# Suppression of cyanobacterial blooms using hydrogen peroxide: effects on phytoplankton, zooplankton and cyanotoxins

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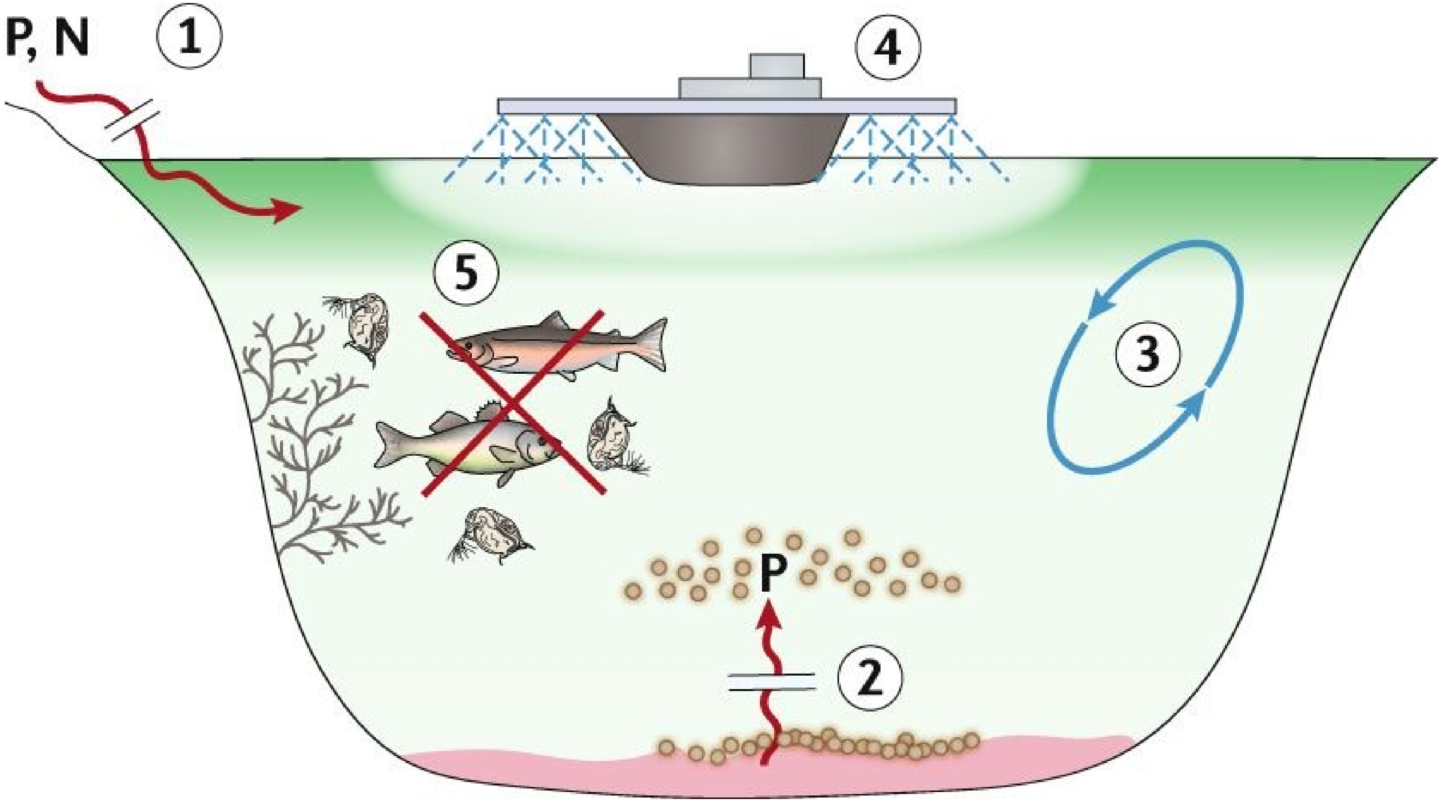
DEMOKRITOS

# Lakes with cyanobacterial blooms: often negative bathing advice



Do not swim!
Blue-greens!

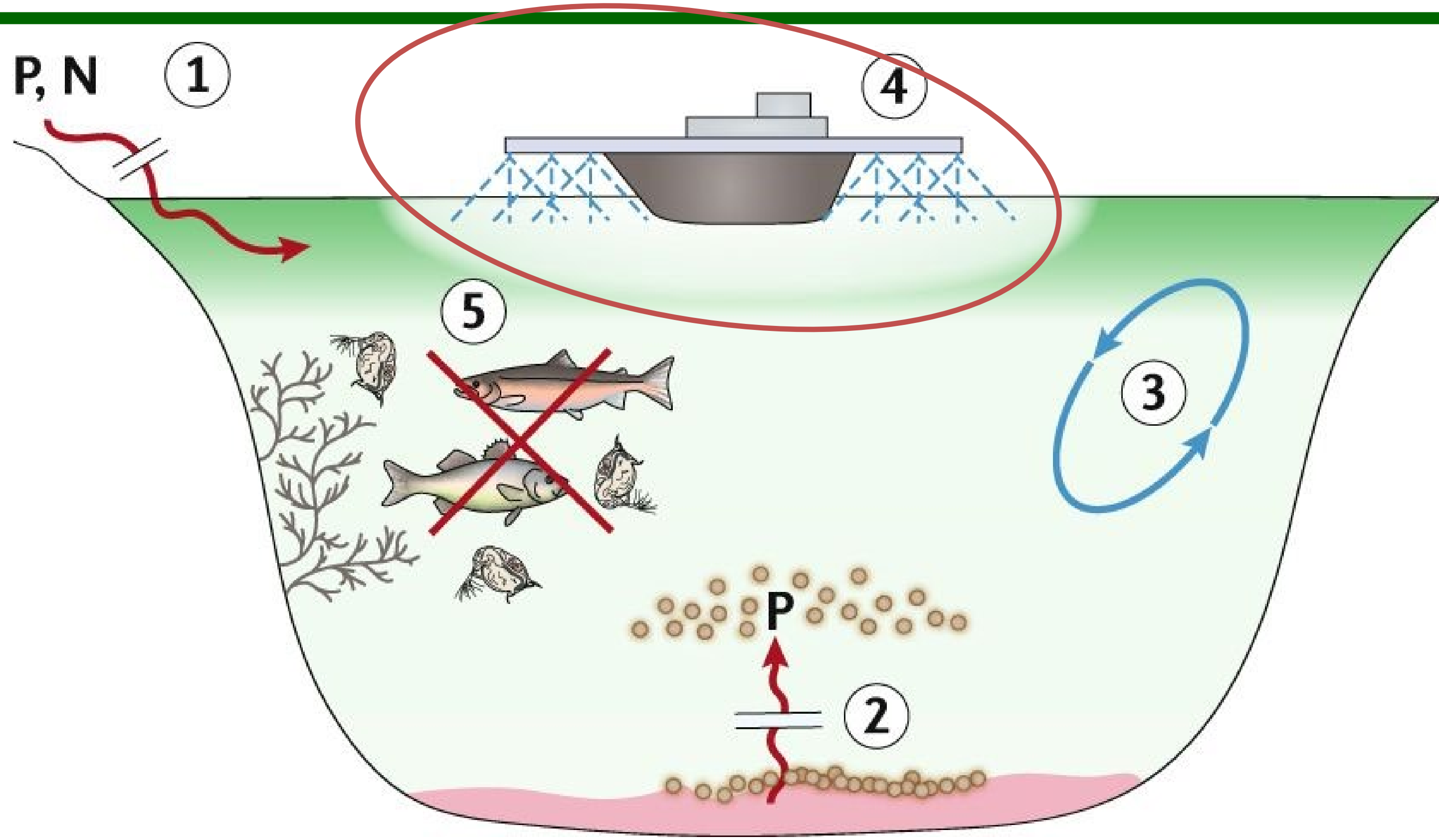
# Strategies for the prevention and control of cyanobacterial blooms




(1) Nutrient management tackles the root of the problem through the reduction of external nutrient inputs.
(2) Addition of phosphate- binding clays and capping of sediments remove nutrients from the water column and store them in the sediment.
(3) Artificial mixing of lakes suppresses buoyant cyanobacteria.
(4) Chemical control can be used in emergencies.
(5) Manipulation of aquatic food webs by removal of planktivorous fish increases zooplankton populations that graze on cyanobacteria.

*Huisman et al. 2018 Nature Rev. Microbiol.*

# Strategies for the prevention and control of cyanobacterial blooms

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# The use of hydrogen peroxide to control cyanobacteria

- $H_2O_2$ breaks down in 1-2 days (2 $H_2O_2$ → 2 $H_20$ + $O_2$)
- Selective killing of cyanobacteria, other phytoplankton are less sensitive
- Effective in a very low concentration (~2.5 mg/l $H_2O_2$): a 3% solution is diluted 15.000x

*Matthijs et al. 2016 Aquat. Ecol.*

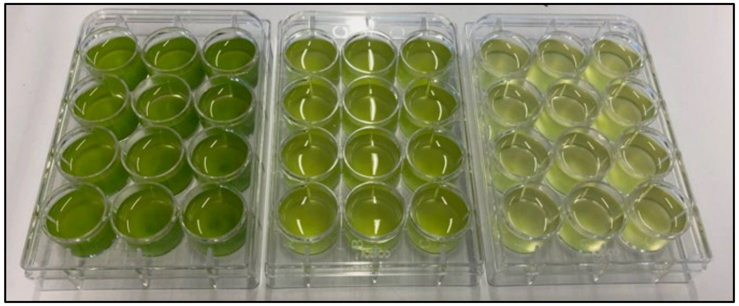
# Research question

What are the effects of $H_2O_2$ on cyanobacteria, algae, zooplankton and cyanotoxins?

(lab studies, whole lake treatments)




# Laboratory studies on the effects of $H_2O_2$



*24-h toxicity laboratory experiments*

## Nine phytoplankton species

**Cyanobacteria**

*Planktothrix agardhii*

*Microcystis aeruginosa*

*Anabaena* sp.

**Green algae**

*Kirchneriella contorta*

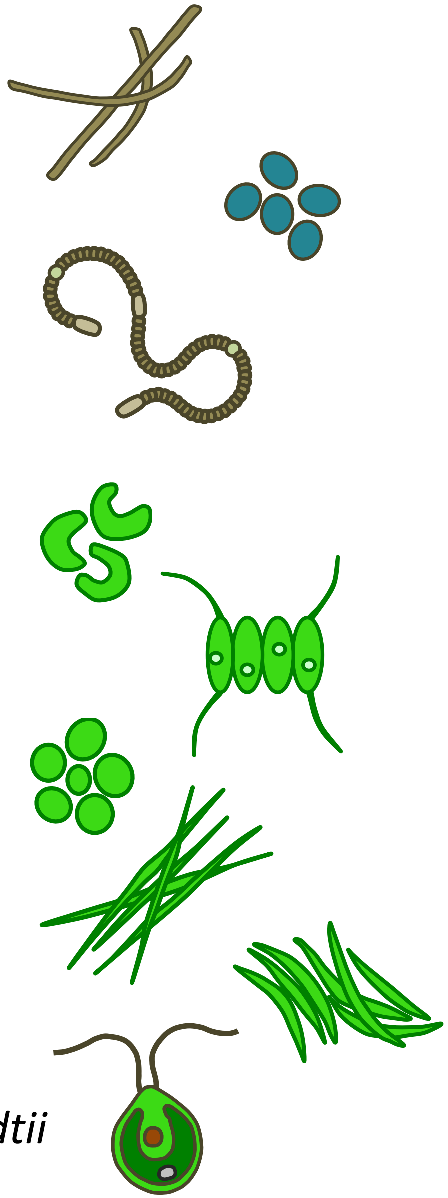
*Desmodesmus armatus*

*Chlorella sorokiniana*

*Monoraphidium griffithii*

*Ankistrodesmus falcatus*

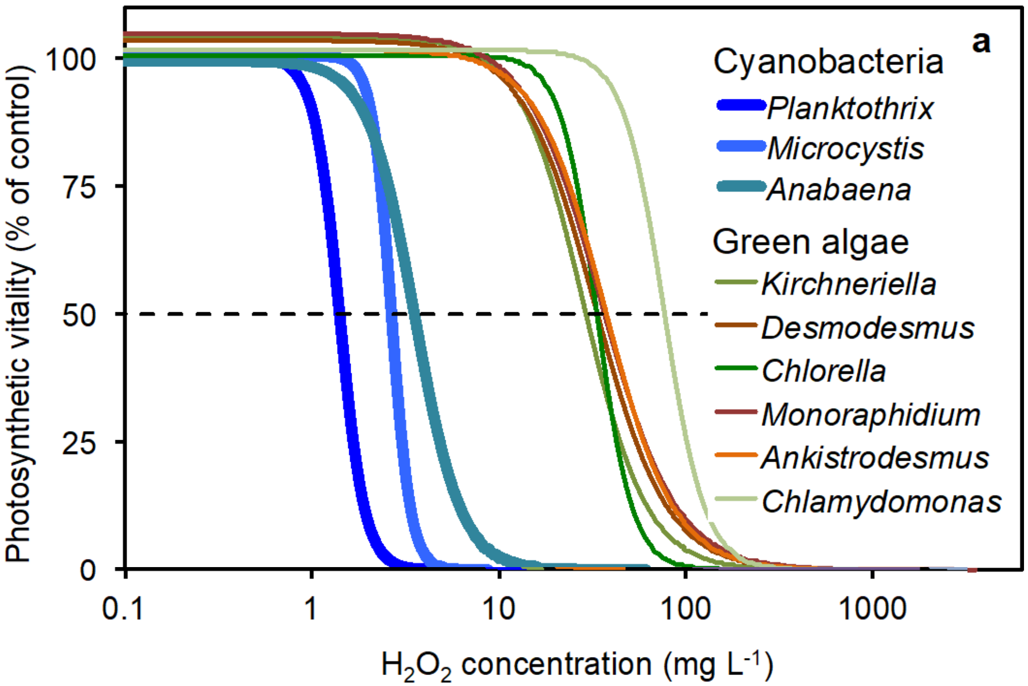
*Chlamydomonas reinhardtii*



All species were cultured under axenic laboratory conditions

*Weenink et al. 2022 Water Research*

# 24-h toxicity laboratory experiments - Results




| PHYTOPLANKTON | $EC_{50}$ (mg $L^{-1}$)1 |
|---|---|
| ***Cyanobacteria*** | |
| *Planktothrix agardhii* | 1.39 ± 0.30 |
| *Microcystis aeruginosa* | 2.62 ± 0.15 |
| *Anabaena* sp. | 3.49 ± 0.63 |
| ***Green algae*** | |
| *Kirchneriella contorta* | 27.7 ± 4.5 |
| *Desmodesmus armatus* | 31.9 ± 5.2 |
| *Chlorella sorokiniana* | 32.6 ± 4.1 |
| *Monoraphidium griffithii* | 34.4 ± 6.4 |
| *Ankistrodesmus falcatus* | 36.2 ± 3.7 |
| *Chlamydomonas reinhardtii* | 74.4 ± 5.8 |

Affected species < 5 mg $L^{-1}$ $H_2O_2$

- *Planktothrix agardhii*
- *Microcystis aeruginosa*
- *Anabaena* sp.

No green algae affected

*Weenink et al. 2022 Water Research*

24-h toxicity laboratory experiments

**Eight zooplankton species**

*Ceriodaphnia dubia* (Cladocera)

*Brachionus calyciflorus* (Rotifera)

*Daphnia pulex* (Cladocera)

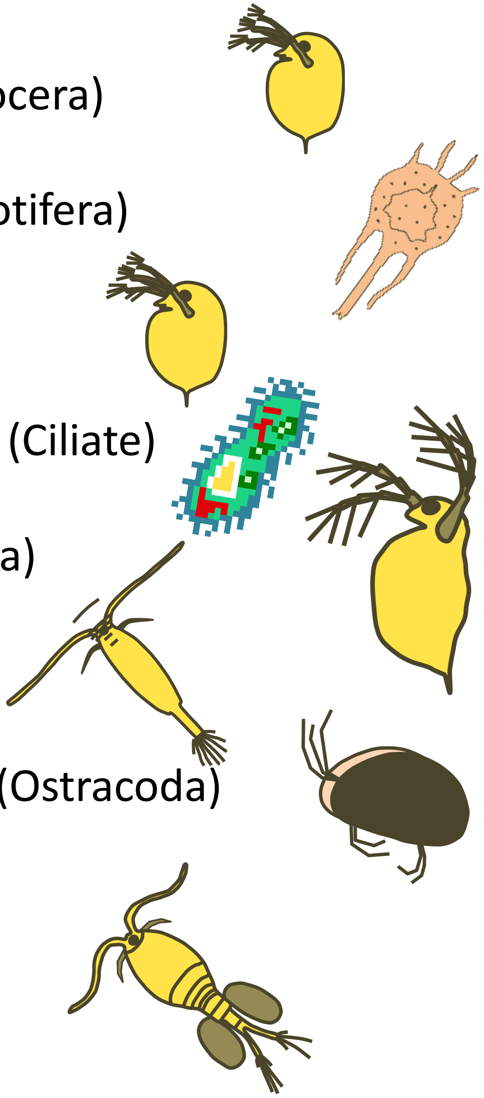
*Tetrahymena thermophila* (Ciliate)

*Daphnia magna* (Cladocera)

*Calanoid* (copepoda)

*Heterocypris incongruens* (Ostracoda)

*Cyclopoid* (copepoda)

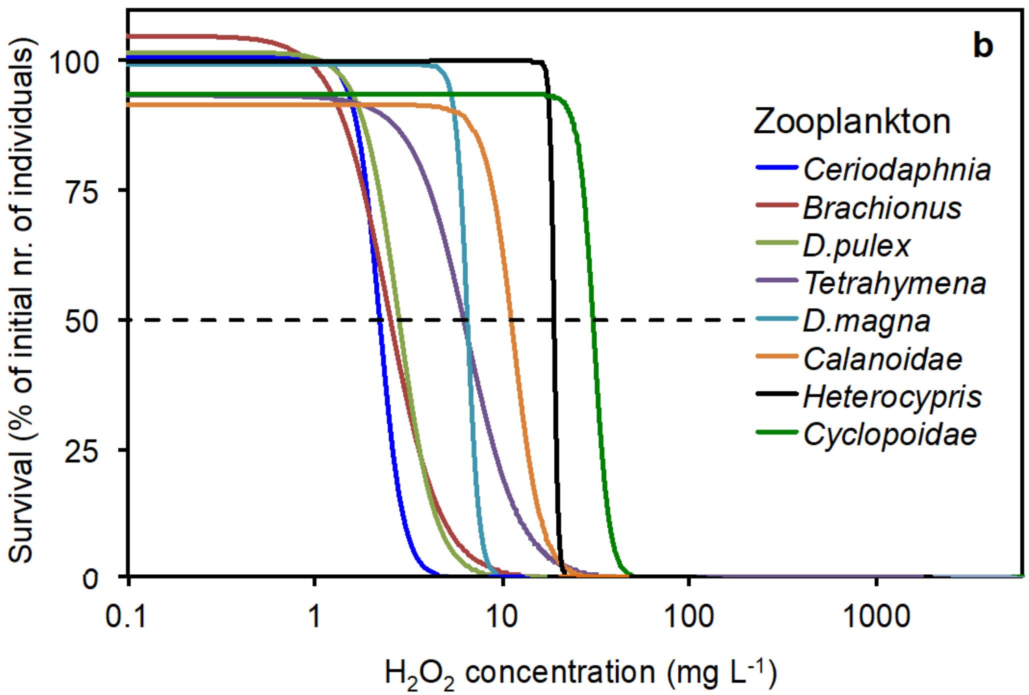


Most species were cultured under laboratory conditions

Copepods were collected from the field

*Weenink et al. 2022 Water Research*

# 24-h toxicity laboratory experiments - Results




| ZOOPLANKTON | $LC_{50}$ (mg $L^{-1}$) |
|---|---|
| *Ceriodaphnia dubia* | 2.20 ± 0.14 |
| *Brachionus calyciflorus* | 2.45 ± 0.40 |
| *Daphnia pulex* | 2.79 ± 0.41 |
| *Tetrahymena thermophila* | 6.50 ± 0.55 |
| *Daphnia magna* | 6.51 ± 0.19 |
| *Calanoid* copepoda | 11.5 ± 1.1 |
| *Heterocypris incongruens* | 18.9 ± 0.3 |
| *Cyclopoid* copepoda | 30.8 ± 3.1 |

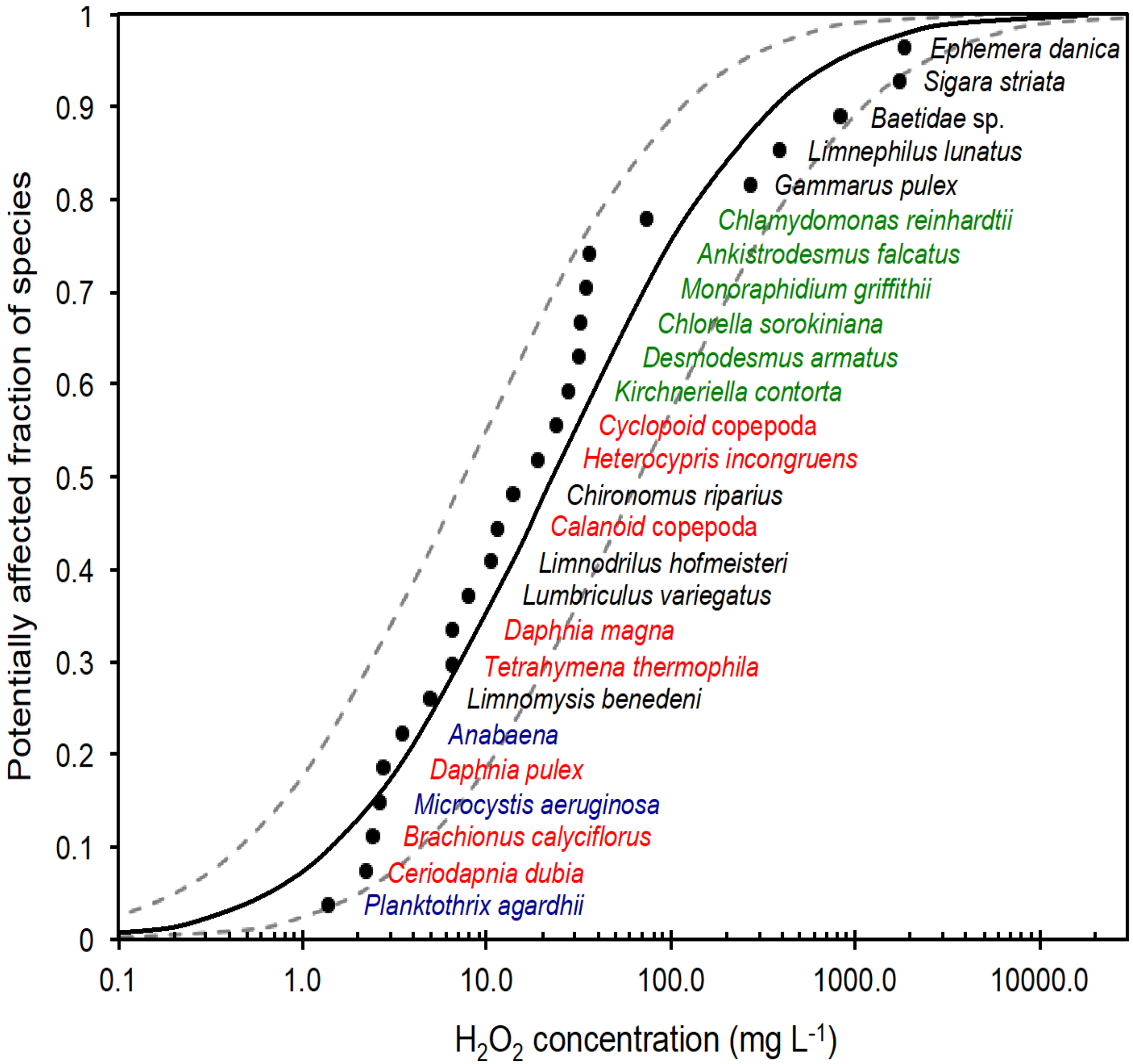
Affected species < 5 mg $L^{-1}$ $H_2O_2$

- *Ceriodaphnia dubia* (relatively small cladoceran)
- *Brachionus calyciflorus* (rotifer)
- *Daphnia pulex* (relatively small cladoceran)

*Weenink et al. 2022 Water Research*

# Species sensitivity distribution (SSD)

The $LC_{50}$ and $EC_{50}$ values were used to construct an SSD, using an online SSD Generator




SSD: a presentation of toxicity data in order to predict effects on ecosystem level

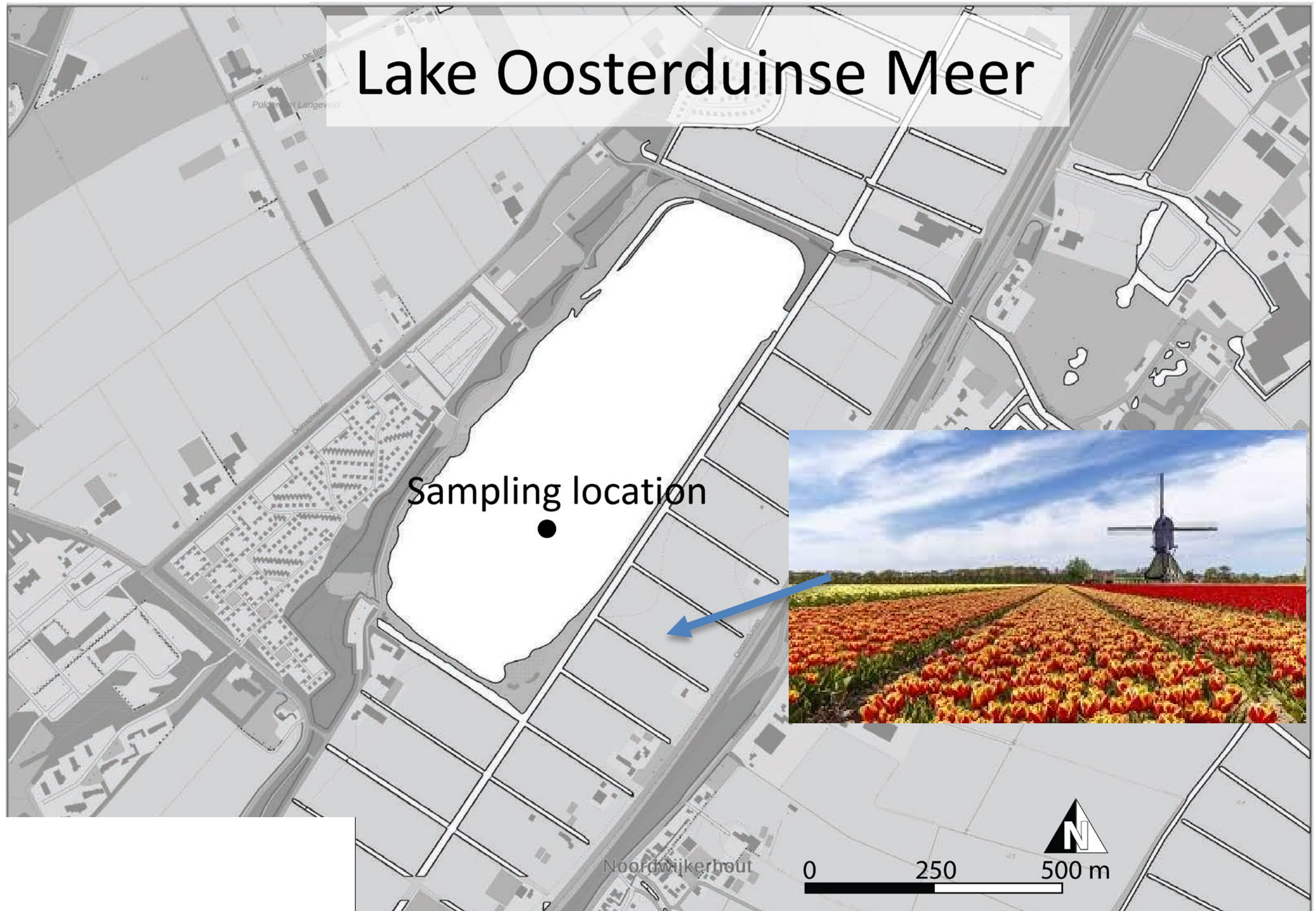
*Blue - cyanobacteria*
*Red - zooplankton*
*Green - green algae*
*Black - macroinvertebrates*

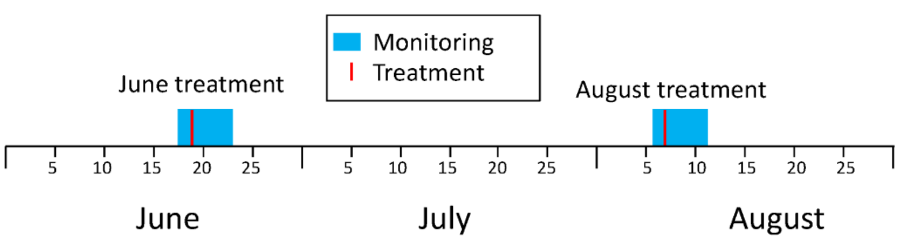
*Weenink et al. 2022 Water Research*

# Field studies

What are the effects of $H_2O_2$ on cyanobacteria, algae, zooplankton and cyanotoxins? (whole lake treatments)

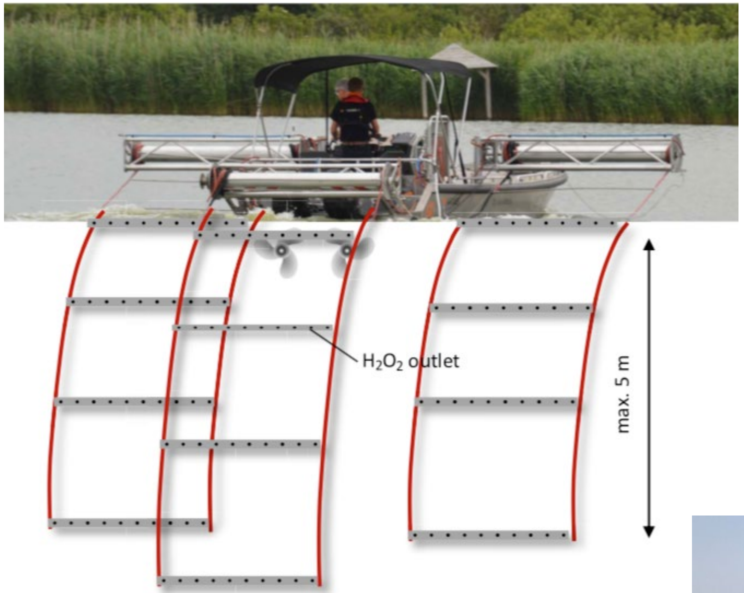
# Field studies in Lake Oosterduinse Meer

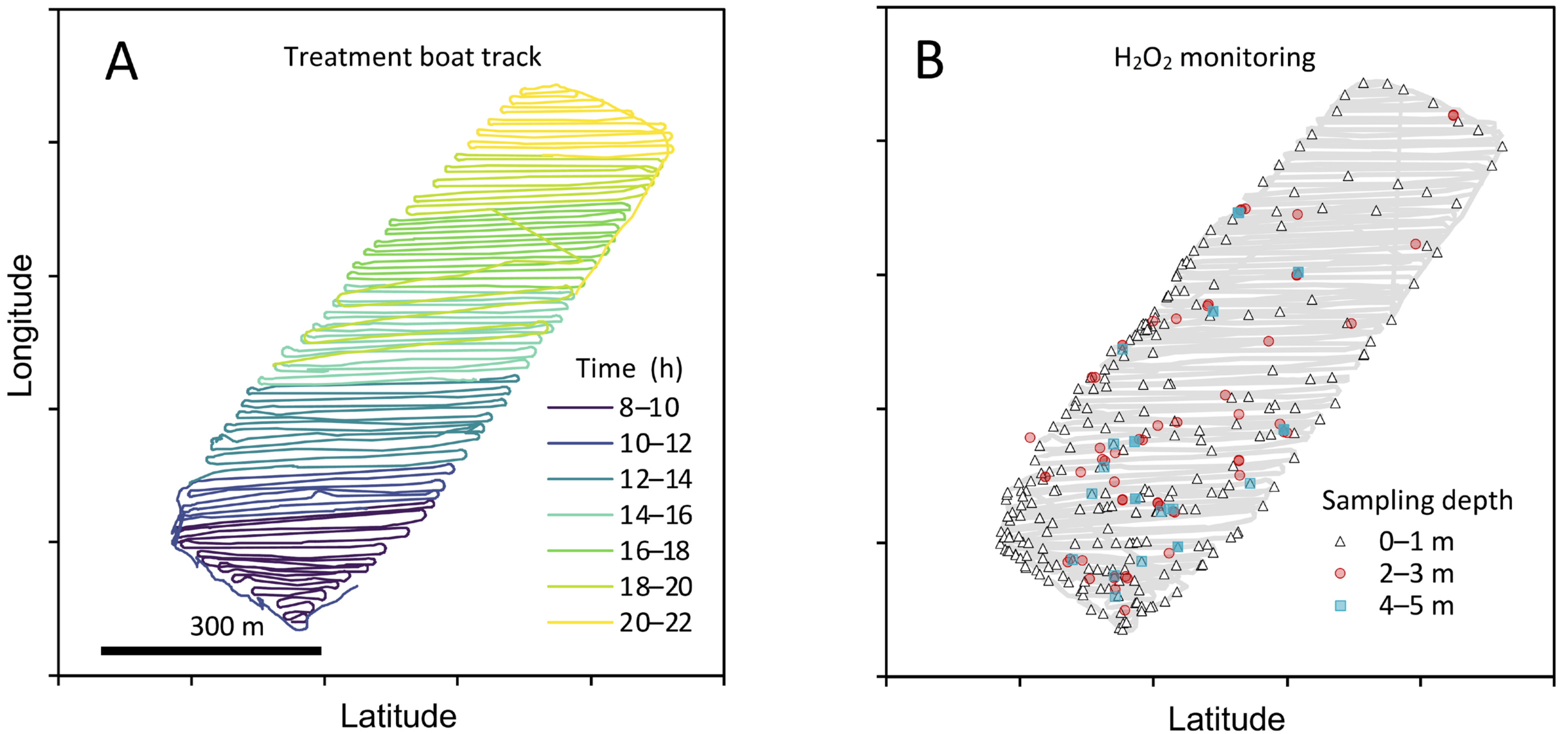

30 ha, avg depth 7 m

# Special boat for dosing $H_2O_2$



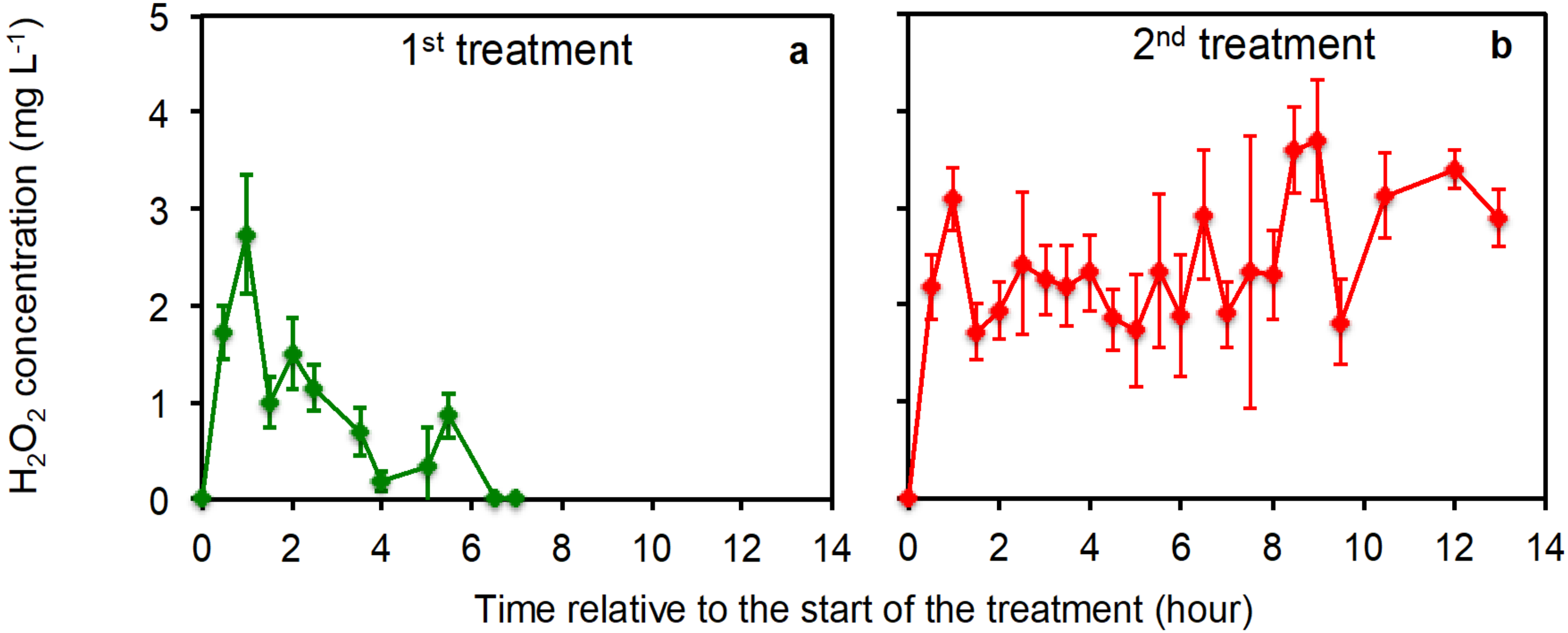

The *'Dr. Hans Matthijs'* treatment boat

# Hydrogen peroxide: treatment boat track and locations of monitoring




*Piel et al. 2021 Microorganisms*

# $H_2O_2$ concentrations of two treatments in Lake Oosterduinse Meer




Average $H_2O_2$ concentration:
1st treatment 1.1 mg $L^{-1}$
2nd treatment 2.2 mg $L^{-1}$

*Weenink et al. 2022 Water Research*

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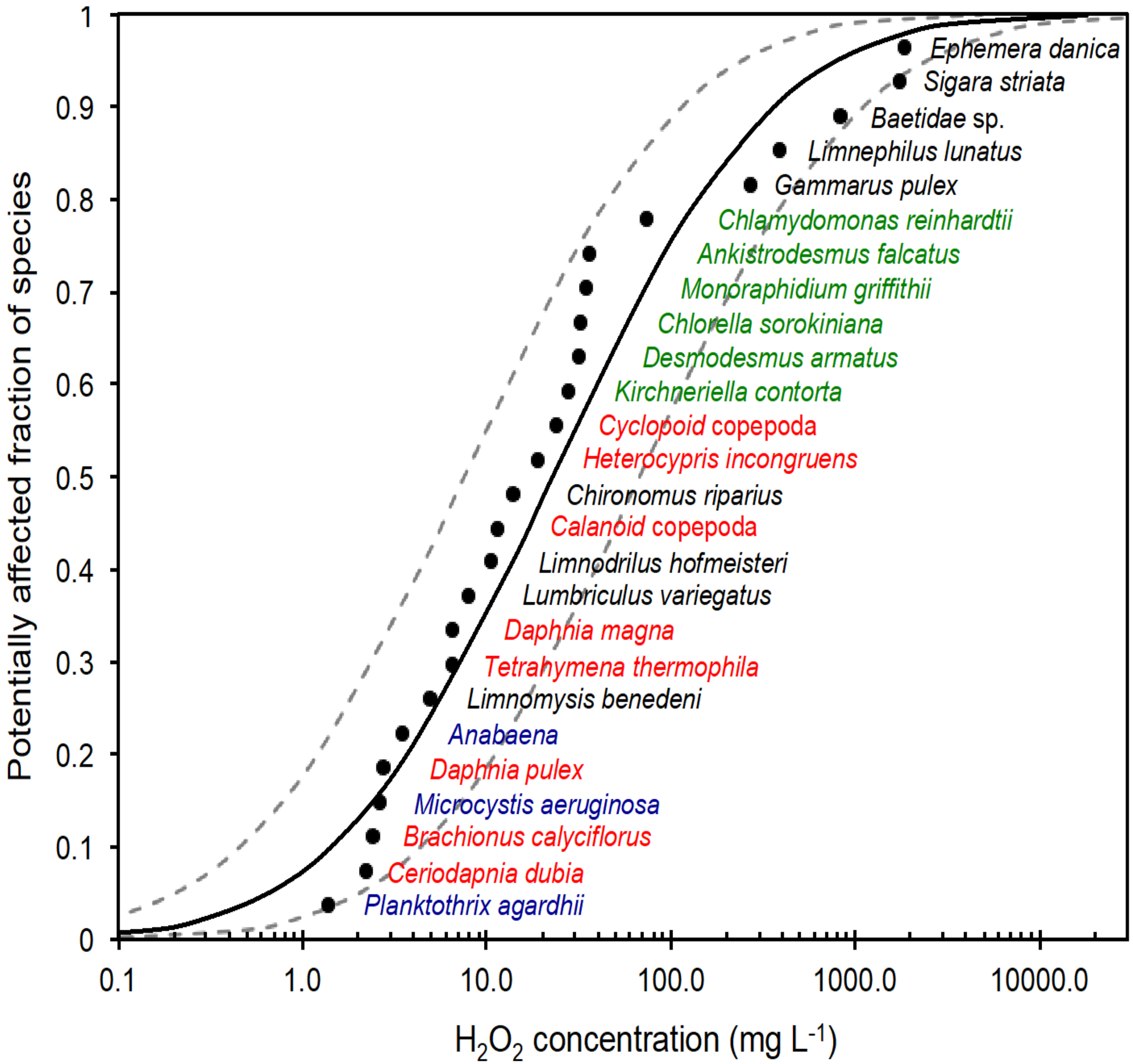


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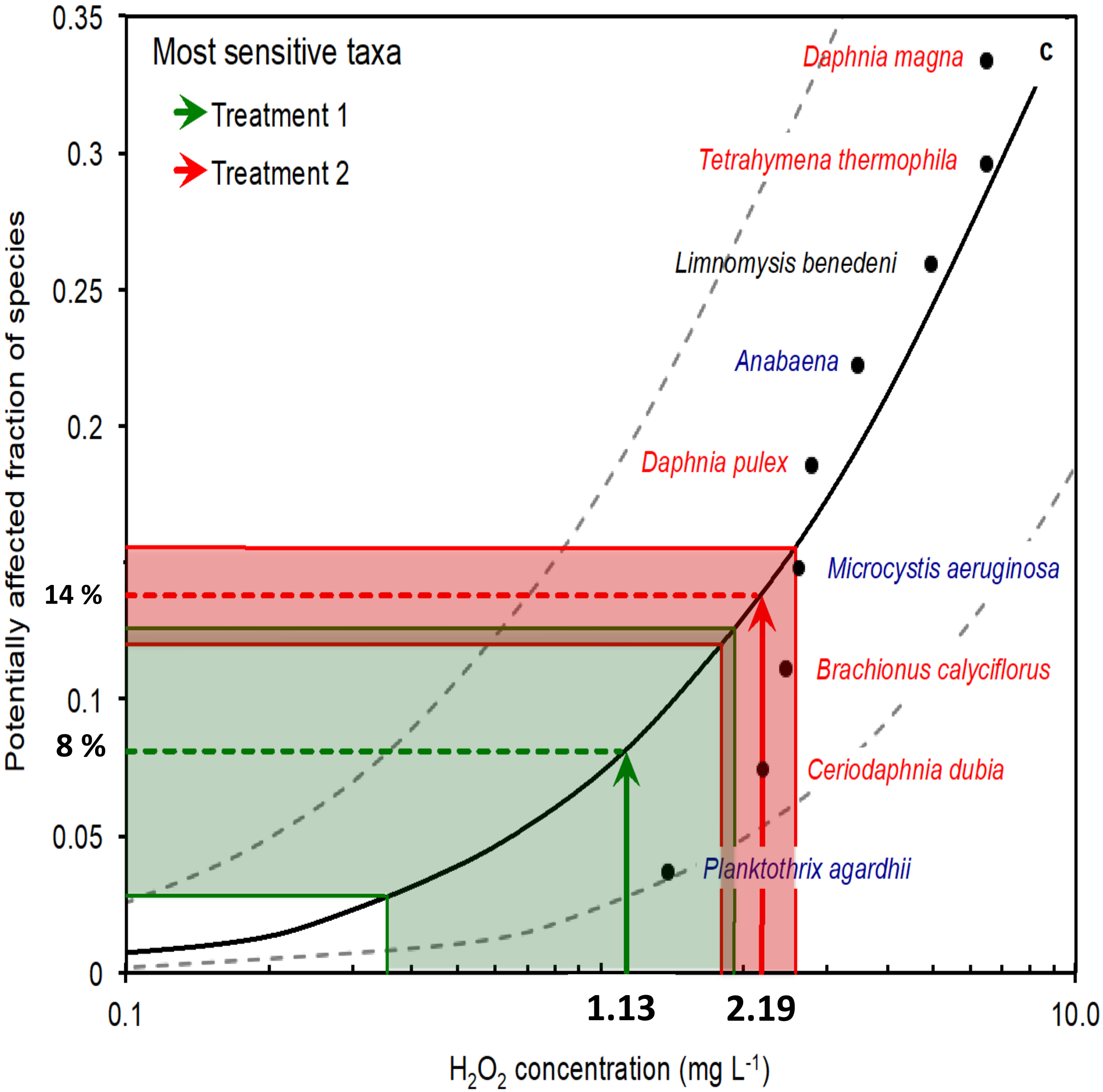
*Weenink et al. 2022 Water Research*

# SSD - predicting species at risk during two $H_2O_2$ treatments




Prediction based on average $H_2O_2$ concentrations

At risk during 1st treatment:

- 8 % of the species
- Only *Planktothrix*
- No non-target species

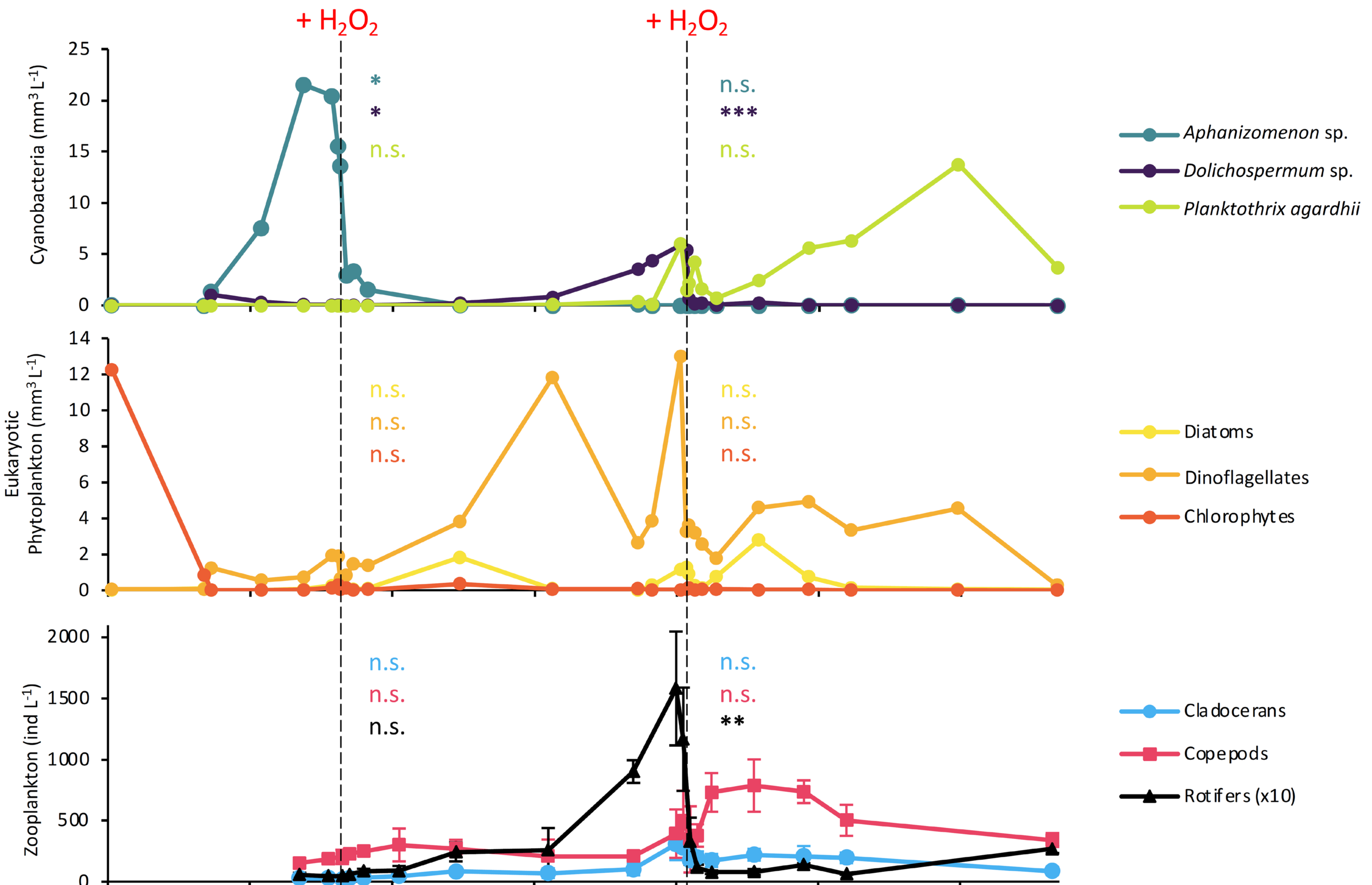
At risk during 2nd treatment:

- 14 % of the species
- *Planktothrix* and *Microcystis*
- non-target: *Ceriodaphnia*
- non-target: *Brachionus*

*Weenink et al. 2022 Water Research*

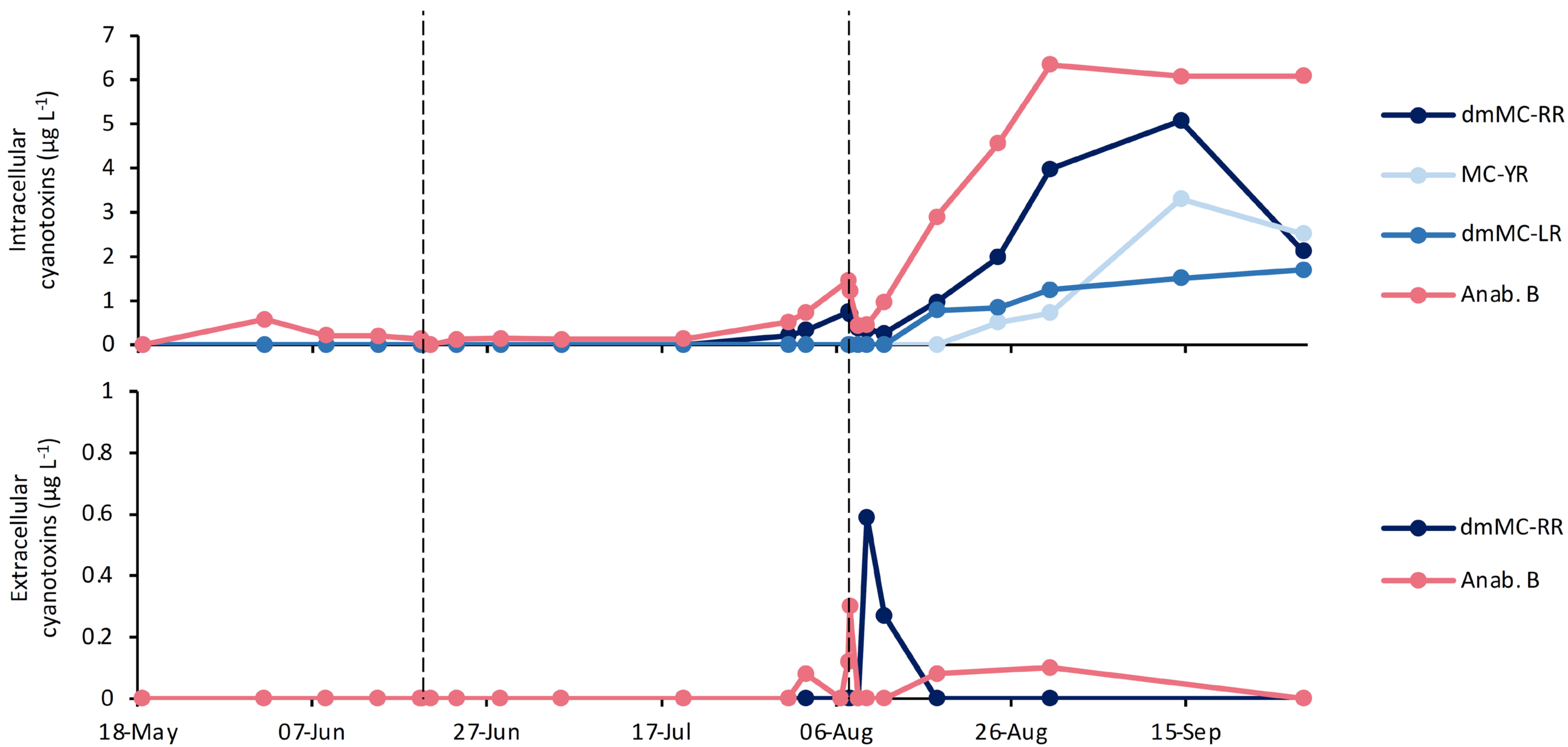
# Lake Oosterduinse Meer before and after treatment

# Effects on phytoplankton and zooplankton composition in Lake Oosterduinse Meer




*Piel et al. 2022 Harmful Algae*

# Effects on cyanotoxins in Lake Oosterduinse Meer



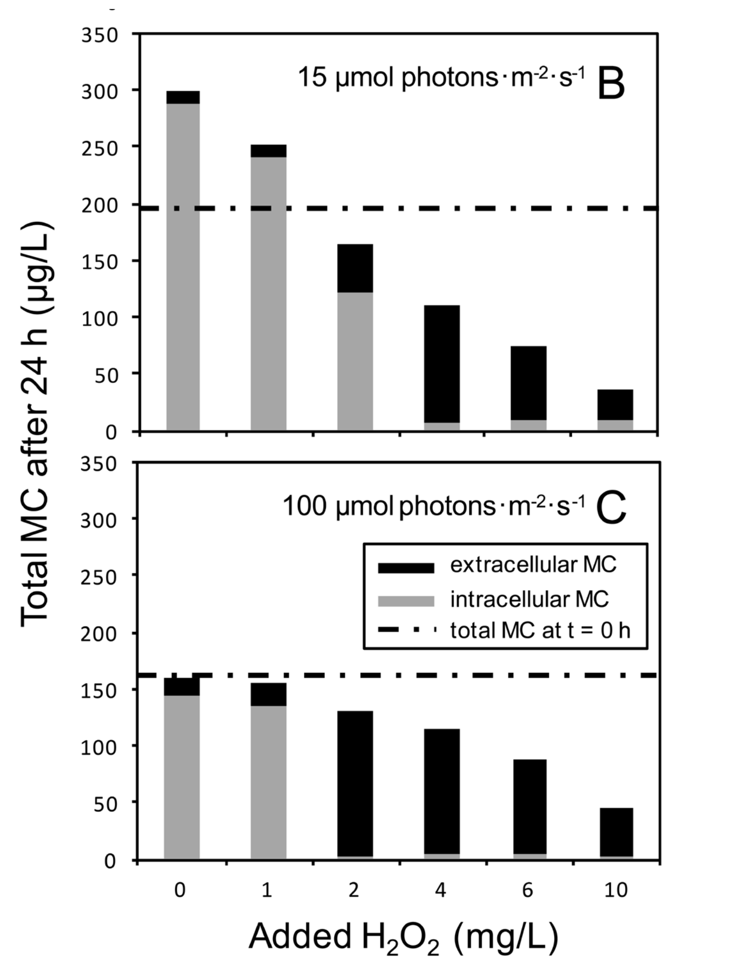

*Piel et al. 2022 Harmful Algae*

# Probable causes of decline of microcystins after addition of $H_2O_2$

- Chemical oxidation by $H_2O_2$

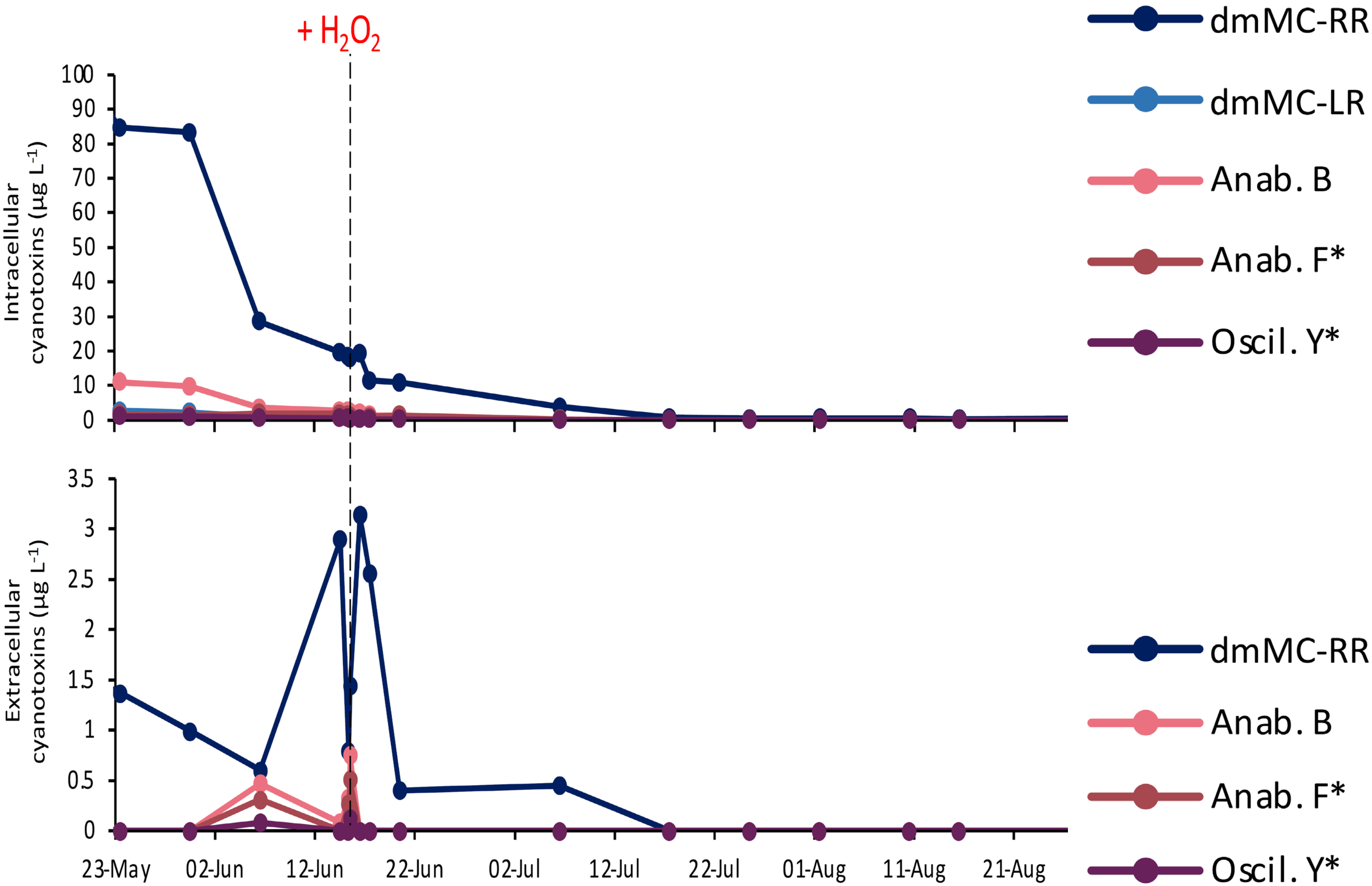
- Breakdown by bacteria
(Dziga et al. 2019 Toxins)

- Temporarily bound to proteins
(Meissner et al. 2013 Environ. Microbiol.; Schuurmans et al. 2018 Harmful Algae)

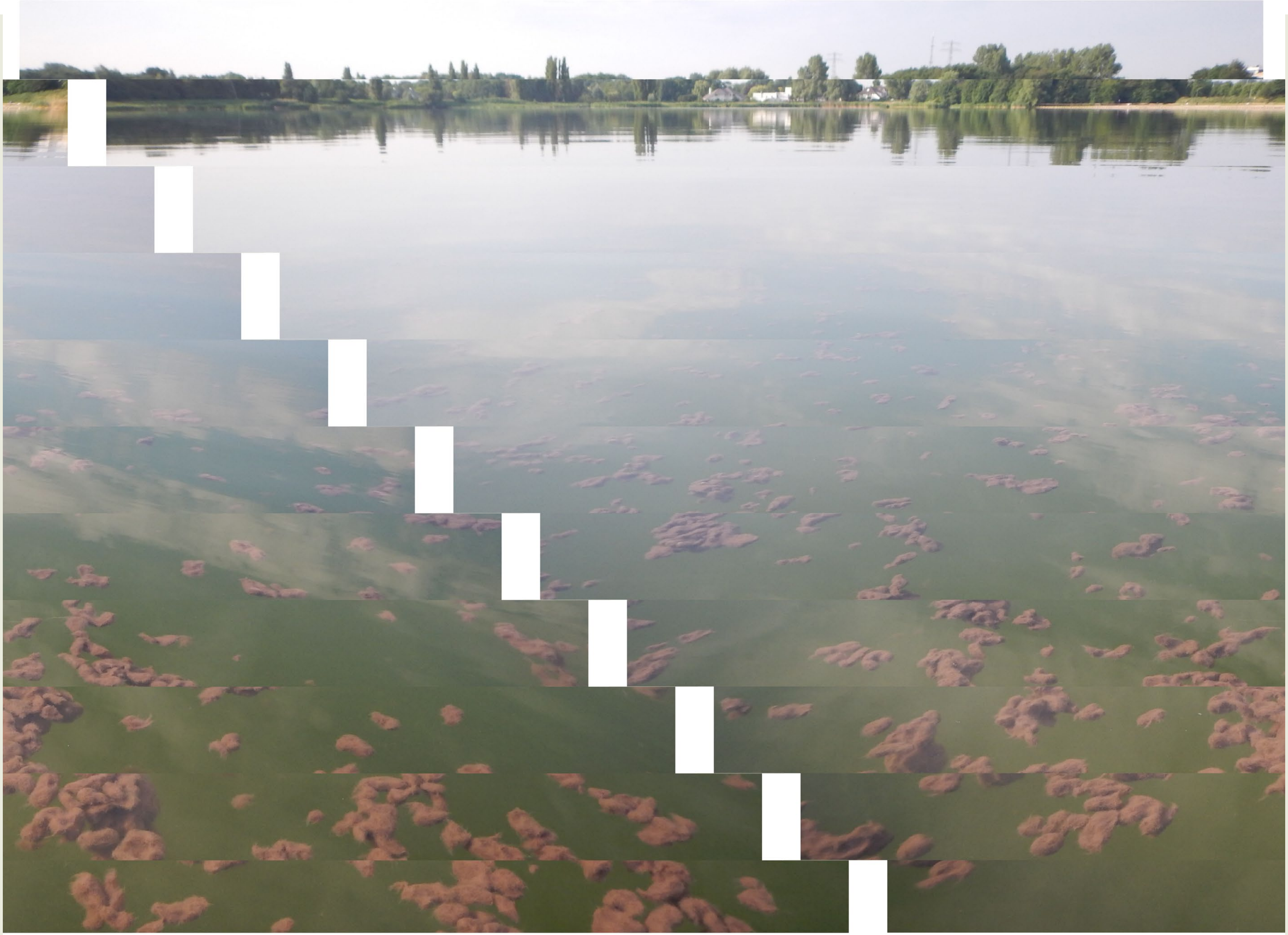



Piel et al. 2019 Toxins

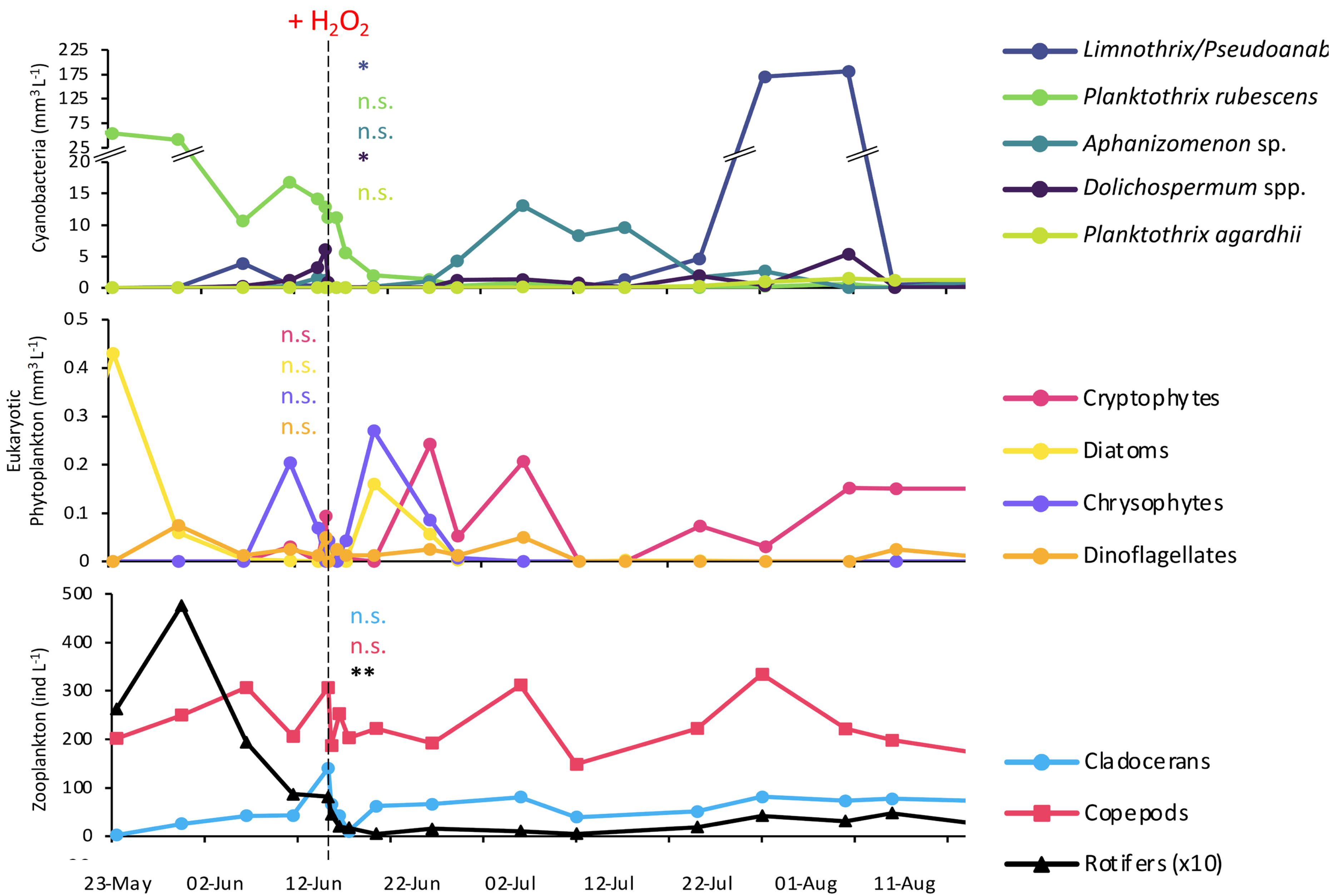
# Cyanotoxins in Lake Klinkenbergerplas




*Piel et al. 2022 Harmful Algae*



# Cyanobacteria, algae and zooplankton in Lake Klinkenbergerplas



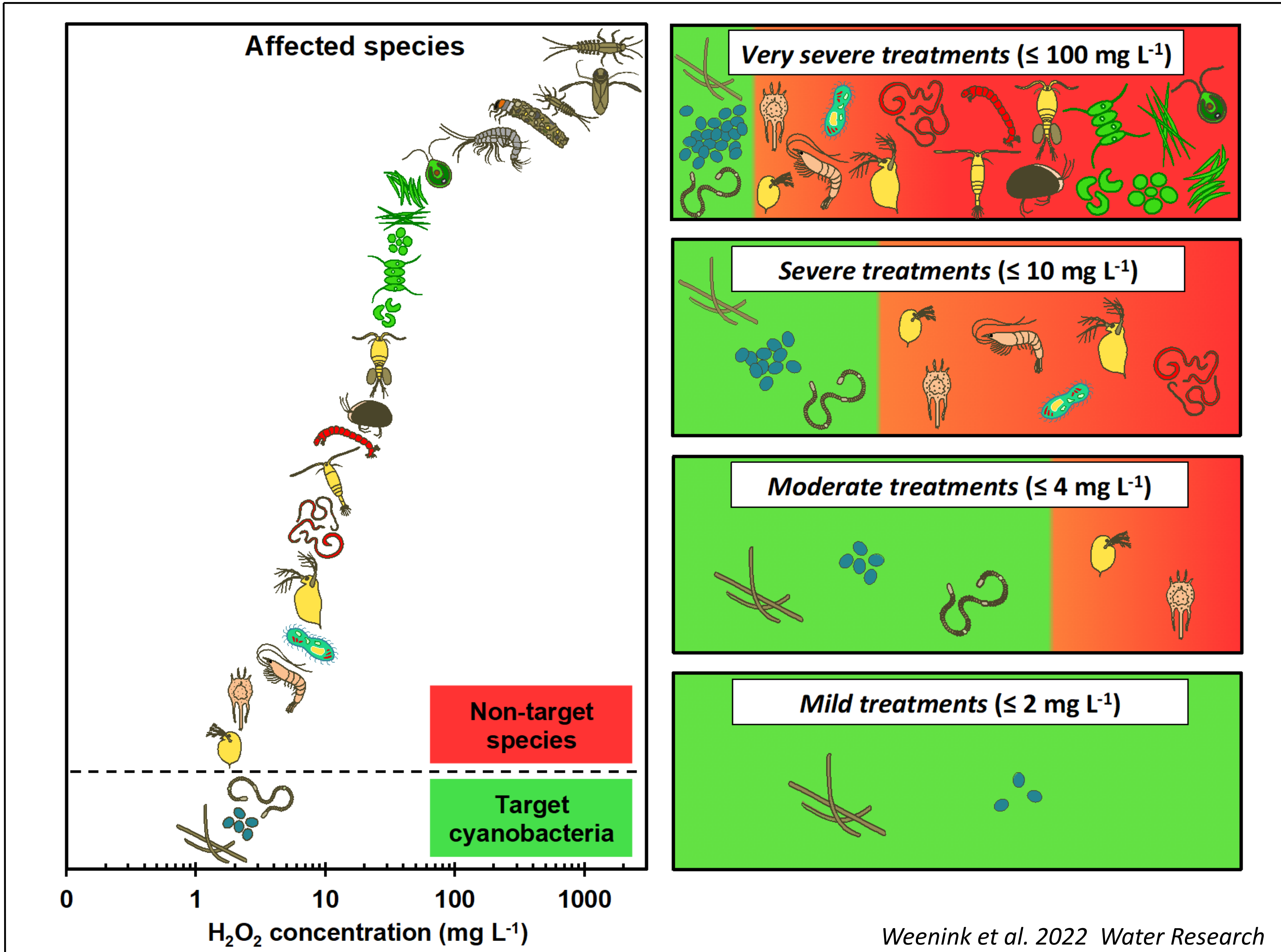
# Conclusions

Cyanobacteria are the most sensitive to $H_2O_2$, but rotifers and small cladocerans are also affected.

Field results aligned well with dose-response relationships observed in laboratory studies.

Cyanotoxin concentrations decreased following hydrogen peroxide treatment.

Recommended $H_2O_2$ concentrations are 2-3 mg/L, though this can vary depending on the specific situation.



Affected species
Non-target species
Target cyanobacteria
0
1
10
100
1000
H2O2 concentration (mg L-1)
Very severe treatments (≤ 100 mg L-1)
Severe treatments (≤ 10 mg L-1)
Moderate treatments (≤ 4 mg L-1)
Mild treatments (≤ 2 mg L-1)
Weenink et al. 2022 Water Research

# Acknowledgements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NWO Nederlandse Organisatie voor Wetenschappelijk Onderzoek

ARCADIS Design & Consultancy for natural and built assets

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Hoogheemraadschap van Rijnland

evides waterbedrijf

gemeente Zoetermeer

Hoogheemraadschap van Schieland en de Krimpenerwaard

kemira

stowa

provincie Zuid Holland

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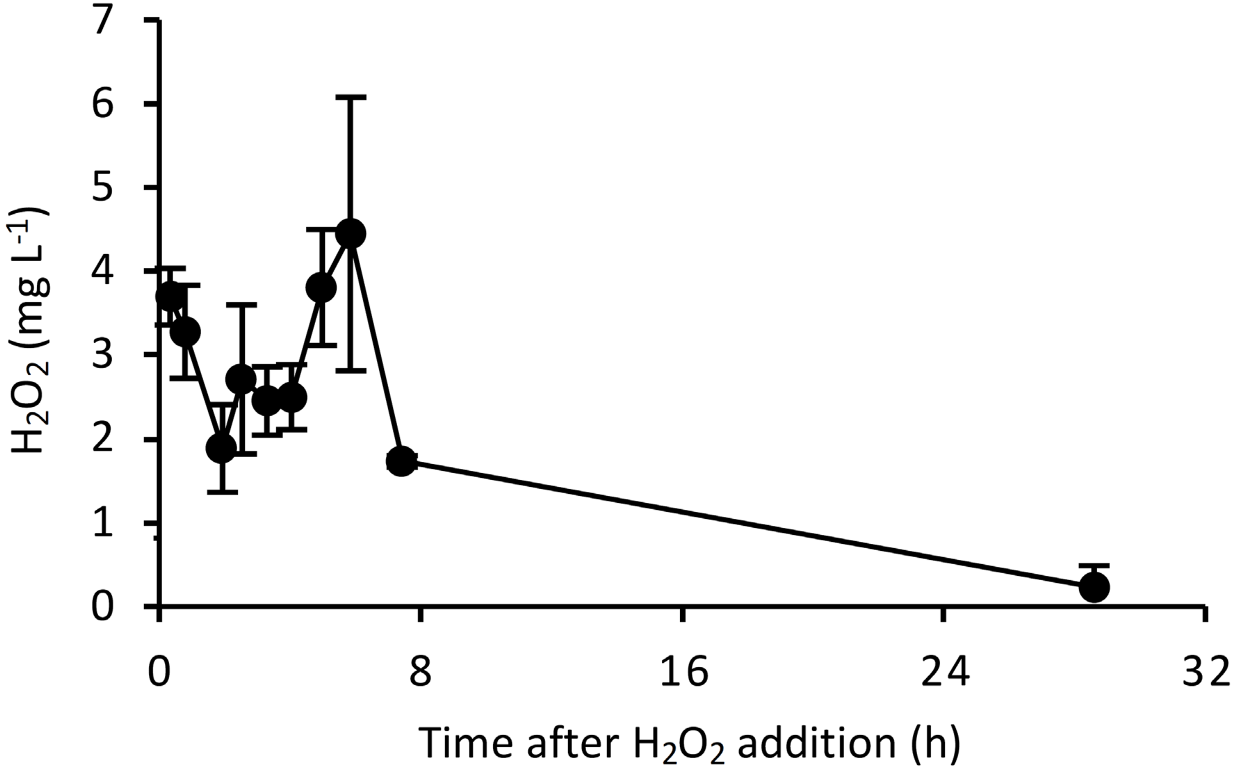
# Hydrogen peroxide concentrations during treatment in Lake Klinkenbergerplas




*Piel et al. 2022 Harmful Algae*

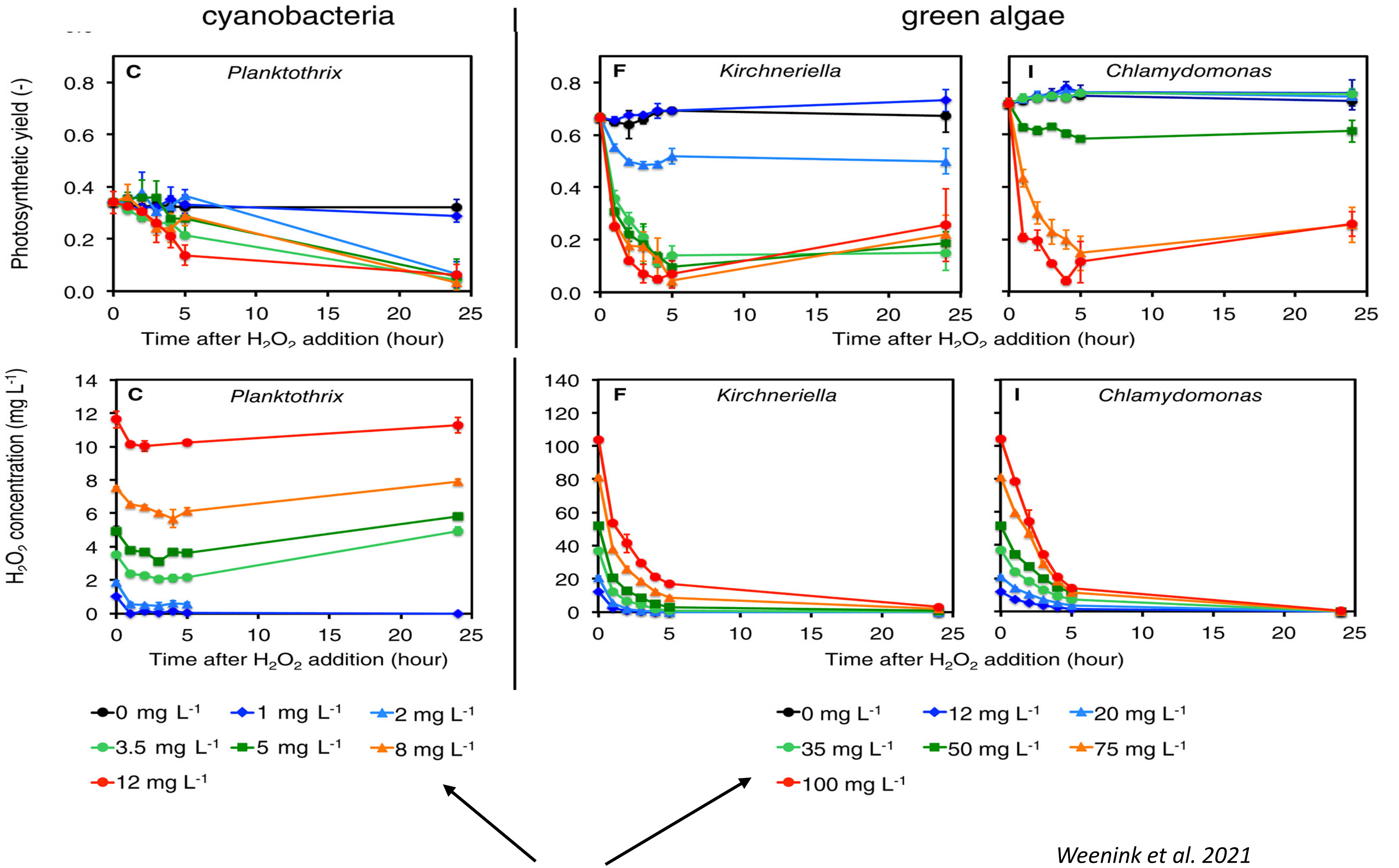
# Lake Klinkenbergerplas



# Water authorities took care of communication with the public


Bathing prohibited due to combatting cyanobacteria

# Effects on cyanobacteria and algae (cultures): Cyanobacteria are more sensitive to $H_2O_2$ and degrade $H_2O_2$ slower than green algae




Note the difference in concentration!

*Weenink et al. 2021*
*Environmental Microbiology*