Modelling sub-daily phytoplankton dynamics and analysing primary production controls in the lower Thames catchment, UK

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A EUROpean training and research network for environmental FLOW management in river basins

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Background

- Phytoplankton blooms in rivers **degrade water quality** and **affect ecosystem structure and functioning**
- Prediction of **phytoplankton growth at shorter time-scales** is crucial to understand **rapid phytoplankton changes** as well as for **prevention of harmful blooms**
- Very **few studies have tested models** to predict sub-daily phytoplankton dynamics, often due to a lack of high-frequency monitoring data
- **High-frequency monitoring** is now possible with the development of relatively cheaper and more robust water quality sensors

Research questions

1. How well can models predict sub-daily phytoplankton dynamics using high-frequency monitoring data in rivers?
2. Following step 1, can we utilise these model outputs to identify physico-chemical controls on phytoplankton growth?

Method

1. High-frequency data

River flows and water quality data for two years (2013-2014) were acquired for the lower River Thames from the Environment Agency (EA) and UKCEH Thames Initiative

Combination of high-frequency sensor data and weekly water quality samples were used (1) as inputs at the top site, and (2) to calibrate the model at the downstream sites

2. Modifying the QUESTOR model

Daily QUESTOR module modified to run at sub-daily time-steps *(QUESTOR model explained in the following slides)*

This process included residence time corrections, changes in model equations and inputs to include hourly time-step calculations

Method

3. Model calibration and validation

In-stream process rates were calibrated using observed data in 2013, and the model fits were assessed for the validation run in 2014

(Time-series of observed versus modelled determinands are shown for one site, Windsor)

Model Goodness-of-fits were assessed using Nash-Sutcliffe Efficiency (NSE) and percentage error in mean (PBIAS)

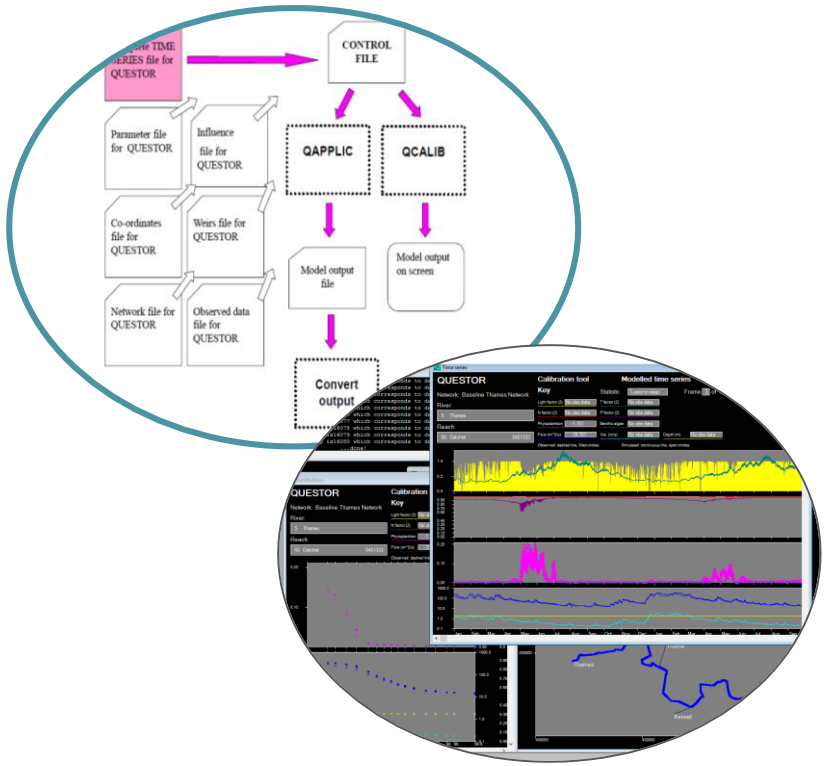
(Summary statistics table for all calibration sites is shown)

4. Application of model outputs

We evaluated the effect of multiple controls on phytoplankton growth including flows, water temperature and nutrients

(Favourable flow and temperature conditions for phytoplankton growth are shown for top and bottom calibration sites)

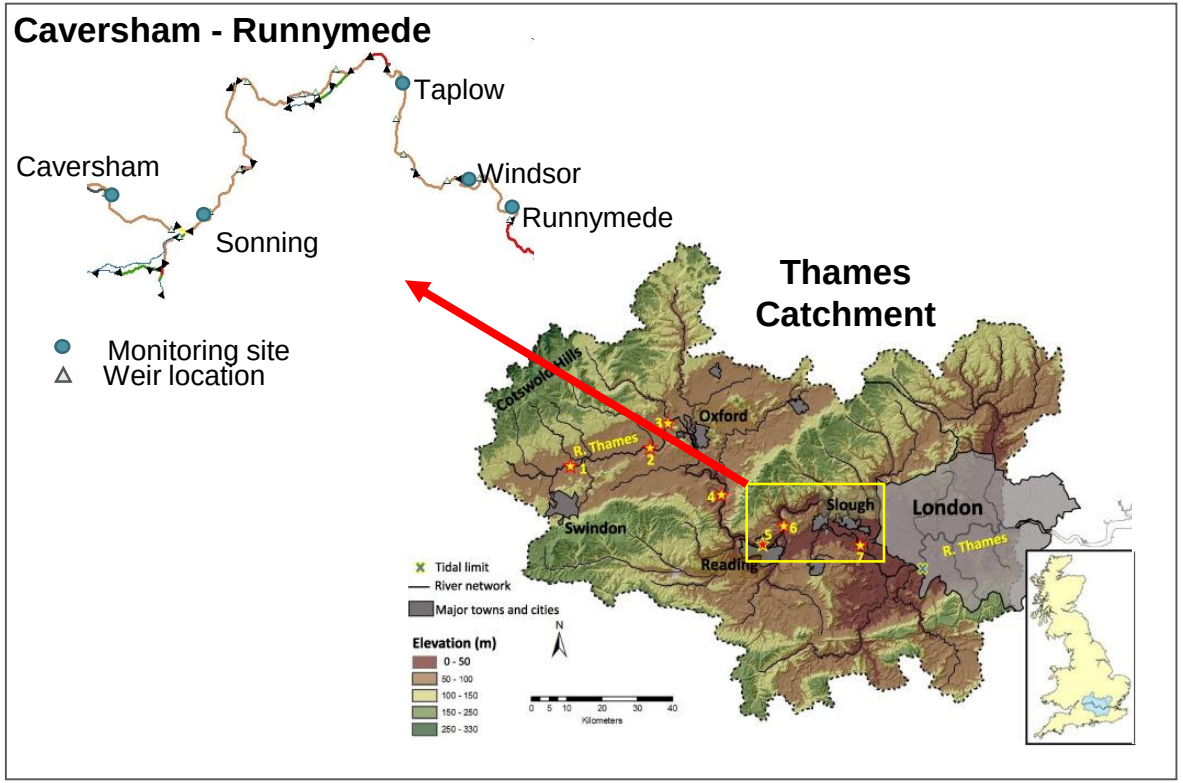
QUESTOR (Quality Evaluation and Simulation Tool for River Systems) sub-daily model



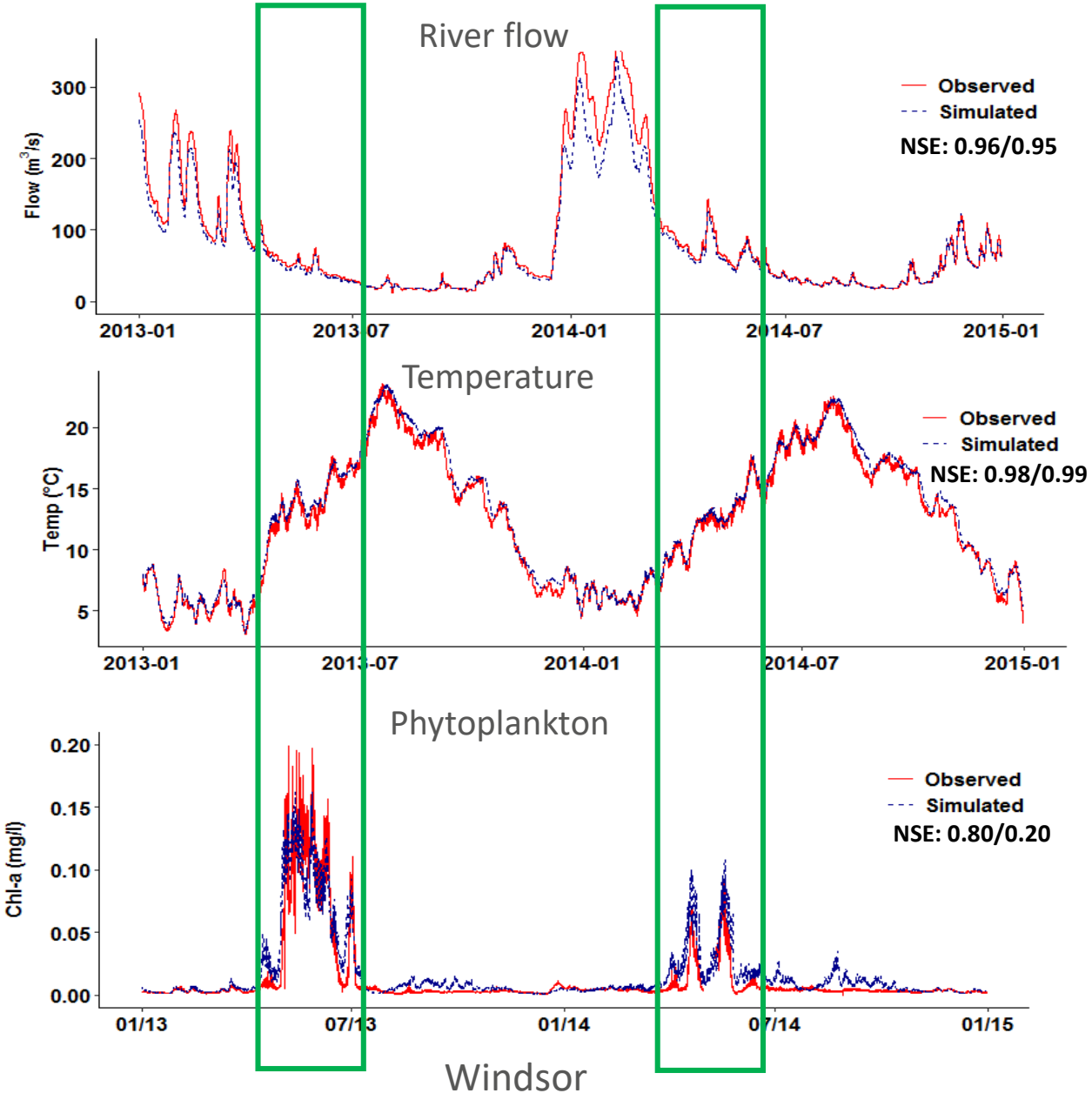
- QUESTOR is an in-stream, mechanistic water quality model that allows users to represent rivers as a network of reaches
- Simulates dynamic solute transport within the river network using 1D, ordinary differential equations with a mass-balance approach
- Equations characterise major processes affecting model determinands, but include empirical coefficients which need to be calibrated
- *S. hantzschii* version (SH module, Waylett et al. (2013)) of daily time-steps QUESTOR model is modified to simulate hourly variations in river water quality (https://doi.org/10.1016/j.jhydrol.2013.05.027)

Study area

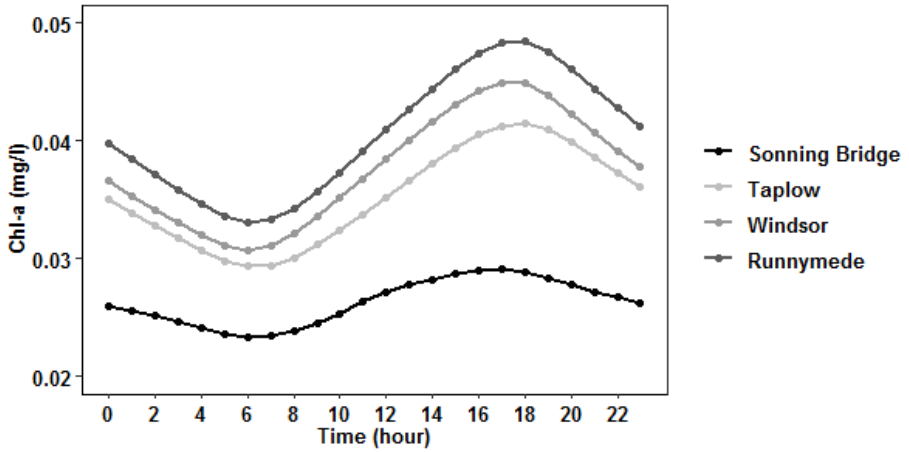
- River Thames is **highly impacted** from flow regulation through locks and weirs, abstractions, loading of pollutants from runoff and sewage discharges
- We implement the QUESTOR sub-daily model for a **62 km long stretch** of the lower Thames for a period of two years (2013-2014)
- The model simulates hourly variation and transport of in-stream **river flows, water temperature, nutrients** and **phytoplankton biomass**



Comparing model outputs with observations



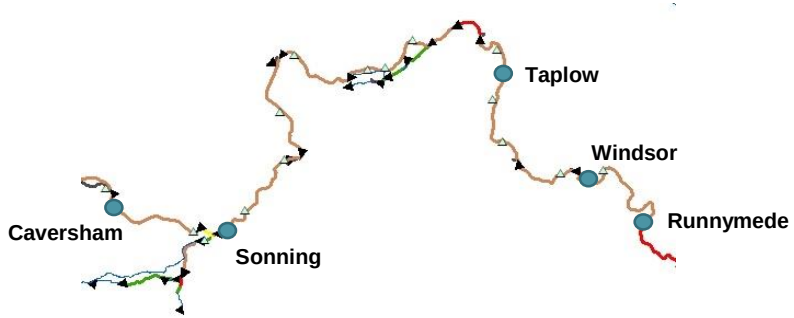
- Seasonality of flows, water temperature, and phytoplankton successfully simulated
- Phytoplankton blooms occur between April and July
- Model successfully captures the timing of blooms and crashes



Diurnal trend of modelled phytoplankton averaged over growing period (April-July)

Model performance: summary statistics

Model performance judged by Nash-Sutcliffe Efficiency (NSE) and percentage error in mean (PBIAS) for calibration (2013) and validation (2014) periods at four downstream sites



Period	Determinand	Sonning		Taplow		Windsor		Runnymede	
		NSE (-)	PBIAS (%)	NSE (-)	PBIAS (%)	NSE (-)	PBIAS (%)	NSE (-)	PBIAS (%)
Calibration (2013) / **Validation (2014)**	Flow					0.96/**0.95**	-9.88/**11.58**		
	Temperature	0.99/**0.98**	-2.14/**-3.87**	0.98/**0.98**	3.80/**3.61**	0.98/**0.99**	3.52/**2.35**	0.99/**0.99**	1.58/**-0.9**
	Chlorophyll-a	0.81/**0.78**	-19.9/**-20.06**	0.87/**-0.19**	26.16/**60.93**	0.80/**0.20**	12.71/**76.73**	0.73/**0.77**	-34.64/**-16.58**
	Nitrate	0.21/**-0.07**	-4.17/**-5.97**					0.31/**0.46**	1.74/**1.55**
	SRP	0.77/**0.80**	2.92/**5.47**					0.75/**0.71**	16.24/**16.11**

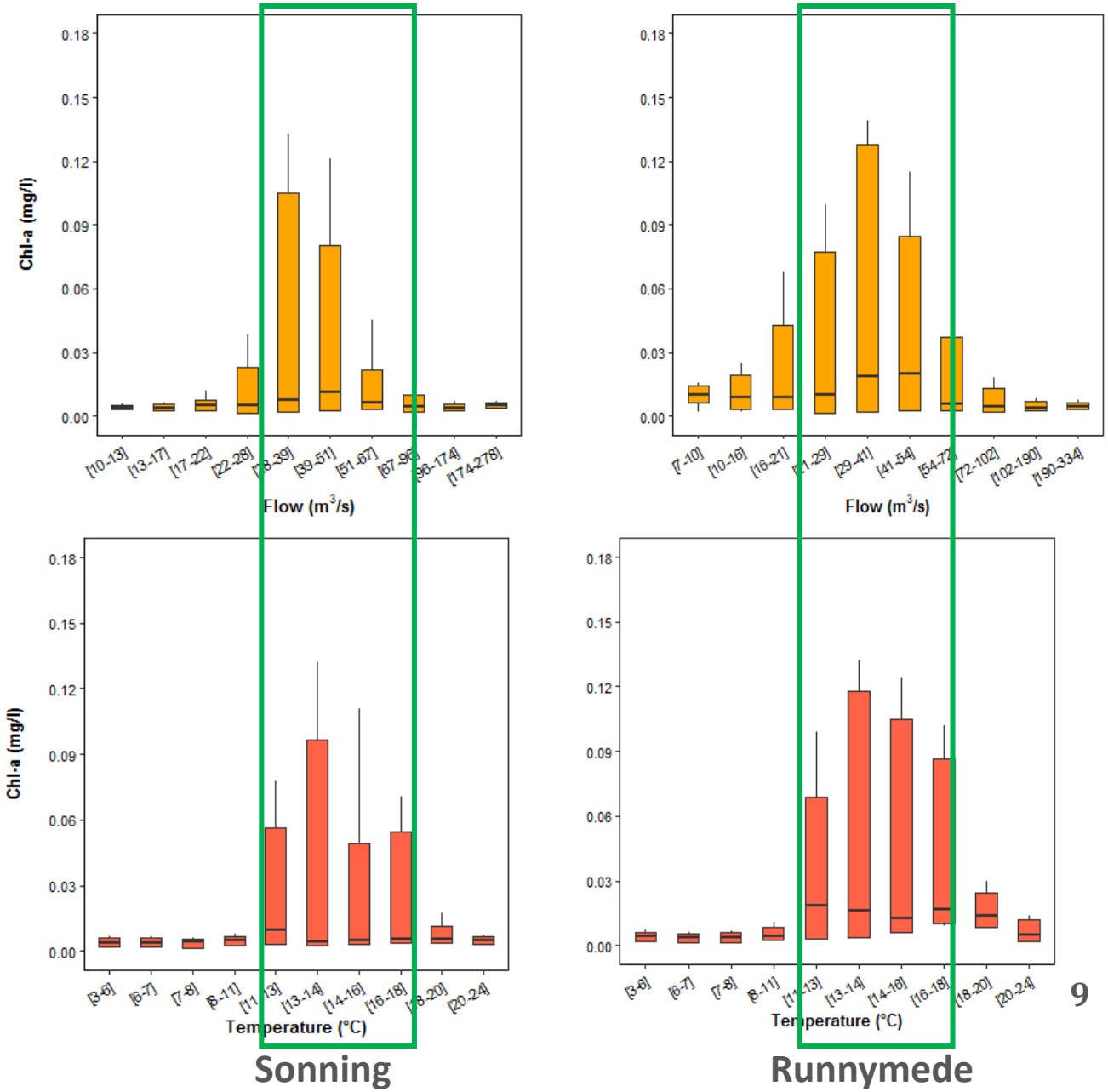
Phytoplankton growth controls

- High **chlorophyll levels (>0.03 mg/l)** only observed within specific flow and temperature bounds
- High phytoplankton levels observed **between 21-63 m^3/s**
- As the model assumes optimum **temperature**, high phytoplankton levels are simulated between **11-18° C**, which can be validated by observations
- High chlorophyll concentrations coinciding with low SRP levels and low flows suggest **phosphorus uptake by phytoplankton biomass** (figure not shown here)

Simulated flow and temperature bounds are comparable to the observed bounds

Variable	Observed bounds		Modelled bounds		
	Caversham*	Windsor	Sonning	Windsor	Runnymede
Flow (m^3/s)	<30	32-68	28-51	30-63	21-54
Temp (°C)	9-19	10-17	11-18	11-18	11-18

(* from Bowes et al. 2016)

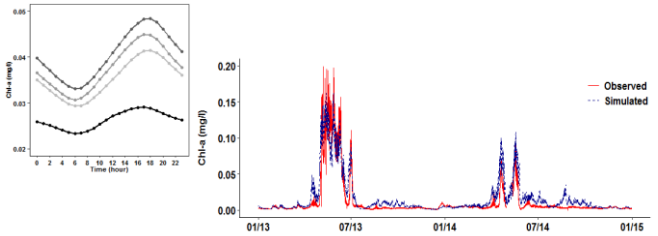


Conclusion

How well can we predict sub-daily phytoplankton dynamics using high-frequency monitoring data in rivers?

- QUESTOR sub-daily model satisfactorily captures diurnal variation of phytoplankton dynamics (NSE>0.7), the magnitude and timing of bloom events, and crucial predictors for water quality management

- This is the first hourly scale phytoplankton modelling study for the River Thames, and one of the first model testing of hourly response at such a wide temporal (2 year) and spatial (> 50 km) extent

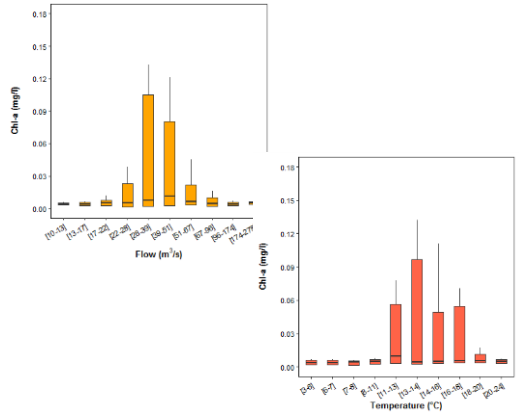


Can we utilise model outputs to identify physico-chemical controls on phytoplankton growth?

- Flow and temperature bounds (21-63 m^3/s and 11-18° C, respectively) identified within which high concentrations of chlorophyll (>0.03 mg/l) occur

- Physical controls are the main limiting factors in the lower Thames, with some nutrient limitation from phosphorus depletion in summer

- Environmental thresholds identified here can be used for preventing algal growth from developing into a major bloom



Thank you

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