Leibniz-Institute of Freshwater Ecology and Inland Fisheries

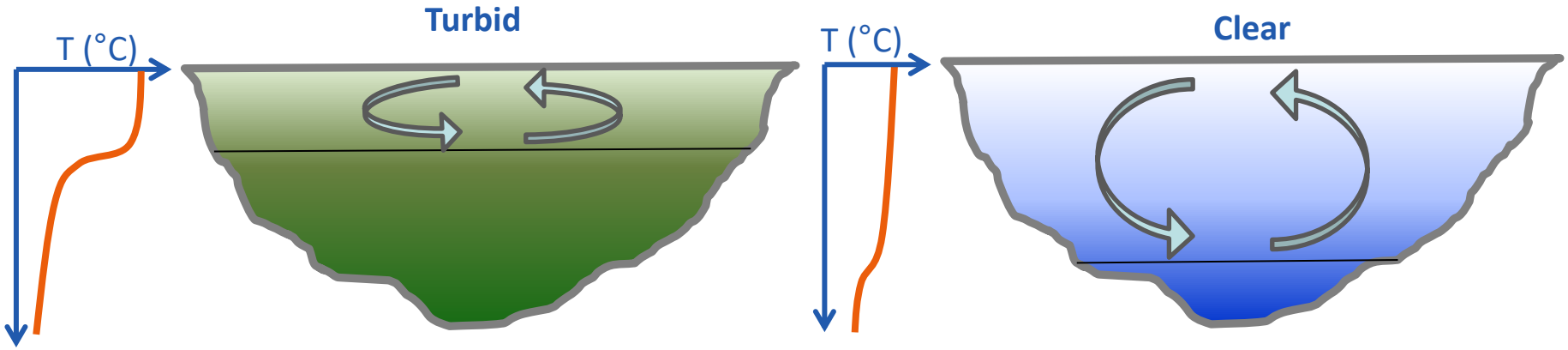
The effect of transparency on stratification and mixing regime in lakes

Tom Shatwell, Wim Thiery, Rita Adrian, Georgiy Kirillin

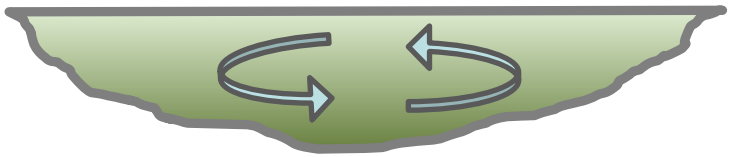
Parameterization of Lakes in Numerical Weather Prediction and Climate Modelling, 18 Oct, 2017

Introduction

- Transparency determines how deep SW radiation penetrates into the water column, and therefore the vertical temperature gradients



- **How does transparency affect the mixing regime of "marginal" lakes?**



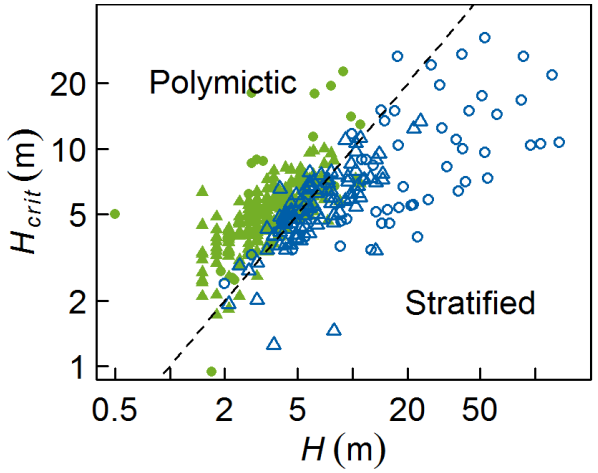
What does the scaling say about transparency?

- Recall the scaling criterion (Georgiy Kirillin's presentation)

$$H_{crit} = C_1 h_{SECCHI} + \sqrt{{C_1}^2 {h_{SECCHI}}^2 + C_2 L L_{MO}}$$

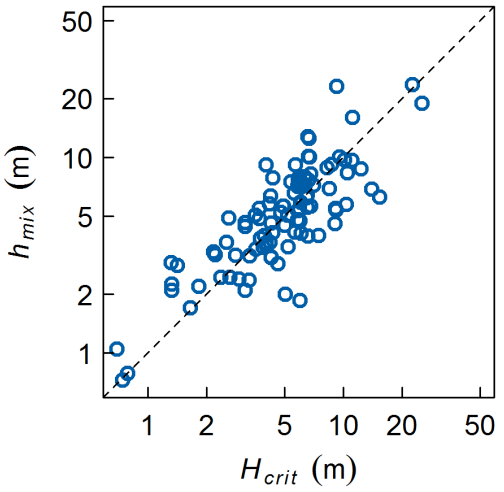
- H_{crit} predicts:

Mixing regime



n = 375, Maine and World Lakes databases

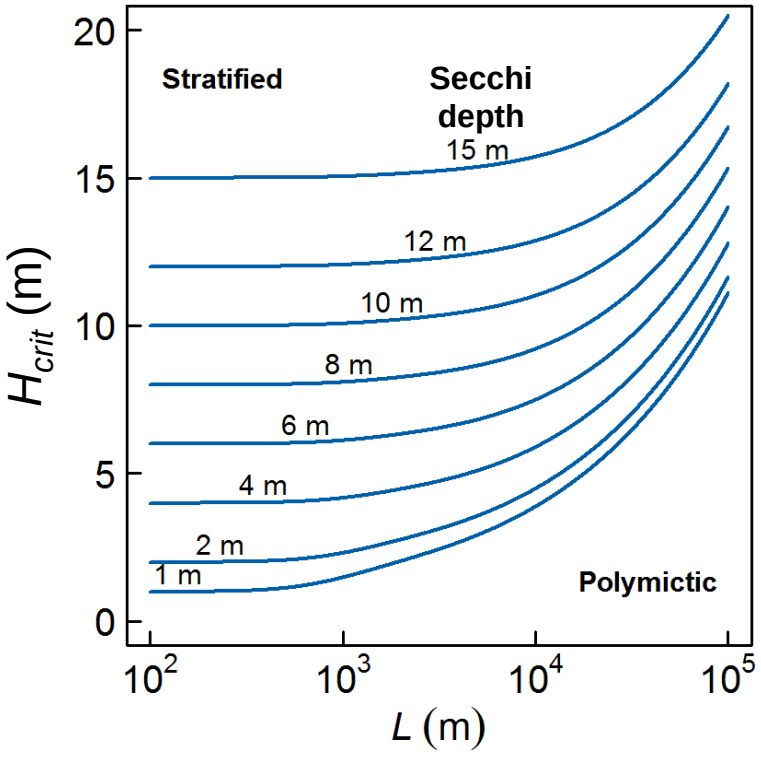
Mixed layer depth



n = 100, Leach et al. L&O, 2017

What does the scaling say about transparency?

$$H_{crit} = C_1 h_{SECCHI} + \sqrt{(C_1 h_{SECCHI})^2 + C_2 L L_{MO}}$$



- In small lakes (L < 1000 m) mixing regime depends on transparency ($H_{crit} \approx h_{mix} \approx h_{SECCHI}$)
- In large lakes, H_{crit} depends on LL_{MO}, especially wind ($H_{crit} \approx h_{mix} > h_{SECCHI}$)
- A change in transparency strongly affects small lakes

→ **Can cause mixing regime shifts in lakes 2 – 10 m deep**

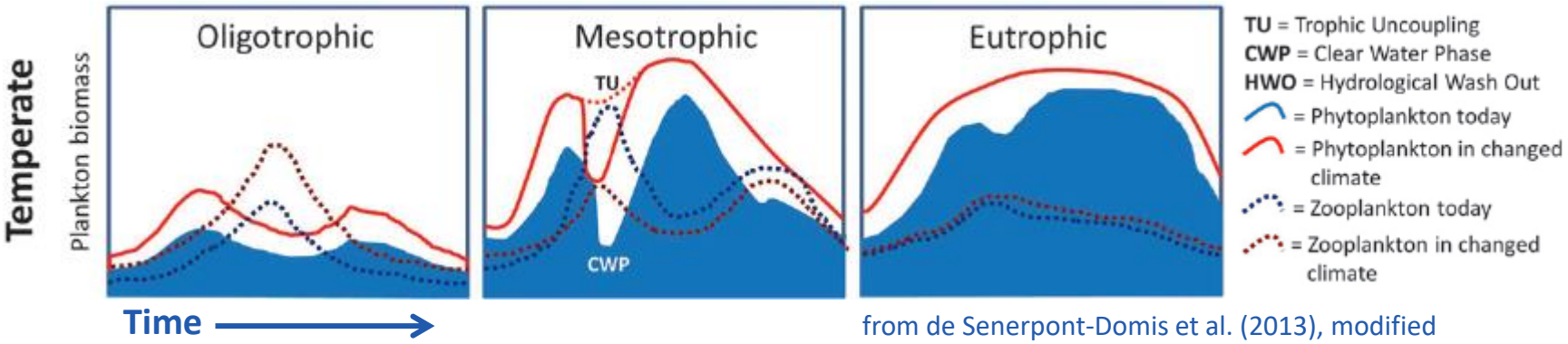
Approach and methods

1. Effect of seasonality of transparency through planktonic interactions on stratification
   - Statistical analysis of long term data of 2 German lakes
   - 1-D hydrodynamic modelling (FLake)

2. Interactions of climate warming and changing transparency
   - Ensemble modelling of 4 German lakes with FLake

1. Effect of seasonality of transparency

- In hardwater lakes, transparency depends mainly on chlorophyll
- Chlorophyll follows seasonal pattern with algal biomass



from de Senerpont-Domis et al. (2013), modified

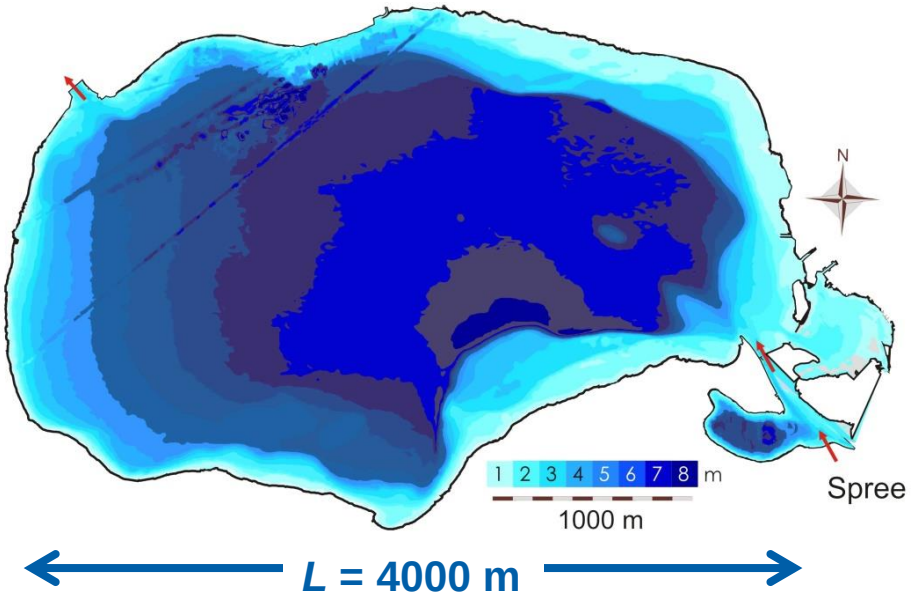
How does seasonal change in transparency, esp. CWP, affect mixing regime of "marginal" lakes?

Study lakes

Lake Müggelsee

Polymictic

Berlin, Germany

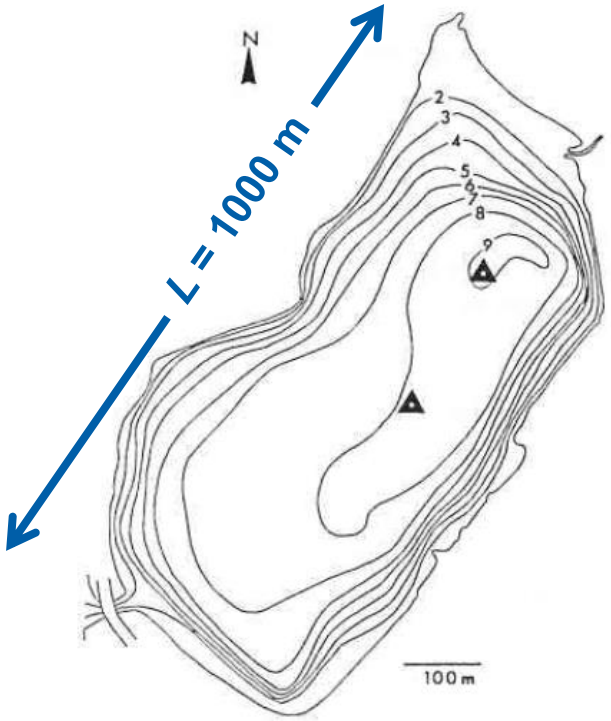


Mean depth	H	= 5 m
Length	L	= 4000 m
Mean Secchi depth	h_{SECCHI}	= 1.4 m

Lake Heiligensee

Dimictic

Berlin, Germany



Mean depth	H	= 6 m
Length	L	= 1000 m
Mean Secchi depth	h_{SECCHI}	= 1.25 m

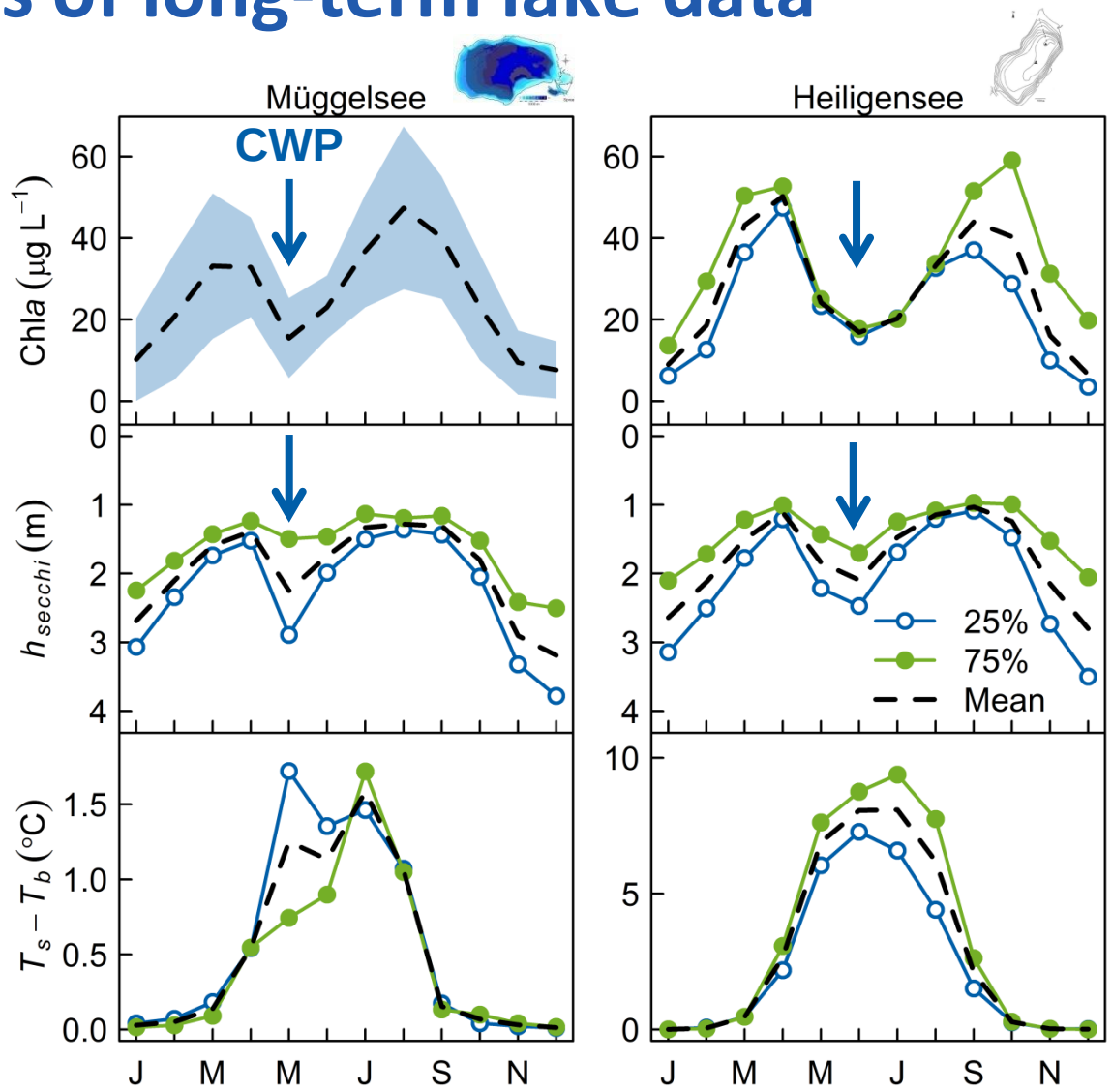
Statistical analysis of long-term lake data

PCA on

- Chlorophyll (chl*a*),
- Secchi depth (h_{SECCHI}),
- Stratification (T_s-T_b)

Lower seasonal variation of transparency correlates with stronger summer stratification

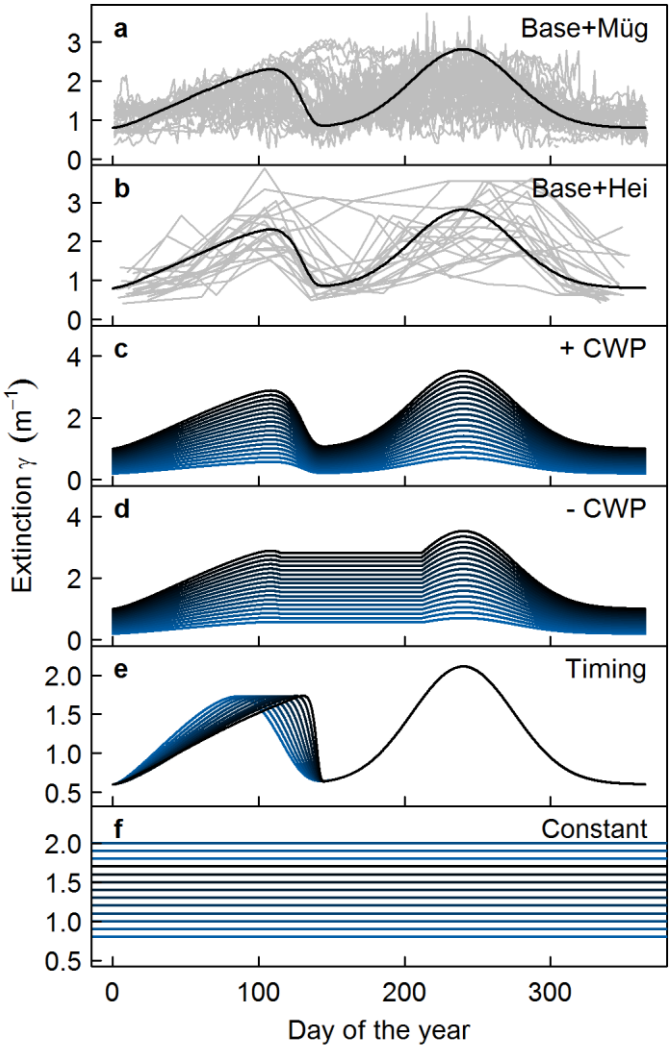
More intense CWP weakens summer stratification



Like symbols are correlated

Hydrodynamic modelling

- Simulate stratification with FLake
- Hypothetical lake somewhere between Müggelsee and Heiligensee
- Compare constant extinction scenarios with seasonally variable extinction



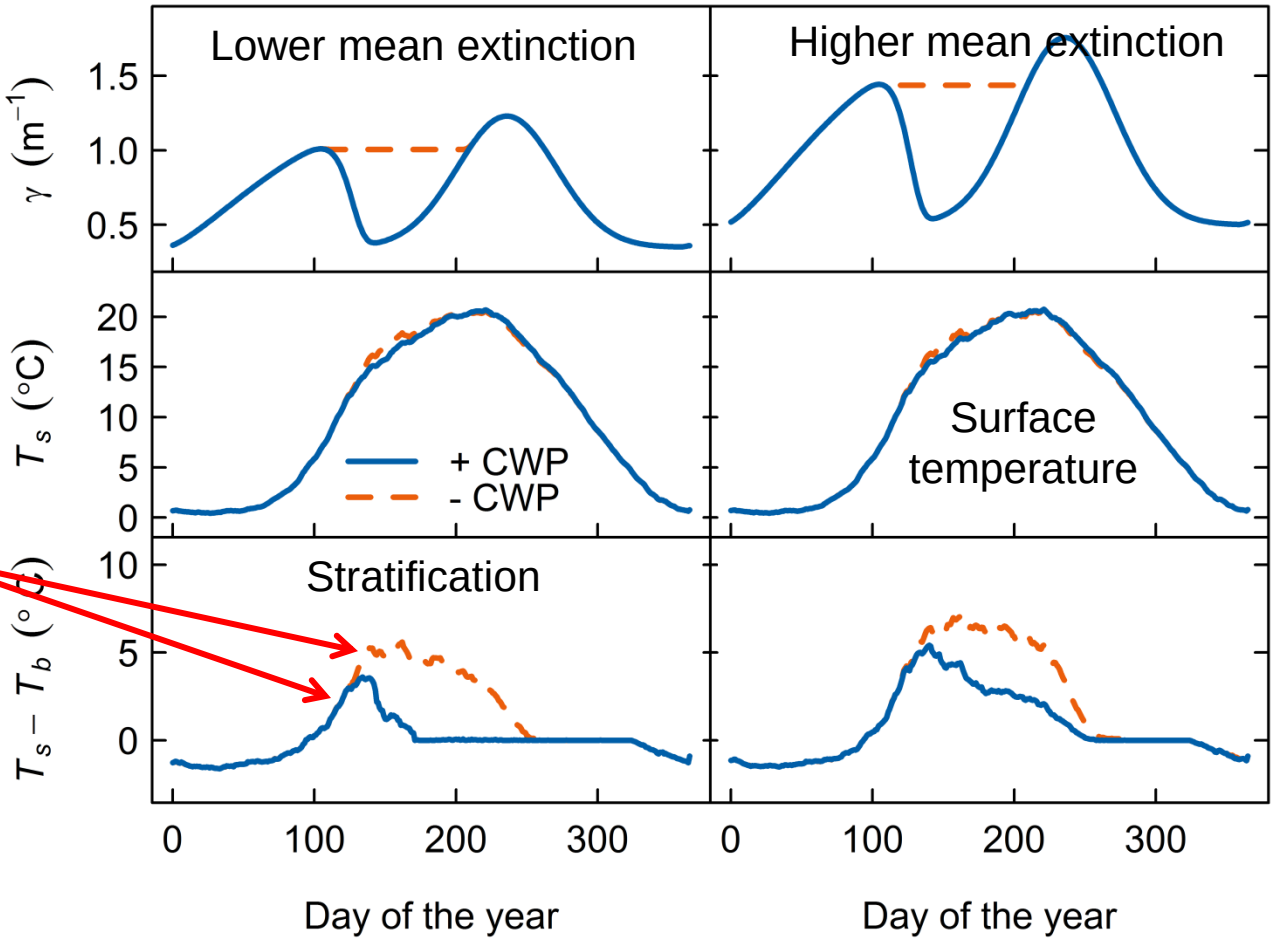
Hydrodynamic modelling

- Model simulations on a generic lake with different seasonal extinction scenarios

Absence of CWP strengthens summer stratification

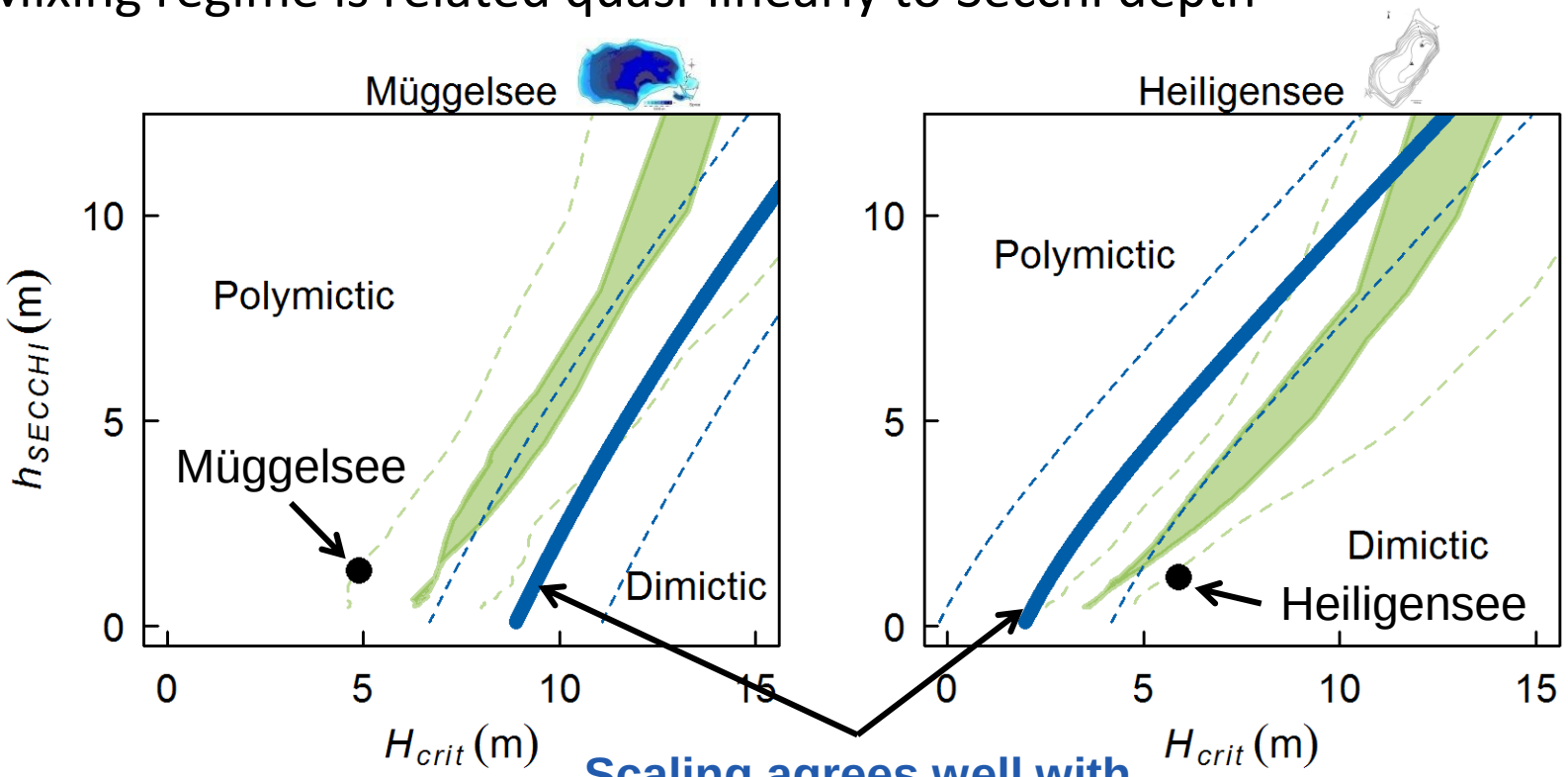
and can alter the mixing regime

Transparency had the greatest influence when the lake was accumulating heat the fastest, i.e. in spring



Mixing regime sensitivity to Clear Water Phase

- Mixing regime is related quasi-linearly to Secchi depth



Scaling agrees well with FLake

Shaded region = polymictic only with CWP

- Narrow but significant region where CWP can alter the mixing regime

2. Interactions between warming and dimming

- Lakes predicted to become dimmer (less transparent) due to warming

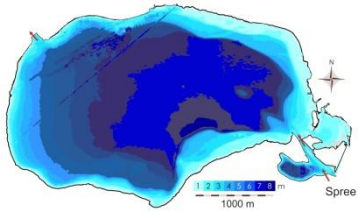
- Contrasting effects:
  - Warming increases surface temperatures
  - Dimming decreases deep water temperatures

- Hypothesis:
  Warming + dimming
  - superimpose to increase thermal gradients and stratification
  - counteract each other to damp changes in lake heat content

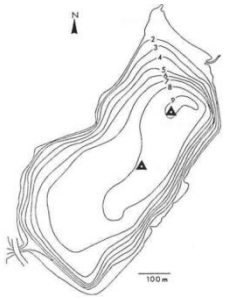
Study lakes

Lake	H (m)	L (m)	h_{SECCHI} (m)
Müggelsee (poly)	5 (8)	4000	2.0
Heiligensee (di)	6 (9)	1000	1.8
Stechlinsee (di)	23 (69)	2000	8.6
Arendsee (di)	29 (51)	4000	3.0

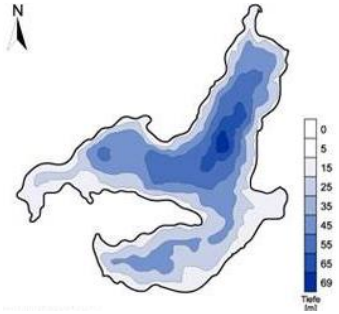
Müggelsee



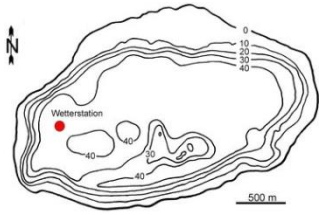
Heiligensee

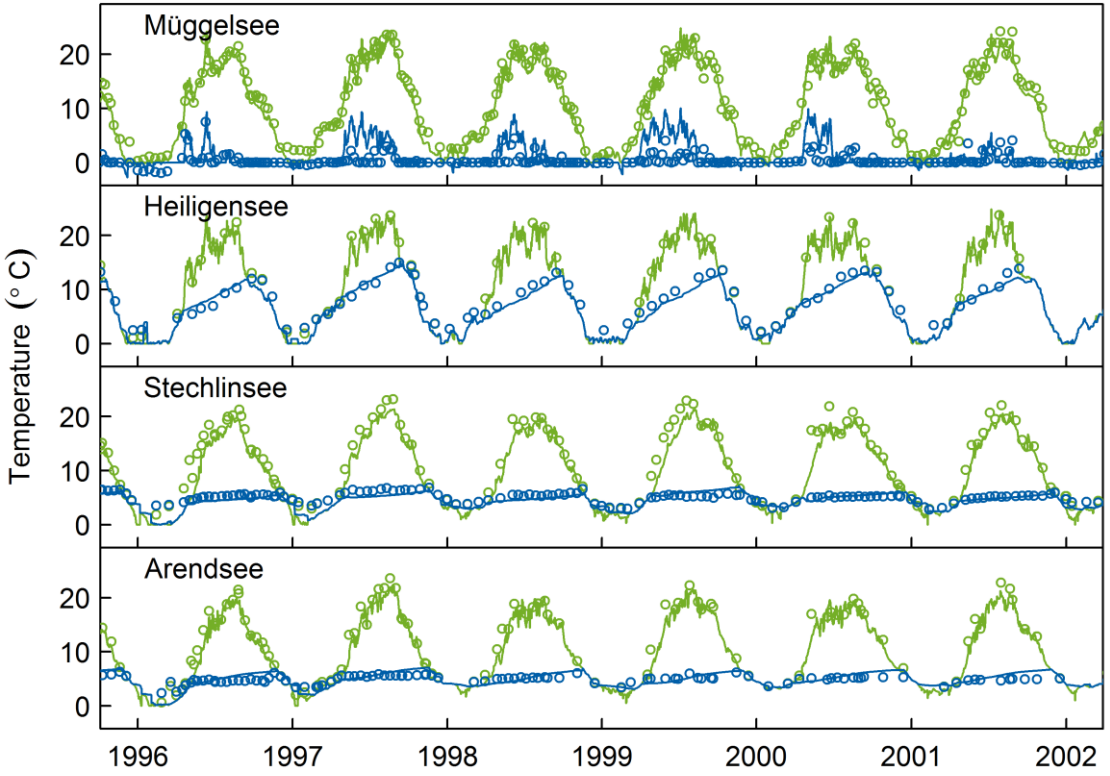


Stechlinsee



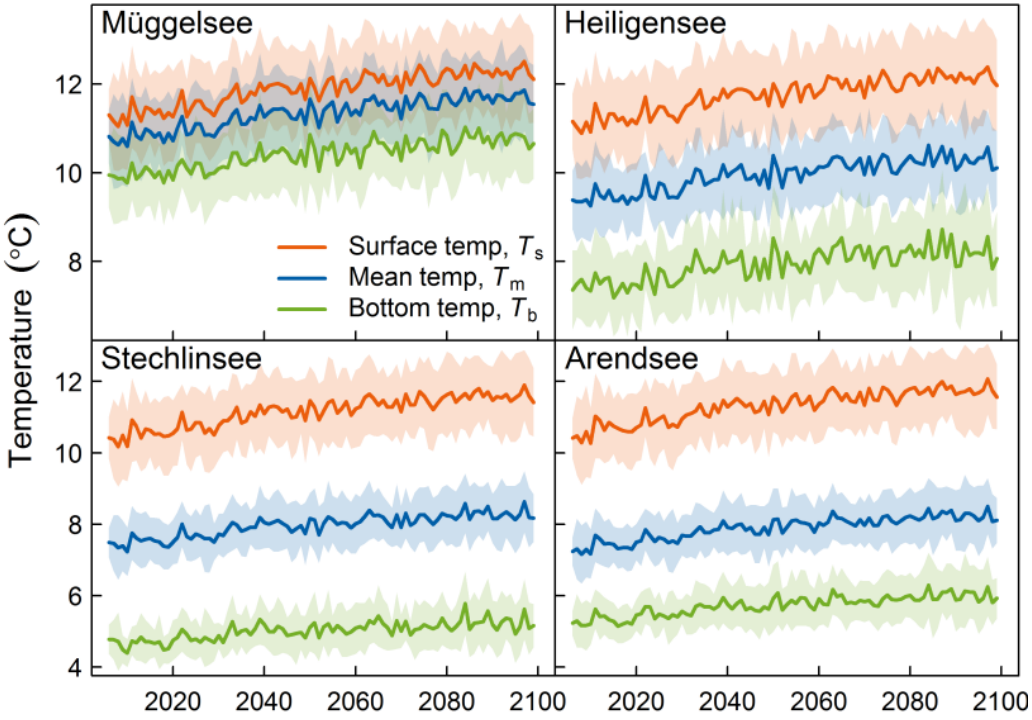
Arendsee

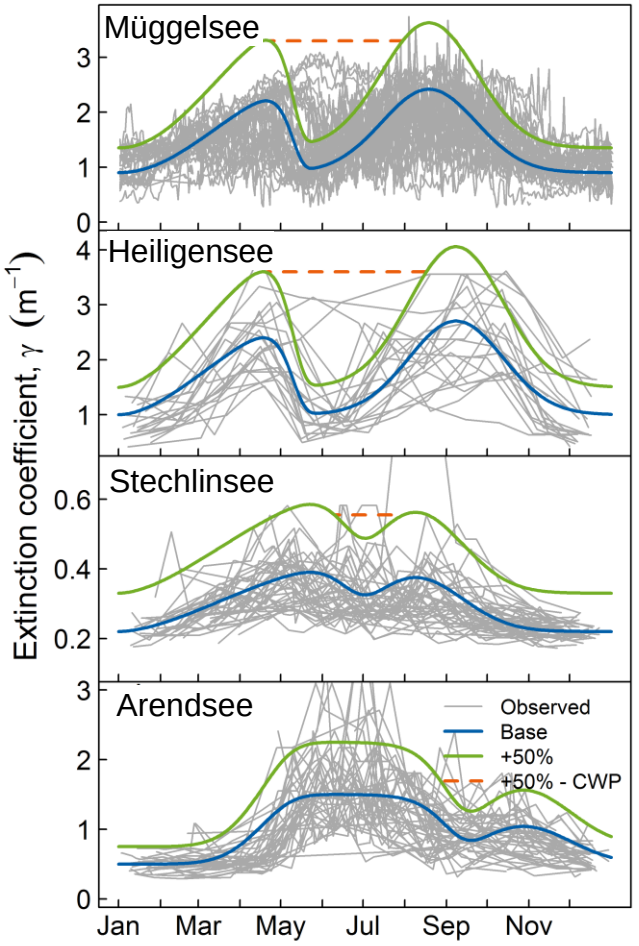




Warming and dimming simulations with FLake

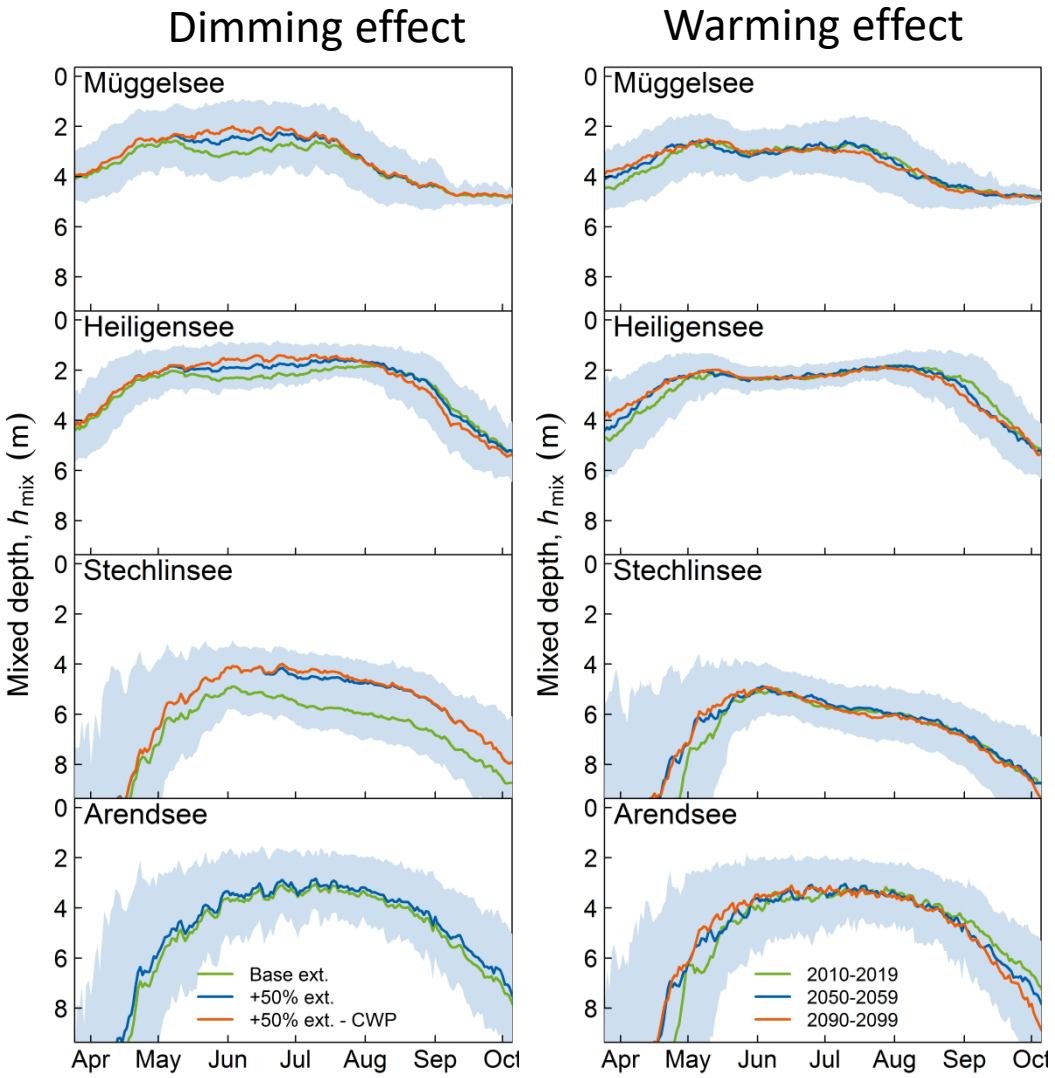
- Ensemble of 12 climate warming projections (RCP4.5)
- Range of extinction coefficients with observed seasonal pattern





Mixed layer depth

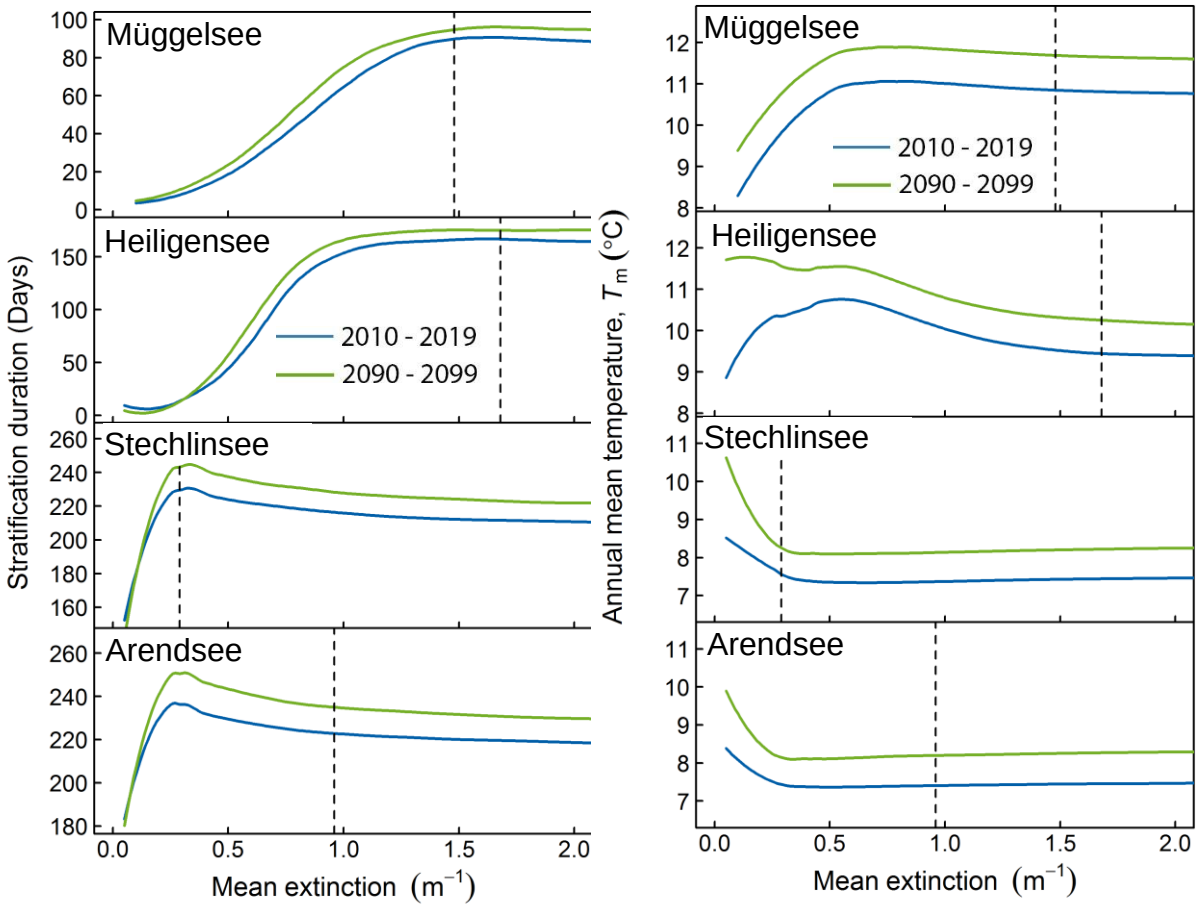
Dimming decreases h_{mix} in summer



Warming has a negligible effect on h_{mix}

Stratification duration and mean temperature

- Dimming:
  strong effect at low extinction
- Warming:
  moderate effect at higher extinction
- Interactions:
  medium tranparency shallowish lakes or ultra-clear deep lakes



Conclusions

- Stratification and mixing regime of small lakes strongly depends on transparency ($H_{crit} \approx h_{SECCHI}$)
- Regime shifts are possible in 2 – 10 m deep lakes
- The clear water phase is the most important planktonic event, and can under some circumstances alter the mixing regime
- Dimming and warming increase stratification in synergy only in relatively clear shallow lakes or ultra-clear deep lakes
- In deep lakes, warming mainly affects stratification duration, while transparency affects h_{mix}.
- The most sensitive lakes to combined dimming and warming are moderately shallow (ca. 4-10 m) and moderately clear (0.5-1.0 m^{-1}) lakes

Acknowledgements

Funding: German Science Foundation (DFG)

Data: IGB, National Centers for Environmental Prediction (NCEP), National Center for Atmospheric Research (NCAR), Maine Volunteer Lake Monitoring Program, International Lake Environment Committee Foundation

Sampling: Thomas Hintze, Bernd Schütze, Reinhard Hölzel, Helgard Täuscher, Ursula Newen

Statistics: Patrick Neale (SERC), Andrew Dolman (BTU Cottbus), Gabriel Singer (IGB)

Discussions: Alena Gsell, Deniz Özkundakci, Ulrike Scharfenberger, Silke R. Schmidt, Torsten Seltmann

Institutions: Smithsonian Environmental Research Center (SERC)

See also:

Shatwell, Adrian, Kirillin, 2016. Planktonic events may cause polymictic-dimictic regime shifts in temperate lakes. Sci. Rep. 6, 24361.

Kirillin, Shatwell, 2016. Generalized scaling of seasonal thermal stratification in lakes. Earth-Sci. Rev. 161, 179-190.

Thank you for listening

IGB Leibniz-Institute of Freshwater Ecology and Inland Fisheries

Smithsonian Environmental Research Center

DFG Deutsche Forschungsgemeinschaft