **0.014**	0.0075 **0.189**	0.0027 **0.067**
extreme **17.27** µg/L	0.1272 **3.180**	0.0454 **1.136**	0.6359 **15.898**	0.2271 **5.678**

- SIGNIFICANT HEALTH RISKS EXIST !
- To minimize risk
  - Addopt appropriate technologies and treatments
  - Establish routine monitoring of MCs during the season

Accumulation of MCs in fish

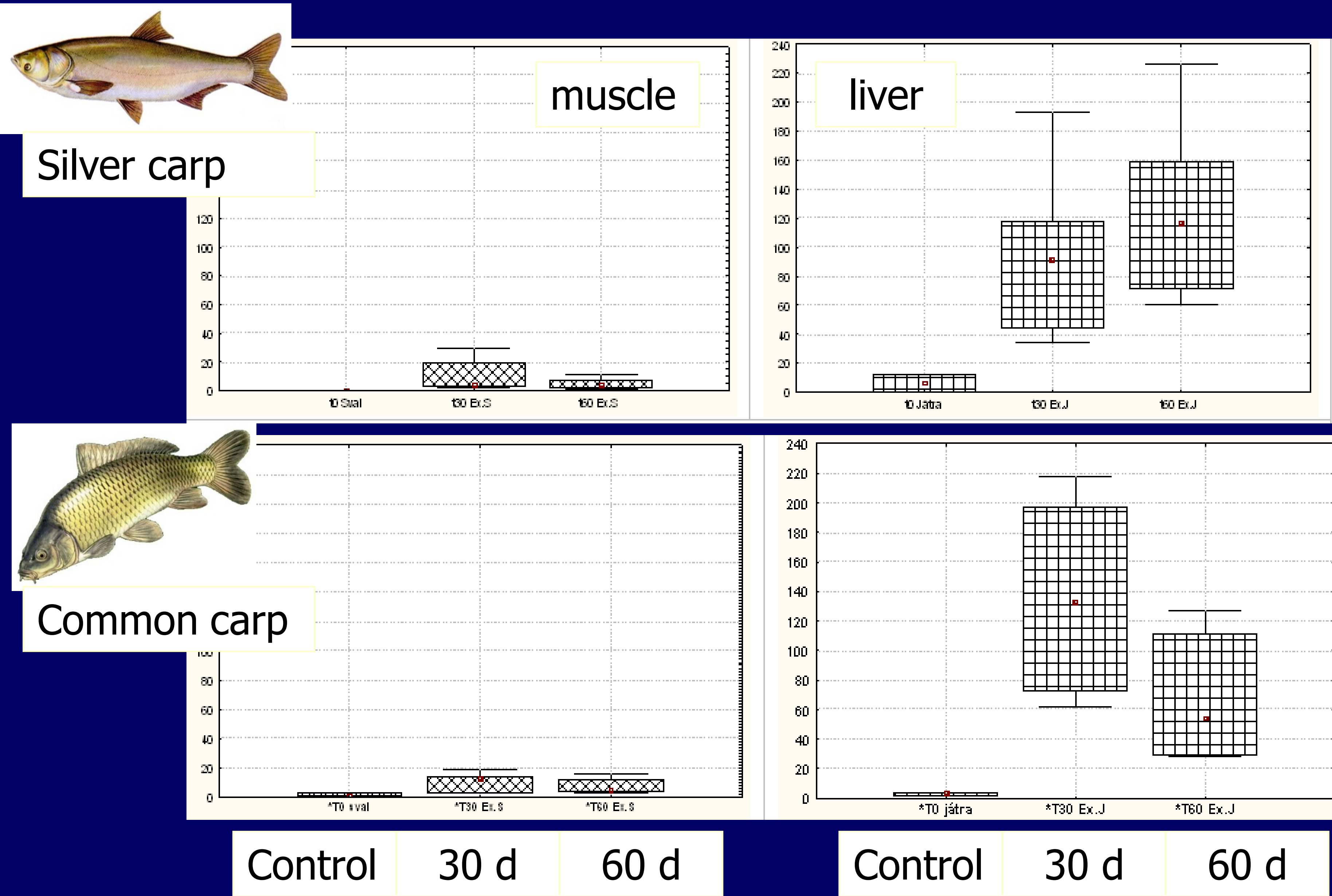


Silver carp

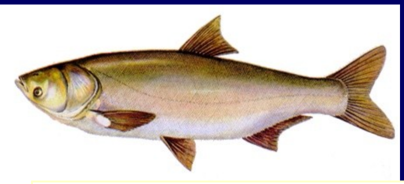


Common carp

Accumulation of MCs in fish



Risk of MCs in edible fish



Silver carp

Common carp

	Max. conc. (dose)	Max. HI	Average conc. (dose)	Average HI
SC: liver	226 ng/g 68 ug	28	106 ng/g 32 ug	13.2
muscle	29 8.8	3.7	8.4 2.5	1.1
CC: liver	217 65	27	132 39	16.5
muscle	18.8 5.6	2.4	8.5 2.6	1.1

100% of food from the contaminated source
avg. person: 60kg, food - 300g *TDI: 0.04 ug/kg/day*

MCs in fish [ng/g f.w.] (Czech Republic reservoirs, 2008)

	Liver		Muscle
	Average	Maximum	
Pike perch	15.6	22.7	0
Amur	2.02	6.1	0
Carp	0.57	1.8	0
Catfish	0	0	0
Silver salmon	4.14	9.5	0

- Exposure to MCs from fish

  Less (if any) significant health risks

RECREATIONAL EXPOSURE

- **Contact dermatitis**

non-specific (!!!!) responsible agents (? MCs, LPS?)

- **Toxins enter the body**

(MCs risk assessment possible)

Risks of MCs: recreational exposure
(US EPA R.A.methodology)

biomass-bound MC	7 days per year (chronic exposure)				1 day acute exposure			
	Guidance level 2 100 000 cells/mL		Guidance level 3 2 000 000 cells/ml		Guidance level 2 100 000 cells/mL		Guidance level 3 2 000 000 cells/ml	
	child (25kg/80ml.h^{-1})	adult (70kg/50ml.h^{-1})	**child** (25kg/80ml.h^{-1})	adult (70kg/50ml.h^{-1})	**child** (25kg/80ml.h^{-1})	adult (70kg/50ml.h^{-1})	**child** (25kg/80ml.h^{-1})	adult (70kg/50ml.h^{-1})
	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**	MC dose (µg.kg^{-1}bw. day^{-1}) **HI**
median concentration **348** µg/g dw	0.00019 **0.005**	0.00004 **0.001**	0.00389 **0.097**	0.00087 **0.022**	0.01013 **0.253**	0.00226 **0.057**	0.20268 **5.067**	0.04524 **1.1310**
extreme concentration **3945** µg/g dw	0.00220 **0.055**	0.00049 **0.012**	0.04406 **1.102**	0.00984 **0.246**	0.11488 **2.872**	0.02564 **0.641**	2.29757 **57.439**	0.51285 **12.823**

- Recreation exposure
  -> significant risks of MCs

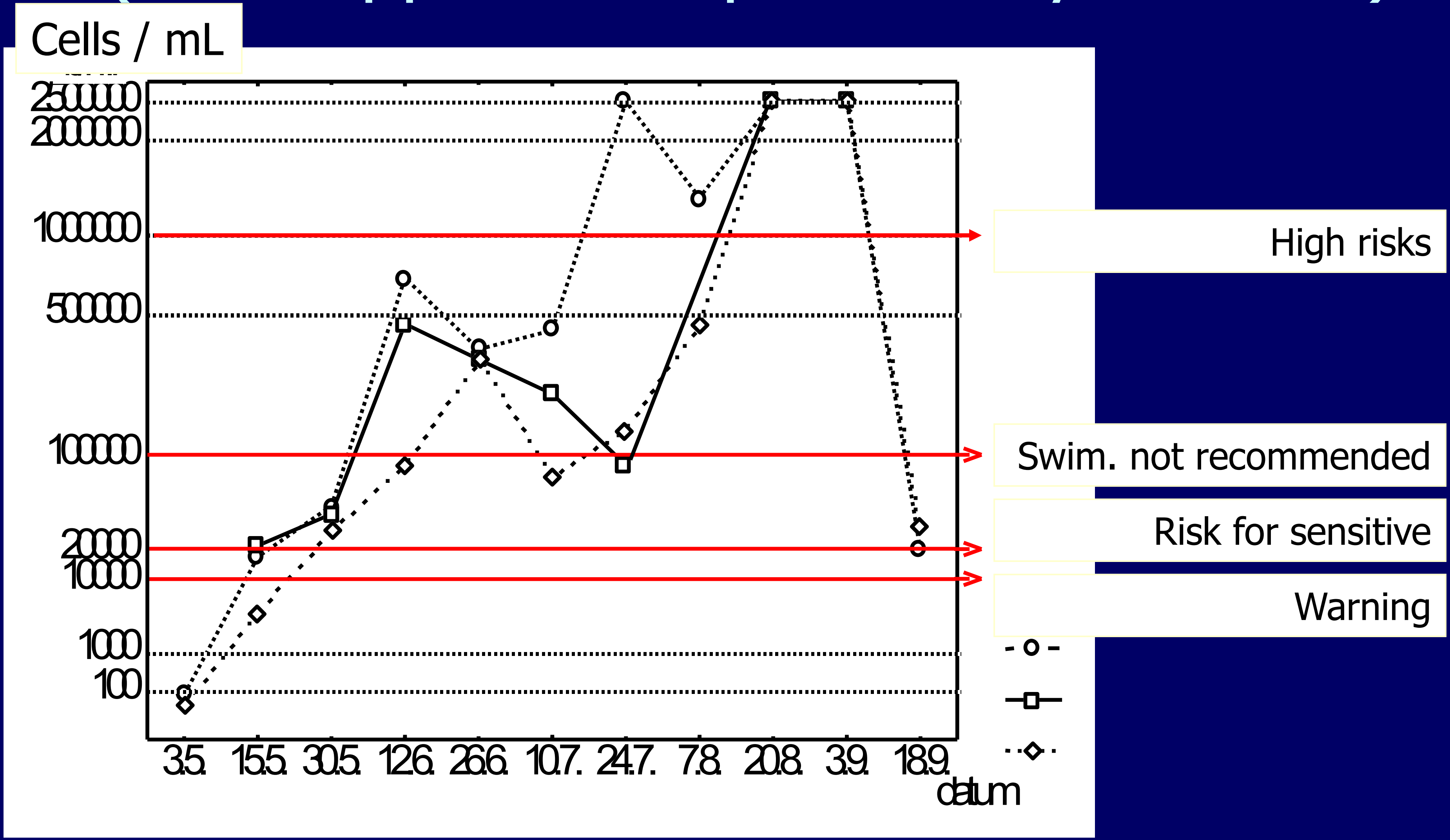
Lipopolysaccharides ?

- **Pyrogenicity of LPS**
  significant in water blooms
  (less in lab cultures)

Sample	Endotoxin activity	
	(EU mg^{-1} d.w.)	(EU mg^{-1} LPS)
Green alga		
P. subcapitata	0	0
Cyanobacterial culture		
P. agardhii	301	35 456
A. flos-aquae	426	38 399
M. aeruginosa	257	36 809
T. variabilis	2 518	270 848
Water bloom		
Planktothrix sp.	61	46 959
Aphanizomenon sp.	7 895	918 118
M. aeruginosa	799	199 895
Microcystis sp.	989	449 576
Anabaena sp.	277	48 699
Heterotrophic bacteria		
E. coli	14 692	1 347 959
K. intermedia	1 702	239 770
P. putida	11 392	1 294 592
P. fluorescens	55	6 669

Bernardová et al. 2008 J Appl Toxicol

Toxic cyanobacteria in recreational reservoirs (WHO approach - „preliminary caution")



Summary
MCs and the health risks

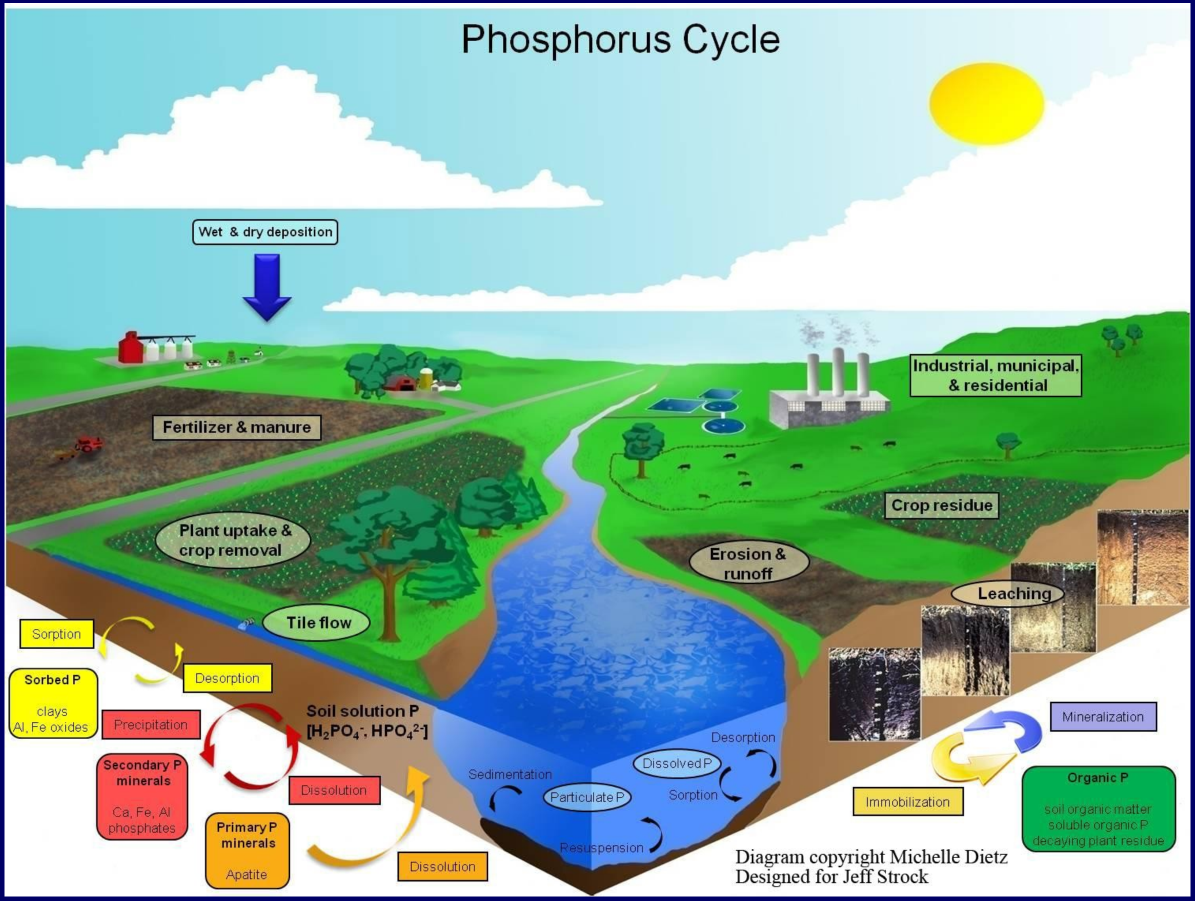
- MCs present in 80-90% of reservoirs
- High MCs concentrations

- **All exposure routes pose significant health risks** under certain scenarios

  ! Recreation, Drinking water

  (MCs accumulated in fish - less important)

How to „manage“ toxic blooms



Successful solution:

Always reservoir-specific

Combinations of methods of PREVENTION + REMEDIATION

How to manage toxic blooms?

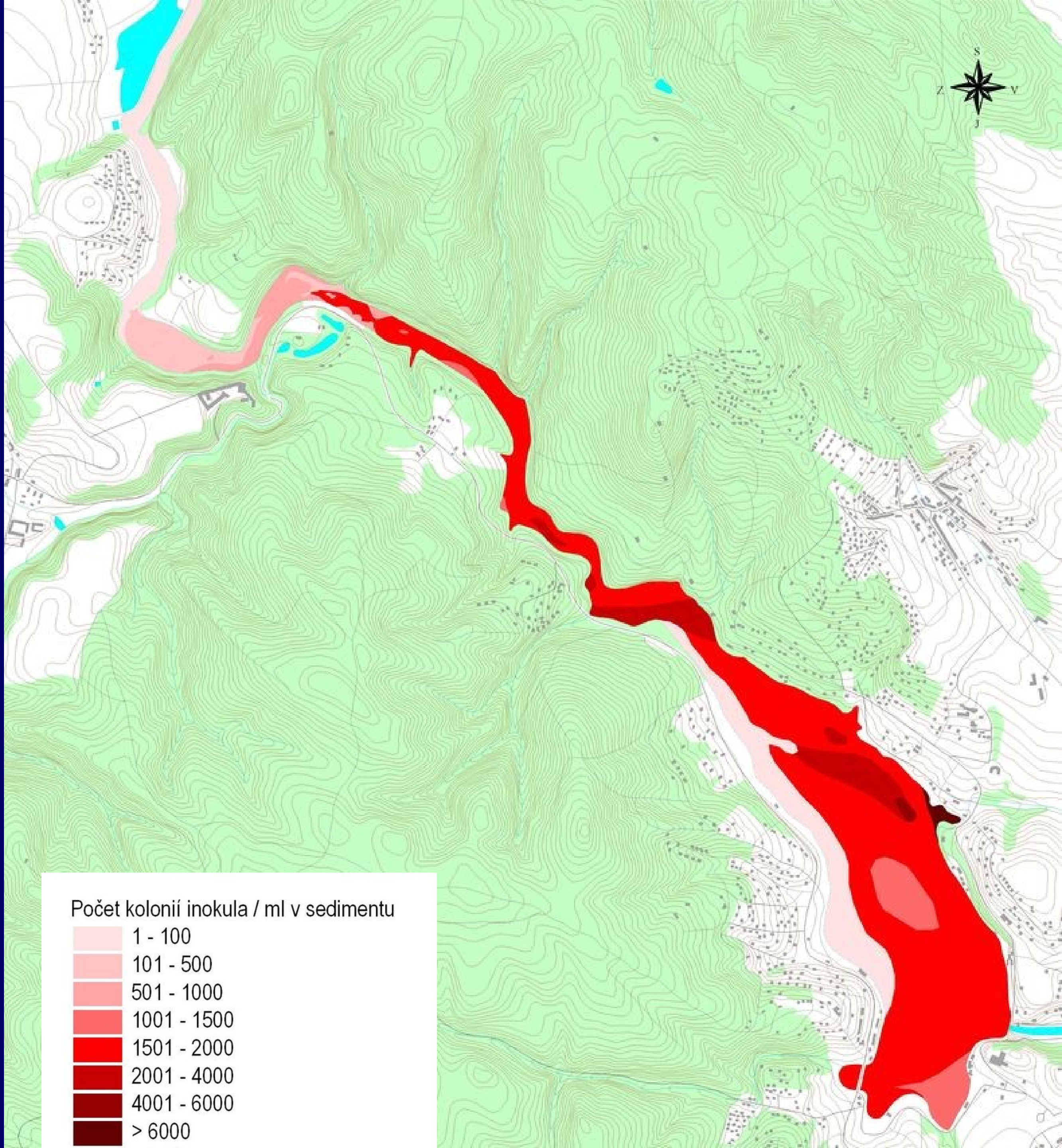
- Limit **nutrient sources** → **river basin (upstream)** / → **in the reservoir**
- **Cyanocides** (chemical, natural - e.g. Humic acids)
- **Flocculants** $Al(OH)_3$ …
- **Biological control** (… planktophagous fish)
- **Others** (mechanical removal, ultrasonic …)

Example

Brno reservoir

sources of cyanobacteria

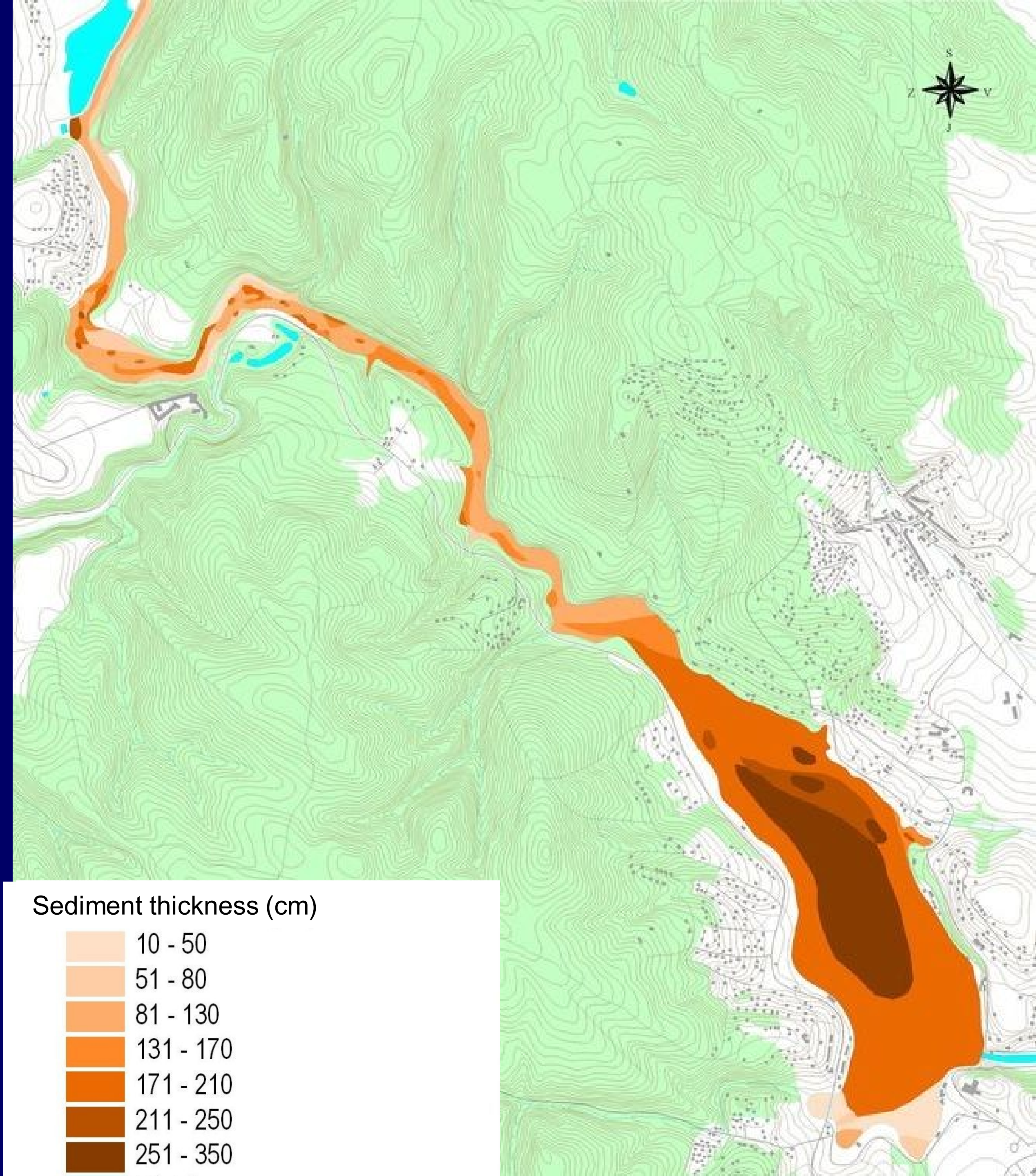
(colonies
in sediment)



Sources of nutrients

... in the reservoir

(sediments up to 3 m thickness)



Sources of nutrients

… upstream

- several small towns & villages (no WWTPs)

- REMOVAL OF Phosphorus from river basin

Lower contamination (P-free)

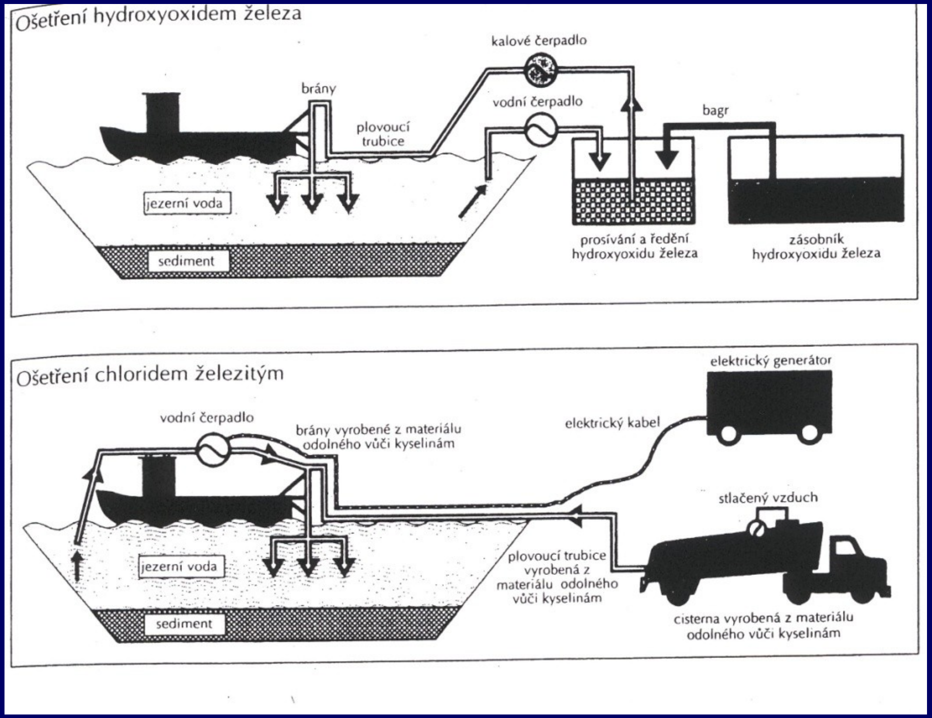
Bulding
+ improvements of WWTPs

Revitalizations (wetlands)

- Phosphorus immobilization „within“ the lake

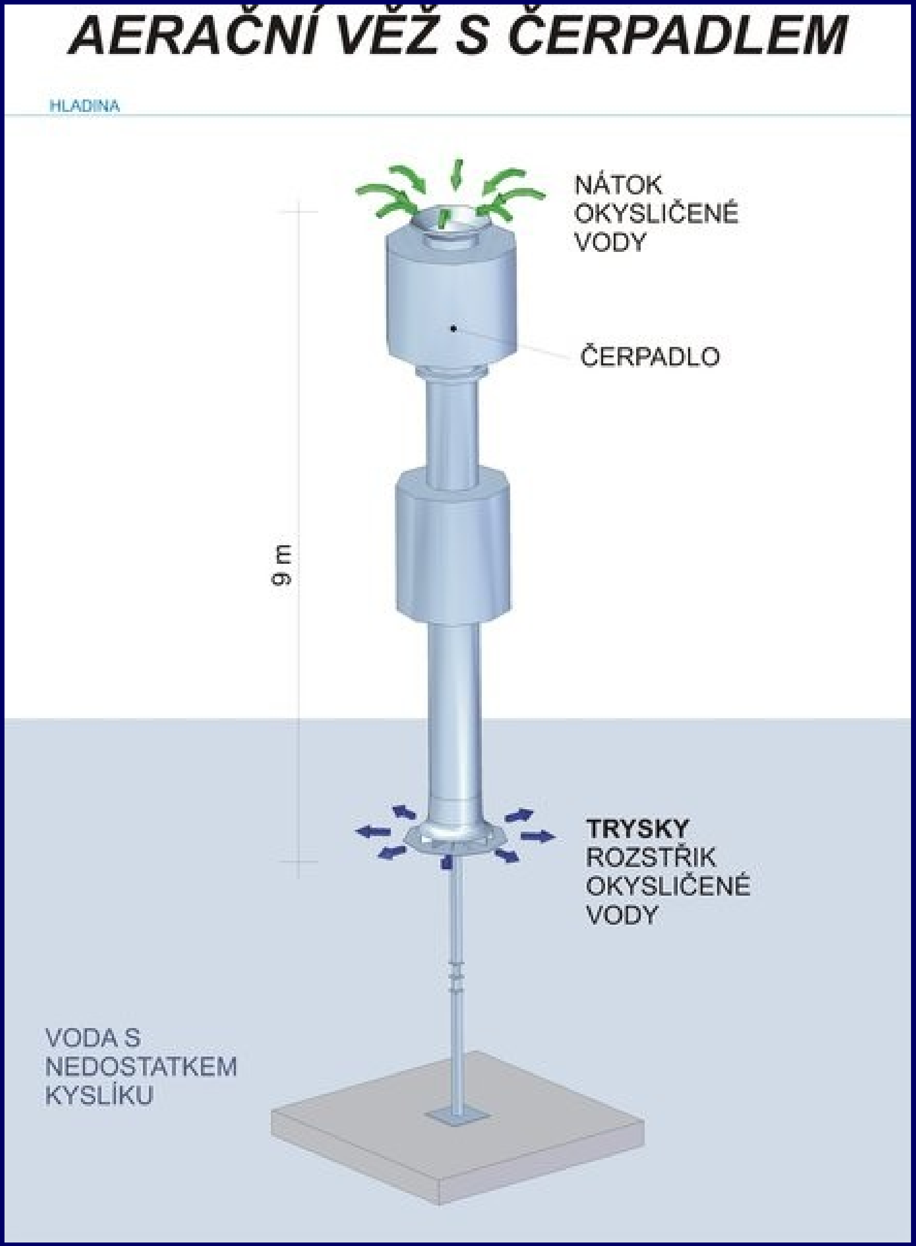
Draining the lake:
Surface chemistry at sediments

Flocculation of P in the river or lake

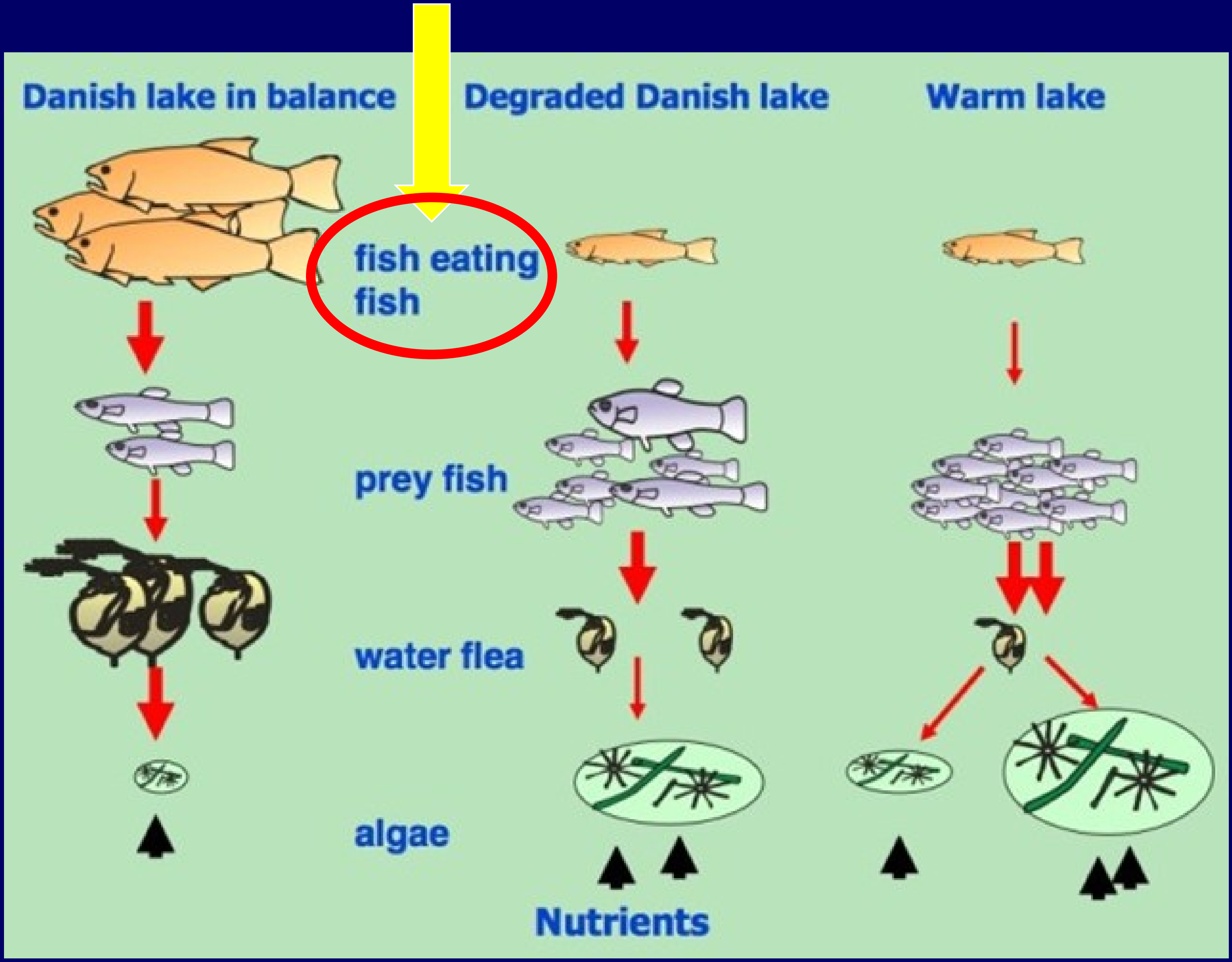


- Aeration towers

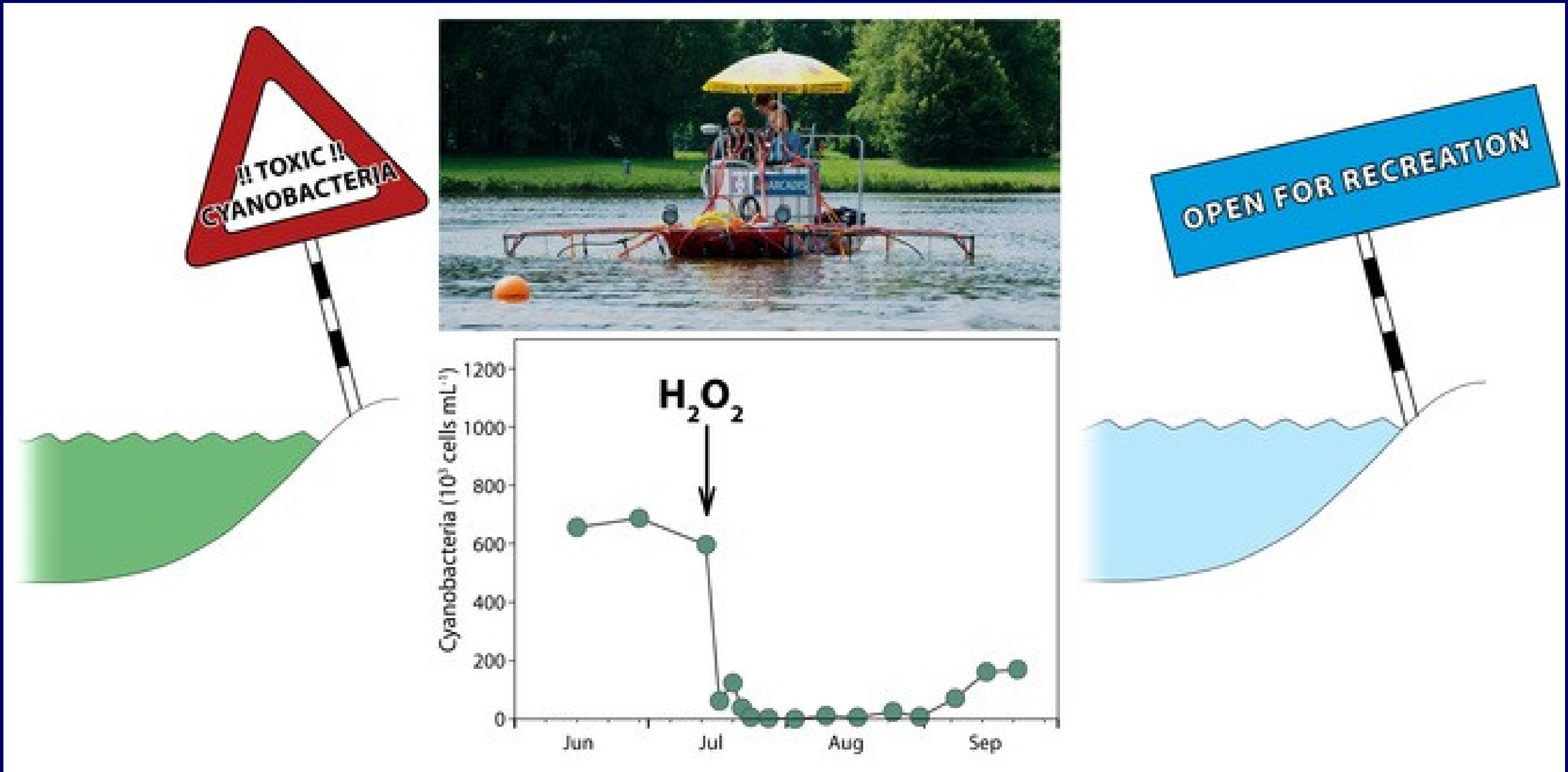
Mechanical mixing, deep water oxidation



- Biological control: manipulation of food chains



- Cyanocide application



POSSIBLE DRAWBACKS:
accidental release of toxins from dead cells → drinking water!

- Mechanical collection of water blooms

CONCLUSIONS

- Eutrophication causes complex risks with complicated management

1) Ecological risks

- **Loss of diversity** … followed by losses of functioning
- **Secondary changes in the environment**
  - hydrochemistry (pH, O_2)
  - loss on natural habitats (makrophytes…)
  - new conditions (associated bacteria - patogenic ?)
- **Susceptibility to catastrophes**

- Direct ecotoxicity of individual (known) cyanotoxins seems to be less important

CONCLUSIONS

2) HEALTH RISKS OF CYANOTOXINS

- **Lower importance** - known toxins (MC) in food chains *(fish)*
- **MC in drinking water** - higher costs needed for management and control
- **Important risk** - recreation !

- **New and less explored risks**

  - new toxins (and their mixtures) - LPS, CYN ...

  - water blooms as „sorbents" of other toxins (metals, POPs)