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Swiss Federal Institute of Aquatic
Science and Technology

Modeling lake metabolism using high-frequency deployment sondes

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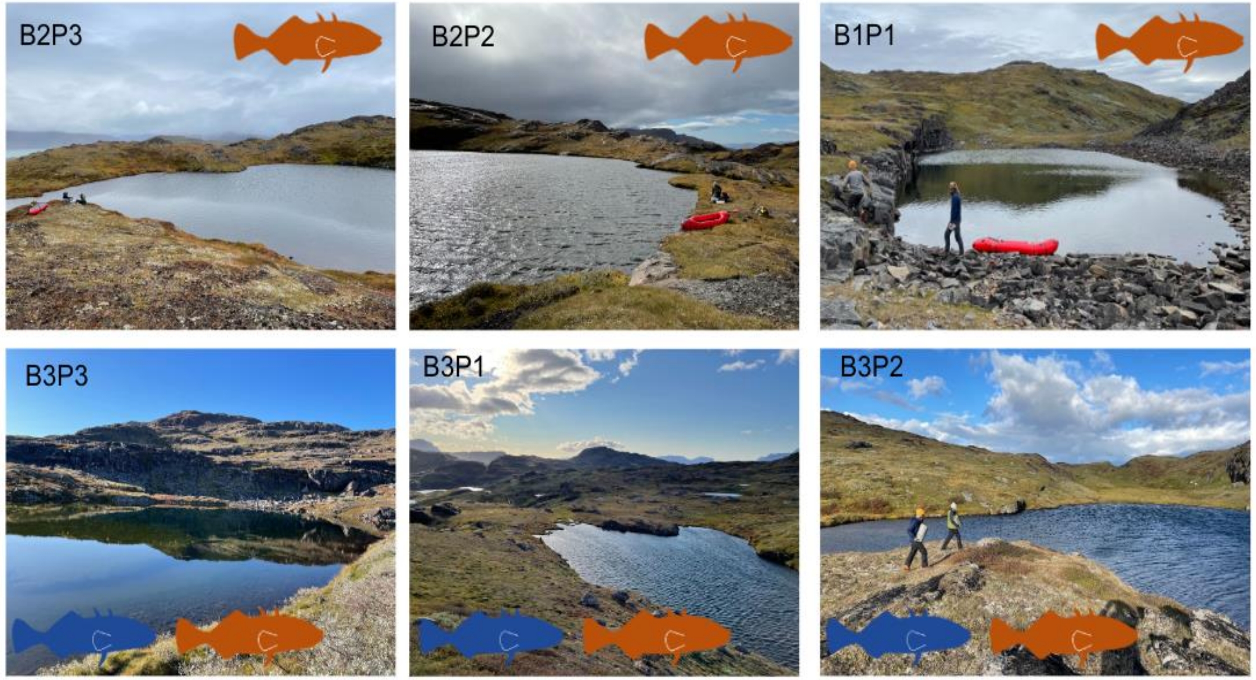
Background

- Sticklebacks introduced in 6 experimental ponds in Greenland, 2019

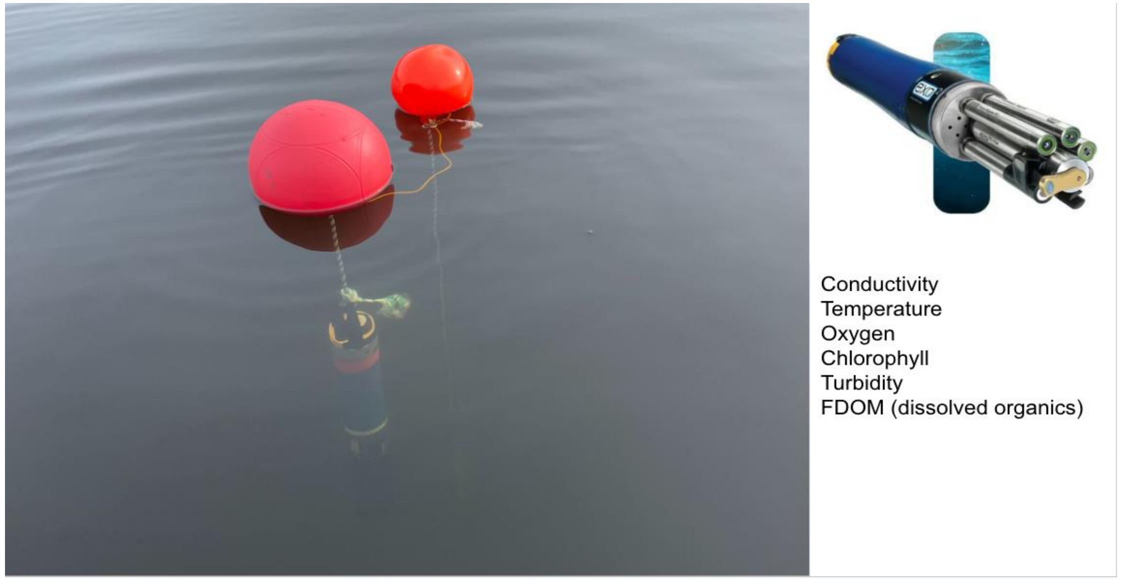


Background

- 6 ponds used as fishless reference

Background

- From the year 2021, all 12 lakes were monitored for several days every summer
- Deployment sondes were used to measure various water-related parameters
- 1 sonde per lake
- Measurements every 2 to 5 minutes



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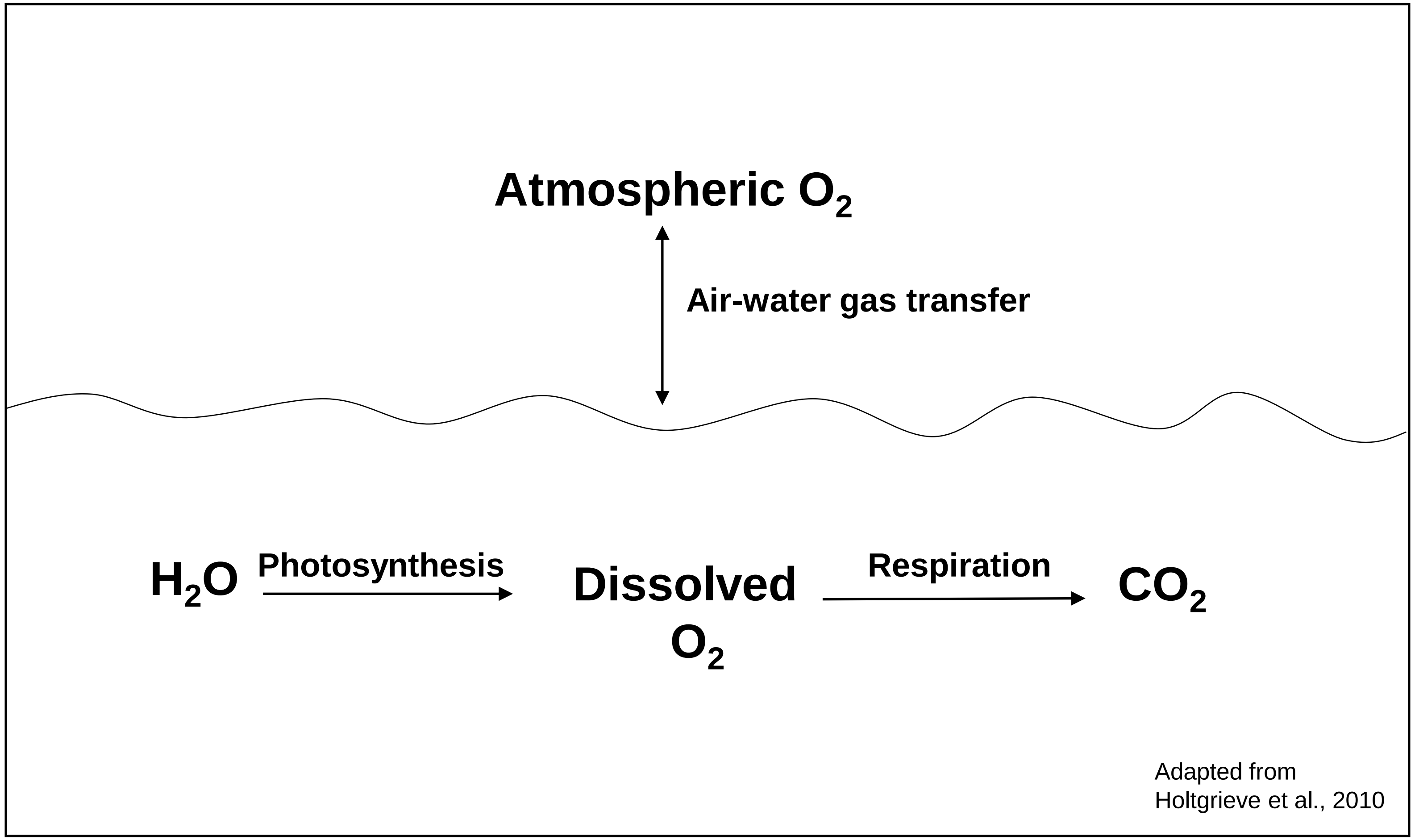
Background: Lake Metabolism

- Often estimated from free-water dissolved oxygen (DO) (Winslow et al., 2016)
- Represents balance between carbon fixation (Gross Primary Production GPP)
- and biological carbon oxidation (ecosystem Respiration R):
  - *Photosynthesis*: $6CO_2 + 6H_2O \xrightarrow{light} C_6H_{12}O_6 + 6O_2$
  - *Respiration*: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- Net Ecosystem Production (NEP) = GPP – R

Background: Lake Metabolism



Research question

How do Sticklebacks affect lake metabolism?

Methods: Data sources

- Time-series data from deployment sondes
- Wind data from radiosonde in Narsarsuaq (https://www.dmi.dk/lokationarkiv/show/GL/3421711/Narsarsuaq/#arkiv)
- Irradiation data from QAS_L automated weather station near Narsarsuaq (https://dataverse.geus.dk/dataset.xhtml?persistentId=doi:10.22008/FK2/IW73UU)
  - Using downwelling shortwave irradiation (tilt corrected)

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Methods: Workflow data preparation

Import raw sonde data

Merge into single dataset

Outlier removal

Cut dataset for equal start and end times

Quality check with control plots

Impute missing values for metabolism modeling

Methods: Bayesian lake metabolism model

- Using the *R* package LakeMetabolizer (Winslow et al., 2016)
- Our choice: Bayesian model using the function *metab.bayesian*
- Estimates daily GPP, R, and NEP
- Distinguishes between 3 categories of DO values:
  - y the DO measurements: $y_t \sim N(\alpha_t, \tau_v)$
  - α the true but unknown values of DO: $\alpha_t \sim N(\alpha^*, \tau_w)$
  - α^* the model estimates of the true DO values

Methods: Bayesian lake metabolism model

- The Bayesian model can be described by the following main equation:

$$\alpha_t = \boldsymbol{\beta} \boldsymbol{X}_{t-1} + k_{t-1} O_{s,t-1}$$

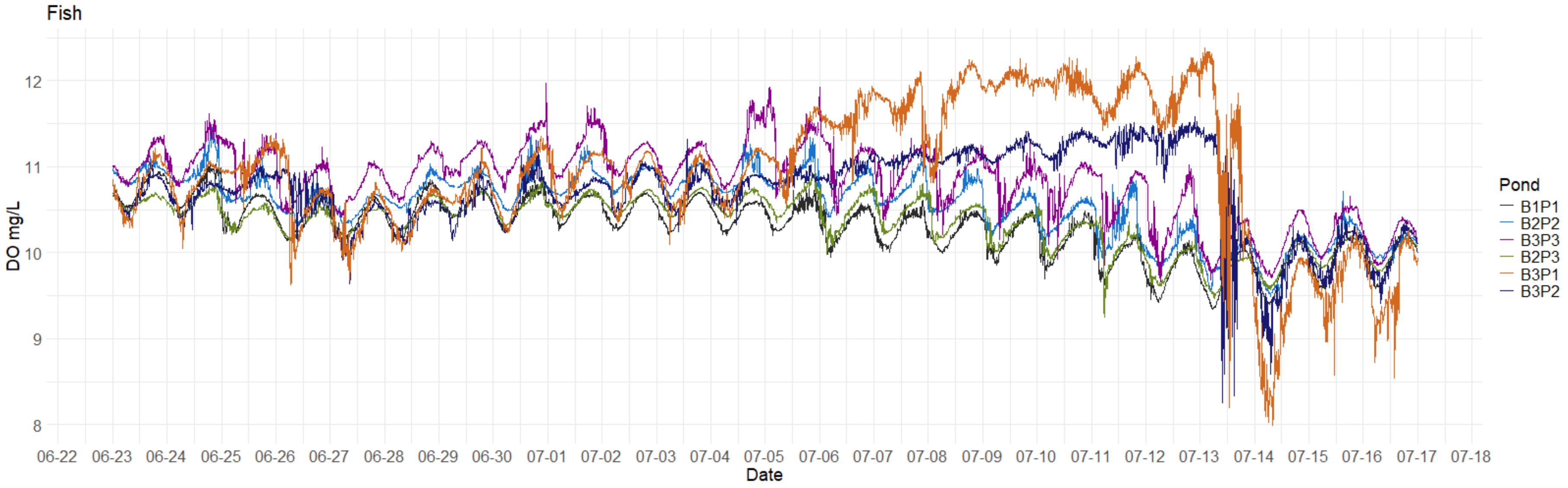
  - $\boldsymbol{\beta} = (\iota, \rho)^T$ a 2×1 vector of parameters to be estimated; ι represents GPP and ρ represents R.
  - $\boldsymbol{X}$ a $n \times 2$ matrix of predictors $\begin{pmatrix} I_{1,\,t-1} & \cdots & \ln T_{1,\,t-1} \\ \vdots & \ddots & \vdots \\ I_{n,\,t-1} & \cdots & \ln T_{n,\,t-1} \end{pmatrix}$; I is irradiance; T is temperature.
  - k is the gas transfer coefficient (modeled from wind); O_s the saturated oxygen concentration for specific temperature.

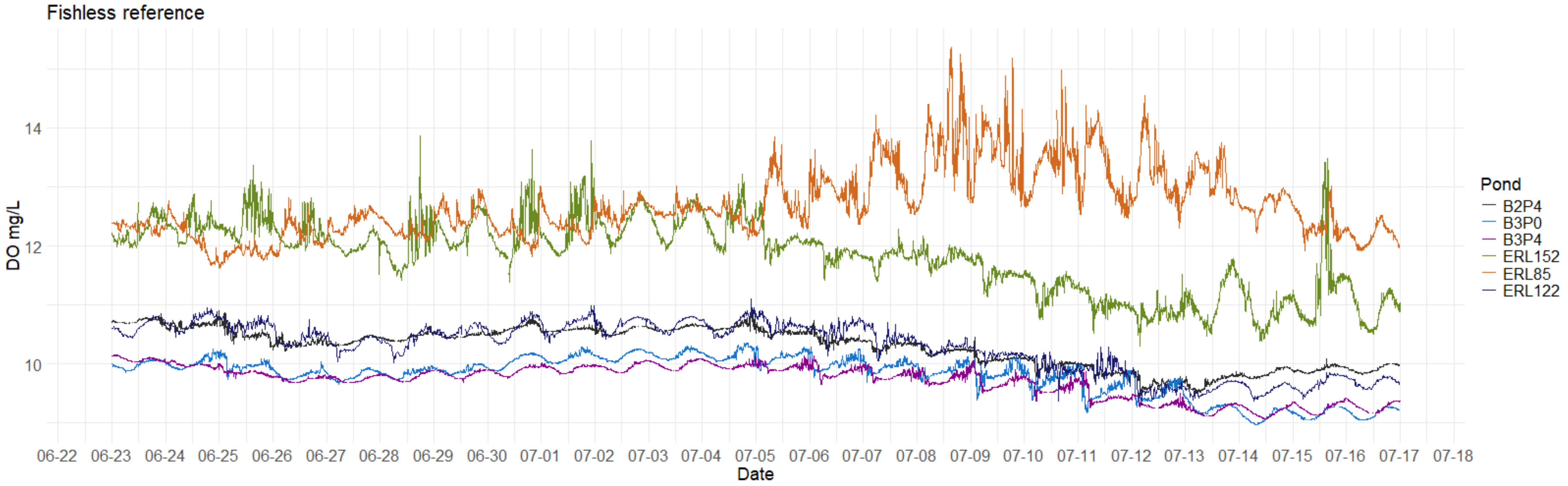
Methods: Bayesian lake metabolism model

Required input data:

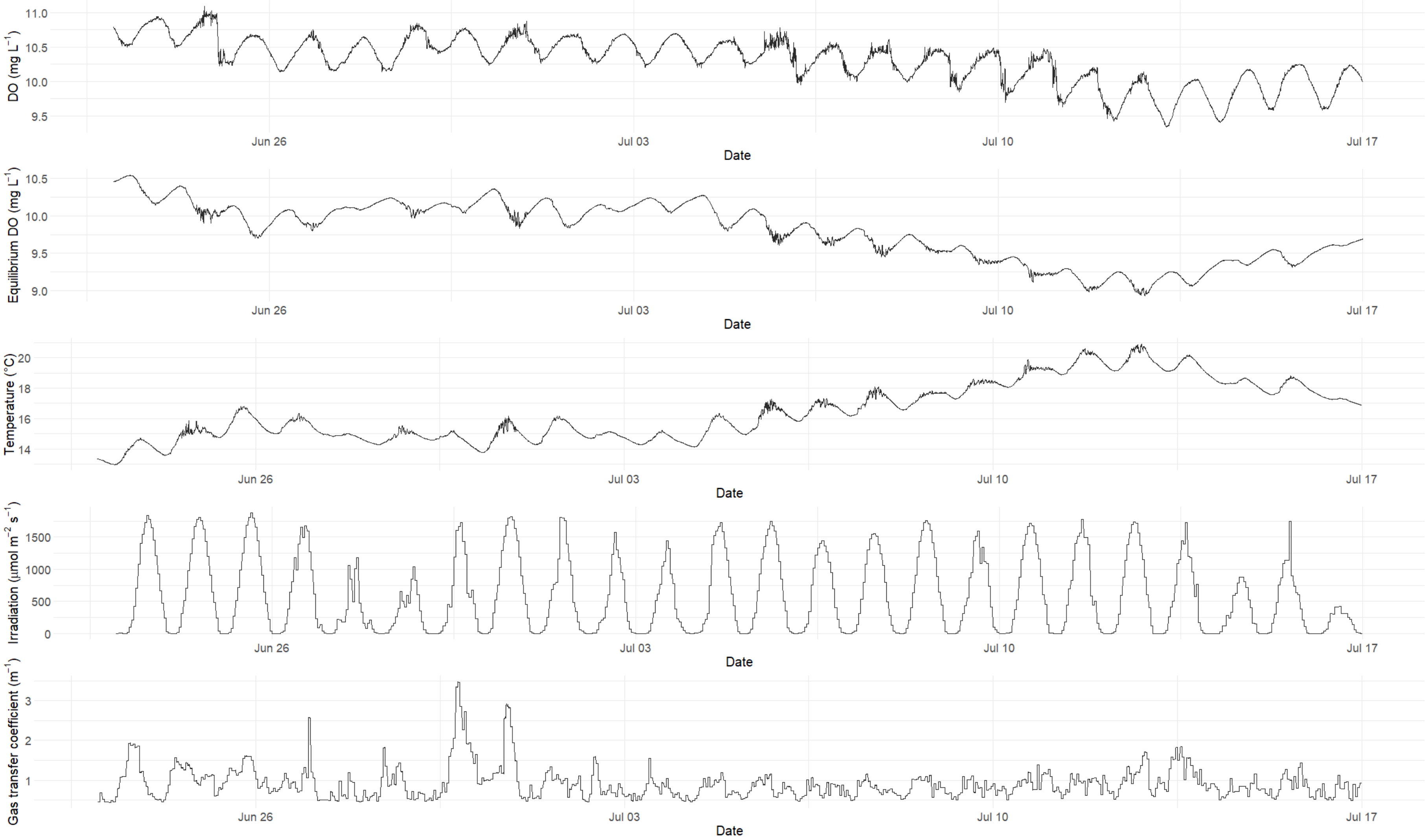
1. DO observations (mg L^{-1})
2. Saturated DO concentration for specific temperature (mg L^{-1})
   - Calculated from water temperature
3. Gas and temperature specific gas transfer coefficient (m^{-1})
   - Estimated from wind data
4. Photosynthetically active radiation (µmol m^{-2} s^{-1})
   - Calculated from irradiation data
5. Mixed layer depth (m)
6. Water temperature (°C)

Results: Data preparation 2023 – Dissolved Oxygen

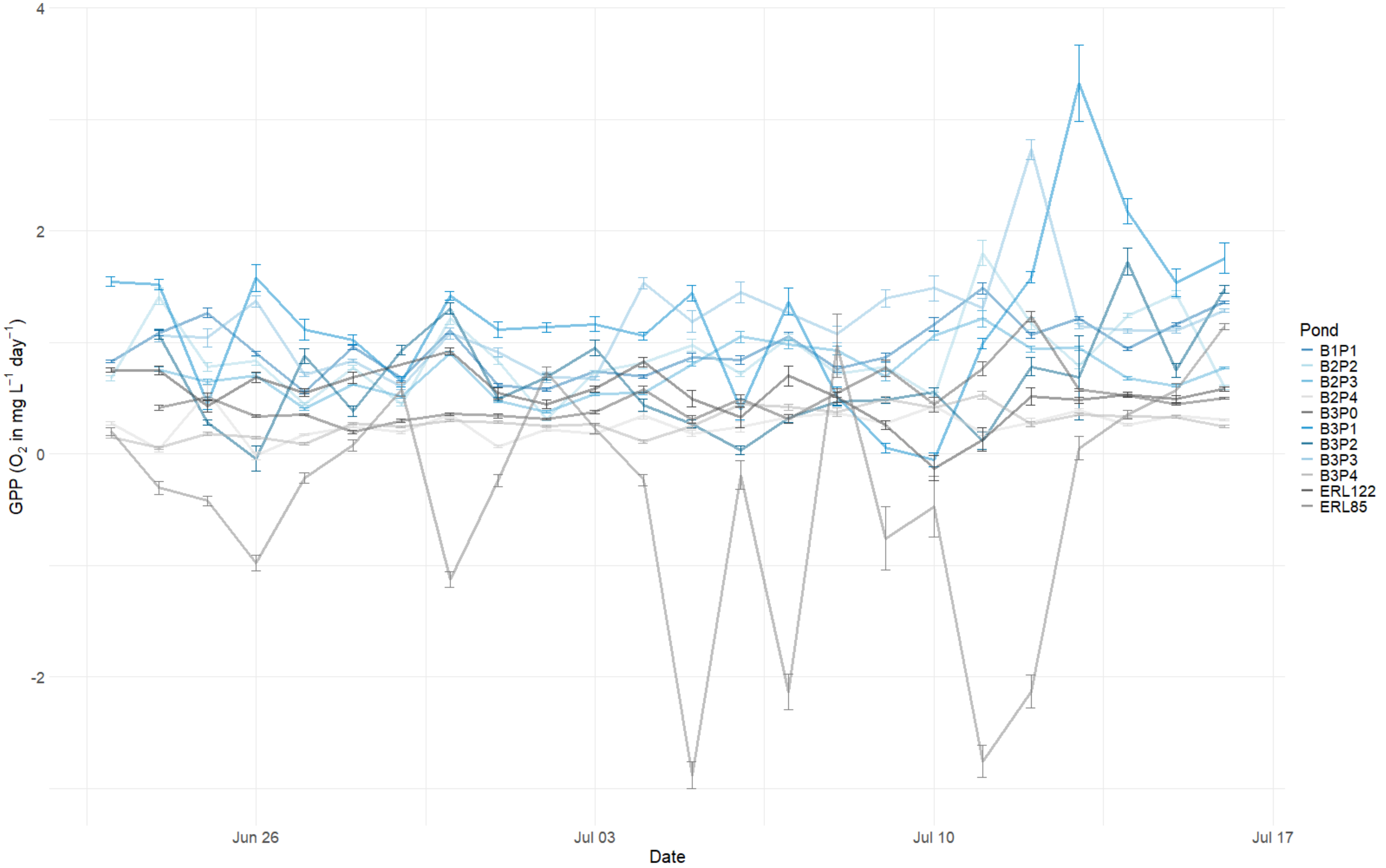




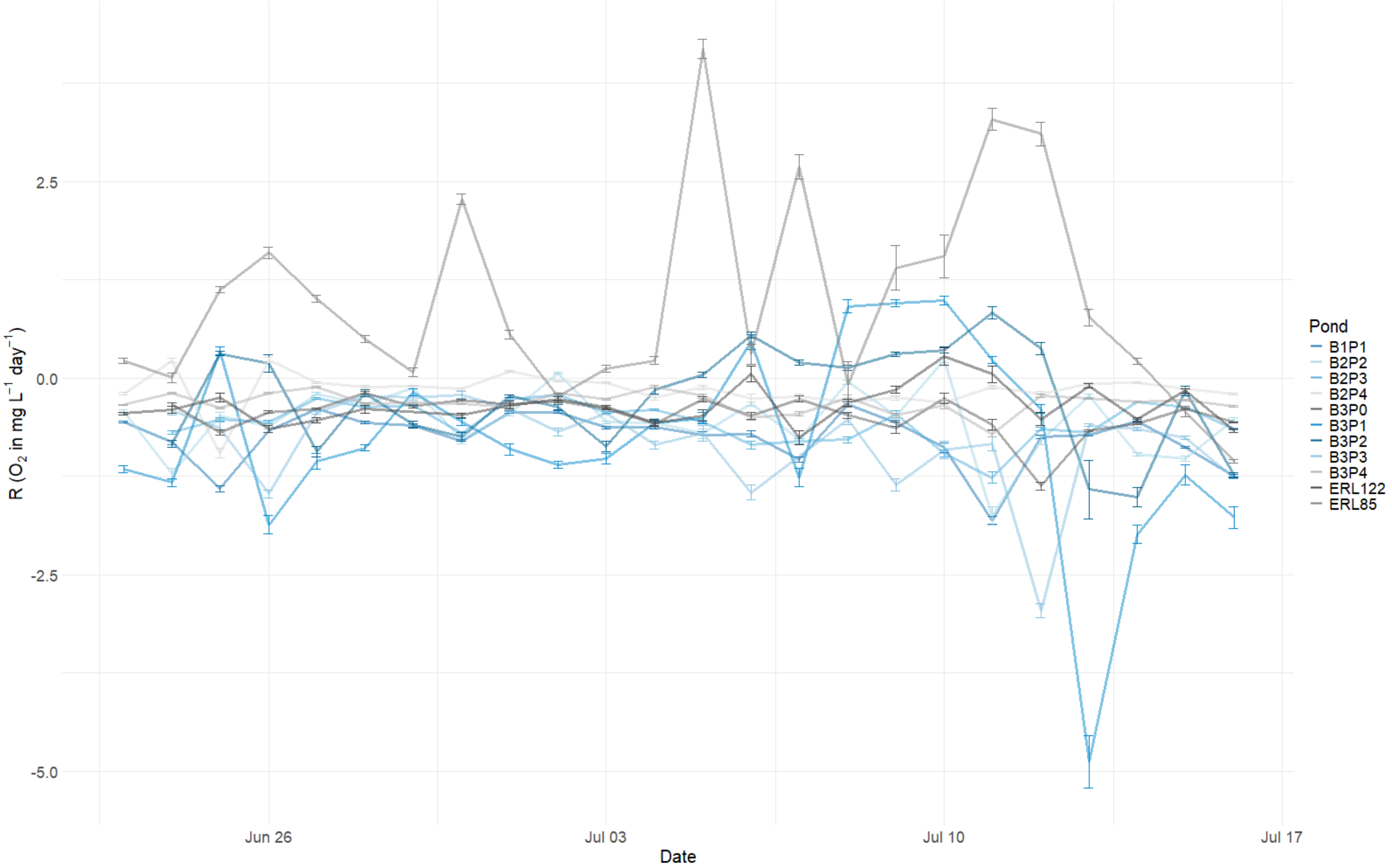
Results: Parameters used to estimate lake metabolism – Example of B1P1 in 2023



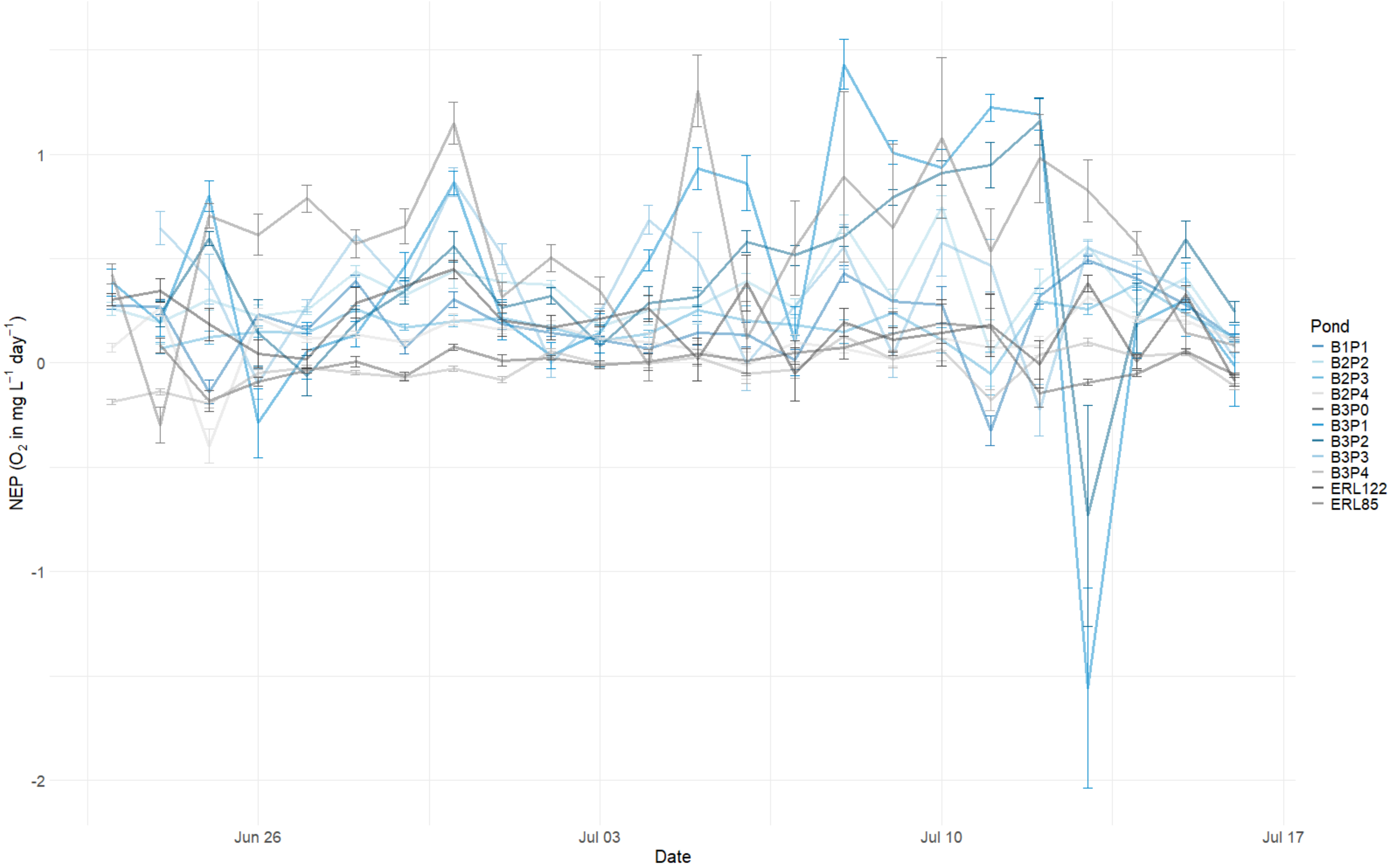
Results: GPP 2023



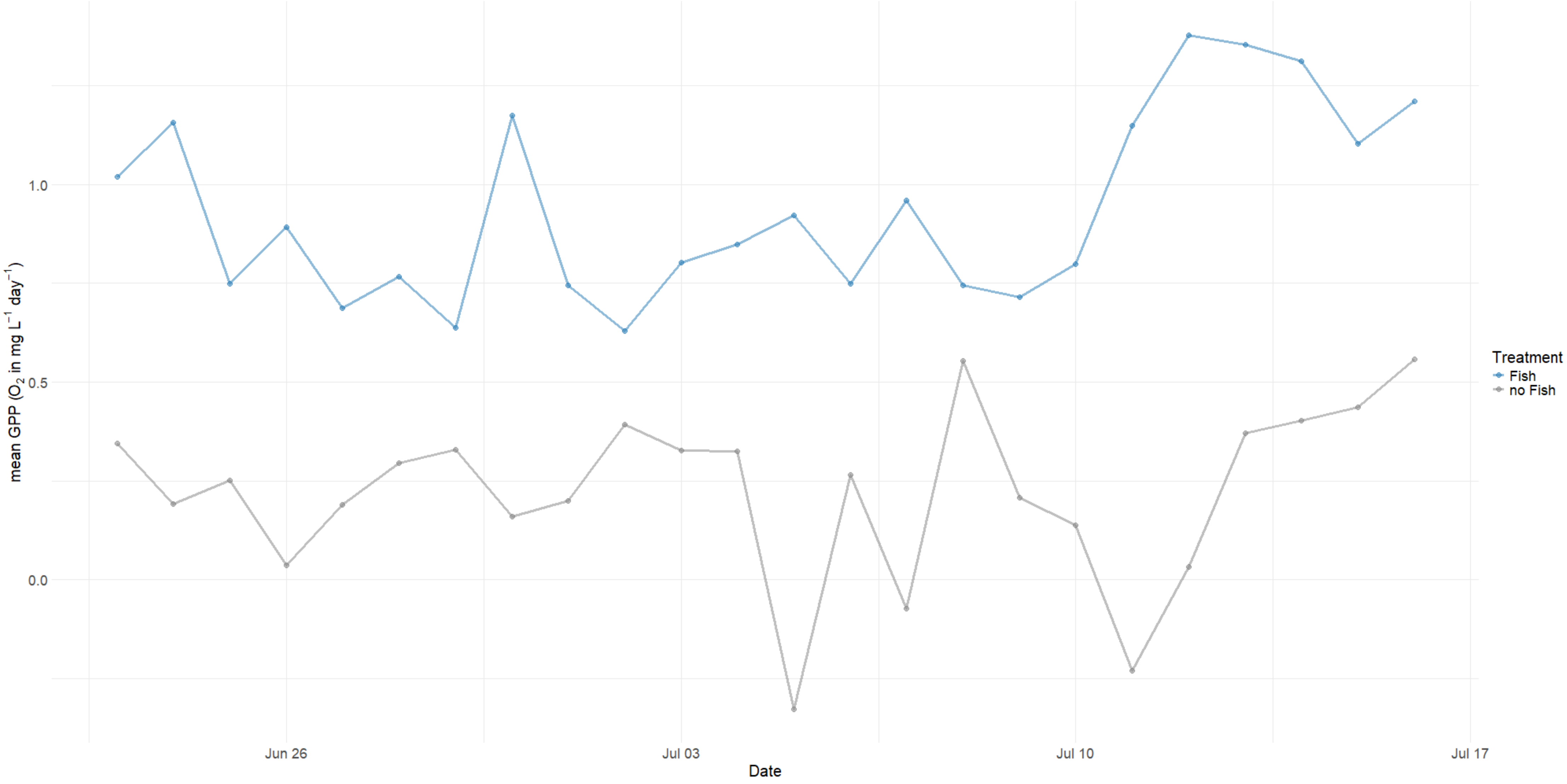
Results: R 2023



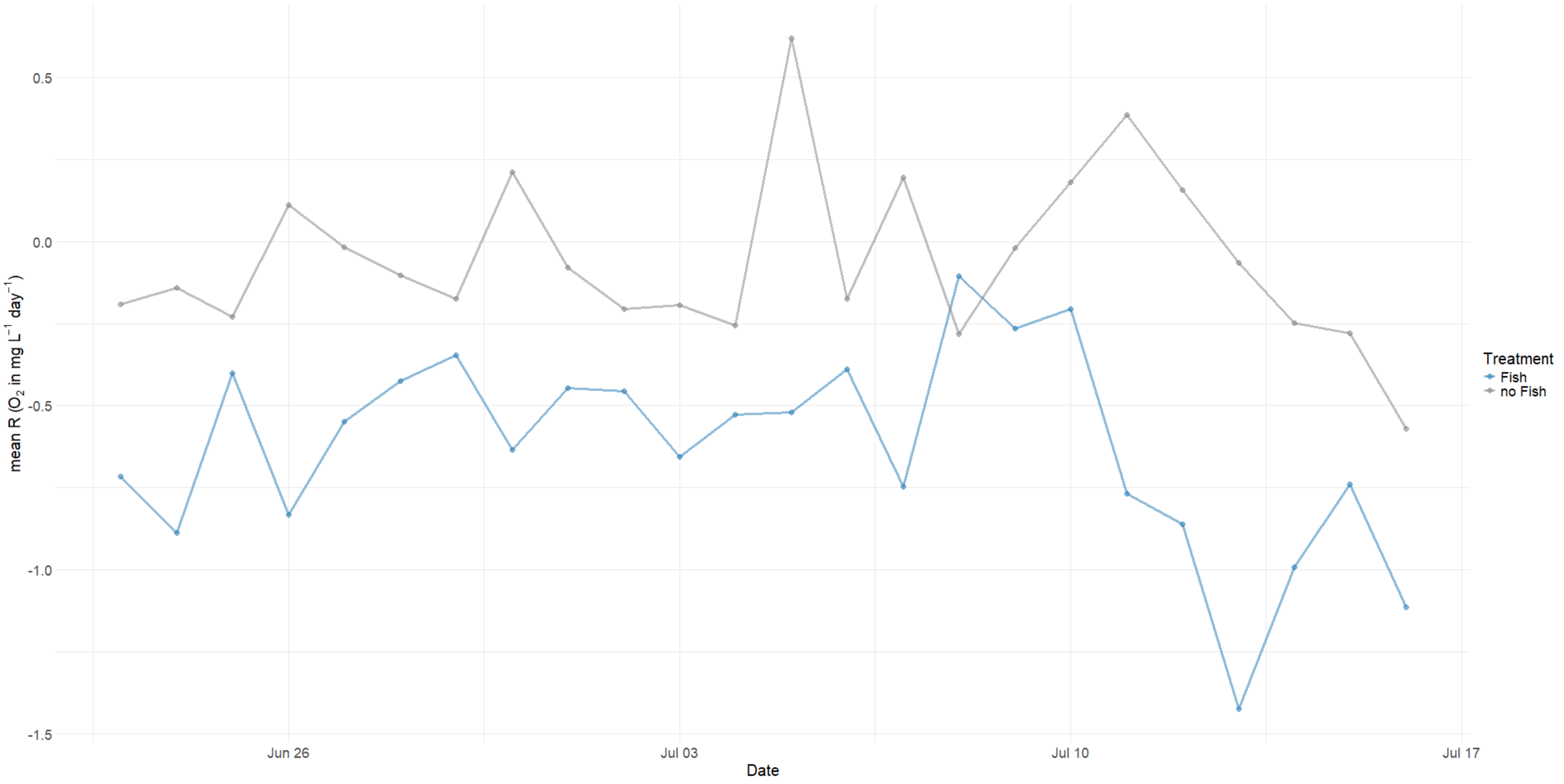
Results: NEP 2023



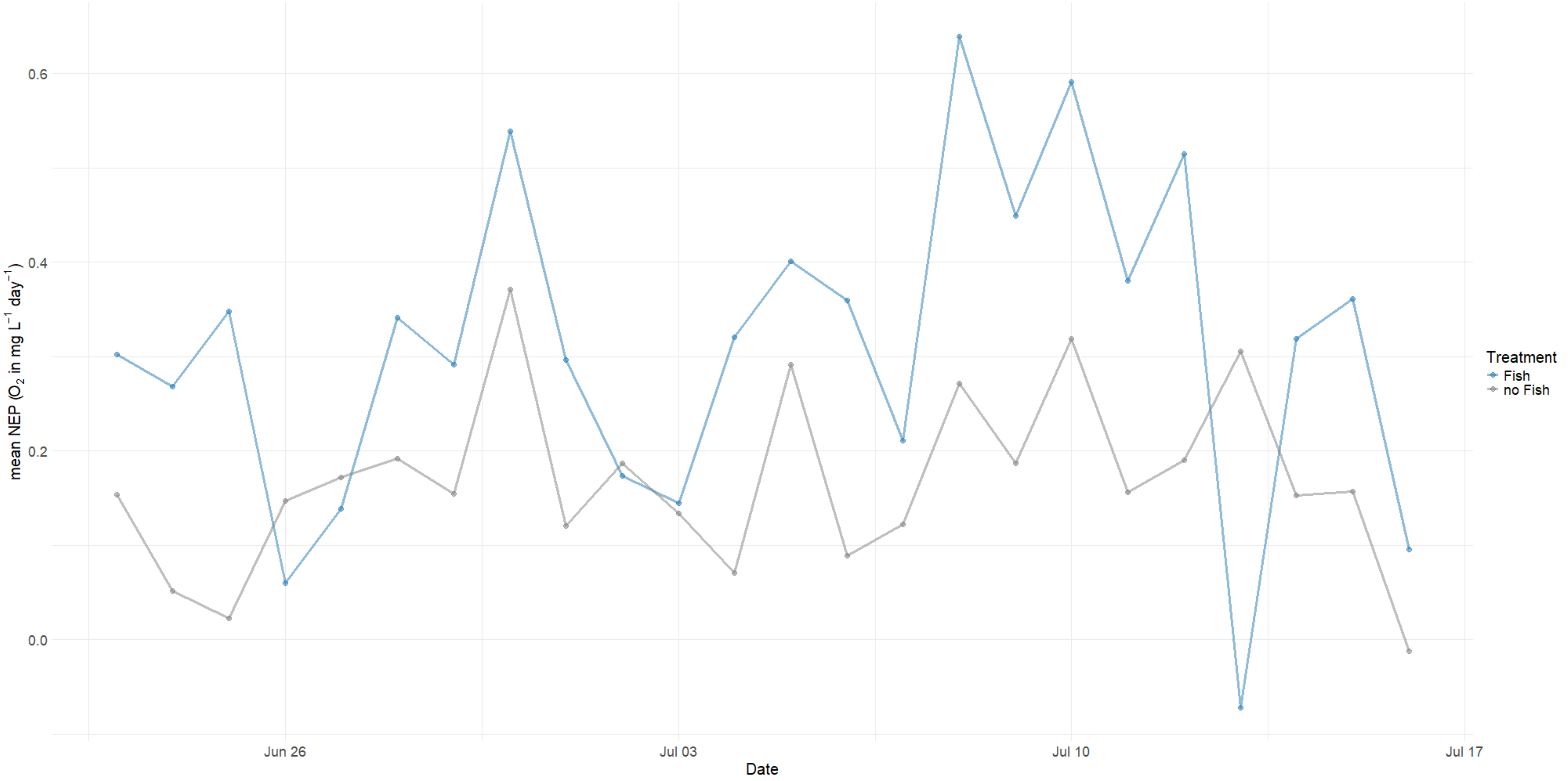
Results: GPP daily means 2023



Results: R daily means 2023



Results: NEP daily means 2023



Preliminary Conclusions

- Sticklebacks likely increase magnitude of daily DO variation
- Sticklebacks likely increase gross primary production
- Sticklebacks likely increase ecosystem respiration

Limitations

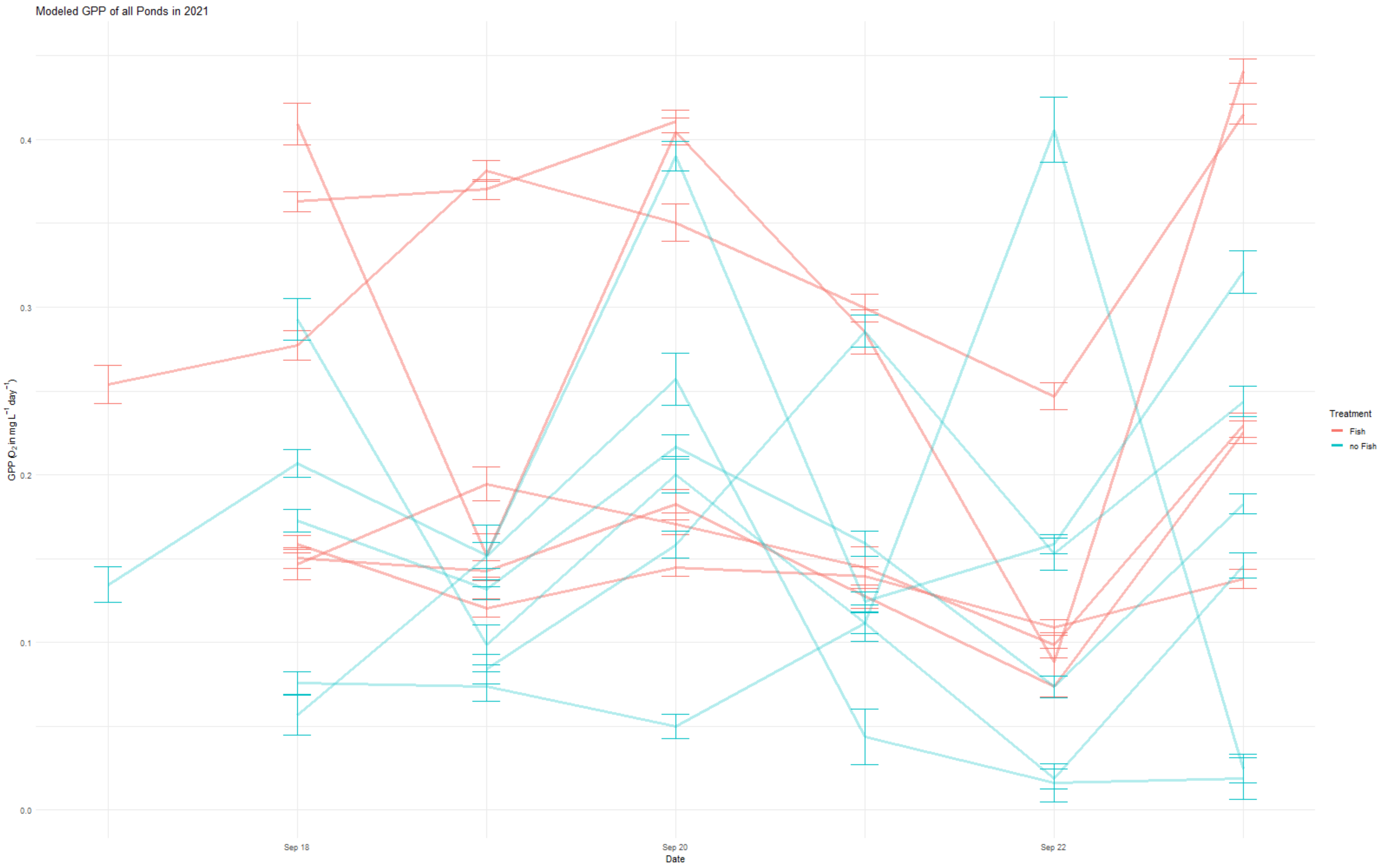
- Until now: Mixed layer depth qualitatively assessed from pond profiles
  - Mixed layer depth = height of surface layer with constant temperature
  - Used to model the gas transfer coefficient
  - Mixed layer is highly dependent on weather conditions
- Supplied wind data should be normalized to 10m sensor height – what is the sensor height of a radiosonde?
  - Consider different source of wind data

Outlook

- Optimize data input for metabolism models – minimize “noise”, maximize signal
  - Mixed layer depth
  - Wind sensor height
  - Deal with impossible GPP and R estimates
- Investigate underlying causal mechanism leading to increased production and respiration in ponds with Sticklebacks
- Think about strategies to synthesize results from 2021, 2022, and 2023

Appendix

Results: GPP 2021

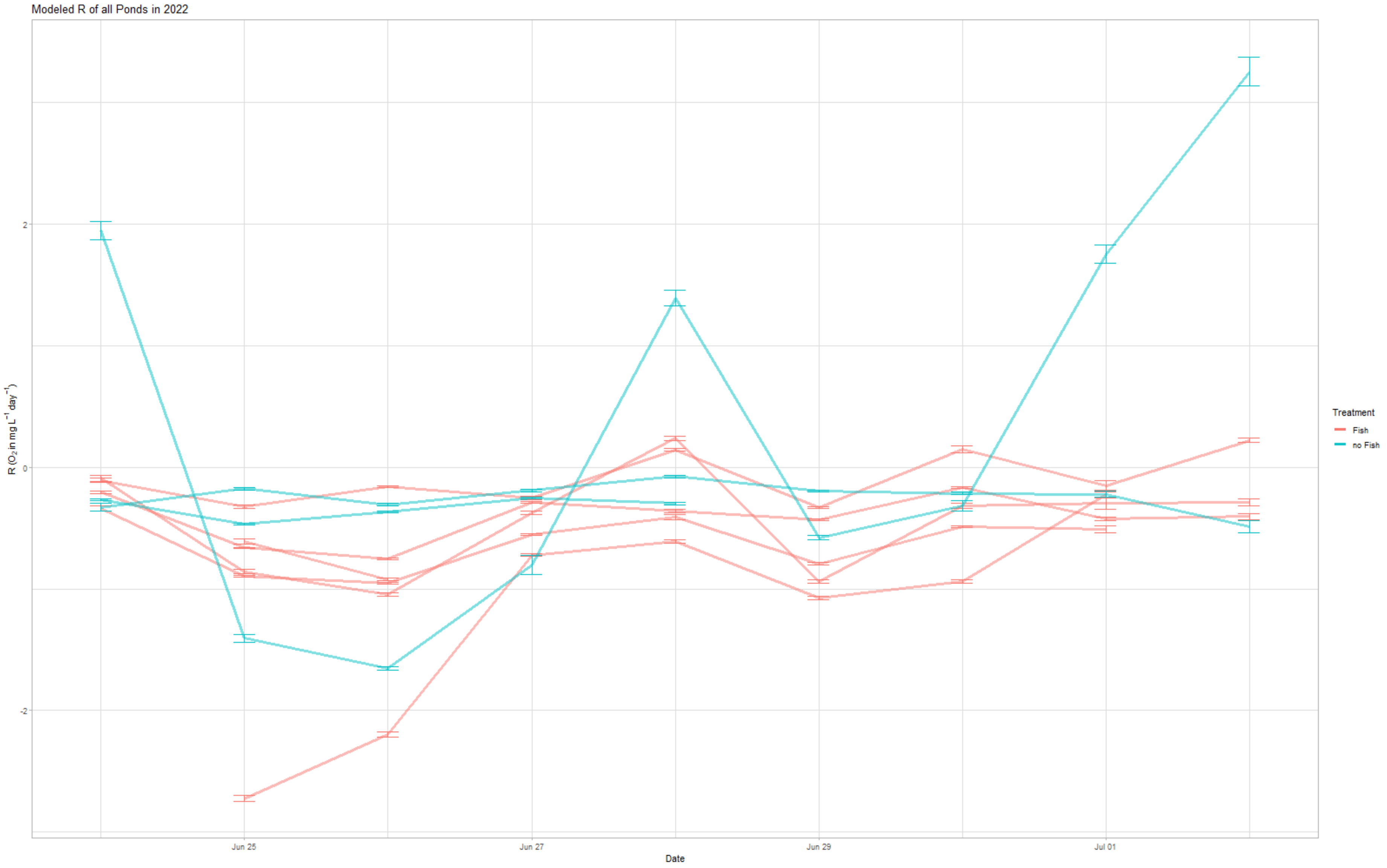


Results: R 2021

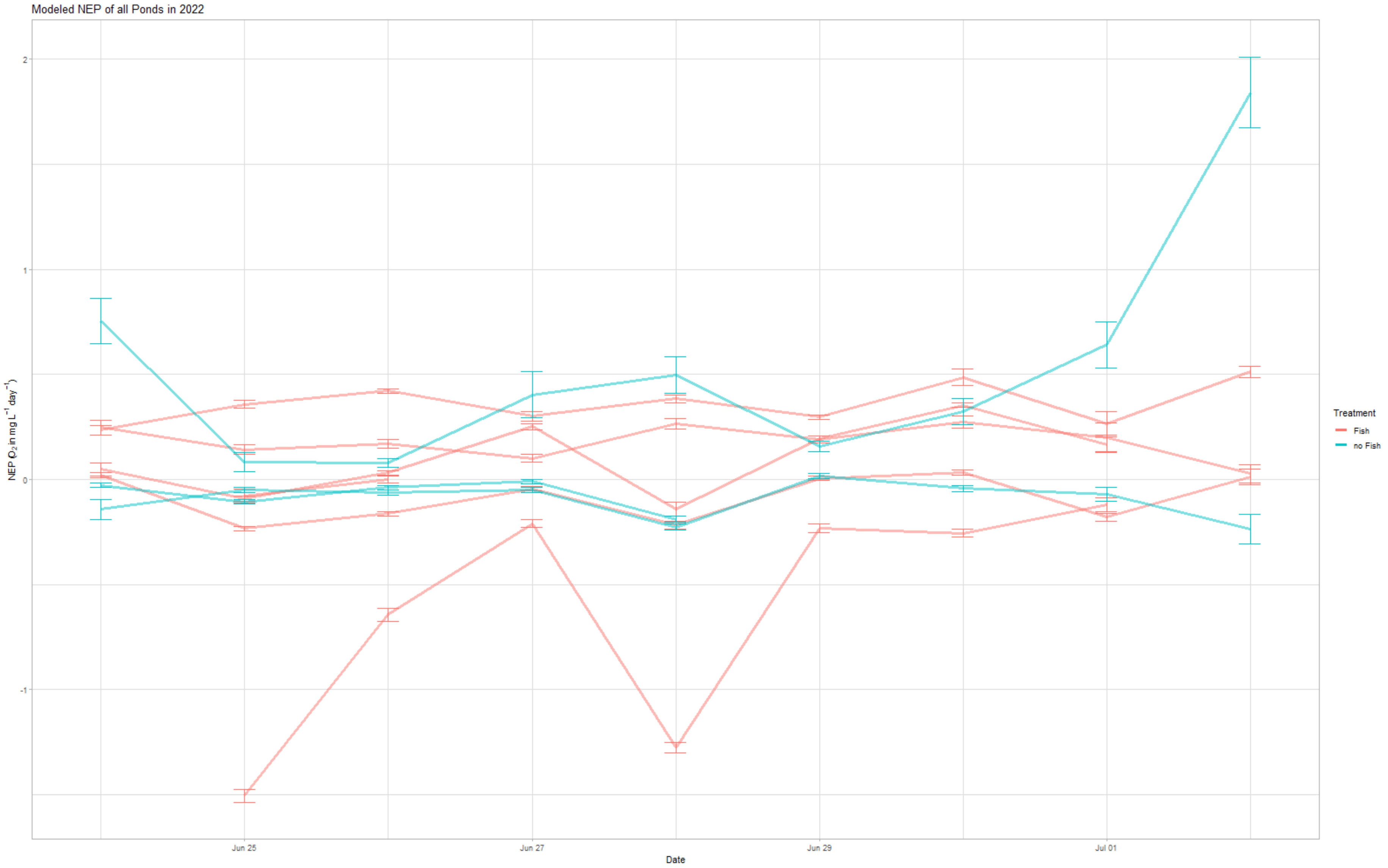
Results: NEP 2021

Results: GPP 2022

Results: R 2022



Results: NEP 2022



Methods: Bayesian lake metabolism model

- *Equation 2*: Obtaining the model estimates of true DO values

$$\alpha_t^* = \begin{cases} \alpha_{t-1} + \alpha_t, if\ k_t = 0 \\ \dfrac{\alpha_t}{k_{t-1}} + \dfrac{-\exp(-k_{t-1})\alpha_t}{k_{t-1}} + \exp(-k_{t-1})\,\alpha_{t-1}, otherwise \end{cases}$$

  - where k the gas transfer coefficient
  - k is estimated separately, depending on wind and mixed layer depth at time t
  - When $k_t = 0$ (i.e. no wind), the modeled DO estimates α^* only depend on α