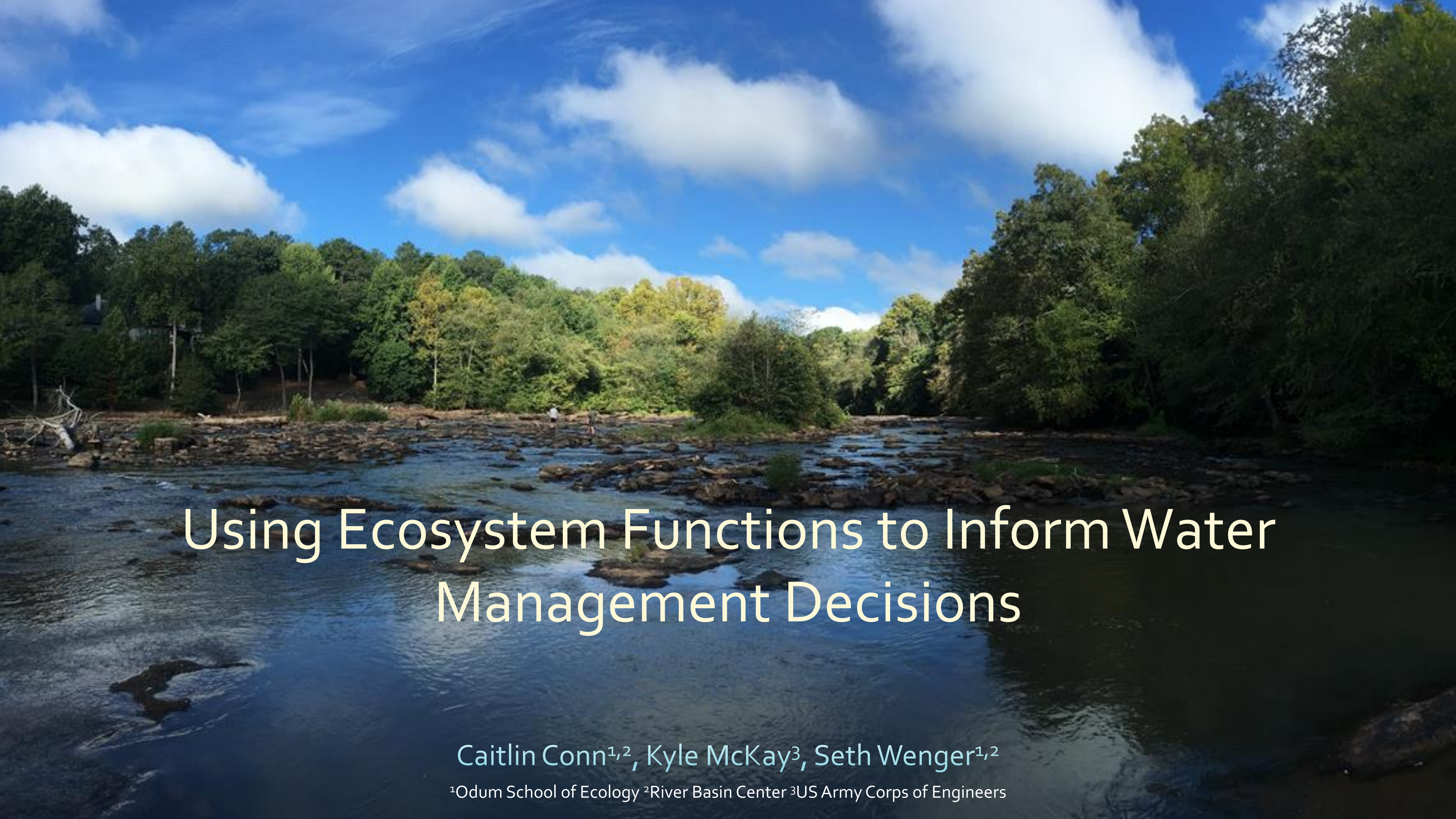


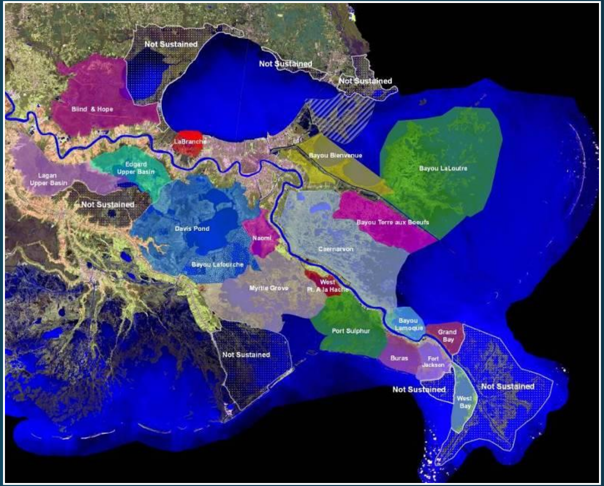
Using Ecosystem Functions to Inform Water Management Decisions

Caitlin Conn[1,2], Kyle McKay[3], Seth Wenger[1,2]

[1]Odum School of Ecology [2]River Basin Center [3]US Army Corps of Engineers

Ecosystem **Restoration in the Corps**

- Purpose: "…to restore significant structure, function and dynamic processes that have been degraded." (ER 1165-2-501)
- Intent: "…to partially or fully reestablish the attributes of a naturalistic, functioning, and self-regulating system." (EP 1165-2-502)
- Scope: "Nationally and regionally significant wetlands, riparian and other floodplain and aquatic systems" (ER 1105-2-100)



Structure v. Function

Structure: "refers to both the composition of the ecosystem (i.e., its various parts) and the physical and biological organization defining how those parts are organized"

Function: "describes a process that takes place in an ecosystem as a result of the interactions of plants, animals, and other organisms in the ecosystem with each other or their environment"

Structure	Function
What ecosystems look like	What ecosystems do
A snapshot in time	Usually a rate
Restoration emphasizes form	Restoration emphasizes process
Emphasize the static condition	Focus on dynamism
Indicates something is wrong	Indicates why it is wrong
Varies in time and space	Varies in time and space
Necessary for restoring a healthy ecosystem	Necessary and sufficient for restoring a healthy ecosystem

Definitions: NRC Report on Ecosystem Services (Heal et al. 2005)
Table after Amy Rosemond (UGA)

Ecosystem Services

- Ecosystem services are "the benefits people obtain from ecosystems"
  - Millennium Ecosystem Assessment (2005)

- Ecosystem goods and services are socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem structures and processes.
  - Murray et al. (2013)

- Structure and function can influence, but are not necessarily services

Plus other services not listed here…

Figure: metrovancouver.org
See also: MEA (2005), Murray et al. (2013), Tazik et al. (2013)

Structure	Process/Function	Services
Fish habitat	Population survival rate	Commercial fishing yield
Channel width	Bank erosion rate	Land gain / loss
Nitrate concentration	Nutrient uptake and transformation rates	Reduced water treatment cost
Wetland plant density or configuration	Storm surge attenuation	Reduced flood damage
Population abundance of salmon (i.e., run size)	Reproductive or survival rates	Subsistence fishing harvest
Biodiversity	Adaptation or speciation rates	Heritage value for future generations
Watershed connectivity	Sediment flux or delivery	Maintenance of wetland elevation under SLR

After Palmer and Febria (2012)

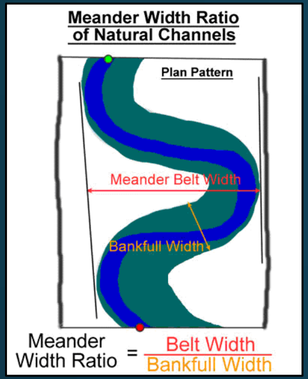
Ecosystem Restoration in the Corps

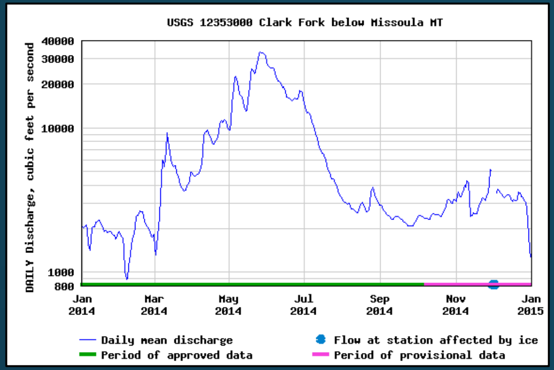
- Purpose: "…to restore significant structure, function and dynamic processes that have been degraded." (ER 1165-2-501)

- Restoration of what?
  - Species? Populations? Communities? Habitat? Water or soil quality?
- Ecosystems!
  - Common definition: a biotic community and its abiotic environment functioning as a system
  - Implies biotic and abiotic
  - "Systems" indicates functions or interactions

Physical Structure

- Historic focus of restoration

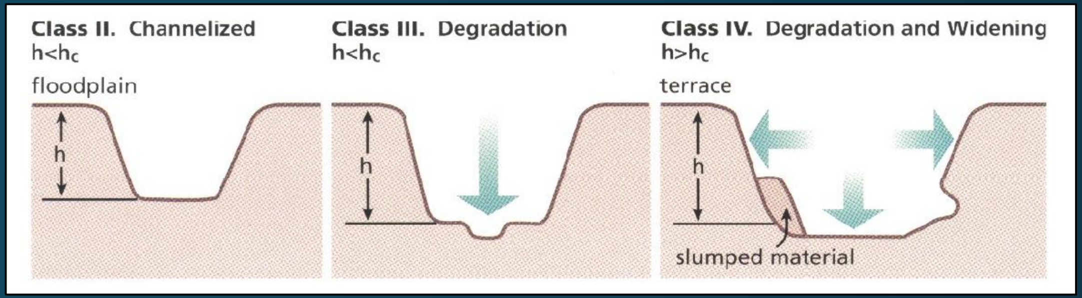




- Examples: hydrodynamics (velocity, depth, etc.), channel shape, water quantity, habitat assessment

Physical Function

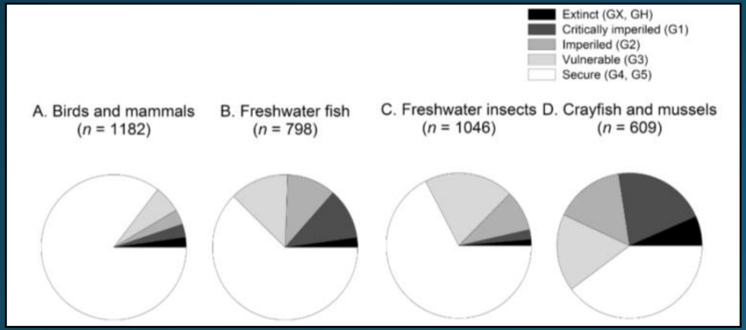
- Growing emphasis and use in restoration



- Examples: sediment transport, channel migration wood recruitment and transport rates

Biotic Structure

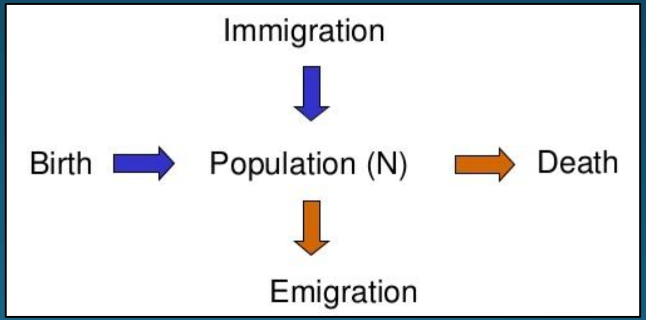
- Growing interest in assessing biotic assemblage

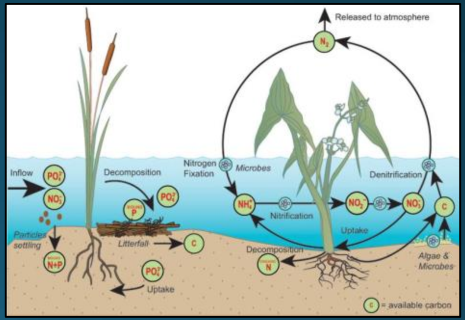


- Examples: species richness, abundance, diversity indices, biomass

Biotic Function

- Less work to date in the restoration community





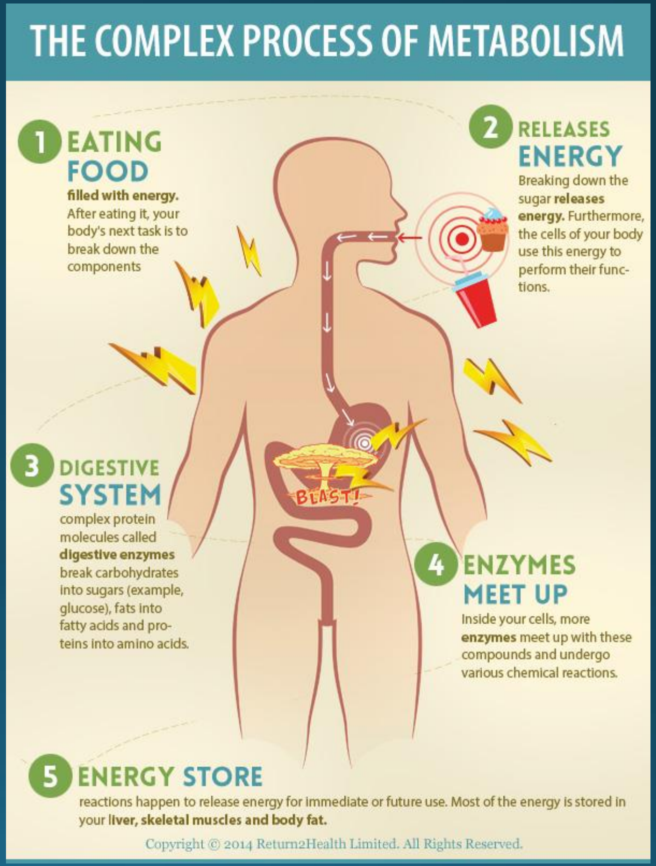
- Examples: demographic rates (reproduction, survival), production, respiration, metabolism, energy flux

Why do we care about biotic function?

- Consider one of the most basic functions, primary production. It's ultimately the source of all life on Earth.
- Biotic function influences structure: if we're going to grow fish, we need energy.

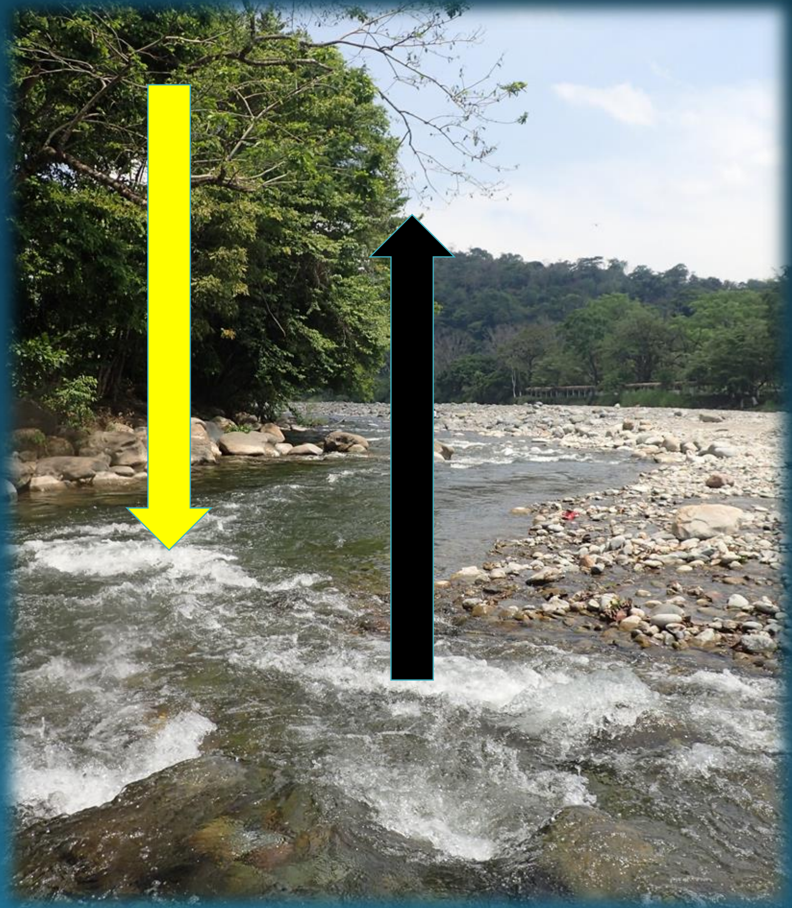
What is “Ecosystem Metabolism”?

- The metabolism of a person is basically the amount of energy going in and out.



What is “Ecosystem Metabolism”?

- We can also talk about the metabolism of a whole river.
  - There’s primary production, which is the energy coming in from the sun.
  - And there’s respiration, which is the energy consumed by all the organisms in the river.



Ecosystem metabolism

- We can also think of metabolism as a balance of carbon.
  - Primary production turns CO_2 into plant biomass
  - Respiration (by plants, bugs, fish) releases CO_2
- OR we can think of metabolism as a balance of oxygen
  - Primary producers release oxygen during the day when photosynthesizing
  - All organisms consume oxygen both day and night for respiration

So how do we manage for biotic function?

- How do we know what it should be?
- Is higher primary production good or bad?

Rivers are dynamic systems

- Production and respiration vary seasonally and depend on antecedent conditions.
- Periodic blooms of filamentous algae can be normal- and can increase production (and respiration).
- High flows scour algae and decrease production.
- Dominant producers change over time.

If we want to manage for ecosystem function, we need to understand these dynamics.

For example, if we knew how flows influenced different primary producers, we could predict the effect of different water withdrawal or dam release scenarios.

So how do we measure biotic function?

- For production, we could go out and measure the biomass of producers– the "standing crop." But this is actually biotic structure.

- There's a problem with using standing crop to infer production.

Biomass and production are only weakly linked

- You could have high biomass of slow-growing, unpalatable cyanobacteria.

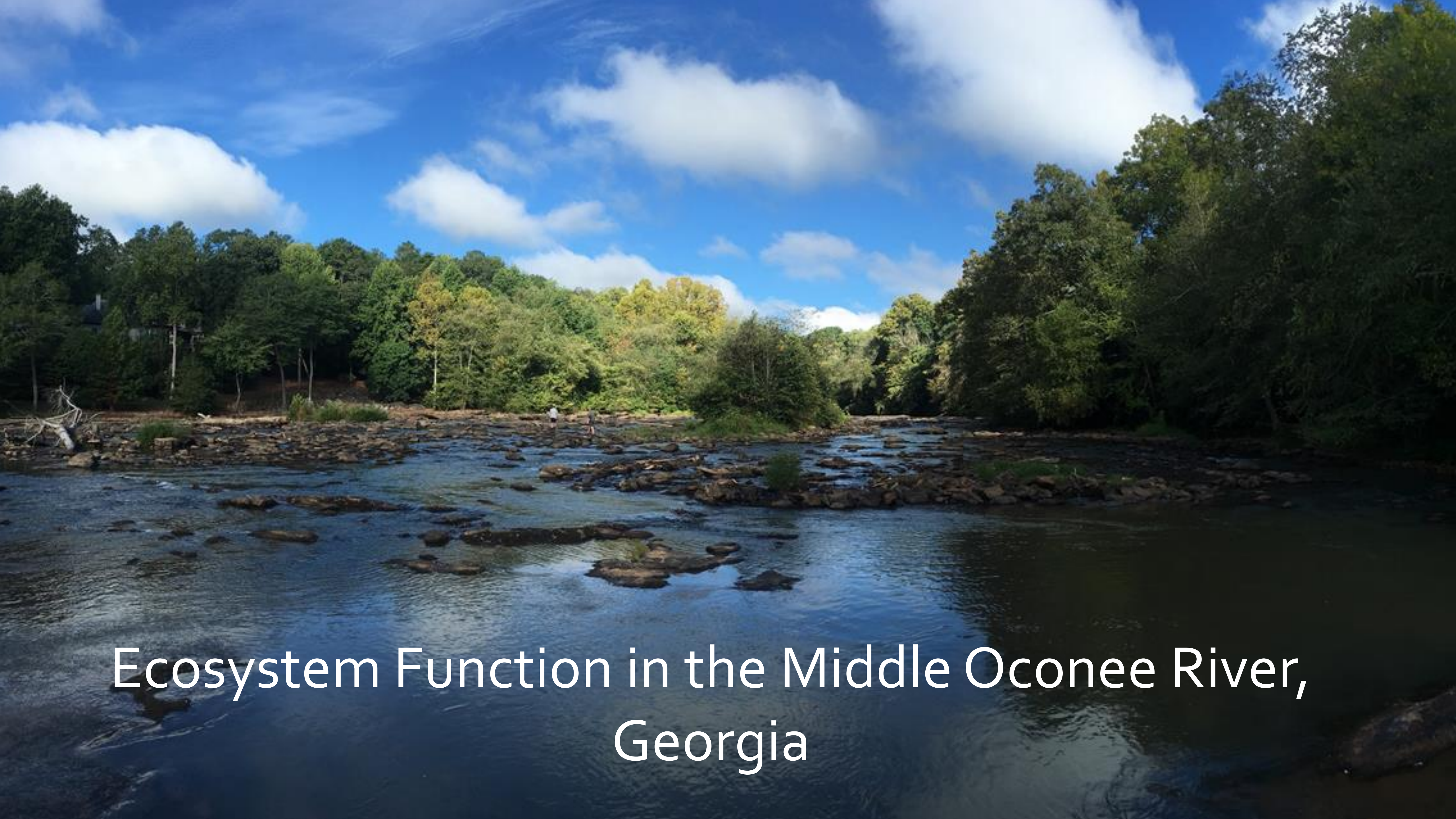
- Or you could have low biomass of fast-growing, delicious diatoms.


© Jan Hamrsky
www.lifeinfreshwater.net

Measuring productivity directly

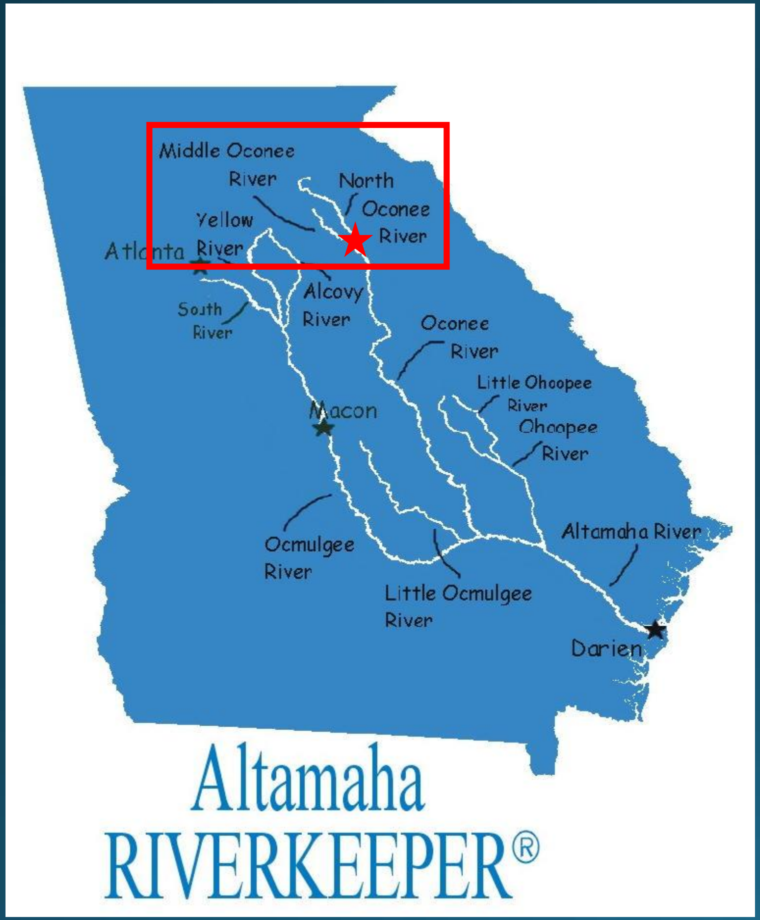
- One way to do it is to measure oxygen in the water. Oxygen increases during the day in proportion to the amount of primary production.

- But if we want to know who is doing what-- what's the algae doing? What are the vascular plants doing?-- we need to measure different primary producers separately.

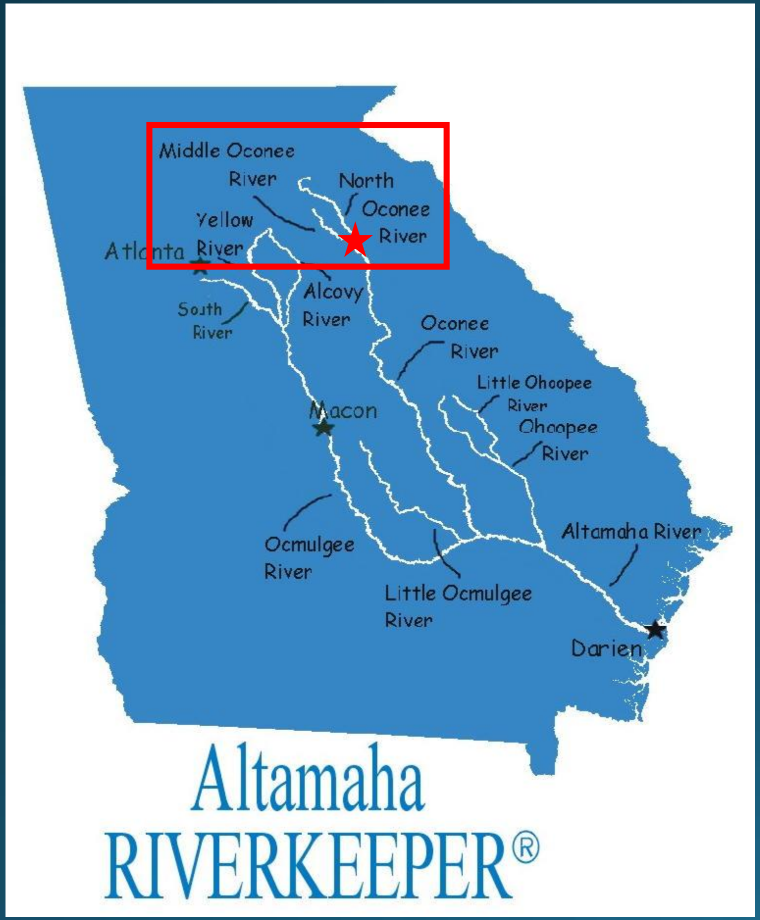


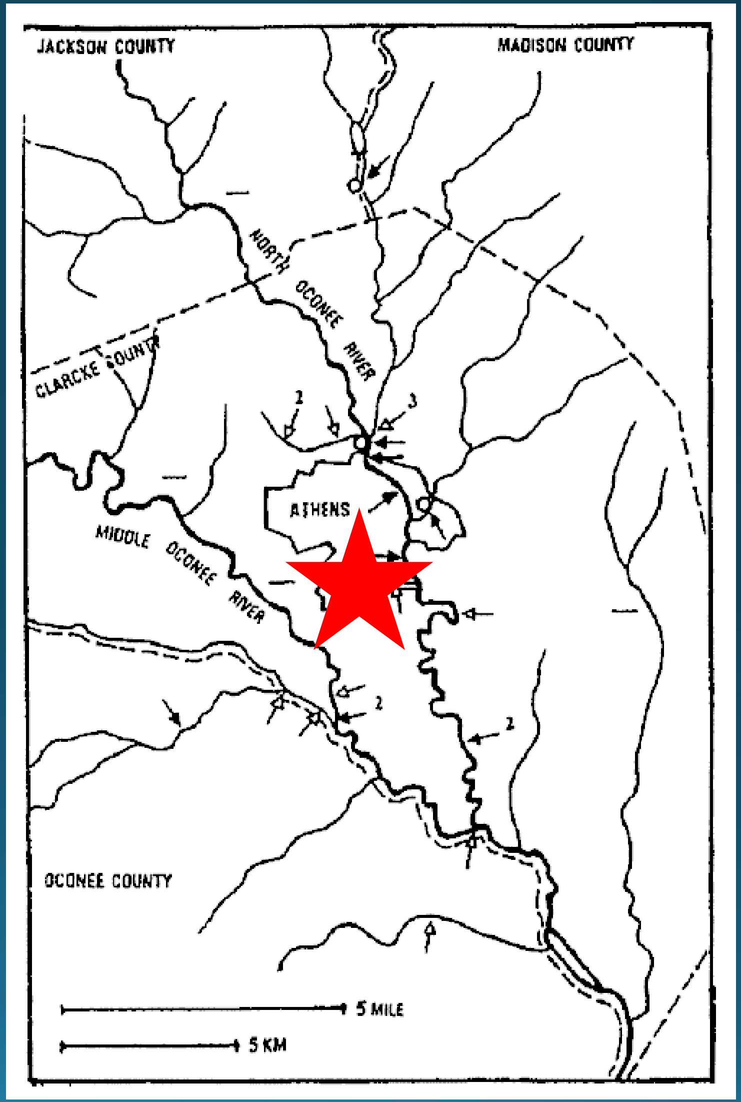
Ecosystem Function in the Middle Oconee River, Georgia

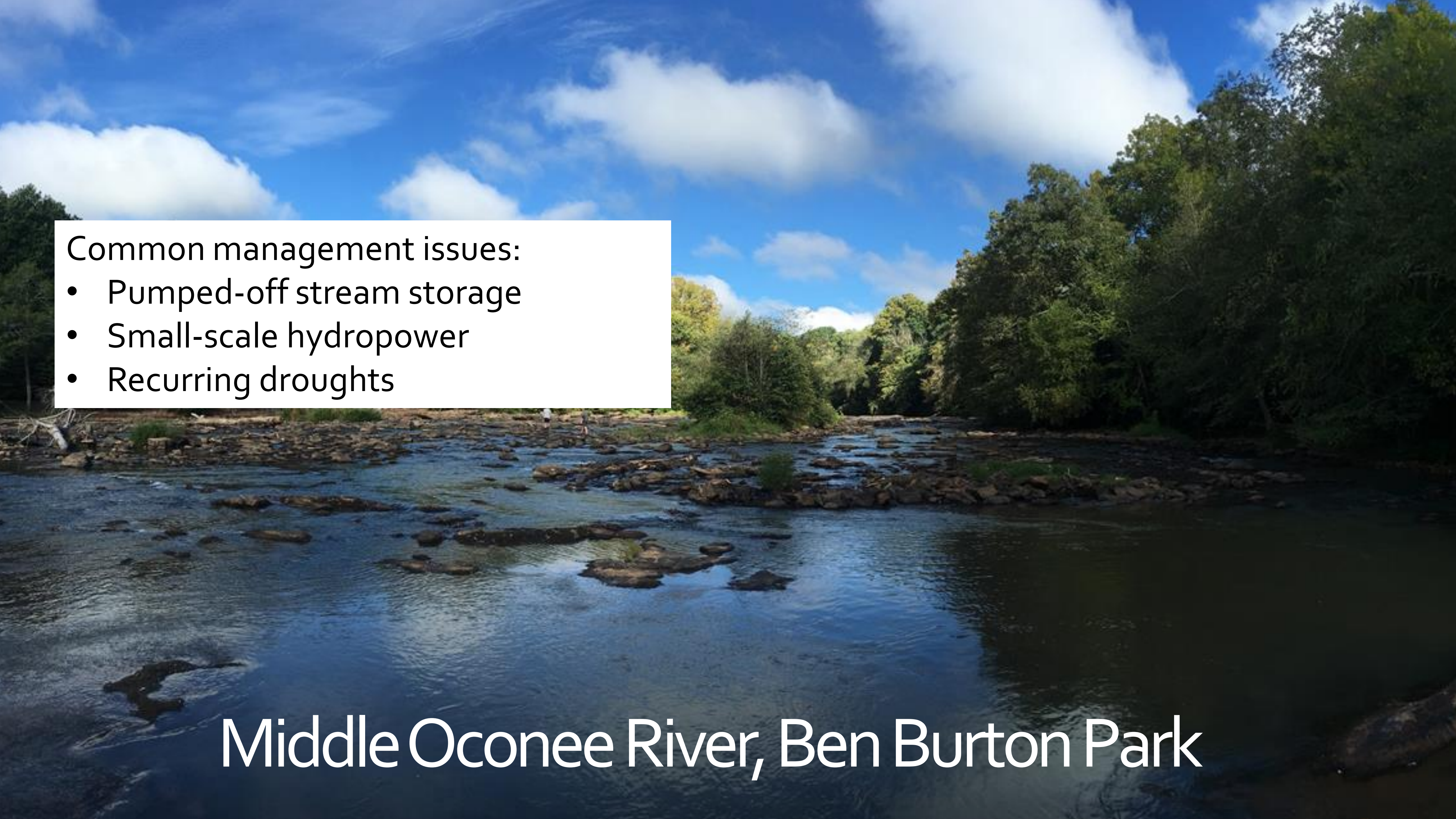
Middle Oconee River



Middle Oconee River







Common management issues:

- Pumped-off stream storage
- Small-scale hydropower
- Recurring droughts

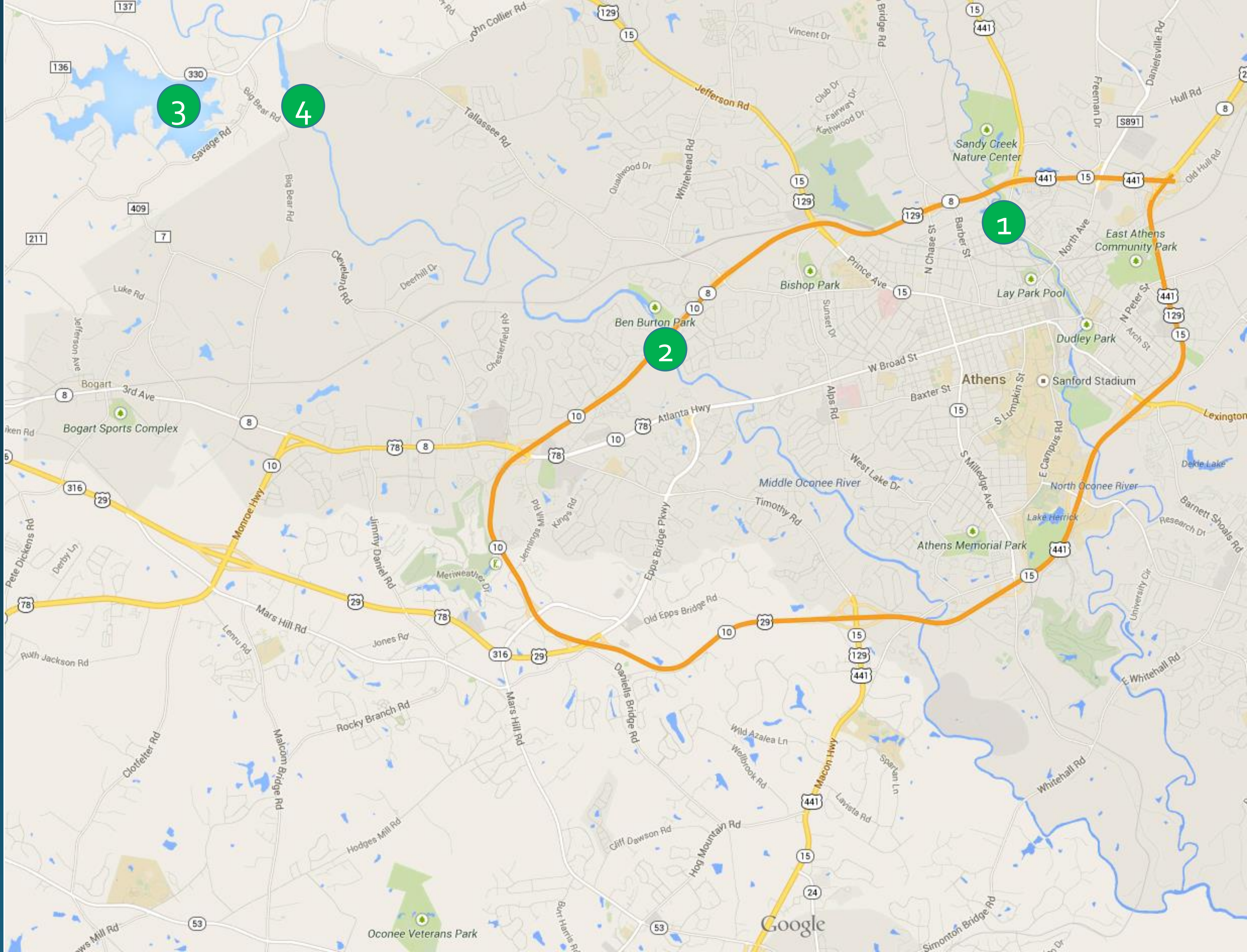
Middle Oconee River, Ben Burton Park

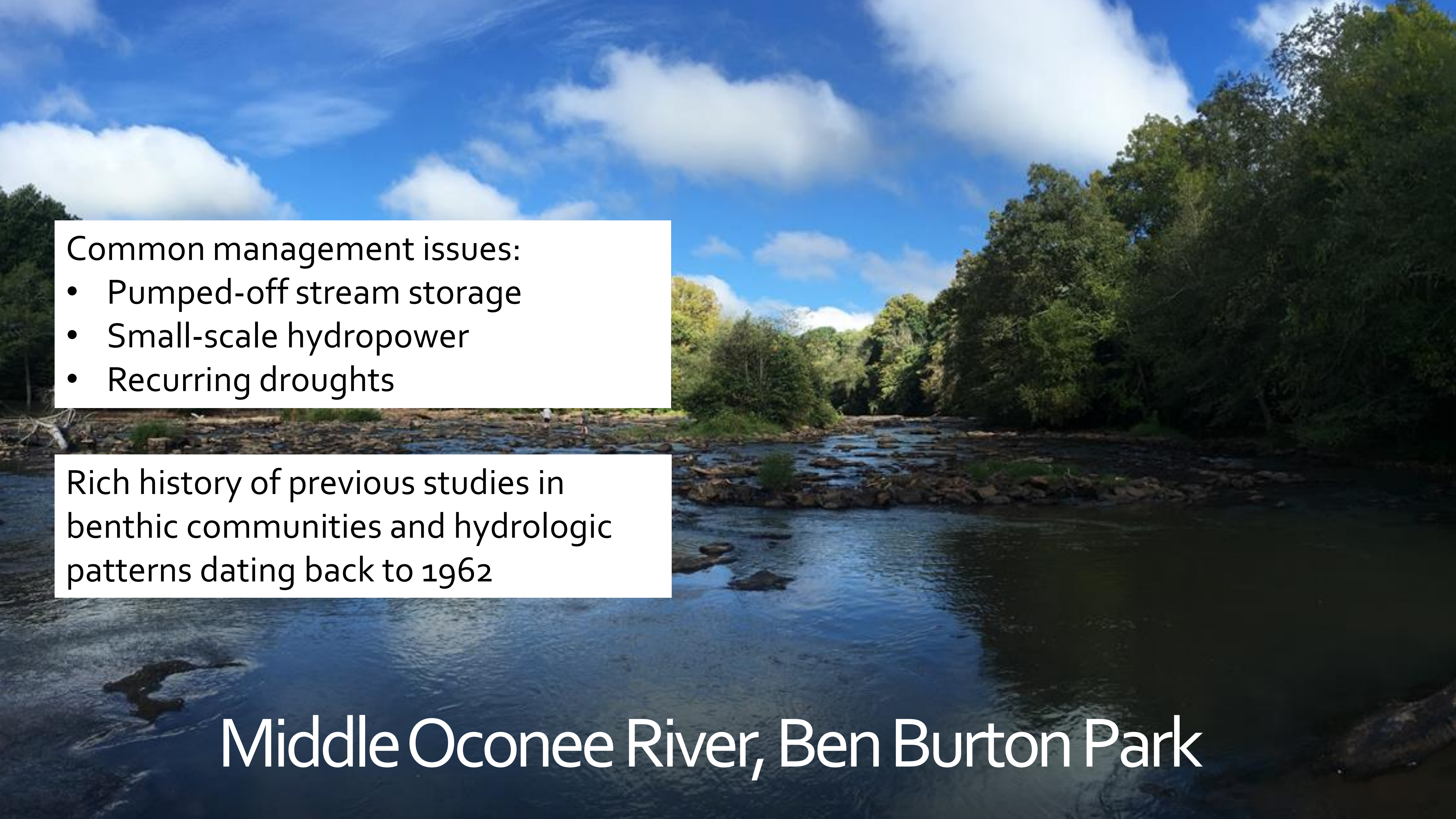
1 - North Oconee

2 - Middle Oconee

3 - Bear Creek Reservoir

4 – Small Hydropower





Middle Oconee River, Ben Burton Park

Common management issues:
- Pumped-off stream storage
- Small-scale hydropower
- Recurring droughts

Rich history of previous studies in benthic communities and hydrologic patterns dating back to 1962

ROLE OF DETRITUS IN THE PRODUCTIVITY OF A ROCK-OUTCROP COMMUNITY IN A PIEDMONT STREAM

Daniel J. Nelson[1] *and Donald C. Scott*
Department of Zoology, University of Georgia

ABSTRACT

A rock outcrop community in a typical southern Piedmont stream was studied to determine its trophic structure and productivity. *Podostemum ceratophyllum* was the primary producer component of the community and also provided a place of attachment and shelter for a rheophilic fauna consisting largely of insects. The primary consumer organisms derived 66% of their energy from allochthonous organic matter consisting largely of leaf material. Productivity by phytoplankton in the river water was insignificant as was respiration in the shifting sand bottom. The river behaved as a heterotrophic stream because of suspended organic detritus in the water. A higher and more variable quantity of particulate detritus was present in the water during summer than winter. This seasonal difference was attributed to stream discharge–stream bed relationships and a more rapid decomposition of organic fragments at higher summer temperatures.

The net annual productivities, determined by the cropping method, in cal/cm² for trophic groups were: *Podostemum* 434, filter feeders 16.8, herbivores 6.51, detritus feeders 1.68, herbivore and detritus feeders 2.78 (total primary consumer 27.8), and carnivore 3.66. The turnover of biomass increased with increasing productivity by individual species but this relationship does not hold true for all communities. A comparison of trophic level production efficiencies and productivities in several communities suggests there are self-regulating mechanisms in natural communities which function bet
sumer groups. Community stability is an important factor for the
productivity in flowing water environments.

A theory of stream succession has been proposed which is base
concept.

EFFECTS OF FLOW ALTERATION ON

THE AQUATIC MACROPHYTE *PODOSTEMUM CERATOPHYLLUM* (RIVERWEED);

LOCAL RECOVERY POTENTIAL AND REGIONAL MONITORING STRATEGY

by

JENNIFER P. PAHL

(Under the Direction of C. Ronald Carroll)

ABUNDANCE AND SURVIVAL OF COMMON BENTHIC BIOTA IN A RIVER

AFFECTED BY WATER DIVERSION DURING AN HISTORIC DROUGHT

by

RACHEL ALLISON KATZ

(Under the Direction of Mary Freeman)

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 51, No. 6 AMERICAN WATER RESOURCES ASSOCIATION December 2015

QUANTIFYING TRADEOFFS ASSOCIATED WITH HYDROLOGIC ENVIRONMENTAL FLOW METHODS[1]

S. Kyle McKay[2]

Accession Number : ADA542365

Title : Evaluating Effects of Pump-Storage Water Withdrawals Using an Individual-Based Metapopulation Model of a Benthic Fish Species

Descriptive Note : Conference paper

Corporate Author : ENGINEER RESEARCH AND DEVELOPMENT CENTER VICKSBURG MS ENVIRONMENTAL LAB

Personal Author(s) : Katz, Rachel A. ; McKay, S. Kyle

PDF Url : ADA542365

Report Date : APR 2011

Pagination or Media Count : 8

Abstract : As demand on freshwater resources increases, managers are increasingly tasked with identifying water withdrawal, storage, and management strategies that minimize impacts on aquatic species. Identifying critical features of the flow regime that sustain particular ecological processes can be difficult due to site and species-specific characteristics. Our goal was to simulate trade-offs between differing water withdrawal strategies for an off-channel, pump-storage reservoir and the ecological-flow requirements of flow-dependent taxa. Using a case study of a 30-km reach of the Middle Oconee River near Athens, we evaluated multiple demographic models for selecting a flow management strategy for maintaining abundance of a native fish species, the Turquoise darter (Etheostoma inscriptum). We developed and applied an individual-based metapopulation model to assess the relative influence of five alternative flow management strategies. Each strategy differed based on the magnitude and timing of water withdrawals. We explicitly incorporated uncertainty in the analysis by applying two alternative flow-survival relationships and stochastic variation in recruitment and survival. The influence of each flow management strategy on fish populations was evaluated based on the mean and standard deviation of darter abundance following a 20-year period of simulated water withdrawals. This evaluation demonstrates the utility of individual based population models to inform a common freshwater flow management problem, balancing economic and ecological flow requirements.

Limnol. Oceanogr., 40(3), 1995, 490–501

Functional structure and production of the benthic community in a Piedmont river: 1956–1957 and 1991–1992

Jack W. Grubaugh[1] *and J. Bruce Wallace*
Institute of Ecology, University of Georgia, Athens 30602-2602

Abstract

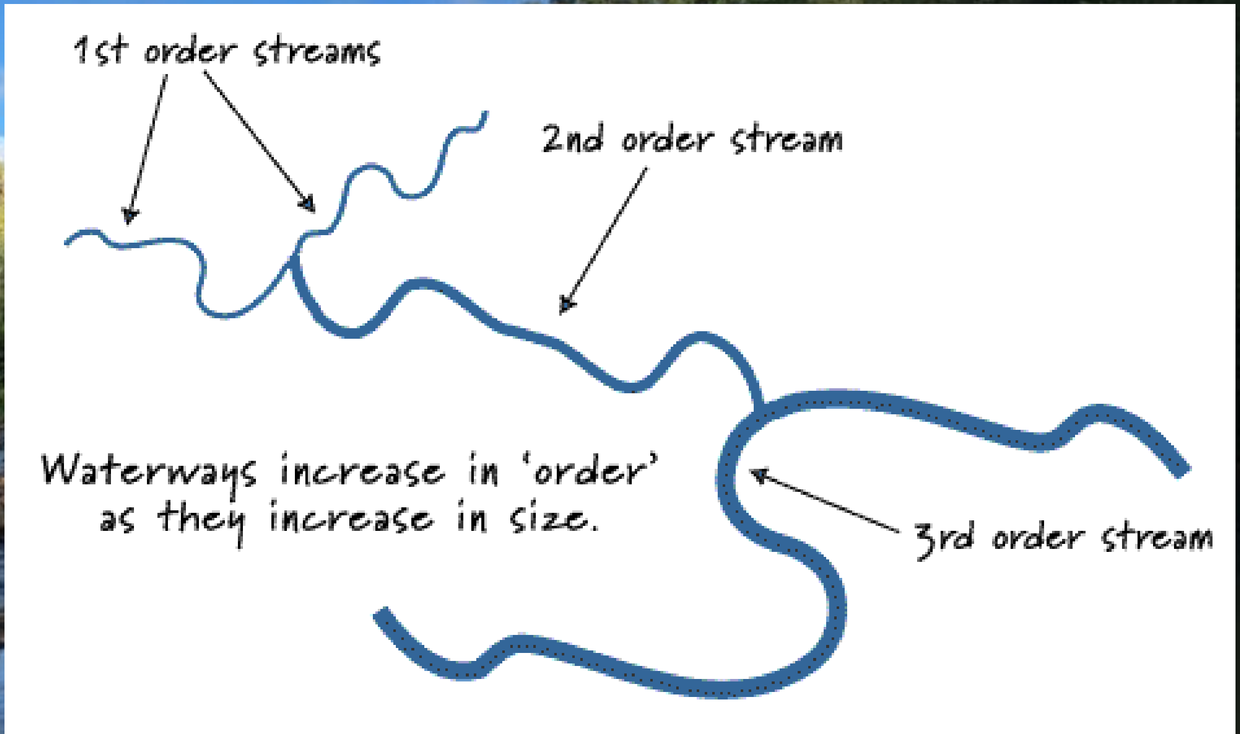
Taxonomic composition and functional group abundance, biomass, and annual production were measured in 1991–1992 for the macroinvertebrate community in a Piedmont river. Abundances and biomass values were influenced by standing crops of *Podostemum ceratophyllum*, a hydrophyte which covered bedrock substratum. Collector-filterers, collector-gatherers, and scrapers dominated functional-group abundance; scrapers and collector-filterers dominated biomass. Benthic production was 181.9 g ash-free dry mass m^{-2} yr^{-1}; 57% was attributable to collector-filterer hydropsychid caddisflies and 13% to a scraper snail. Results were compared to a previous study conducted at the same site in 1956–1957. Physical parameters of temperature and discharge regimes, *P. ceratophyllum* standing crops, and riparian vegetation were similar between studies, but marked changes in land use had occurred within the catchment. Benthic community structure was dominated by small, multivoltine collector-gatherers and microfilterers in 1956–1957; in 1991–1992 dominant taxa consisted of larger, longer lived macrofilterers and scrapers. Changes in community structure and indices of biotic integrity indicate stream condition improved in 1991–1992 relative to 1956–1957; changing land-use practices are implicated as the key factor for improvement.

Middle Oconee River, Ben Burton Park

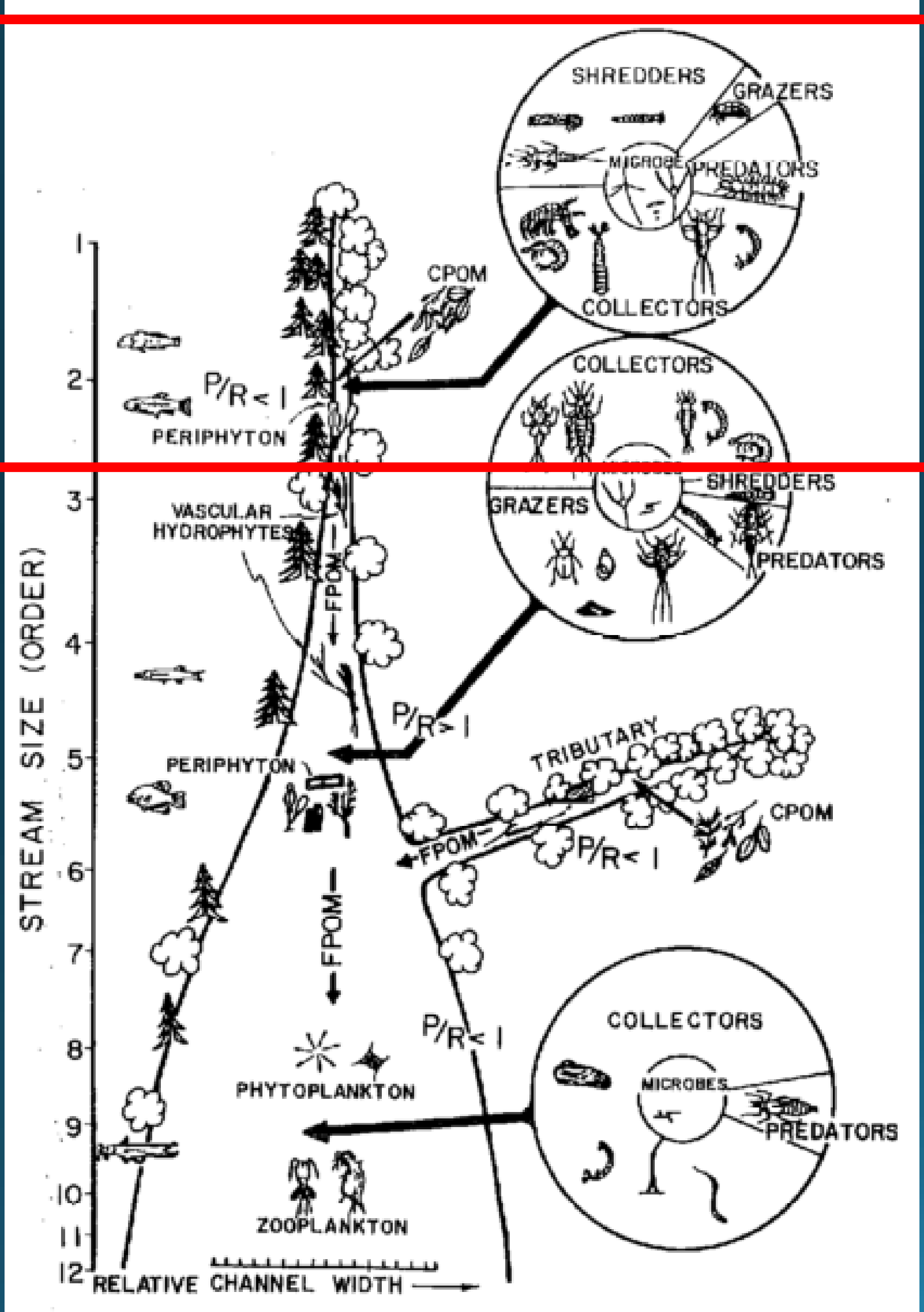
Common management issues:

- Pumped-off stream storage
- Small-scale hydropower
- Recurring droughts

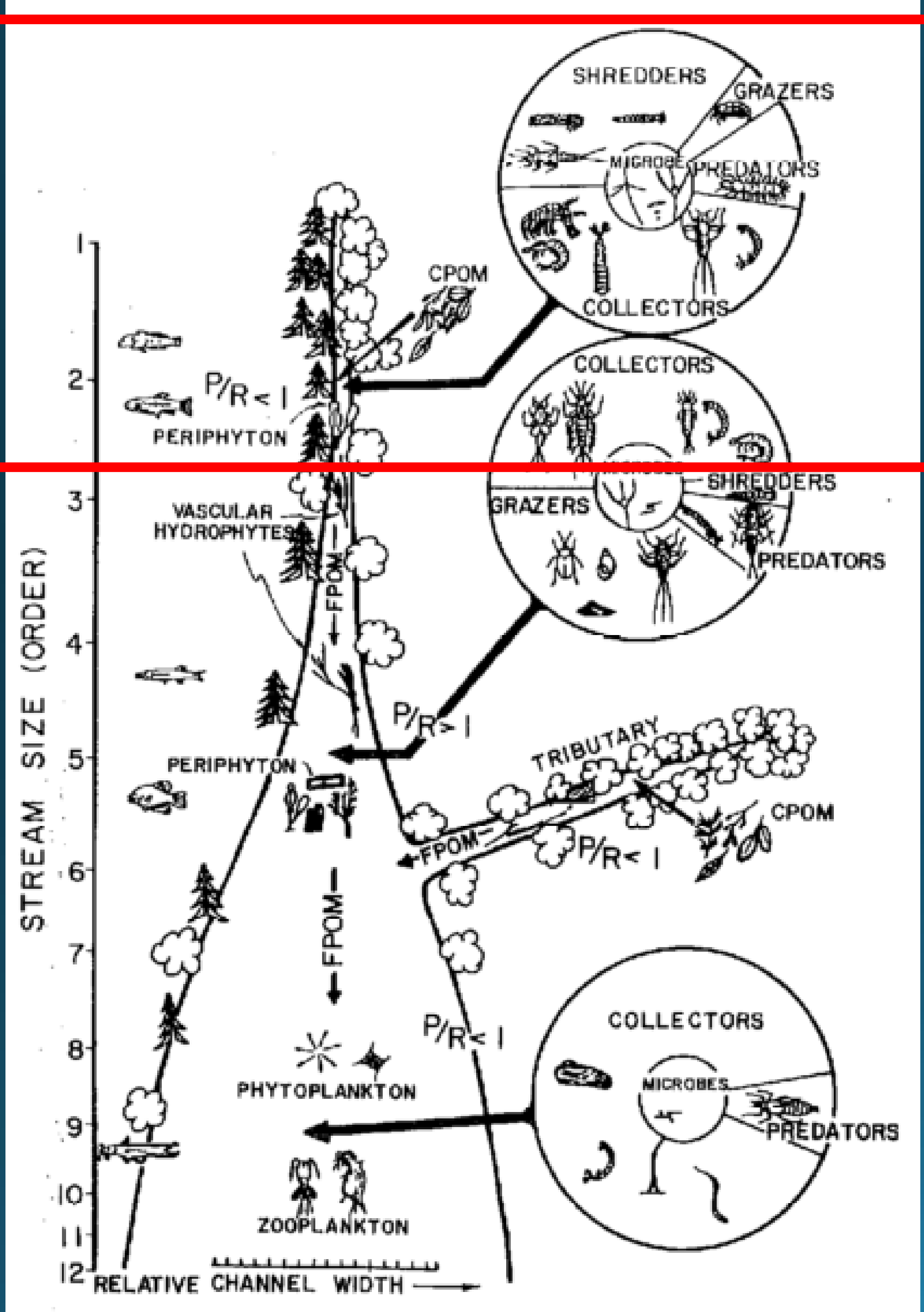
Rich history of previous studies in benthic communities and hydrologic patterns dating back to 1962



Prince William Conservation Alliance

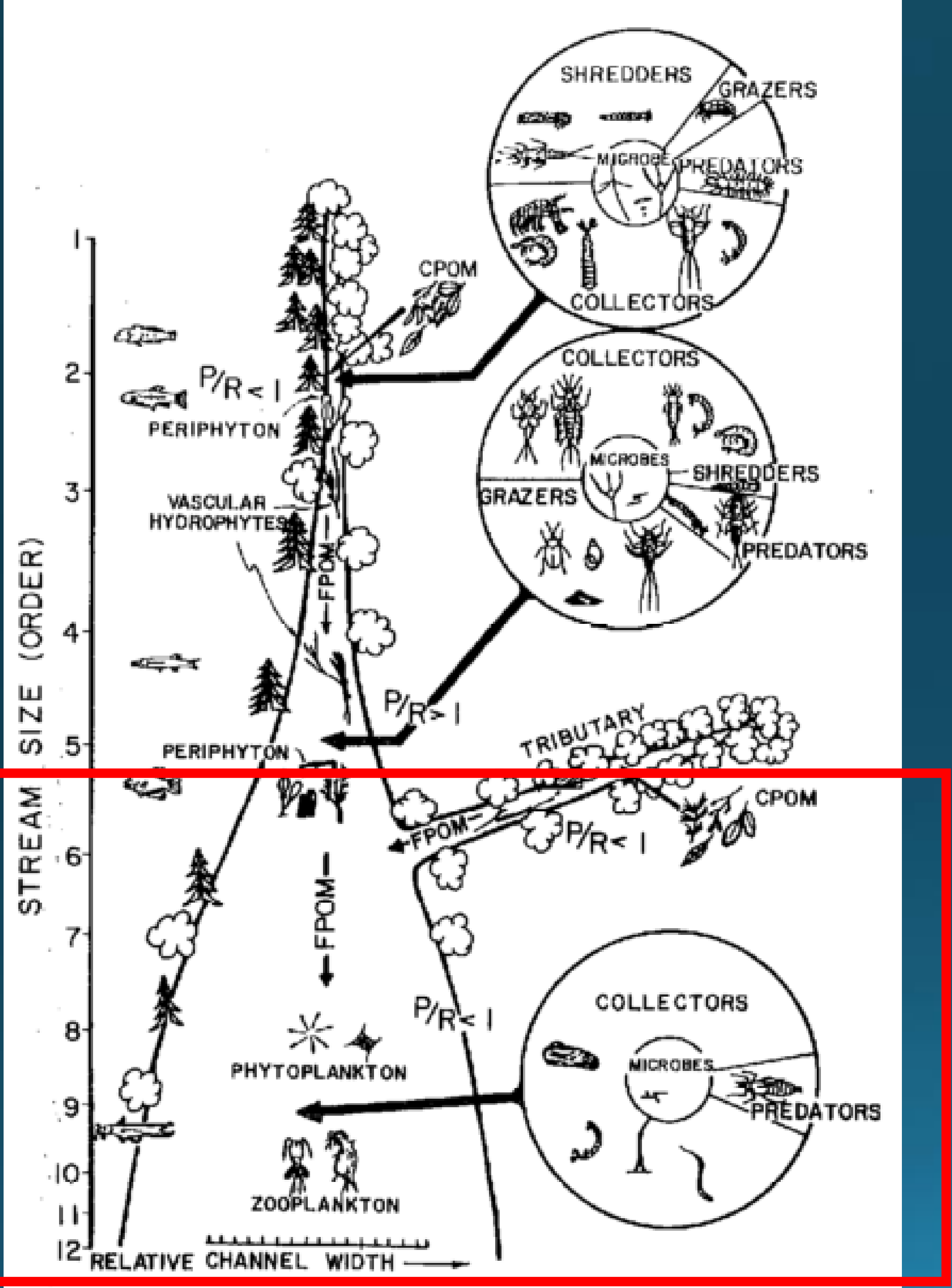


Vannote et al. 1980

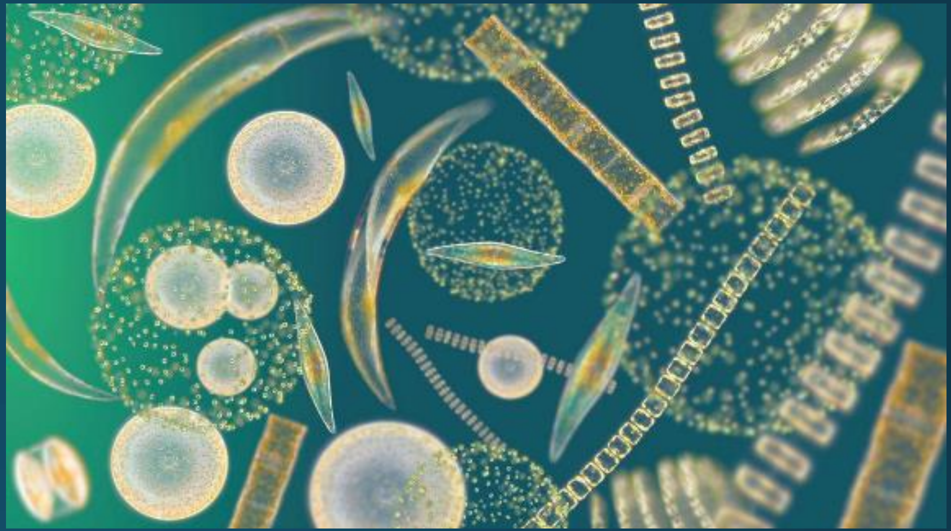


Vannote et al. 1980

Biofilm or Periphyton

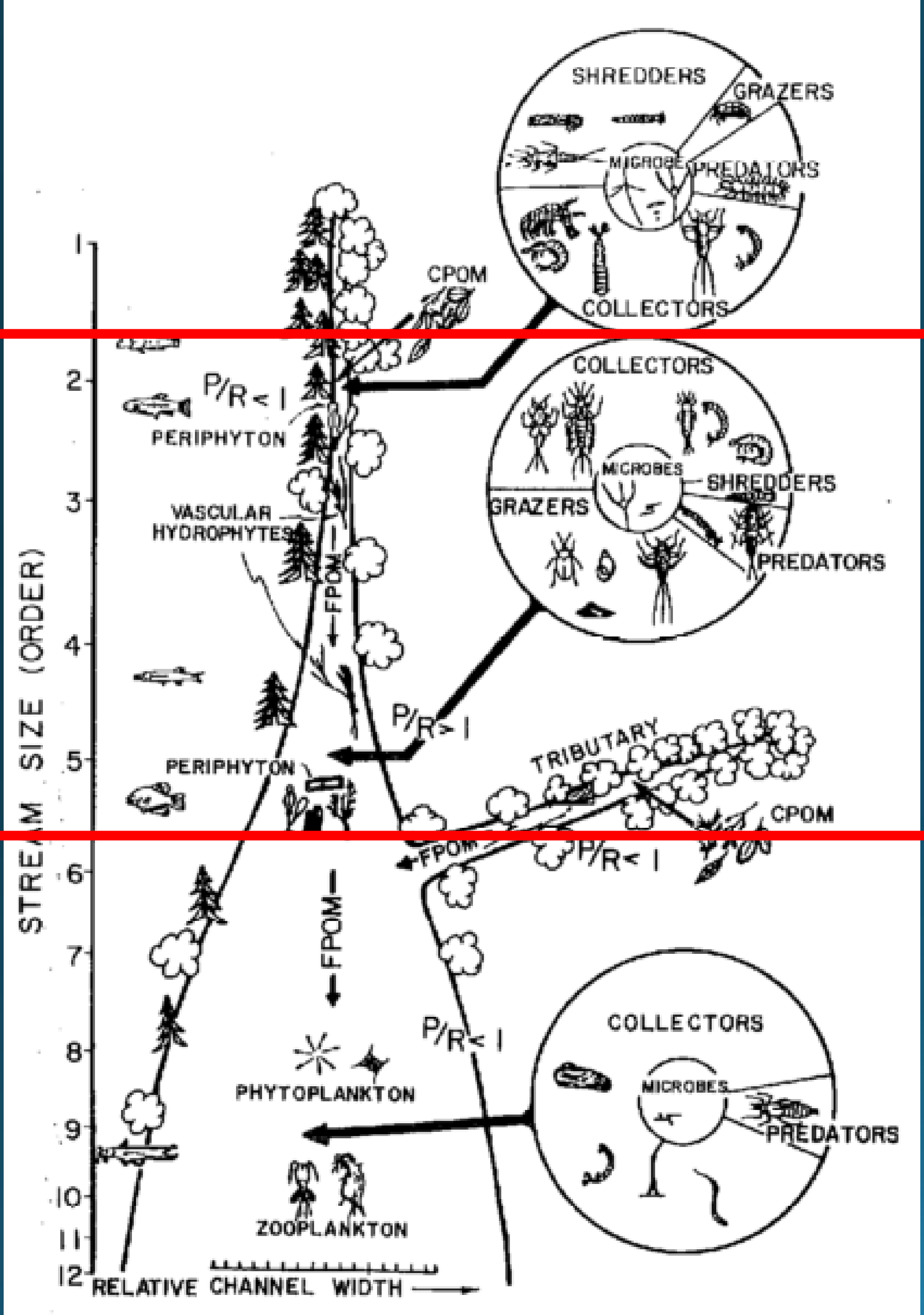


Vannote et al. 1980



Phytoplankton

Photo Credit: Smithsonian Magazine

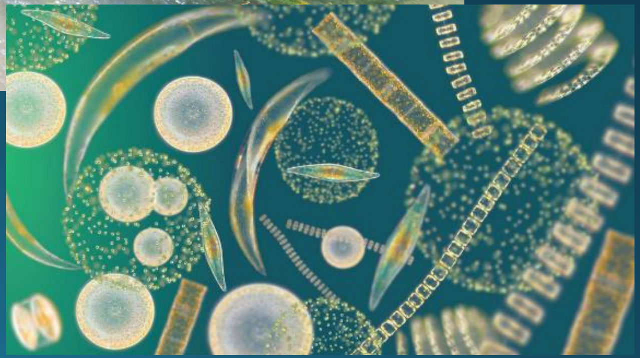


Vannote et al. 1980

Biofilm

Aquatic Plant: Podostemum

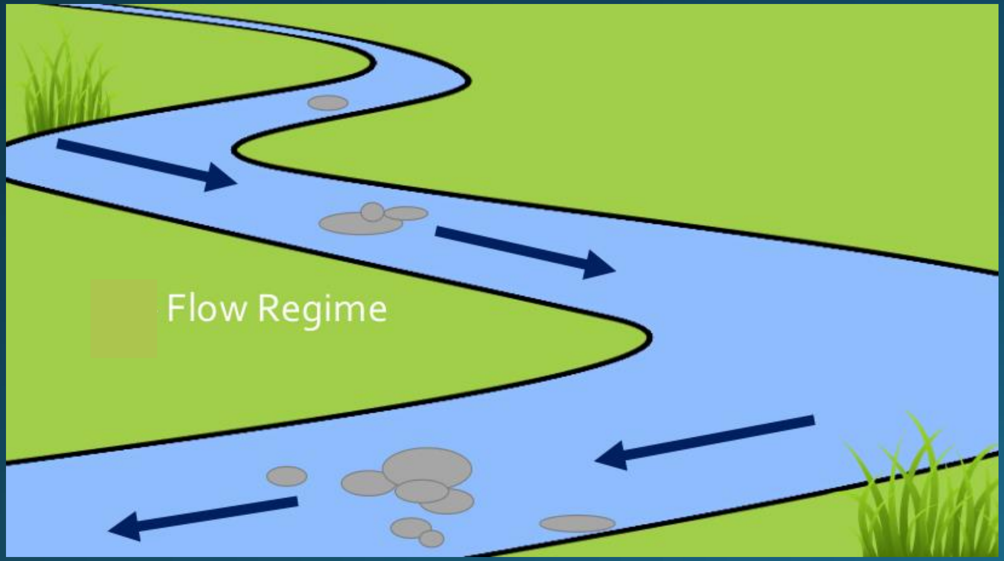
Filamentous Algae

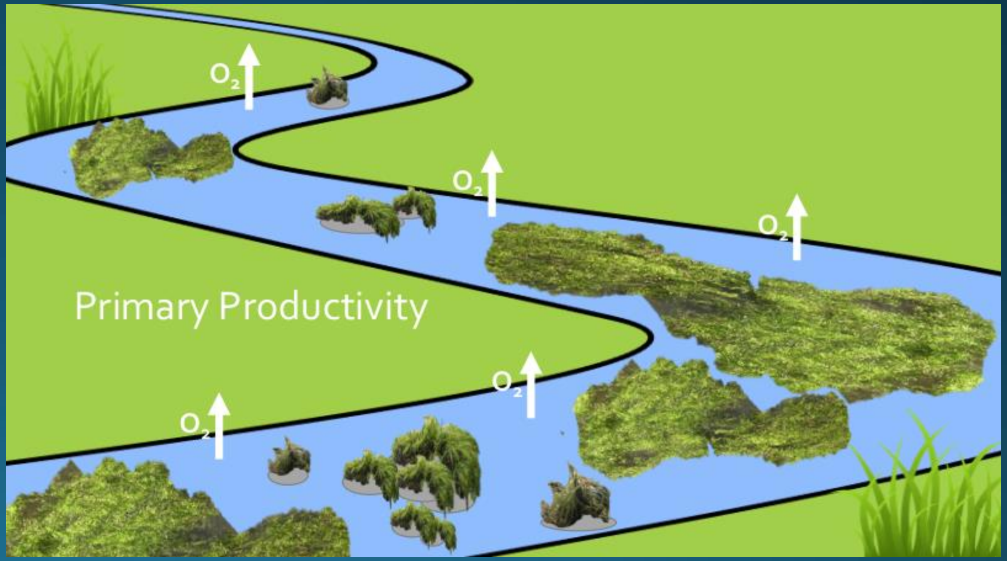


Phytoplankton

Research Objective

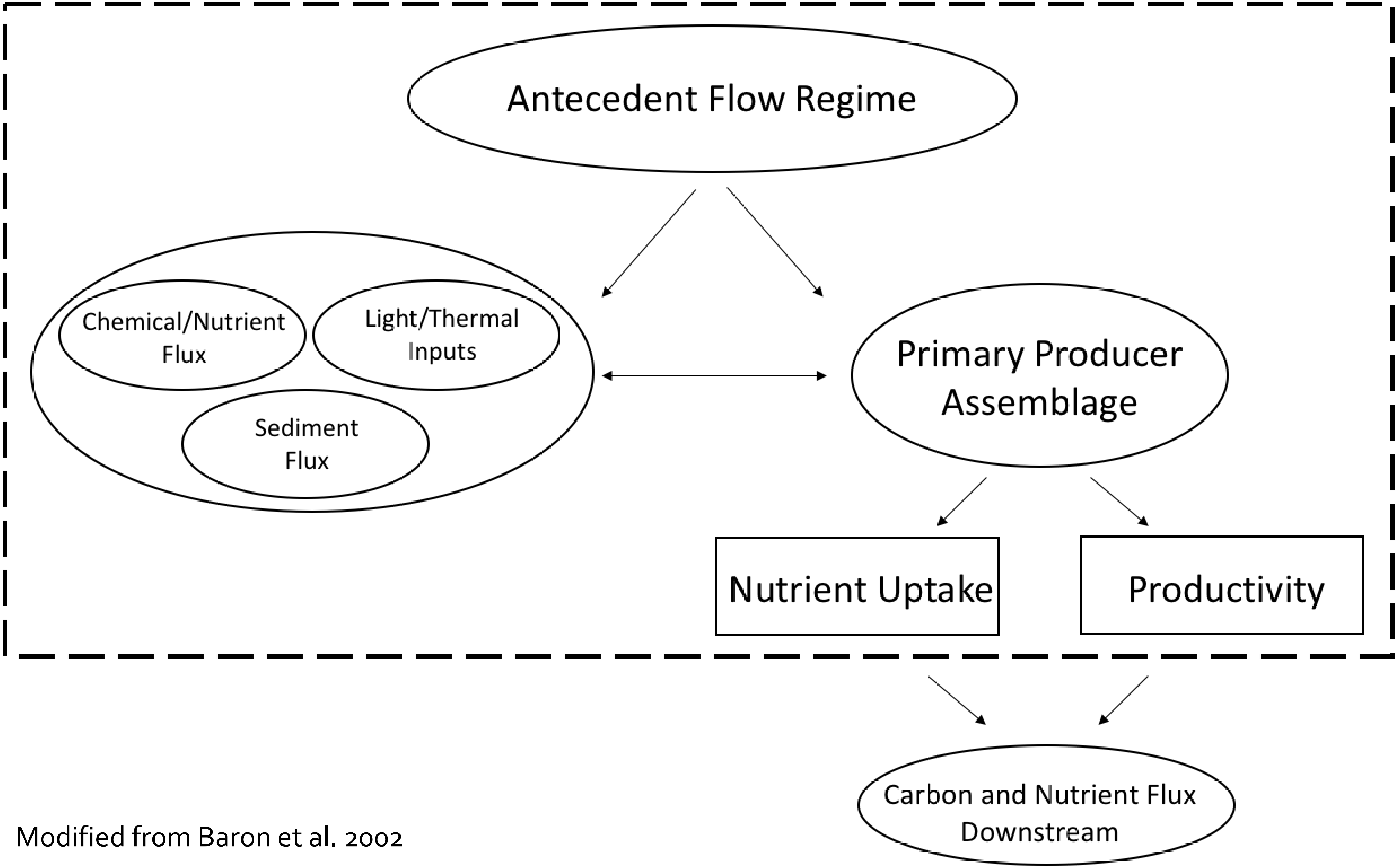
- To quantify the effects of flow variability on primary productivity





Current Research Objective

- To quantify the effects of antecedent flow conditions on primary productivity
- To determine ecosystem response under different management and climate scenarios

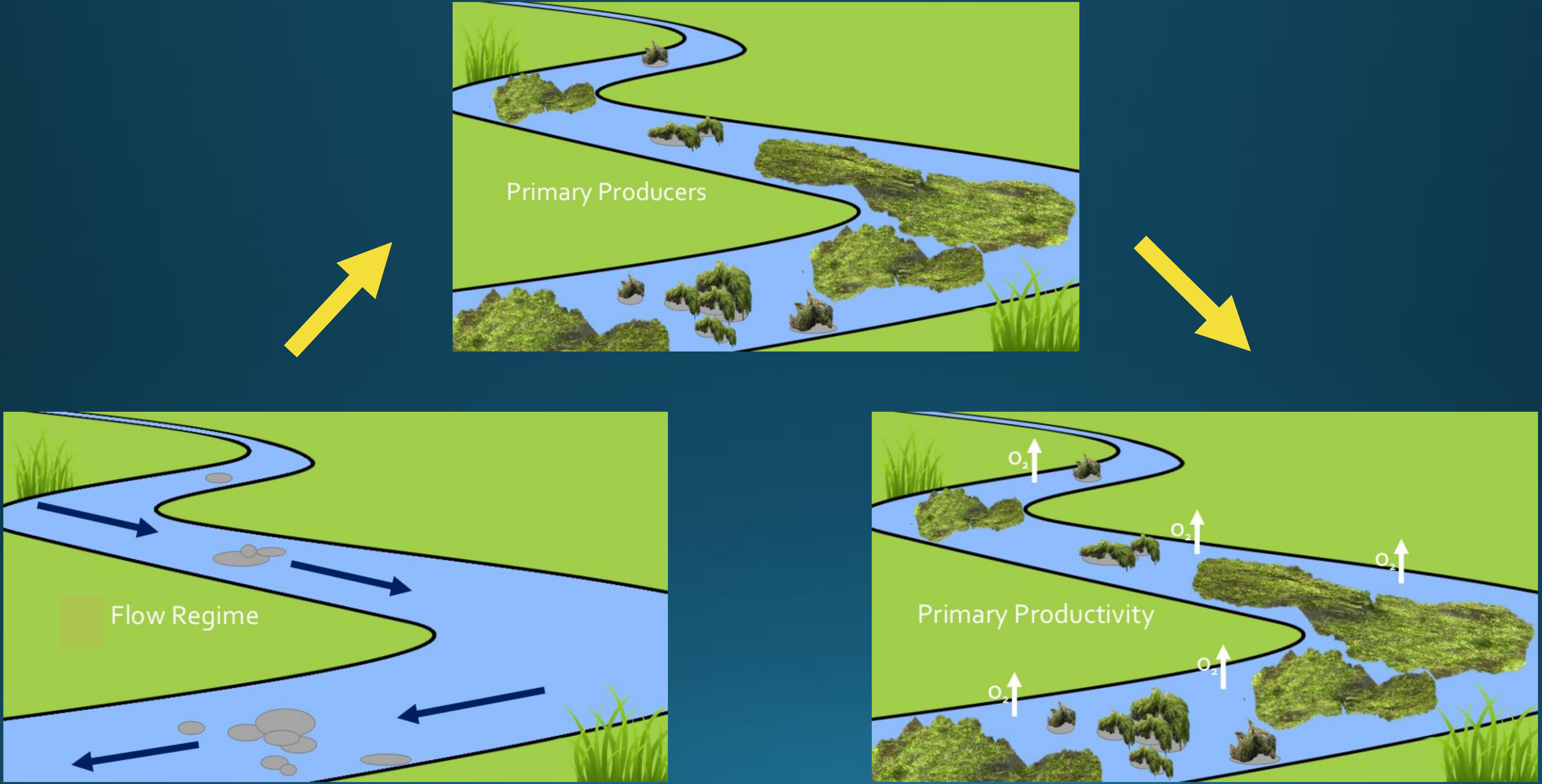


Modified from Baron et al. 2002

Predictions

- *Biotic components associated with each substrate have different per-unit mass productivity rates which may change seasonally and under different hydrologic regimes.*

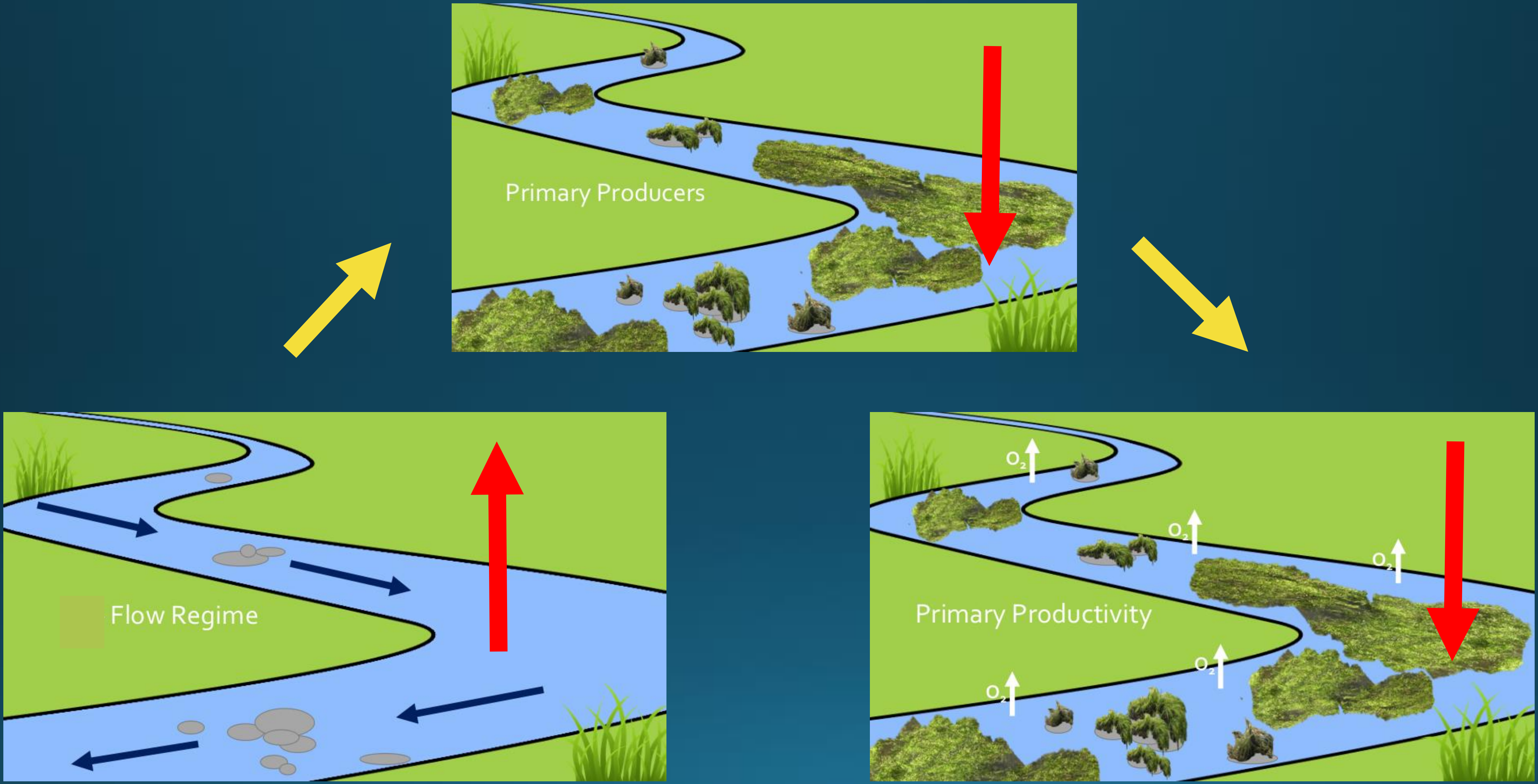
IDENTITY AND BIOMASS



Predictions

- *Biotic components associated with each substrate have different per-unit mass productivity rates which may change seasonally and under different hydrologic regimes.*
- *Extreme antecedent flow events are likely to reduce productivity by decreasing producer biomass, but that productivity at intermediate conditions is likely governed by the potentially contrasting responses of each biotic component to hydrologic variability.*

IDENTITY AND BIOMASS



Predictions

- *Biotic components associated with each substrate have different per-unit mass productivity rates which may change seasonally and under different hydrologic regimes.*
- *Extreme antecedent flow events are likely to reduce productivity by decreasing producer biomass, but that productivity at intermediate conditions is likely governed by the potentially contrasting responses of each biotic component to hydrologic variability.*
- *Variability in type and biomass of dominant biotic components resulting from hydrologic variability can explain dominant patterns in whole-stream metabolism.*

Research Components

USACE Hydrology Model

Chamber Studies

Monthly Biomass Sampling

Whole Stream Data Logging

Modeling Ecosystem Function

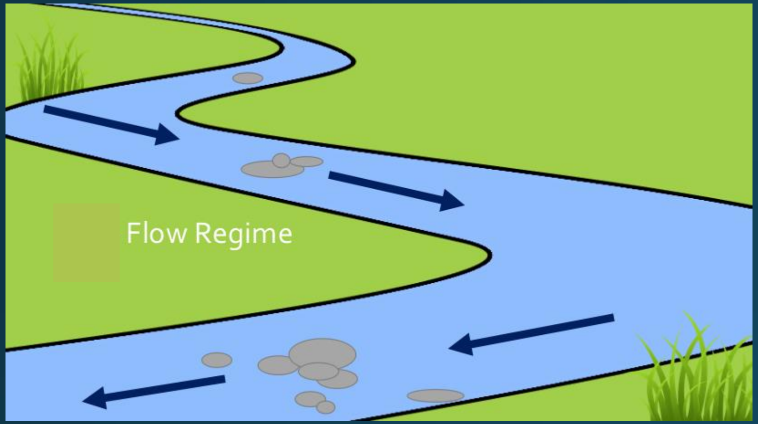
1512 *P.J. Mulholland* et al.

Table 2 Results of stepwise multiple regression analysis for rates of gross primary production (GPP), respiration (R) and net ecosystem production (NEP) (n = 8 for each regression)

Dependent variable	Independent variable	Parameter estimate (SE)	r^2	Prob > F
log GPP	Intercept	−1.737 (0.349)		0.0042
	log PAR	0.994 (0.147)	0.720	0.0011
	SRP	1.027 (0.338)	0.181	0.0288
	Full model		0.901	0.003
R	Intercept	4.104 (1.175)		0.013
	SRP	0.356 (0.129)	0.561	0.033
R (P = 0.15)	Intercept	3.775 (1.031)		0.0146
	SRP	0.255 (0.125)	0.560	0.0966
	A_s	9.572 (5.463)	0.167	0.1401
	Full model		0.73	0.0387
log(NEP + 10)	Intercept	0.298 (0.164)		0.1195
	log PAR	0.381 (0.150)	0.529	0.0437

Research Components

USACE Hydrology Model

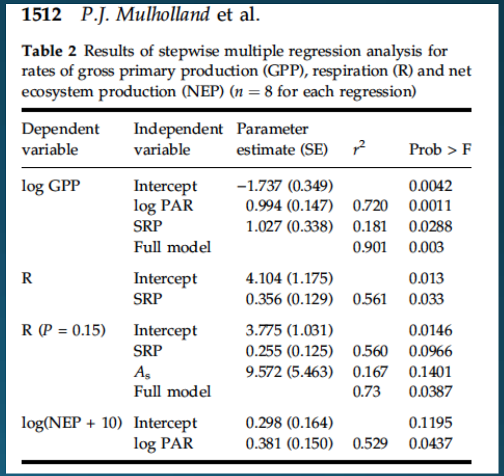


Chamber Studies

Monthly Biomass Sampling

Whole Stream Data Logging

Modeling Ecosystem Function



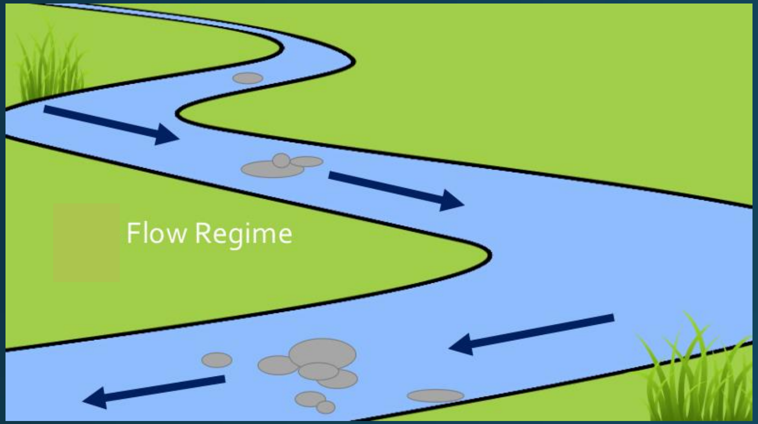
1512 *P.J. Mulholland* et al.

Table 2 Results of stepwise multiple regression analysis for rates of gross primary production (GPP), respiration (R) and net ecosystem production (NEP) ($n = 8$ for each regression)

Dependent variable	Independent variable	Parameter estimate (SE)	r^2	Prob > F
log GPP	Intercept	−1.737 (0.349)		0.0042
	log PAR	0.994 (0.147)	0.720	0.0011
	SRP	1.027 (0.338)	0.181	0.0288
	Full model		0.901	0.003
R	Intercept	4.104 (1.175)		0.013
	SRP	0.356 (0.129)	0.561	0.033
R ($P = 0.15$)	Intercept	3.775 (1.031)		0.0146
	SRP	0.255 (0.125)	0.560	0.0966
	A_s	9.572 (5.463)	0.167	0.1401
	Full model		0.73	0.0387
log(NEP + 10)	Intercept	0.298 (0.164)		0.1195
	log PAR	0.381 (0.150)	0.529	0.0437

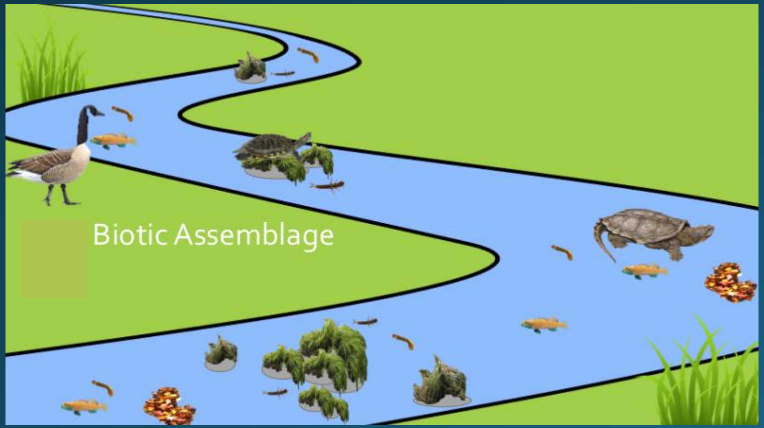
Research Components

USACE Hydrology Model



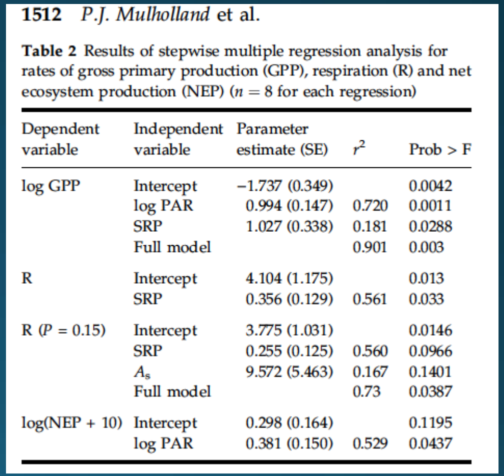
Chamber Studies

Monthly Biomass Sampling



Whole Stream Data Logging

Modeling Ecosystem Function



1512 *P.J. Mulholland* et al.

Table 2 Results of stepwise multiple regression analysis for rates of gross primary production (GPP), respiration (R) and net ecosystem production (NEP) (n = 8 for each regression)

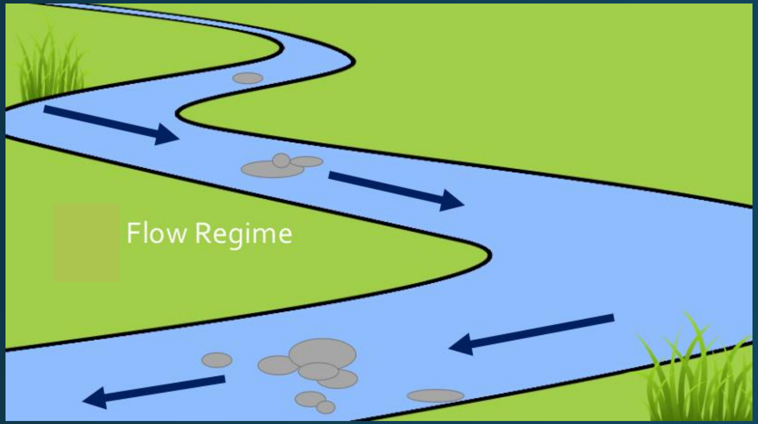
Dependent variable	Independent variable	Parameter estimate (SE)	r^2	Prob > F
log GPP	Intercept	−1.737 (0.349)		0.0042
	log PAR	0.994 (0.147)	0.720	0.0011
	SRP	1.027 (0.338)	0.181	0.0288
	Full model		0.901	0.003
R	Intercept	4.104 (1.175)		0.013
	SRP	0.356 (0.129)	0.561	0.033
R (P = 0.15)	Intercept	3.775 (1.031)		0.0146
	SRP	0.255 (0.125)	0.560	0.0966
	A_s	9.572 (5.463)	0.167	0.1401
	Full model		0.73	0.0387
log(NEP + 10)	Intercept	0.298 (0.164)		0.1195
	log PAR	0.381 (0.150)	0.529	0.0437

Biomass Sampling

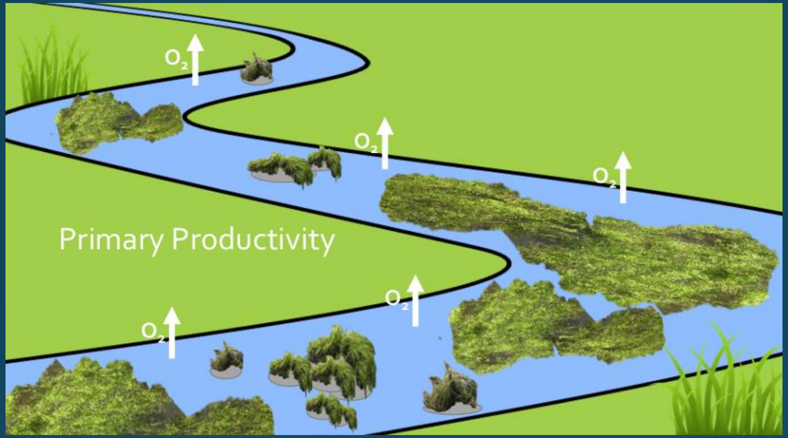
Photo credit: Phillip Bumpers, Amy Rosemond

Research Components

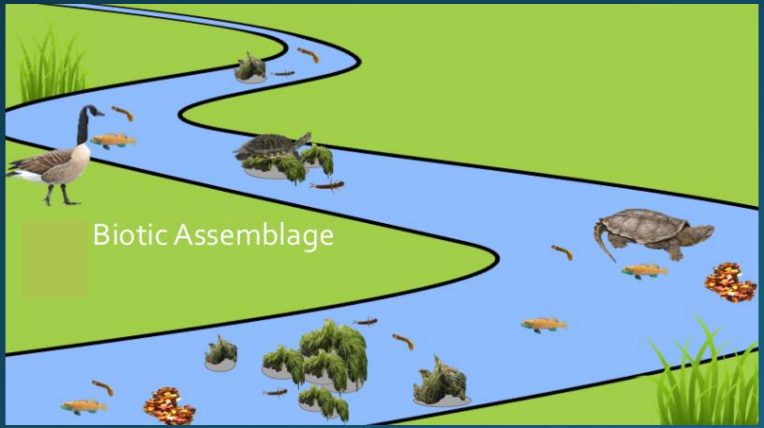
USACE Hydrology Model



Chamber Studies

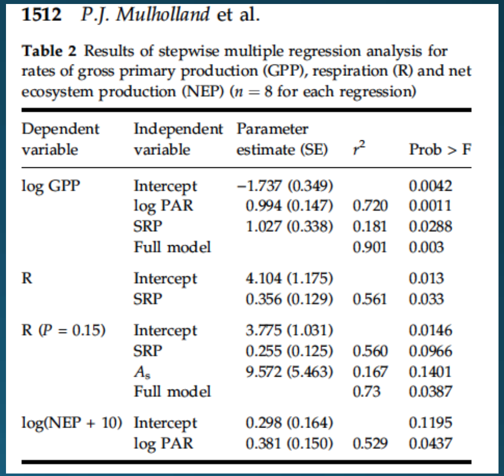


Monthly Biomass Sampling



Whole Stream Data Logging

Modeling Ecosystem Function

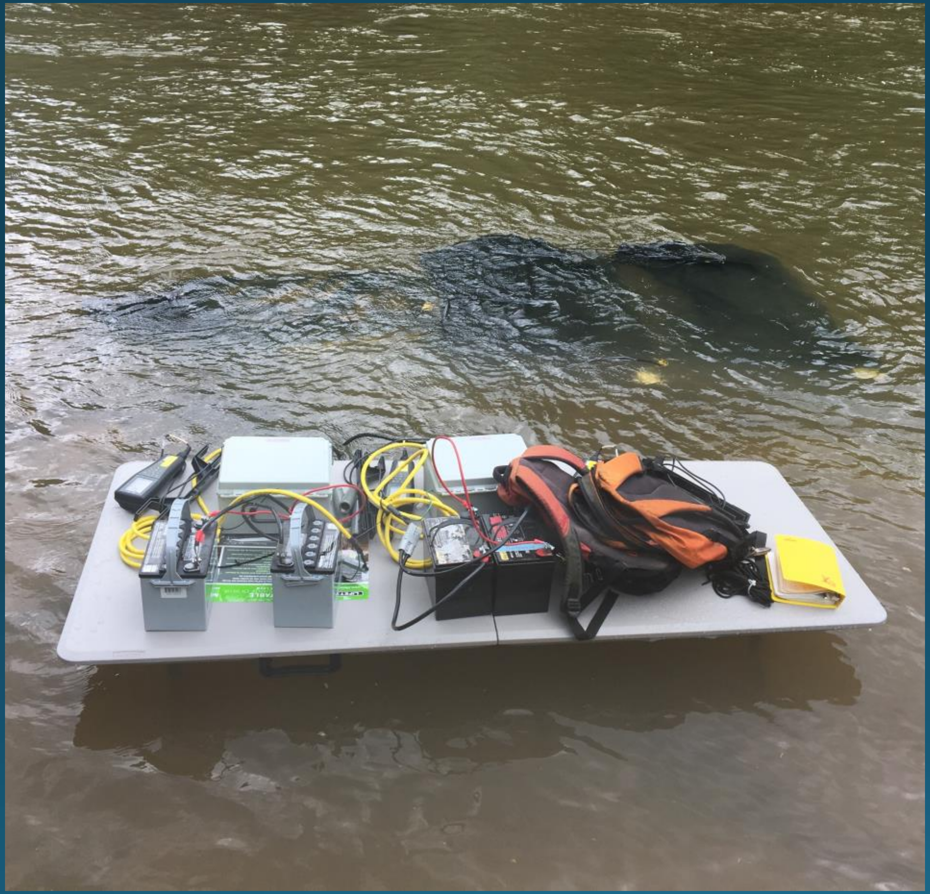


1512 *P.J. Mulholland* et al.

Table 2 Results of stepwise multiple regression analysis for rates of gross primary production (GPP), respiration (R) and net ecosystem production (NEP) (n = 8 for each regression)

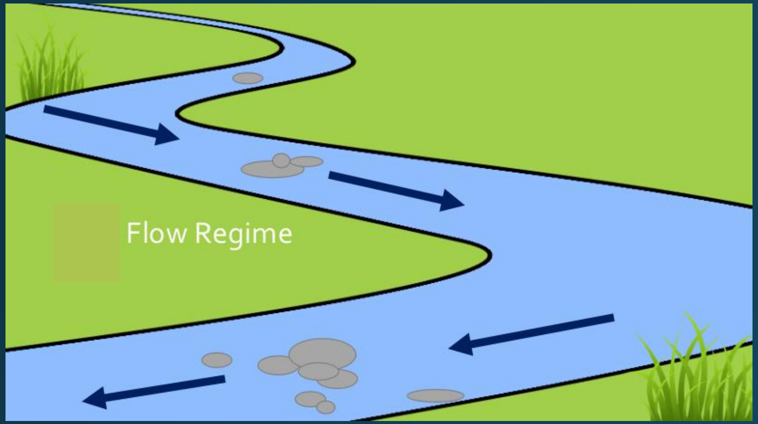
Dependent variable	Independent variable	Parameter estimate (SE)	r^2	Prob > F
log GPP	Intercept	−1.737 (0.349)		0.0042
	log PAR	0.994 (0.147)	0.720	0.0011
	SRP	1.027 (0.338)	0.181	0.0288
	Full model		0.901	0.003
R	Intercept	4.104 (1.175)		0.013
	SRP	0.356 (0.129)	0.561	0.033
R (P = 0.15)	Intercept	3.775 (1.031)		0.0146
	SRP	0.255 (0.125)	0.560	0.0966
	A_s	9.572 (5.463)	0.167	0.1401
	Full model		0.73	0.0387
log(NEP + 10)	Intercept	0.298 (0.164)		0.1195
	log PAR	0.381 (0.150)	0.529	0.0437

Chamber Studies

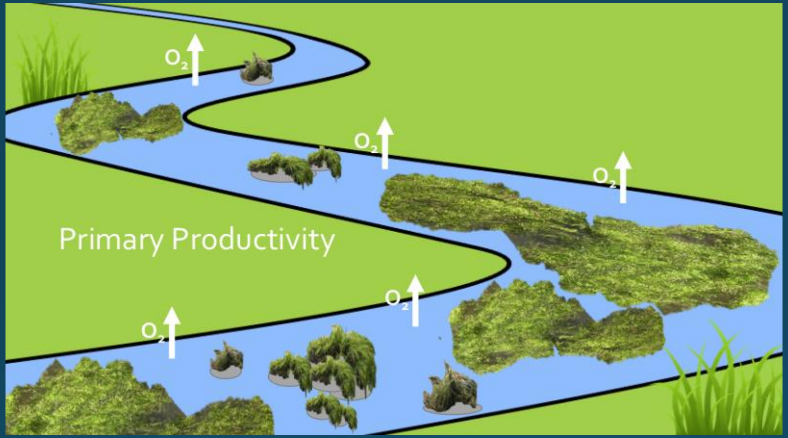


Research Components

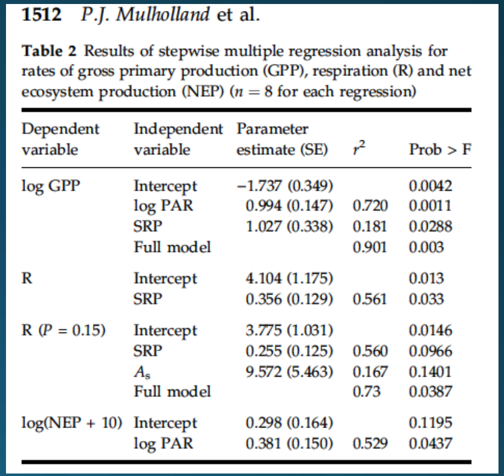
USACE Hydrology Model



Chamber Studies



Modeling Ecosystem Function

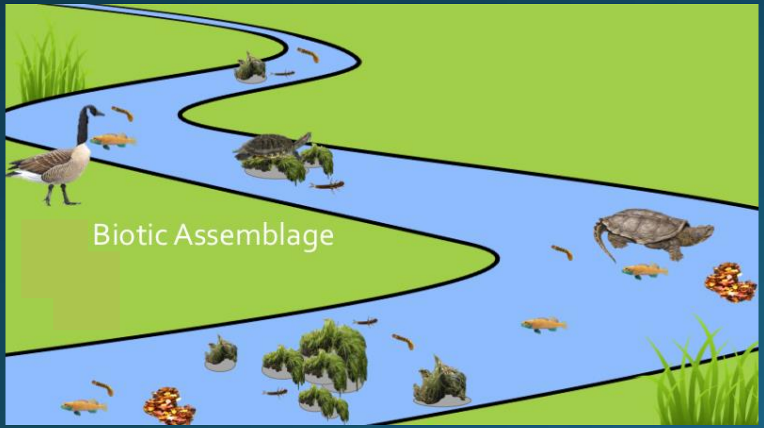


1512 *P.J. Mulholland* et al.

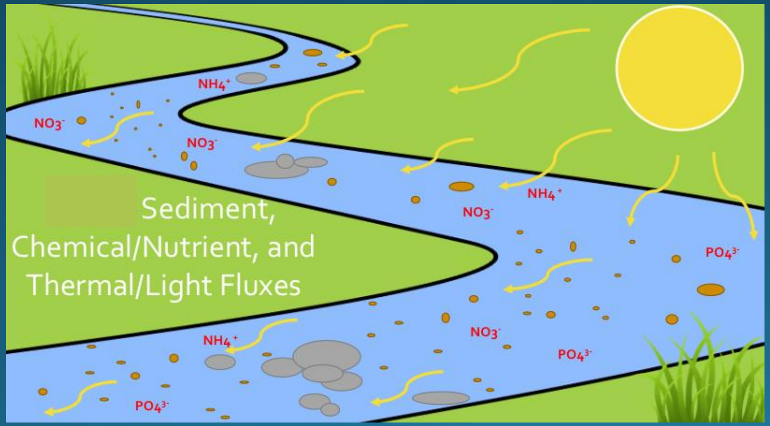
Table 2 Results of stepwise multiple regression analysis for rates of gross primary production (GPP), respiration (R) and net ecosystem production (NEP) (n = 8 for each regression)

Dependent variable	Independent variable	Parameter estimate (SE)	r^2	Prob > F
log GPP	Intercept	−1.737 (0.349)		0.0042
	log PAR	0.994 (0.147)	0.720	0.0011
	SRP	1.027 (0.338)	0.181	0.0288
	Full model		0.901	0.003
R	Intercept	4.104 (1.175)		0.013
	SRP	0.356 (0.129)	0.561	0.033
R (P = 0.15)	Intercept	3.775 (1.031)		0.0146
	SRP	0.255 (0.125)	0.560	0.0966
	A_s	9.572 (5.463)	0.167	0.1401
	Full model		0.73	0.0387
log(NEP + 10)	Intercept	0.298 (0.164)		0.1195
	log PAR	0.381 (0.150)	0.529	0.0437

Monthly Biomass Sampling

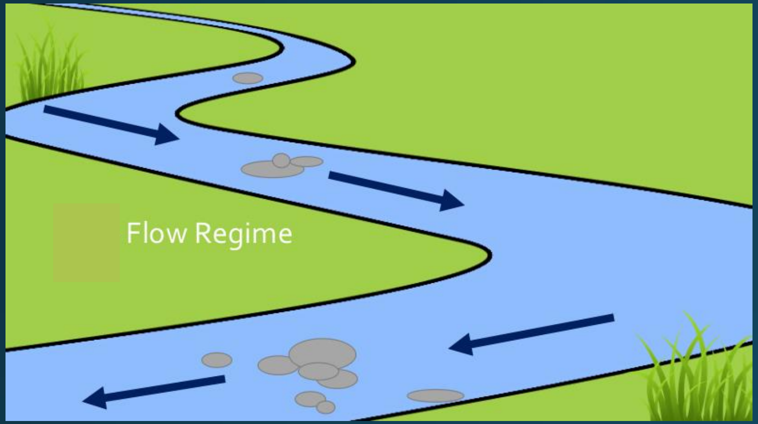


Whole Stream Data Logging

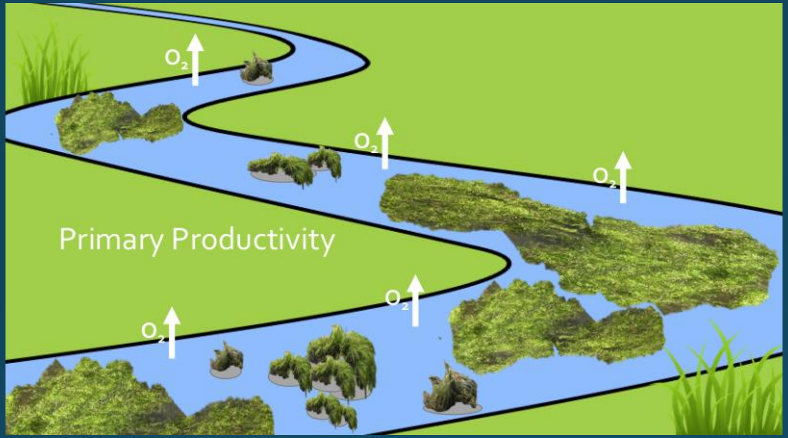


Research Components

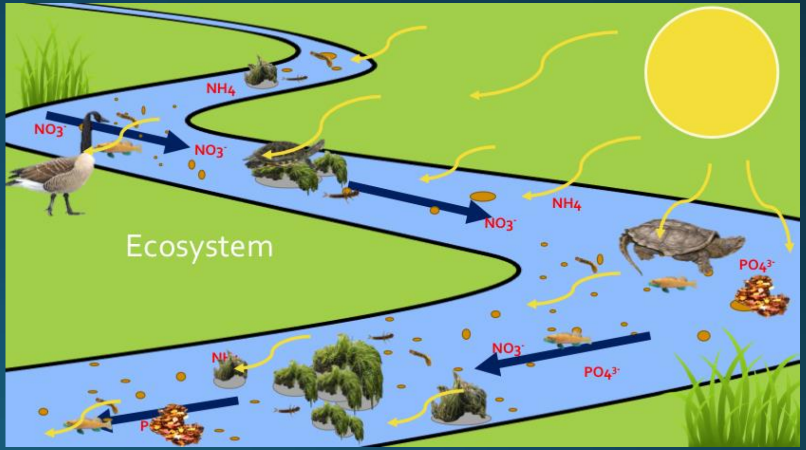
USACE Hydrology Model



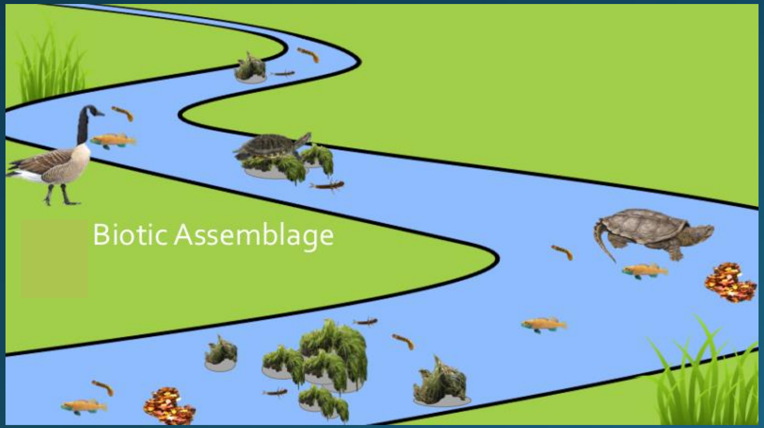
Chamber Studies



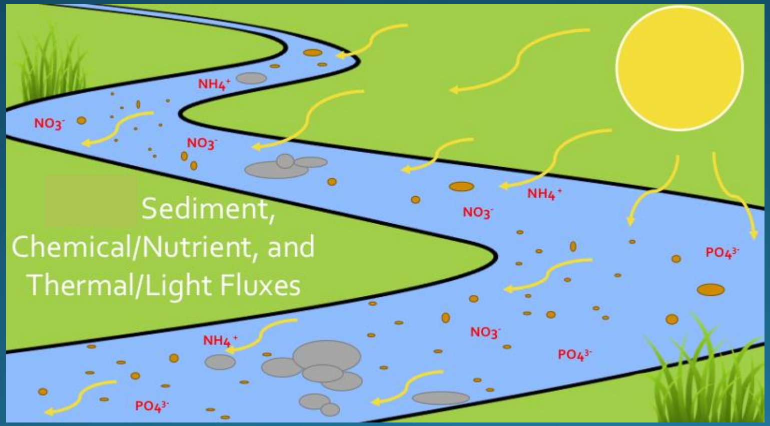
Modeling Ecosystem Function



Monthly Biomass Sampling



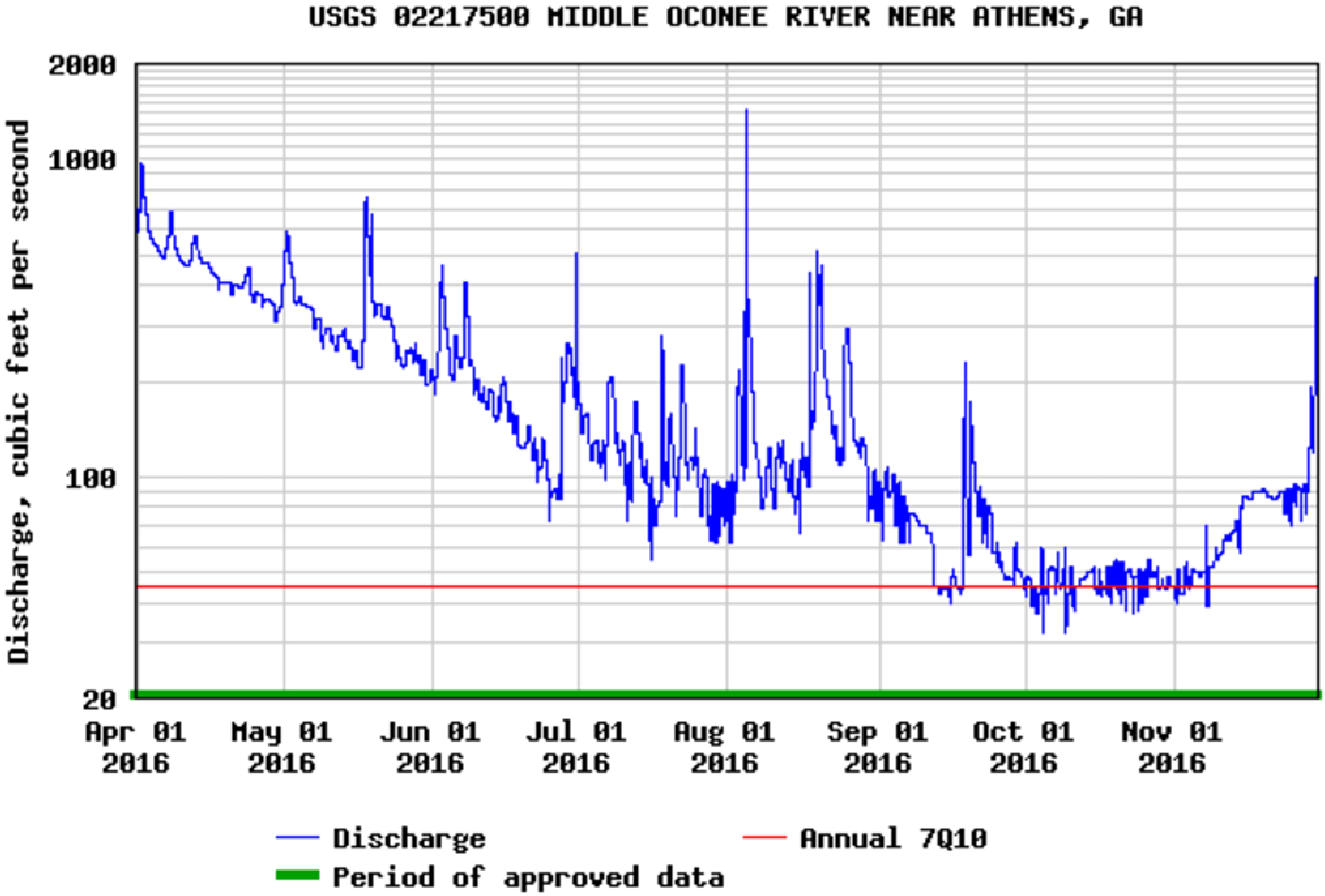
Whole Stream Data Logging

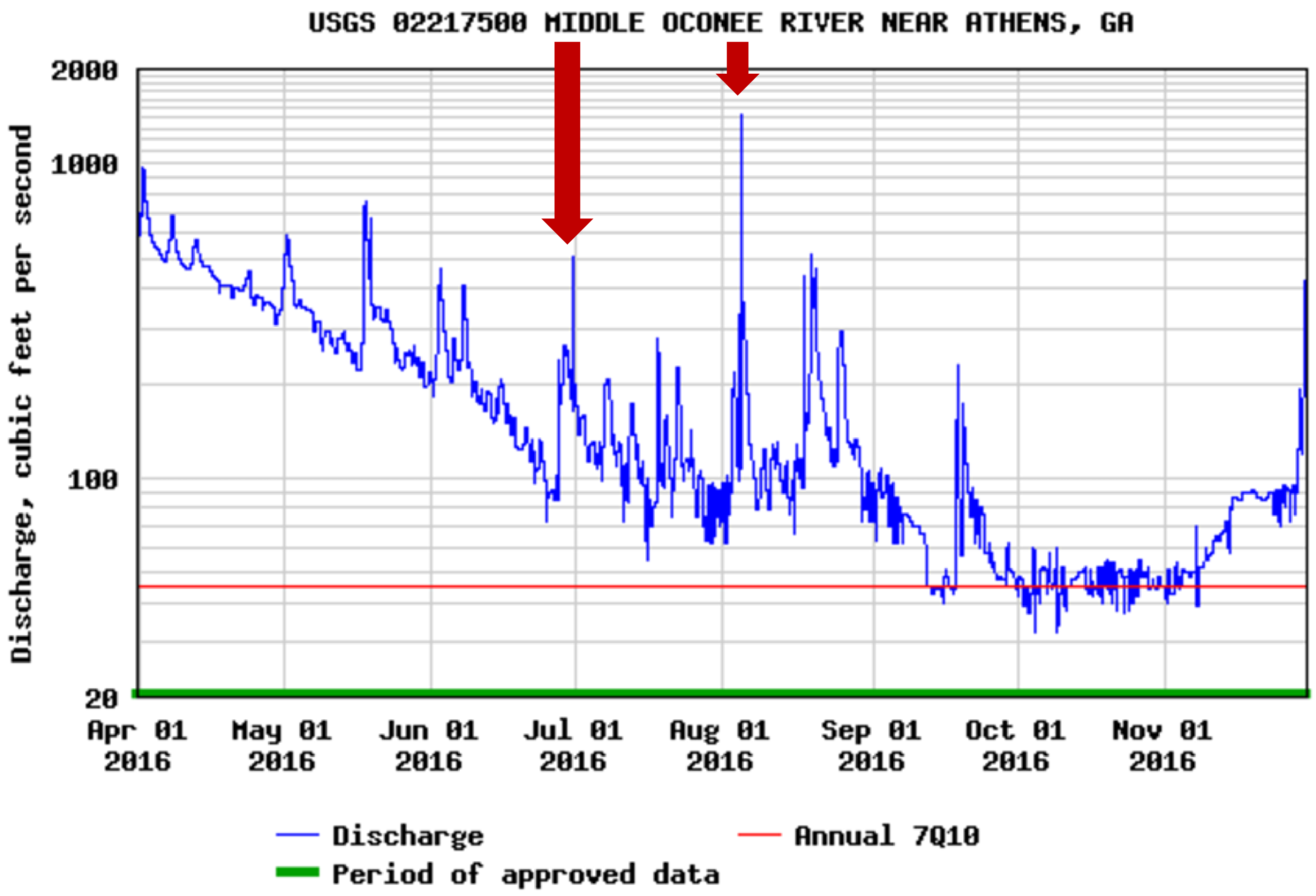


Primary Producer Community

- Macrophytes
  - *Podostemum ceratophyllum*
- Algae
  - Filamentous Green
  - Red Algae
  - Diatoms
  - Biofilm/Periphyton
- Phytoplankton

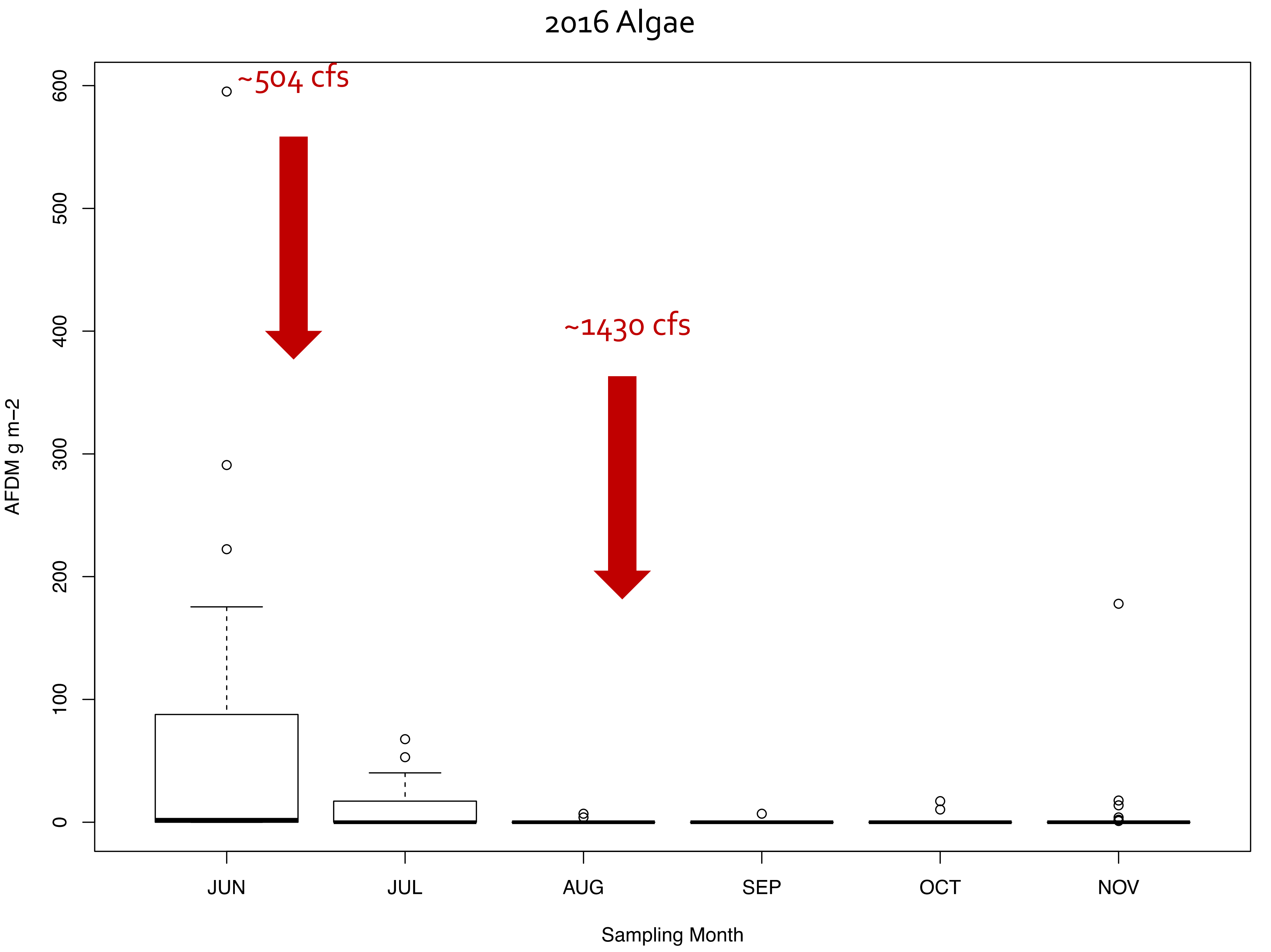
Photo credit: Phillip Bumpers


USGS 02217500 MIDDLE OCONEE RIVER NEAR ATHENS, GA
Discharge, cubic feet per second
2000
1000
100
20
Apr 01 2016
May 01 2016
Jun 01 2016
Jul 01 2016
Aug 01 2016
Sep 01 2016
Oct 01 2016
Nov 01 2016
Discharge
Annual 7Q10
Period of approved data

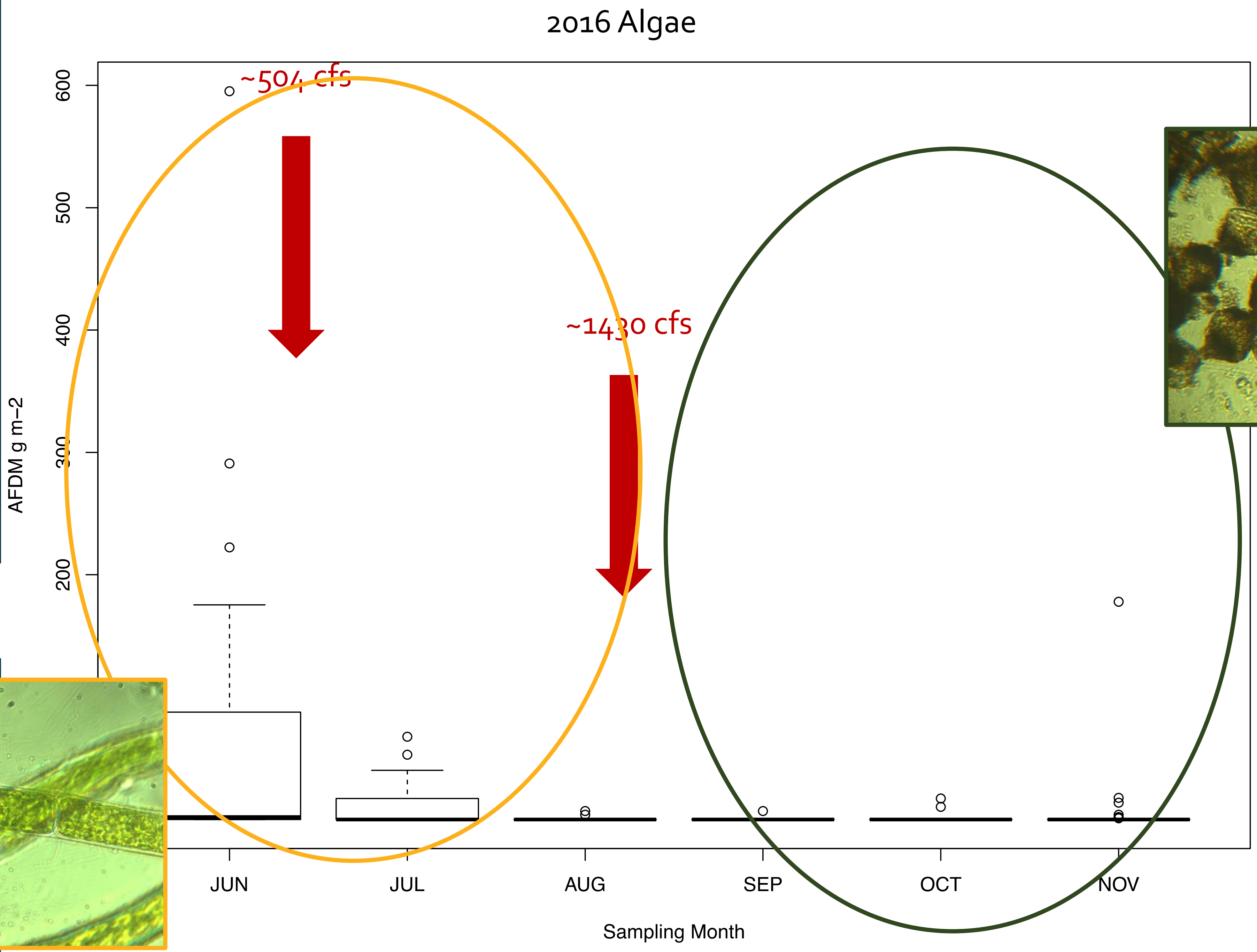

USGS 02217500 MIDDLE OCONEE RIVER NEAR ATHENS, GA
Discharge, cubic feet per second
2000
1000
100
20
Apr 01 2016
May 01 2016
Jun 01 2016
Jul 01 2016
Aug 01 2016
Sep 01 2016
Oct 01 2016
Nov 01 2016
Discharge
Annual 7Q10
Period of approved data

Before and After High Flows

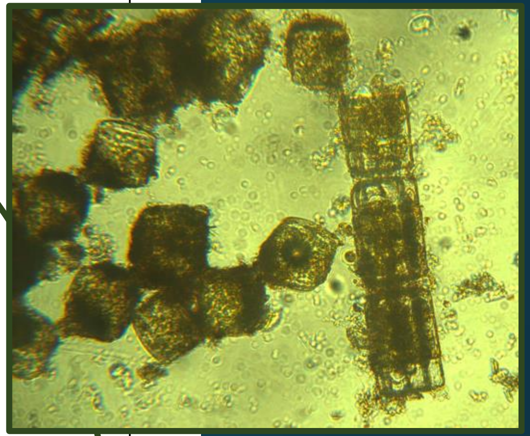
Photo credit: Phillip Bumpers


2016 Algae
~504 cfs
~1430 cfs
AFDM g m−2
0
100
200
300
400
500
600
JUN
JUL
AUG
SEP
OCT
NOV
Sampling Month

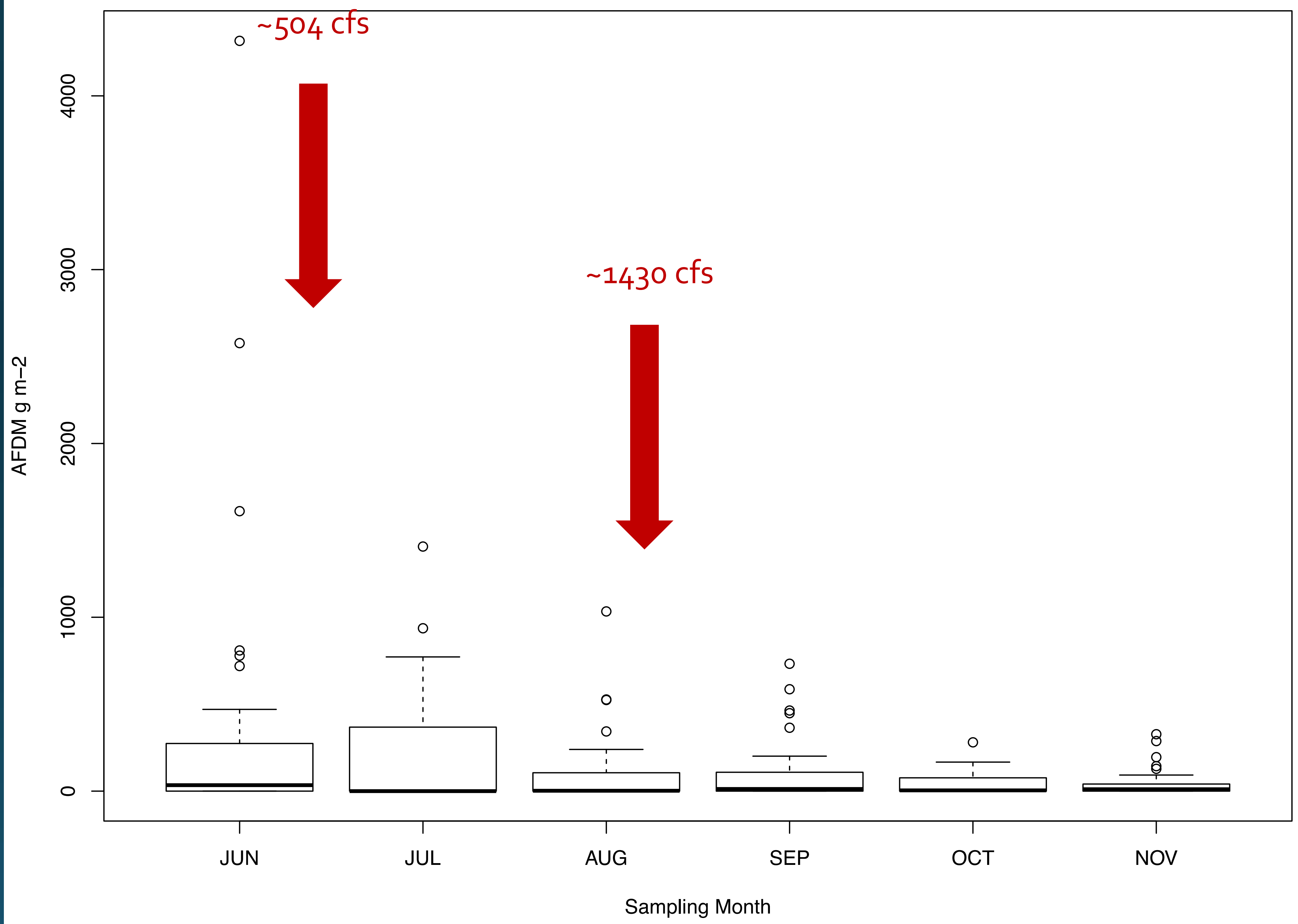
Filamentous Algae



Diatom



2016 Podostemum



February 2017

Turbidity = <10 NTU, Discharge = 191 cfs

April 2017

Turbidity = 355 NTU, Discharge = 3920 cfs

Metabolism

- Podostemum (bottom left)
- Phytoplankton (top right)
- Biofilm (bottom right)

An Honest Discussion

- Where we our in our understanding of function?

- Could structure be enough of an indicator of function?

Acknowledgements

Thank you to the Wenger lab, Rosemond lab, and the many undergraduates, fellow graduate students, and staff who have helped me already!

US Army Corps of Engineers®

UNIVERSITY OF GEORGIA
River Basin Center