# Eutrophication Risk Assessment Using Bayesian Calibration of Process-Based Models

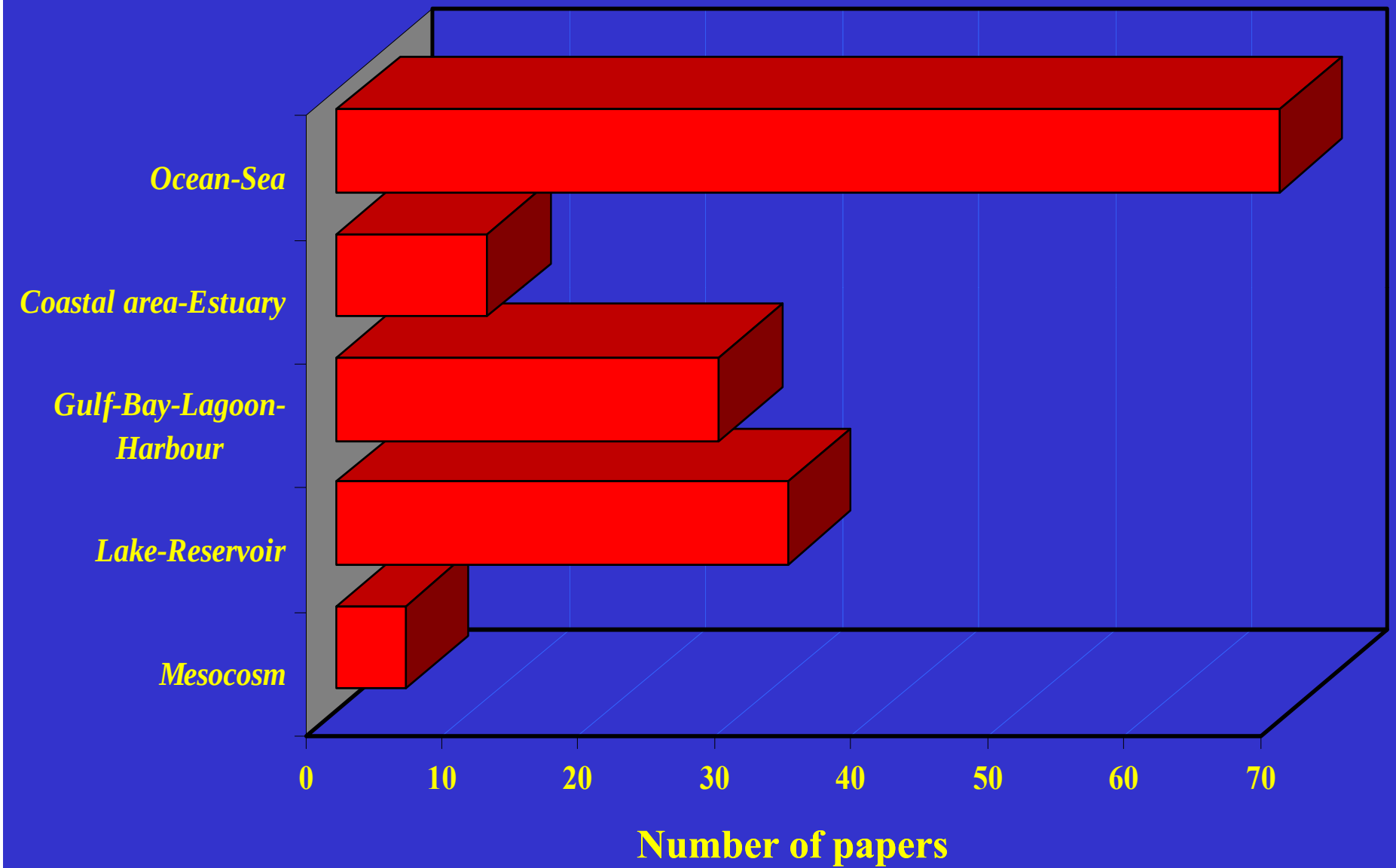
Weitao Zhang, Gurbir Perhar, Evangelia Massos, George B. Arhonditsis

University of Toronto

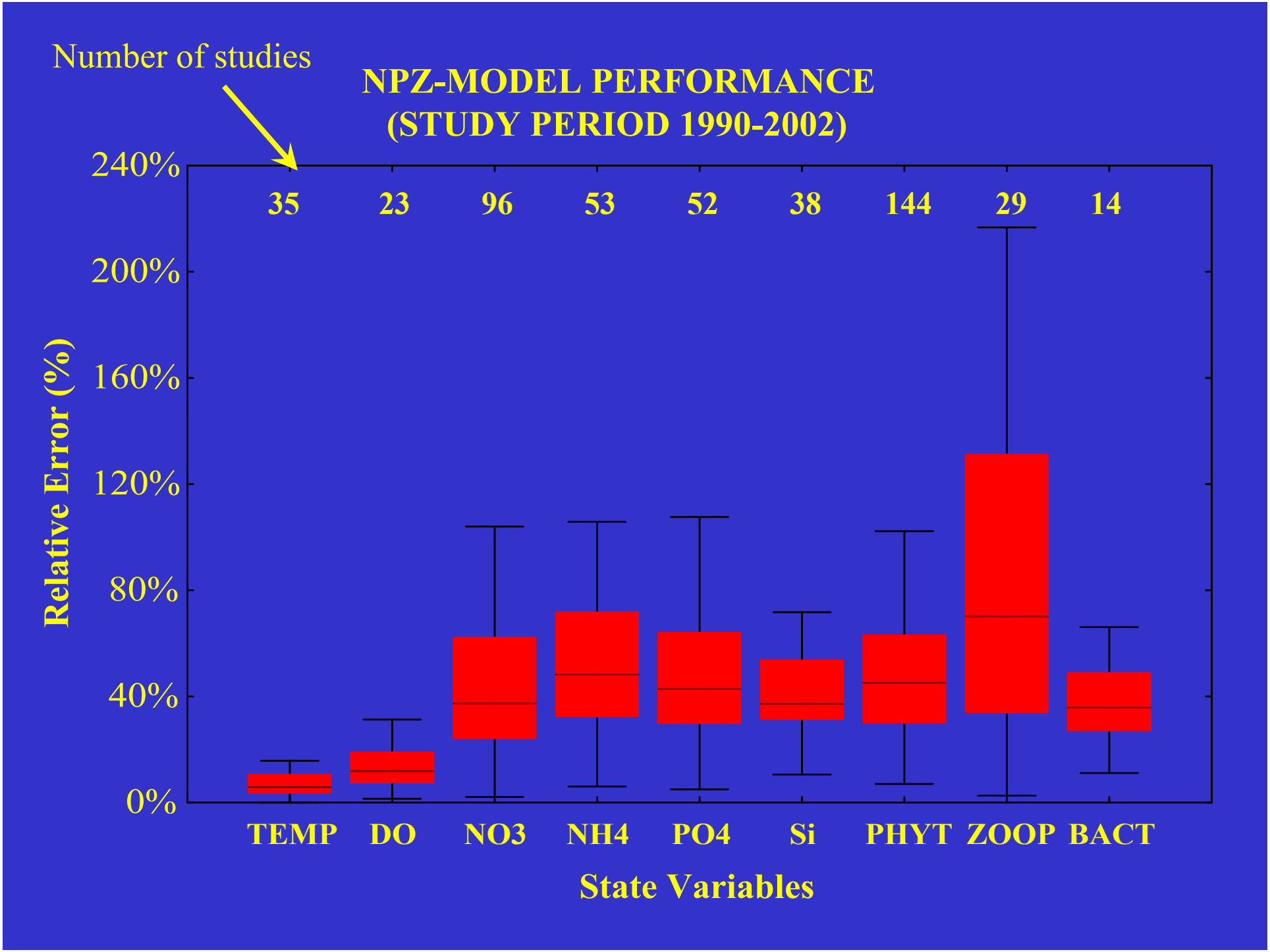
# ***Outline***

- ***Evaluation of the current state of aquatic biogeochemical modeling: Where are we?***
- ***Citation analysis: Which factors determine their citation frequency?***
- ***Bayesian calibration of aquatic biogeochemical models***

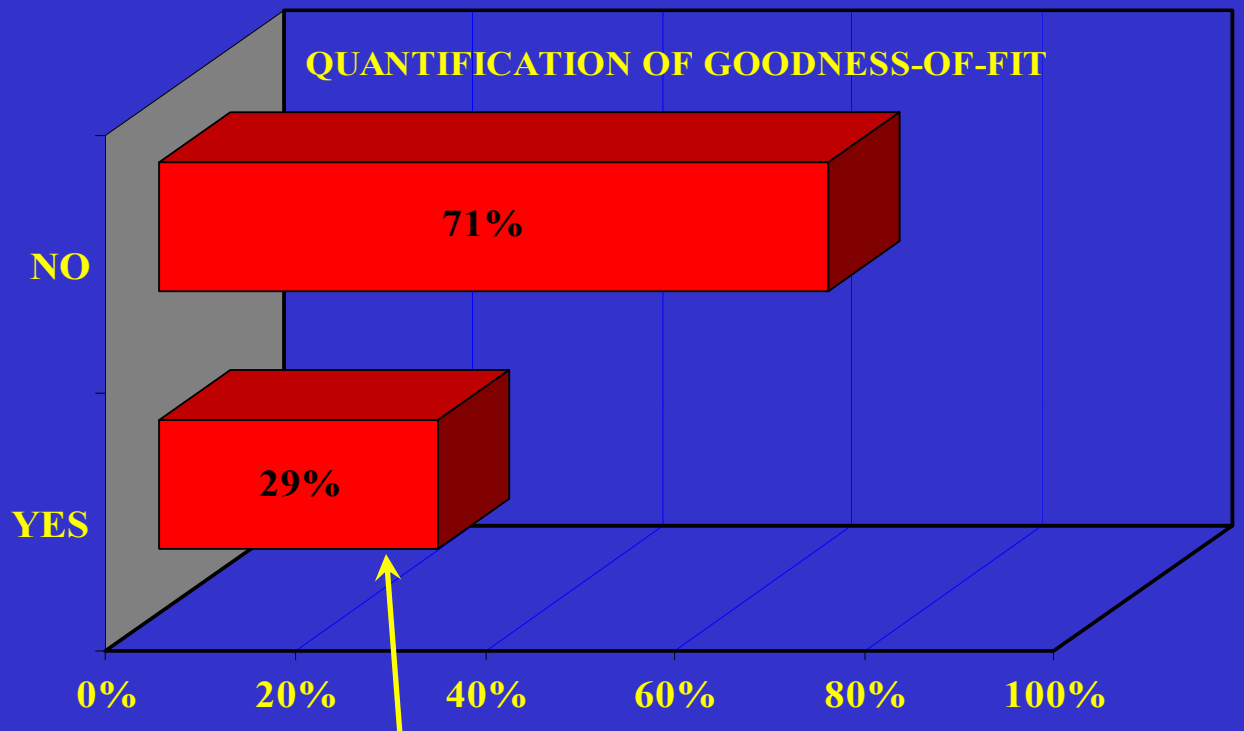
# Types of modeled aquatic ecosystems (Study period 1990-2002)



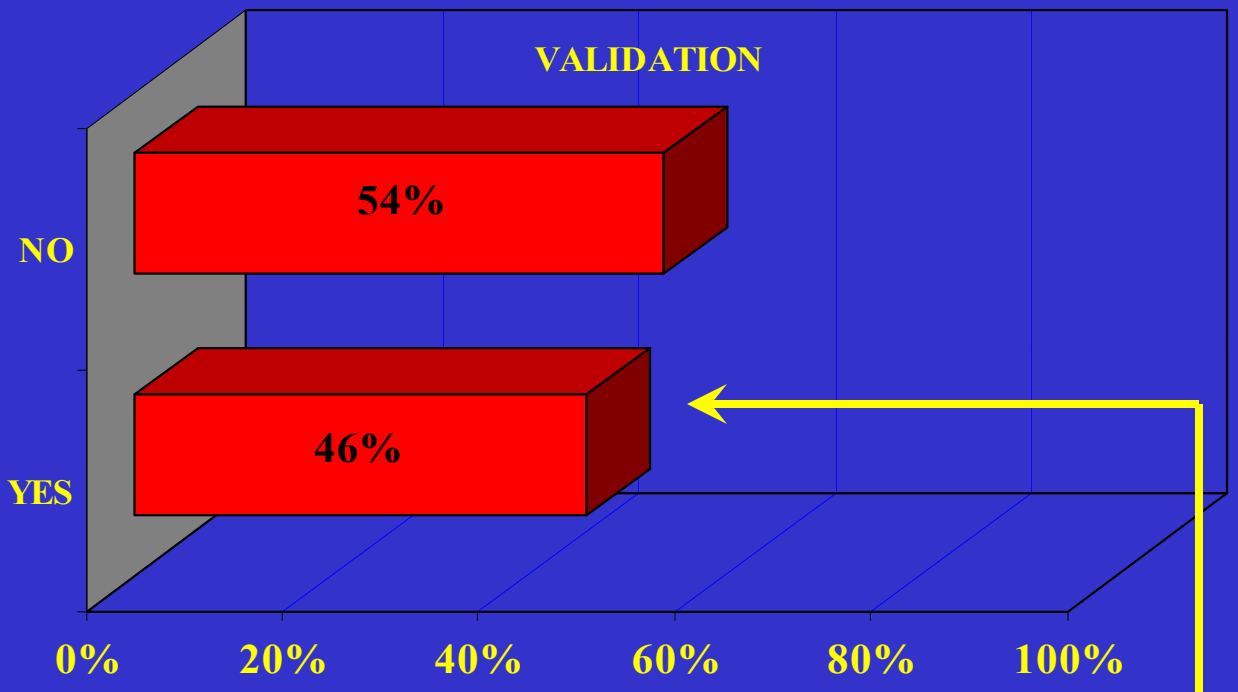
***How well do the numerical aquatic biogeochemical models simulate real-world dynamics?***


Number of studies
NPZ-MODEL PERFORMANCE
(STUDY PERIOD 1990-2002)
240%
200%
160%
120%
80%
40%
0%
Relative Error (%)
35
23
96
53
52
38
144
29
14
TEMP
DO
NO3
NH4
PO4
Si
PHYT
ZOOP
BACT
State Variables

***How consistently do modelers follow conventional modeling procedures?***



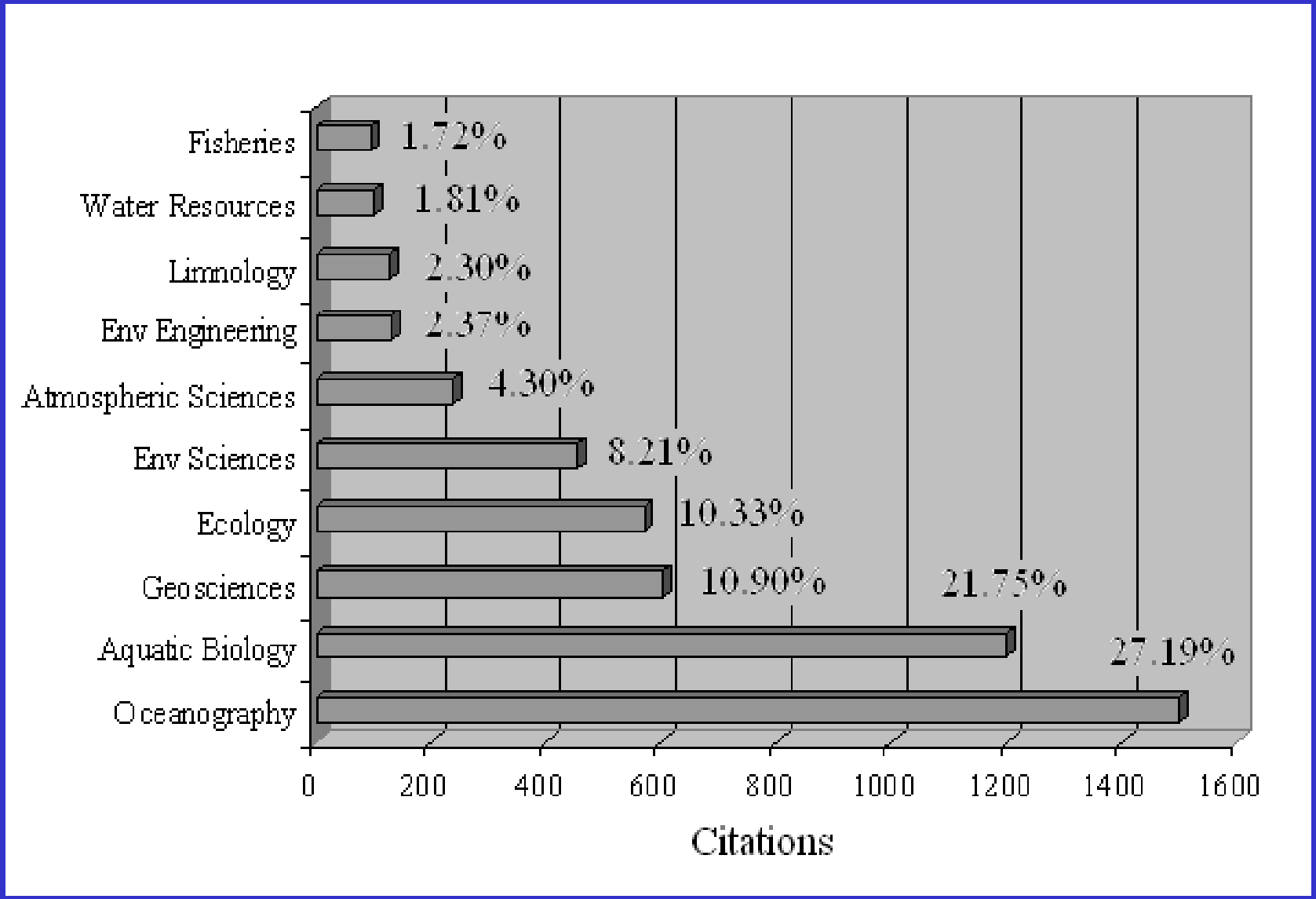

Only a small fraction (<6%) of the studies objectively quantified the model's performance by applying all appropriate measures of fit (e.g., RE, mean absolute error) and statistical significance (e.g., *t*-test, regression analysis)



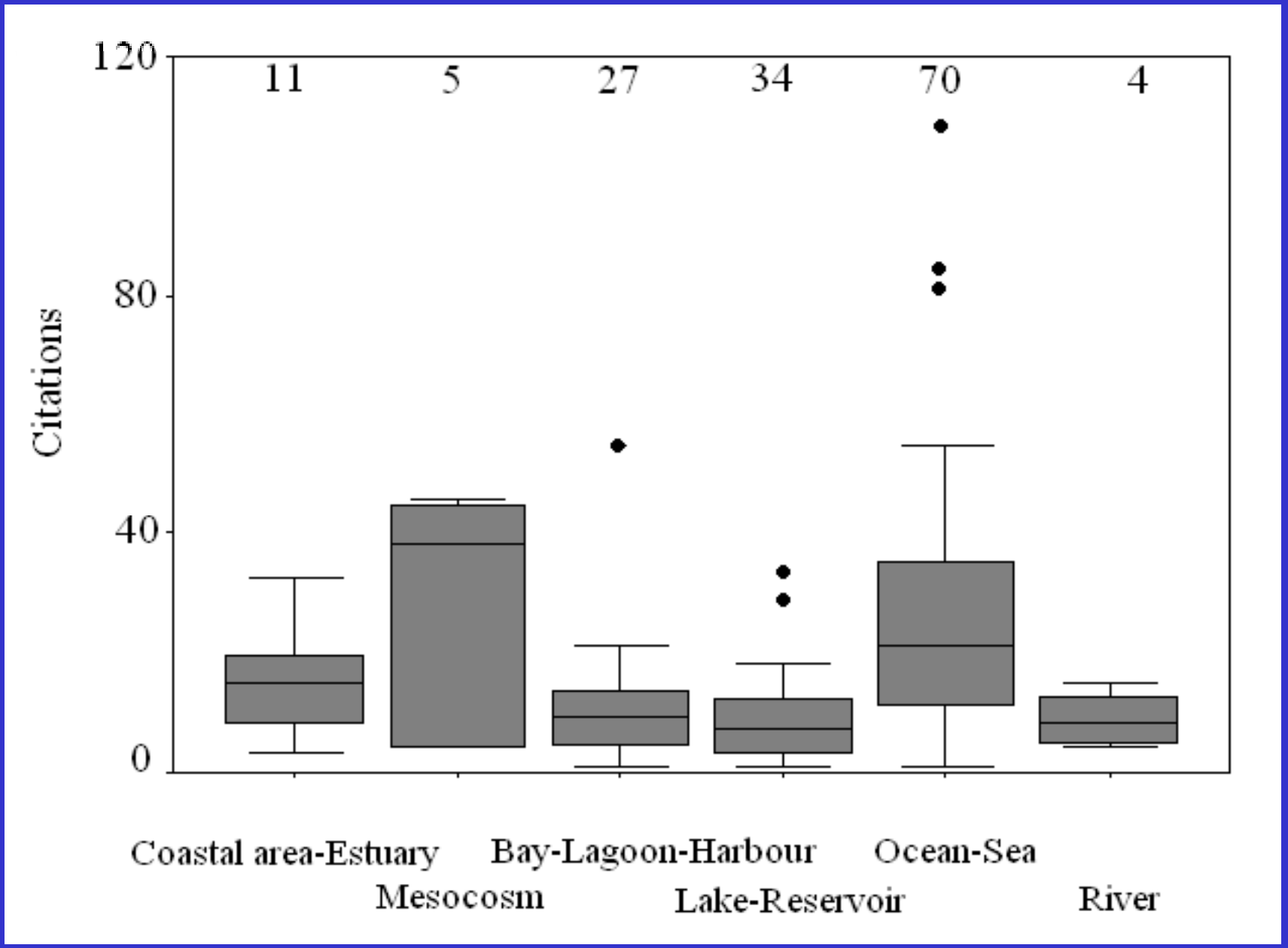

- Predictive validation
- Structural validation
- Model transferability

***What can we learn from their citation frequency?***

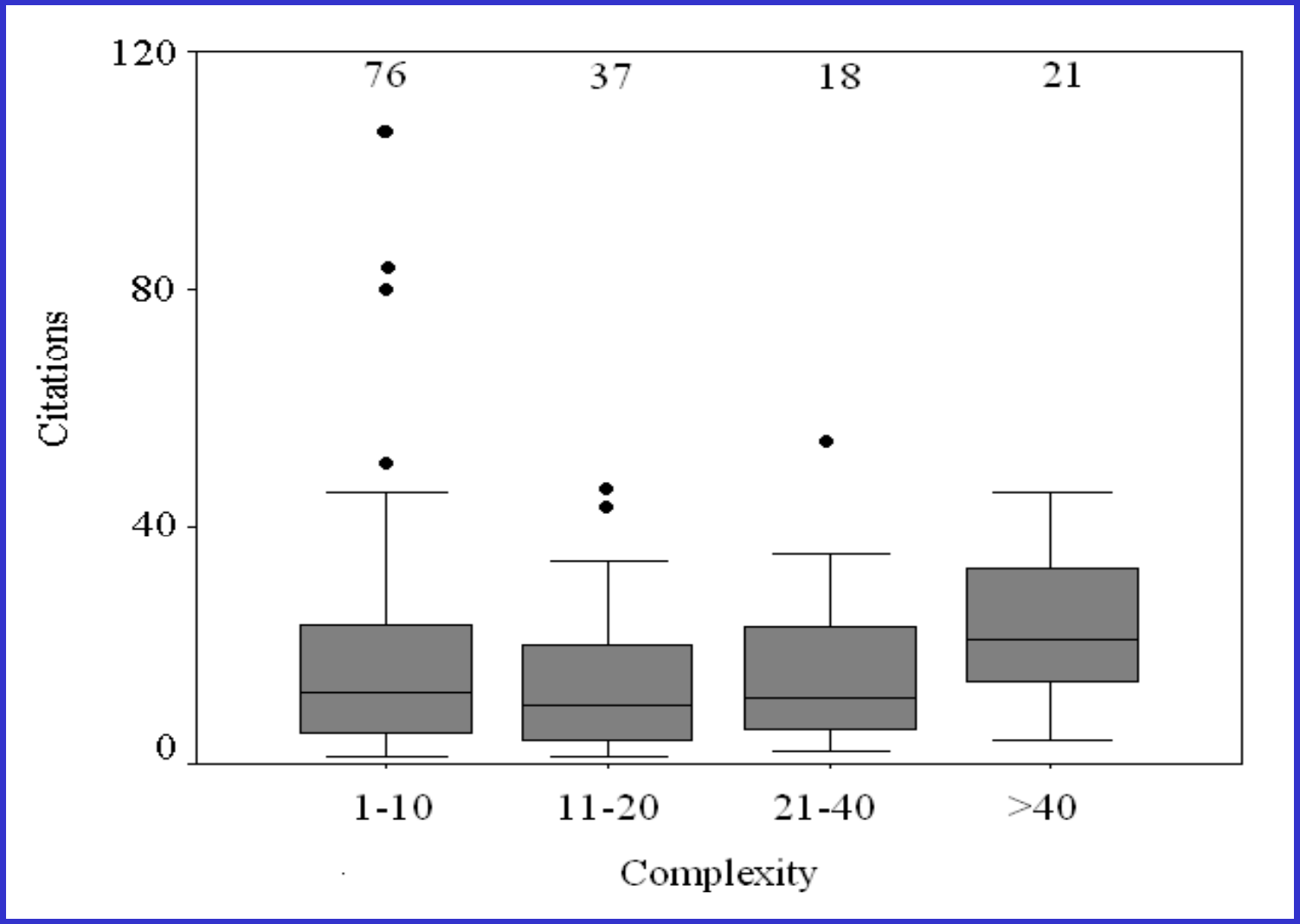
# Scientific classification of the papers that cite modeling studies



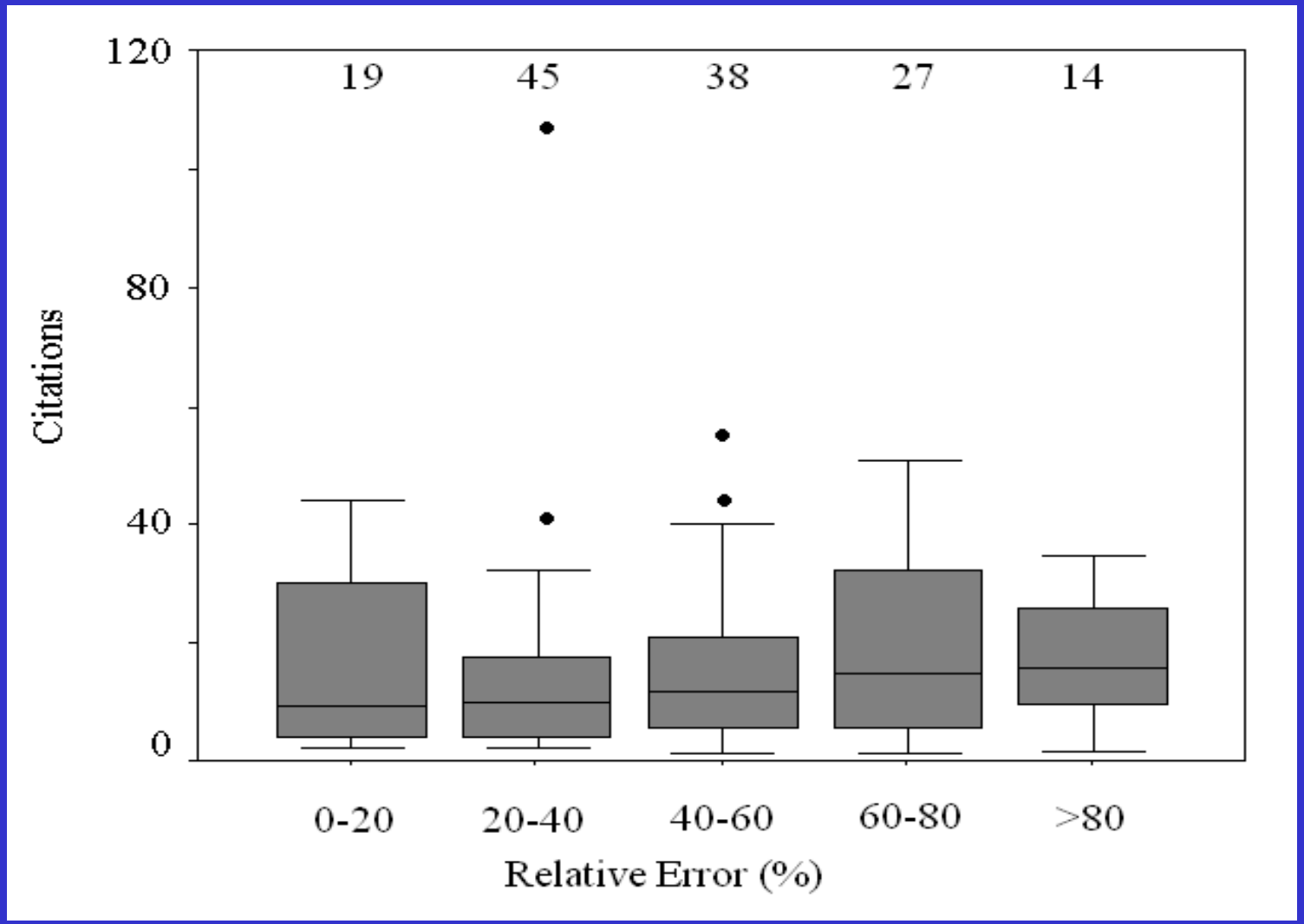
# Citation frequency for different types of modeled ecosystem



# Model Complexity & Citation Frequency



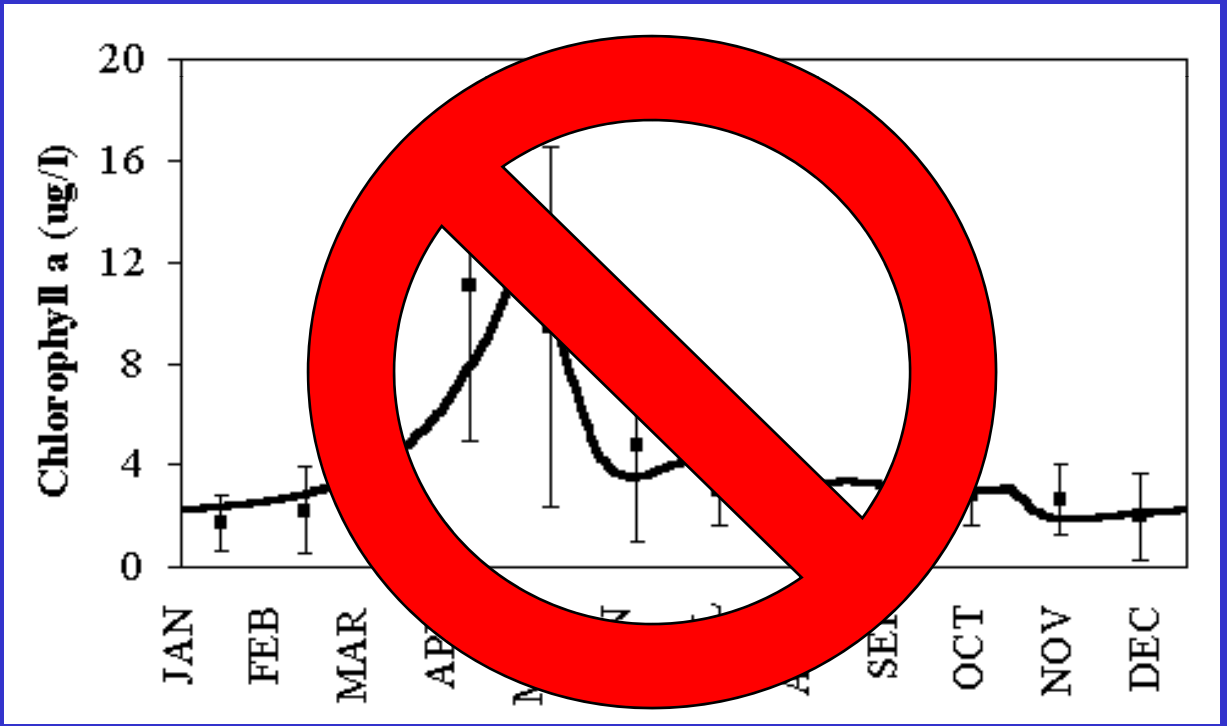
# Model Performance & Citation Frequency



**The analysis provided evidence that modeling papers are cited mainly *based on the questions being asked*; models that aim to elucidate oceanic patterns are more highly cited than models developed for addressing local water quality management issues regardless of their methodological features and technical value.**

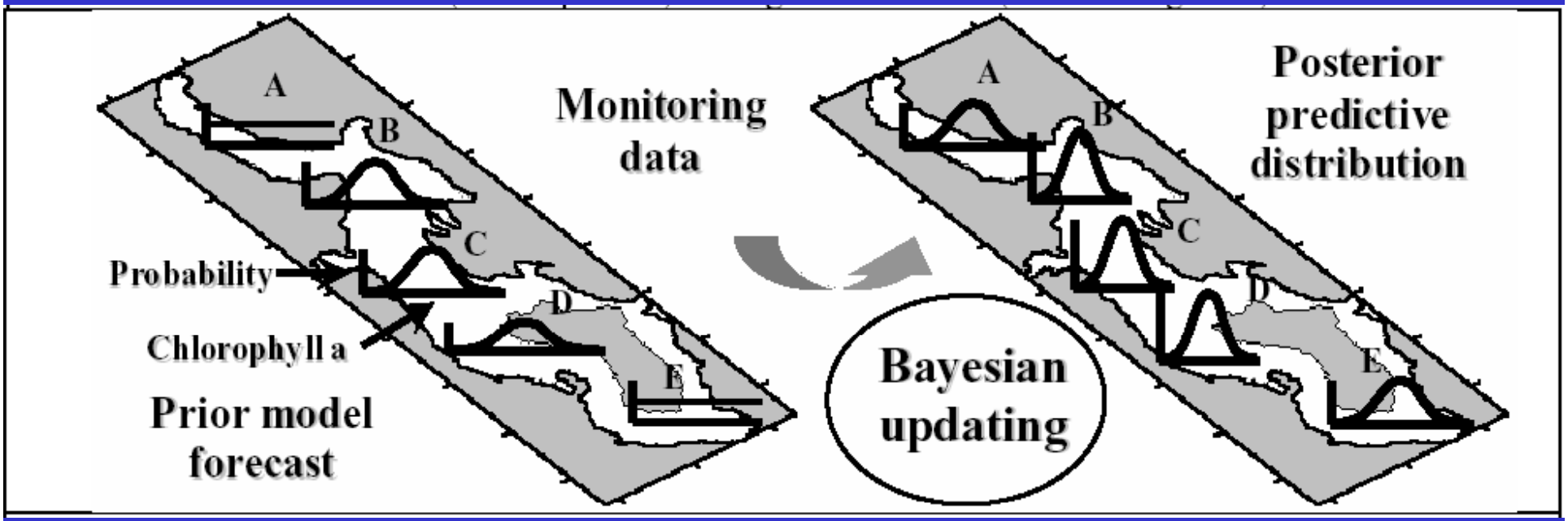
# *Bayesian calibration of mechanistic aquatic biogeochemical models*

# *We do not have the knowledge for deterministic statements!*



***The only defensible strategy for supporting the policy-makers is….***

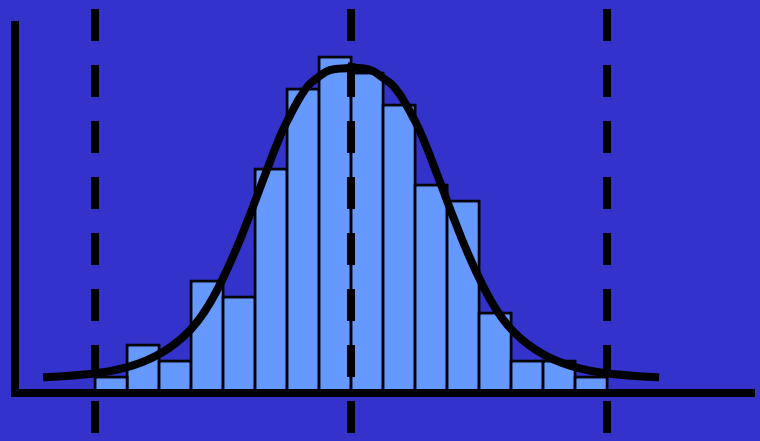
# ….the adoption of probabilistic statements



# *Prior Knowledge on the system*

***Plausible literature range of parameter (min, max)***

**Assignment of a probability distribution (e.g., Normal, Lognormal)**



# *Bayes' theorem*

$$p(\theta|D) \propto p(\theta)\, L(D|\theta)$$

**Posterior belief on θ after observing the new data**

**Prior beliefs on θ**

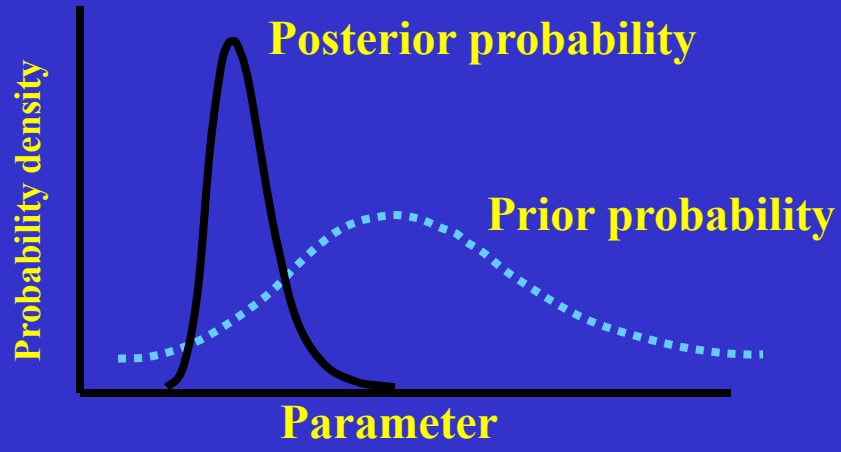
***likelihood function*: used to update the prior beliefs on θ to account for the new data**

## *Sequential updating*

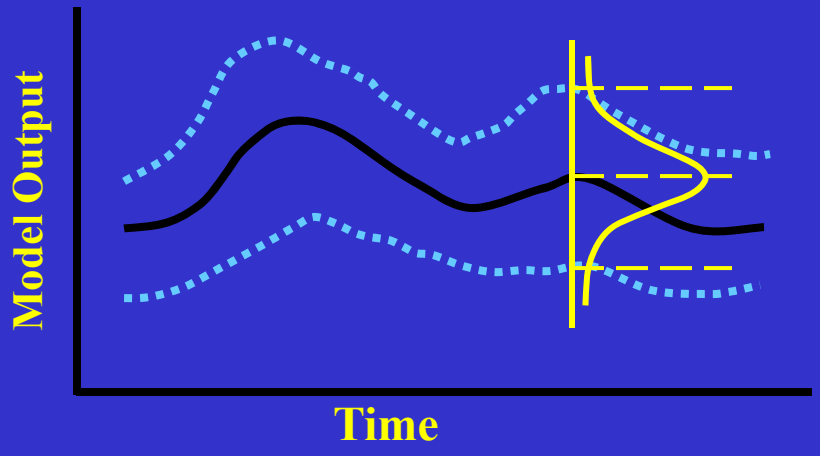
- **Repeated use of the Bayes' theorem**
- **Current posterior becomes prior when new data are available**

# Benefits

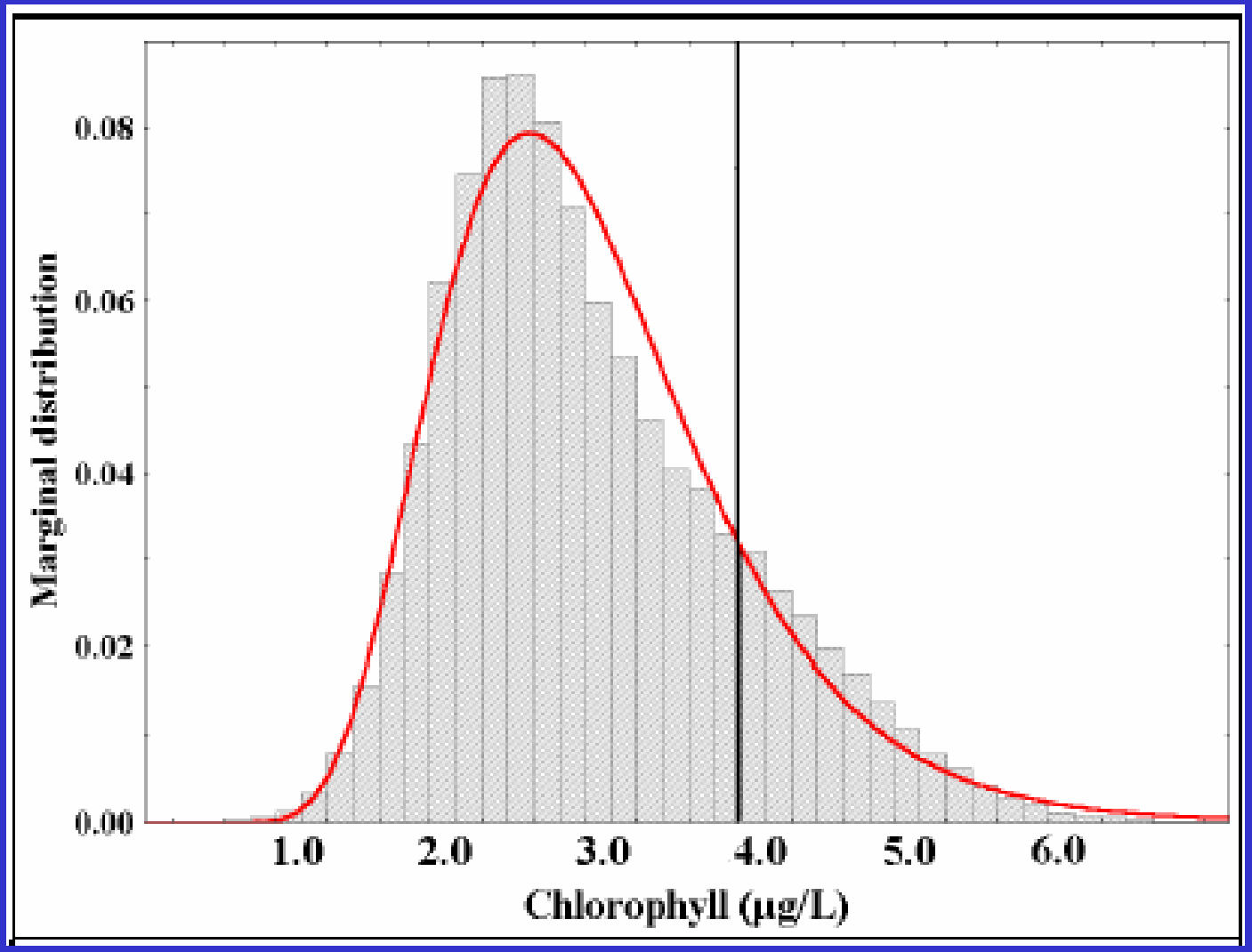
- **Identification problem**



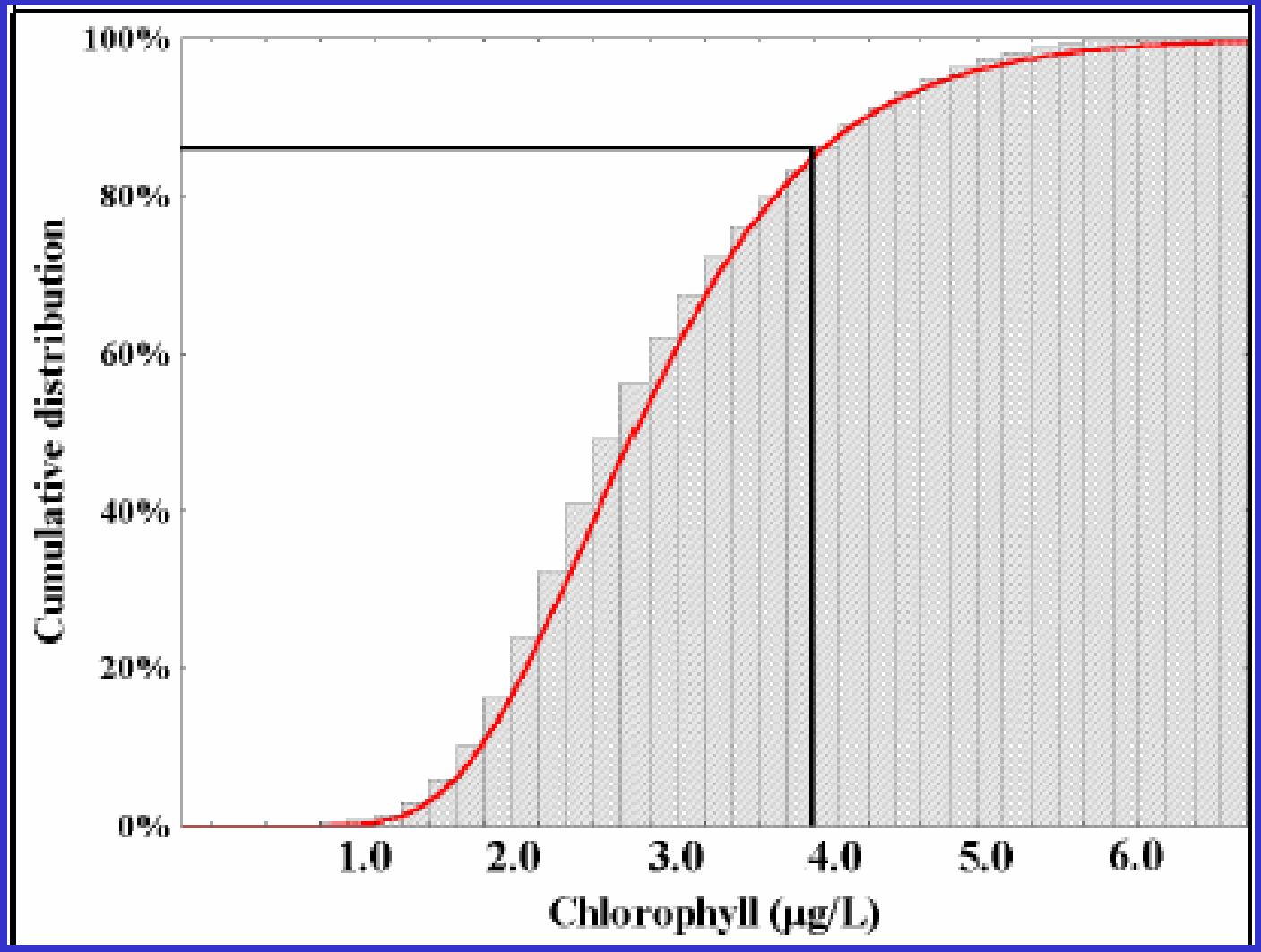

- **Realistic predictive uncertainty estimates**



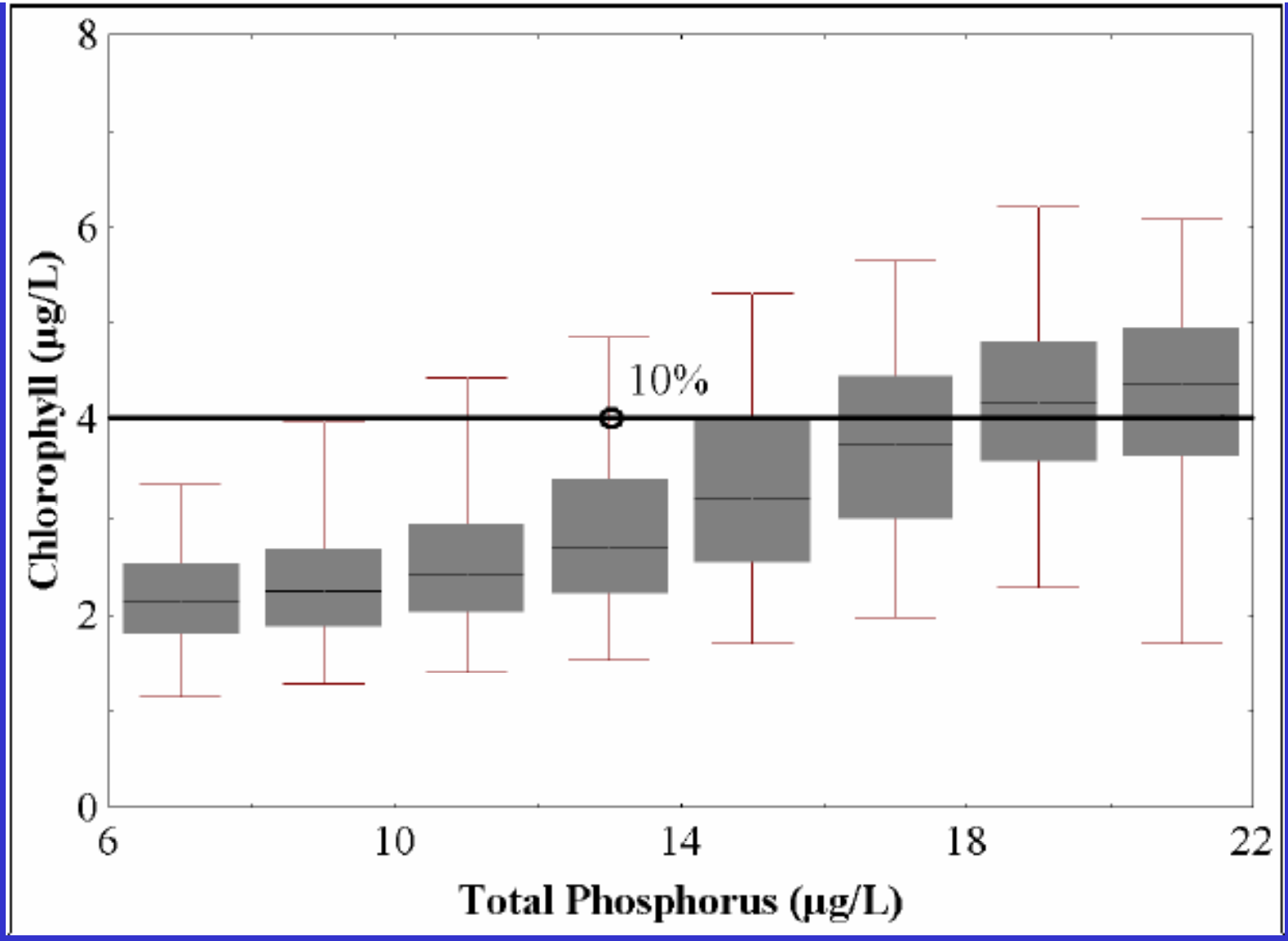
# Realistic uncertainty estimates of the ecological forecasts



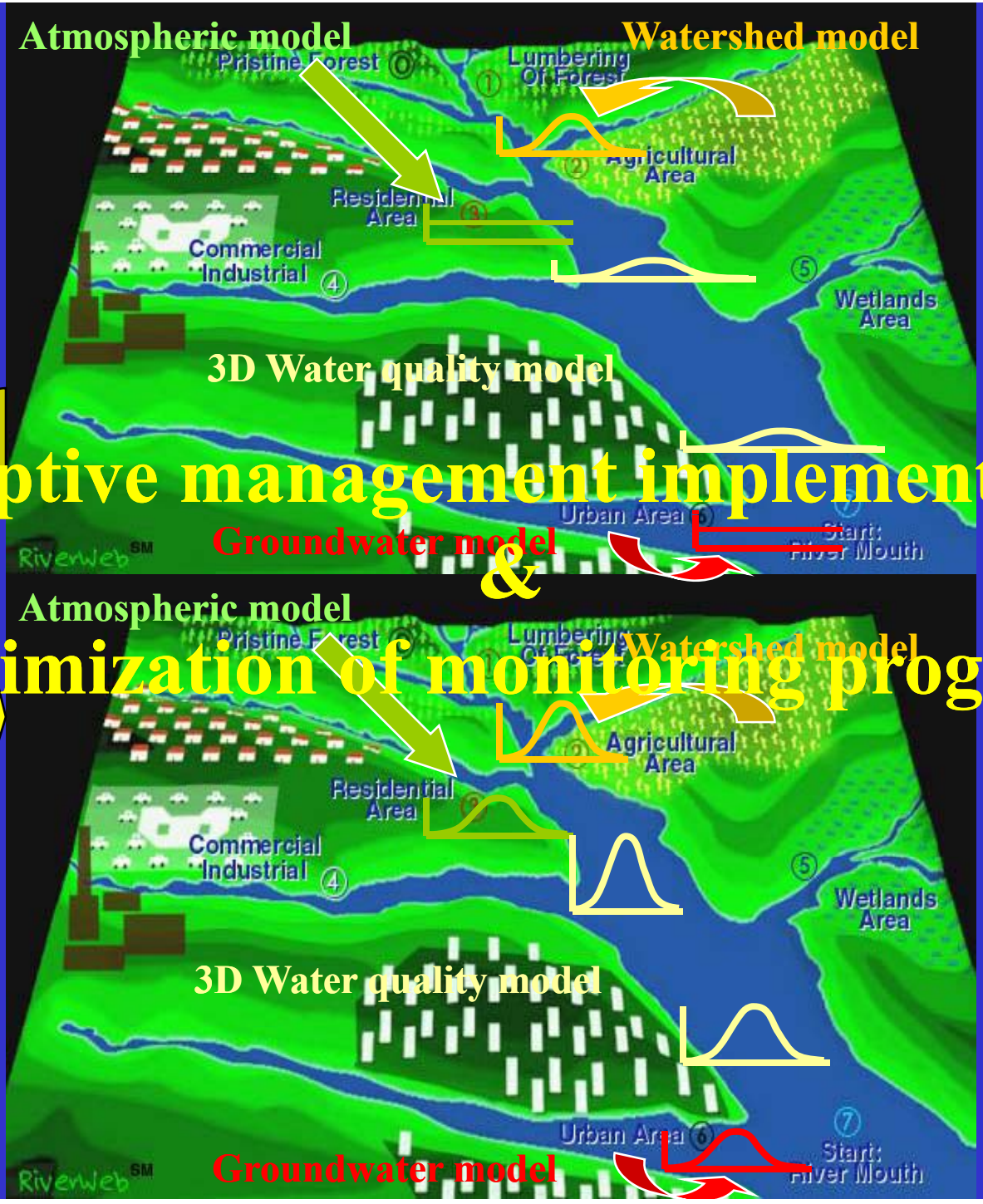
# *Eutrophication Risk Assessment*




There is 15% probability that chlorophyll will be higher than 4 µg/L during the summer stratified period in Lake Washington.




The model predictions suggest that if our target for the chlorophyll level of 4 µg/L is an exceedance frequency lower than 10%, then the summer TP concentrations should be lower than 14 µg/L




# Adaptive management implementation

Bayesian updating

&

# Optimization of monitoring programs

## *REFERENCES*


- *Arhonditsis, G.B., Brett, M.T., 2004. Evaluation of the current state of mechanistic aquatic biogeochemical modeling. Mar Ecol-Prog Ser 271: 13-26.*
- *Arhonditsis, G.B., B.A. Adams-VanHarn, L. Nielsen, C.A. Stow, K.H. Reckhow 2006. Evaluation of the current state of mechanistic aquatic biogeochemical modeling: citation analysis and future perspectives. Environmental Science & Technology 40, 6547-6554.*
- *Arhonditsis, G.B., S.S. Qian, C.A. Stow, E.C. Lamon, K.H. Reckhow. Eutrophication risk assessment using Bayesian calibration of process-based models: Application to a mesotrophic lake. Ecological Modelling: In press.*