Effect of Freshwater Aquaculture on Epilimnetic Nitrogen, Phosphorus, and Chlorophyll A Levels

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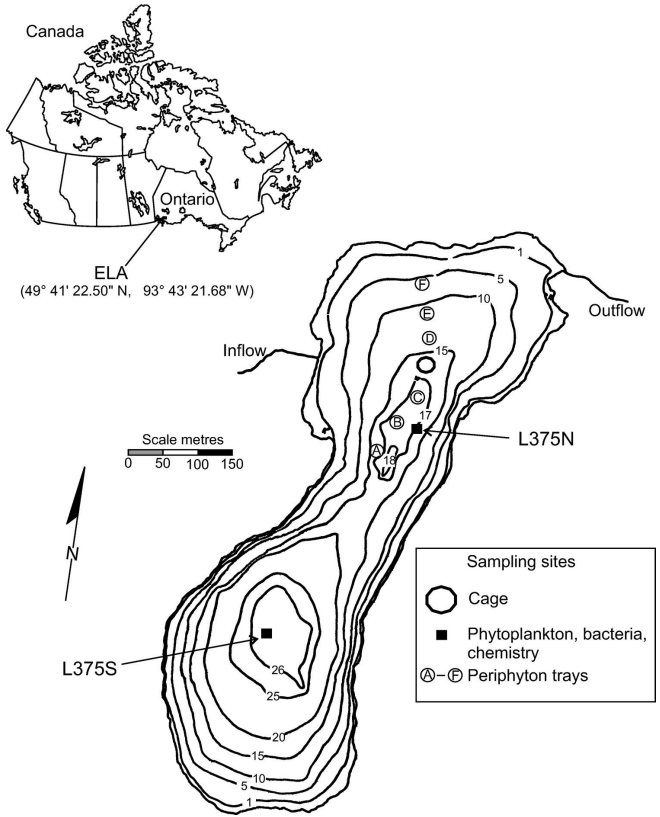
Why we should study aquaculture and why it matters

- Aquaculture part of the solution towards global food security[1,2]
- Environmental impacts of freshwater aquaculture largely unknown[3]
  - Water quality degradation
  - Impacts on biota
- Cumulative impacts of aquaculture on a whole aquatic system is difficult to study

1. Costello et al., 2020
2. Garlock et al., 2022
3. Yan, 2005

IISD-ELA Lake 375 - Aquaculture Experiment

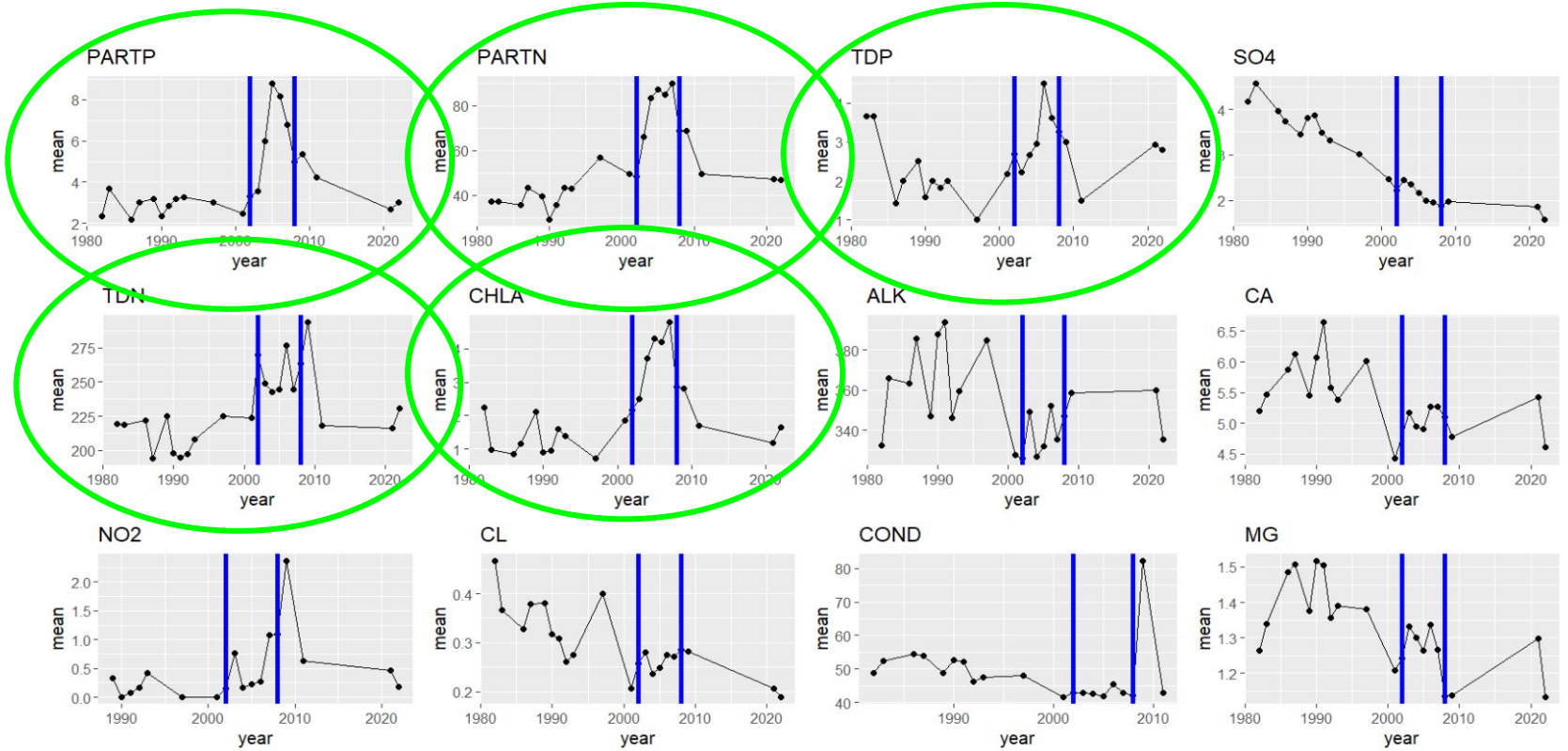


Findlay et al., 2009

- Oligotrophic (max depth 26 m)
- Dimictic (mixes twice a year)
- Experimental period: 2003-2007
- 10,000 female rainbow trout raised annually 10x10m aquaculture cage
- Measurements of water chemistry, fish health, other ecosystem impacts (e.g. zoop and native fish pops)

Water Chemistry Data Exploration

Average annual value of variables over time in epilimnion

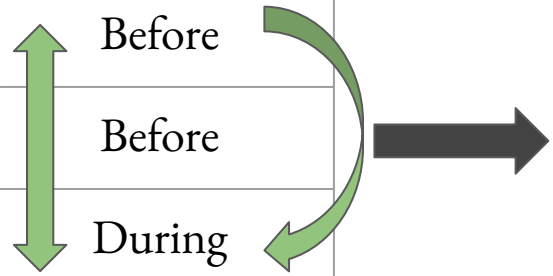


Methodology

1. Explored the data and its distributions
2. Ran preliminary Anovas, GLMs and Linear Mixed Models for model selection
3. Ran 3 main statistical analyses
    a. Linear Mixed Models
    b. Permutation Tests for group means
    c. ARIMA for Forecasting
4. Created Interpolated Graphs for each variable.

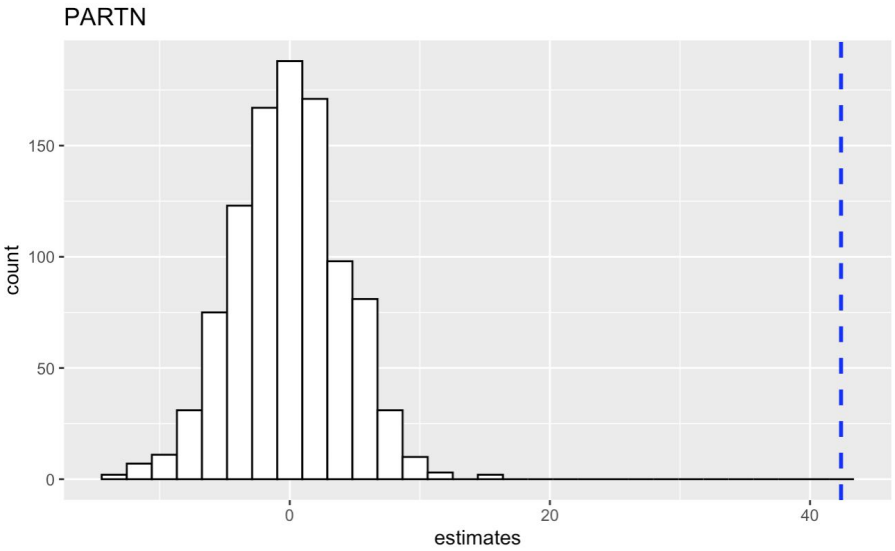
Permutation Analysis

Results	Treatment
2.00	Before
0.50	Before
5.20	During
5.30	During
4.80	During

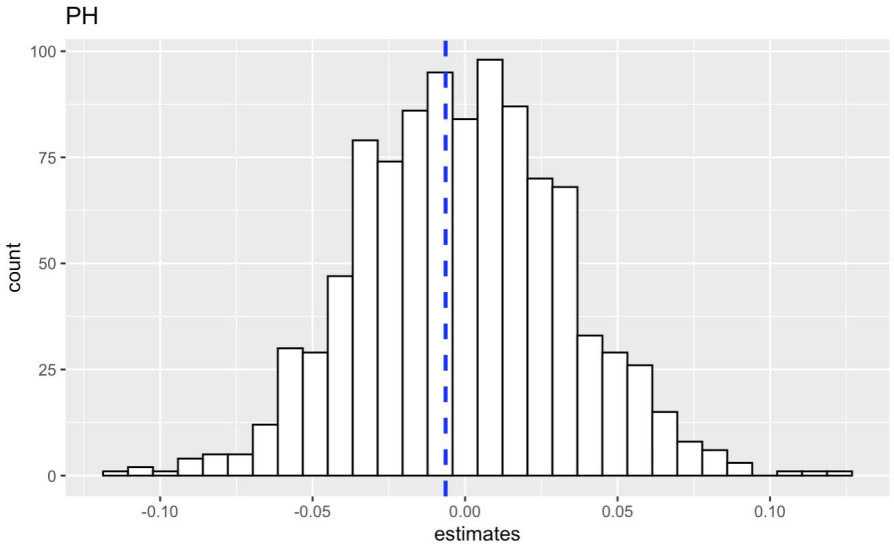


Results	Treatment
2.00	Before
0.50	During
5.20	Before
5.30	Before
4.80	During

Permutation in Action

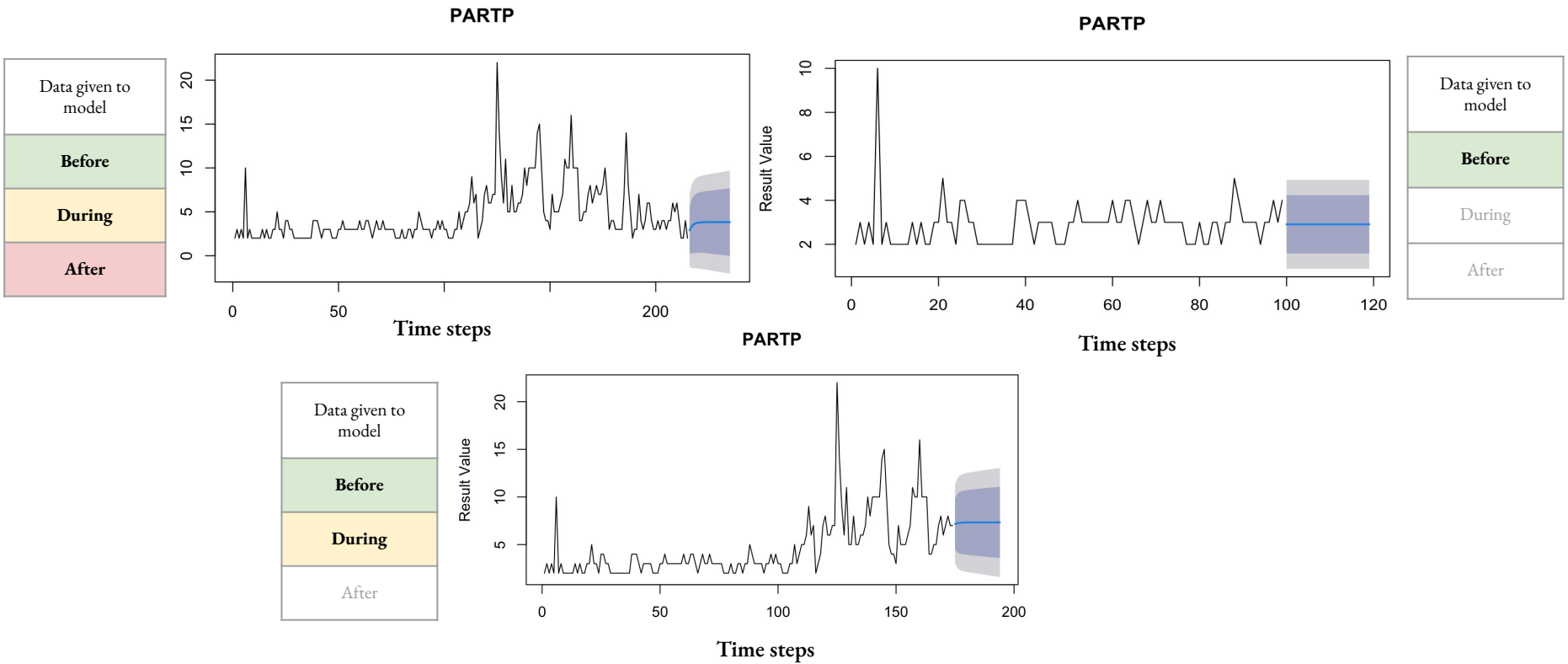


A Significant Result



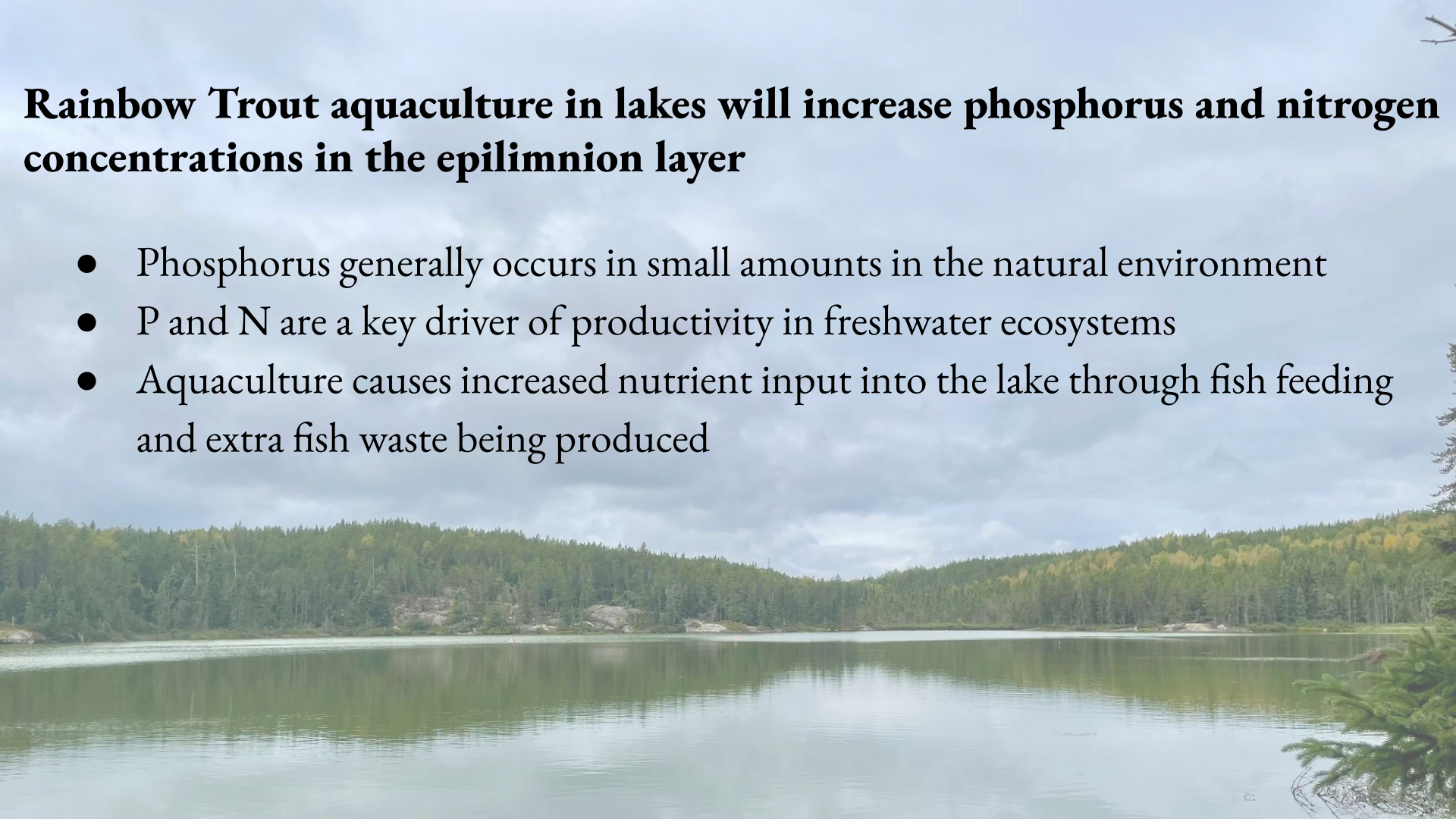
A Not So Significant Result

Forecasting With ARIMAs

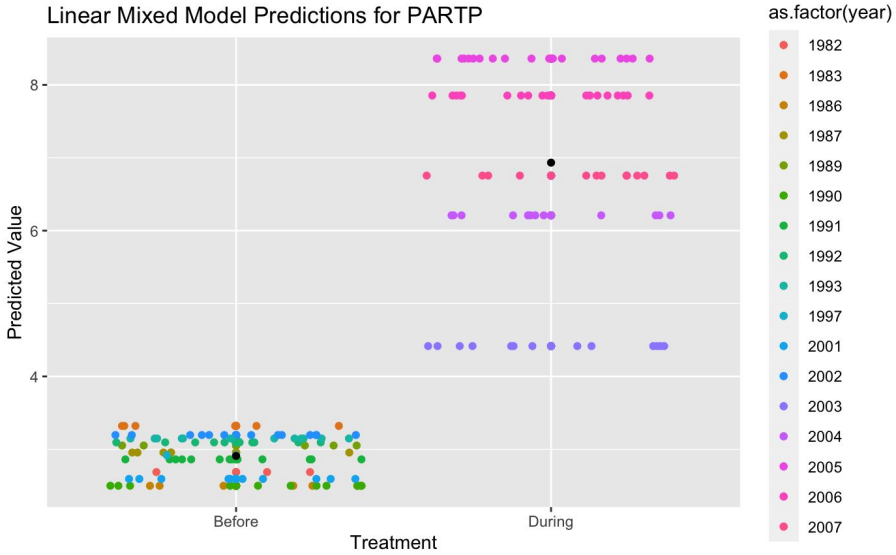


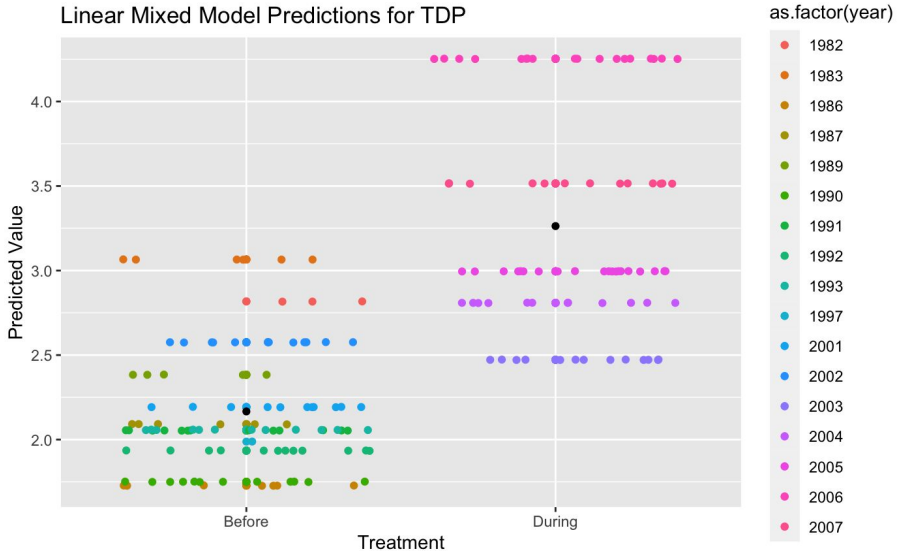
Rainbow Trout aquaculture in lakes will increase phosphorus and nitrogen concentrations in the epilimnion layer

- Phosphorus generally occurs in small amounts in the natural environment
- P and N are a key driver of productivity in freshwater ecosystems
- Aquaculture causes increased nutrient input into the lake through fish feeding and extra fish waste being produced



Phosphorus levels increased significantly after aquaculture



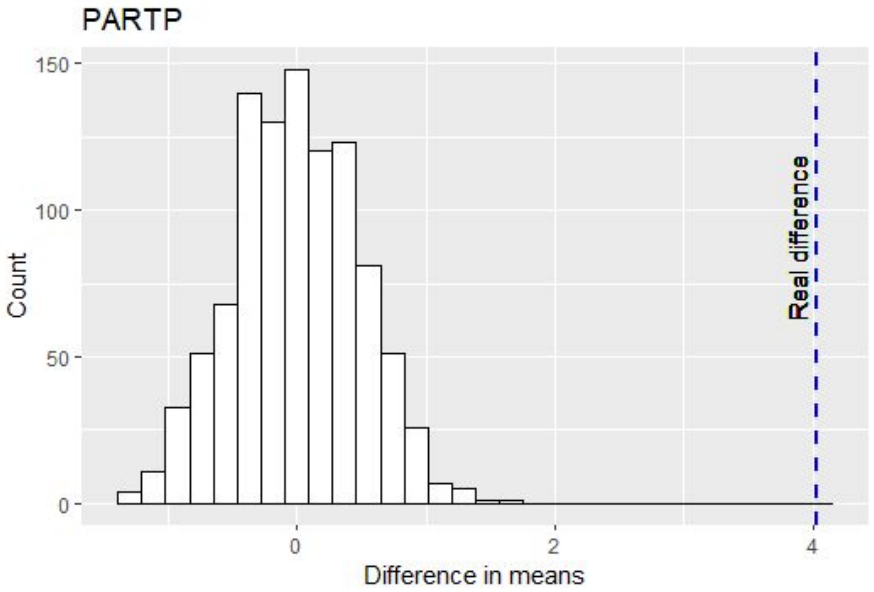


Effect size of treatment on PARTP: 3.81712ug/L

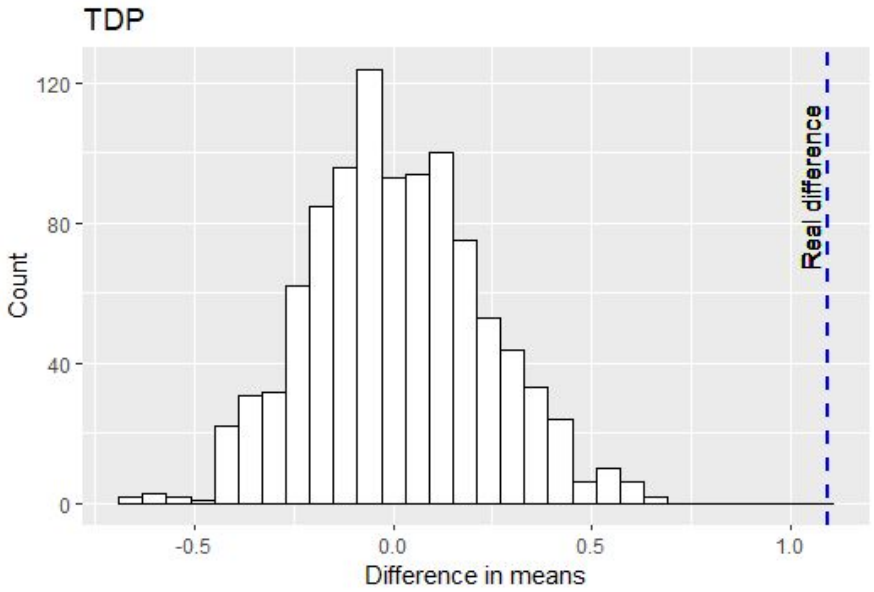
Characteristic	P Value
PARTP	1.244521e-05
TDP	1.694702e-02

Effect size of treatment on TDP: 0.98891ug/L

Phosphorus levels increased significantly after aquaculture

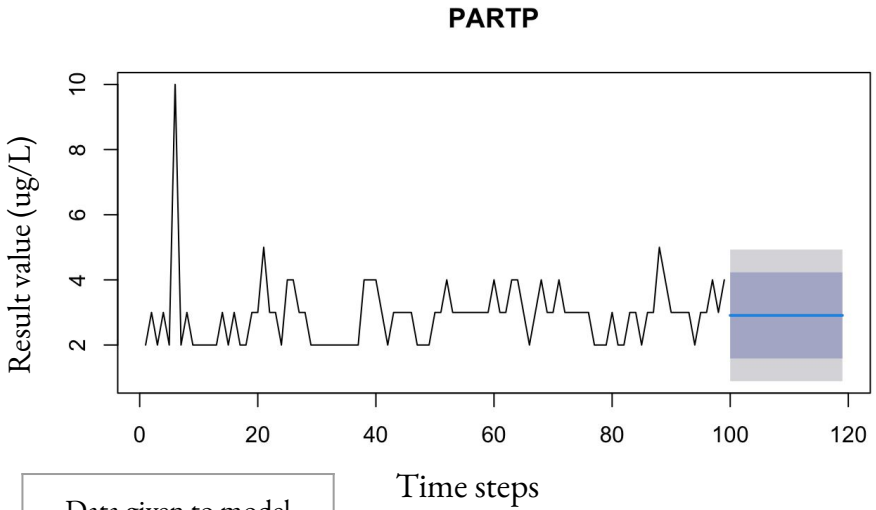


Real difference (PARTP): 4.0242

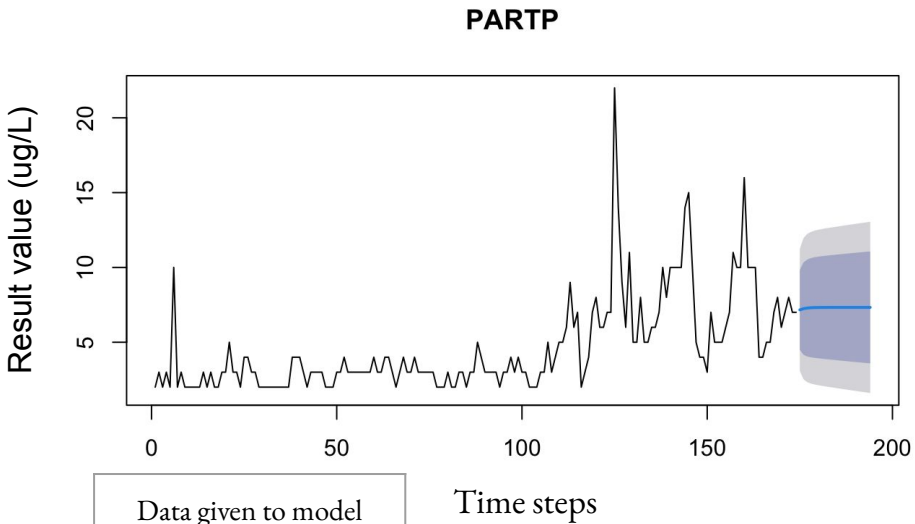


Real difference (TDP): 1.0965

ARIMA predicts phosphorus levels will change with aquaculture

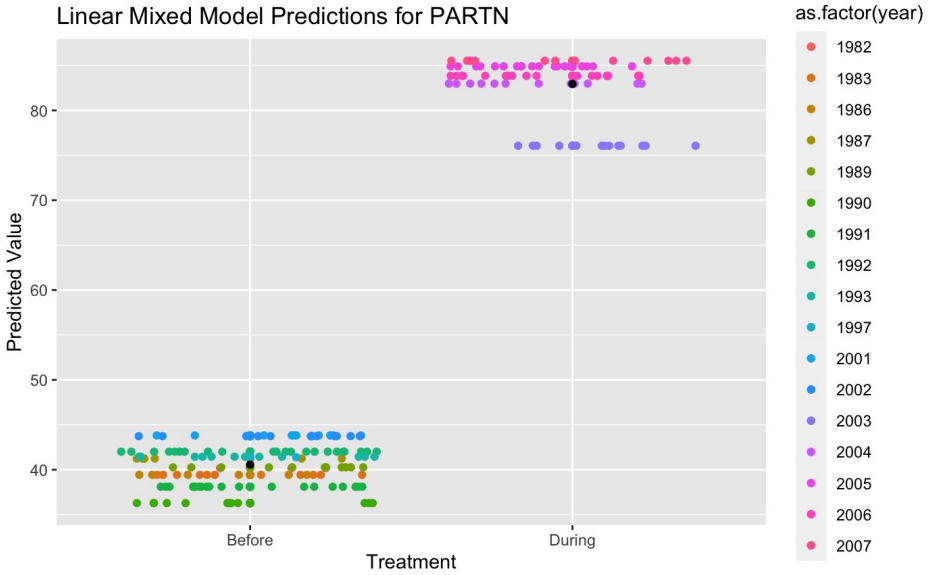


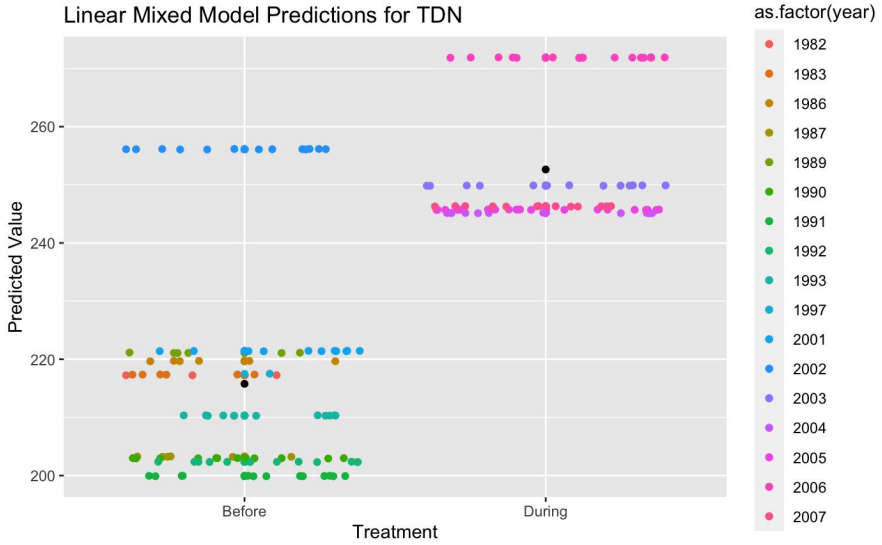
Data given to model
Before
During
After



Data given to model
Before
During
After

Nitrogen levels increased significantly with aquaculture



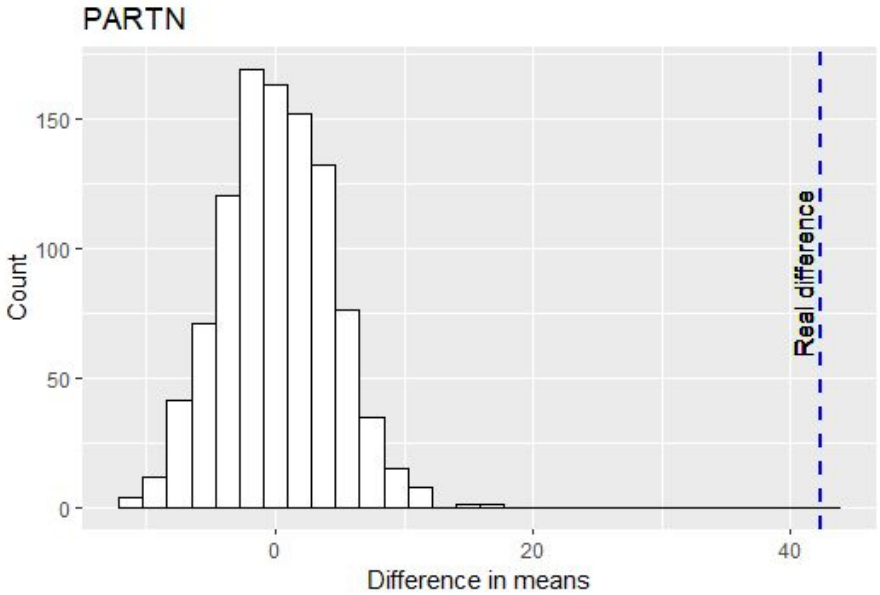


Effect size of treatment on PARTN: 42.0569ug/L

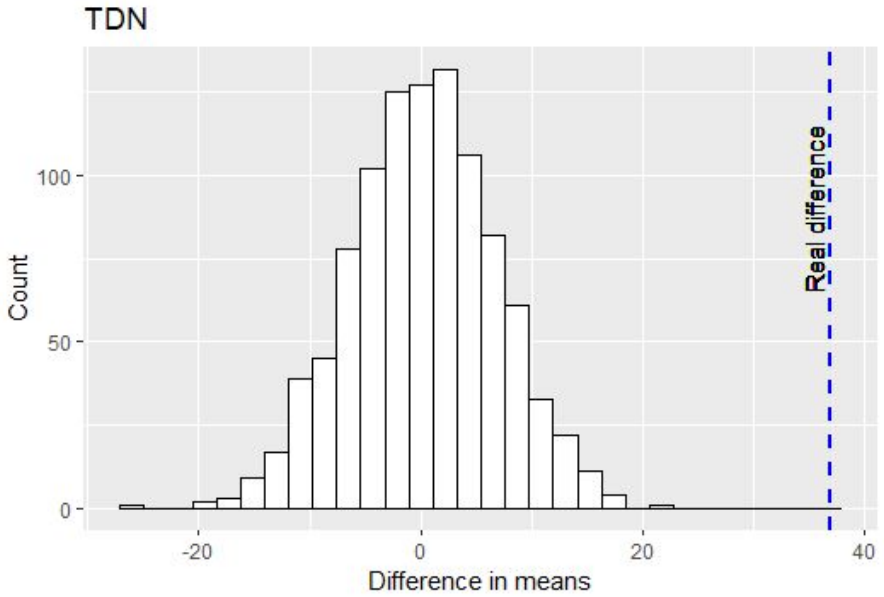
characteristic	P value
PARTN	1.820811e-08
TDN	2.859588e-03

Effect size of treatment on TDN: 36.0133ug/L

Nitrogen levels increased significantly with aquaculture

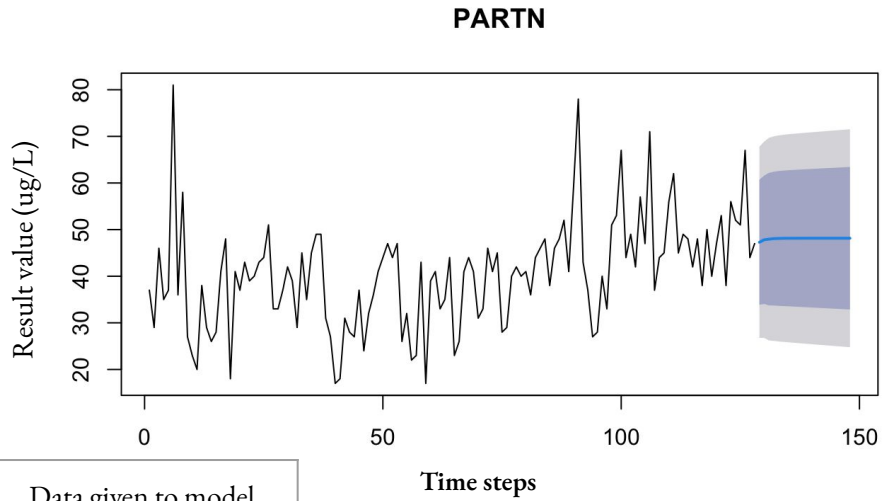


Real difference (PARTN): 42.384



Real difference (TDN): 36.8571

ARIMA predicts different trend if aquaculture continues



Data given to model
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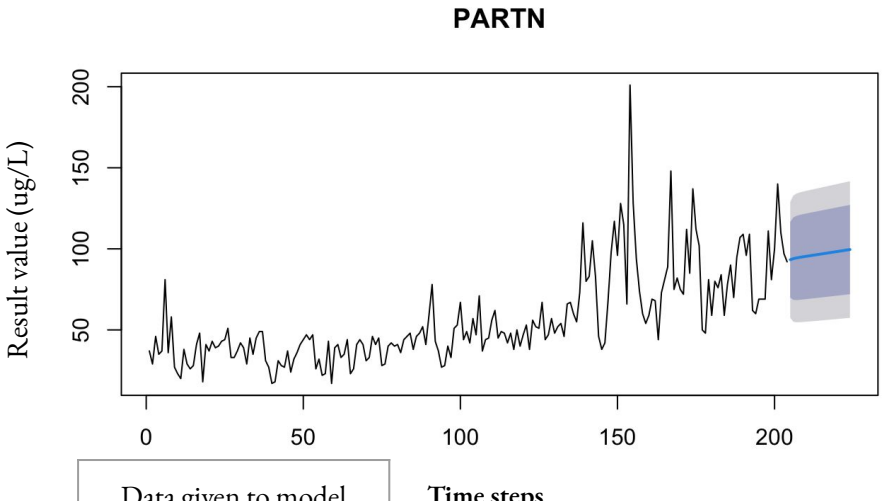
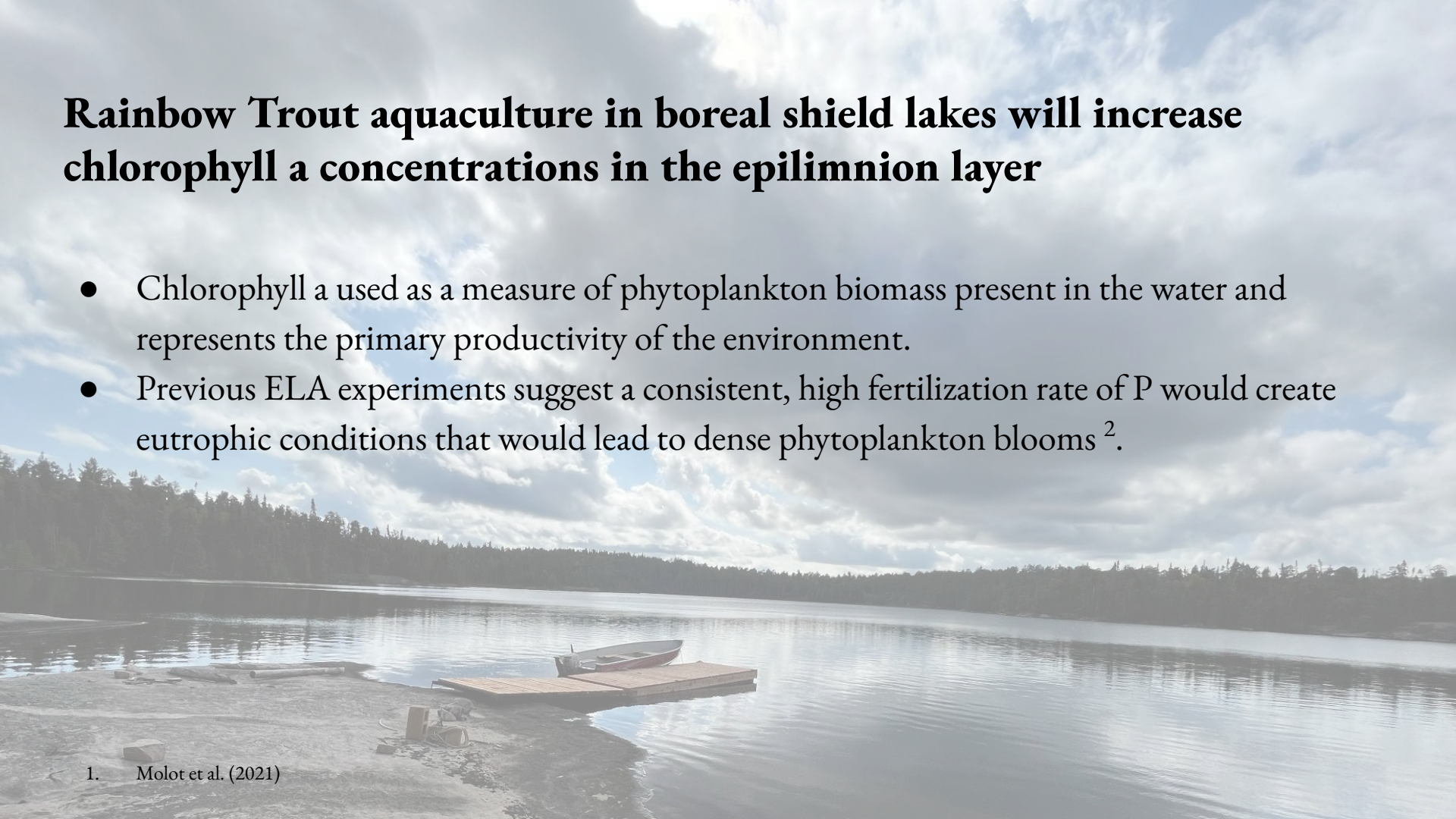
During
After



Data given to model
Before
During
After

Rainbow Trout aquaculture in boreal shield lakes will increase chlorophyll a concentrations in the epilimnion layer

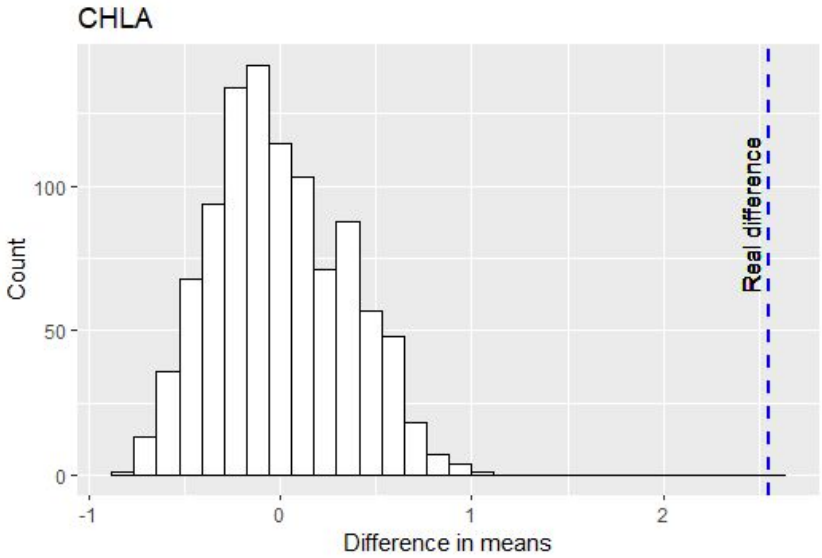
- Chlorophyll a used as a measure of phytoplankton biomass present in the water and represents the primary productivity of the environment.
- Previous ELA experiments suggest a consistent, high fertilization rate of P would create eutrophic conditions that would lead to dense phytoplankton blooms [2].



1. Molot et al. (2021)

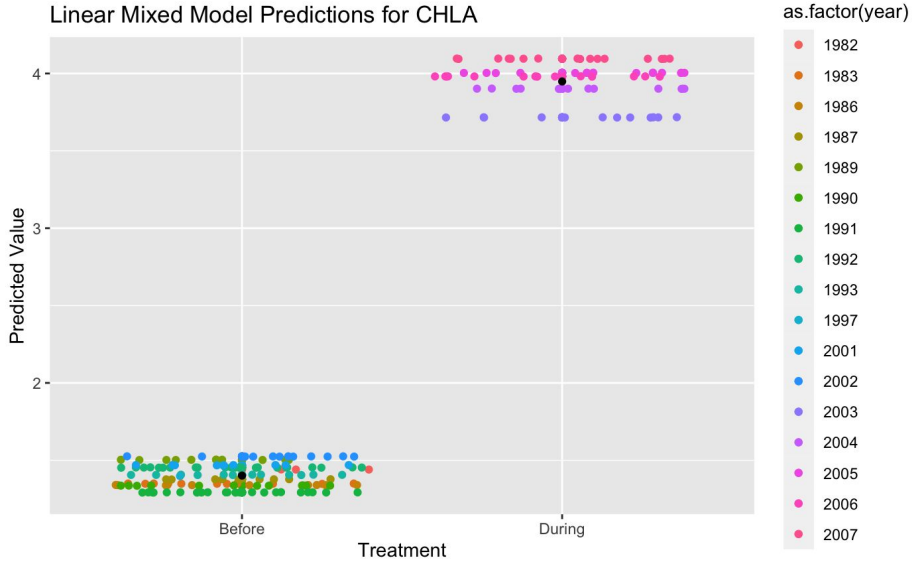
Chlorophyll a experiences significant increases with aquaculture

Permutation



The difference in group means in our real data lies above the 95% confidence interval set by the null distribution of the permutation test.

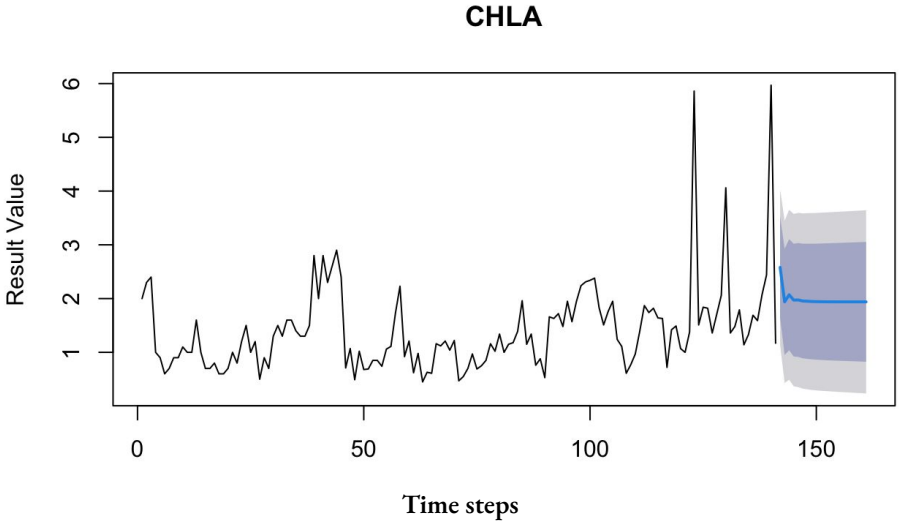
Linear Mixed Model



Effect size of treatment on CHLA: 2.532380107ug/L

characteristic	P value
CHLA	1.137034e-07

ARIMA forecasting shows predicted increases in Chlorophyll A



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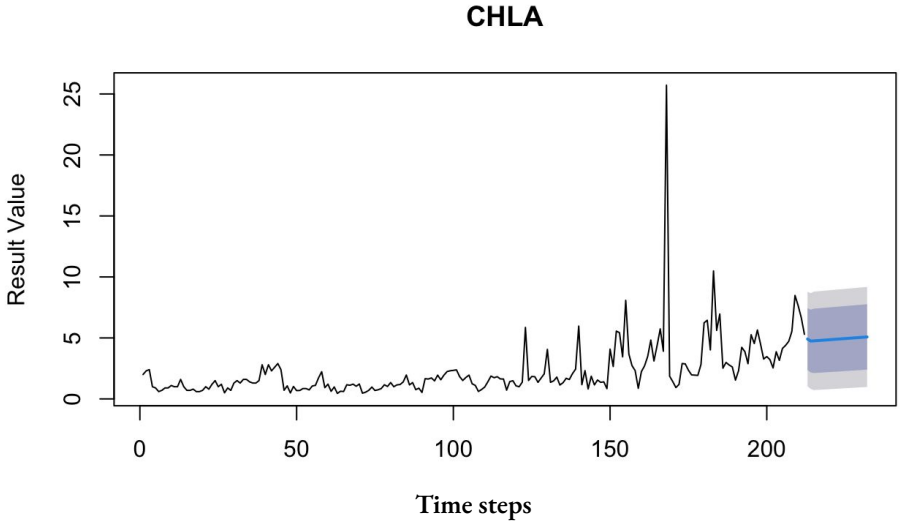
After



Data given to model
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During
After

Phosphorus and nitrogen implications

Oligotrophic -> Eutrophic?

- Cage rainbow trout aquaculture releases ~7.3kg of P into environment for every 1 tonne of fish produced [1]
- Increased nutrient input can stimulate primary production eutrophication, changes in species community composition [2]

Effects of nutrient addition not as large as the addition itself (lake was not eutrophic!)

- Particulate phosphorus settled at a rate >6cm/s, meaning that it is unavailable to algae and bacteria in the epilimnion until thermal mixing occurs [1, 3]
- Dissolved N levels in epilimnion lower than expected, likely due to sedimentation of solid waste and increased transformation of ammonia into nitrates and nitrites [1,4]

1. Azevedo et al. (2011)
2. Findlay et al. (2009)
3. Bristow et al. (2008)
4. McDonald et al. (1996)

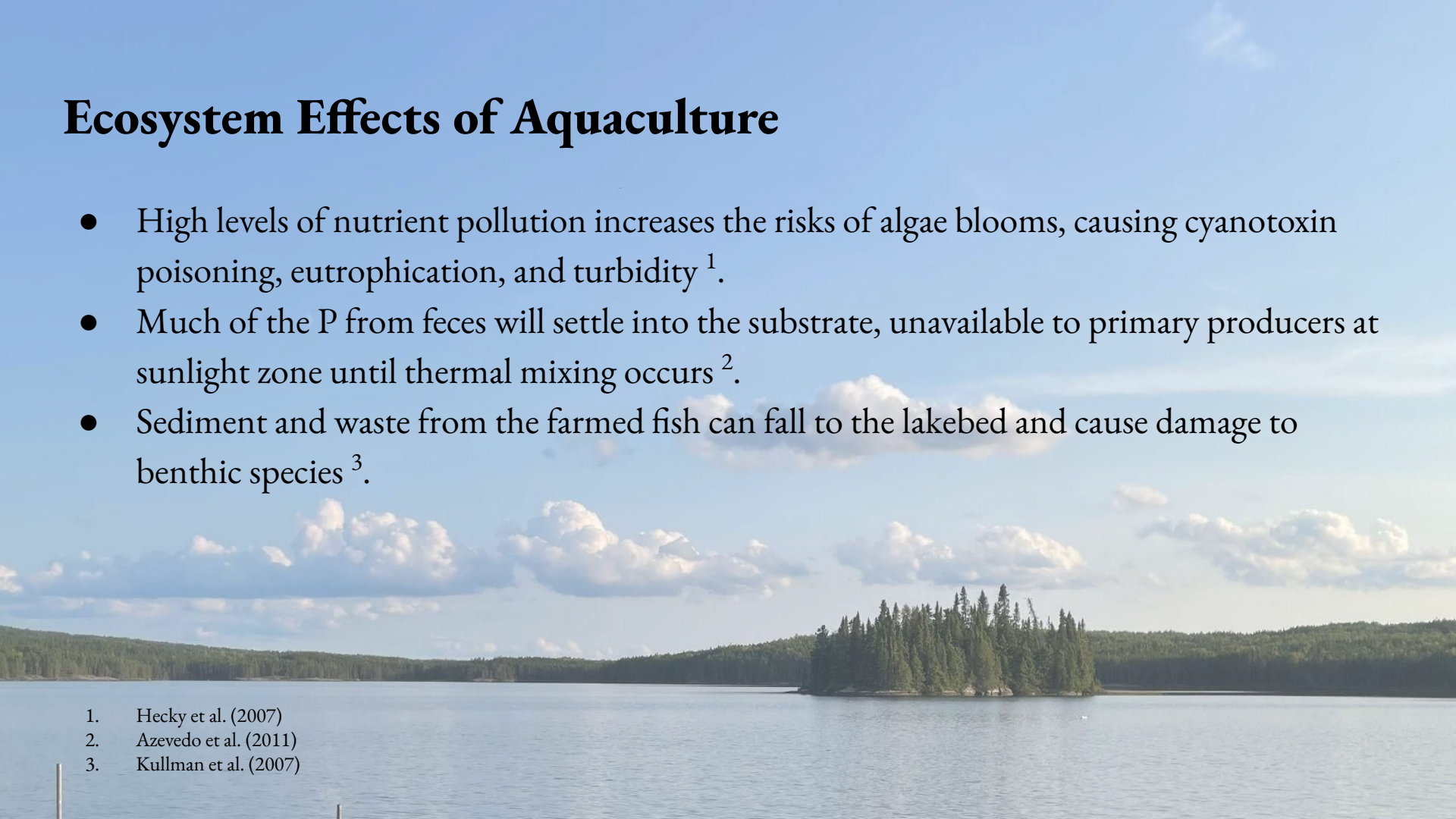
Ecosystem Effects of Aquaculture

- Aquaculture waste introduced high levels of phosphorus into the lake.
- The heavy P loading leads to an increase in nitrogen-fixing cyanobacteria, thus increasing N without anthropogenic input [1].
- Native species, minnows in particular, progressively shifted their diet towards the novel energy source from aquaculture [2].

1. Molot et al (2021)
2. Kullman et al. (2009)

Ecosystem Effects of Aquaculture

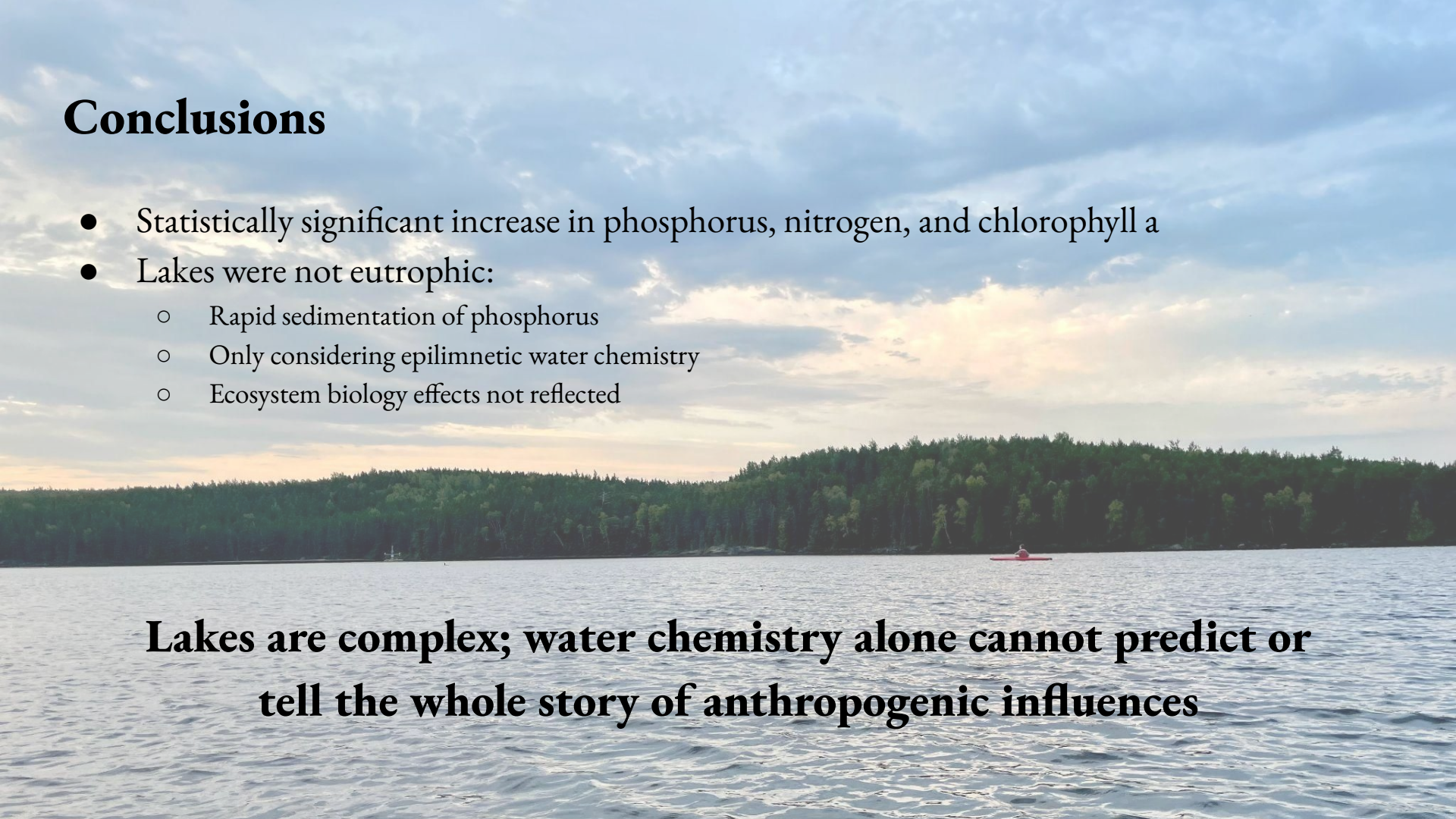
- High levels of nutrient pollution increases the risks of algae blooms, causing cyanotoxin poisoning, eutrophication, and turbidity [1].
- Much of the P from feces will settle into the substrate, unavailable to primary producers at sunlight zone until thermal mixing occurs [2].
- Sediment and waste from the farmed fish can fall to the lakebed and cause damage to benthic species [3].



1. Hecky et al. (2007)
2. Azevedo et al. (2011)
3. Kullman et al. (2007)

Conclusions

- Statistically significant increase in phosphorus, nitrogen, and chlorophyll a
- Lakes were not eutrophic:
  - Rapid sedimentation of phosphorus
  - Only considering epilimnetic water chemistry
  - Ecosystem biology effects not reflected



Lakes are complex; water chemistry alone cannot predict or tell the whole story of anthropogenic influences

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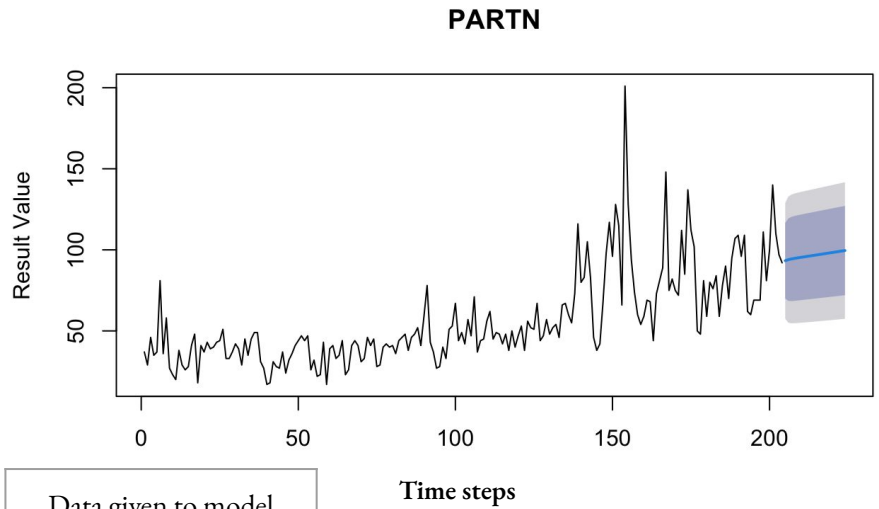
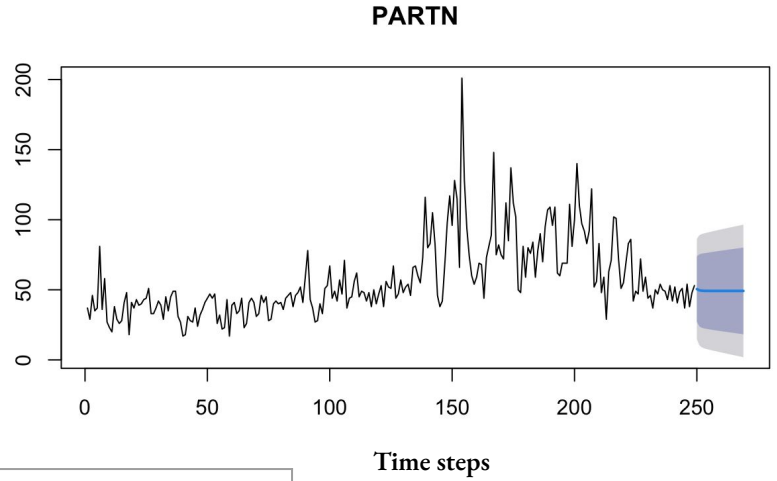


Data given to model

Before

During

After



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Before

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