Modeling riverine macrophyte growth to improve ecological outcomes of river management

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

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

Image: Mebane et al. 2014 *Hydrobiologia*
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)
Objectives

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

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

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)

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
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

<table>
<thead>
<tr>
<th>Plant growth</th>
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<th>A</th>
<th>B</th>
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## Model review: biomass loss

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## Mechanistic models: feedbacks

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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*
Objectives

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- Case study: *Podostemum ceratophyllum* (hornleaf riverweed)
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)
Habitat suitability modeling: Plan B

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

Dietterich and Hallmark *in prep.*
Growth modeling: conceptual model

Dietterich et al. 2022
Growth modeling: numerical model

- Discharge
- Velocity
- Water Quality
- Suspended sediment
- Chlorophyll a
- Nutrients
- Turbidity
- Turbulence
- pH
- Herbivory
- Scour
- Light Regime

Biomass Removal → Growth → Dispersal

Biomass

Extent (realized niche)

= Included in model

= Planned / in progress

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. $R^2 = 0.56$, $p < 0.001$
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, 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.

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Laura Rack
Phillip Bumpers
Mackenzi Hallmark

Aquatic Nuisance Species Research Program

River Basin Center
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