The Role of Flow and Transport Processes in Ridge/Slough/Tree Island Pattern Dynamics

Laurel Larsen, Nicholas Aumen, Christopher Bernhardt, Vic Engel, Thomas Givnish, Scot Hagerthey, Judson Harvey, Lynn Leonard, Christopher McVoy, Gregory Noe, Martha Nungesser, Kenneth Rutcheay, Fred Sklar, Tiffany Troxler, John Volin, Debra Willard
Make sure to see…

- Role of Flow in a Sustainable Everglades workshop, Thursday 10:30-5:40, Royal Palm VI-VII
- Poster session II, Thursday 5:40-7:00, Orchid Ballroom
Geography and Geomorphology

Well-preserved

Degraded

(Science Coordination Team 2003)
Vegetation Changes in the WCAs

(Science Coordination Team 2003)

Also see Wu et al., *Ecol. Complex.* 2006
Stability of distinct ridges and sloughs indicated from the paleoecological record

(Bernhardt and Willard, in review)
Hydro-ecological feedbacks shape the ridge and slough landscape

Additions from Givnish et al. 2008

- Invasion of woody plants on more aerated ridges → tree islands
- P enhancement on tree islands by guano
- Tree island expansion/elongation limited by P transport

(Larsen, Harvey, and Crimaldi, Ecological Monographs 2007)
Peat Accretion Feedback Governs Vertical Landscape Dimension

- Predicted differential peat accretion behavior confirmed by *PeatAccrete* model
- Peat accretion feedback caused vertically stable ridges, but lateral spreading still occurred
- Vertical ridge stability was more sensitive to water level than P concentration

(Givnish et al., *Global Ecol. Biogeogr.*, 2008)

(Larsen et al., *Ecol. Monogr.* 2007)
Nutrient supply drives differences in net rate of carbon accumulation

Differential peat accretion

(Ross et al., *Hydrobiologia* 2006)

(Wetzel et al., *Plant Ecol.*, in press)
Particulate nutrient transport high, but role in landscape differentiation uncertain

- Particulate P = 31% of water column TP. Most P associated with microbial biomass.
- Suspended particle sources are bacteria and periphyton 'rain', but only infrequently benthic floc.

(Noe et al., *Limnol. Oceanogr.* 2007)
Greater flow speed in slough

- Flow velocities typically less than 2 cm s\(^{-1}\)
- Slough velocity 30% (Harvey) to 50% (Leonard) greater than ridge velocity
- Specific discharge in slough 100% greater than ridge (Harvey)

\[ p = 0.118, F_{(1,33)} = 2.56 \]

\[ p < 0.0001, F_{(1,842)} = 31.52 \]

(Leonard et al., Hydrobiologia 2006)
Role of flow pulses in controlling surface-water velocity

(Harvey et al., in review)
Velocities highly sensitive to vegetation/landscape pattern

- Determined mean flow velocities and dispersion coefficients in landscapes with different vegetation coverage and degree of degradation using SF$_6$ tracer

- Flows are in laminar to transitional regime

- Flow velocities relatively insensitive to water depth but highly sensitive to vegetation cover

- Flow direction aligned with ridge and slough landscape in well-preserved regions but controlled by regional forcing (i.e., water management) in degraded regions

(Variano et al., in review; Ho et al., in review)
Flow dependent on vegetation coverage

(L. Leonard, pers. comm.)

ANCOVA: \( p = 0.9295, F = 0.0081 \)
Velocity and bed shear stress affected by vegetation community

- Vegetative drag is higher in ridges compared with sloughs (Harvey et al., submitted) and also in degraded regions compared with well-preserved ridge and slough regions (Variano et al., submitted).
- Bed shear stress in sloughs is significantly lowered by presence of *Eleocharis* spp. (Larsen et al., in prep.)
Present-day particle concentrations low, with little ridge/slough differentiation

- No difference in ambient suspended sediment concentrations and physical and biogeochemical particle characteristics between ridge and slough.
- Greater water discharge in sloughs results in greater material loading through sloughs compared to ridges.
- Suspended sediment concentrations are low, dominated by fine particles (9 μm average), and generally not related to water velocity → ambient flows are below sediment entrainment thresholds. Greater sediment concentrations are associated with wind, bioturbation, and hurricanes.

(Noe et al., in review)

![Graph showing flow velocity](image1.png)

![Map showing Wilma](image2.png)

(Harvey et al., in review)
Benthic Annular Flume Studies

Paddles

0.12 m

OBS

Racetrack Flume Studies

Laser Doppler velocimeter

Digital floc camera

Peat/floc bed

Dowels to simulate sawgrass

Natural Floc Mobilization Experiments

LILA Flume Tracer Experiments

Sediment redistribution
Entrainment threshold of floc seldom reached in present-day Everglades

<table>
<thead>
<tr>
<th>Critical entrainment threshold</th>
<th>Sustained entrainment threshold</th>
<th>Notes</th>
<th>Study</th>
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</thead>
<tbody>
<tr>
<td>0.01 Pascals bed shear stress (~2 cm s(^{-1}) in racetrack flume)</td>
<td>0.02 Pascals bed shear stress (~4 cm s(^{-1}) in racetrack flume)</td>
<td>Depth-averaged velocity associated with threshold bed shear stress varies with water surface slope, depth, and vegetation community</td>
<td>Racetrack flume (Larsen et al., <em>in review</em>)</td>
</tr>
<tr>
<td>~2 cm s(^{-1})</td>
<td>3-5 cm s(^{-1})</td>
<td>Measured 5 cm above bed, unvegetated</td>
<td>Benthic annular flume (Hagerthey. <em>pers. comm.</em>)</td>
</tr>
<tr>
<td>3.2-5.3 cm s(^{-1})</td>
<td>N/A</td>
<td>Depth-averaged, in field (vegetated). Agreed with modeling predictions.</td>
<td>Natural floc mobilization (Larsen et al., <em>in review</em>)</td>
</tr>
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</table>
Restoration Recommendations

- Efforts to restore flow should focus primarily on reducing vegetative biovolume in sloughs and increasing surface-water slope by instituting a pulsed-flow regime.
- Bed shear stresses associated with restored flows should be at least 0.01 Pascals in sloughs.
- Restored flows should have low P content to maintain oligotrophic conditions and prevent vegetation compositional shifts.
- Sawgrass monocultures will unlikely revert to a corrugated ridge and slough landscape if flows are restored, unless sloughs are manually seeded. However, restoration of flow will preserve and enhance existing landscape patterning.
Remaining Uncertainties/Future Directions

- Duration of flows needed to maintain a stable, interconnected RSL
- Restoration timescales – related to rates of carbon and nutrient cycling (tricky!)
- Surface-water slopes achievable through pulsed-flow management regime
- Required balance between flow management and vegetation manipulation
- Particulate nutrient sources and sinks/role of fine particles

Large-scale field manipulations
Field/lab experimentation

G. Noe
Modeling
Role of transport processes in maintaining vegetation heterogeneity in Everglades similar to other systems
### Status of Science Coordination Team (2003) Hypotheses

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<tr>
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<td>Sloughs formed by erosion, arising from “consequent drainage” on recently uplifted surface</td>
<td>Unlikely. The RSL was aggrading at the time of formation, and the landscape formed in a wetter environment than present</td>
<td>Bernhardt, Willard; Bernhardt et al., <em>USGS OFR</em> 2004, Willard et al., <em>Rev. Paleobot. Palynol.</em> 2001</td>
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<td>Fire may have created initial patterning</td>
<td>Unlikely due to wet origin of landscape, its stability over millennia, and the pervasive occurrence of RSL patterning throughout Everglades</td>
<td>Bernhardt, Willard; Bernhardt et al., <em>USGS OFR</em> 2004, Willard et al., <em>Rev. Paleobot. Palynol.</em> 2001</td>
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<td>Sediment transport during high flows prevented net sedimentation in sloughs and caused ridges and tree islands to elongate</td>
<td>Likely explanation of longitudinal and lateral landscape features.</td>
<td>Engel, Hagerthey, Harvey, Larsen, Leonard, Noe, Nungesser</td>
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<td>Altered hydroperiods (e.g., depths, duration) alone permit colonization of sloughs by emergent vegetation or cause changes in decomposition rates that induce flattening</td>
<td>Cannot explain degradation that has occurred in some areas with unaltered hydroperiods. However, in some places, may contribute to degradation</td>
<td>Givnish, Larsen, Saunders, Volin; SCT 2003</td>
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Velocity and bed shear stress affected by vegetation community

Spike Rush, Utricularia, and Periphyton

\[ \bar{U} = 0.25 \text{ cm s}^{-1} \]

Spike Rush ONLY

\[ \bar{U} = 0.68 \text{ cm s}^{-1} \]

No Vegetation

\[ \bar{U} = 0.78 \text{ cm s}^{-1} \]

(Leonard et al., Hydrobiologia 2006)
Flow speeds in “free-flowing” sites 3-5x higher than “confined” sites

(Riscassi and Schaffranek, 2004; Harvey et al., in review)
NMS ordination: water depth highly significant to vegetation community composition

Axis 3 ≈ classic microtopographic gradient

Axis 2 ≈ proximity to tree islands gradient

(Givnish et al., Global Ecol. Biogeogr. 2008)