Modeling riverine macrophyte growth to improve ecological outcomes of river management

Lee H. Dietterich, Suhey Ortiz Rosa, and S. Kyle McKay

US Army Engineer Research and Development Center, Environmental Laboratory

University of Georgia, River Basin Center

Lee.Dietterich@gmail.com

https://sites.google.com/view/usace-wrises

ANSRP Aquatic Nuisance Species Research Program

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

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Riverine macrophytes

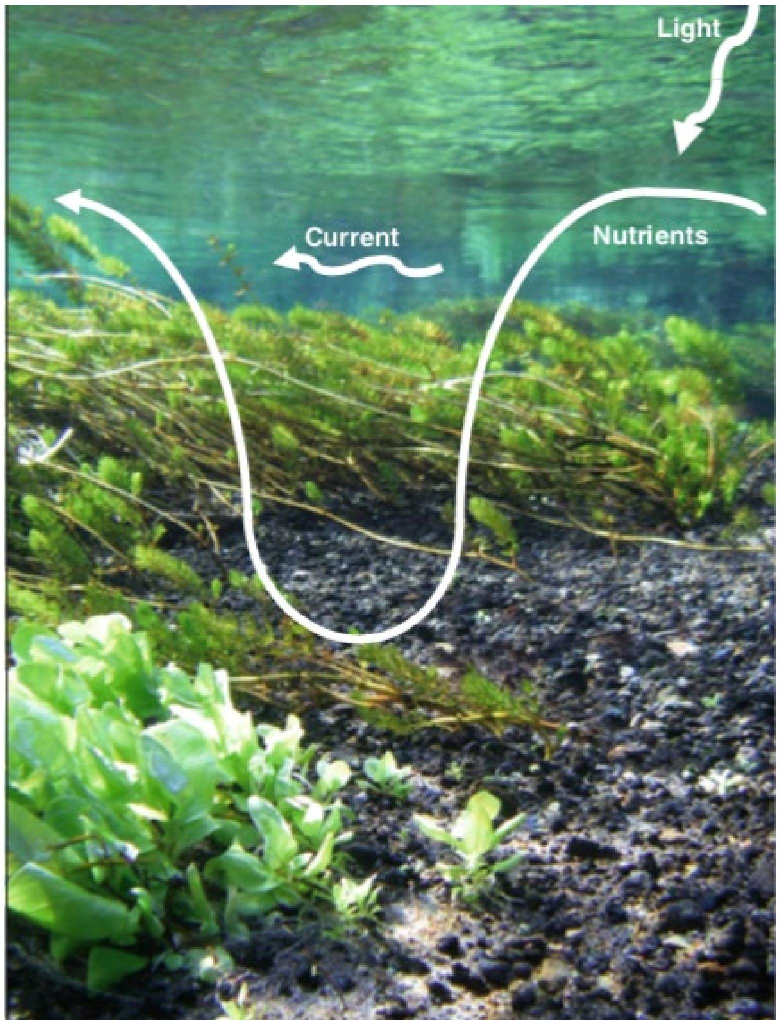

Image: Mebane et al. 2014 *Hydrobiologia*

- True plants growing in rivers
- Affect and are affected by:
  - Light
  - Nutrients/toxins
  - Sediment
  - Hydraulic flow
  - Other organisms (competition, herbivory)
  - Human water use

Need for riverine macrophyte models

- Models important for learning and forecasting
- Can inform water management
- Riverine macrophyte models scarce
- Models from other systems may not work well in rivers
    - Unidirectional water flow

Objectives

- Review existing modeling approaches
- Compile a framework for model development
- Case study: *Podostemum ceratophyllum* (hornleaf riverweed)

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Modeling approaches: hydrogeomorphic

- Focus on hydraulic flow or geomorphology
- Macrophyte growth in varying detail
- Macrophytes as route to hydraulic roughness or sediment dynamics

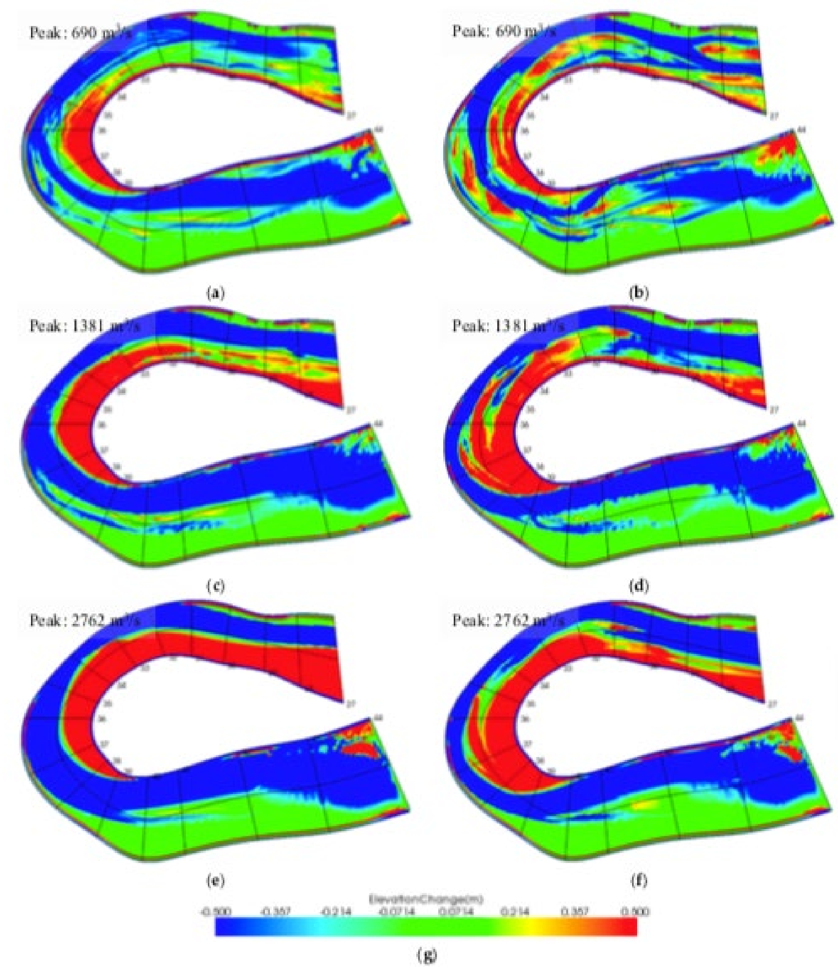

Image: Kang et al. 2018 *Water*

Larsen et al. 2007, Berger and Wells 2008, Gurnell et al. 2012, Kang et al. 2017

Modeling approaches: biogeochemical

- Focus on carbon or nutrient cycling
- Macrophytes as time-variable oxygen equivalents (Park and Uchrin 1997)

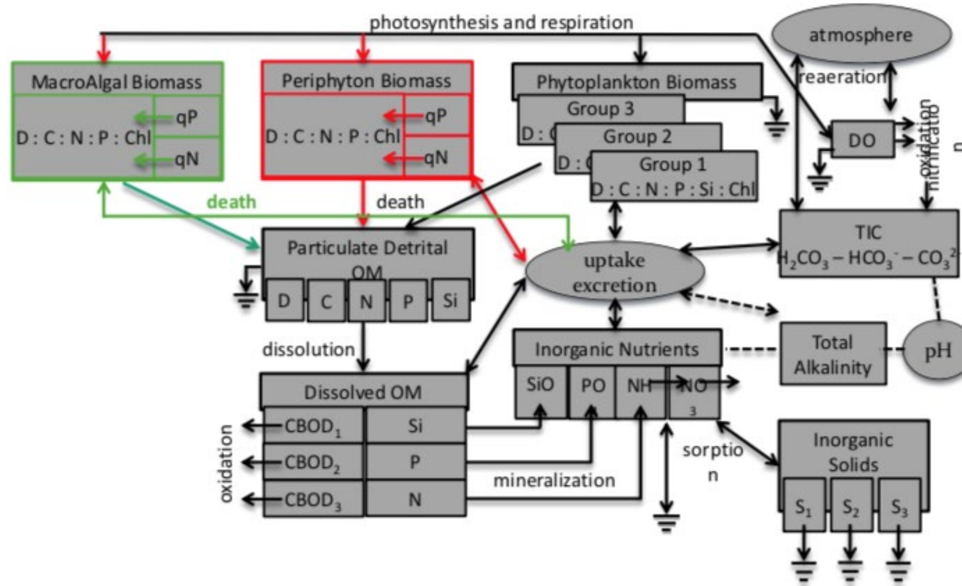

Figure 4. State Variables and Processes in Modified Model

Image: Martin et al. (WASP8)

Modeling approaches: ecological

- Focus on spatial patterns of occurrence
- Dispersal patterns/mechanisms (Chiarello and Barrat-Segretain 1997)
- Effects of flow regime on habitat suitability (Ochs et al. 2018)
- Algal growth mechanistic, but only depth and light determine macrophyte habitat suitability (Hua and Yong 2009)

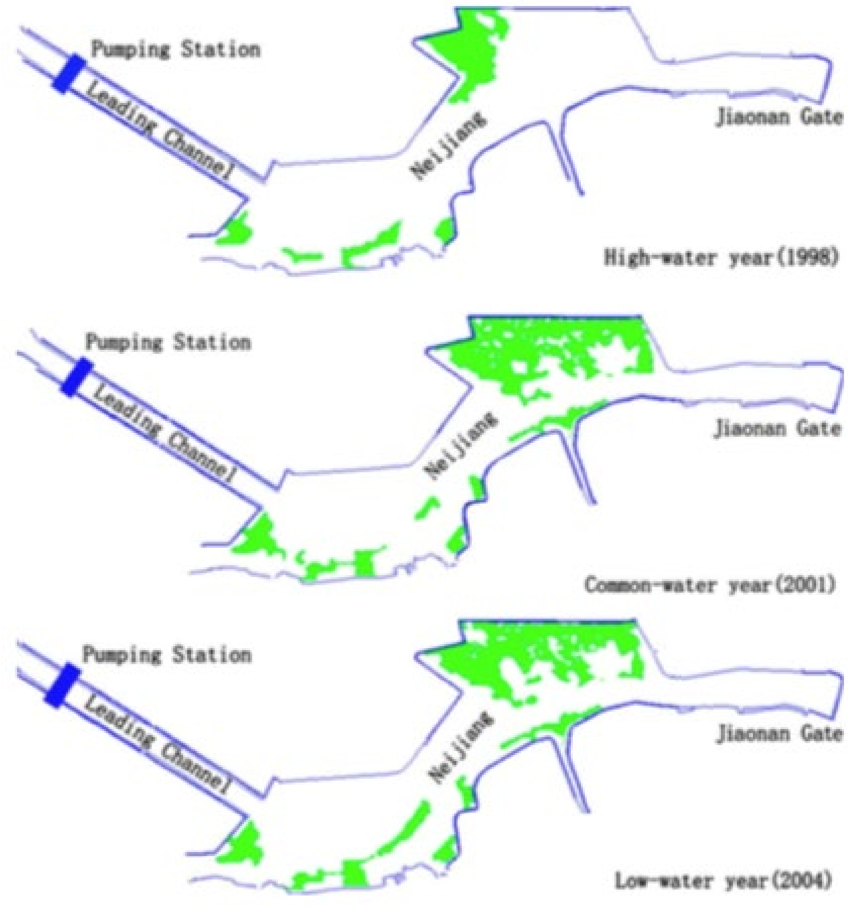

Fig. 11 Distribution of *Vallisneria spiralis* restoration area after water operation in different level years

Image: Hua and Yong 2009
Water Resource Mgt

Modeling approaches: mechanistic

- Reductionist level of detail
- Light
  - Availability at water surface
  - Attenuation by water and suspended material
  - Efficiency of plant light use
- Nutrients
  - Availability to plant
  - Uptake kinetics
- Macrophyte biology
  - Growth stage transitions
  - Tissue-specific respiration

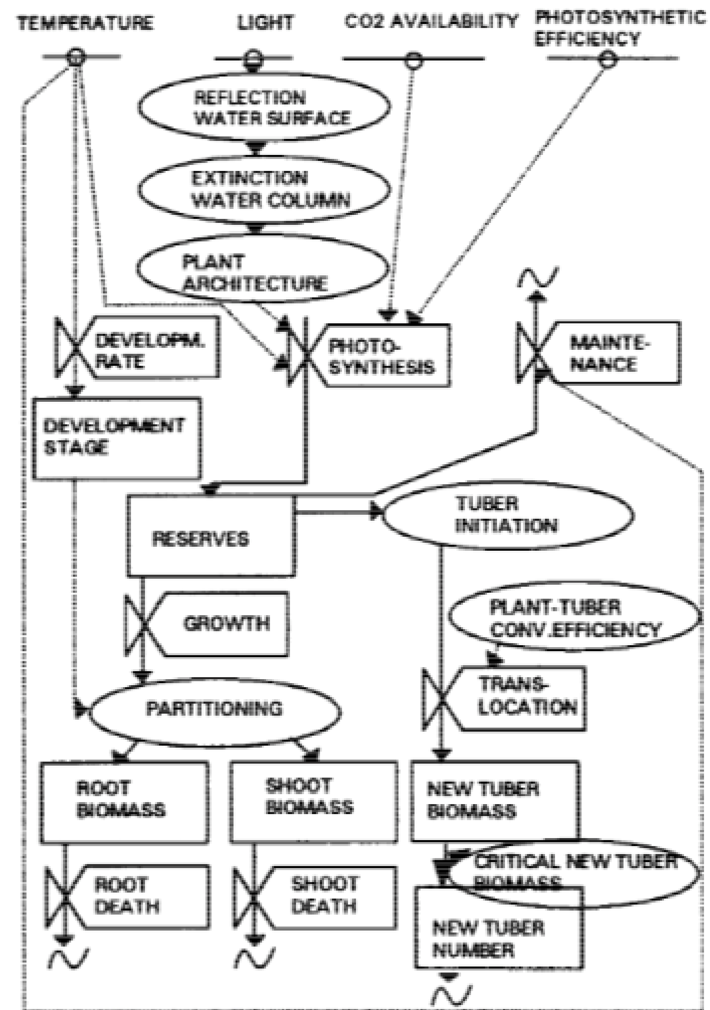

Image: Best et al. 2001 *Hydrobiologia*

Wright and McDonnell 1986, Davis and McDonnell 1997, Best et al. 2001, Best and Boyd 2003, Garbey et al. 2006, Best and Boyd 2007, Berger and Wells 2008, WASP, CASM, ATP, MEDALUS, and more

Formal literature review

- Search for mechanistic models simulating riverine macrophyte growth over time
- Web of Science search: 344 results
  - (ALL=(river OR lotic) AND (ALL=(plant grow* OR plant biomass OR plant produc* OR macrophyte grow* OR macrophyte biomass OR macrophyte produc*)) AND (ALL=(numerical model OR simulation model OR quantitative model)) AND (ALL=(mechanis* OR Michaelis-Menten OR physics-based OR dynamic)))
- Also included gray literature

Dietterich et al. *in prep*

Literature review: biomass growth

	Model abbreviation	A	B	C	D	E	F	G	H	I	J	K	L	Number of models that include process
Plant growth	Macrophyte germination, establishment, or dispersal	Yes	No	No	Optional	No	No	No	No	No	Optional	No	No	3
	Light availability at water surface	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	11
	Light attenuation in water column	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	8
	Temperature limitation of growth	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	10
	Nutrient limitation of growth	C, N, P 1	N, P, Si 1	C, N, P	P	P	No	No	P	N, P	N, P	N, P	P	10
	Carbon source	CO2	No	DIC	No	No	No	CO2	No	No	No	H2CO3, HCO3-, CO2	No	4

Dietterich et al. *in prep*

Model review: biomass loss

	Model abbreviation	A	B	C	D	E	F	G	H	I	J	K	L	Number of models that include process
Biomass loss mechanics	Temperature affects biomass loss	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	8
	Respiration	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	9
	Mortality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12
	Herbivory	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	4
	Intraspecific competition for light (self-shading)	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	8
	Intraspecific competition for space	No	No	No	No	No	Yes	Yes	No	No	No	No	No	2
	Interspecific competition for light	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	7
	Interspecific competition for space	No	No	No	No	No	No	No	No	No	No	Yes	No	1
	Scour	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	8
	Flow effects on macrophytes other than scour	No	No	No	No	No	Yes	Yes	No	No	No	No	No	2
	Burial	No	No	No	No	No	No	No	No	No	No	No	No	0
	Desiccation	No	No	No	No	No	No	No	No	No	No	No	No	0

Dietterich et al. *in prep*

Mechanistic models: feedbacks

	Model abbreviation	A	B	C	D	E	F	G	H	I	J	K	L	Number of models that include process
Feedbacks and other stream processes	Macrophytes affect hydraulic flow	No	No	Yes	No	No	No	No	No	No	No	No	No	1
	Macrophytes affect stream nutrient concentrations	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	No	6
	Macrophytes capable of luxury nutrient uptake	Yes	No	No	No	No	No	No	No	No	No	Yes	No	2
	Stream nutrient cycling	C, N, P	C, N, P, Si	C, N, P	No	No	No	No	C, P, B	C	C, N, P	C, N, P, Si	Yes 2	8
	Dissolved oxygen	Yes	No	Yes	No	No	No	No	No	No	No	Yes	Yes 2	4
	Suspended sediment	Yes	No	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	6

Dietterich et al. *in prep*

Objectives

- Review existing modeling approaches
- **Compile a framework for model development**
- Case study: *Podostemum ceratophyllum* (hornleaf riverweed)

Insights from systematic review: framework for model development

- Specific nature of macrophyte growth
- Macrophyte requirements for growth
- Environmental and anthropogenic factors affecting growth and survival
- Feedback effects of macrophytes on environment

Dietterich et al. *in prep*

Insights from systematic review: accessibility, open science, and modularity

- Accessibility
  - 5/12 models publicly available
- Open science
  - Share both models and source code
- Modularity
  - Improves adaptability among systems

Dietterich et al. *in prep*

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Case study: *Podostemum ceratophyllum* (hornleaf riverweed)

- Aquatic flowering plant
- Widespread in eastern North American rivers
- Favors rocky substrates and fast currents
- Foundation species
  - Provides food
  - Provides habitat
  - Reduces flow
  - Improves water quality

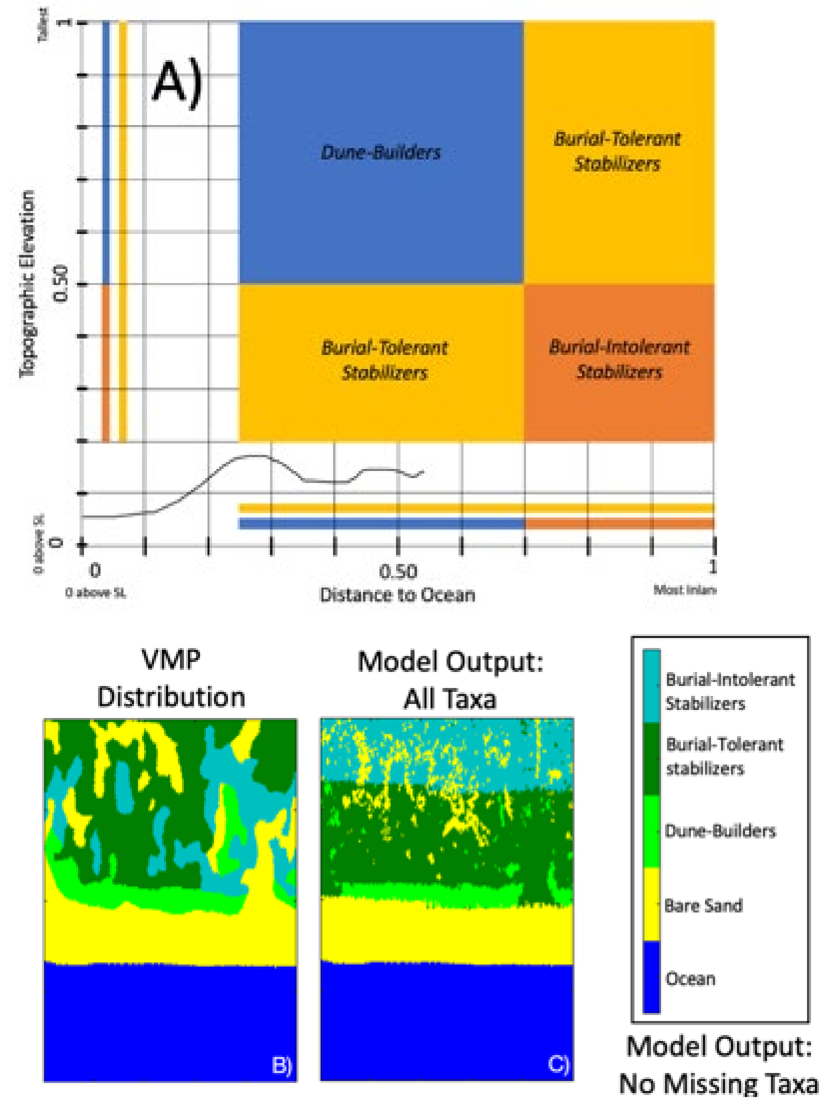
Wood and Freeman 2017, Wood et al. 2019

Two-step modeling approach

- Model distribution (habitat suitability) at reach scale
  - Where might *Podostemum* be able to grow? (~fundamental niche)
- Within reaches, simulate growth over time
  - How does *Podostemum* biomass respond to environmental conditions (~realized niche)

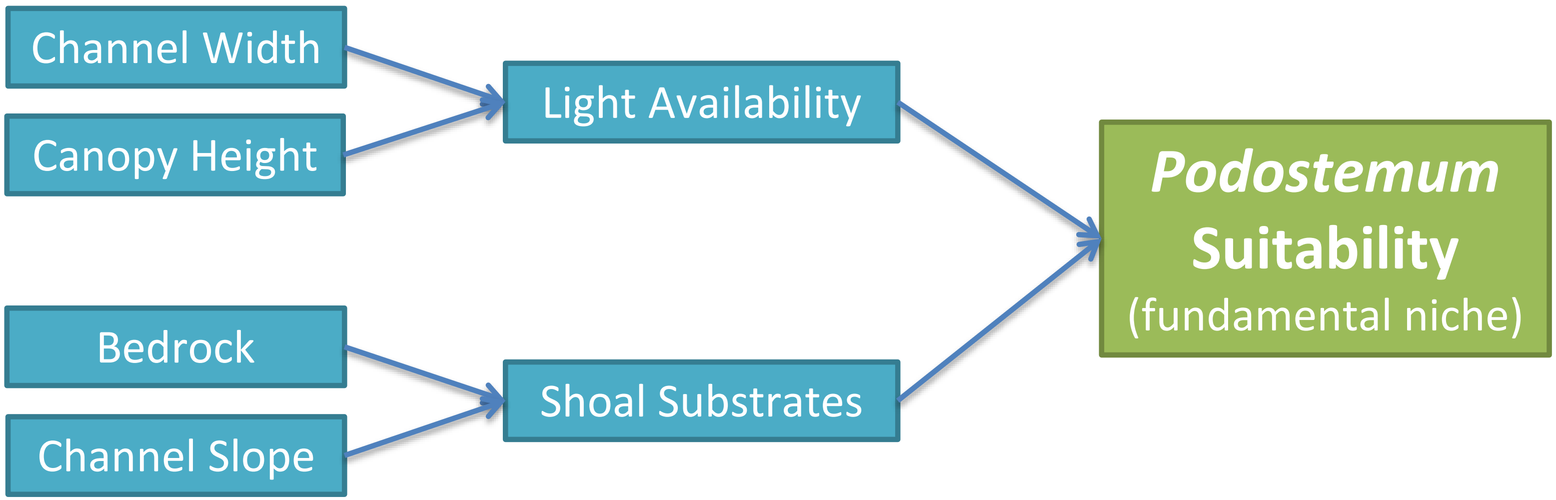
Habitat suitability modeling: Plan A

- VegInit
- Use 2-4 habitat variables to define fundamental niche
- Stochastically populate model map based on known habitat conditions



Charbonneau et al. 2022

Habitat suitability modeling: Plan A



- Light Availability: doable
- Shoal Substrates: much harder (Gailleton et al. 2019)

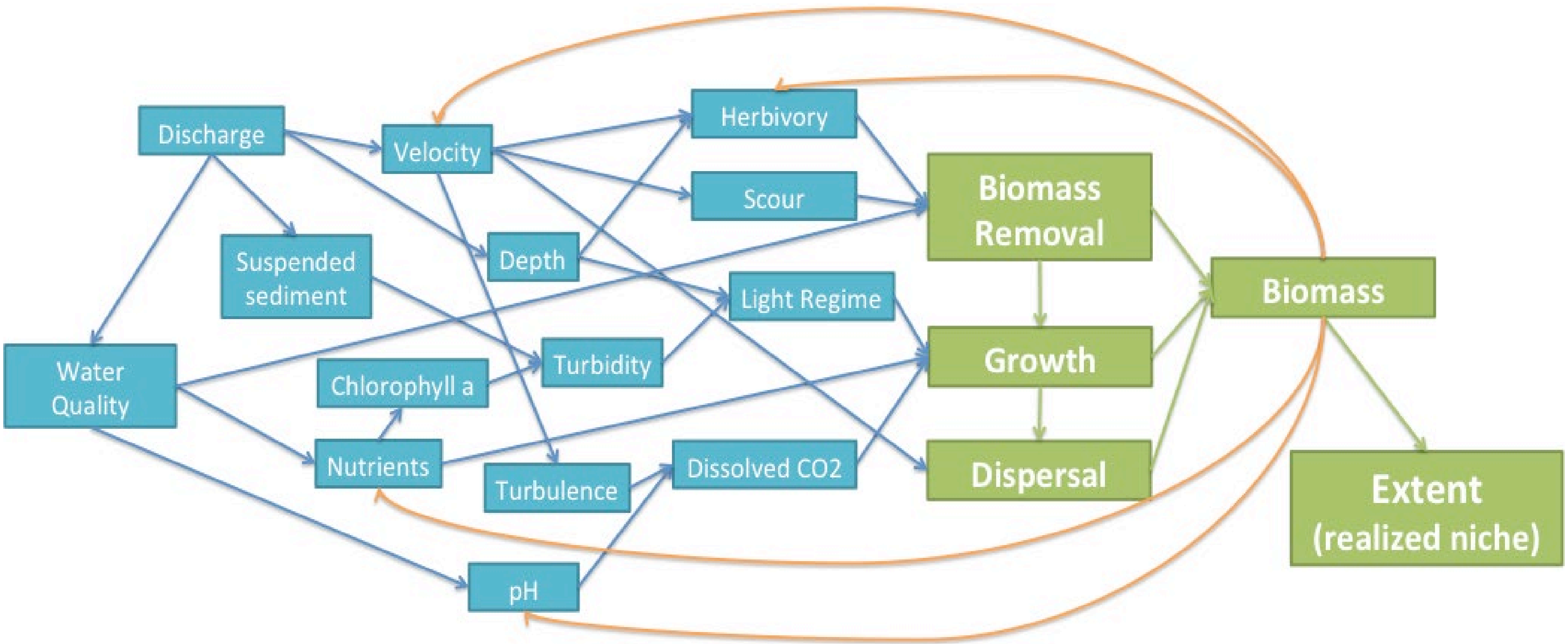
Dietterich et al. 2022

Habitat suitability modeling: Plan B

- Map shoals in Google Earth (M. Hallmark)
- Goal: thorough set of likely habitats
- Criteria
  - ≥10 m river length
  - ≥10 m away from another shoal
  - Visual evidence of rapid flow (ripples) and rocky substrate

Dietterich and Hallmark *in prep.*

Growth modeling: conceptual model



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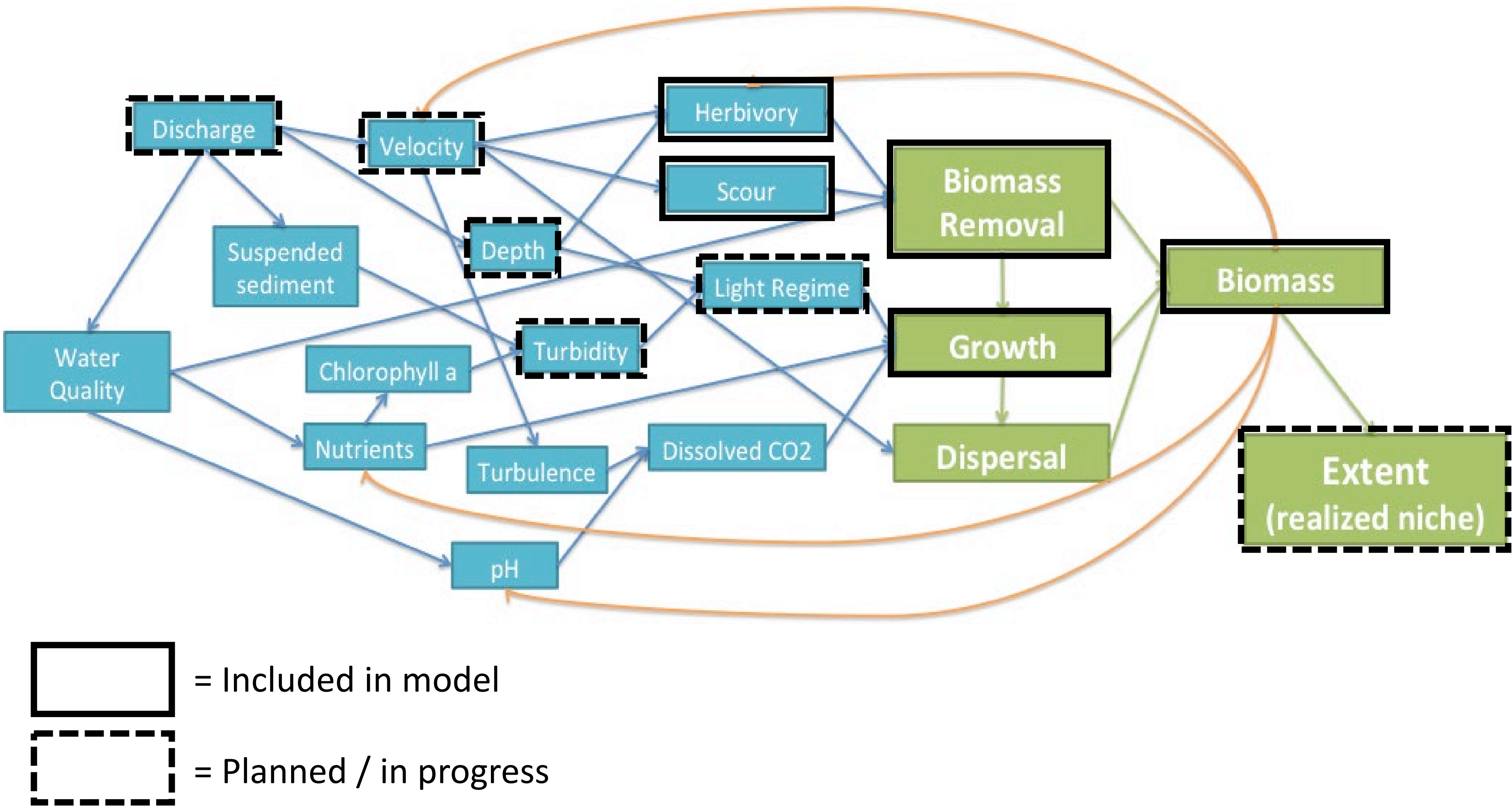
Growth modeling: numerical model



Dietterich et al. 2022

Model Structure

- R package: Riverweed
  - Goal: make available for easy, widespread use
- Workflow
  - Biomass growth
  - Biomass loss
  - Utility functions

Riverweed model: specific nature of macrophyte growth

- Stem length and biomass
- Empirical: exponential and logistic growth
- Mechanistic: photosynthesis

Photo above: Wood and Freeman 2017

Lower photos: Laura Rack

Riverweed model: macrophyte requirements for growth

- Substrate via habitat suitability
- Water depth via habitat suitability
- Light and photosynthesis coming soon
- Nutrients coming later

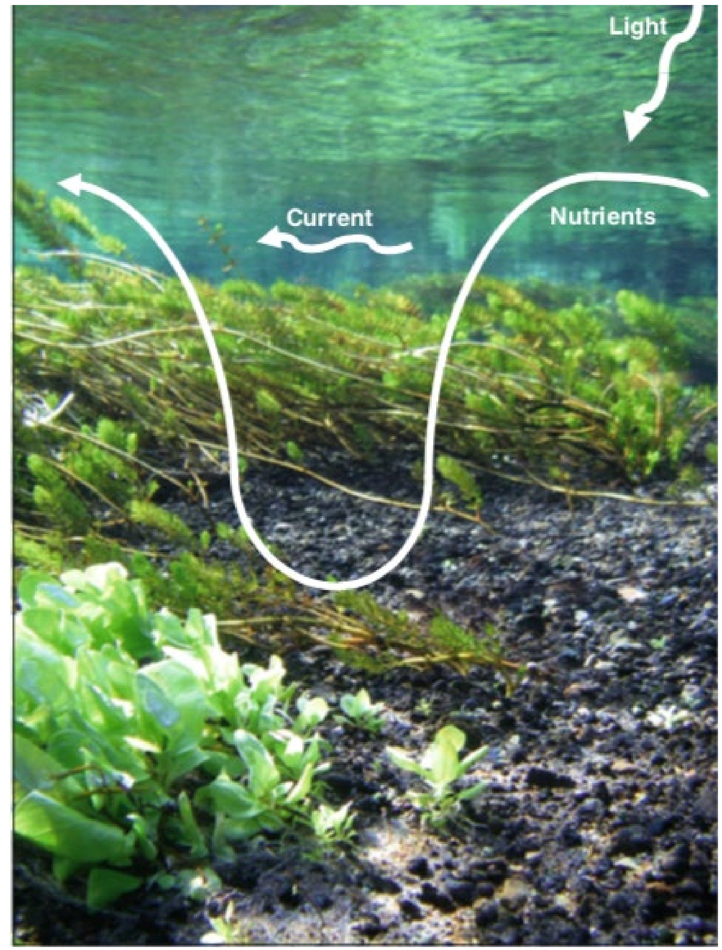


Image: Mebane et al. 2014 *Hydrobiologia*

Riverweed model: factors affecting growth and survival

- Herbivory at low flows
- Scour at high flows
- Max size / breakage

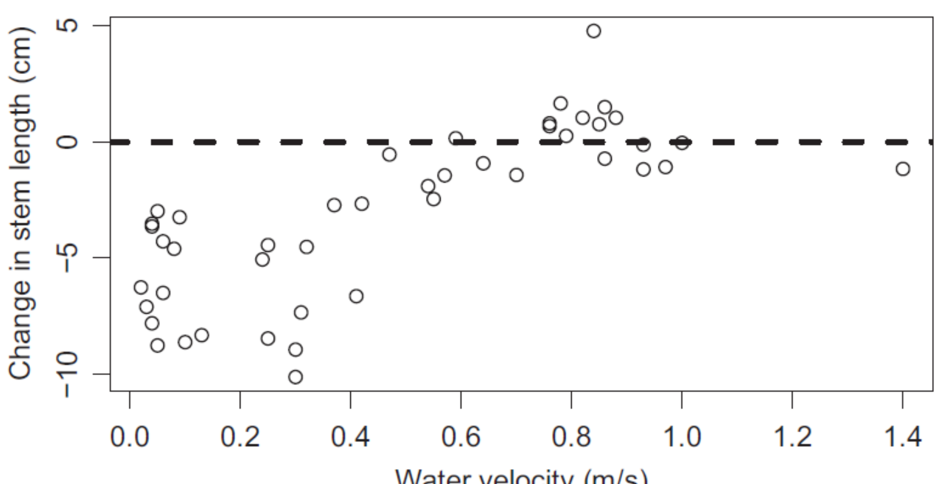


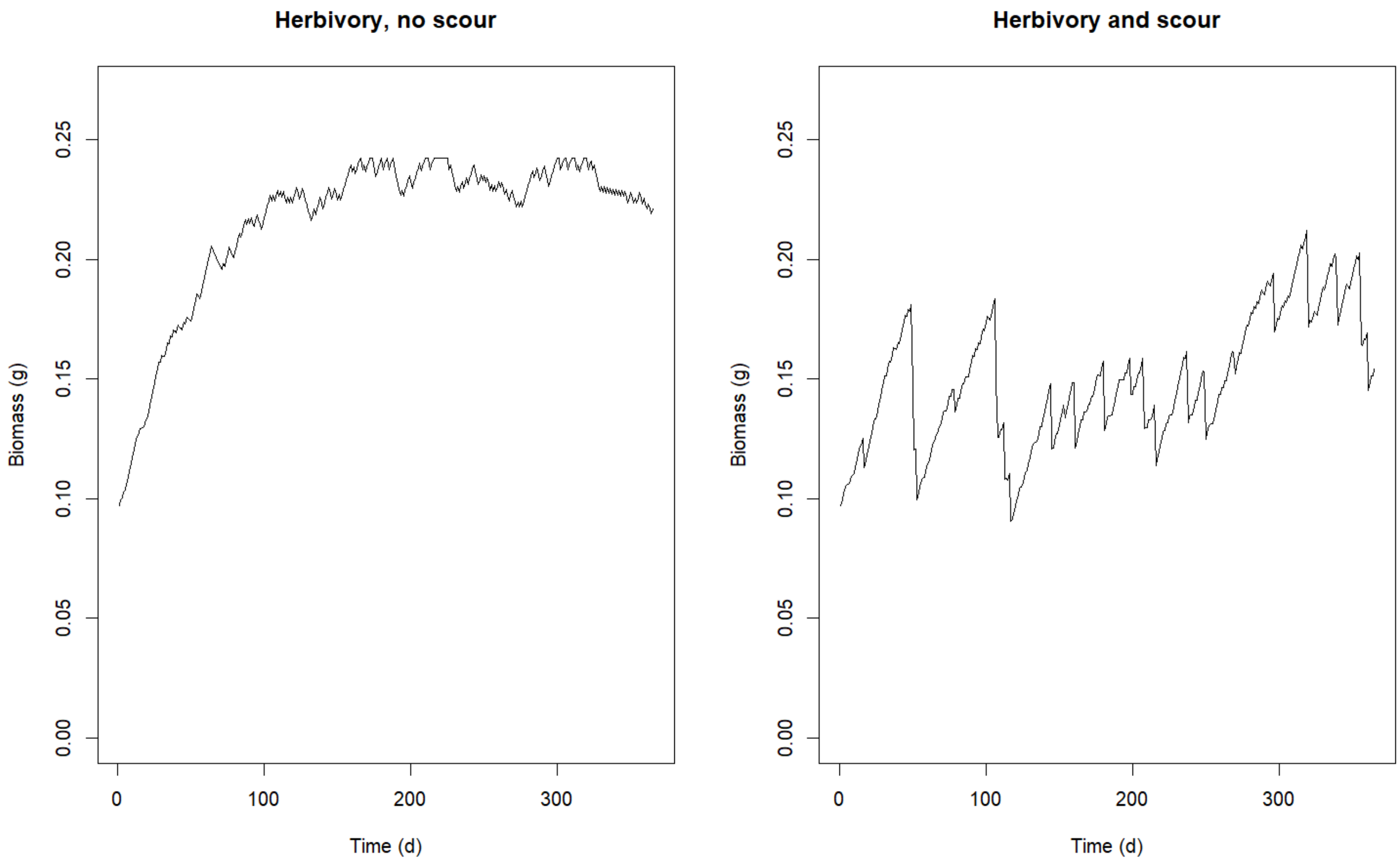
FIGURE 3 Herbivory influence on change in stem length of *Podostemum ceratophyllum* 12 days after translocation in the Middle Oconee River, plotted in relation to water velocity measured on 10 July 2015, $R^2 = 0.56$, $p < 0.001$s

Wood et al. 2019

Riverweed model: feedback effects of macrophytes on environment

- Future directions and applications
- May include:
  - Biodiversity
  - Organic matter
  - Nutrients
  - Sediment
  - Flow

Riverweed model: initial results



Future plans

- Reach scale application in Middle Oconee River
- Bathymetric and hydraulic model
- Evaluate model against detailed field data (Conn et al. in prep)

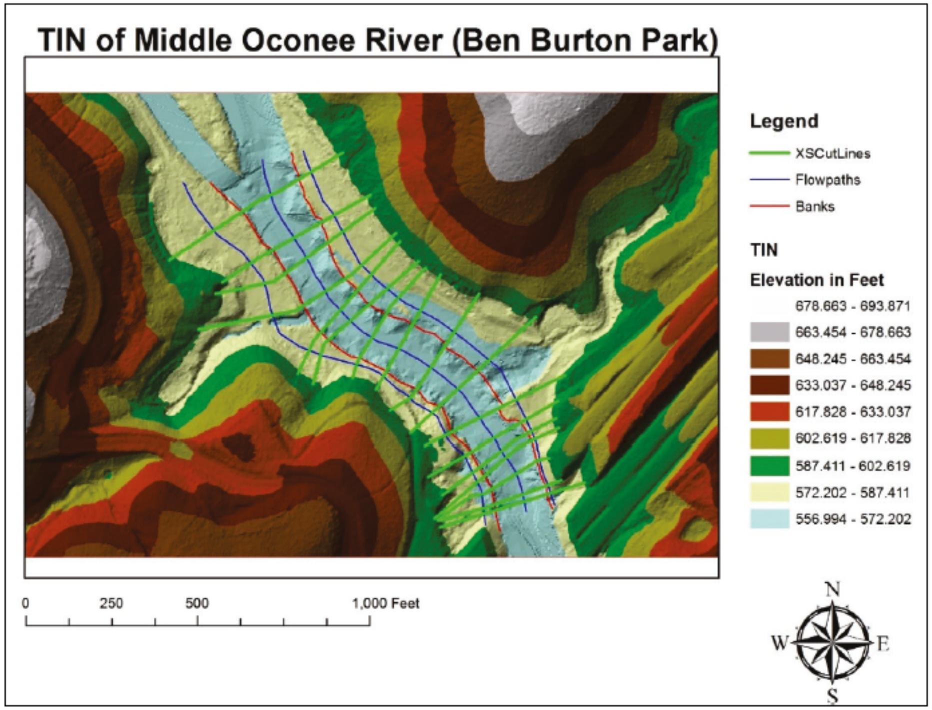


Figure 2. Topographic and bathymetric map of the study reach on the Middle Oconee River near Athens, GA. Surveyed cross sections are shown in green, primary main channel and floodplain flow paths in blue (derived from HEC-GeoRAS), and top of bank in red.

Bhattacharjee et al. 2019

Summary

- Macrophytes have numerous and important effects on ecosystems, and merit modeling
- Many ways to model macrophyte growth
- Models vary in processes included
  - High coverage of photosynthesis, nutrients, mortality
  - Low coverage of herbivory, burial, desiccation
- *Podostemum* growth model
  - Simple functions can produce plausible growth
  - Model development actively ongoing

Products

- Dietterich LH, Ortis Rosa S, McKay SK, and Swannack TM. 2022. Toward improved models of riverine macrophytes. Proceedings of 2022 EWRI World Environmental & Water Resources Congress.
- Wood JL, Dietterich LH, Leasure DR, Maddox TR, Loftis KM, Wenger SJ, Skaggs JW, Rosemond AD, and Freeman MC. Elemental composition and potential toxicity of the riverine macrophyte *Podostemum ceratophyllum* Michx. reflects land use in eastern North America. In revision for *Science of the Total Environment*.
- Dietterich LH, Ortiz Rosa S, and McKay SK. Mechanistic modeling of riverine macrophyte growth: A systematic review. In preparation for *Aquatic Botany*.
- Dietterich LH and Hallmark M. Known and prospective rocky shoal locations in three rivers in Georgia, US. In preparation for Dryad repository.
- Dietterich LH and McKay SK. Riverweed package. In preparation for CRAN-R project library.
- Dietterich LH, McKay SK, et al. Insights from modeling *Podostemum ceratophyllum* Michx. with the Riverweed R package. In preparation for *Freshwater Science*.

Acknowledgments

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WRISES team

https://sites.google.com/view/usace-wrises

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ENGINEER RESEARCH & DEVELOPMENT CENTER

ANSRP Aquatic Nuisance Species Research Program

Seth Wenger

Mary Freeman

James Wood

Caitlin Conn

Laura Rack

Phillip Bumpers

Mackenzi Hallmark

River Basin Center
UNIVERSITY OF GEORGIA