Hydralab+: Representing timescales of biological change in flume experiments

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1. Motivation

- Coastal, estuarine and fluvial environments are vulnerable to future climate change due to **non-linear responses** to shifts in boundary conditions such as rising sea levels and more frequent extreme events (i.e. intense rainfall or storm surges)

- **Biota** are an integral part of these environments, since organisms are often at the interface between water and sediment transport systems

- A **full system-understanding** of climate change impacts therefore requires consideration of the interaction between organisms and the morphodynamics of sedimentary systems under predicted variations in hydrodynamic forcing

- **Flume experiments** provide opportunity to isolate and quantify the impact of different forcing regimes on biota under controlled conditions

- However, many past experiments have not considered biota under multiple timescales or variable forcing regimes due to **disparities in scaling between hydrodynamics, morphodynamics and biota**

2. Representations of biota in flume experiments: a review of techniques in the context of climate forcing and timescales of change

Natural environment

- Under threat from climate change impacts, such as rising sea level or more frequent floods/storm surges
- Hard to monitor in-situ interactions between biota and sediment/water due to complexities of systems and timescales required to observes impacts of changes in forcing
- Requires experimental modelling of natural environment processes

Riparian vegetation

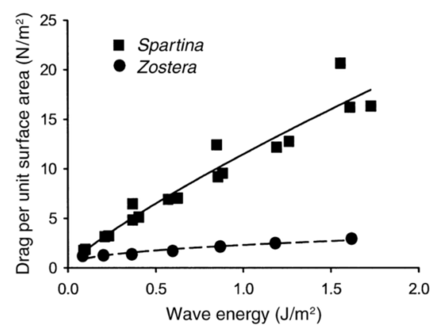
Seagrass in coastal environment

Control and isolate forcing conditions

Real vegetation in lab

- Monitor biological-sediment/water interactions under controlled conditions
- 1:1 temporal and spatial scales
- Requires effective husbandry to keep vegetation healthy and alive
- Does the behaviour of vegetation in flumes accurately replicate behaviour in natural environment?

Effect of macroalgal mats on wave and current dynamics. Tambroni et al. (2015)

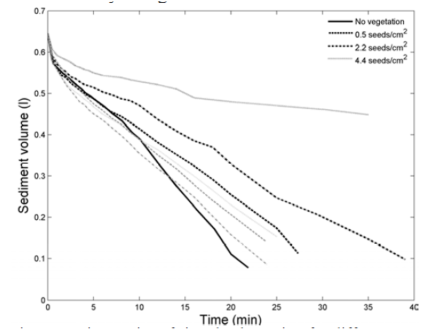


Effect of different plant stiffnesses (Spartina = stiff, Zostera = flexible) on drag under different wave climates. Bouma et al. (2005)

Increase temporal and spatial scale of study

Small-scale vegetation

- Allows scaling of system with small scale species used as surrogate for larger vegetation (e.g. alfalfa for riparian vegetation)
- Can study longer temporal and larger spatial scales to understand system behaviour beyond what is possible in field (e.g. meandering dynamics)
- Accurate replication of full size system?
- Long experimental run time (due to growing behaviour)
- Past experiments lack variability in forcing conditions (e.g. flood hydrographs)



Bank erosion under different vegetation densities. Van de Lageweg et al. (2010)

Accurately model dynamic environments under range of future scenarios

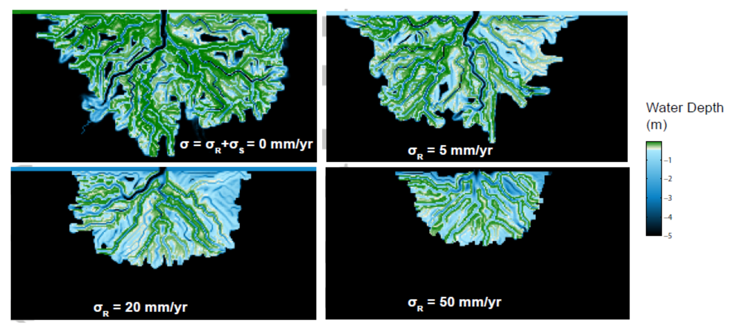
Model calibration

Simplify and scale vegetation properties

Reduce experimental runtime

Numerical modelling

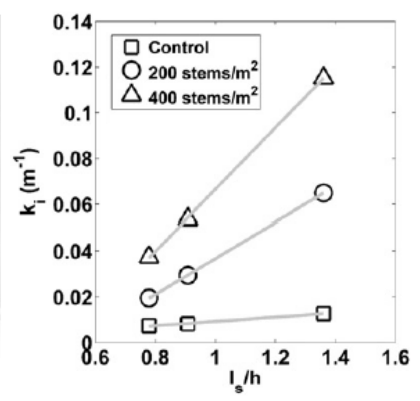
- Key for understanding impacts of climate change on systems at range of scales
- Parameterise key processes in the environments using evidence from field and physical models
- Able to model the sensitivity of systems under multiple forcing scenarios including different rates of sea level rise or storm wave height
- Simulate short term response to individual events and allogenic and autogenic system response to long term trends
- Requires important understanding from experiments for accurate modelling of systems



Delta dynamics under rising sea level: Liang et al. (in press)

Surrogate vegetation in lab

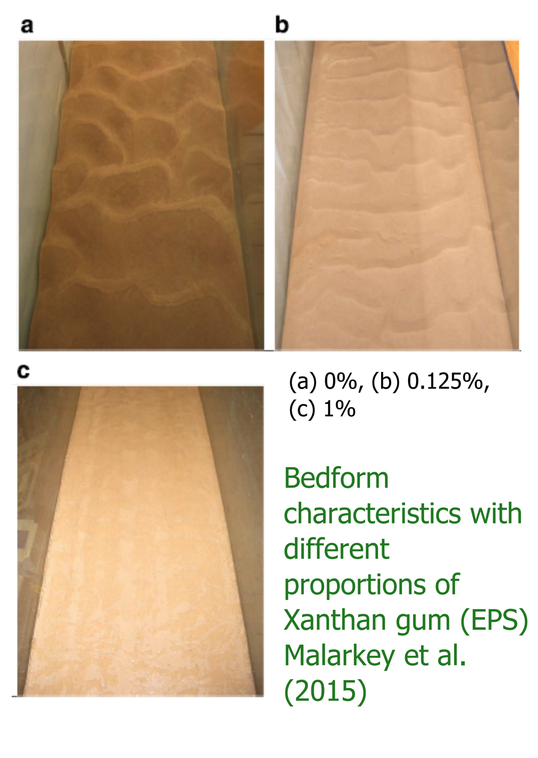
- Able to simplify the structure of the vegetation to include just the important parameters (e.g. stiffness, canopy density)
- Scale surrogates to examine vegetation behaviour under longer temporal and larger spatial resolutions
- Potentially loses the complexity of vegetation and its interactions with sediment/water - is the behaviour realistic?
- Can not 'grow' through time so hard to simulate (i) seasonal changes or (ii) progressive changes in vegetation density/size in response to forcing



Effect of relative submergence (l_s/h) of surrogate vegetation on wave attenuation (k_i): Anderson and Smith (2014)

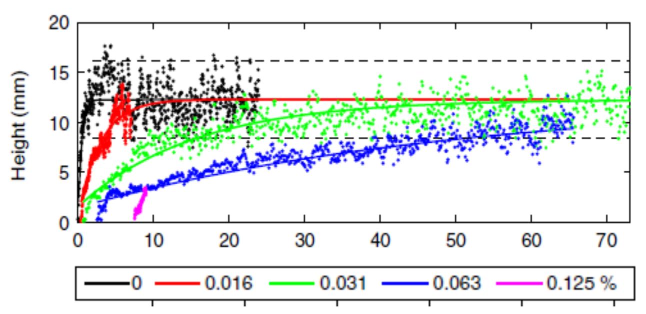
Chemical surrogates

- Simulate extracellular polymeric substances (EPS) to replicate cohesive effects of vegetation on sediment (e.g. natural biofilms)
- Can reduce experimental runtime as no need for periods of vegetation growth
- Activate and reactivate quickly to simulate different conditions: able to model progressive trends?
- Uncertainty in 'best practice' for surface preparation
- Removes effect of vegetation on flow hydraulics (e.g. slower flow and decreased erosive power)- is this important factor or can it be simulated using EPS?



(a) 0%, (b) 0.125%, (c) 1%

Bedform characteristics with different proportions of Xanthan gum (EPS) Malarkey et al. (2015)



Model calibration

3. Future requirements of experimental studies

a. Accurate representations of biota over a range of spatial and temporal scales

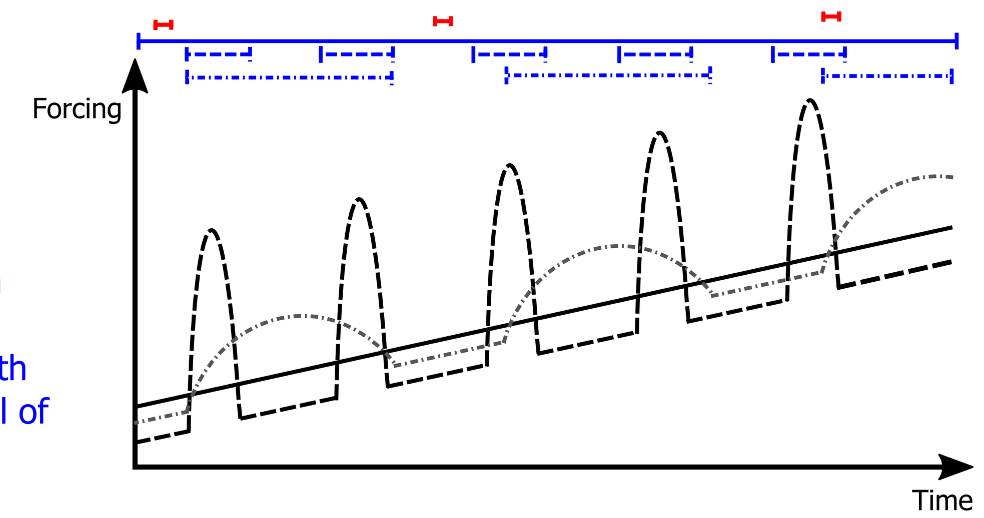
Develop protocols for effective use of surrogates (chemical and physical) to replicate the complexities of biological processes and interactions with sediment/water in coastal, estuarine and fluvial environments within flume experiments.

Forcing: Progressive changes in forcing and inclusion of variability at different timescales

Monitoring:

Existing: Monitoring of snapshots of future time in different experiments (event scale)

Required: Simulate longer timescales including both progressive forcing and variabilities. Separate signal of individual extreme events from longer term trend



b. Simulate complex forcing regimes (see black lines in diagram above)

Existing experiments often model dynamic internal response of systems to fixed forcing conditions over short timescales (i.e. snapshots of systems under different fixed conditions). Simulation of the role of external drivers (e.g. sea level rise) over long timescales required.

Additional representation of short term variability in forcing (e.g. storms) superimposed on longer term trend would help identify holistic system response to climate forcing.

c. Identification and isolation of trends (see red and blue lines in diagram above)

Monitor and isolate the long term impact of progressive changes in forcing from the shorter term impacts of individual events in the systems.

4. Testing the solutions

- Study of development and characteristics of natural biofilms (in saline and fresh water)

- Development and testing of chemical surrogates for physical models to simulate cohesivity characteristics of natural biofilms and/or riparian vegetation

- Braided river experiments with small scale vegetation (e.g. alfalfa) with variable hydrological regimes/biological densities

References

Anderson and Smith (2014) Coastal Engineering 83, 82-92; **Bouma et al. (2005)** Ecology 86 (8), 2187-2199; **Liang et al. (in press)** Journal of Geophysical Research - Earth Surface; **Malarkey et al. (2015)** Nature Comms 6, 6257; **Tambroni et al. (2015)** Advances in Water Resources; **van de Lageweg et al. (2010)** Riverflow 2010, volume 2, 1331-1338

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