Mathematical modeling of biophysical processes affecting oyster reef development

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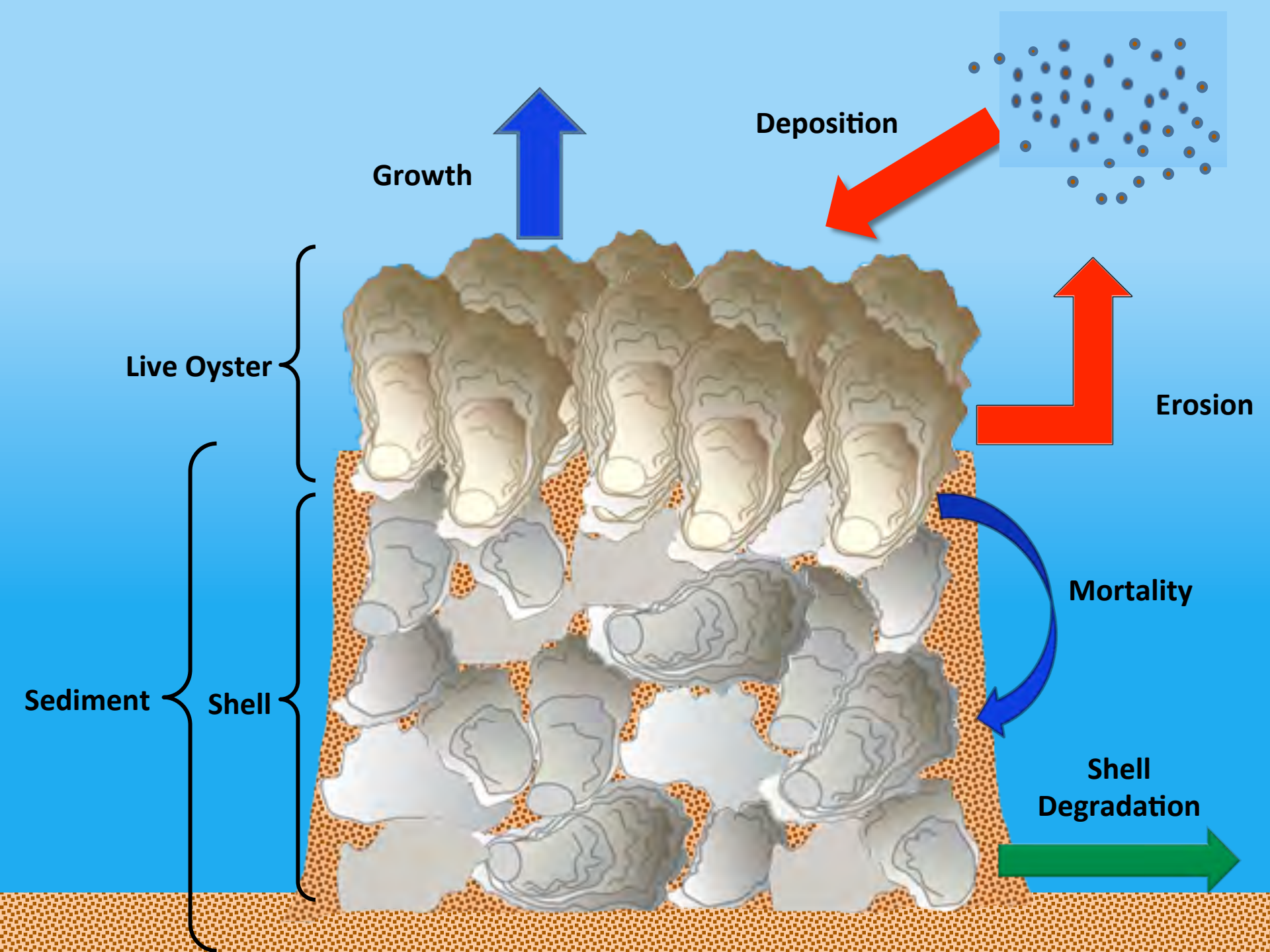
Introduction

- Oysters perform important ecosystem services but populations have declined substantially over the past century.
- Currently there is a push for oyster reef restoration.
- Smothering of oysters by sediment limits the success of some of these reefs.
- Aim of the model is to predict the success of oyster reef restoration projects in environments with different physical conditions.


Growth
Deposition
Live Oyster
Erosion
Mortality
Sediment
Shell
Shell
Degradation

Jordan-Cooley Model

Growth

Mortality

Oyster Volume (O)

$$\frac{dO}{dt} = rOf(d)(1 - O/k) - \mu f(d)O - \varepsilon(1 - f(d))O$$

Mortality

Shell Degradation

Shell Volume(B)

$$\frac{dB}{dt} = \mu f(d)O + \varepsilon(1 - f(d))O - \gamma B$$

Erosion

Deposition

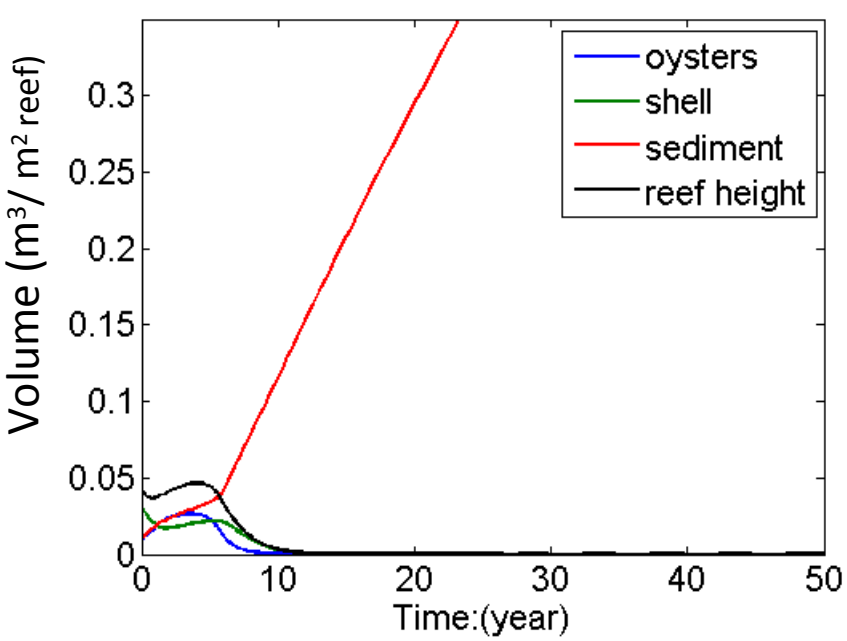
Sediment Volume (S)

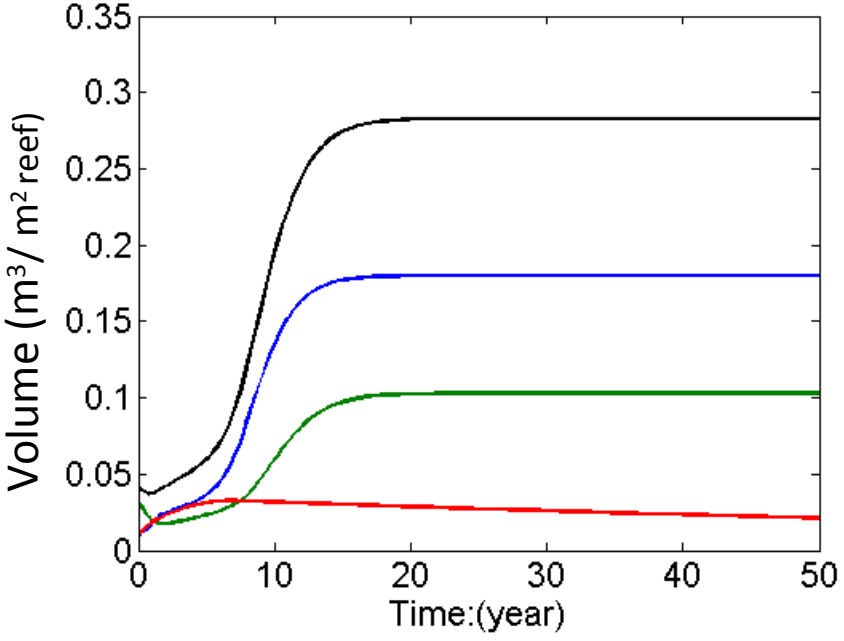
$$\frac{dS}{dt} = -\beta S + Cge^{-FO/Cg}$$

Bifurcation Point

- Bifurcation Point-the point of transition between alternative stable states
- Initial oyster and sediment volumes kept constant at 0.01 m and the initial shell volume was varied.

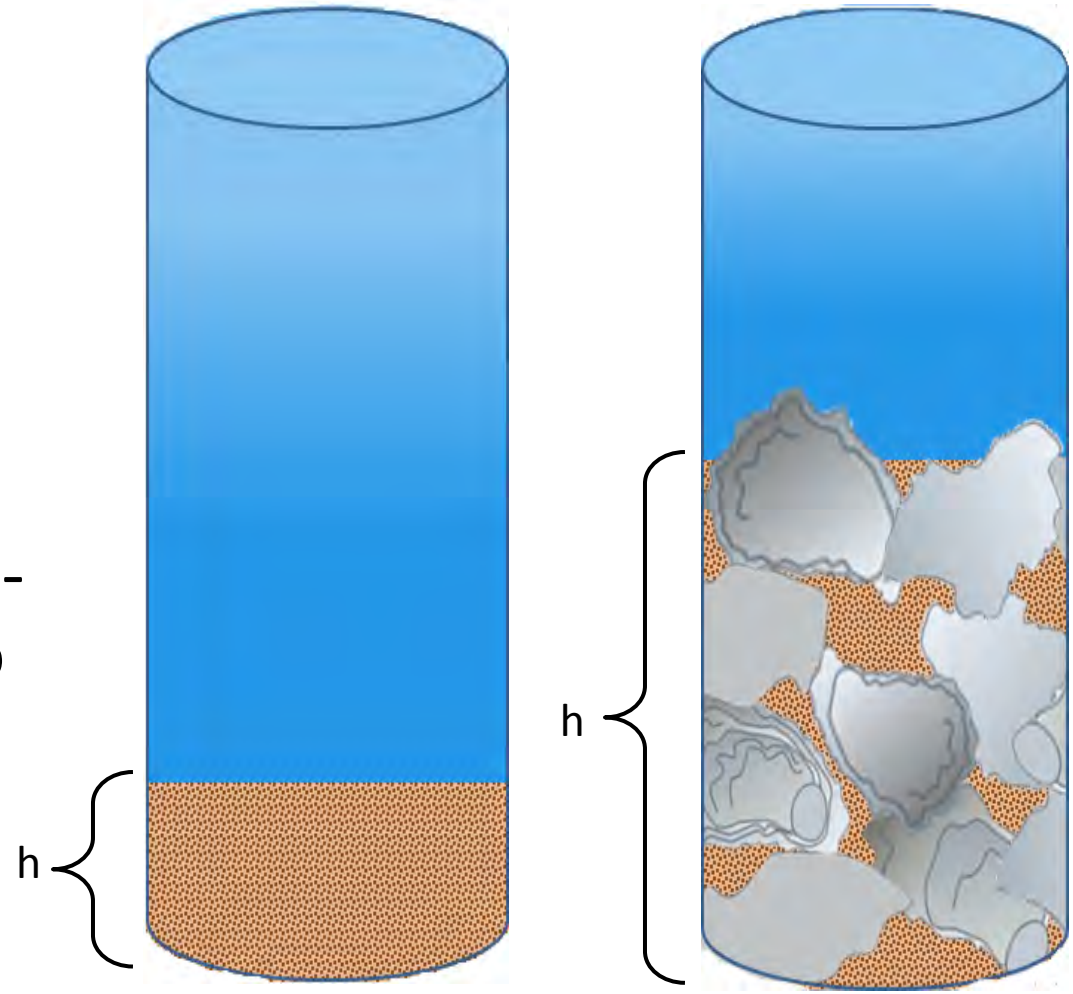
Bifurcation Point: 0.032 m





Revision of the model

- Volume fraction-failed to account for the shell:sediment ratio
- Growth term- negative growth does not make physical sense
- Deposition and erosion-constants were used to model physically variable processes



Volume Fraction

$$h(O) = \frac{O}{\gamma_{O+B}}$$

$$h(B) = \frac{B}{\gamma_{O+B}}$$

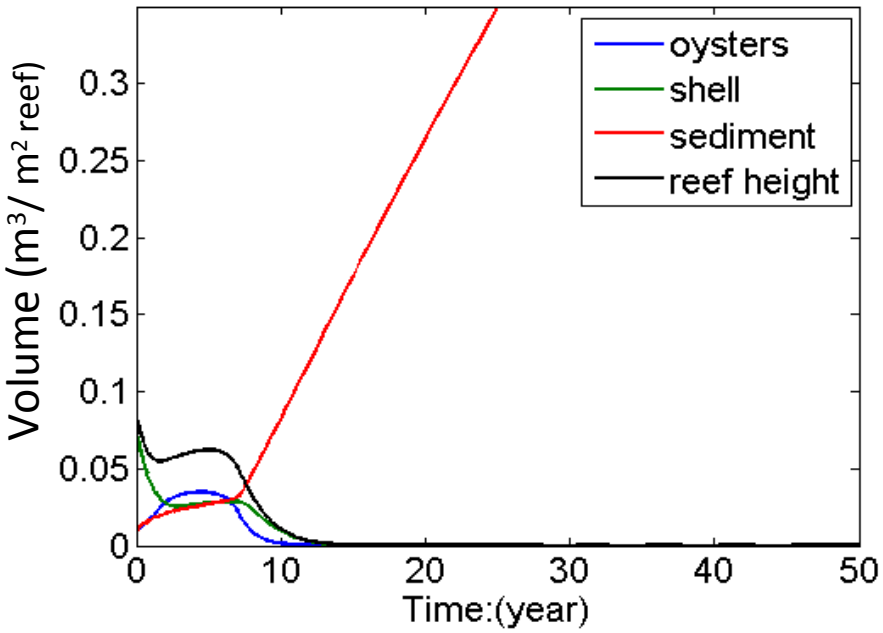
$$h(S) = \frac{S}{\gamma_s}$$

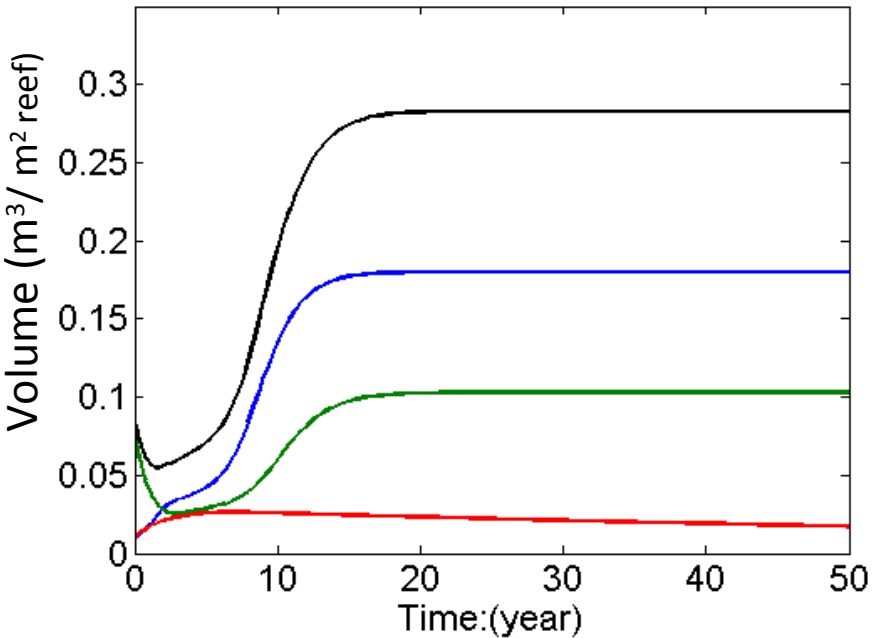
h = height of layer (m)

γ_{O+B} = volume fraction of shell and oyster

γ_S = volume fraction of sediment

Bifurcation Point: 0.032 m → 0.074 m





Growth Term

Jordan-Cooley Model

Growth= $rOf(d)(1-O/k)$

Instantaneous Growth Rate Carrying Capacity

Revised Model

A =Assimilation R =Respiration

Growth= $A-R$

Density Dependent Growth Reduction

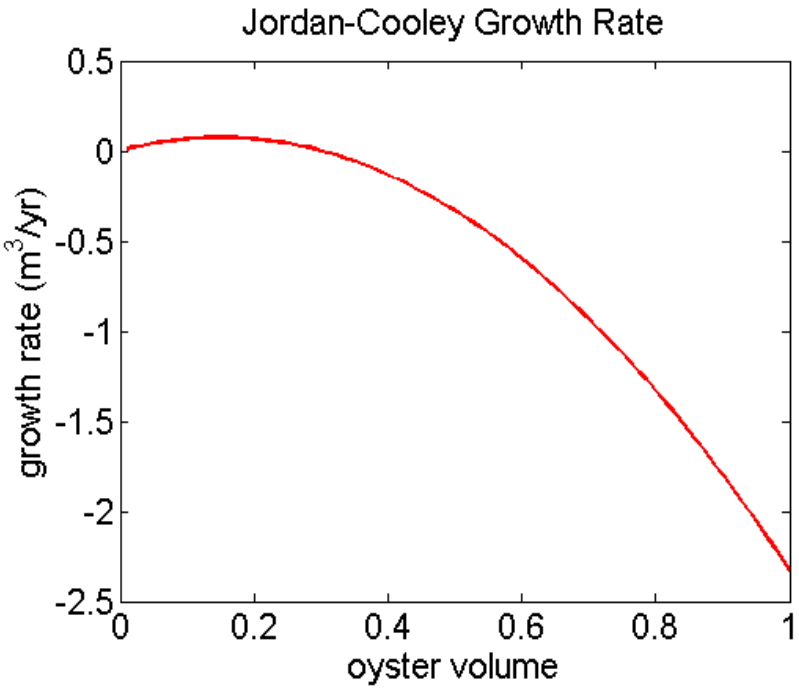
Filtration Rate Constant Based On Flow Speed

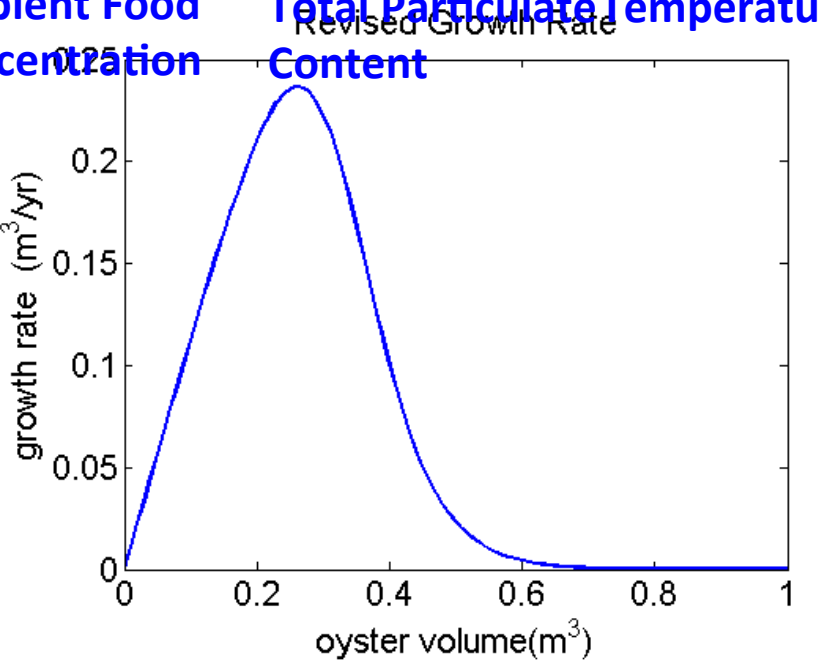
Constant Assimilation Dependent on Flow Speed

Ambient Food Concentration

Total Particulate Content

Temperature

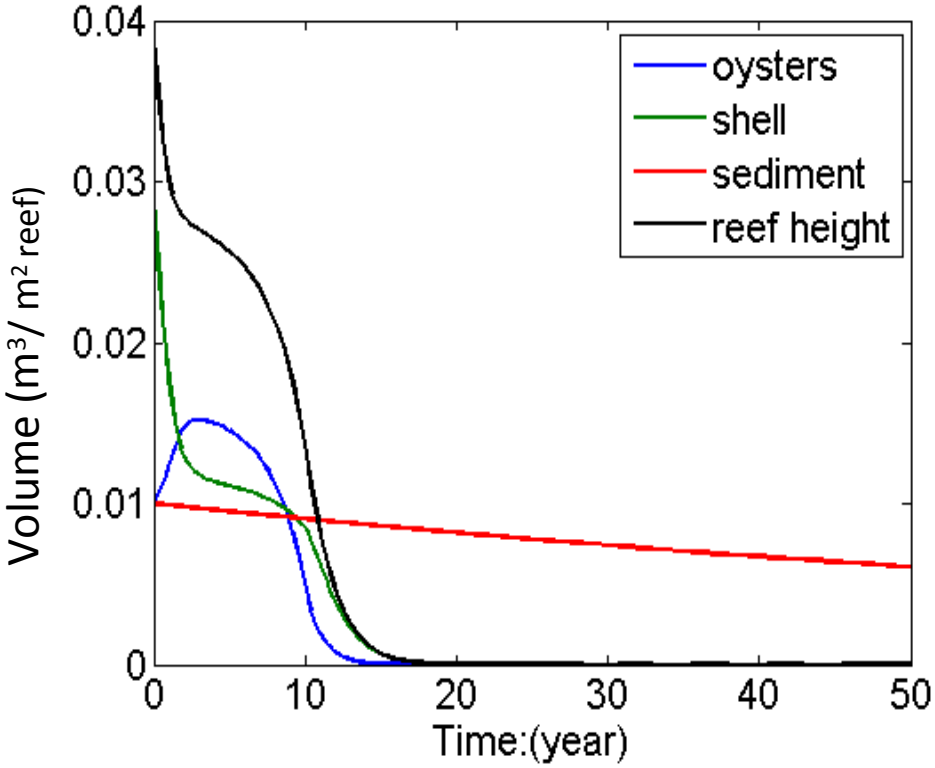


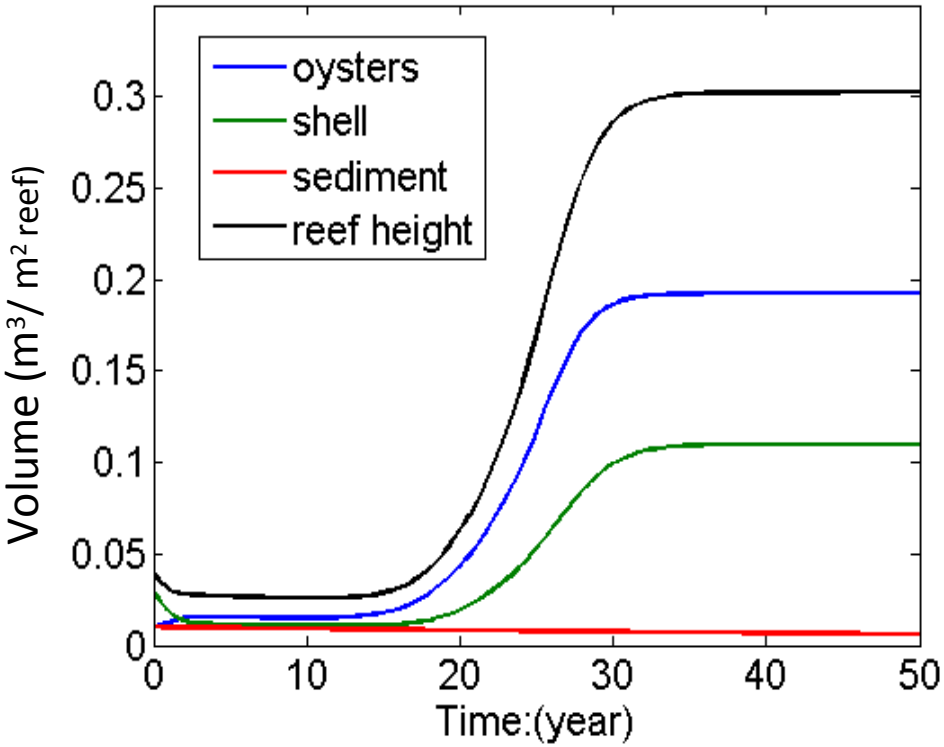


Revised Growth Term Model Runs

Bifurcation Point

0.074 m → 0.03 m





Deposition

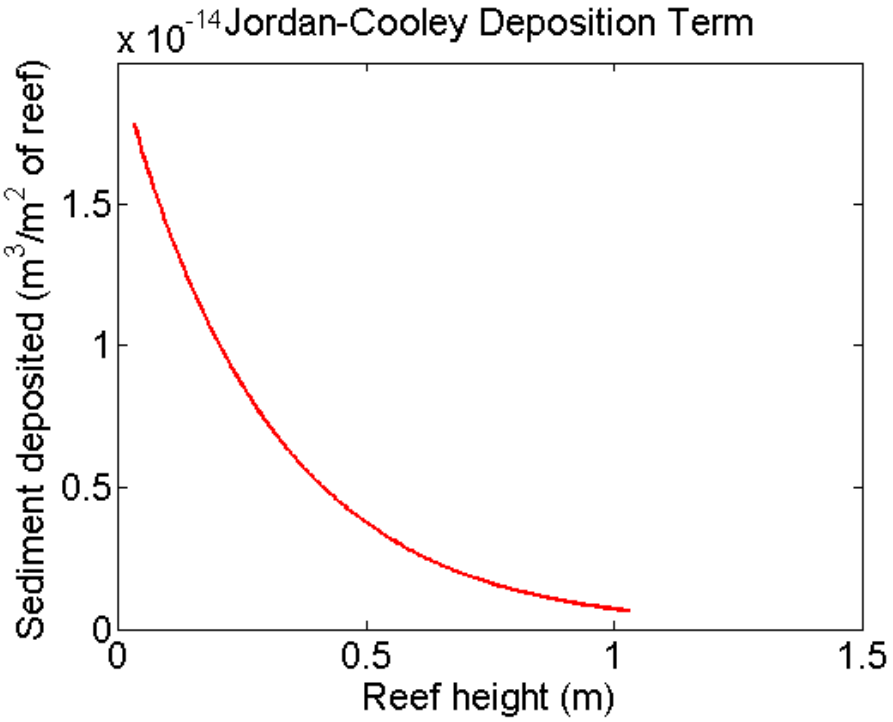
Jordan-Cooley Model

Maximum Deposition Rate

Maximum Sediment Filtration Rate

$$D = Cge^{-F0/g}$$

Reduction in Deposition with Reef Height



Revised Model

Rouse Sediment Concentration Profile

Settling Velocity

Grain Size

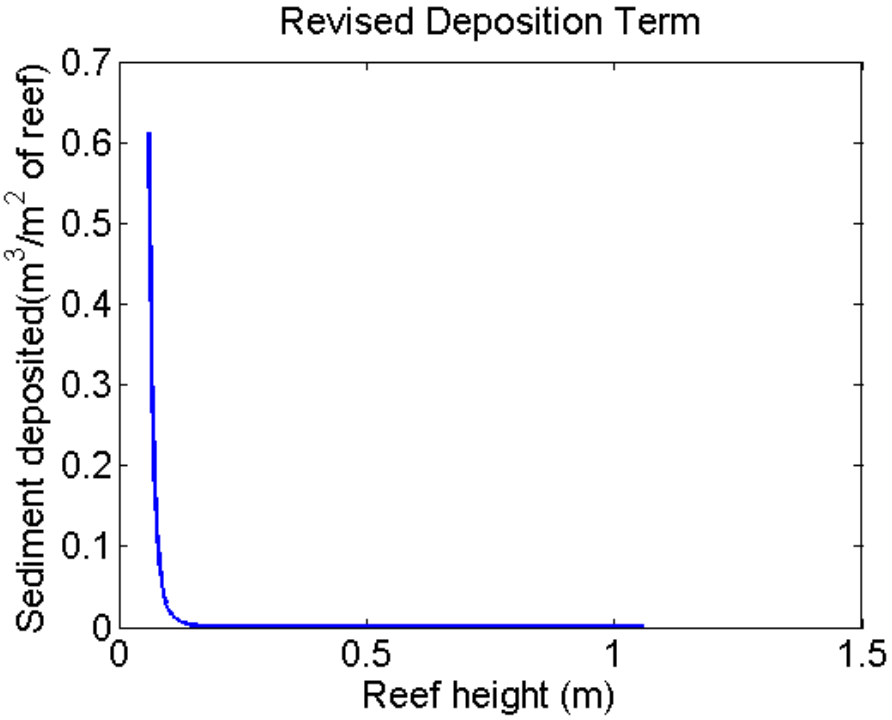
$$D = c \cdot W_s$$

Depth of Water

Frictional Velocity of Water

Settling Velocity Sediment Density of Water

Water Density



Erosion

Jordan-Cooley Model

Sediment Erosion Rate

$E = -\beta \cdot S$

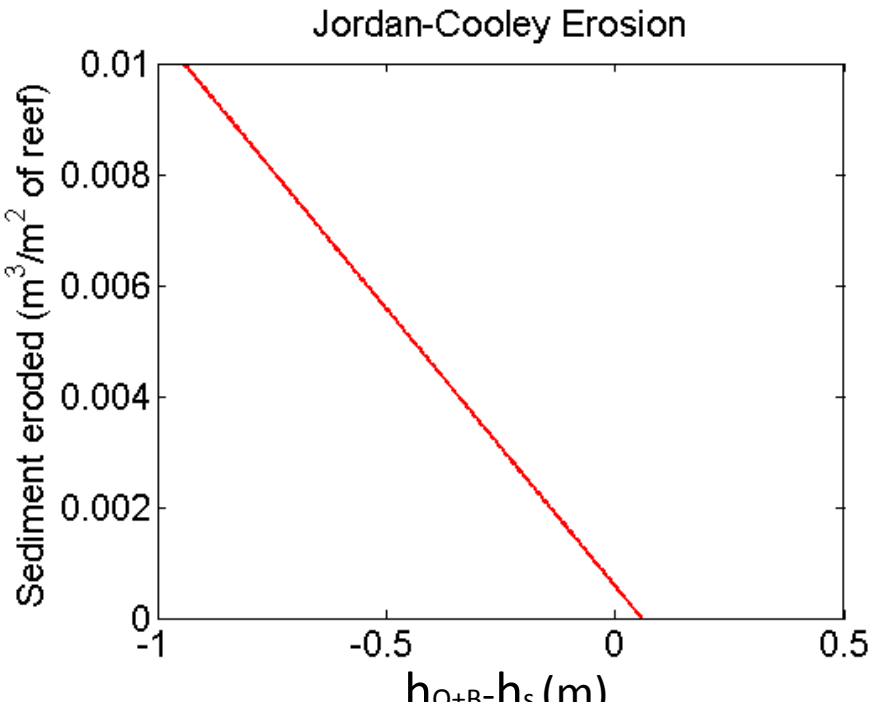
Sediment Volume

Decay of Shear Stress with Reef Height

Frictional Velocity

Shear Stress

Sediment Height



Revised Model

$E = \theta \cdot \Gamma$

Destabilizing Term

Stabilizing Term

Shields Parameter

Sediment Density

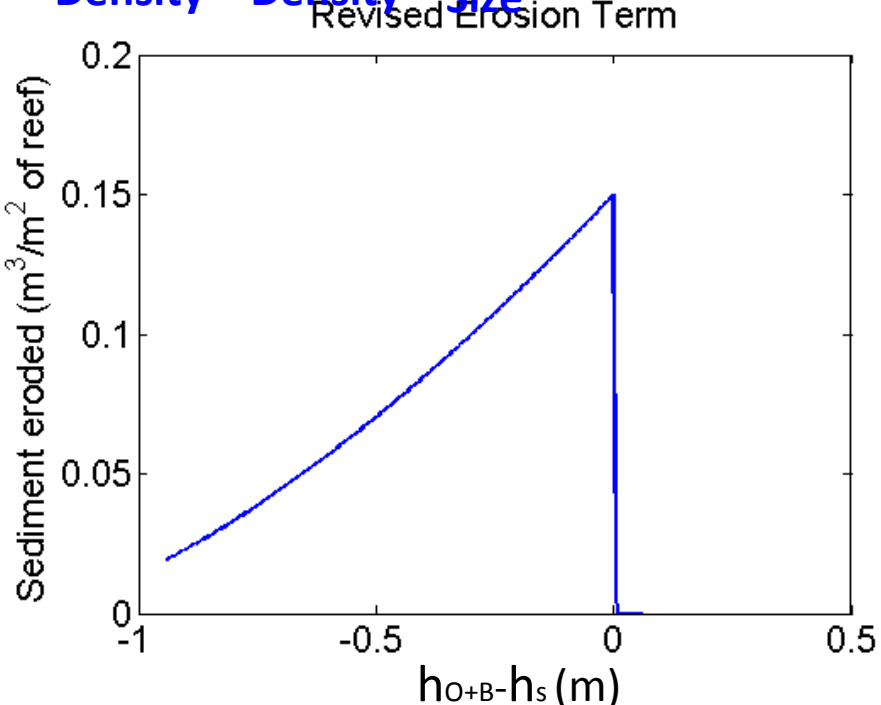
Water Density

Grain Size

Critical Shields Parameter

Water Density

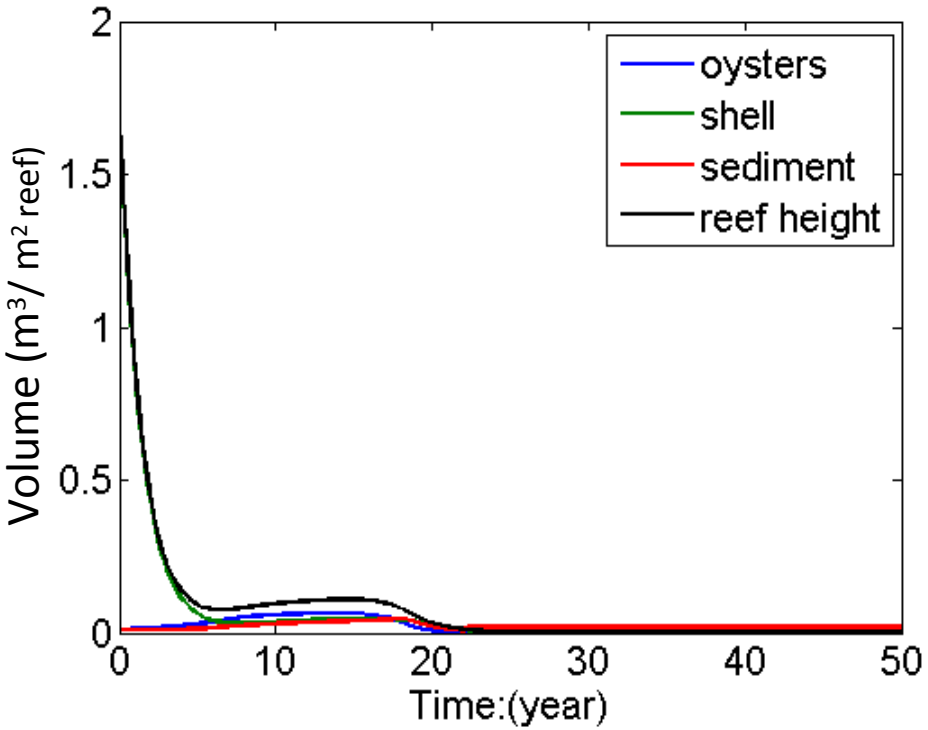
Grain Size

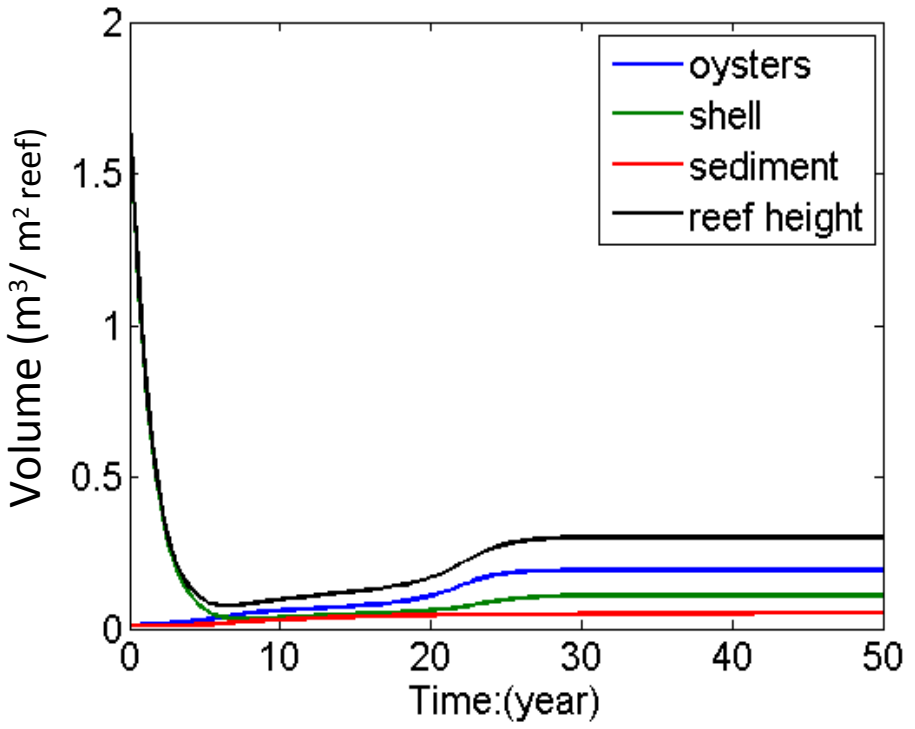


Revised Sedimentation Term Model Runs

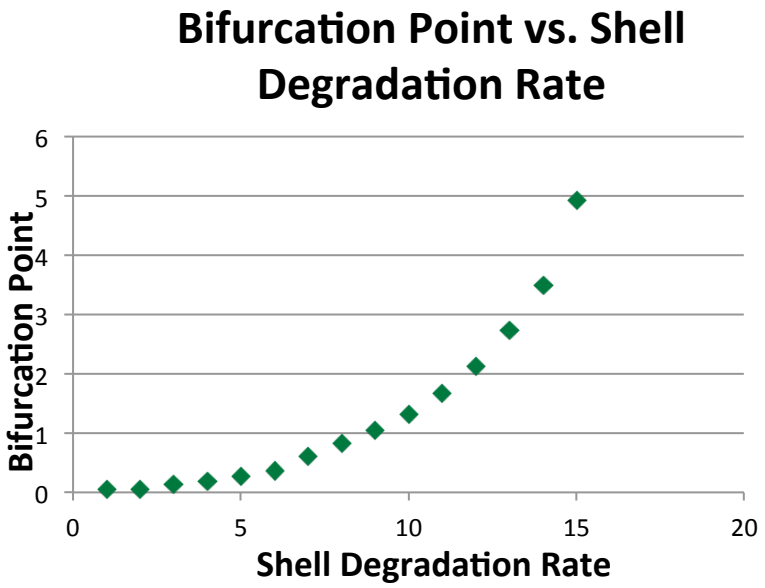
Bifurcation Point

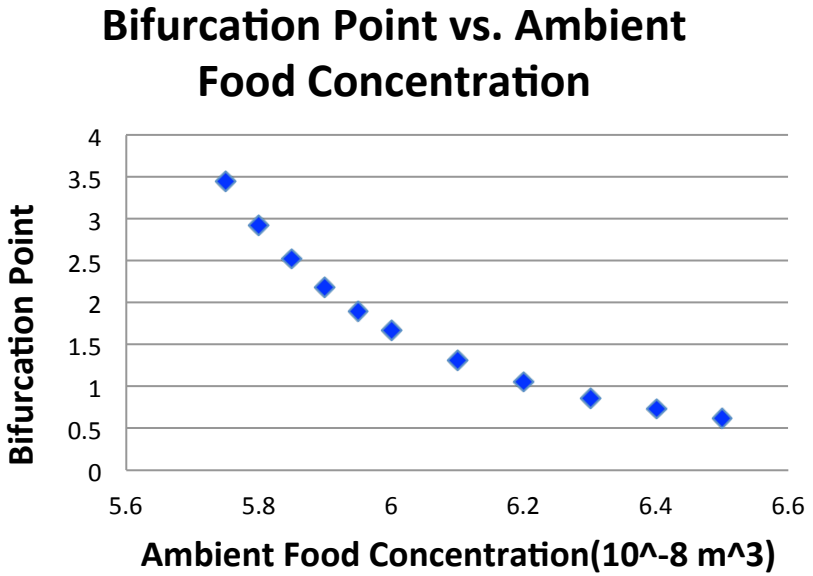
0.03 m → 1.67m

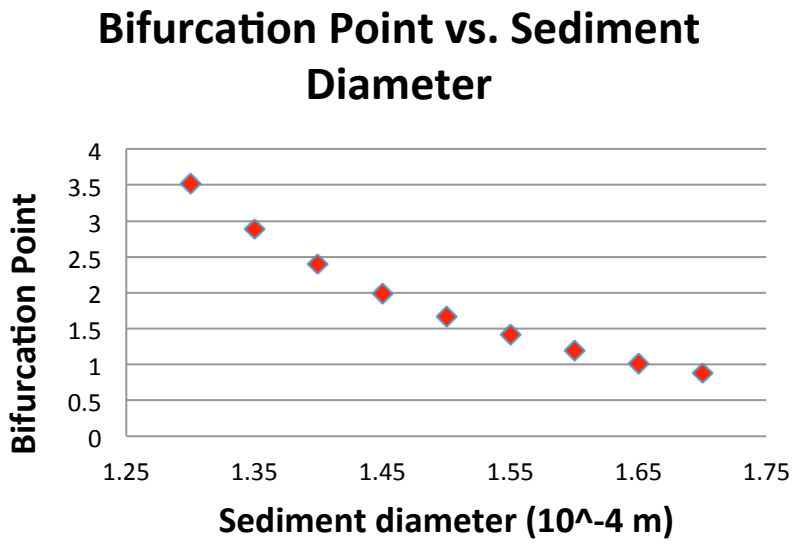


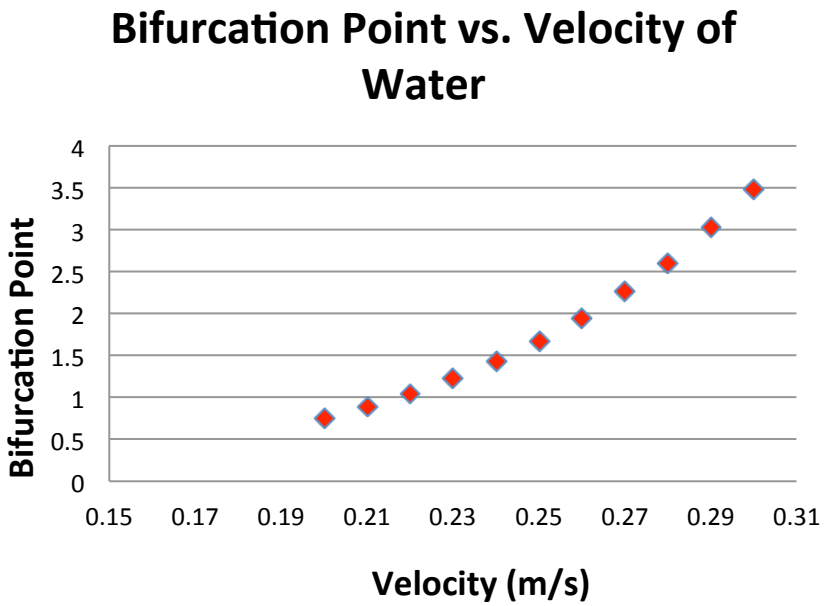


Sensitivity Analysis







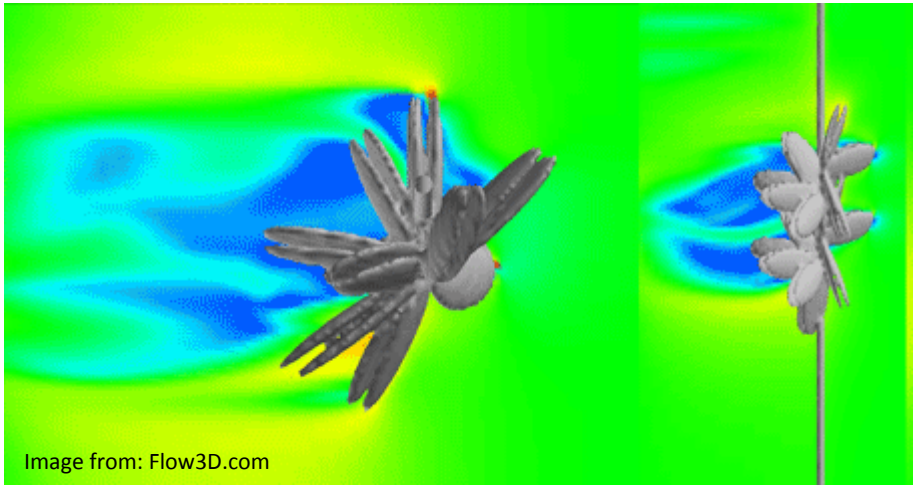


Applicability of the Model

- Final bifurcation point of 1.67 m on a similar scale to successful restored reefs constructed by Peterson et al.
- Identifying the sensitivity of the model to different parameters facilitates understanding of how the model results might deviate from the physical environment.
- Contributes to understanding about how physical processes impact reef restoration success.
- Can be used to identify the relative success of restored reefs under different environmental conditions.

Future Work

- Identifying the cause of the difference in magnitude between the deposition and erosion terms
- Introducing a term that adds the eroded sediment back into the Rouse profile
- Adding a horizontal component to the model



Acknowledgements

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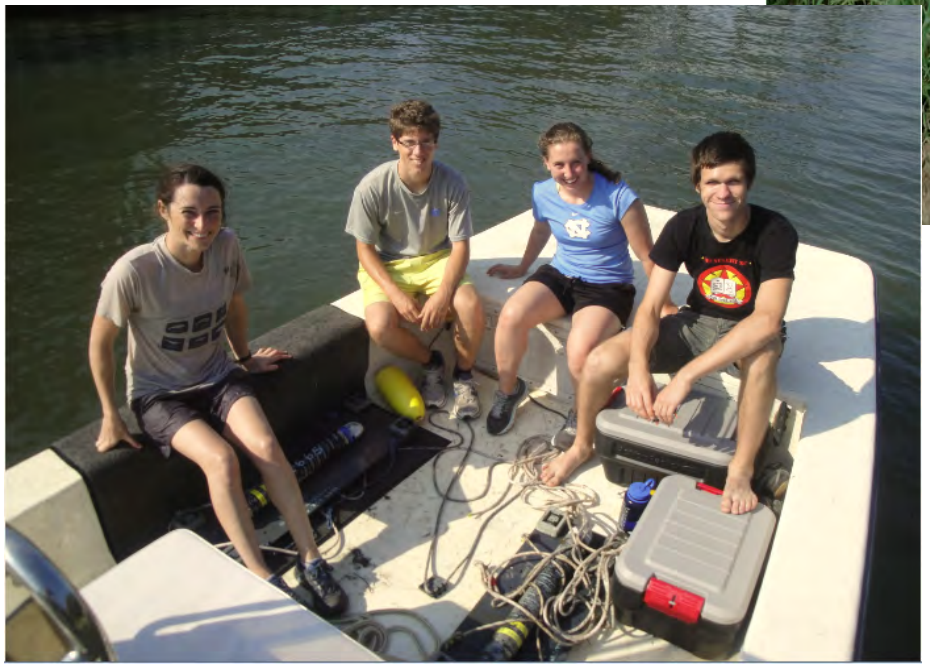

Questions?