Dissolved Oxygen Dynamics in the Upper Suwannee River Basin

George Vellidis

Who Am I?

- Professor of Biological & Agricultural Engineering
- Located at University of Georgia’s Tifton Campus

Research Partners

- University of Georgia
  - Catherine Pringle, Richard Carey, Jason Todd, Andrew Mehring – Institute of Ecology
  - Gary Hawkins, Anna Cathey, Barb Crompton – Biological & Agricultural Engineering
- USDA-ARS Southeast Watershed Research Laboratory
  - Richard Lowrance, David Bosch, Joe Sheridan
- Georgia DNR – Environmental Protection Division
  - Roy Burke

Acknowledgements

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  - by Hatch and State funds allocated to the Georgia Agricultural Experiment Stations,
  - and by USDA-ARS CRIS project funds.

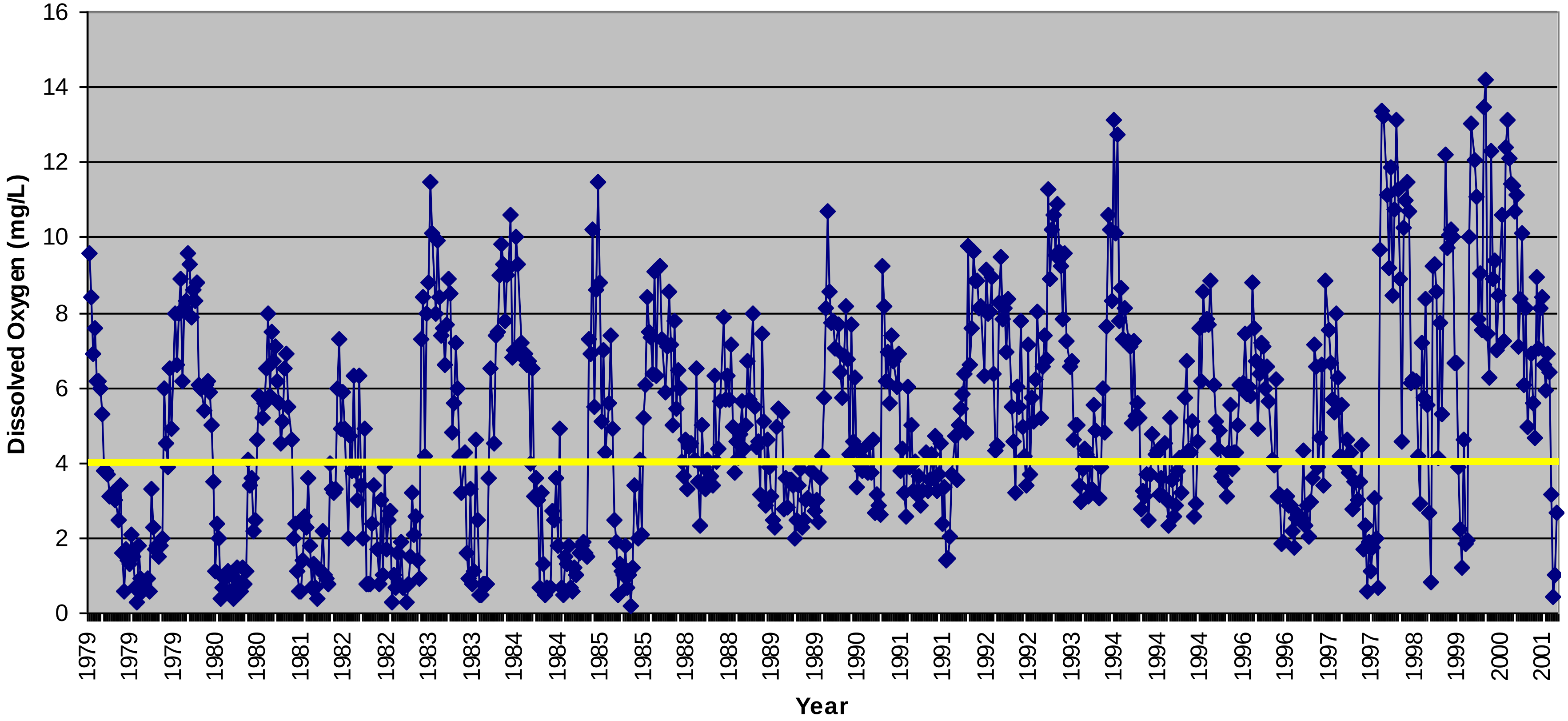
Presentation Summary

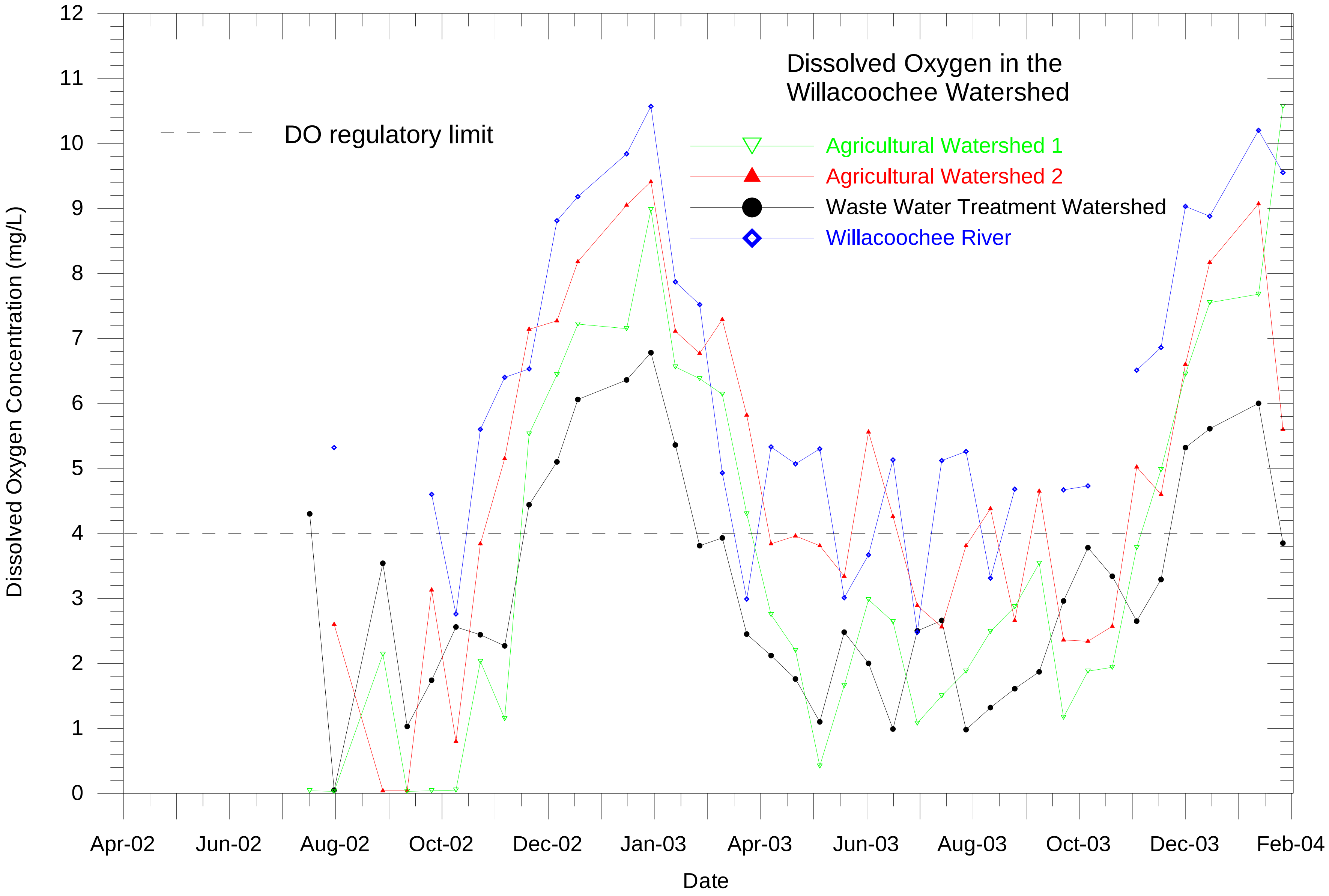
- Summary of dissolved oxygen issues
- Description of research project
- Conclusions

Why is Dissolved Oxygen an Issue?

- Coastal plain streams have DO below standards
  - 4 mg/L
  - Is this standard reasonable?
  - What is DO in minimally impacted streams?

Little River Watershed DO




Dissolved Oxygen in the
Willacoochee Watershed
DO regulatory limit
Agricultural Watershed 1
Agricultural Watershed 2
Waste Water Treatment Watershed
Willacoochee River
Dissolved Oxygen Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
Apr-02
Jun-02
Aug-02
Oct-02
Dec-02
Jan-03
Apr-03
Jun-03
Aug-03
Oct-03
Dec-03
Feb-04
Date

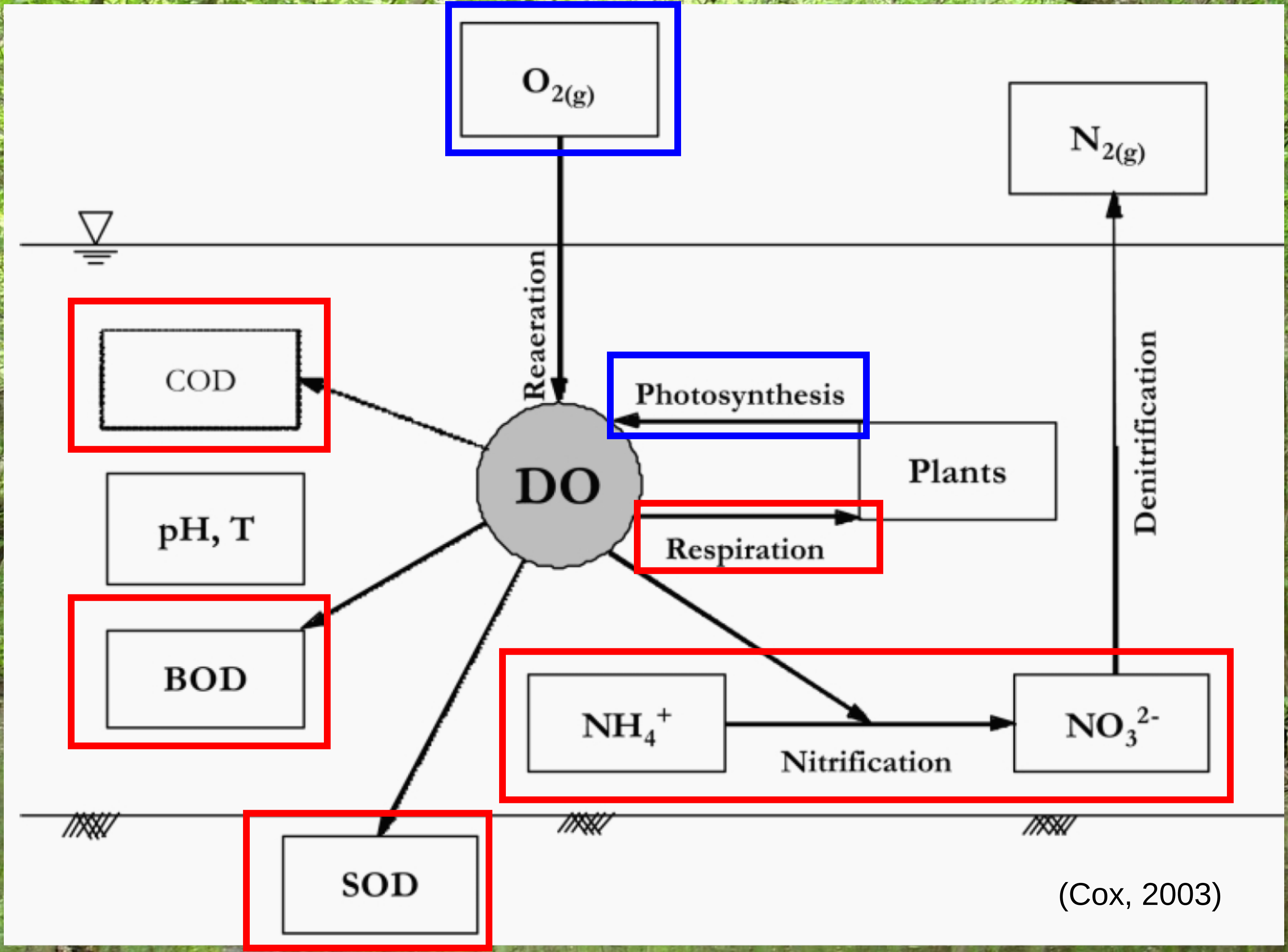
DO and TMDLs


GEORGIA
Alapaha
Little
Satilla River Basin
Suwannee River Basin
St. Marys River Basin
Ochlockonee River Basin
Withlacoochee
Upper Suwannee
FLORIDA
N
W
E
S
20
0
20 Miles


OCHLOCKONEE
SUWANNEE
SATILLA
ST. MARYS

Project Objectives

- To determine the causes and effects of low dissolved oxygen in the rivers, streams, and wetlands of the Suwannee River Basin
- To train and educate stakeholders about these issues and the effect that their actions have on dissolved oxygen


$O_{2(g)}$
$N_{2(g)}$
Reaeration
Denitrification
COD
Photosynthesis
DO
Plants
pH, T
Respiration
BOD
NH_4^+
Nitrification
NO_3^{2-}
SOD

(Cox, 2003)

Ecological Processes

- Understand ecological processes governing DO dynamics in coastal plain streams
    - nutrient enrichment / primary production
    - sediment oxygen demand (SOD)
    - role of in-stream wetlands and swamps
    - simulate DO dynamics

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Nutrient Enrichment / Primary Production

- Determine enrichment state of 3 watershed types
- Passive diffusion periphytometer (PDP) to measure algal response to nutrient enrichment
- Project completed

Richard Carey – Ecology M.S. Student

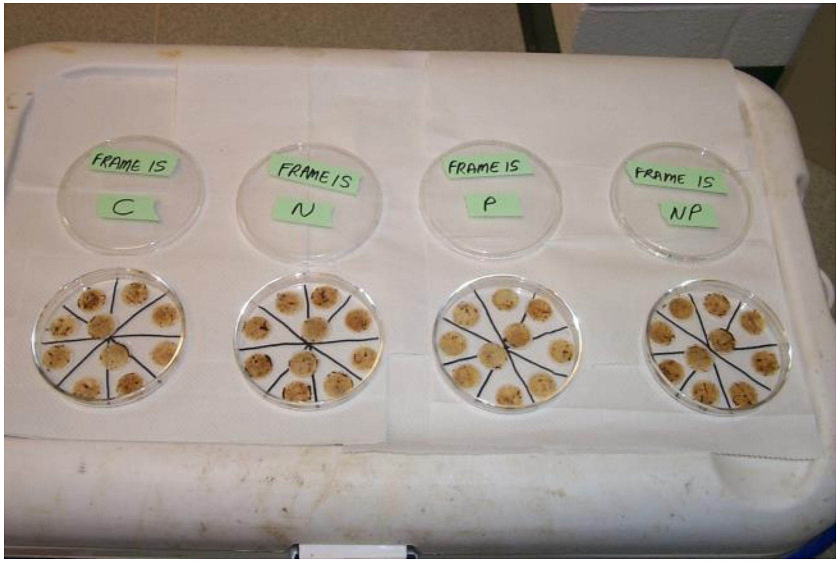
Carey, Richard O., George Vellidis, Richard Lowrance, and Catherine M. Pringle, 2007. Do Nutrients Limit Algal Periphyton in Small Blackwater Coastal Plain Streams? *Journal of the American Water Resources Association* (*JAWRA*) 43(5):1183-1193.

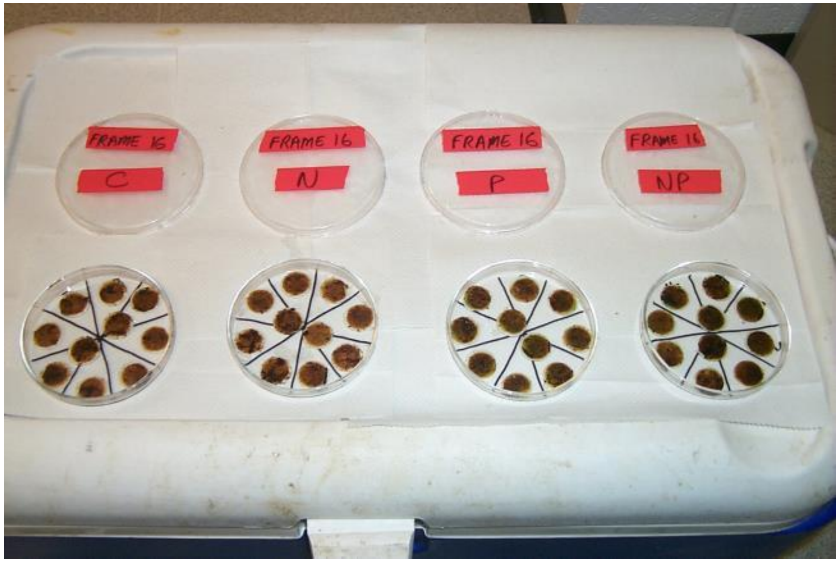

Shade
Sun

Metal rod

5 cm diameter schedule 40 PVC

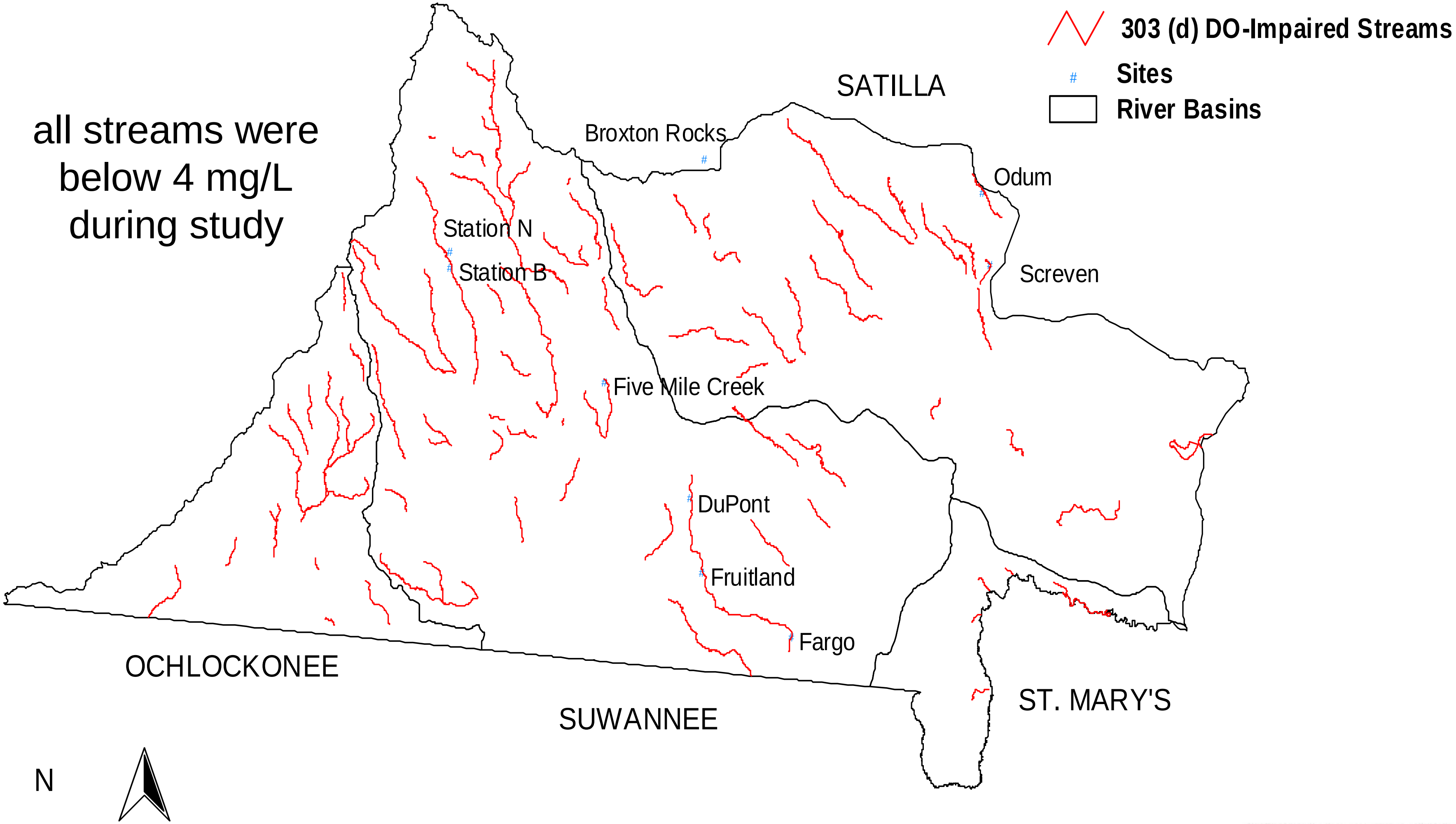
V-shaped front


FRAME 15
C
FRAME 15
N
FRAME 15
P
FRAME 15
NP

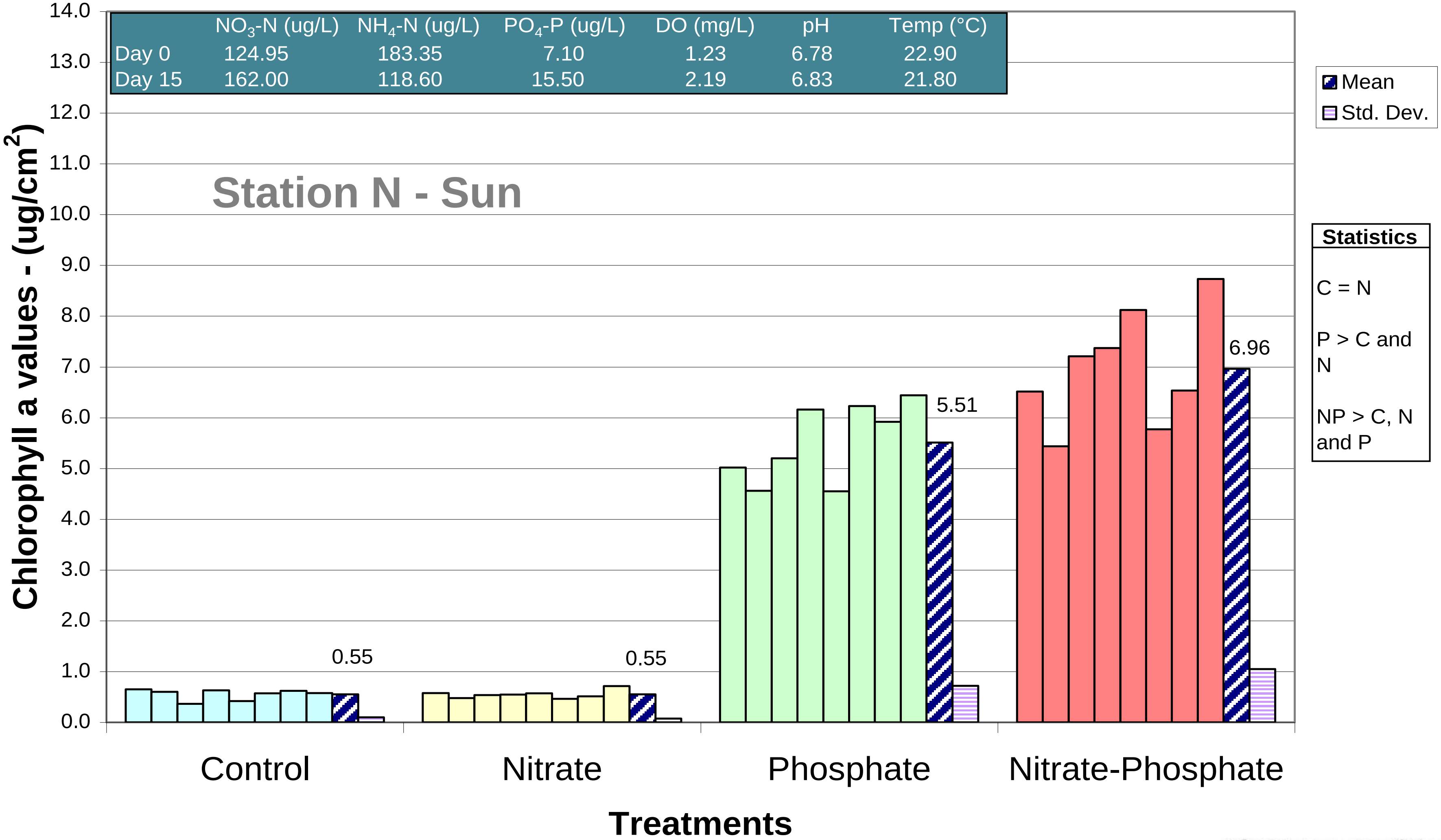

FRAME 16
C
FRAME 16
N
FRAME 16
P
FRAME 16
NP

PDP Study Sites

all streams were below 4 mg/L during study



Chlorophyll *a* Concentrations



	NO_3-N (ug/L)	NH_4-N (ug/L)	PO_4-P (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	124.95	183.35	7.10	1.23	6.78	22.90
Day 15	162.00	118.60	15.50	2.19	6.83	21.80

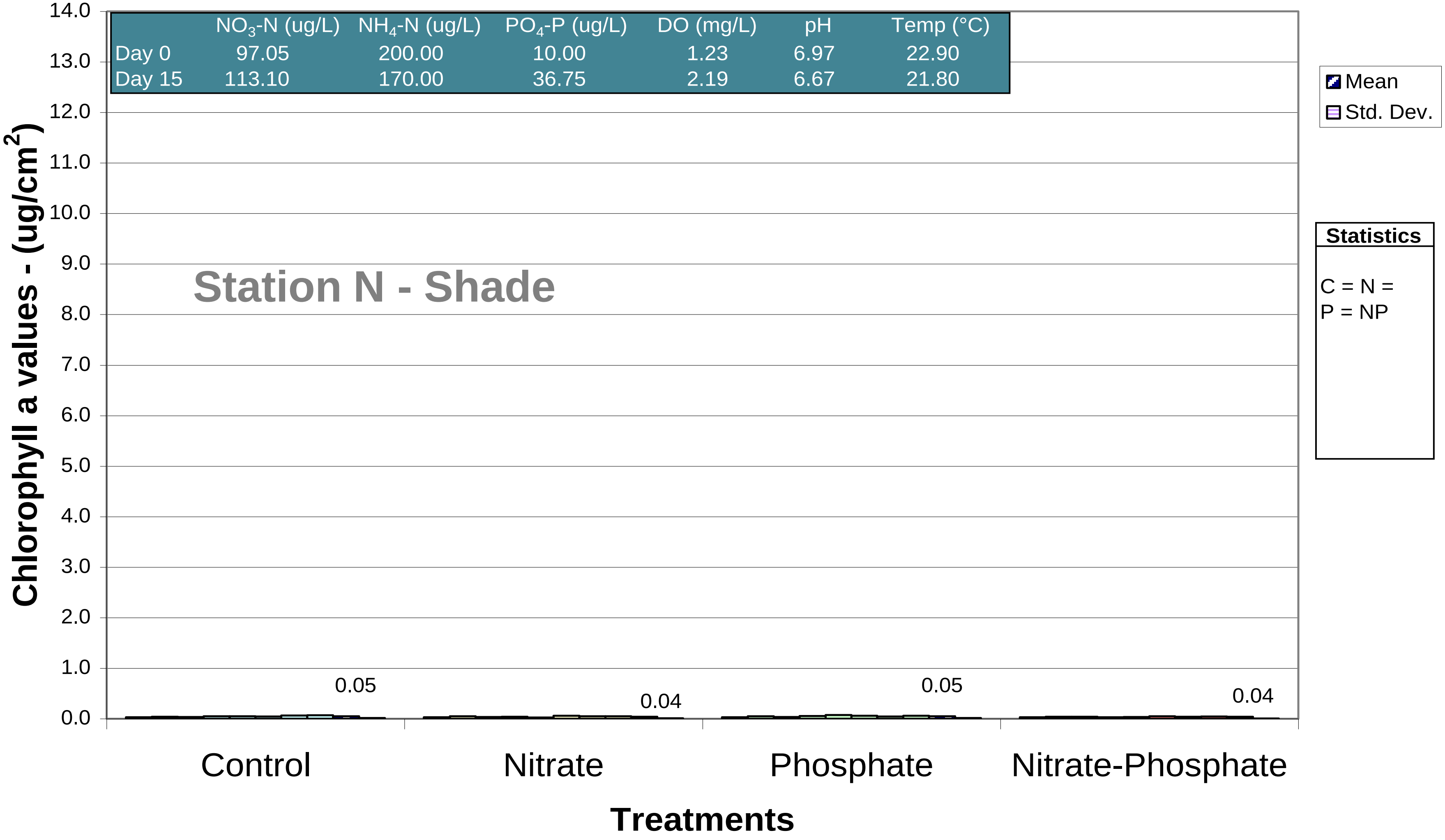
Statistics

C = N

P > C and N

NP > C, N and P

Chlorophyll *a* Concentrations

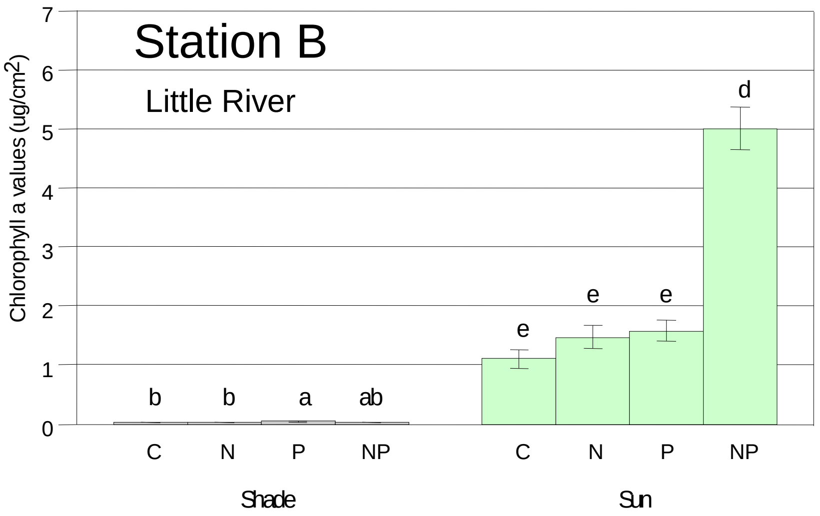


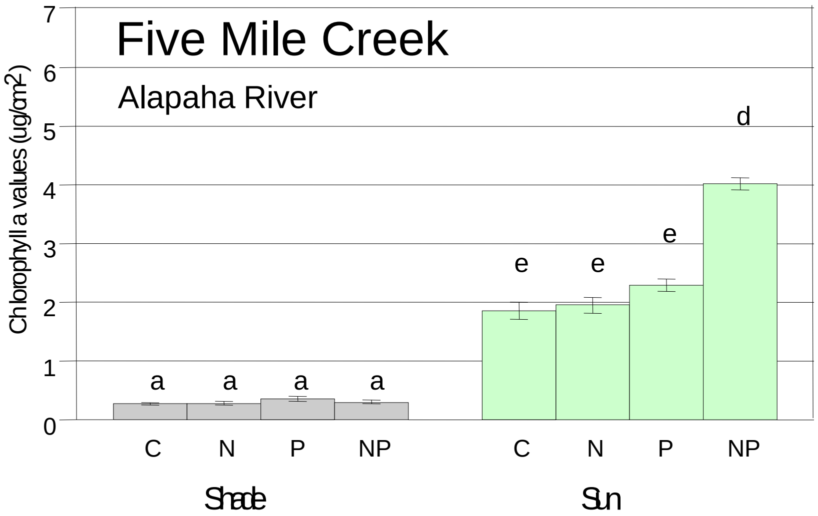
	NO_3-N (ug/L)	NH_4-N (ug/L)	PO_4-P (ug/L)	DO (mg/L)	pH	Temp (°C)
Day 0	97.05	200.00	10.00	1.23	6.97	22.90
Day 15	113.10	170.00	36.75	2.19	6.67	21.80

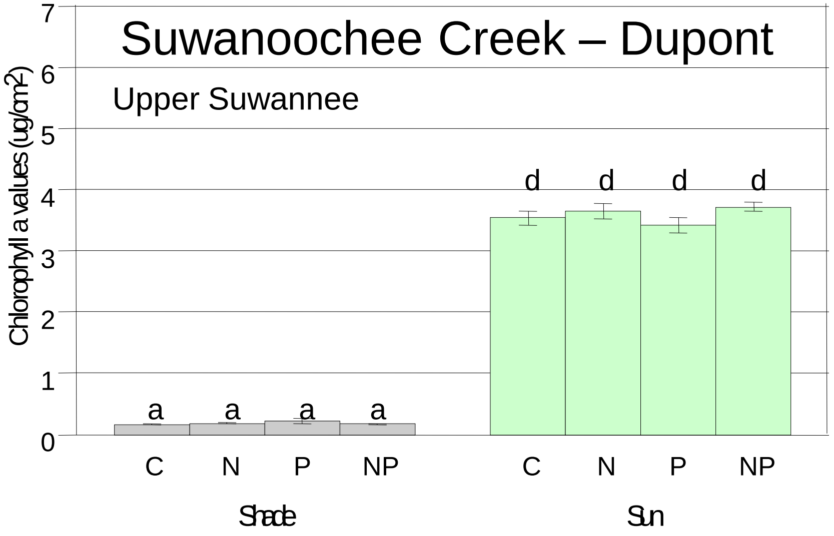
Statistics

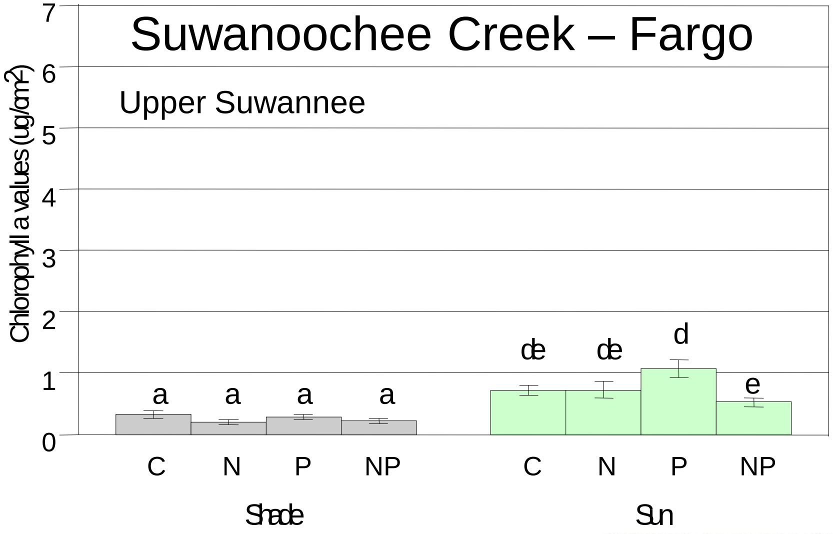
C = N =
P = NP

Chlorophyll *a* Concentrations



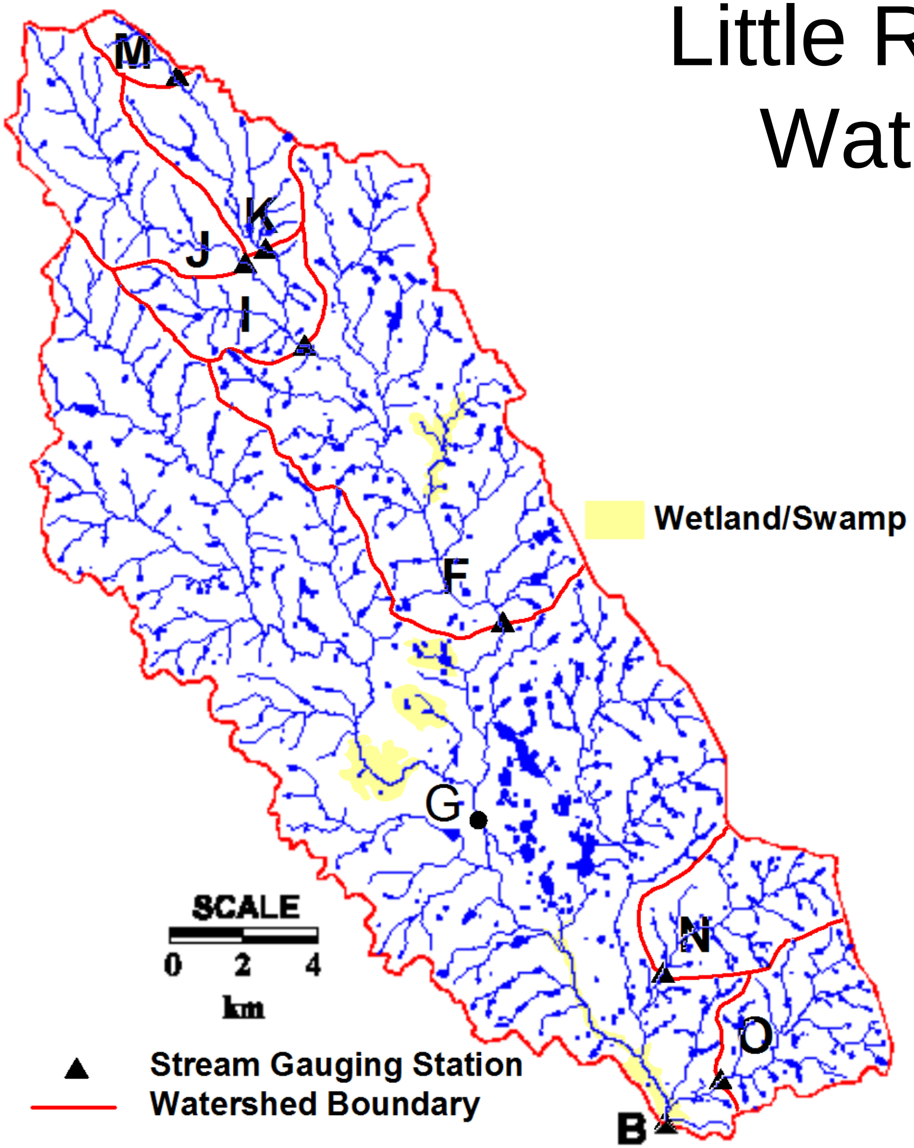




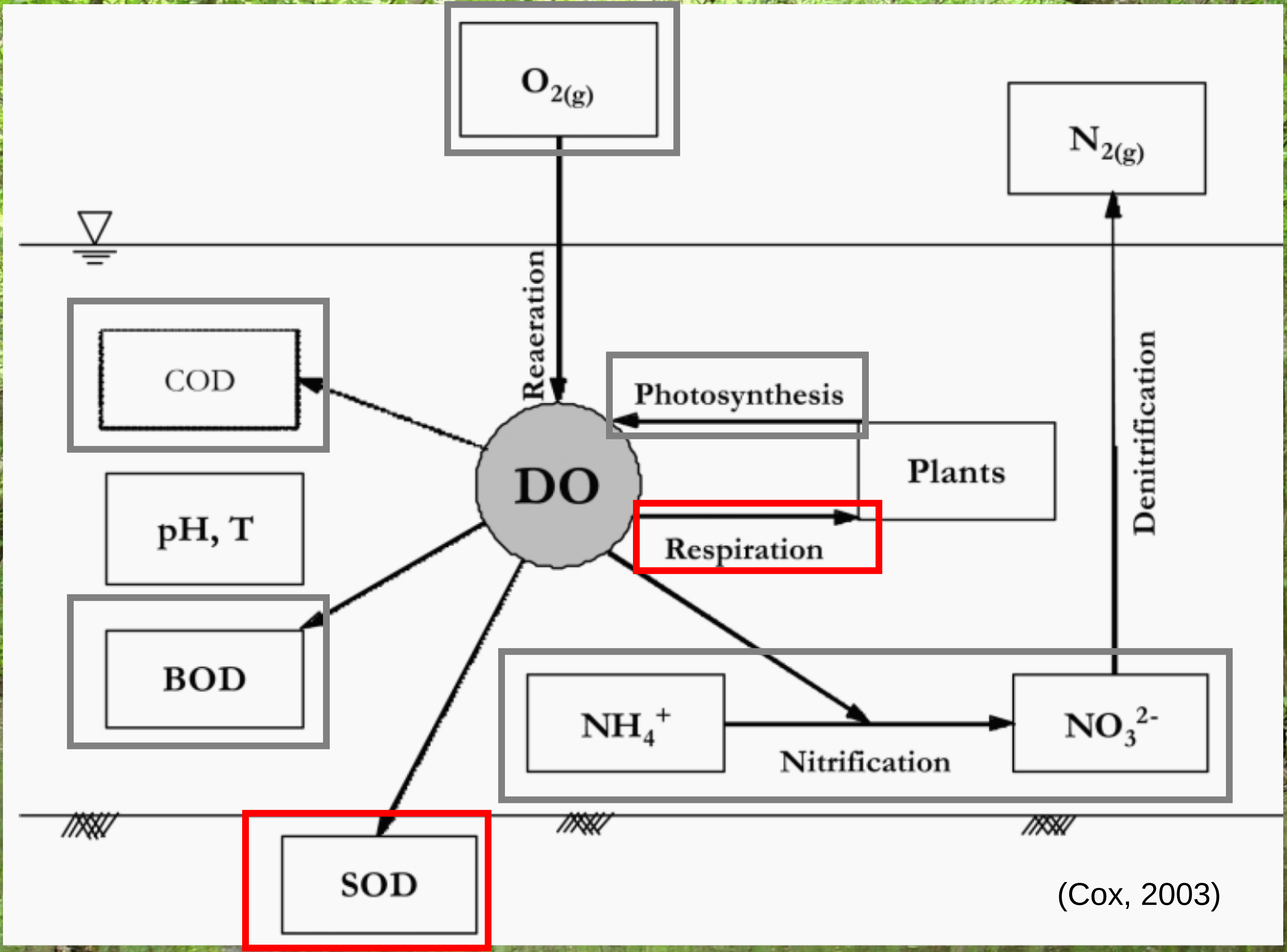


Lower 4 River Basins

Little River Experimental Watershed (LREW)



- Blackwater streams
- Low gradient
- High temperatures
- Intermittent flow
- Braided channels
- Large floodplains
- In-stream swamps


$O_{2(g)}$
$N_{2(g)}$
Reaeration
COD
Photosynthesis
DO
Plants
Respiration
Denitrification
pH, T
BOD
NH_4^+
Nitrification
NO_3^{2-}
SOD

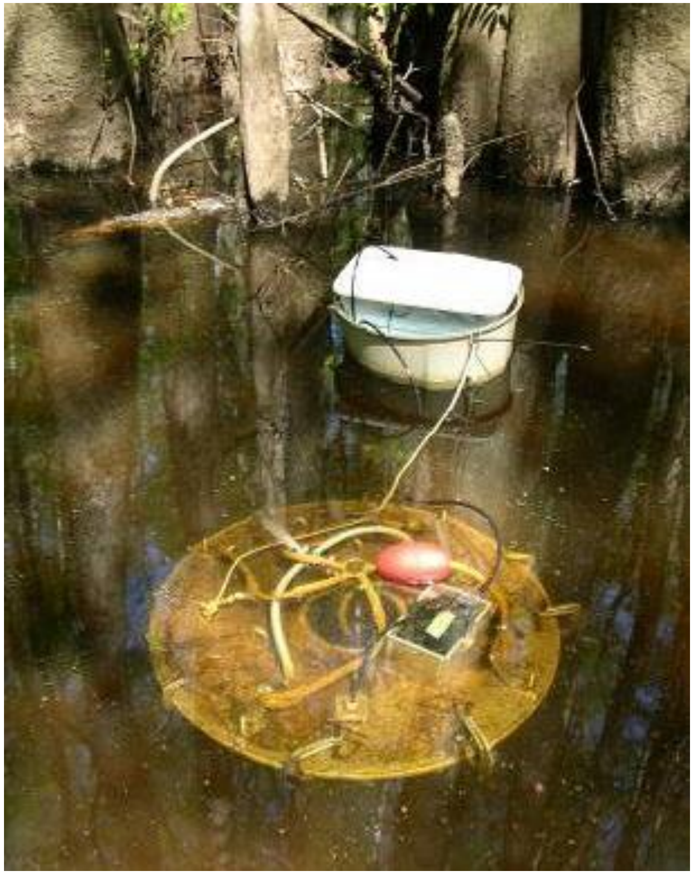
(Cox, 2003)

Sediment Oxygen Demand – SOD

- The rate at which DO is removed from the water column due to the decomposition of organic matter on the bottom and within the bottom sediments
- SOD a combination of two processes:
  - biological respiration of benthic organisms residing on the bottom or in the sediment
  - chemical oxidation of reduced substances found within the sediment matrix
- Three methods: estimation, laboratory, and *in situ* measurements

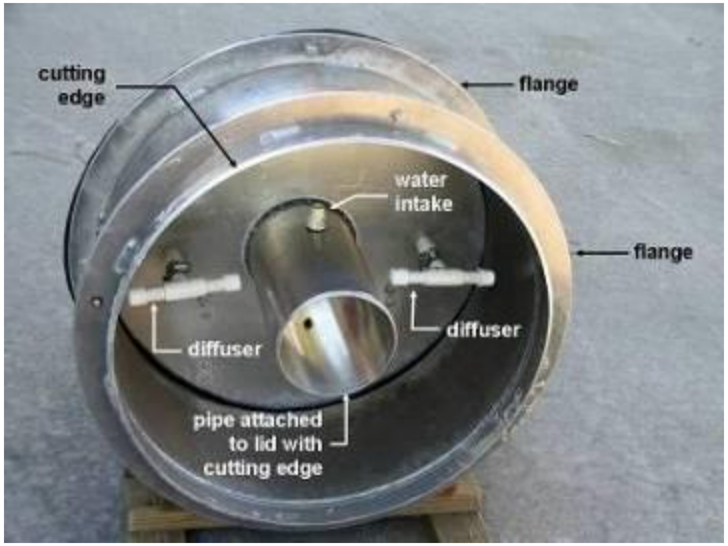
Hypotheses

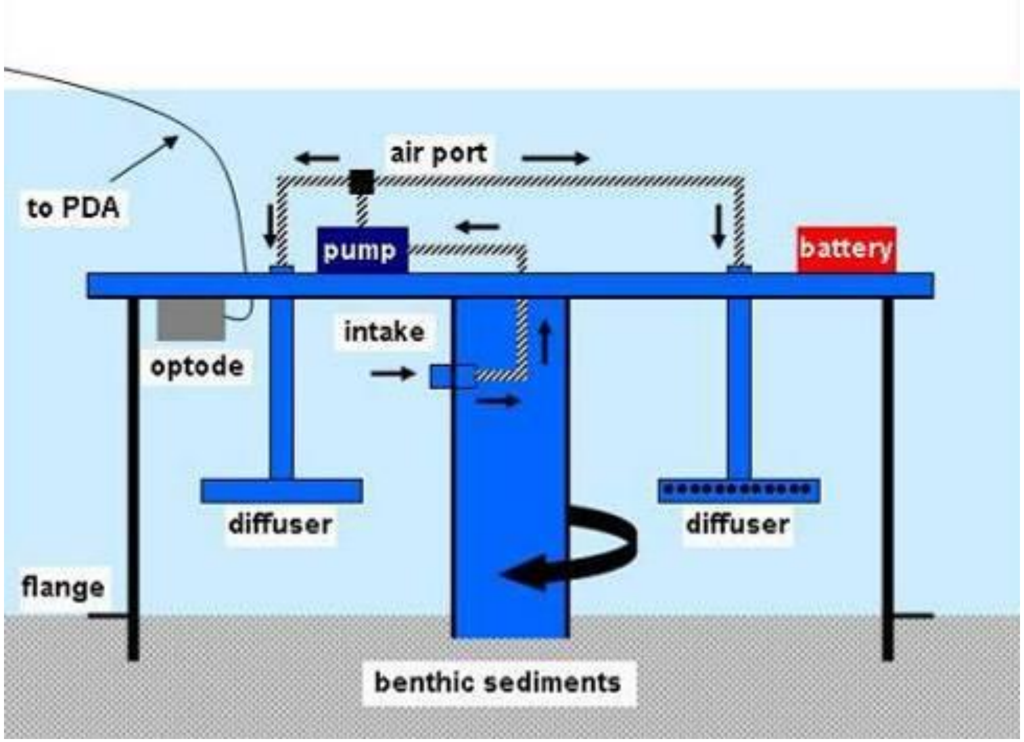
- SOD is the principal sink of DO in these swamps
- Soil organic matter is a driving factor of SOD
- Jason Todd – Ecology Ph.D. student



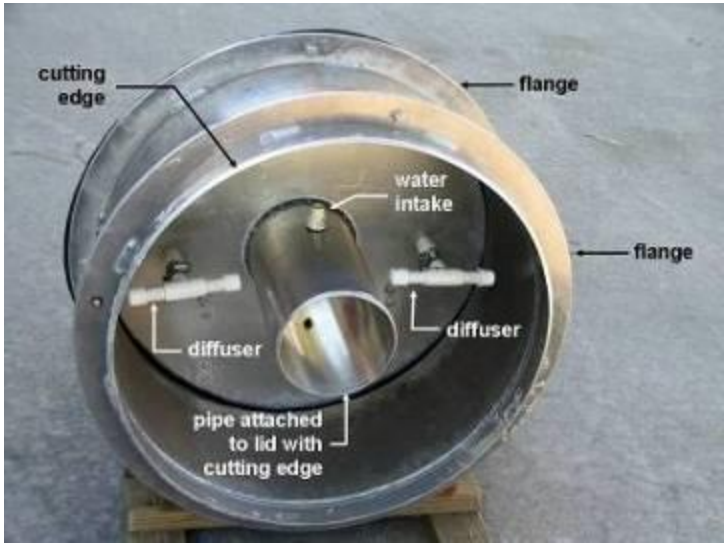
Todd, M. J., G. Vellidis, R.R. Lowrance, and C.M. Pringle. 2009. High sediment oxygen demand within an instream swamp in southern Georgia: Implications for low dissolved oxygen levels in coastal blackwater streams. *Journal of the American Water Resources Association* 45(6):1493-1507. DOI 10.1111.j.1752-1688.2009.00380.x.

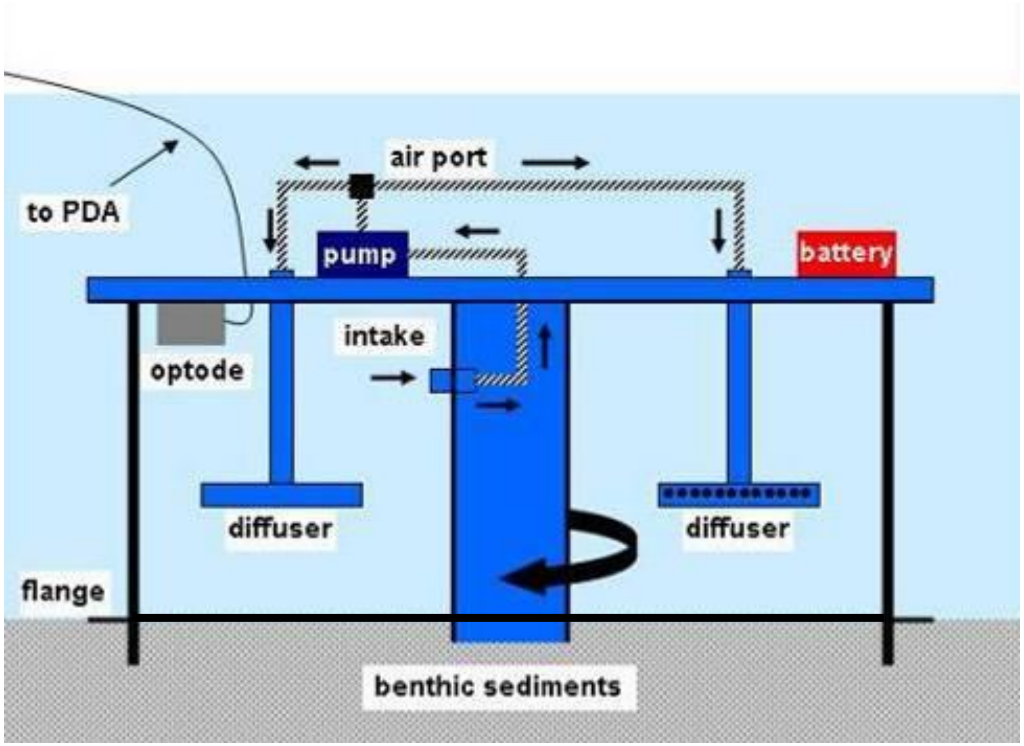
SOD Chambers



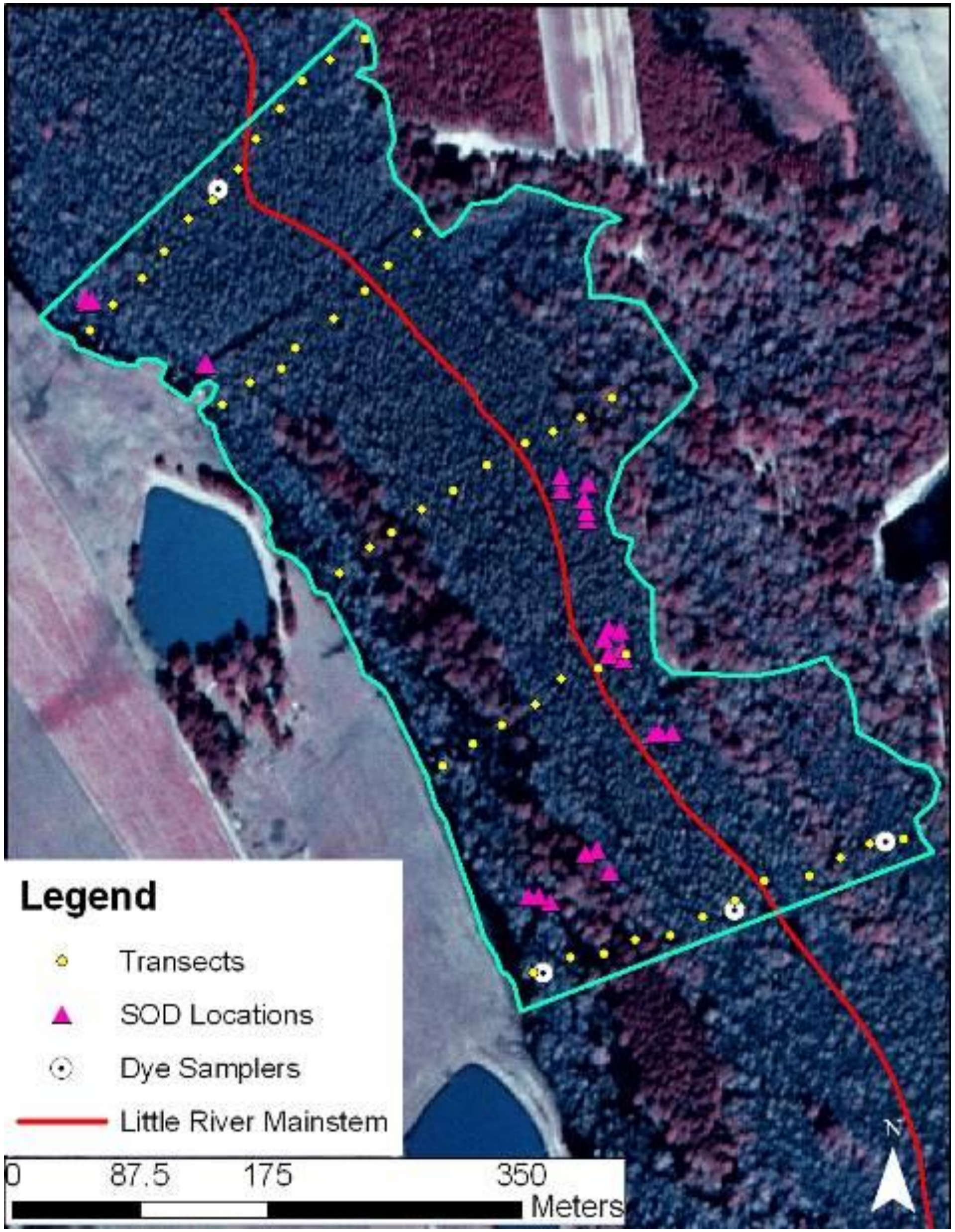


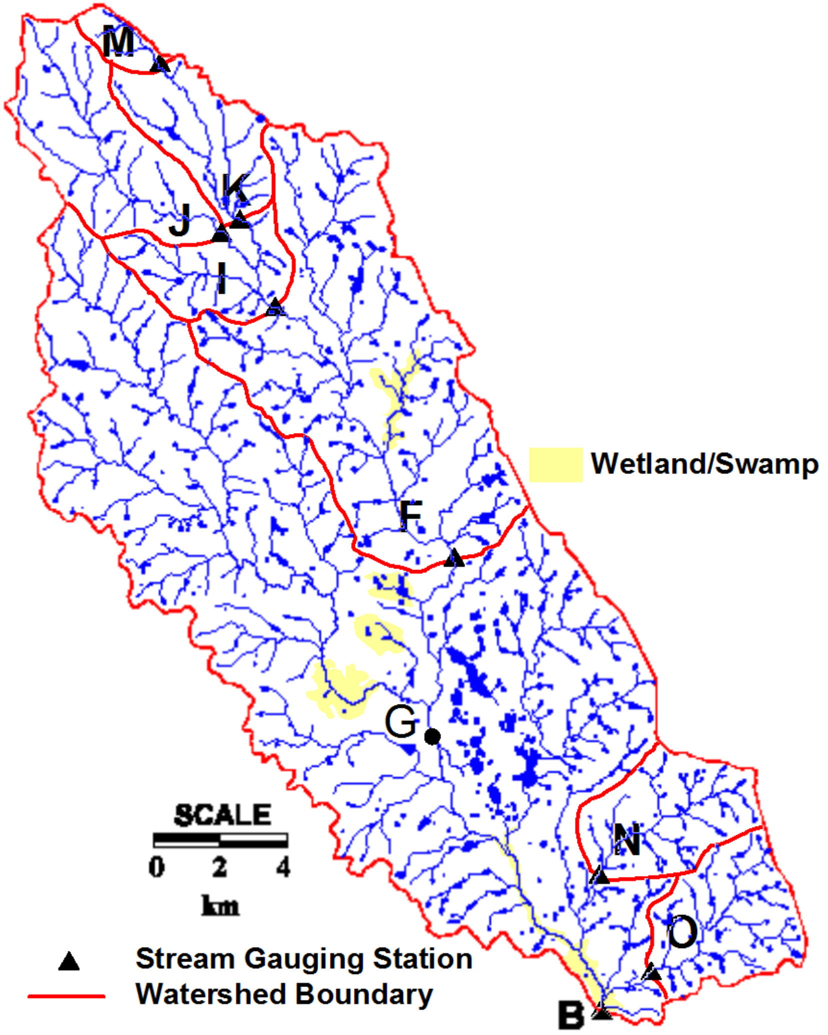
SOD Control Chamber



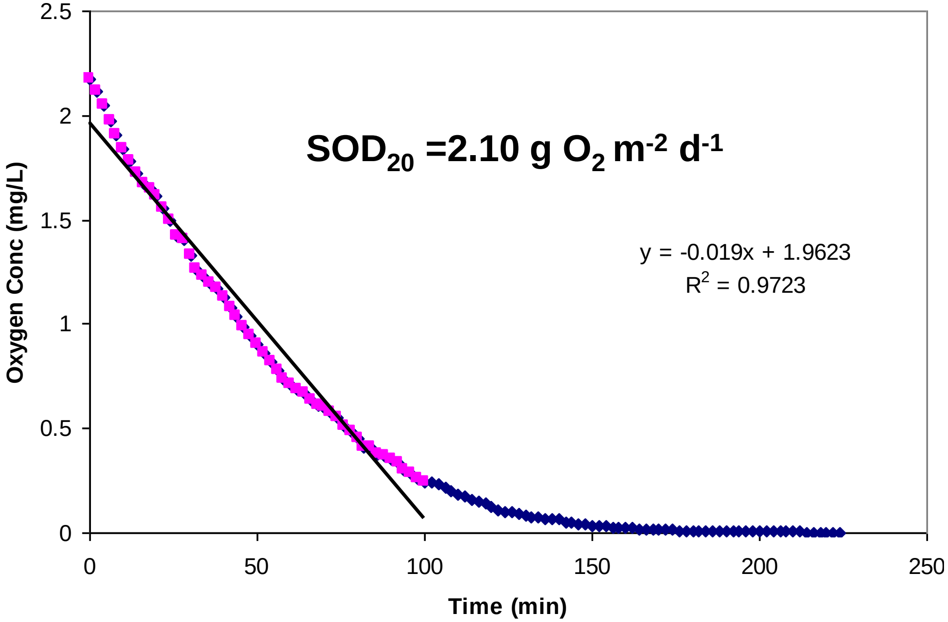



control
chamber 1
chamber 3
chamber 2

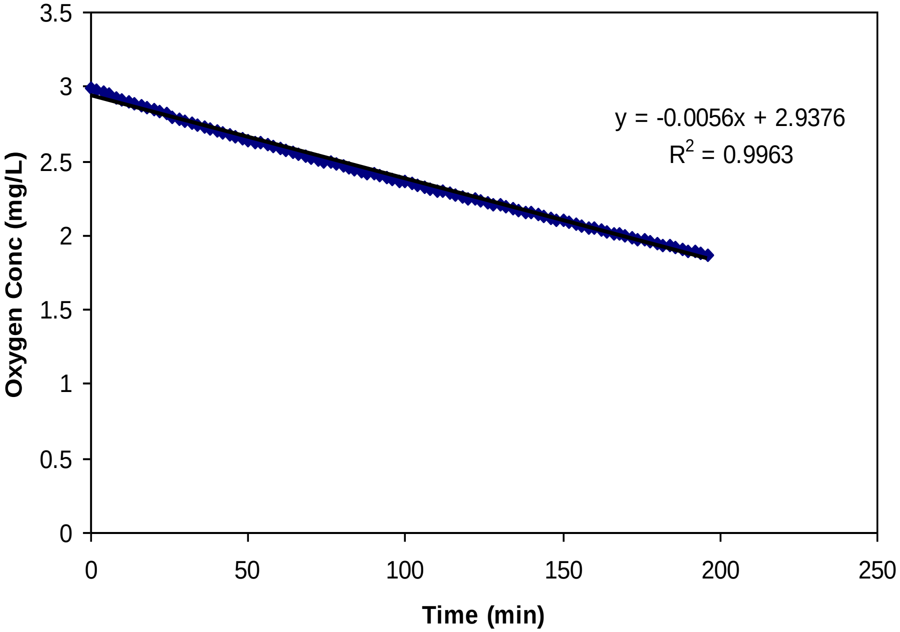

Legend
Transects
SOD Locations
Dye Samplers
Little River Mainstem
0
87.5
175
350
Meters
N


M
K
J
I
F
G
N
O
B
Wetland/Swamp
SCALE
0
2
4
km
Stream Gauging Station
Watershed Boundary

Measured SOD Rates



SOD_{20} =2.10 g O_2 m^{-2} d^{-1}



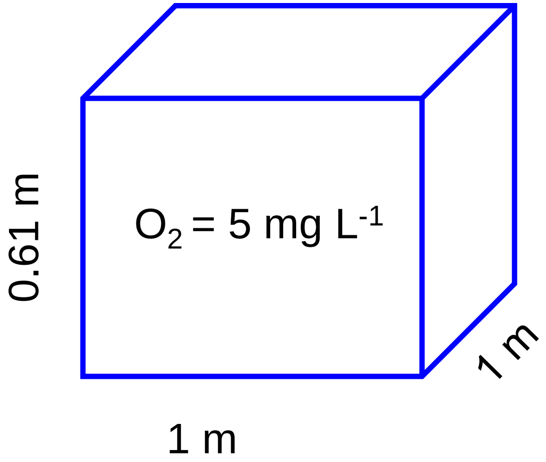
$$SOD = 1.44\frac{V}{A}\left(b_1 - b_2\right)$$

b_1 = slope of oxygen depletion curve

b_2 = slope of oxygen depletion curve from control

V, A = volume and area of chamber

How long will it take for SOD to consume DO 5 mg L^{-1} (drop from 9 to 4 mg L^{-1})



= 610 L = 3050 mg O_2

Min measured SOD Rate (1.31 g $O_2 \times m^{-2} d^{-1}$) = 2.3 d

Max measured SOD Rate (14.19 g $O_2 \times m^{-2} d^{-1}$) = 0.2 d

Avg SOD Rate (4.96 g $O_2 \times m^{-2} d^{-1}$) = 0.6 d

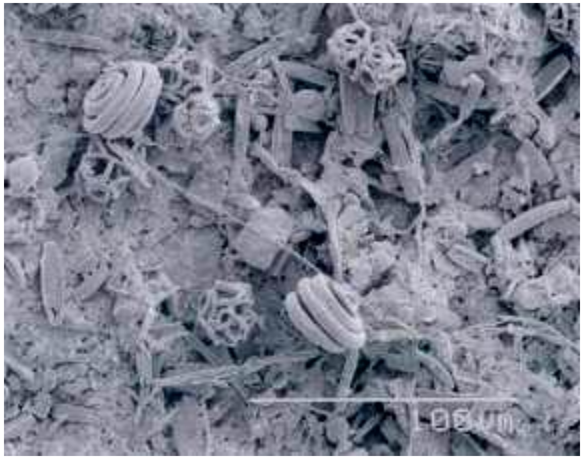
SOD Conclusions

- Literature values for SOD rates for southeastern United States rivers range between 0.33 – 0.77 g O_2 m^{-2} d^{-1} (*Truax et al., 1995*).
- Stream study (*Crompton, 2007*):
  - 0.6 – 1.4 g O_2 m^{-2} d^{-1} in agricultural watersheds
  - 0.9 – 2.5 g O_2 m^{-2} d^{-1} in forested watersheds
- In the swamp: 1.3 – 14.2 g O_2 m^{-2} d^{-1} (avg = 4.96 g O_2 m^{-2} d^{-1})
  - 65% of swamp values above the highest value recorded in stream channels
  - 31/32 higher than literature values

Microbial Respiration

- Fungi, diatoms, bacteria
- Substrate quality – hospitable patches in the landscape
  - Leaf litter (a.k.a. microbial landscape)

Fungi and diatoms on submerged leaf →



Hypotheses

- Microbial respiration is an important component of SOD
- Oxygen uptake rates differ among litter species
- Relative contributions of litter species change over time due to changes through breakdown process
- Andrew Mehring – Ecology Ph.D. student

Five Common Coastal Plain Tree Species

recalcitrant ⟷ labile / “hospitable”

Quercus nigra

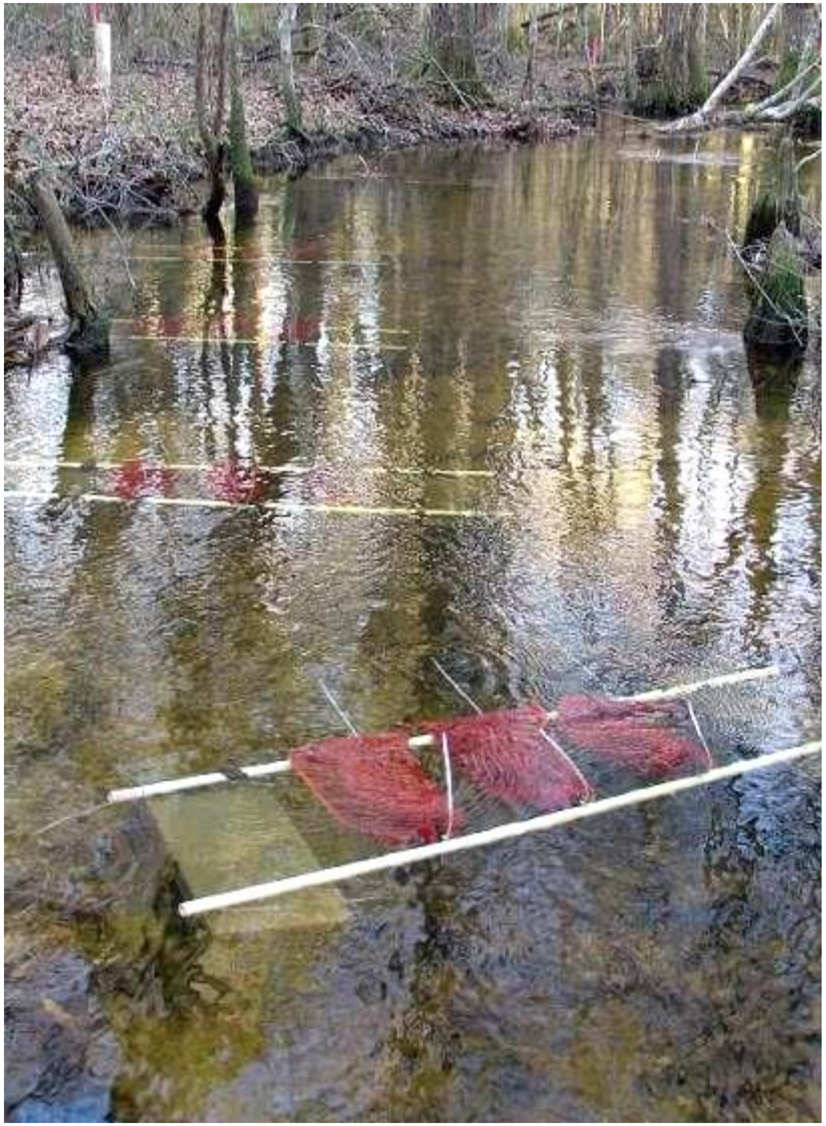
Nyssa sylvatica

Taxodium sp.

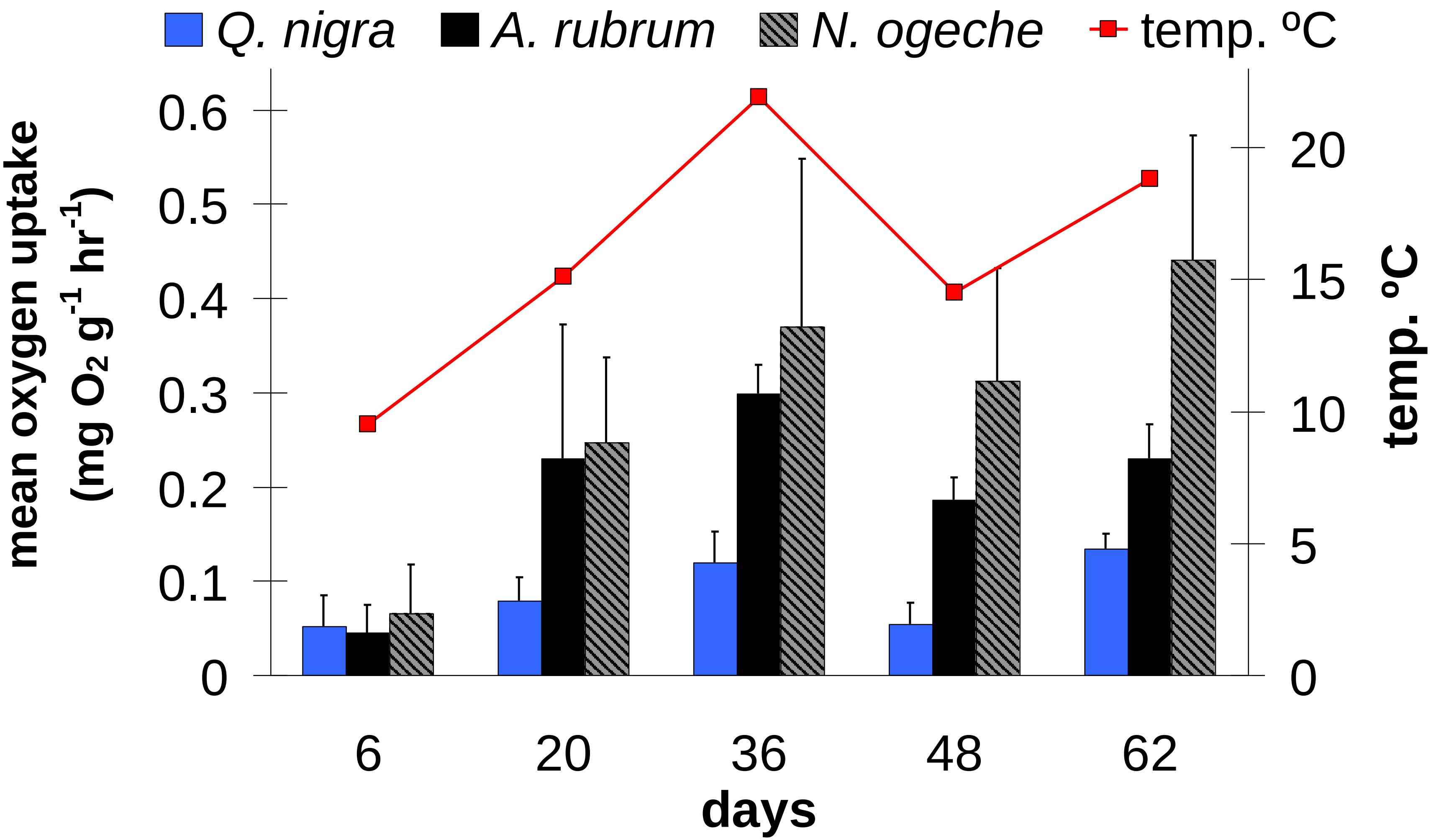
Nyssa ogeche

Acer rubrum

Methods



- Tracked breakdown and respiration (*Benfield 2006, Gulis & Suberkropp 2003*)
- Randomized complete block design – 2 sites



ANCOVA results:

tree species	$F_{2,31}=8.90$	*p*=0.0009
time (days)	$F_{4,31}=3.55$	*p*=0.017
temperature	$F_{1,31}=12.22$	*p*=0.0014

Standing Stock Above Sediment Layer

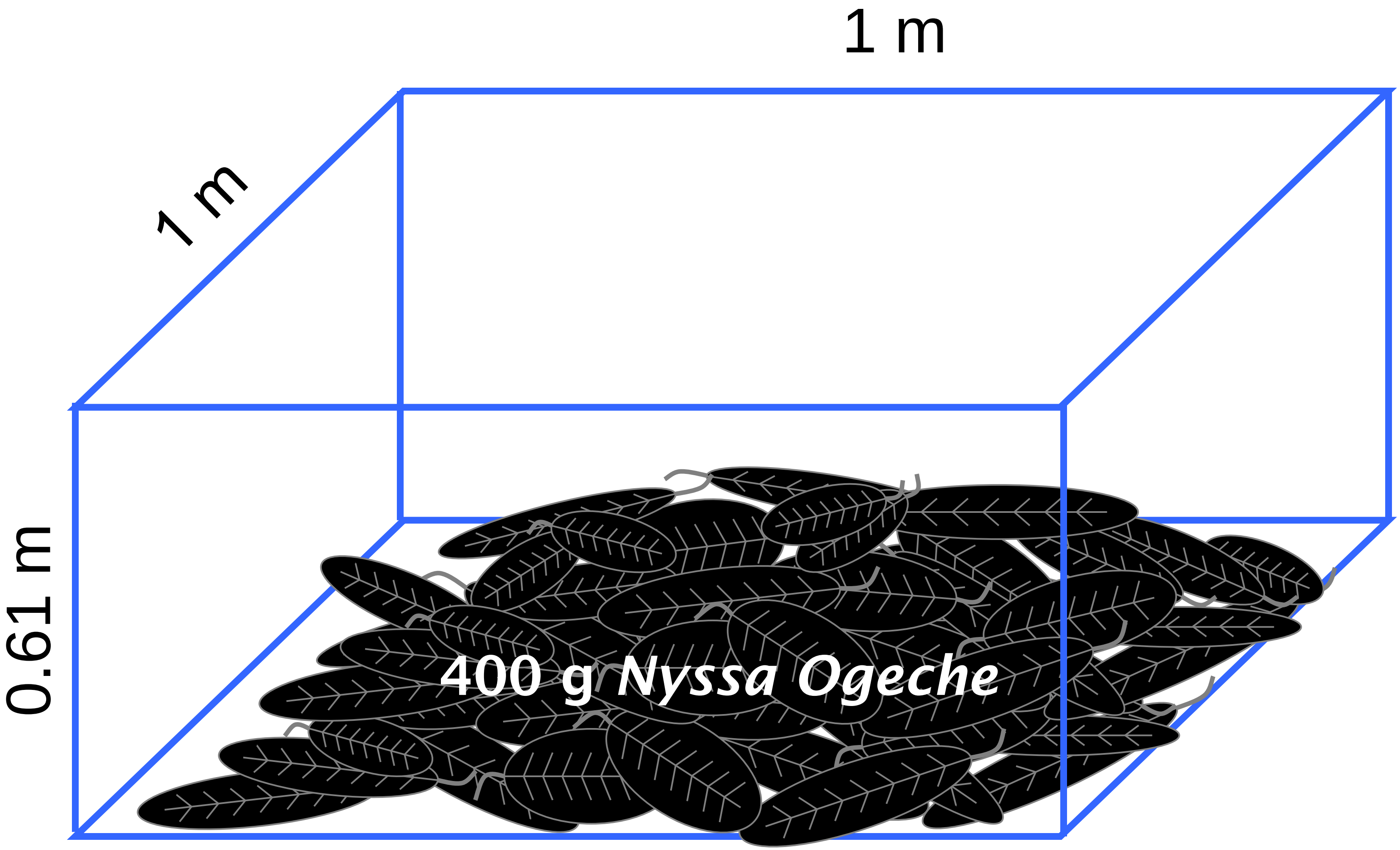
1 m^2 of benthos

TOTAL ~ 570 grams

leaf litter ~ 400 grams

volume = 610 L H_2O

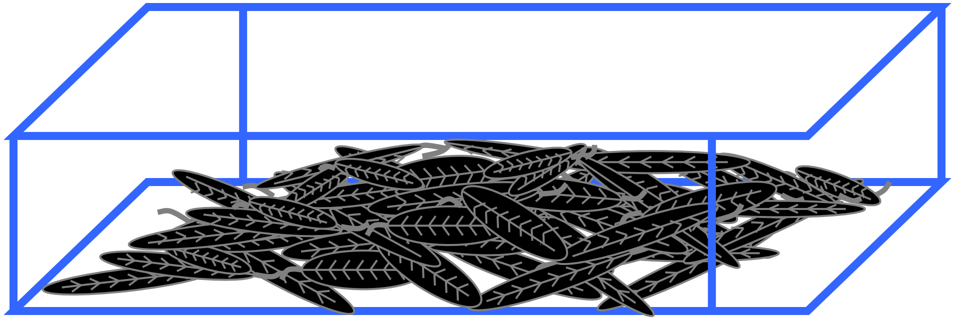
initial DO = 9.0 mg L^{-1}



610 L H_2O

initial DO = 9.0 mg L^{-1}

400 g *Nyssa ogeche*

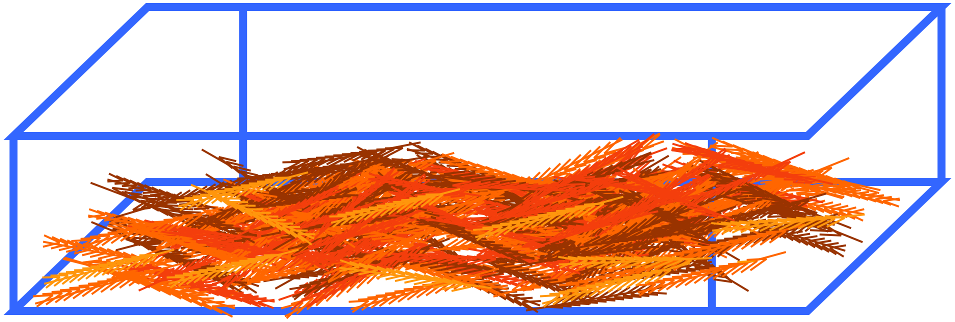


0.6 mg O_2 g^{-1} hr^{-1}

x 400 g

5760 mg O_2 day^{-1}

400 g *Taxodium distichum*



0.3 mg O_2 g^{-1} hr^{-1}

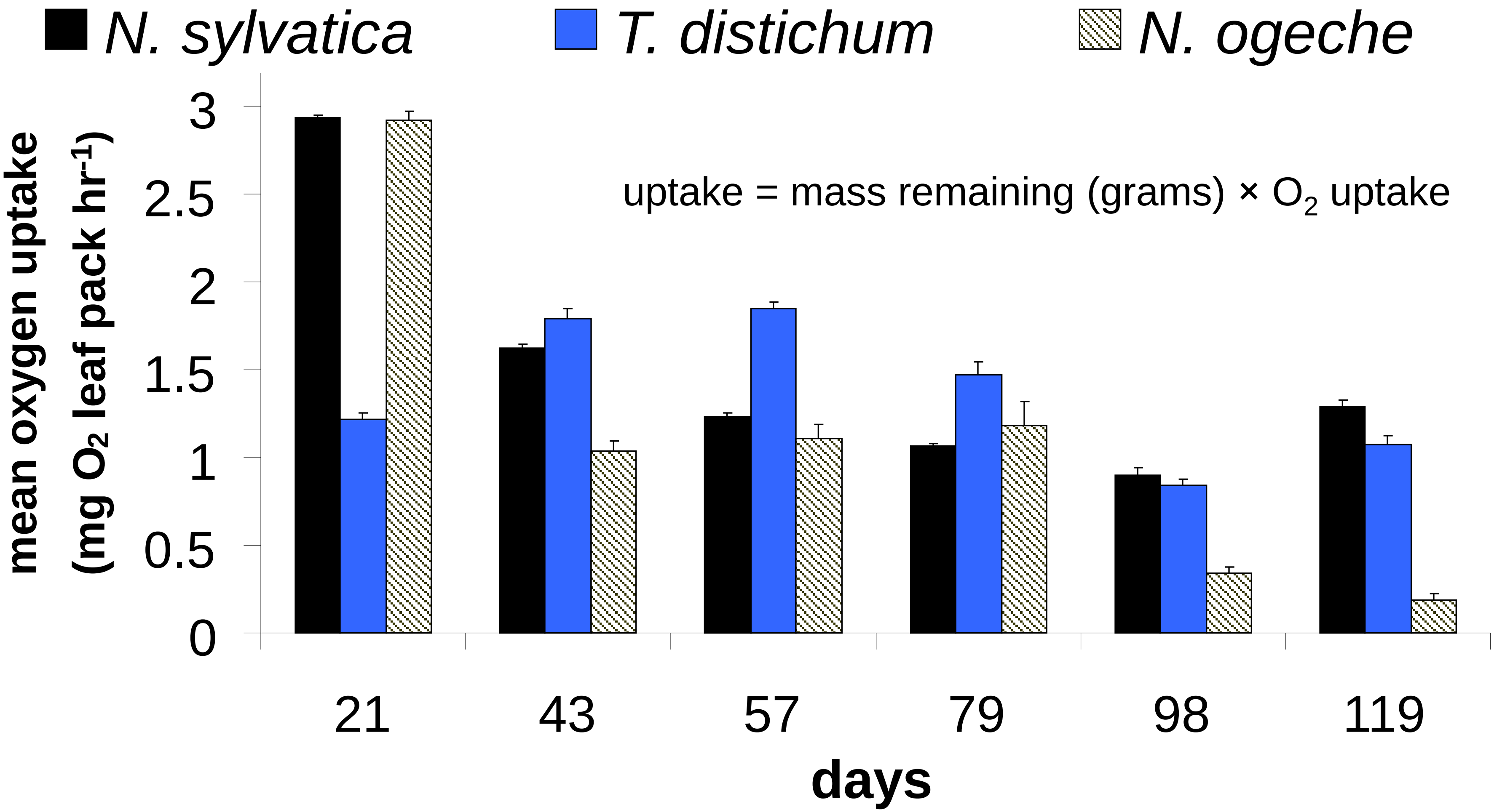
x 400 g

2880 mg O_2 day^{-1}

4.0 mg L^{-1} → 12.5 hours

25 hours

O_2 Uptake Per Leaf Pack



uptake = mass remaining (grams) × O_2 uptake

Overall Conclusions

- Nutrient enrichment not the cause of low DO
- Litterfall respiration: 0.9 – 5.8 g O_2 m^{-2} d^{-1}
- SOD: 1.3 – 14.2 g O_2 m^{-2} d^{-1}
- Litterfall respiration is important component of SOD
- Previous work by J. Todd showed high retention time
  - 15 - 27 hrs to flow through 1350 m of swamp
- Avg SOD rates can completely account for DO depletion – even under cool temperatures

Project Impact

- Georgia EPD is using a “natural conditions” low DO standard
- Many low DO streams without point sources removed from 303(d) list
- Reduced taxpayer costs for unnecessary TMDLs
- More work needed to separate anthropogenic effects from natural conditions

Thank you for your attention !!

For more information:

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