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Bureau of Clean Water

Eutrophication Cause Determination Protocol

Water Resources Advisory Committee

October 25, 2017

Charlie McGarrell

Tom Wolf, Governor

Patrick McDonnell, Secretary

Intended Use of the Protocol

- Follow-up to Aquatic Life Use (ALU) Impairment Decision Made with an Appropriate DEP Assessment Protocol
- Listing Nutrients – Eutrophication as A Cause of ALU Impairment Under Category 5 of the Integrated Report
- Streams With a Drainage Area of Up to 350 mi^2

Definition of Stream Eutrophication

Eu = “Well” and Troph = “Nourished”

- Process by Which Nutrient Enrichment
- Stimulates the Growth of Plants & Algae
- Alters the Quant & Qual of Organic Matter Available as Food for Stream Organisms
- Modifies Stream Ecosystem Metabolism

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Stream Ecosystem Metabolism

- Biophysical Process of How Energy in the Form of Organic Matter is:
  - Acquired from External Sources
  - Produced In-Stream via Photosynthesis
  - Utilized By Stream Organisms via Respiration

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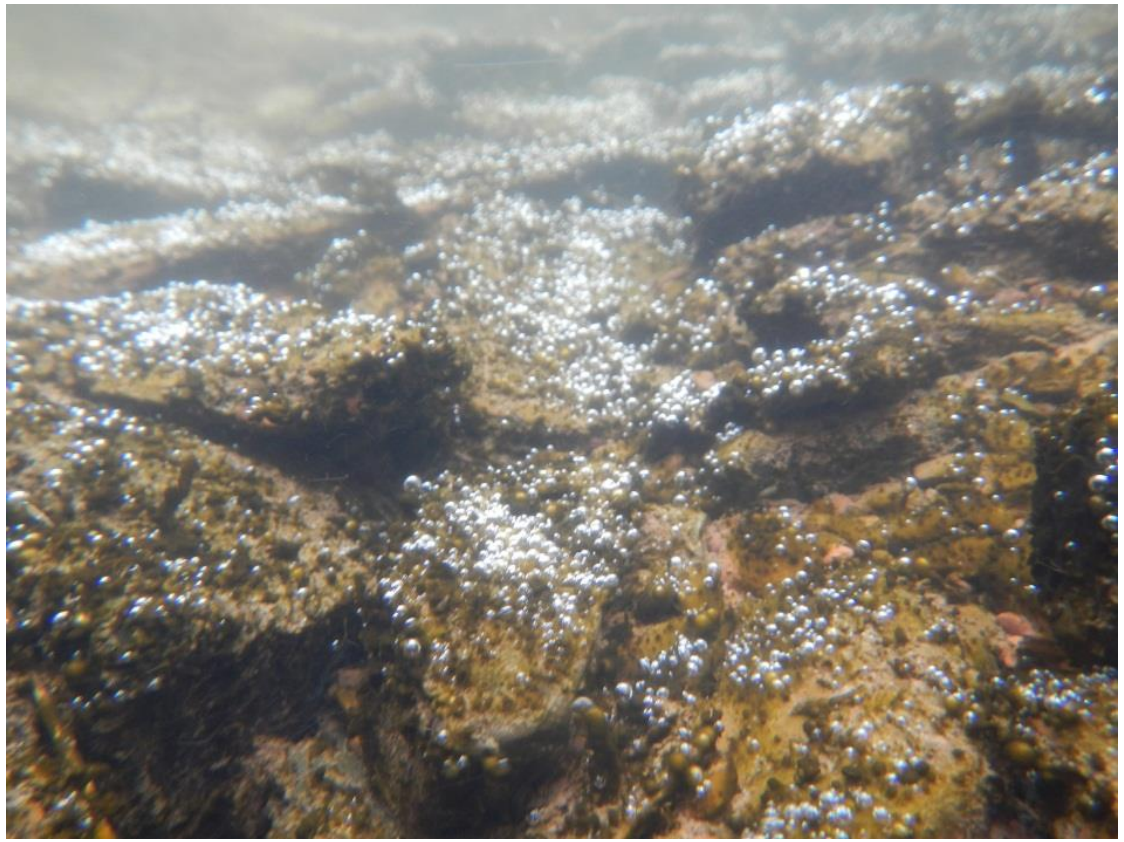
Technical Foundation of the Protocol



Odum's Open-Water Diel DO Method of Measuring Stream Ecosystem Metabolism (Odum 1956)

$$\Delta O_2/\Delta t = P - R - K - A$$

- Photosynthesis:

$$6CO_2 + 6H_2O \xrightarrow{\text{Light Energy}} C_6H_{12}O_6 \text{ (Organic Matter)} + 6O_2$$

- Respiration:

$$C_6H_{12}O_6 \text{ (Organic Matter)} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

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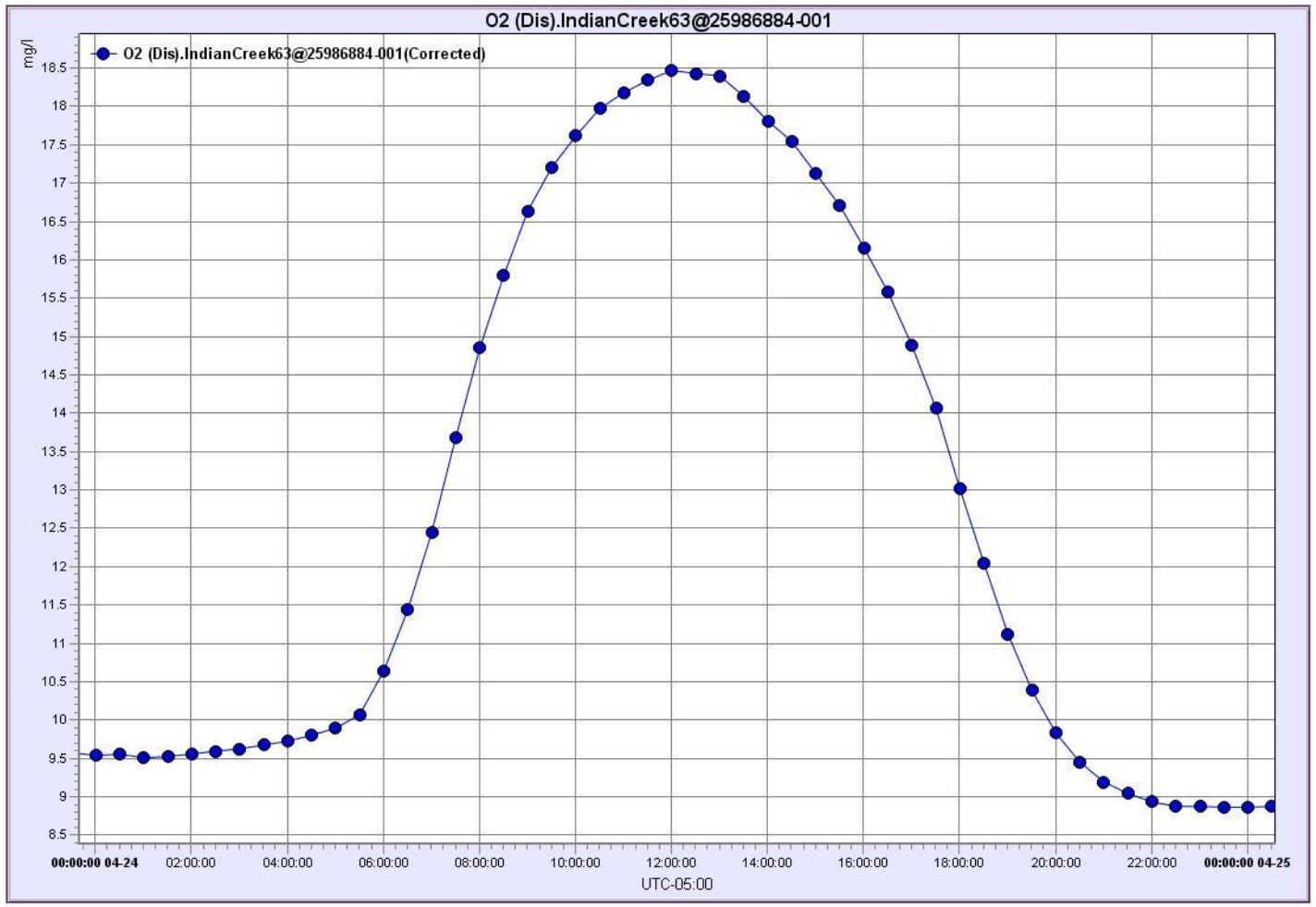
Protocol Uses Diel DO Swings as Indicator of Metabolic Conditions



- Photosynthesis Rates are Light-Dependent and Fluctuate on Diel (Daily) Cycle
- Photosynthesis ↑DO
- Respiration ↓DO
- Amplitude of Diel DO Swings Reflect P and R Rates and Overall Ecosystem Metabolic Conditions

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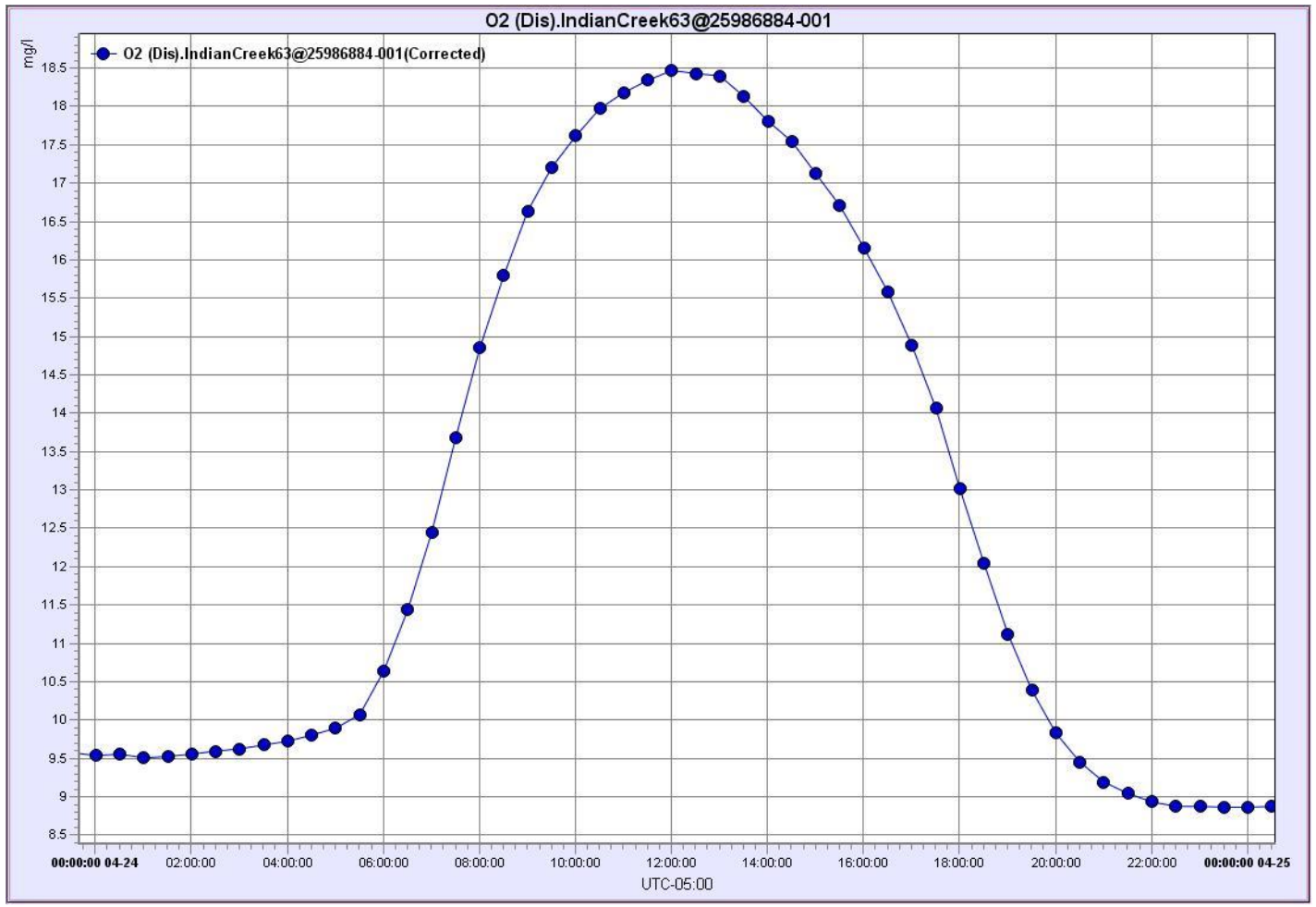
Protocol Uses Diel DO Swings as Indicator of Metabolic Conditions



- Amplitude of Diel DO Swings are Compared to the Swings of Reasonably Healthy Streams (Benchmark Values)
- Diel DO Swings > Benchmark Values Indicate that Eutrophication has Substantially Altered Stream Metabolic Conditions, and
- Nutrients-Eutrophication are Determined to be A Cause of ALU Impairment

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Data Used to Develop the Protocol

- Continuously Monitored DO, pH, & Temp (Readings every ½ Hour)
- March - April – May Timeframe
- 2013 thru 2016 Sample Seasons
- TP and TN Approximately Monthly
- At Least One Benthic Chl-a Sample at Most Stations
- One Macro IBI Sample at Each Station

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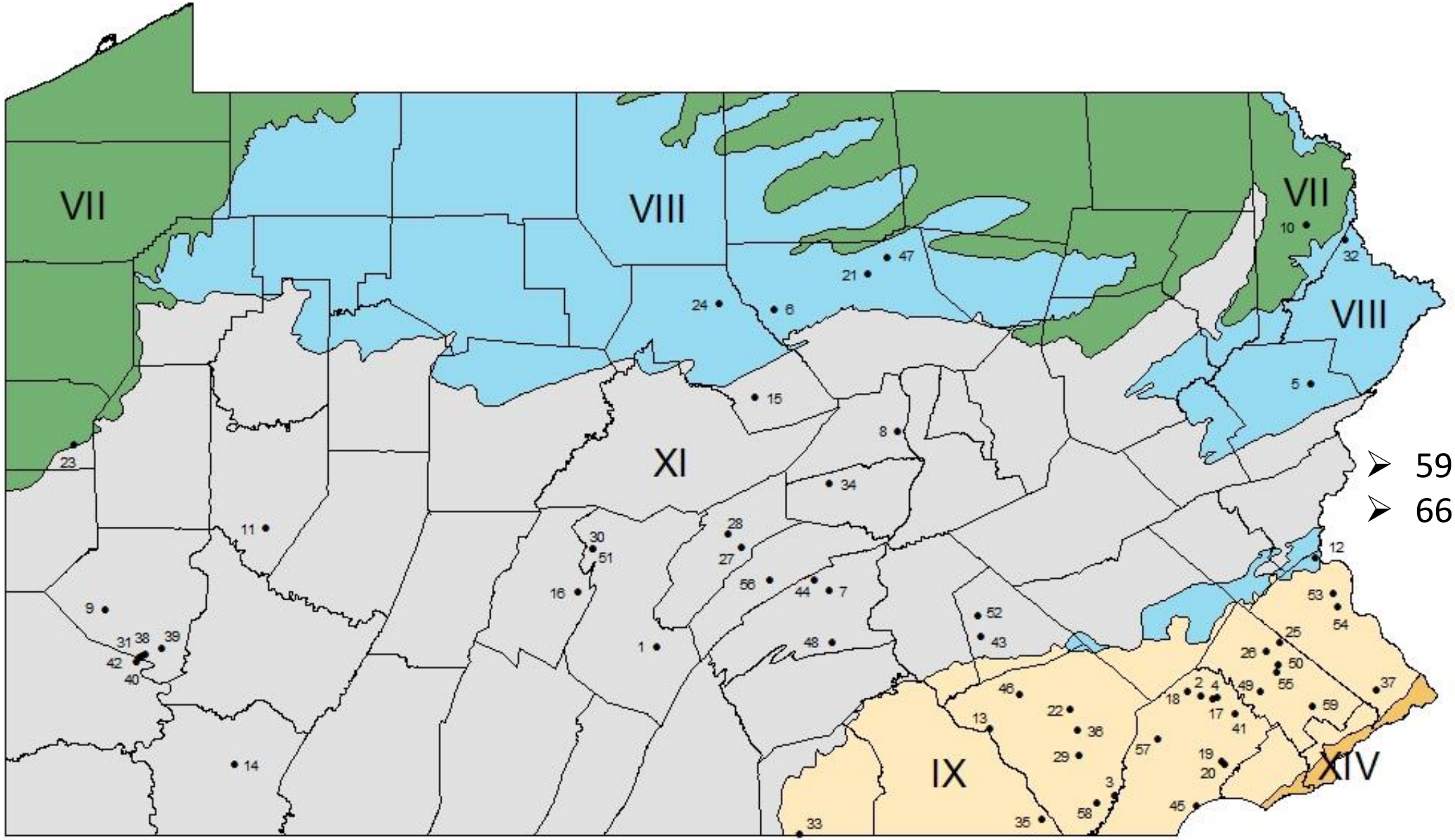
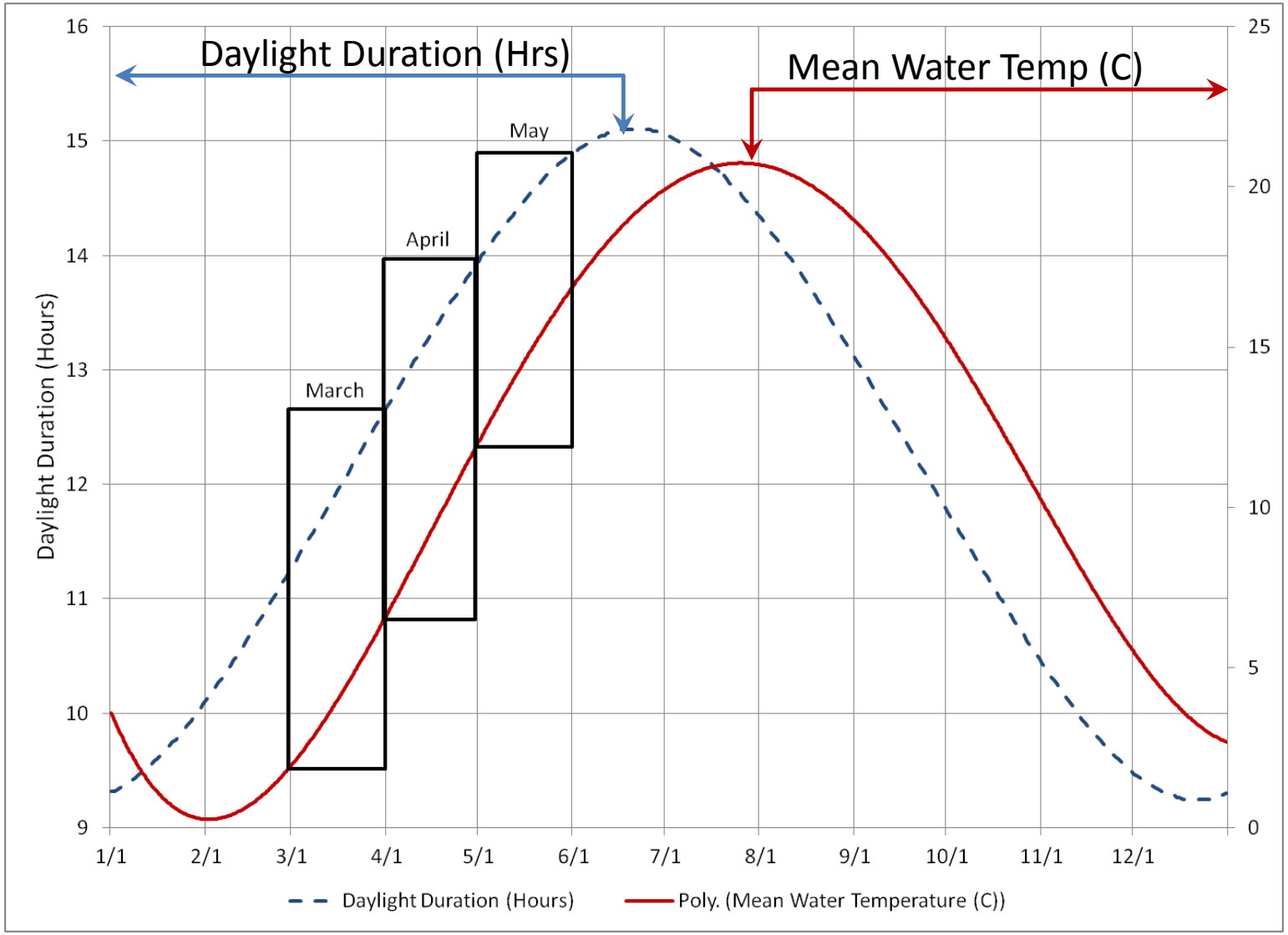
Sample Stations & EPA Nutrient Ecoregions



Efforts to Account for Natural Variability



March - April - May Timeframe

- Pre or Early Leafout / Shading
- Insect Emergence

Monthly

- Daylight Duration
- Water Temperature
- Stream Q / Velocity Scour

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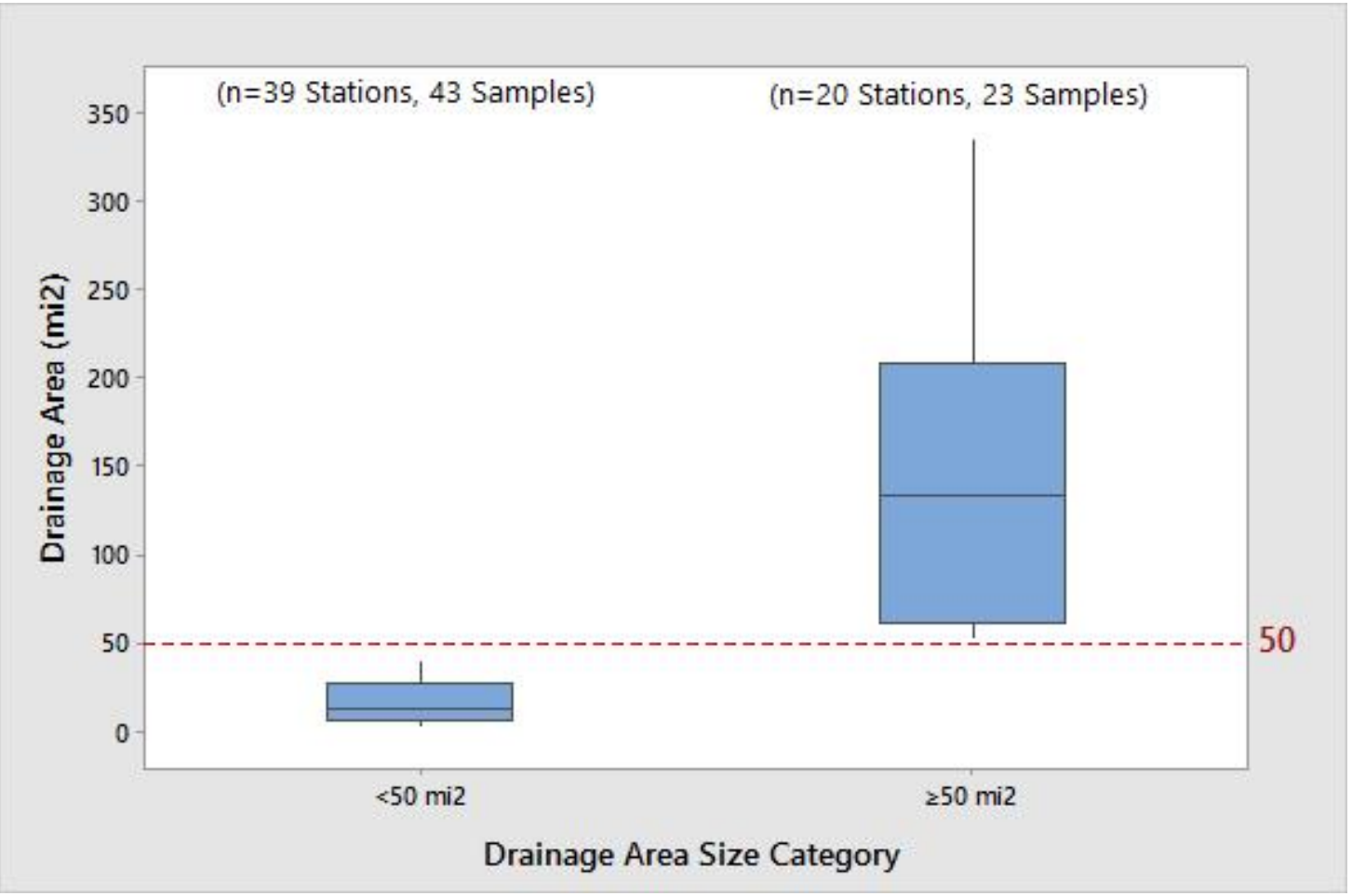
Efforts to Account for Natural Variability



Drainage Area Size Categories

- <50 mi^2 and 50 - 350 mi^2
- 6D-200 Macro Protocol
- Water Depth and Volume
- Turbidity
- Irradiance of Benthic Periphyton

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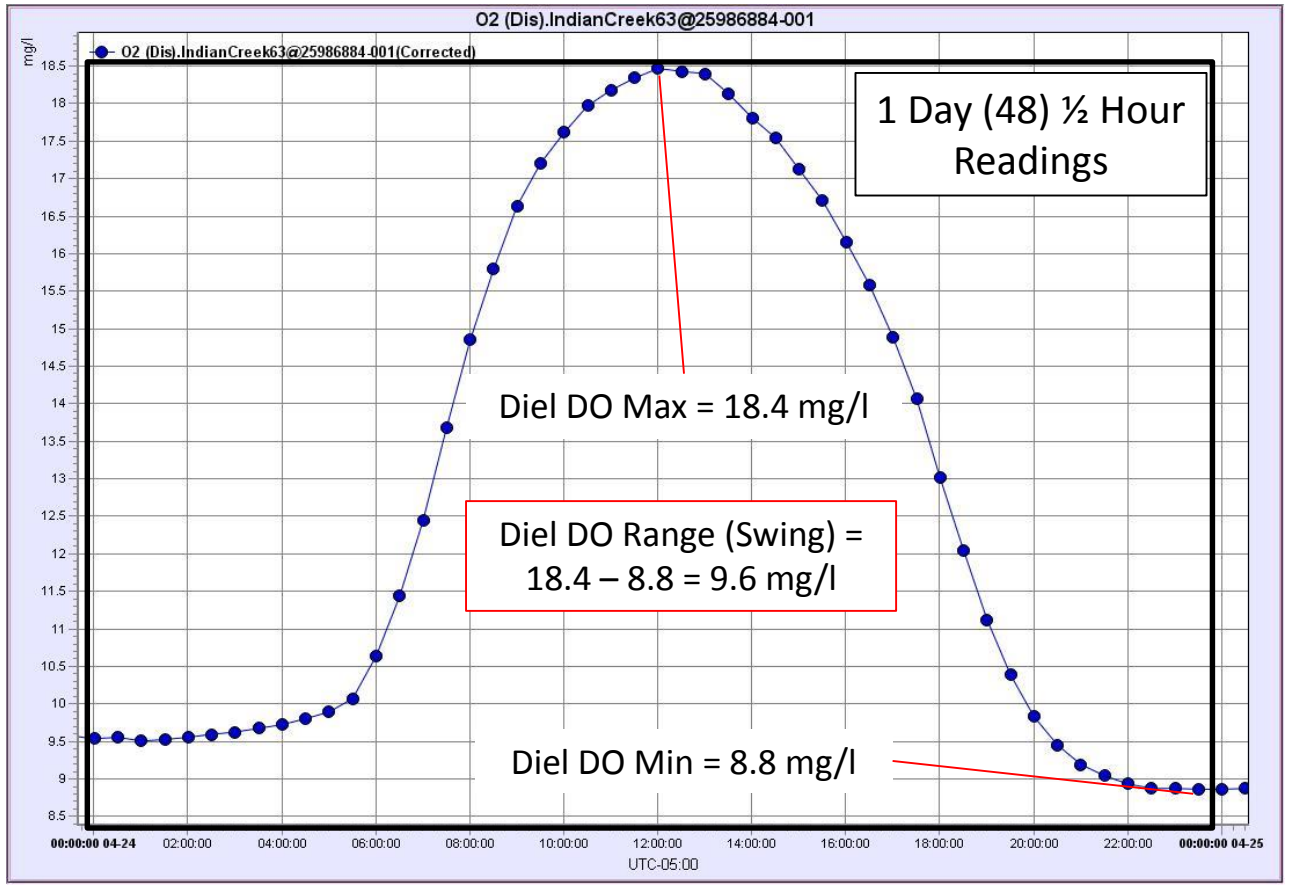
Quantification of Diel DO Conditions



- Diel DO Swing = Daily DO Max – DO Min
- Only Use Days With at Least 75% of the Day Monitored (Minimum of (36) ½-Hr Readings)

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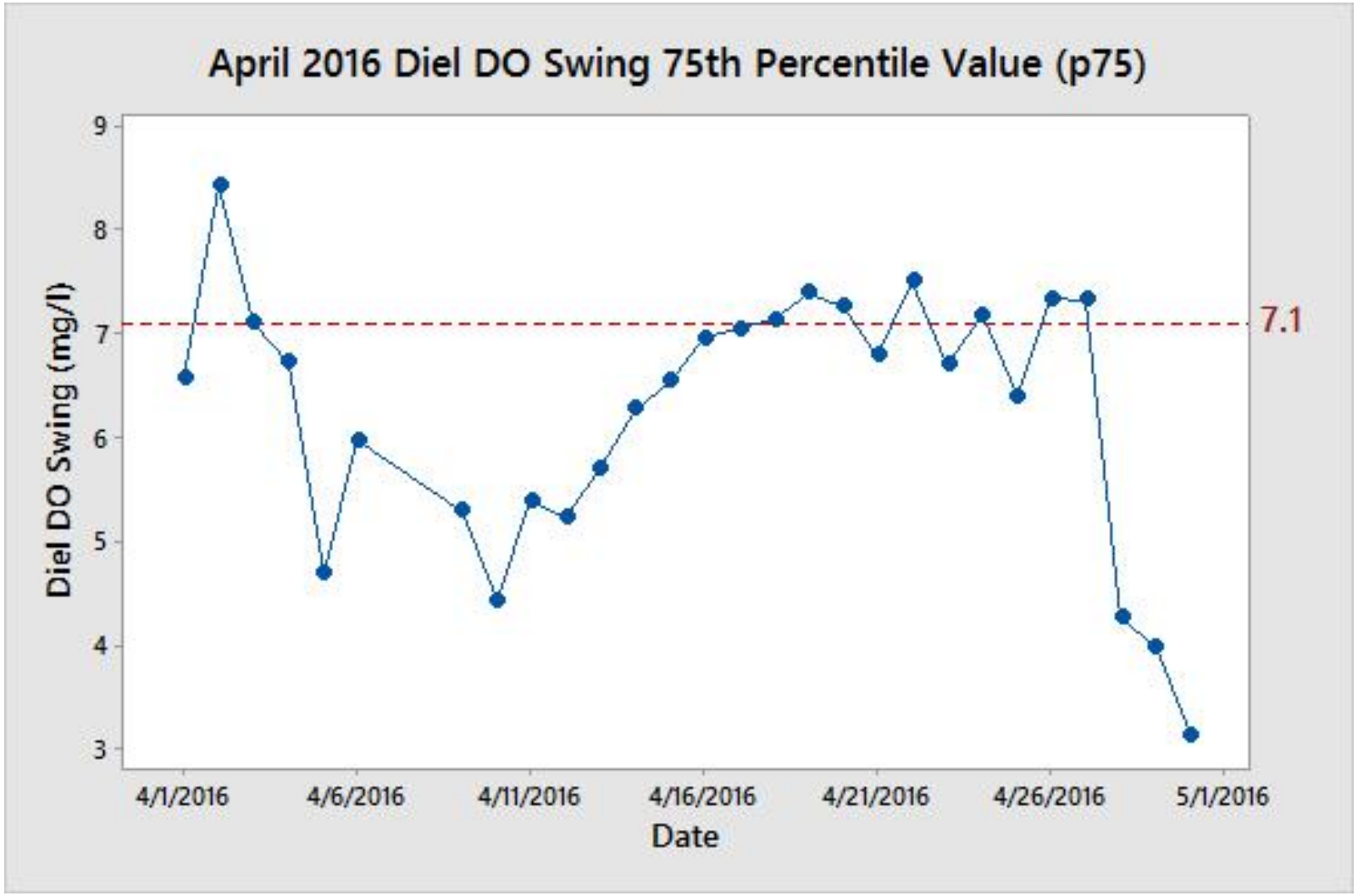
Diel DO Swings Summarized by Month



- 75th Percentile Value of Diel DO Swings Recorded Within a given Month
- Minimum of Half the Month with Diel DO Swing Values
- 1,340 ½-Hour DO Readings
- 28 Days

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Benchmark Sample Screening Criteria

- ALU Attaining Streams With Macroinvertebrate IBI Score ≥53
- Mean TP, TN, and Benthic Chl-a Values Could Not Be Statistical Outliers
  - [Q1 - (1.5 X IQR)] or [Q3 + (1.5 X IQR)]
- Benchmark Values Represent the Upper Threshold of Photosynthesis and Respiration Rates of Reasonably Healthy Streams

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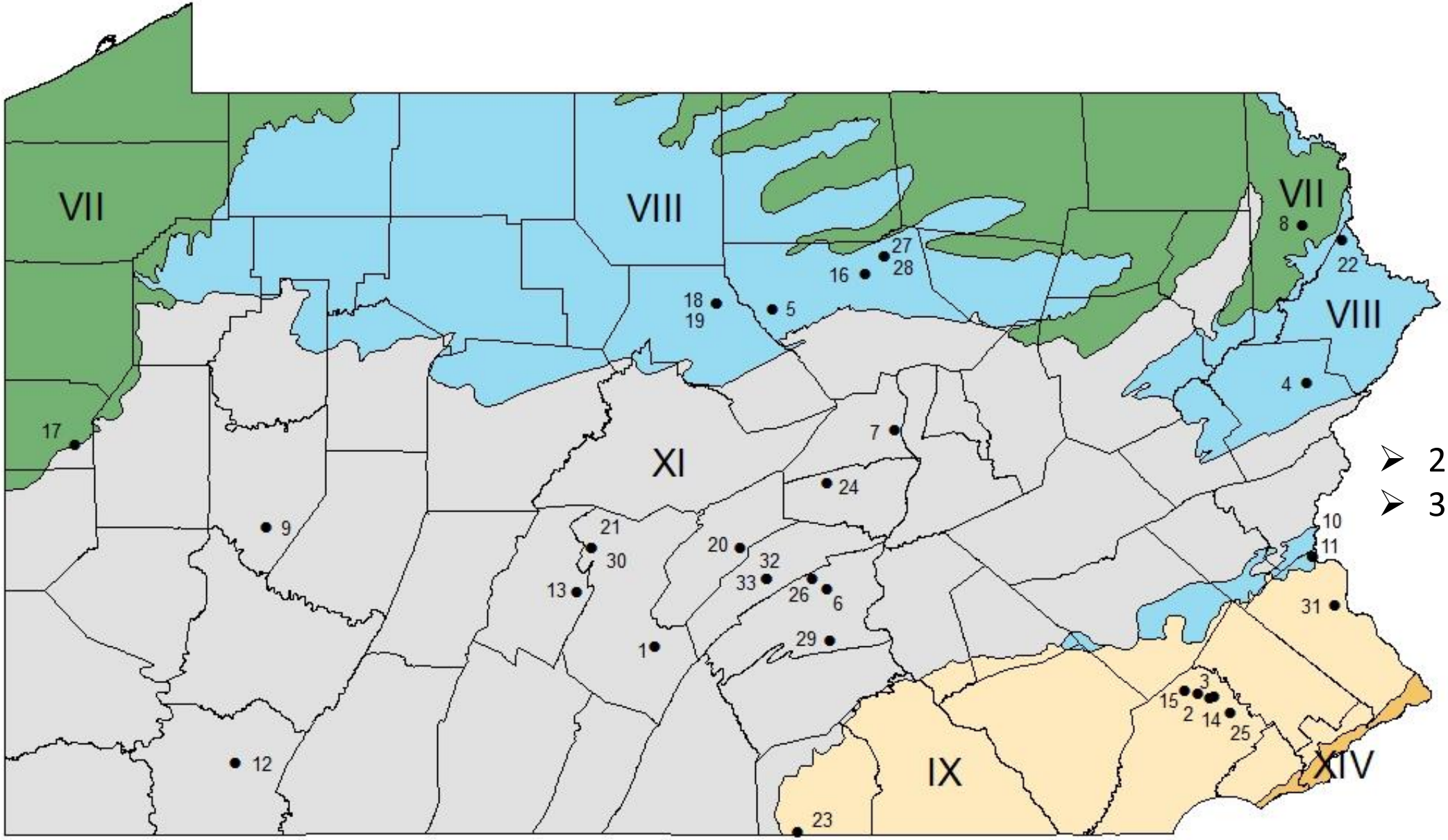
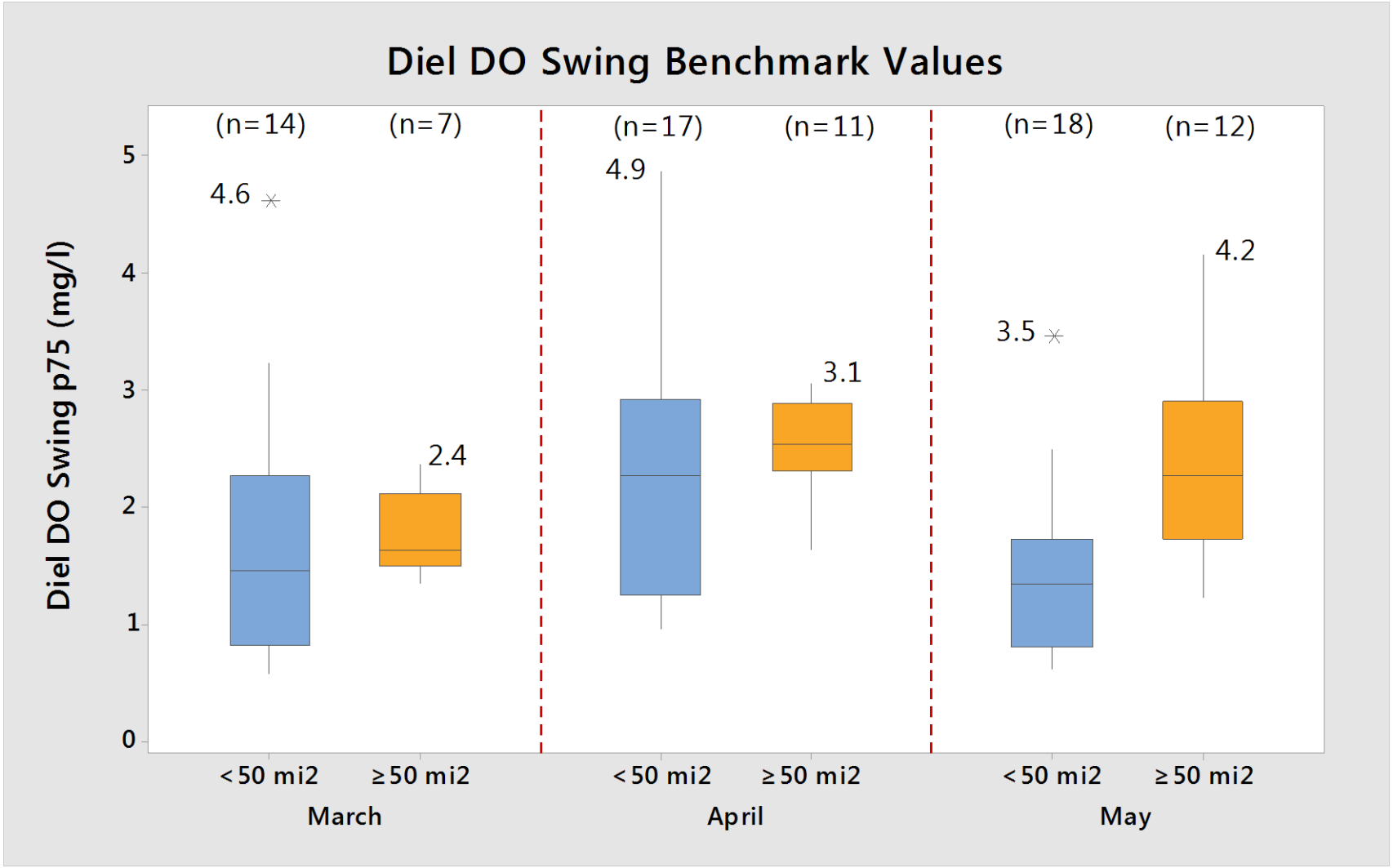
Benchmark Sample Stations



- 29 Stations
- 33 Samples

Monthly p75 Diel DO Swing Benchmark Values



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Application of Benchmarks to Dataset

Application of Benchmarks to Entire Dataset (N=66)

	Aquatic Life Use Attaining	Aquatic Life Use Impaired
No Exceedance of Any Monthly Diel DO Swing Benchmark Value	36	7
Exceedance of One or More Diel DO Swing Benchmark Values	3	20

Cause of ALU Impairment:
Nutrients - Eutrophication

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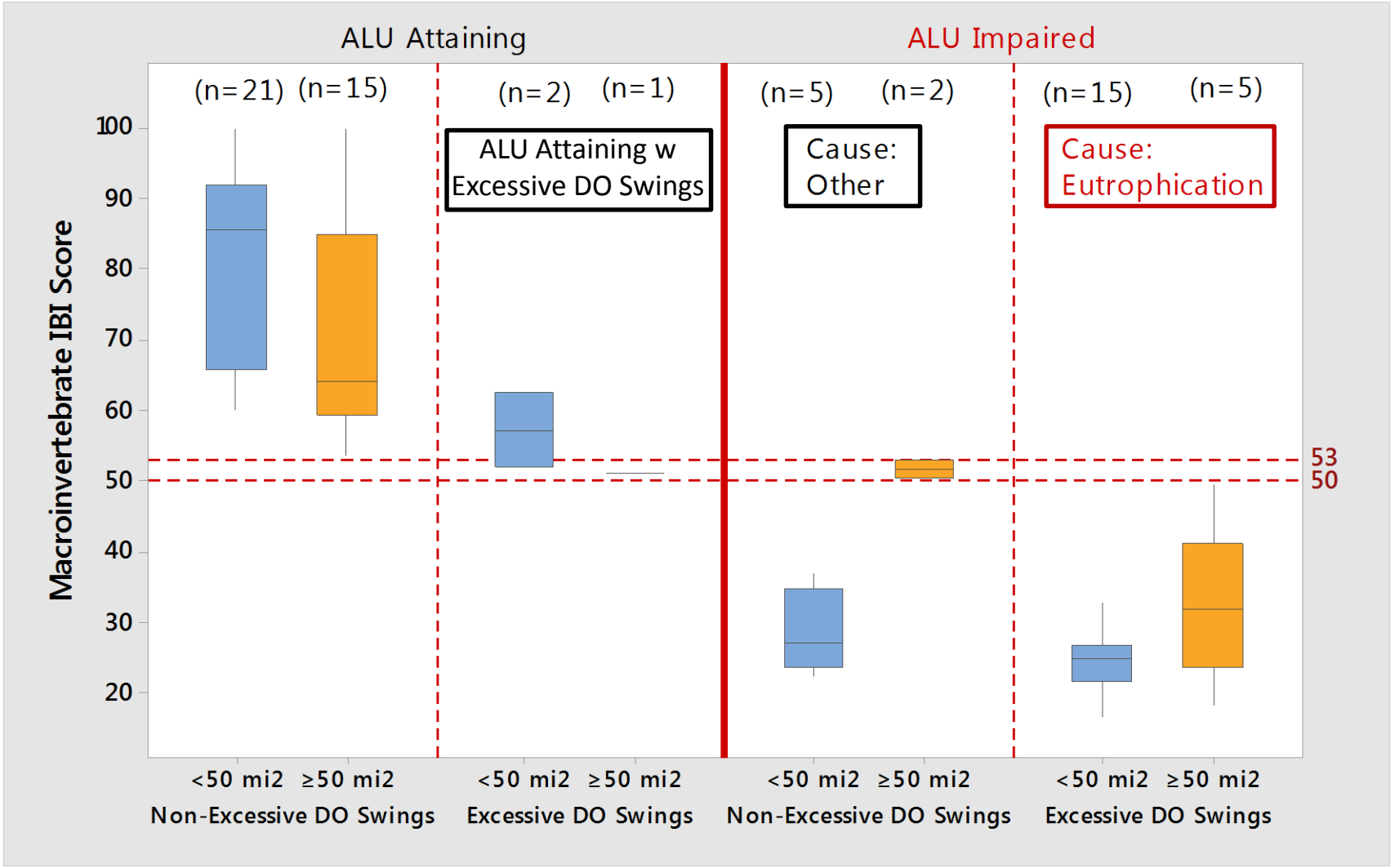
Application of Benchmarks to Entire Dataset (N=66)



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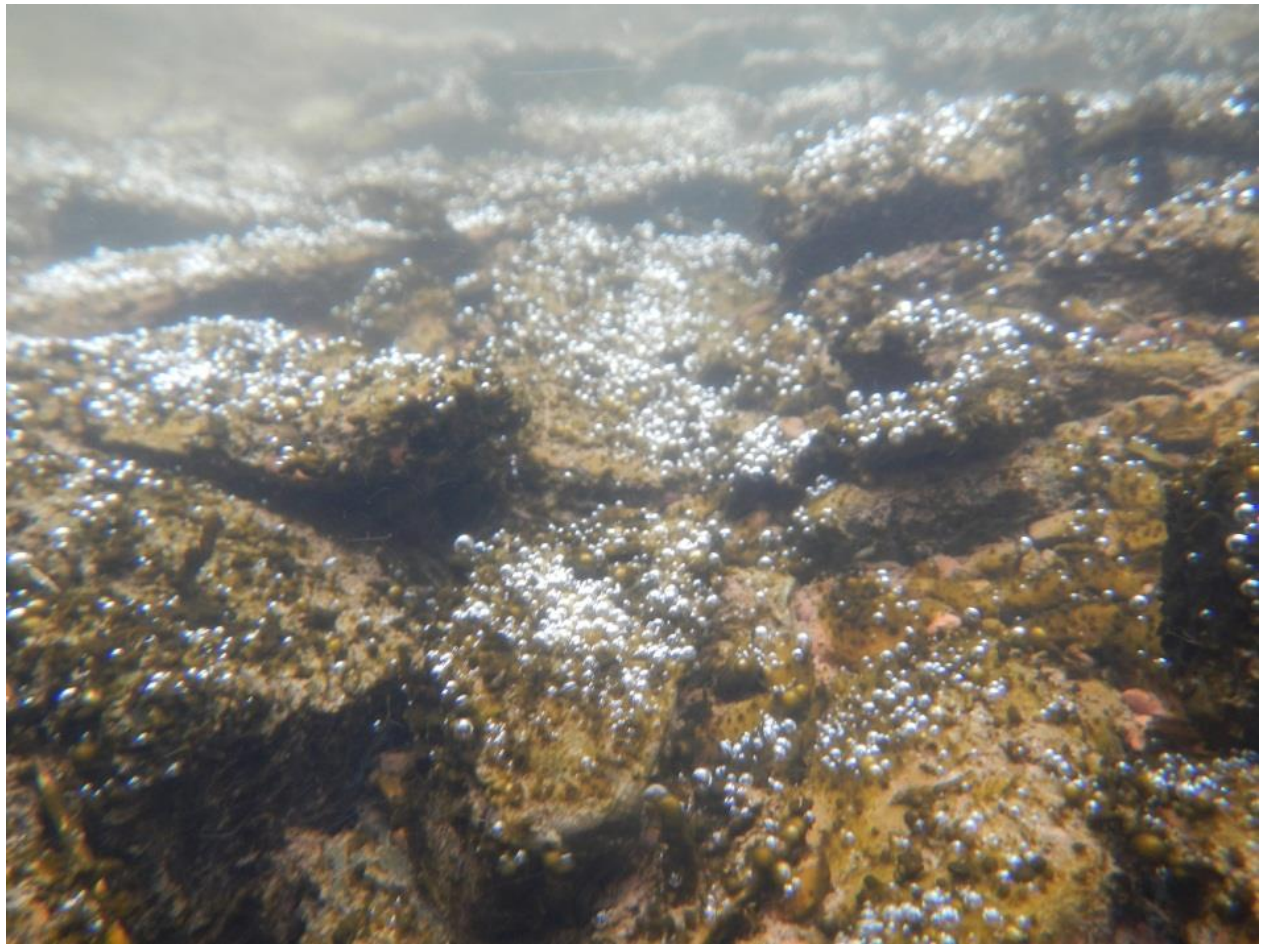
A Critical Assumption of the Protocol



- The Magnitude of Diel DO Swings Reflect:

- Stream Photosynthesis Rates
- Ecosystem Respiration Rates
- Overall Ecosystem Metabolic Conditions

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Additional Analyses to Confirm Accuracy of Assumption (N=59)

	Aquatic Life Use Attaining	Aquatic Life Use Impaired
No Exceedance of Any Monthly Diel DO Swing Benchmark Value	36	X
Exceedance of One or More Diel DO Swing Benchmark Values	3	20

- Reasonable to Assume that Diel DO Swings Reflect Photosynthesis and Respiration Rates (Overall Metabolic Conditions)
- 7 ALU Impaired Samples With Cause: Other to Establish a Clear Gradient of Trophic Conditions
- Relationships Between DO and pH Swings

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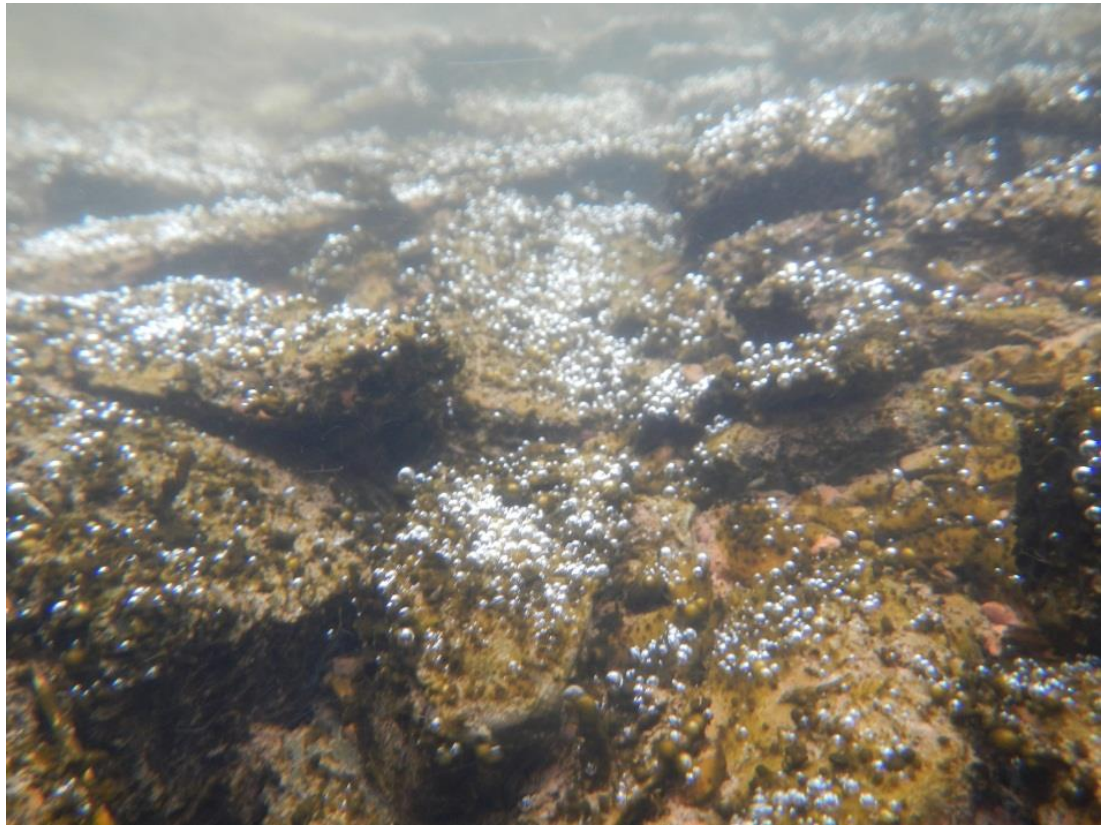
Photosynthesis and Respiration Influences Both DO and pH on a Diel Cycle



- Photosynthesis:

$$6CO_2 + 6H_2O \xrightarrow{\text{Light Energy}} C_6H_{12}O_6 \text{ (Organic Matter)} + 6O_2$$

- Respiration:

$$C_6H_{12}O_6 \text{ (Organic Matter)} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

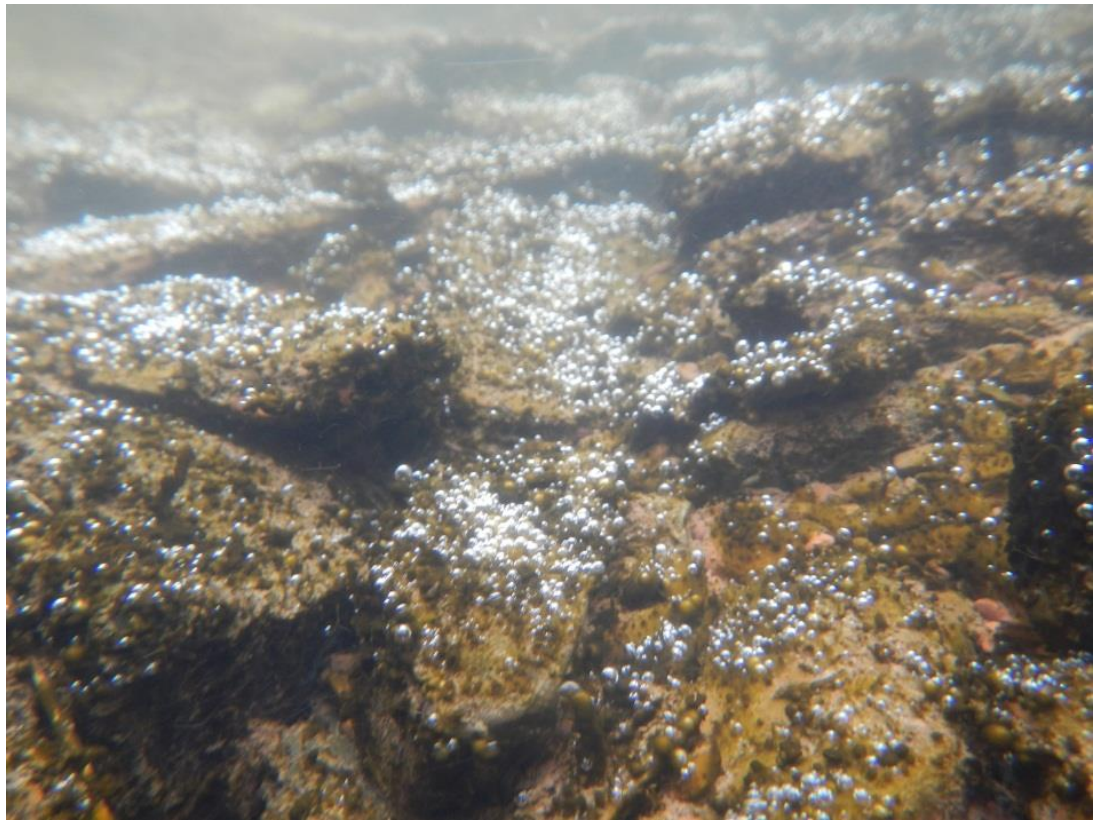
- ΔCO_2 → Δ DIC pH Buffer System → Δ pH

Removal of CO_2 during photosynthesis shifts equilibrium (higher pH) →

$$CO_2(gas) \leftrightarrow CO_2(aq) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}, \text{ and } CO_3^{2-} + H_2O \leftrightarrow HCO_3^- + OH^-$$

← Addition of CO2 during respiration shifts equilibrium (lower pH)

Photosynthesis and Respiration Influences Both DO and pH on a Diel Cycle



- Photosynthesis: ↑DO ↓CO_2 and ↑pH
- Respiration: ↓DO ↑CO_2 and ↓pH
- If Photosynthesis and Respiration Are Driving Diel DO Swings, There Should Be a Relationship Between the Magnitude of Diel DO and Diel pH Swings

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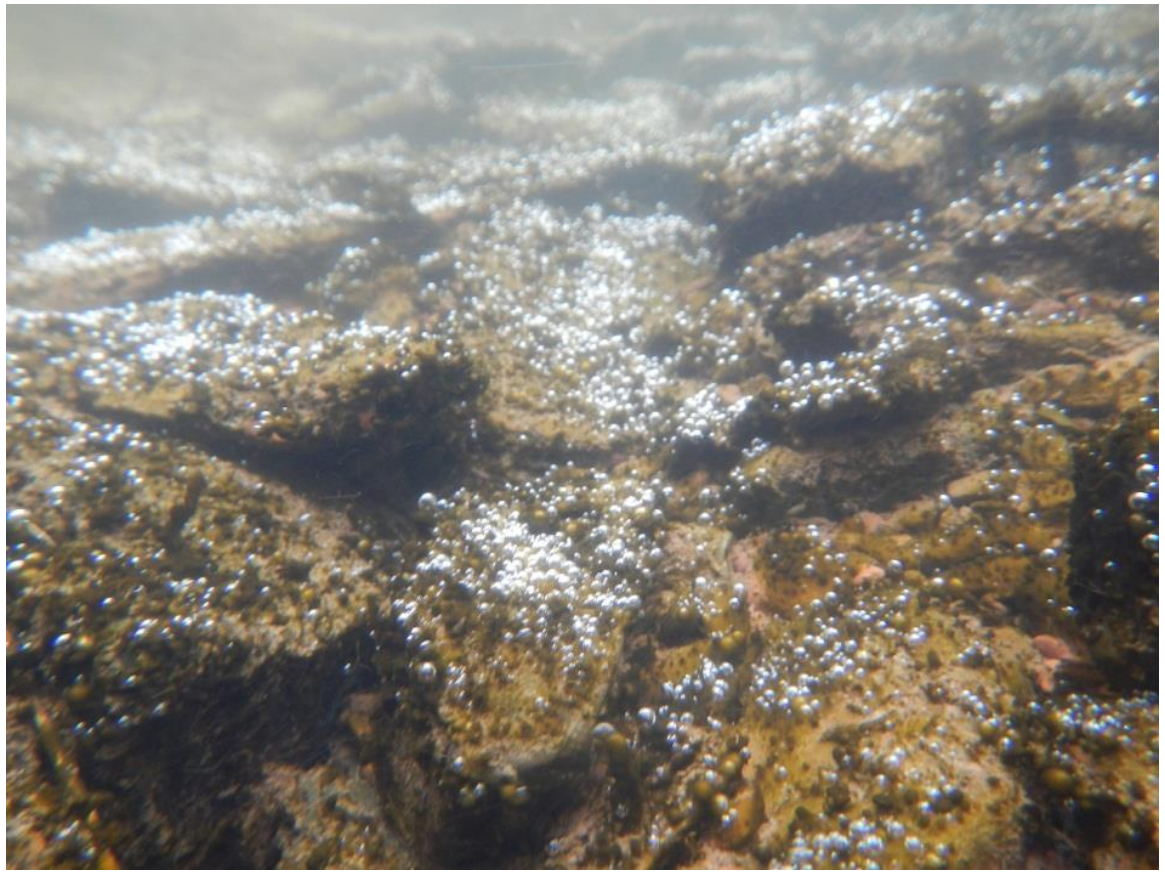
Photosynthesis and Respiration Influences Both DO and pH on a Diel Cycle



➢ If DO and pH Swings Are Not Correlated:

- DO Swings Are Not Driven by Photosynthesis
- **Heterotrophic System**

➢ If DO and pH Swings Are Correlated:

- DO Swings Are Driven by Photosynthesis
- **Autotrophic System**

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Heterotrophic System: Diel DO and pH Relationship Hyner Run

Hyner Run 2016 Clinton Co (Eco VIII, 26.6 mi²)

- ALU Attaining
  - Macro IBI = 100
  - Mean Chl-a = 24 mg/m²
  - Mean TP = 0.010 mg/L
  - Mean TN = 0.26 mg/L

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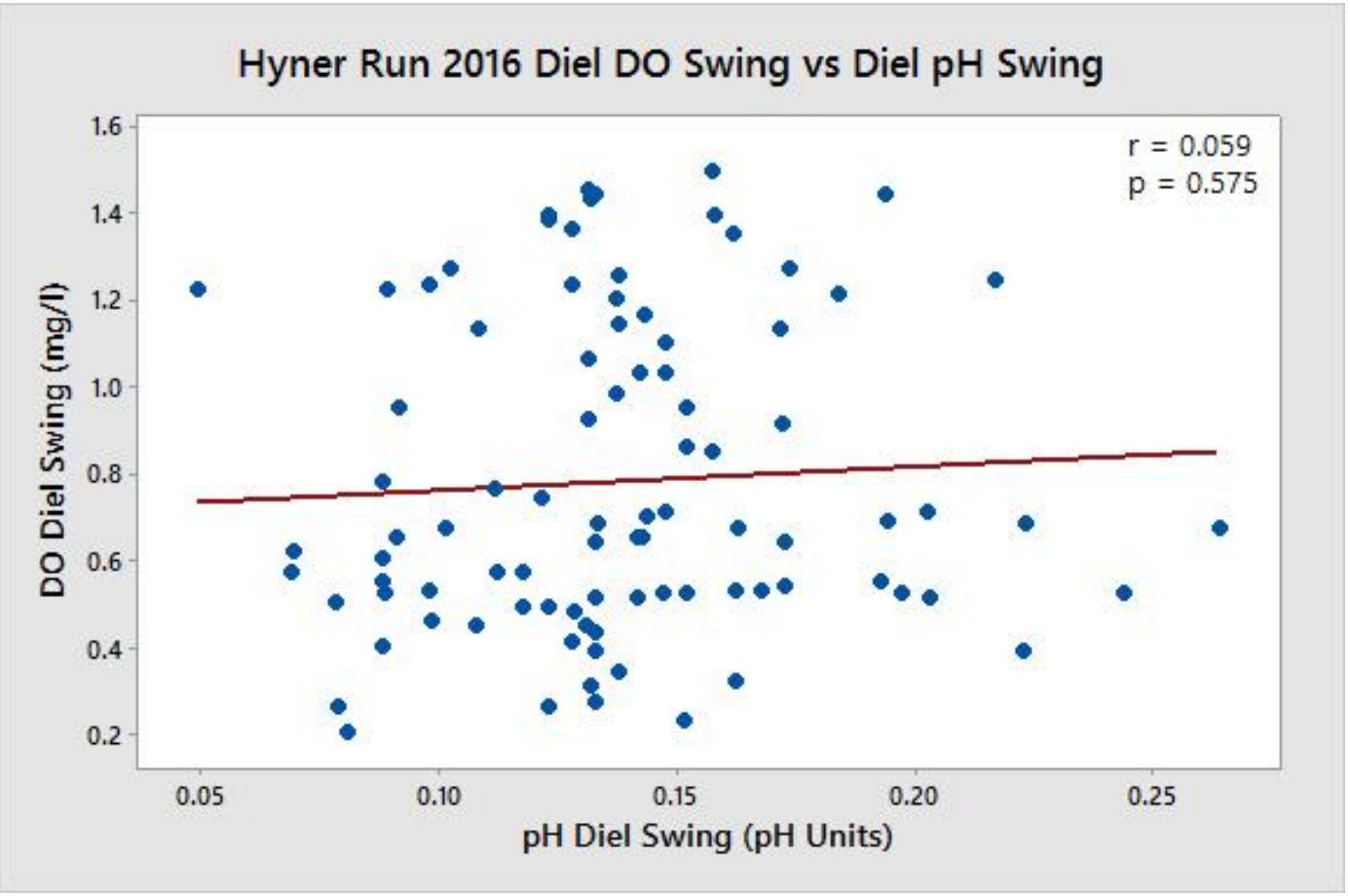
Heterotrophic System: Diel DO and pH Relationship Hyner Run

Hyner Run 2016 (March – May Data)

Diel DO Swing – Diel pH Swing

r = 0.059, p = 0.575



Hyner Run 2016 Clinton Co (Eco VIII, 26.6 mi²)

- No Correlation DO & pH
- Photosynthesis Not Driving DO Swings
- **<u>Predominantly Heterotrophic</u>** Organic Matter (Energy) from Outside Source Not In-Stream Photosynthesis

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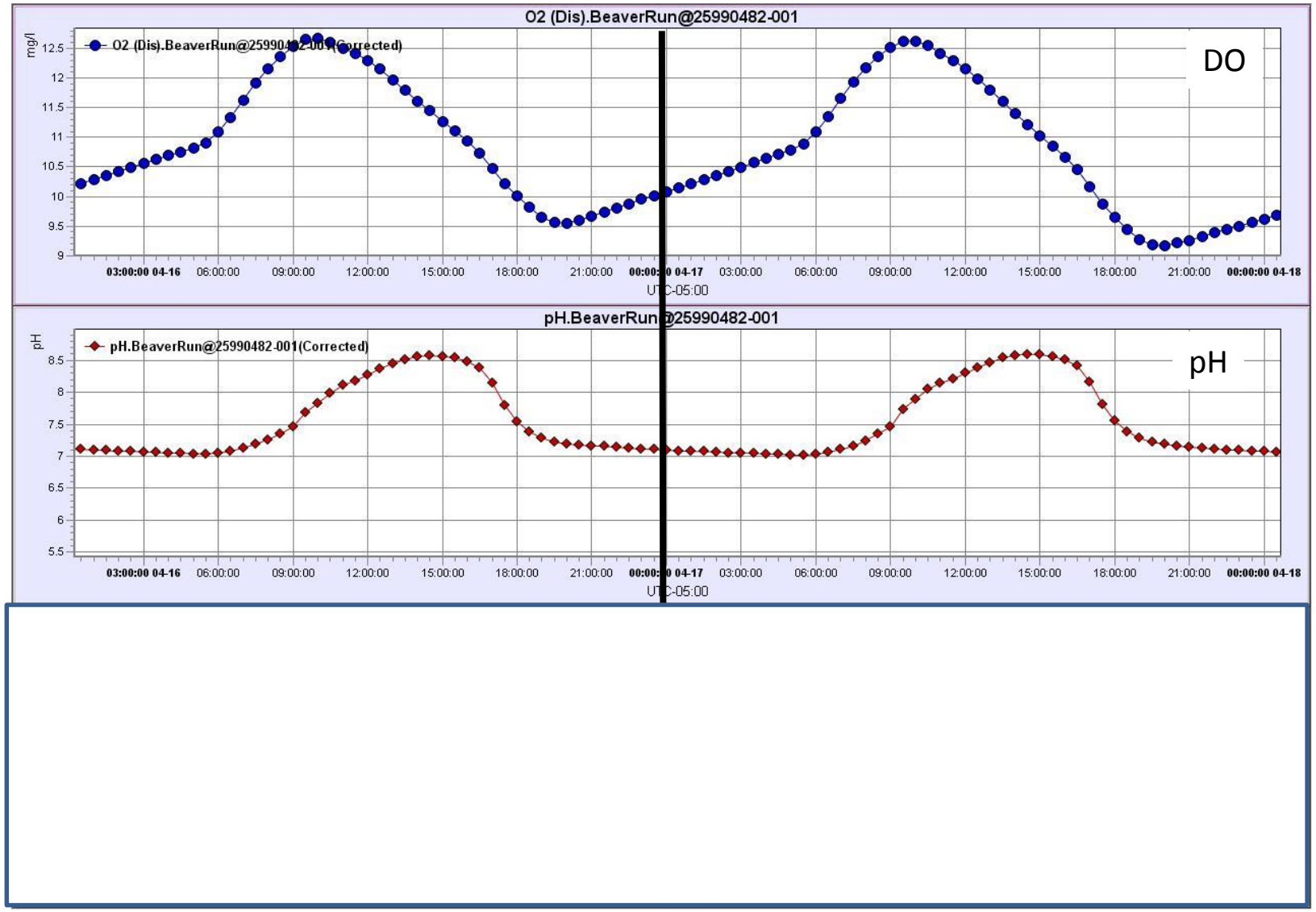
Autotrophic System: Diel DO and pH Relationship Beaver Run



Beaver Run 2016 Chester Co (Eco IX, 5.0 mi²)

- ALU Attaining
  - Macro IBI = 73
  - Mean Chl-a = 190 mg/m²
  - Mean TP = 0.028 mg/L
  - Mean TN = 1.00 mg/L

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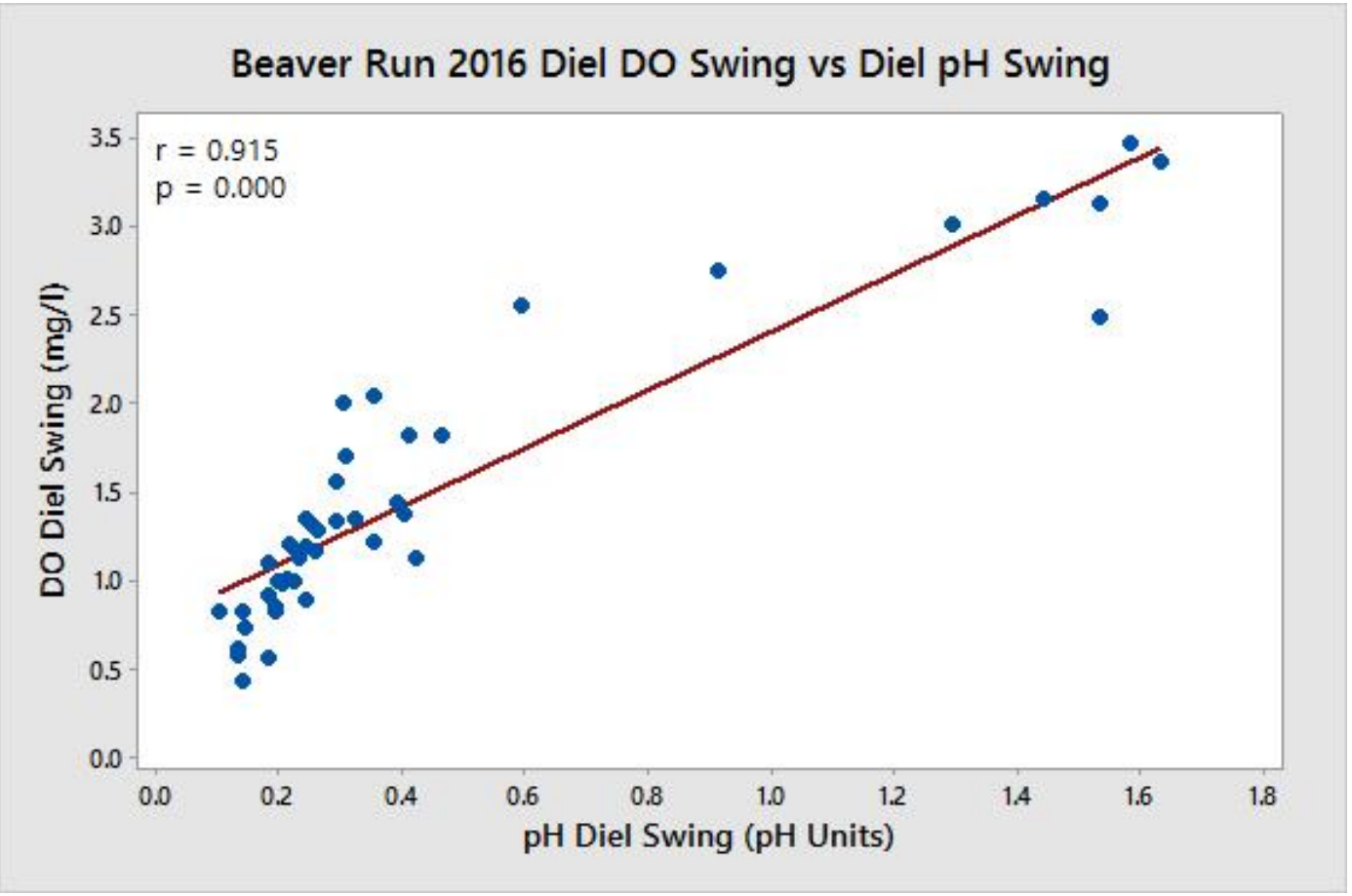
Autotrophic System: Diel DO and pH Relationship Beaver Run

Beaver Run 2016 (March – May Data)

Diel DO Swing – Diel pH Swing

r = 0.915, p = 0.000



Beaver Run 2016 Chester Co (Eco IX, 5.0 mi²)

- Strong Correlation DO & pH
- DO Swings Driven by Photosynthesis
- **<u>Predominantly Autotrophic</u>**
  Organic Matter (Energy) from In-Stream Photosynthesis

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Trophic Status Based on Eutrophication Cause Determ Protocol

DO Swings Driven by Photosynthesis (Based on DO– pH Swing Correlation r-Value)	General Trophic Category	Excessive Diel DO Swings (Relative to Protocol Benchmark Values)	Nutrient-Trophic Status Category
No	Heterotrophic	No	Oligotrophic (9)
Yes	Autotrophic	No	Mesotrophic (30)
		Yes	Eutrophic (20)

Cause of ALU Impairment:
Nutrients – Eutrophication (n=20)

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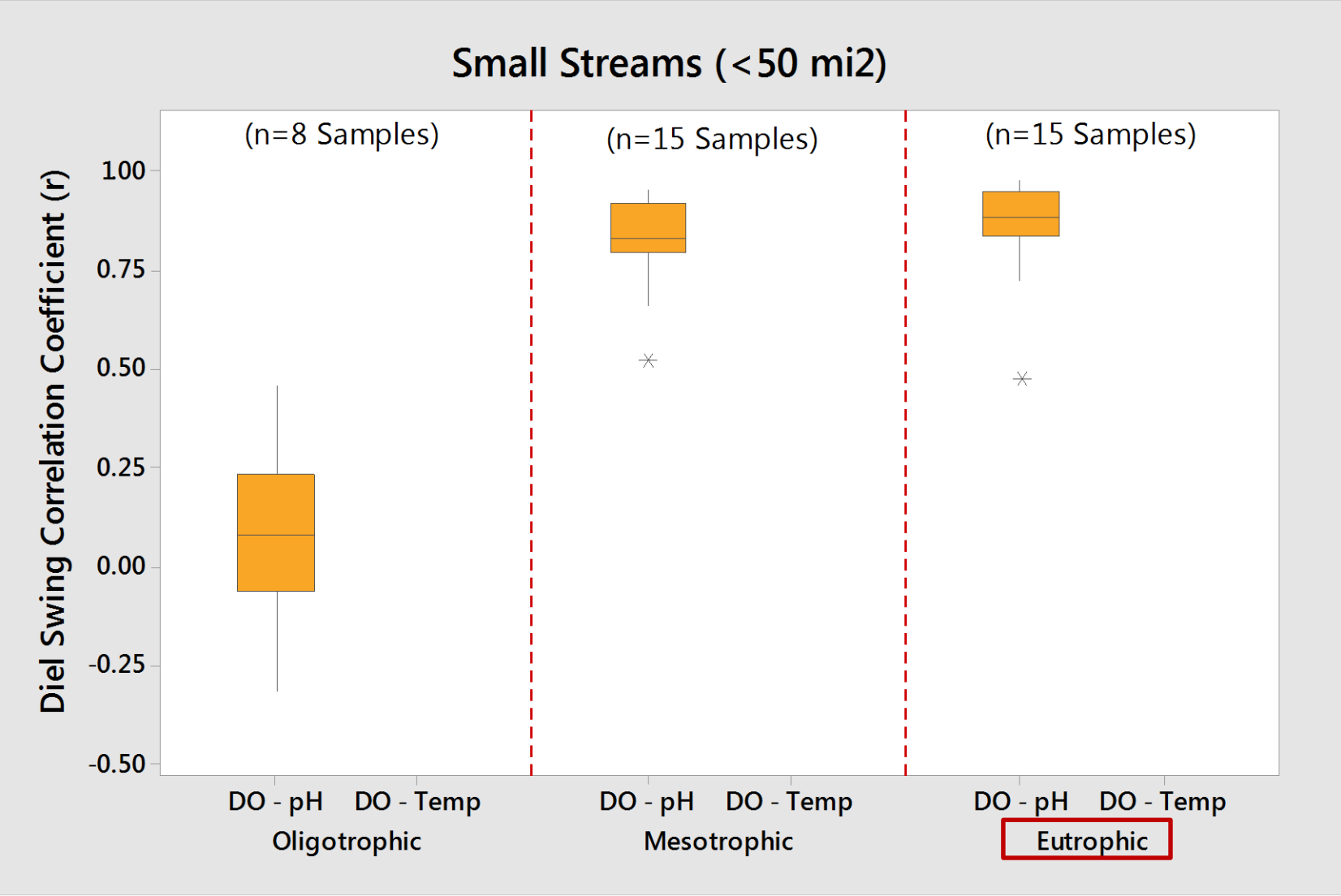
Trophic Status (Small Streams)



- Heterotrophic = Oligotrophic
- Autotrophic Split Based on ECD Protocol Results
- Autotrophic with Excessive DO Swings = Eutrophic
- Autotrophic w/o Excessive DO Swings = Mesotrophic

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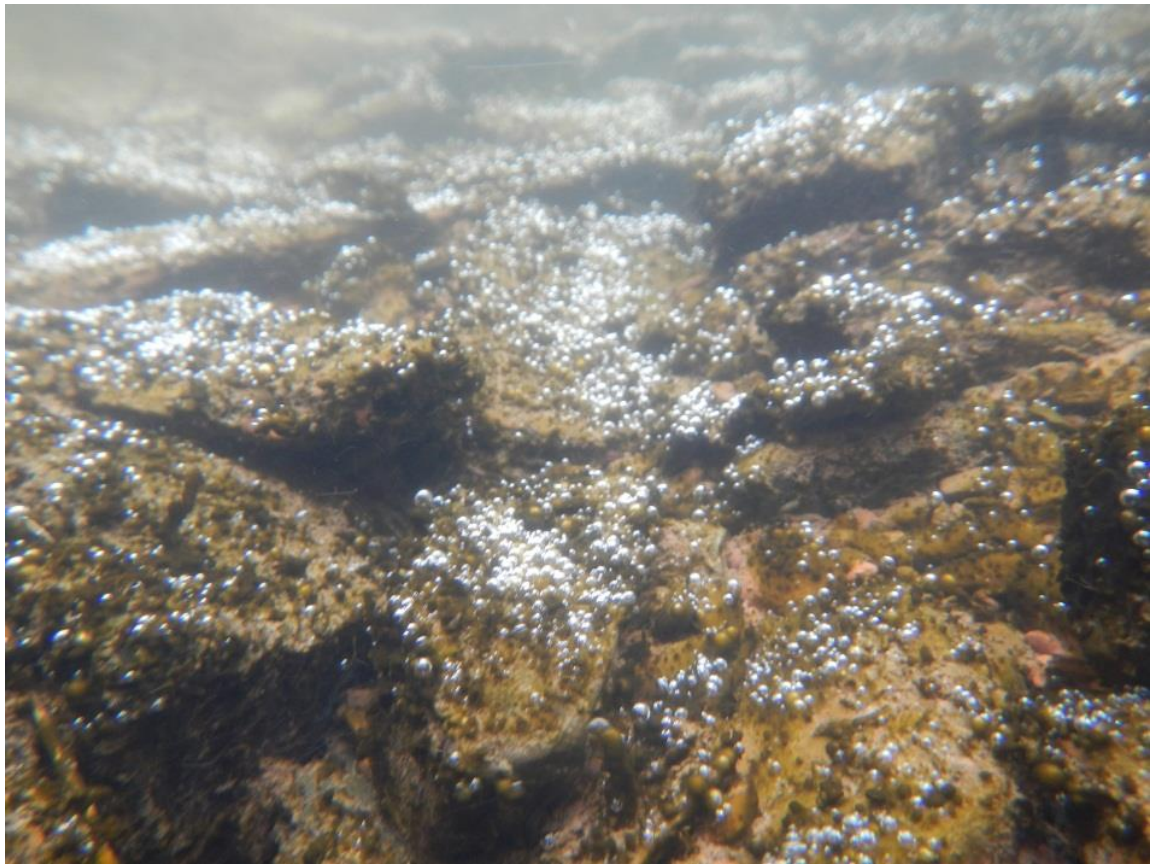
Water Temperature Influences Stream DO Levels on a Diel Cycle



- Diel DO and Temp Relationships Support Assumption that DO Swings Reflect Stream Photosynthesis Rates
- Water Temp↑ DO Solubility↓
- Water Temp Fluctuates on a Diel Cycle and Peaks in Afternoon and Cools Throughout the Evening and Early-Morning Hours
- The Strength of the Relationship Between Diel DO Swings and Diel Temp Swings Reflects the Influence of Temp on DO Swings

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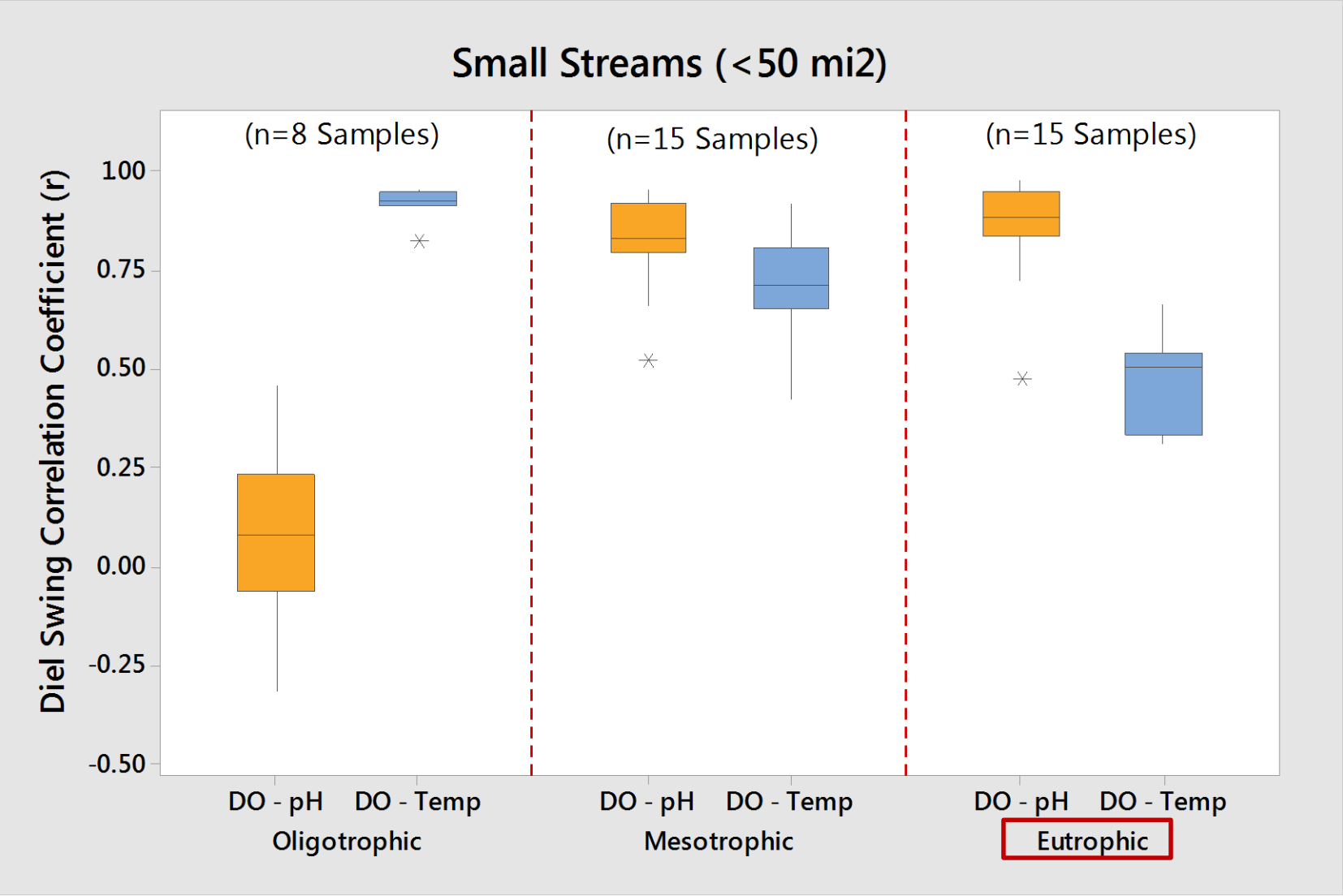
Trophic Status (Small Streams)



- Heterotrophic = Oligotrophic
- Autotrophic Split Based on ECD Protocol Results
- Autotrophic with Excessive DO Swings = Eutrophic
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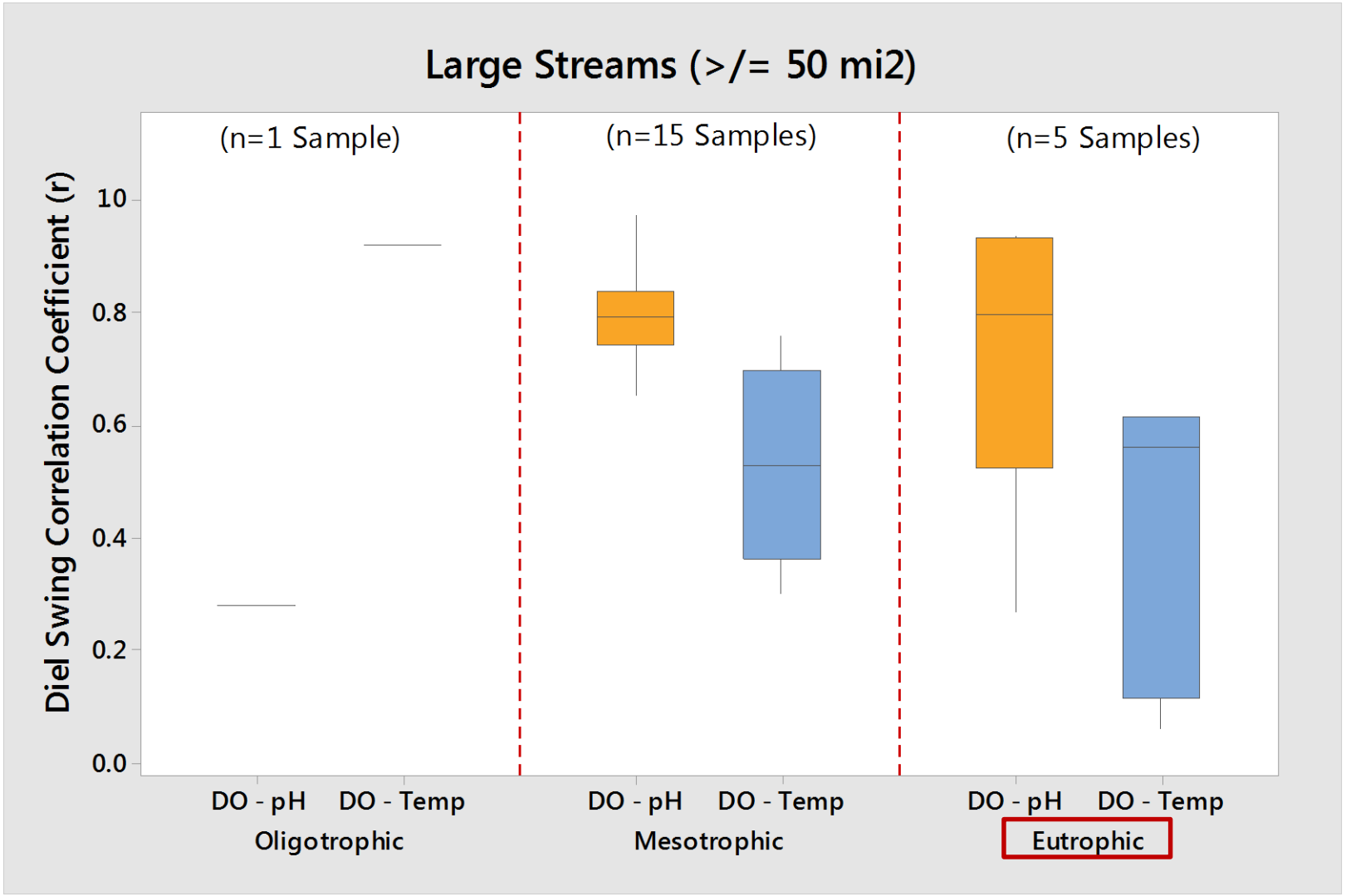
Trophic Status (Large Streams)



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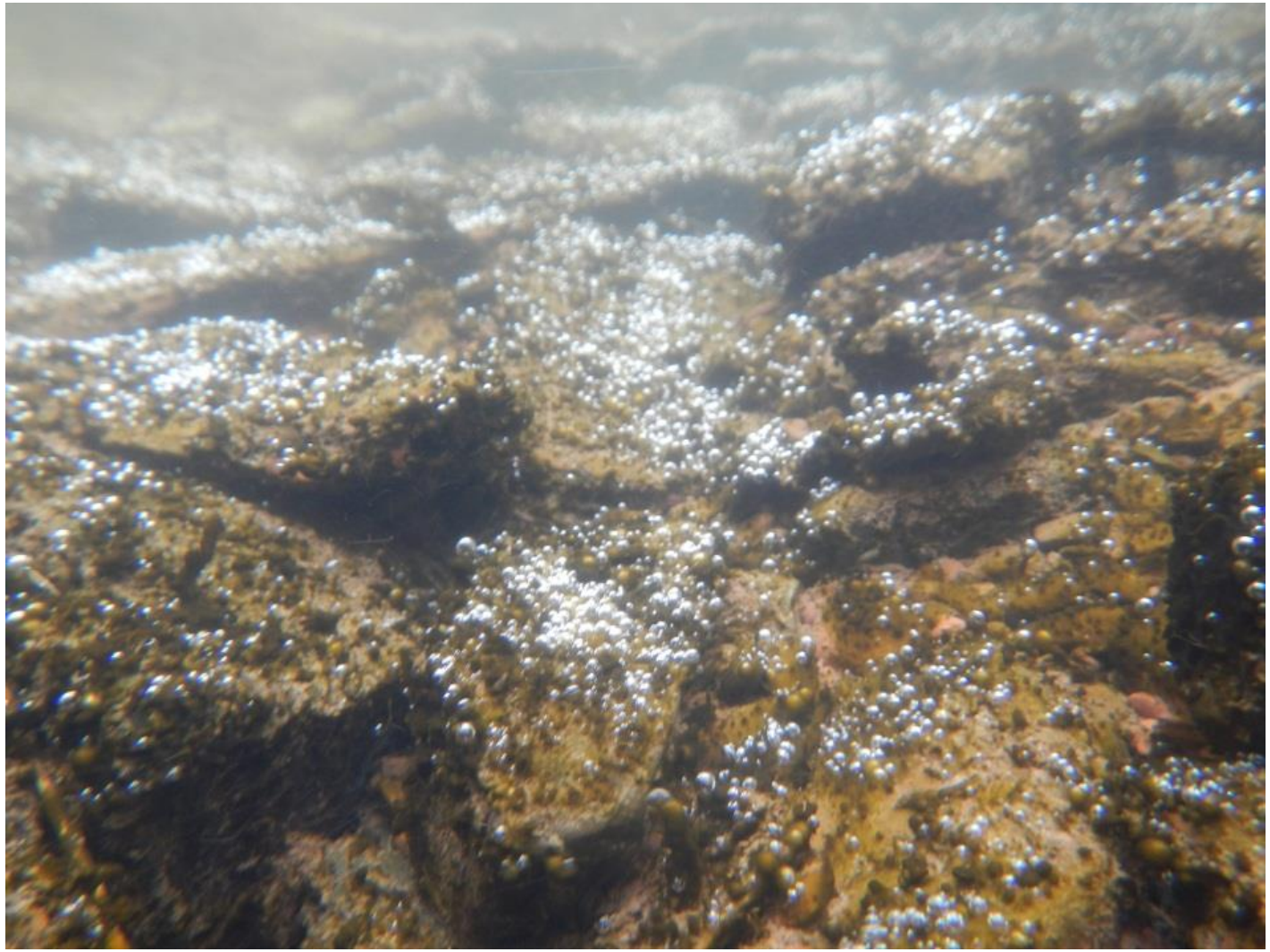
Time of Day Diel Max DO Reflects Trophic Status



- Water Temp↑ DO Solubility↓
- If DO Swings are Driven by Temp, Max DO Should Occur Near Time of Min Temp

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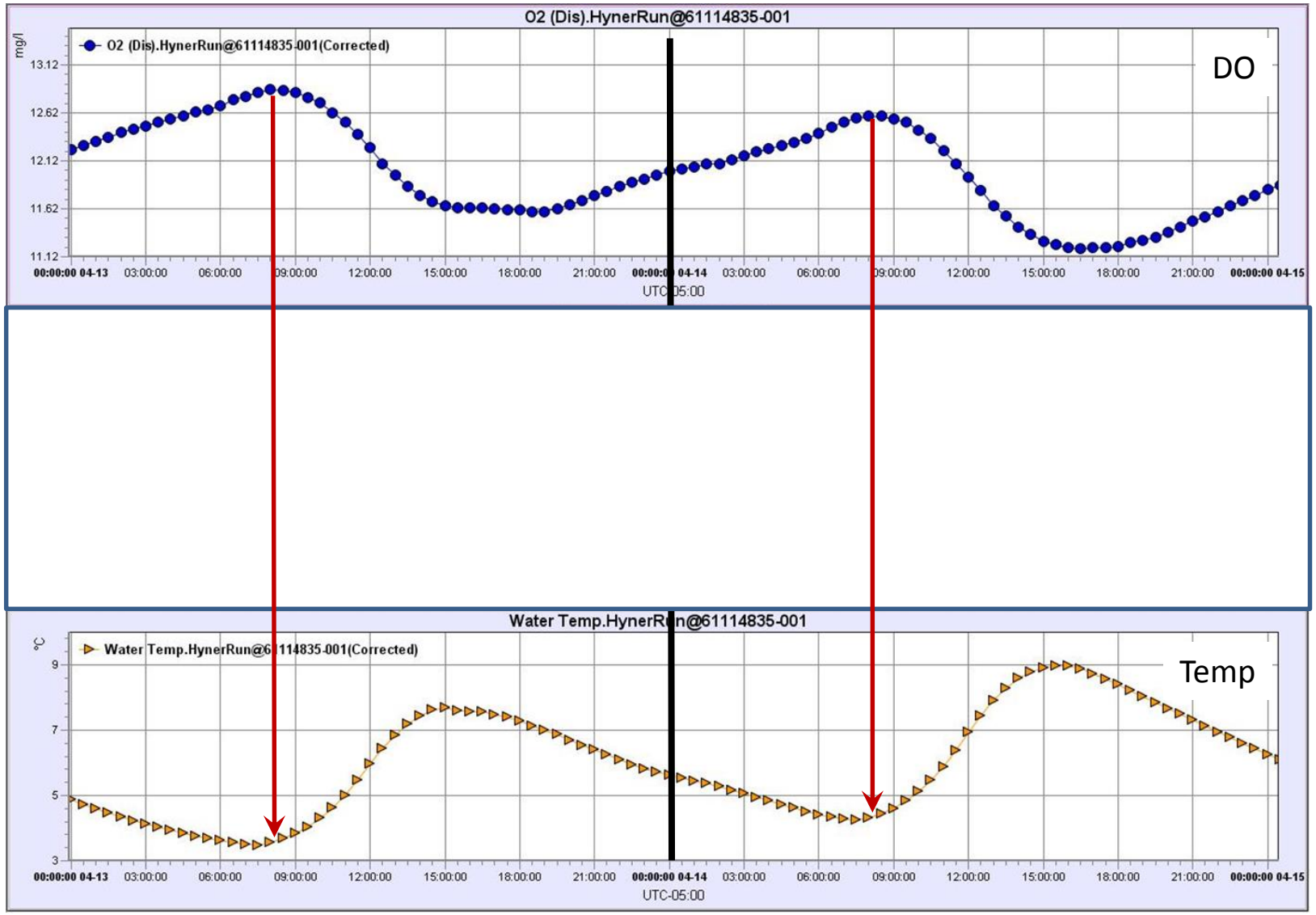
Time of Diel DO Max Hyner Run (Oligotrophic)



Hyner Run 2016 Clinton Co

- Time of Max DO = Min Temp
- DO Swings Driven by Temp Not Photosynthesis
- **<u>Predominantly Heterotrophic</u>** Organic Matter (Energy) from Outside Source Not Photosyn

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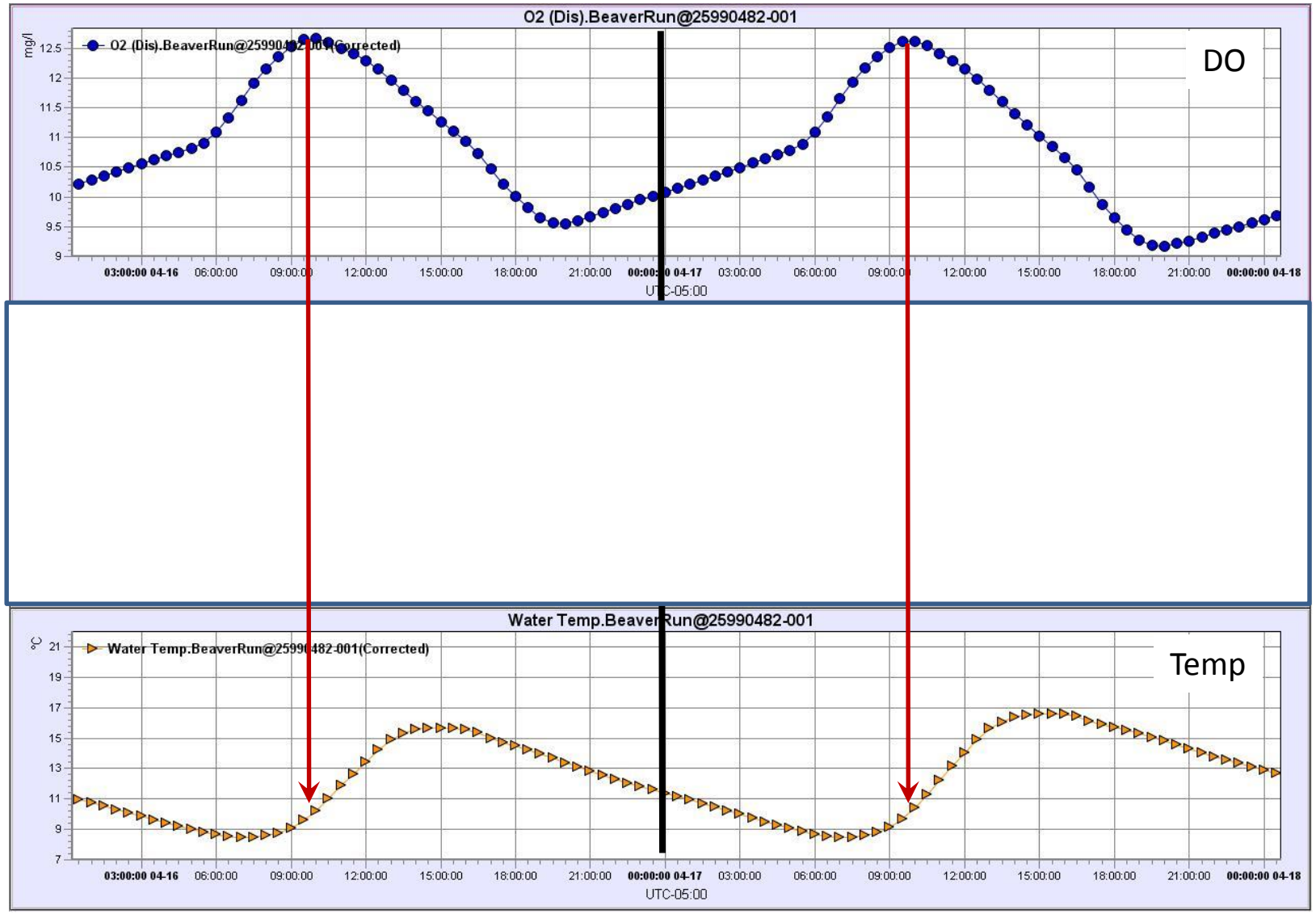
Time of Diel DO Max Beaver Run (Mesotrophic)



Beaver Run 2016 Chester Co

- Time of Max DO 2-3 Hours After Min Temp
- DO Swings Driven by Photo-synthesis and Water Temp
- **Predominantly Autotrophic** Organic Matter (Energy) from Photosynthesis

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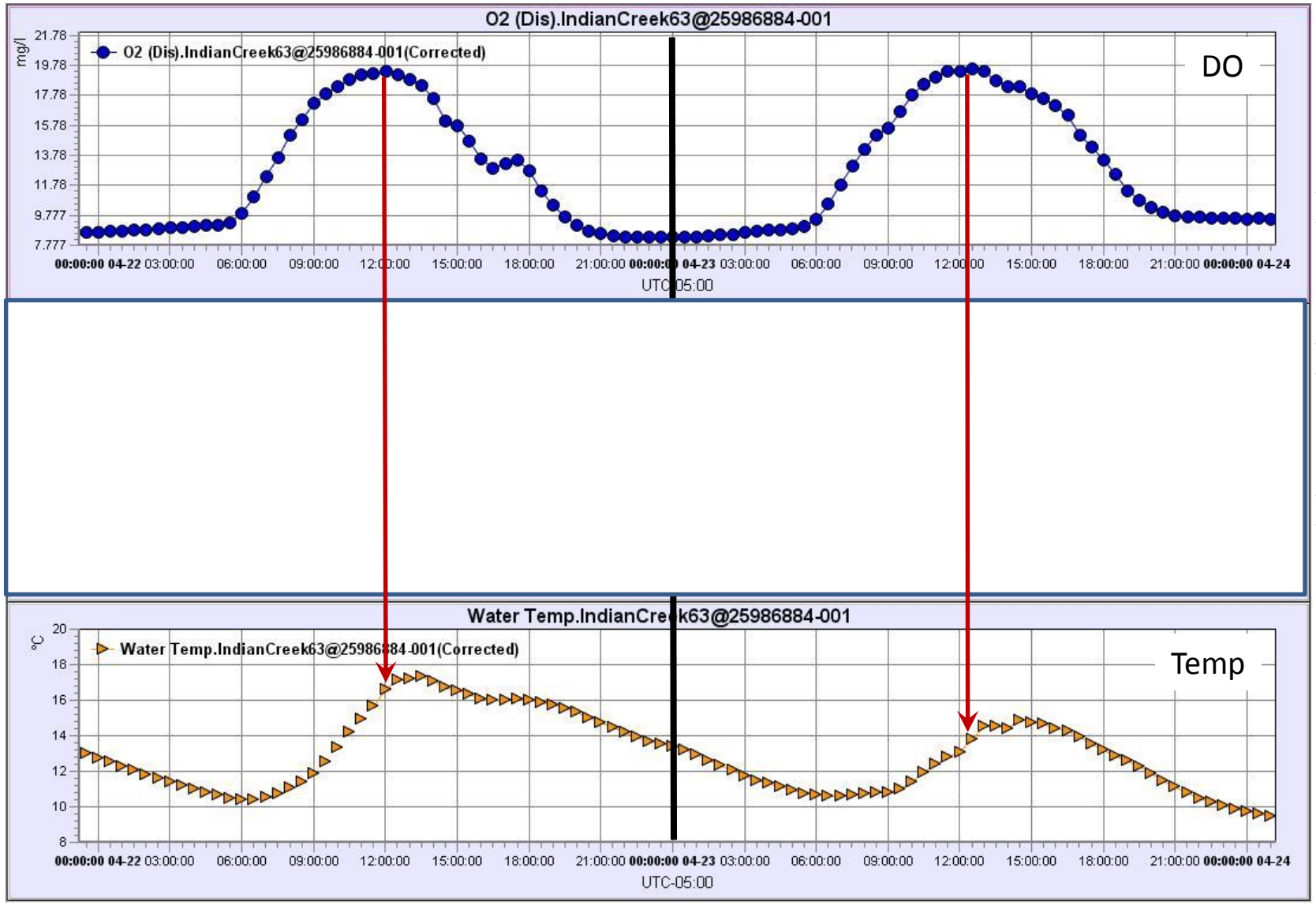
Time of Diel DO Max Indian Cr (Rt 63) (Eutrophic)



Indian Cr (Rt 63) 2014 Montgomery Co

- Time of Max DO Close to Time of Max Temp (Min Solubility)
- Excessive DO Swings Driven by Photosynthesis
- Autotrophic : Eutrophic

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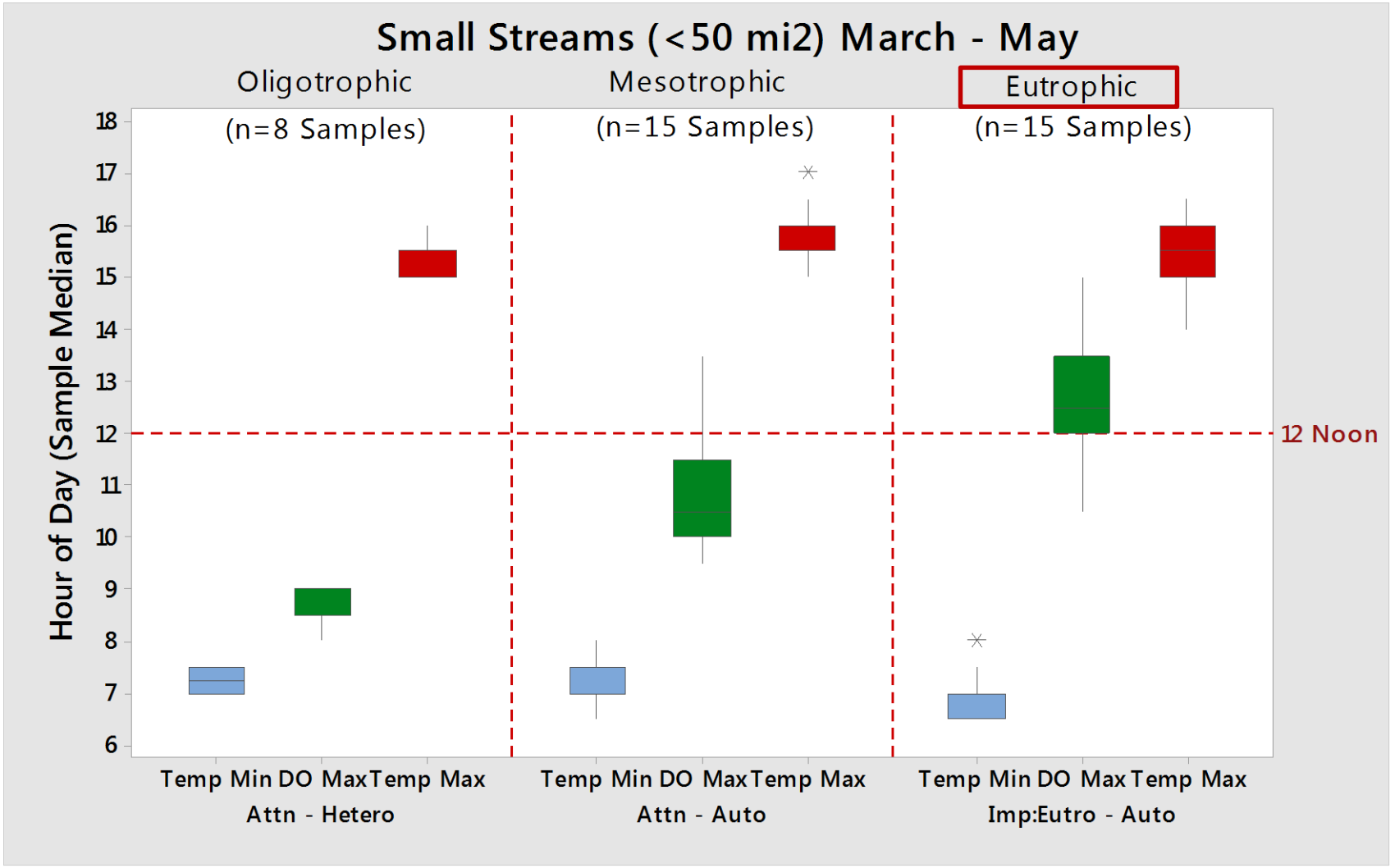
Time-of-Day of Max DO by Trophic Status (Small Streams)



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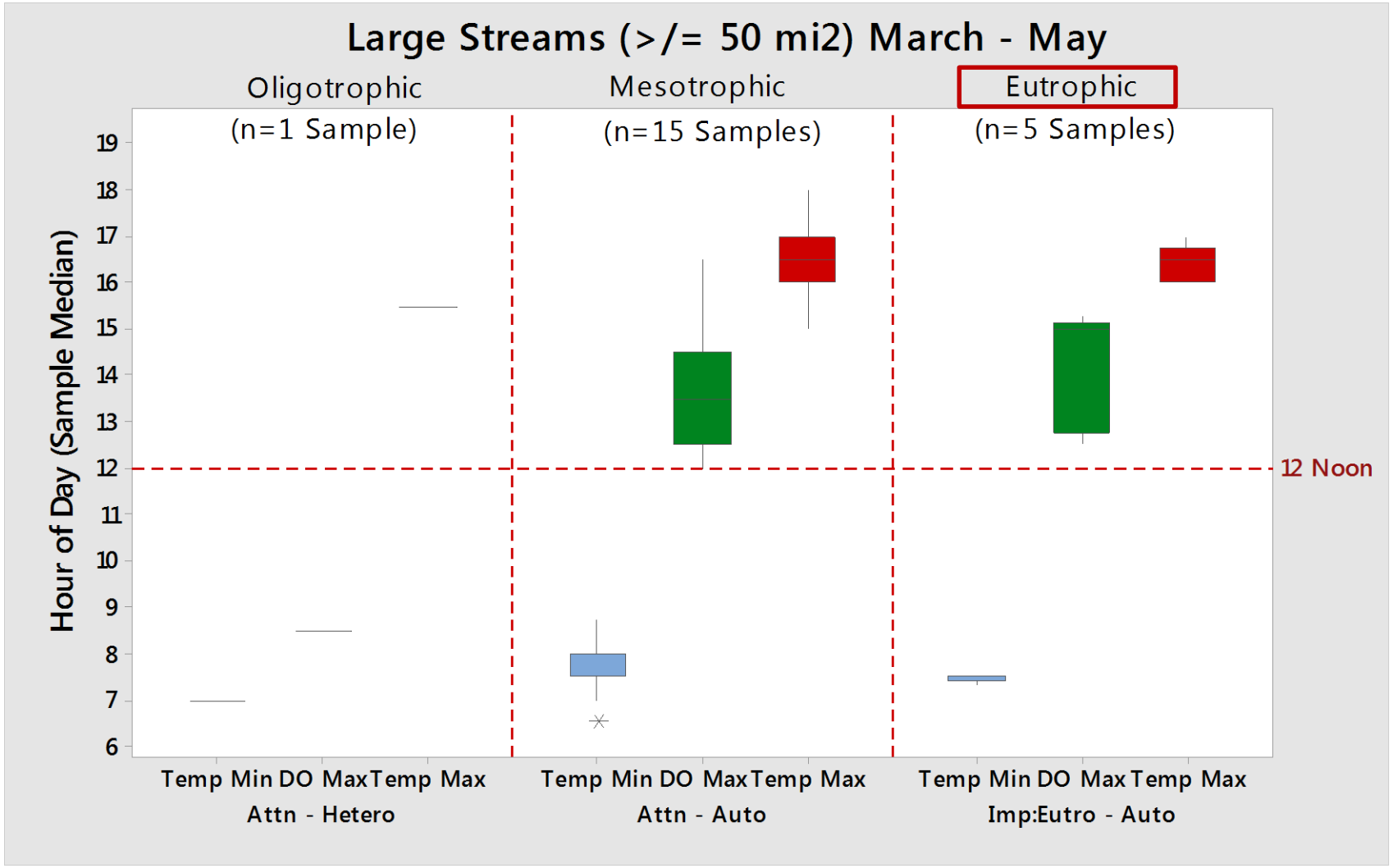
Time-of-Day of Max DO by Trophic Status (Large Streams)



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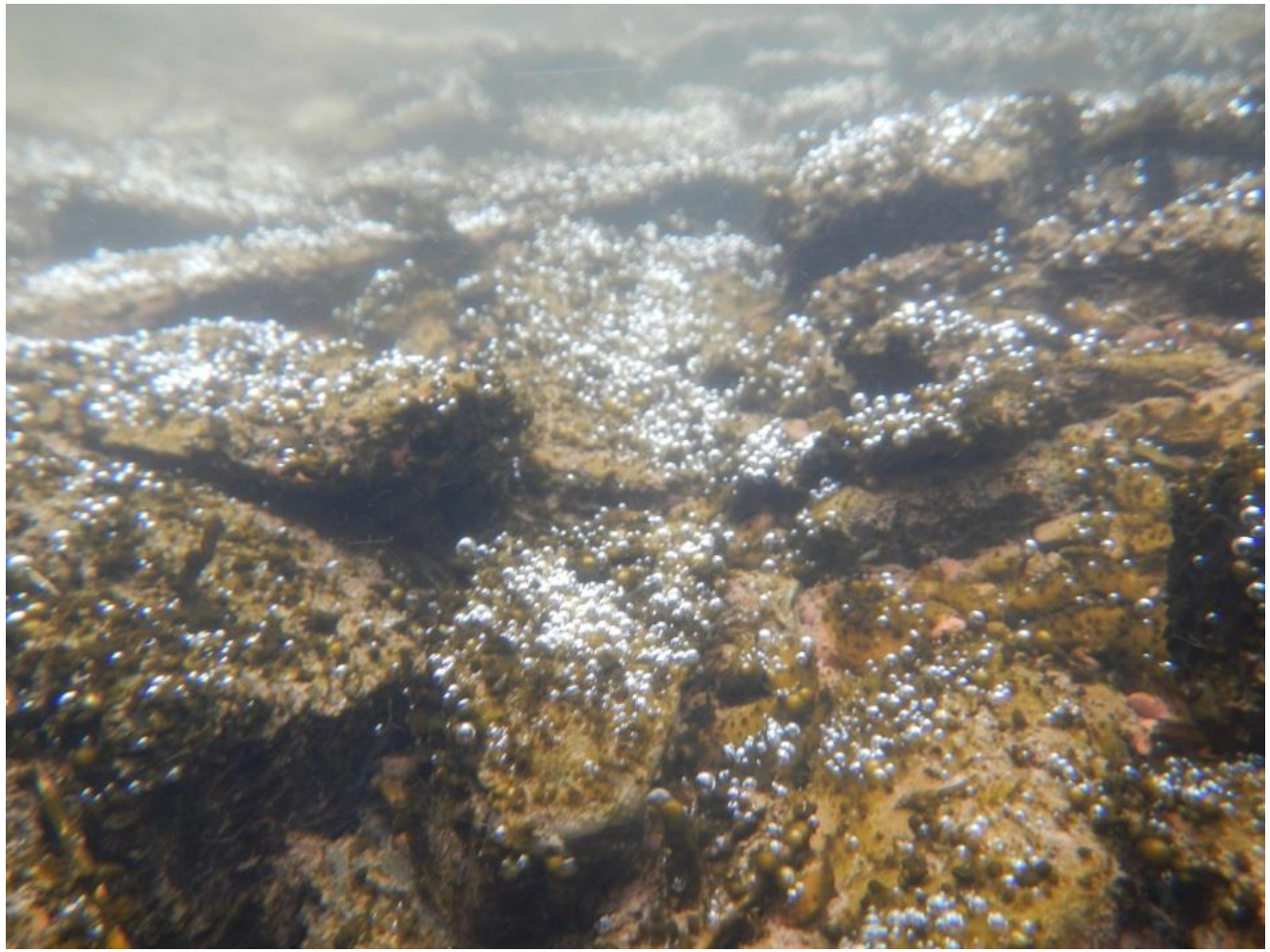
Second Critical Assumption of the Protocol



- Excessive Diel DO Swings Indicate that:
  - Degraded Ecosystem Health is Linked to Nutrient Enrichment and the Eutrophication Process
- Land Use, Nutrient, Benthic Chl-a, and Benthic Macroinvertebrate IBI Data Support this Assumption

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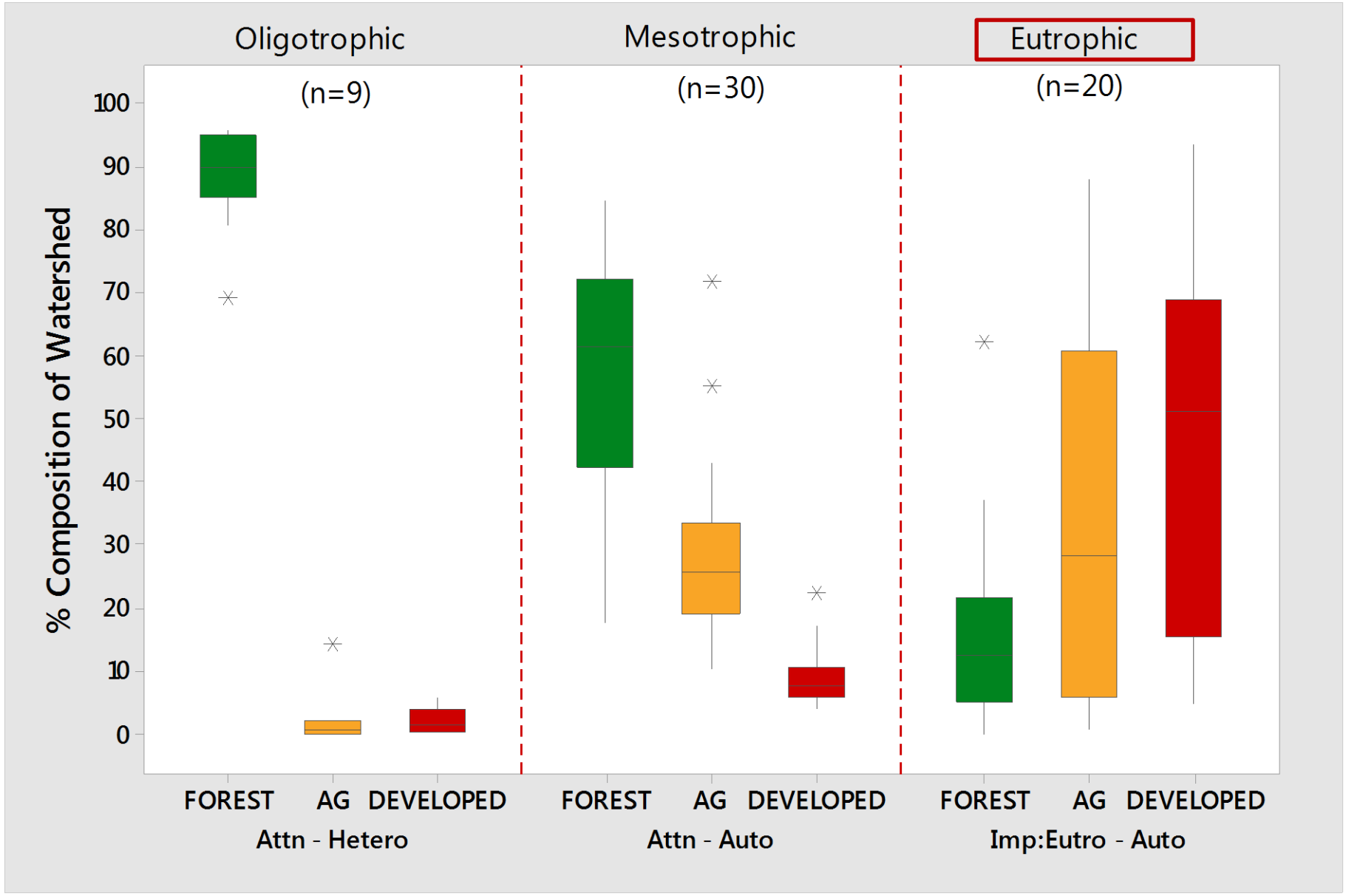
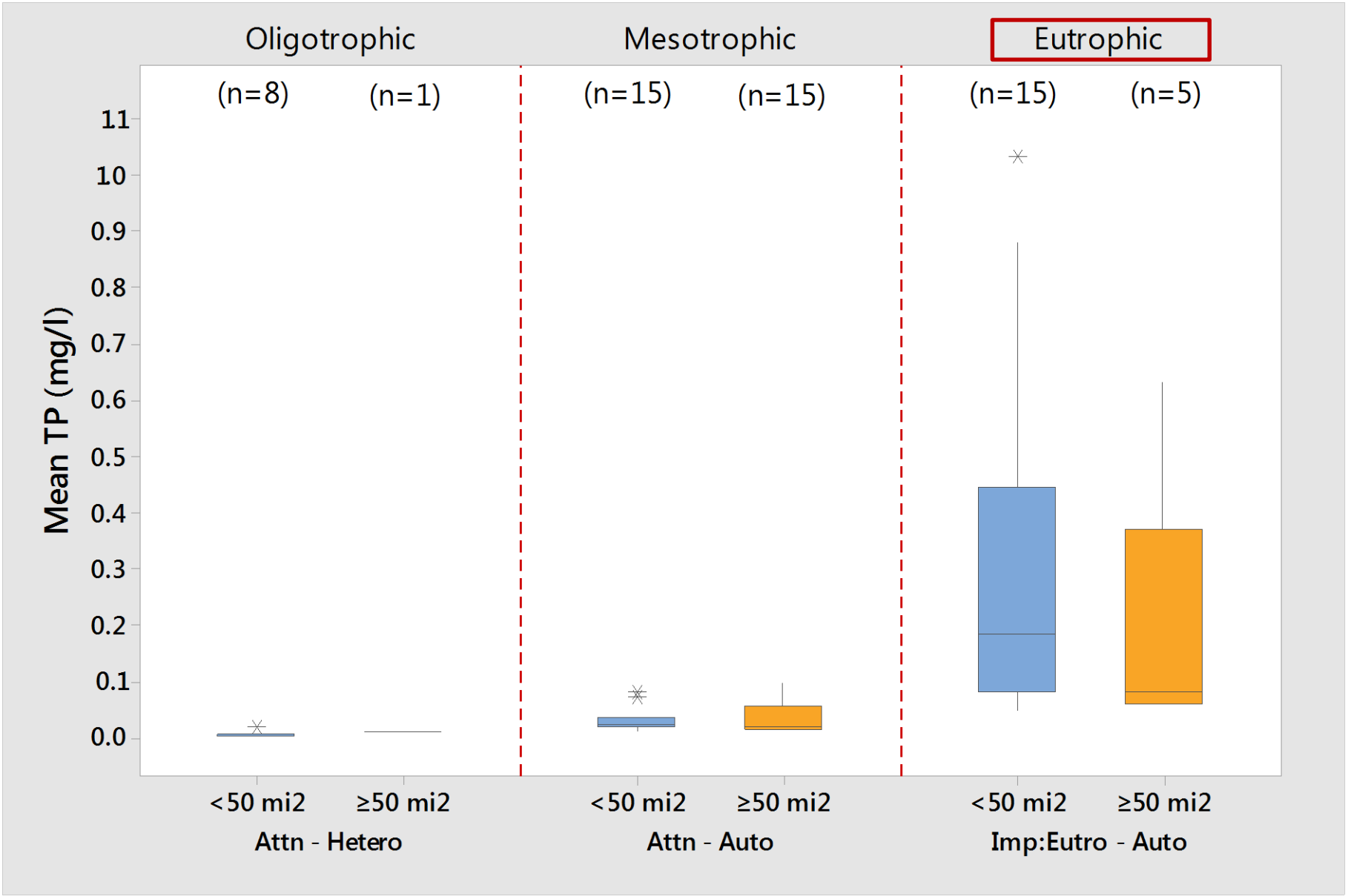
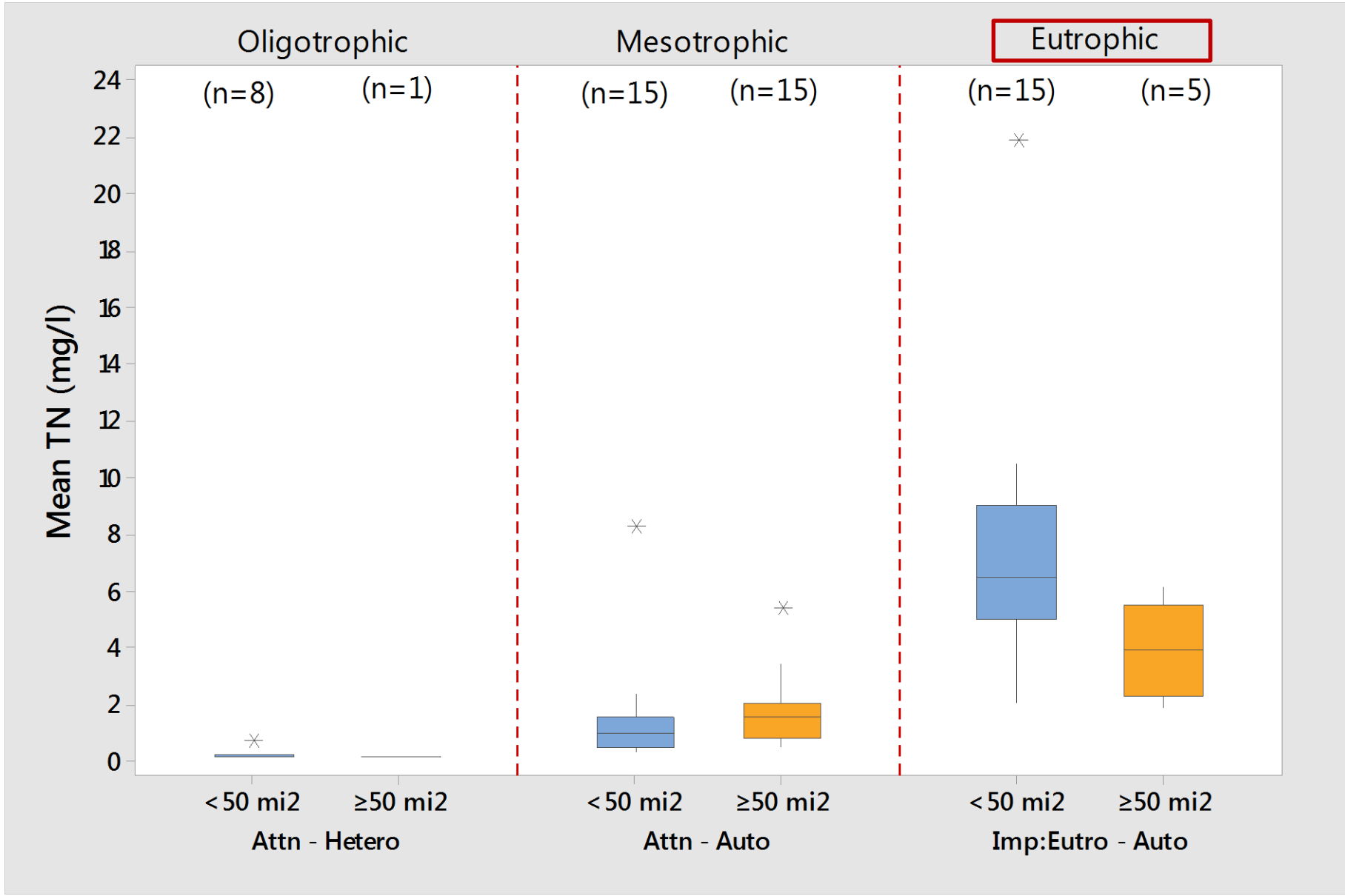
Land Use Composition by Trophic Status (Small & Large Streams)



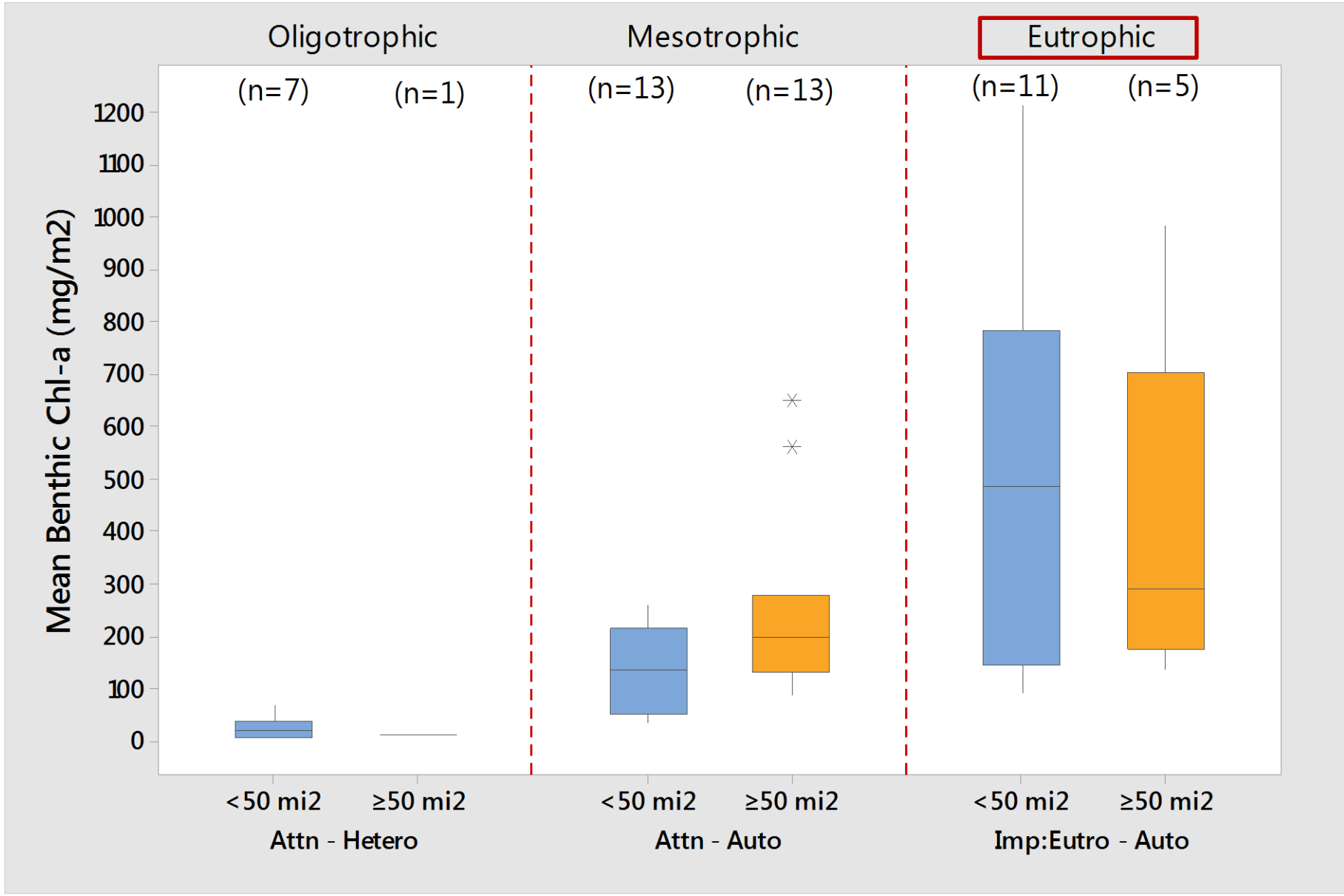
Mean Total Phosphorus by Trophic Status



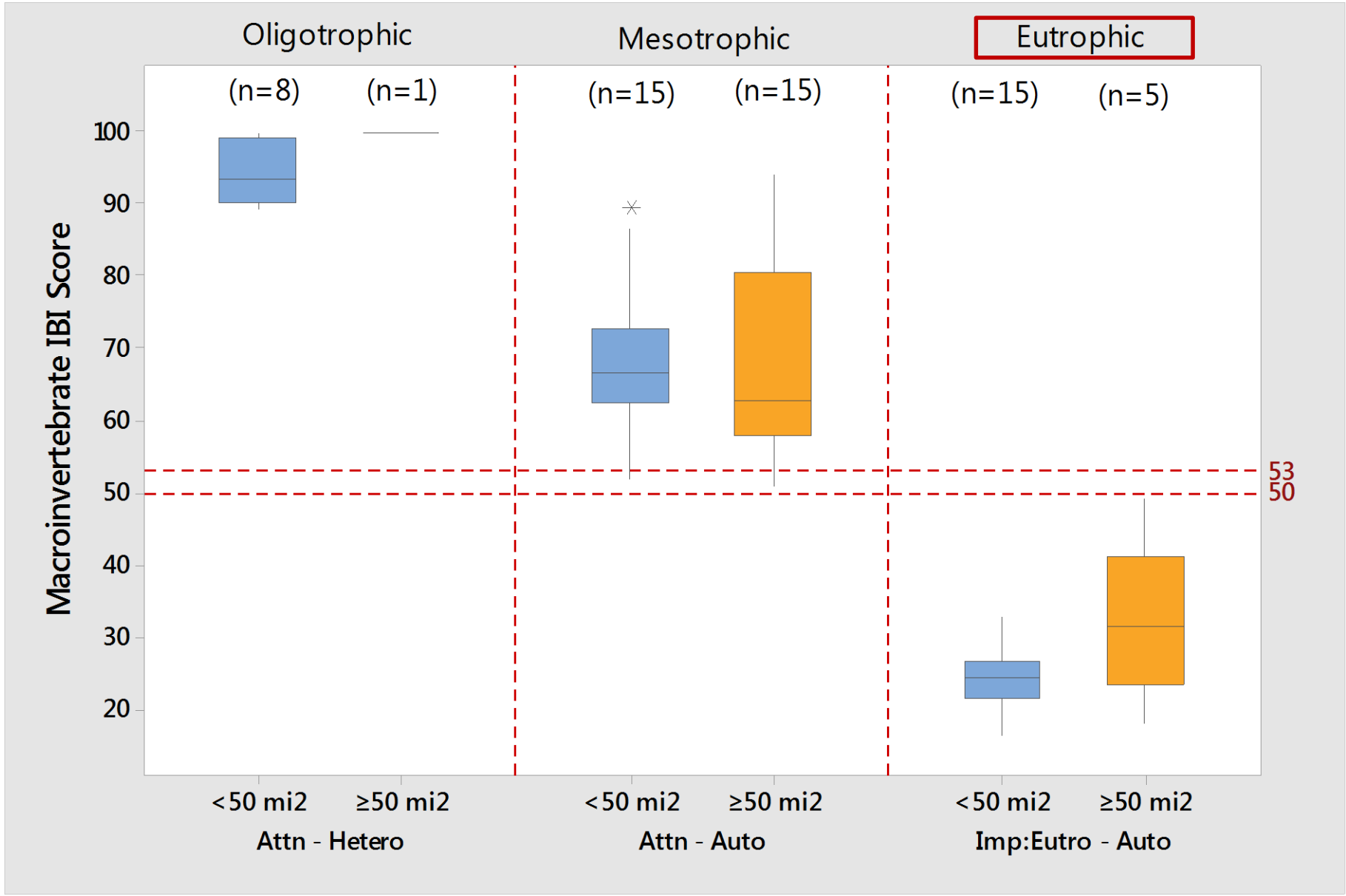
Mean Total Nitrogen by Trophic Status



Mean Benthic Chlorophyll-a by Trophic Status



Macro IBI Score by Trophic Status



Summary

- Protocol Uses Diel DO Swings as an Indicator of Stream Photosynthesis & Ecosystem Respiration Rates
- Excessive Diel DO Swings Indicate the Eutrophication Process has Substantially Altered Stream Metabolic Conditions and Eutrophication Is Identified as A Cause of ALU Impairment
- The Results of the Protocol are Supported by Analysis of :
  - DO-pH and DO-Temp Relationships
  - Time-of-Day of Max DO
  - Mean Benthic Chl-a, TP, TN Values
  - Watershed Land Use Composition

Questions

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