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

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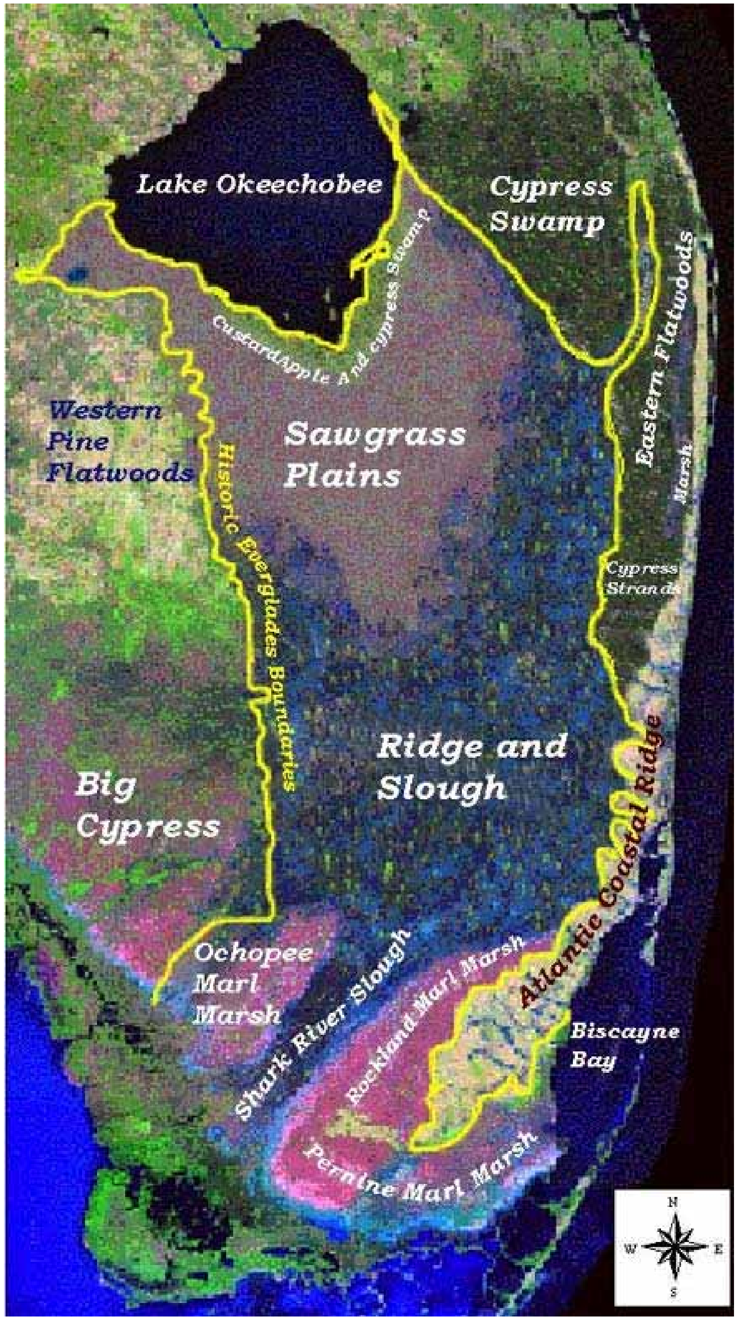
Make sure to see…

- **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

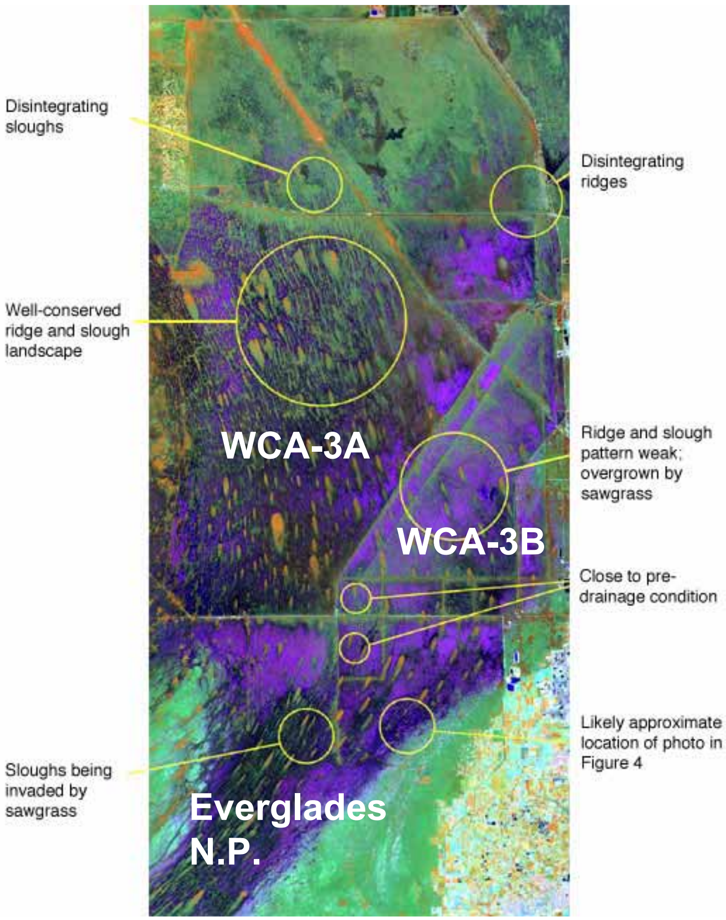


Well-preserved

Degraded

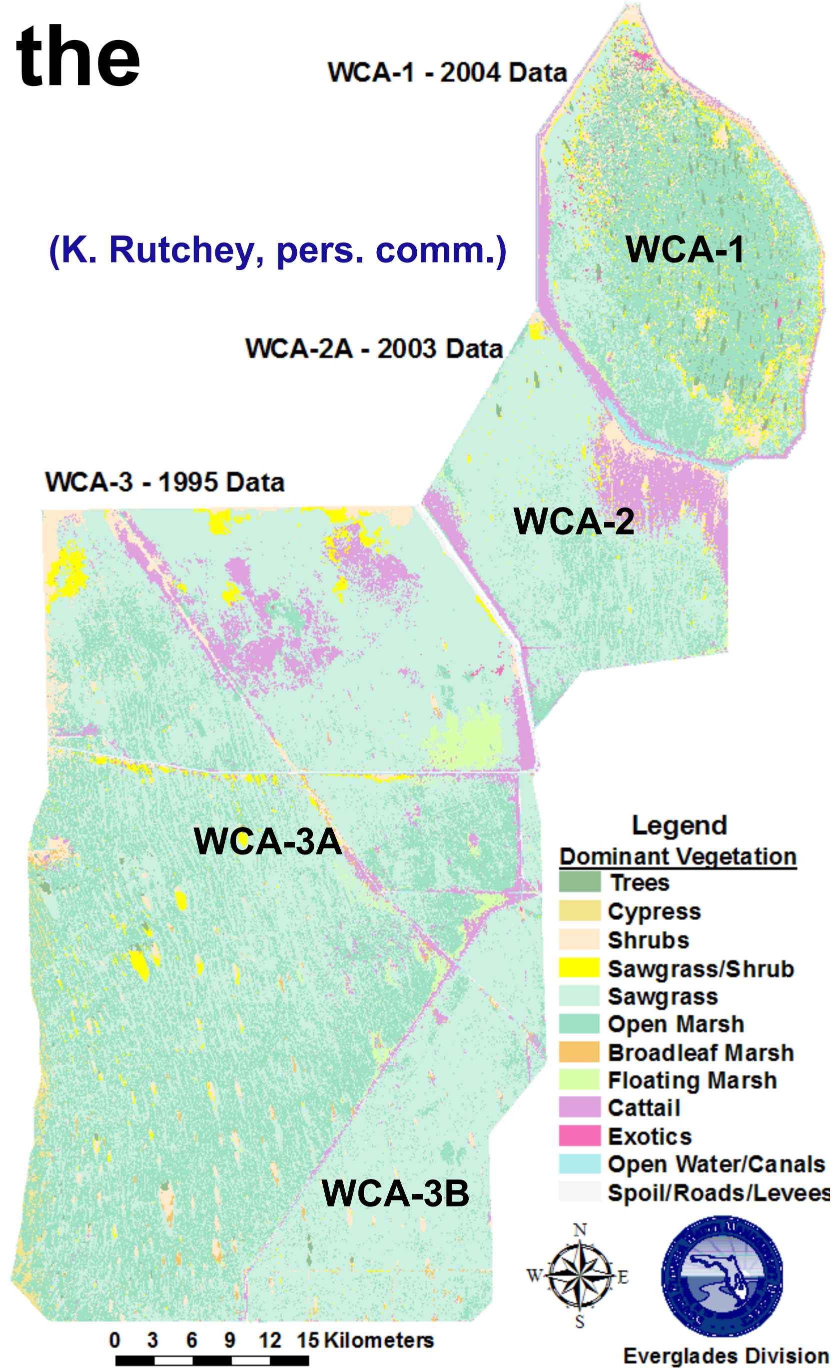
(Science Coordination Team 2003)

Vegetation Changes in the WCAs



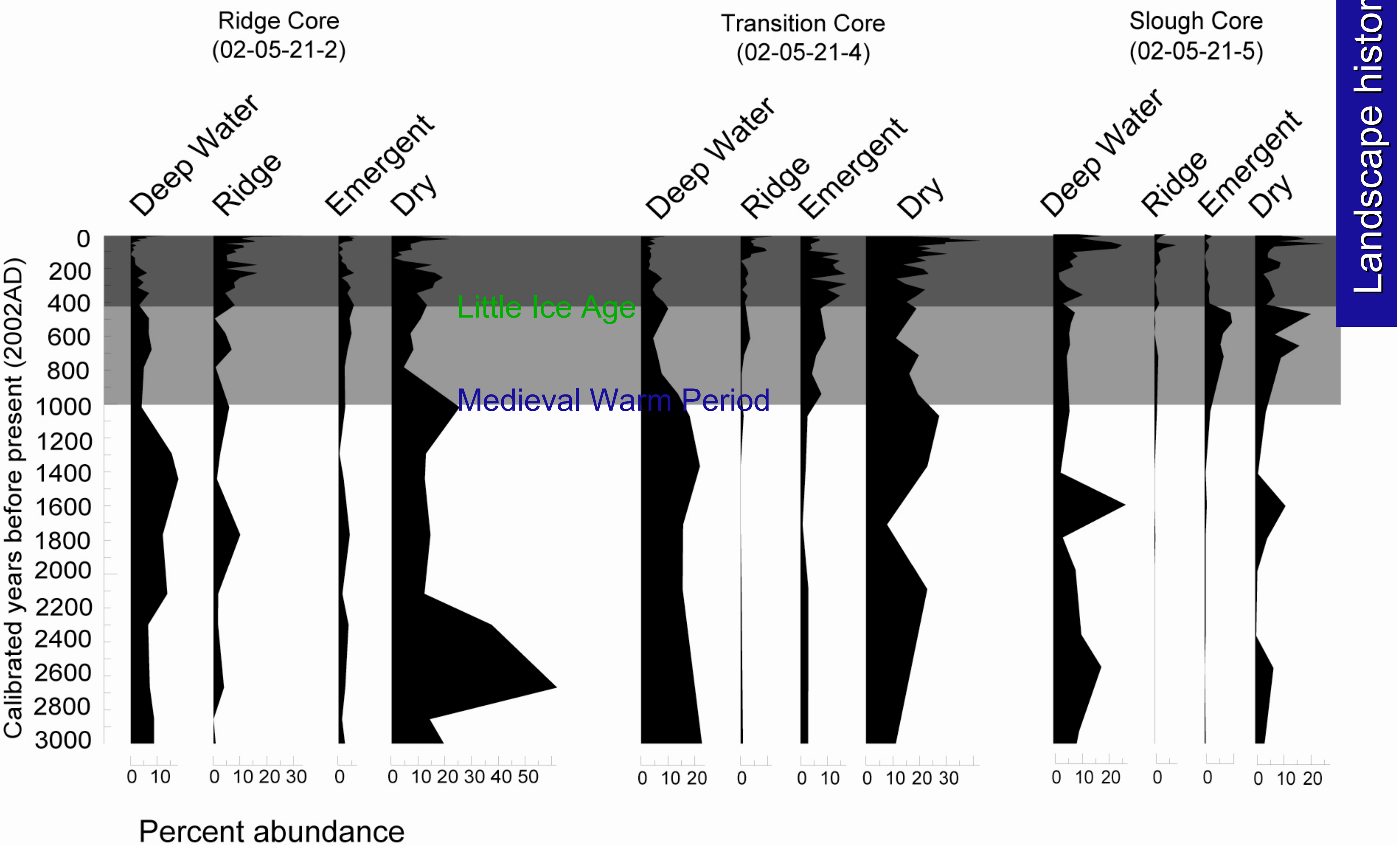
(Science Coordination Team 2003)

(K. Rutchey, pers. comm.)



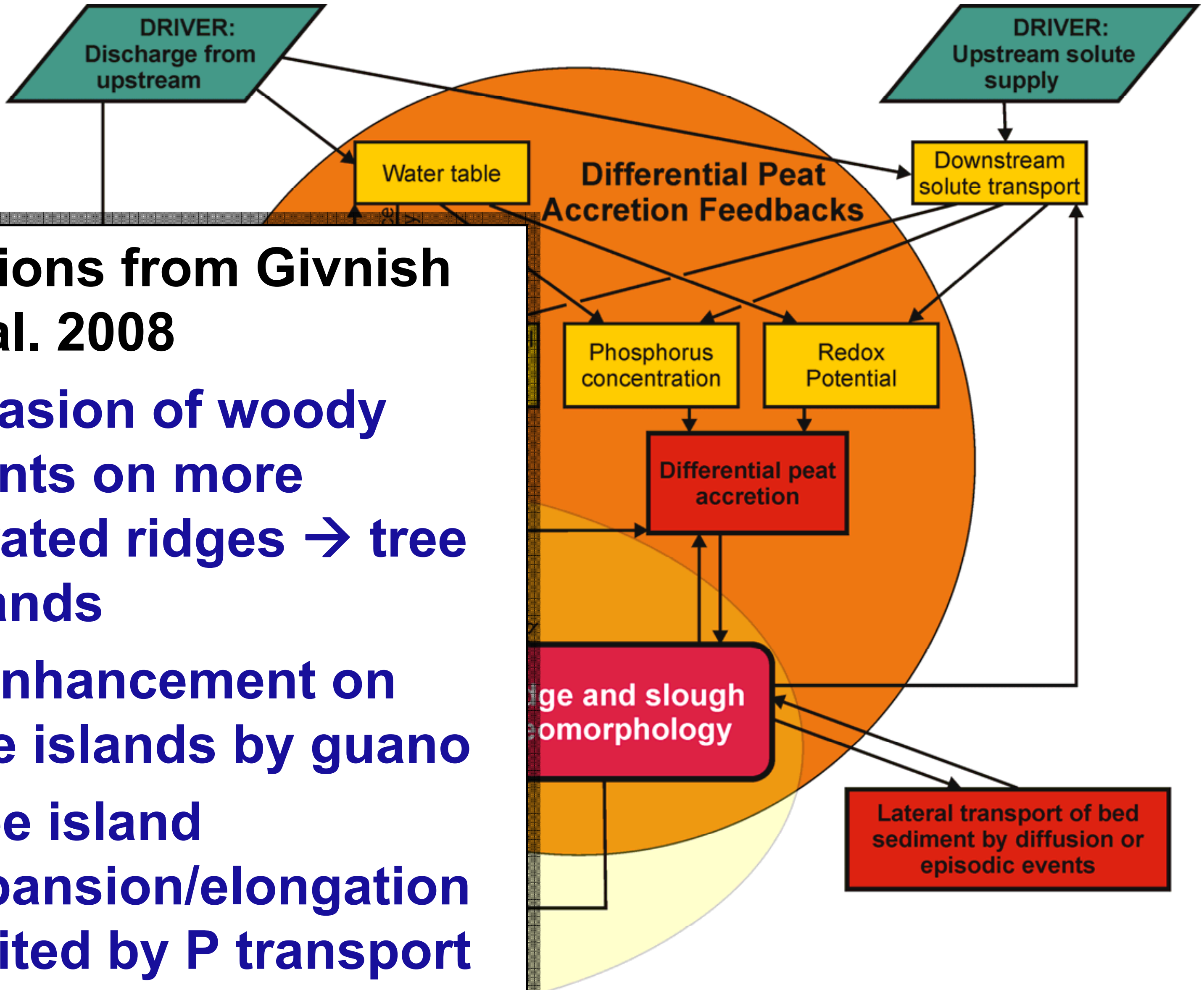
Also see Wu et al., *Ecol. Complex.* 2006

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

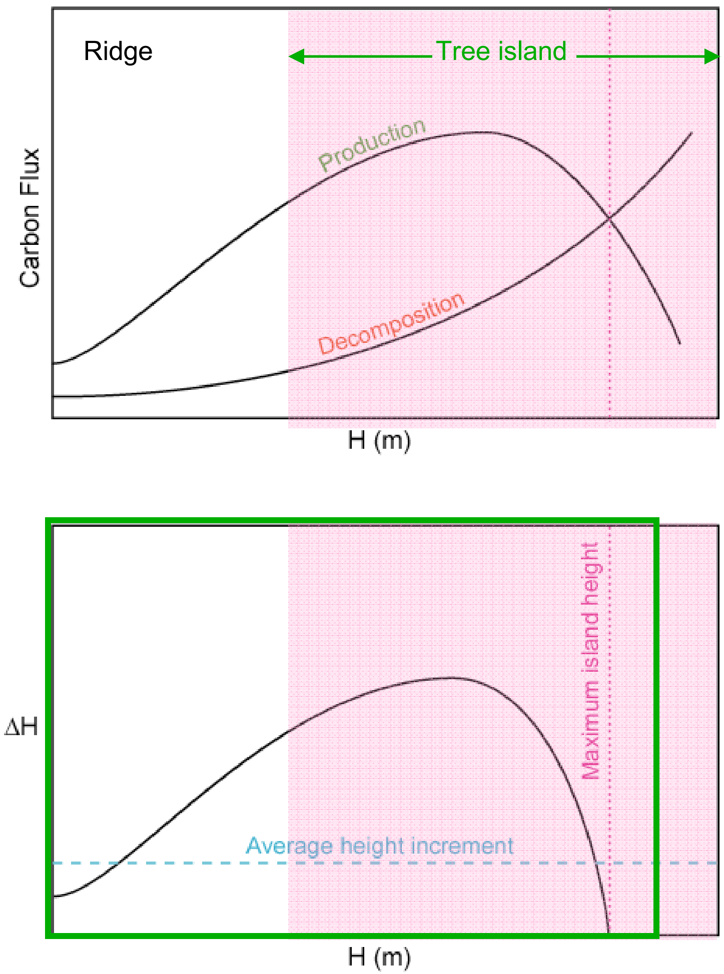


Additions from Givnish et al. 2008

- 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

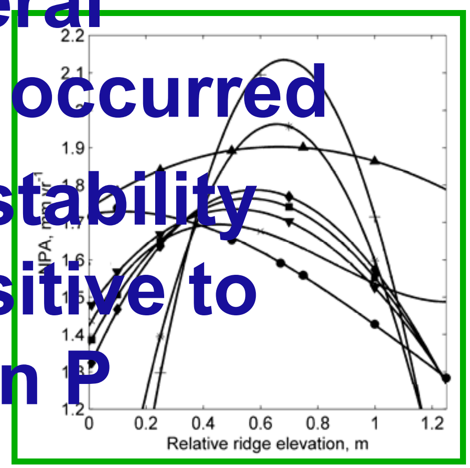
(Larsen, Harvey, and Crimaldi, *Ecological Monographs* 2007)

Peat Accretion Feedback Governs Vertical Landscape Dimension



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

- **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**



(Larsen et al., *Ecol. Monogr.* 2007)

Differential peat accretion

Nutrient supply drives differences in net rate of carbon accumulation

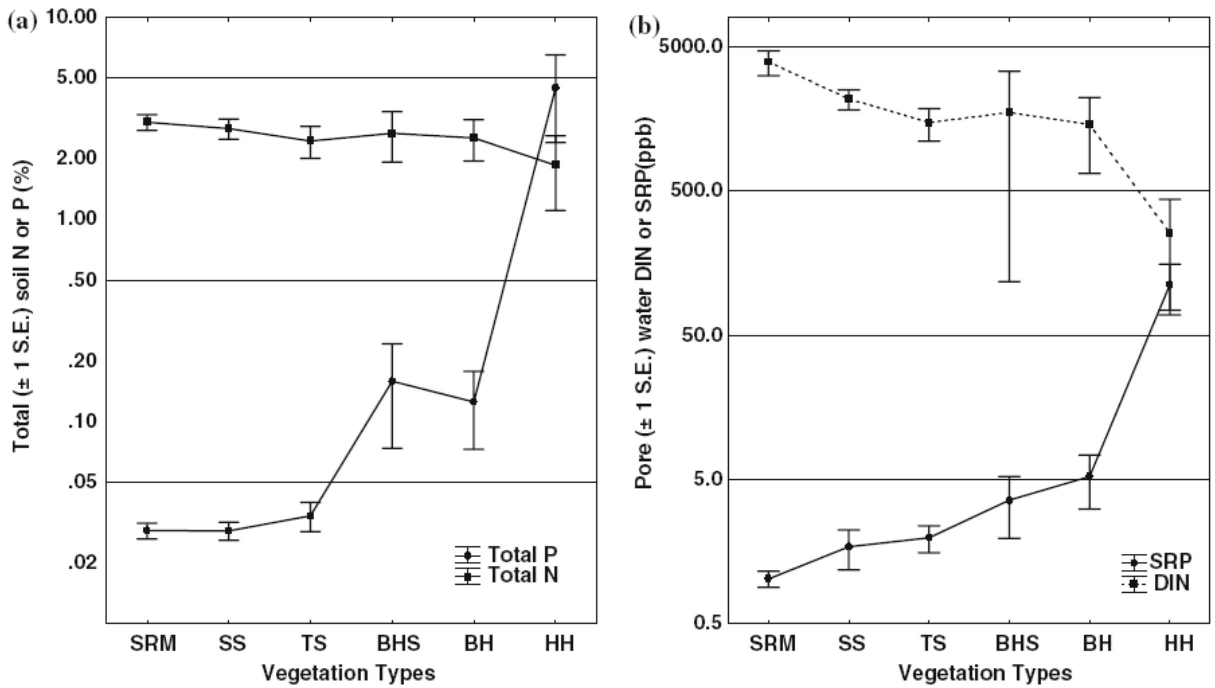
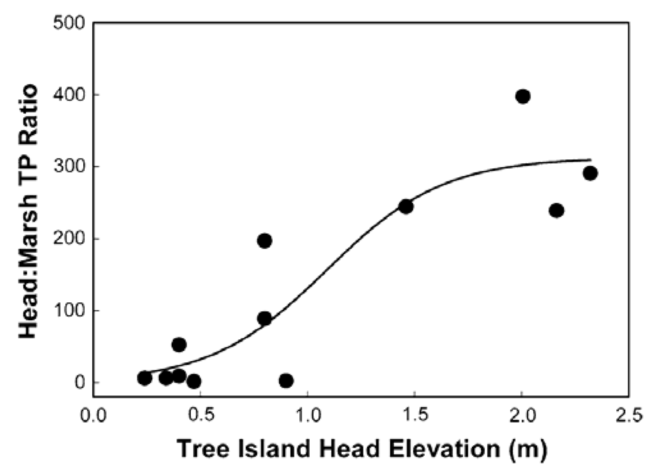


Figure 3. Soil and pore water nutrient concentrations in six Shark Slough vegetation types. (a) Total N and P content in soils; (b) DIN and soluble reactive phosphorus in pore water. Vegetation types are arranged from most persistently flooded at left to least flood-prc at right. SRM, Spikerush marsh; SS, Sparse Sawgrass marsh; TS, Tall Sawgrass marsh; BHS, Bayhead Swamp forest; B, Bayhe forest; HH, Hardwood Hammock.

(Ross et al., *Hydrobiologia* 2006)



(Wetzel et al., *Plant Ecol.*, in press)

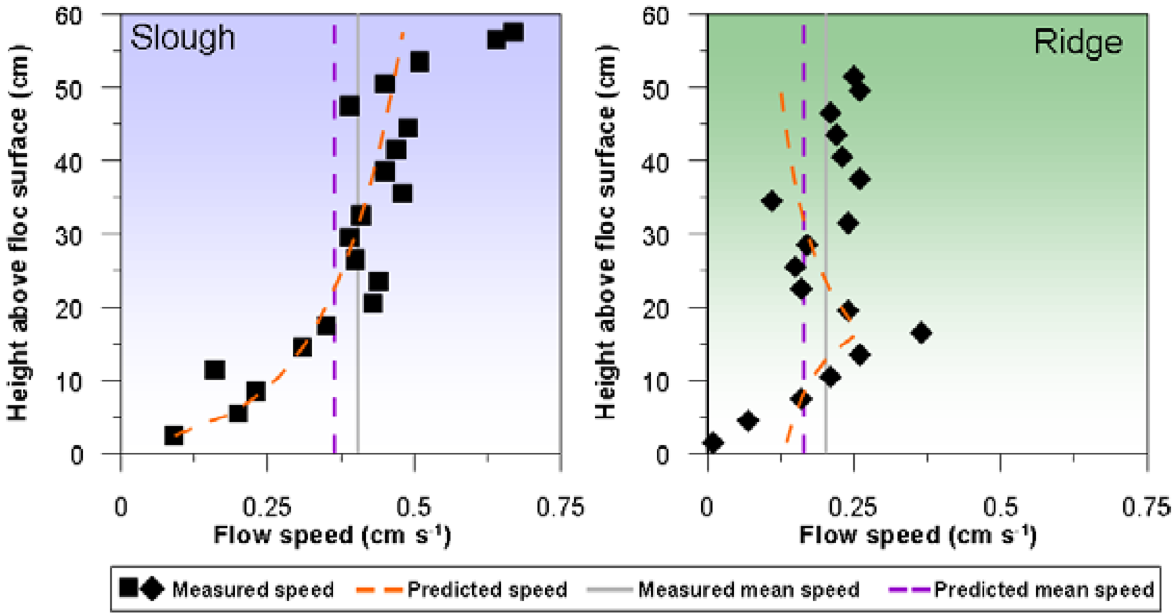
Differential peat accretion

Particulate nutrient transport high, but role in landscape differentiation uncertain

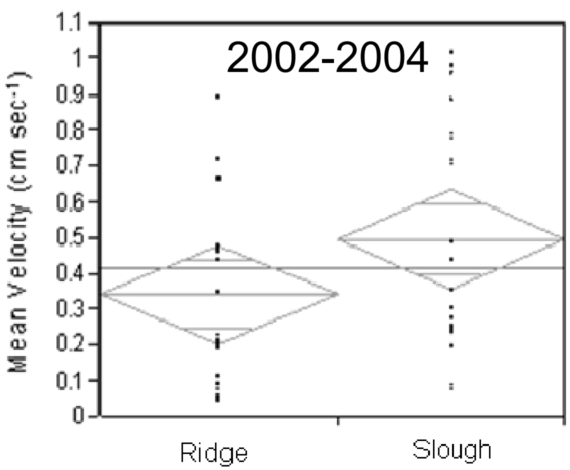
- **Particulate P = 31% of water column TP. Most P associated with microbial biomass.**
- **Suspended particle sources are bacteria and periphyton 'rain', but only infrequently benthic floc.**

(Noe et al., *Limnol. Oceanogr.* 2007)

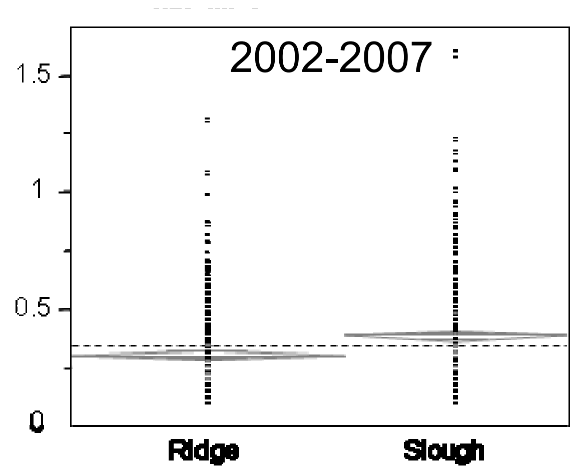
Greater flow speed in slough



(Harvey et al., in review)



p=0.118, $F_{(1,33)}$ = 2.56



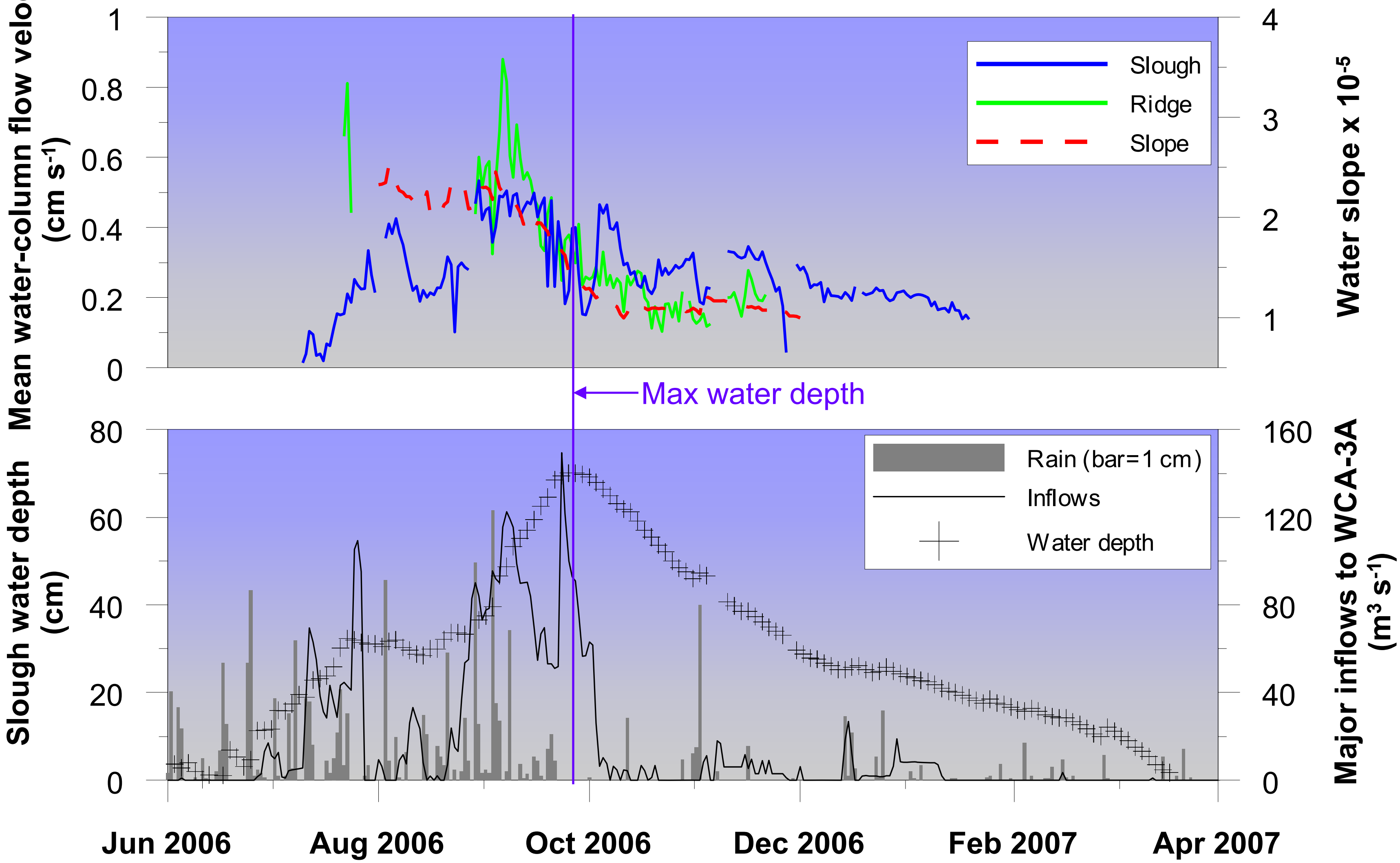
p < 0.0001, $F_{(1,842)}$ = 31.52

(Leonard et al., *Hydrobiologia* 2006)

- **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)**

Sediment redistribution

Role of flow pulses in controlling surface-water velocity



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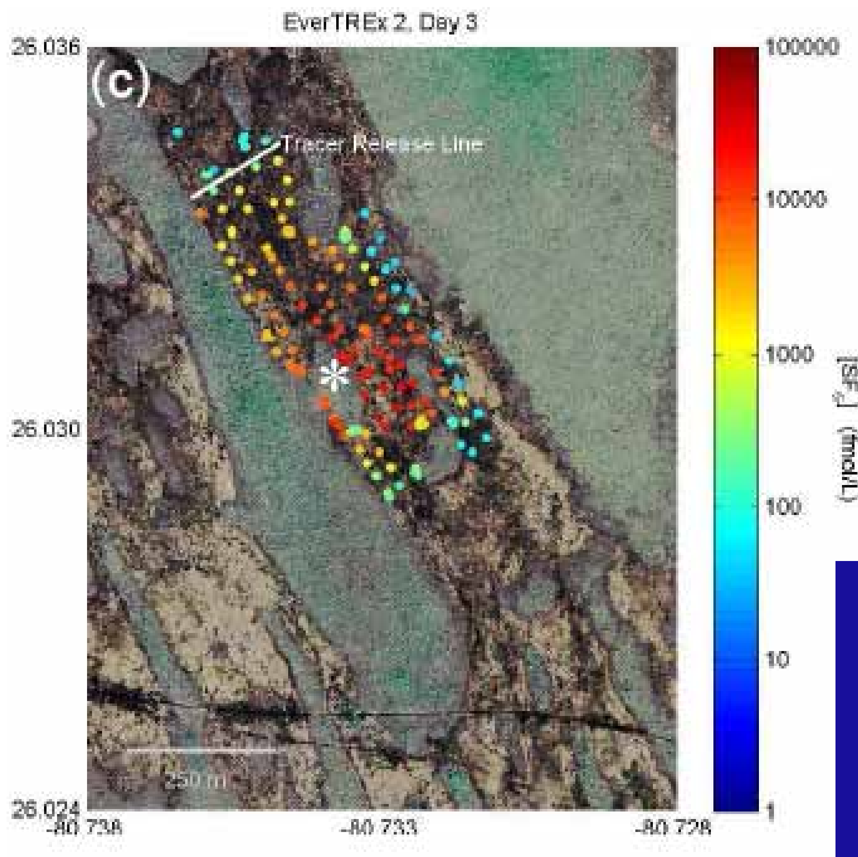
(Harvey et al., *in review*)

Sediment redistribution

Velocities highly sensitive to vegetation/ landscape pattern

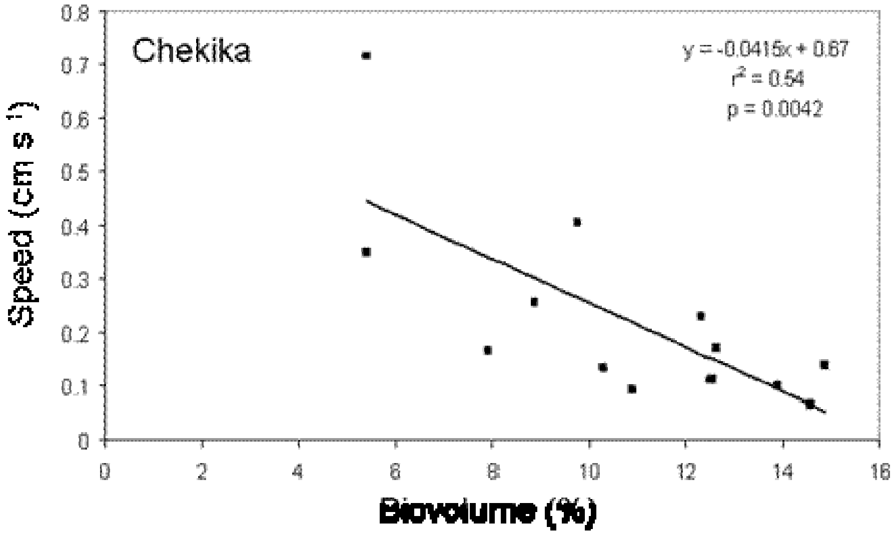
- **Determined mean flow velocities and dispersion coefficients in landscapes with different vegetation coverage and degree of degradation using SF_6 tracer**
- **Flows are in laminar to transitional regime**
- **Flow velocities relatively insensitive to water depth but highly sensitive to vegetation 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**

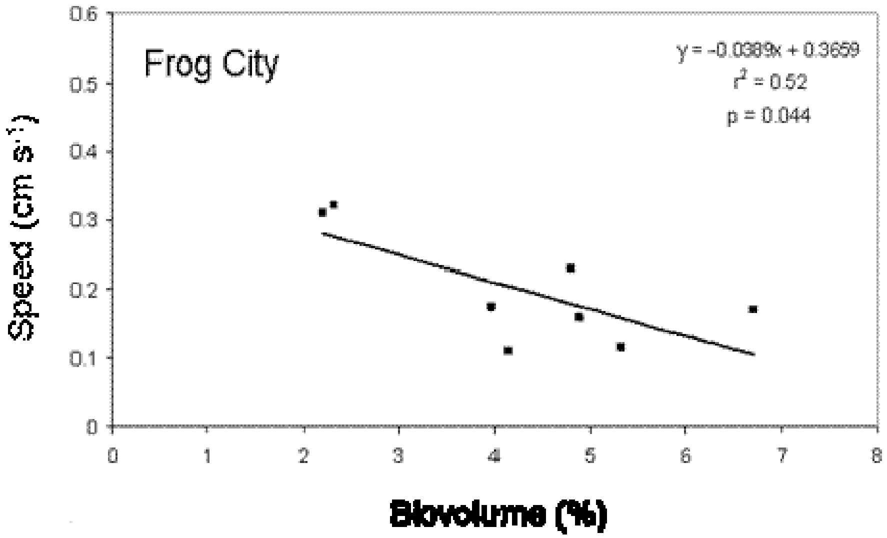


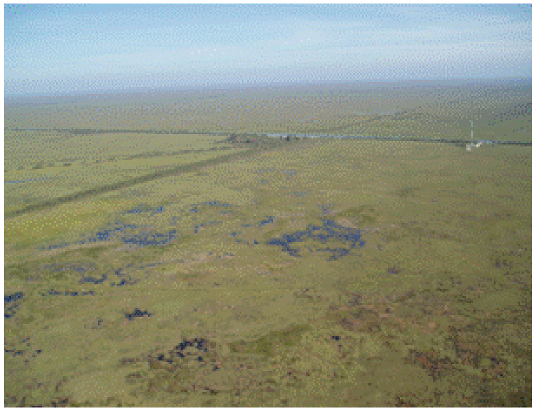
(Variano et al., *in review*; Ho et al., *in review*)

Sediment redistribution

Flow dependent on vegetation coverage







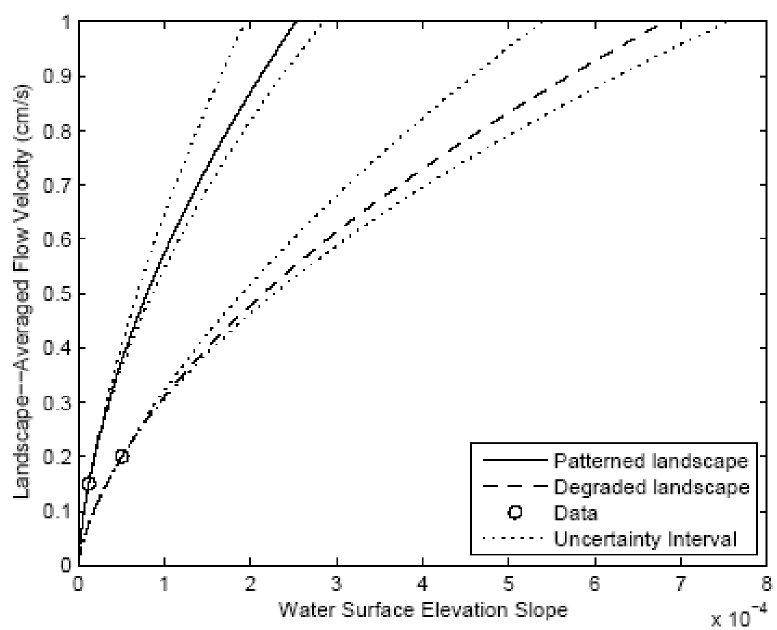
(L. Leonard, *pers. comm.*)

ANCOVA: p = 0.9295, F = 0.0081

Sediment redistribution

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.)**



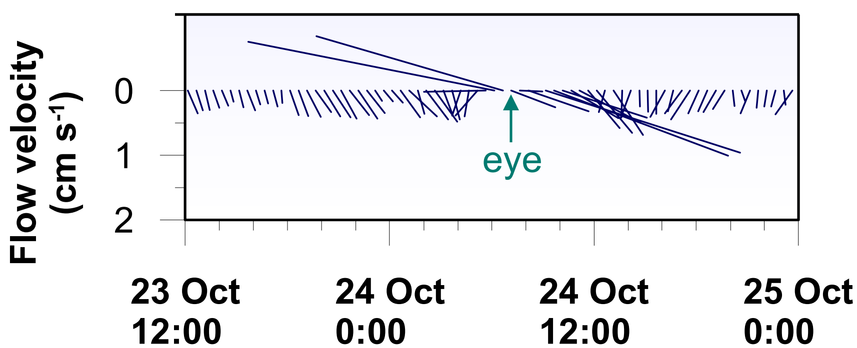
(Variano et al., *in review*)

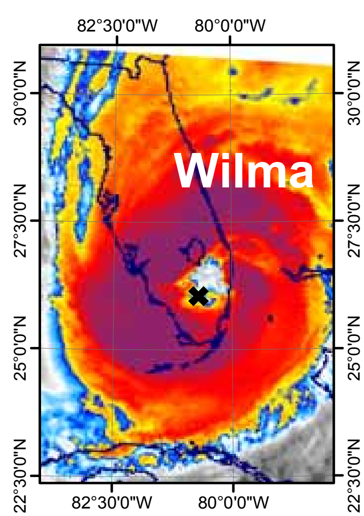
Sediment redistribution

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)





(Harvey et al., *in review*)

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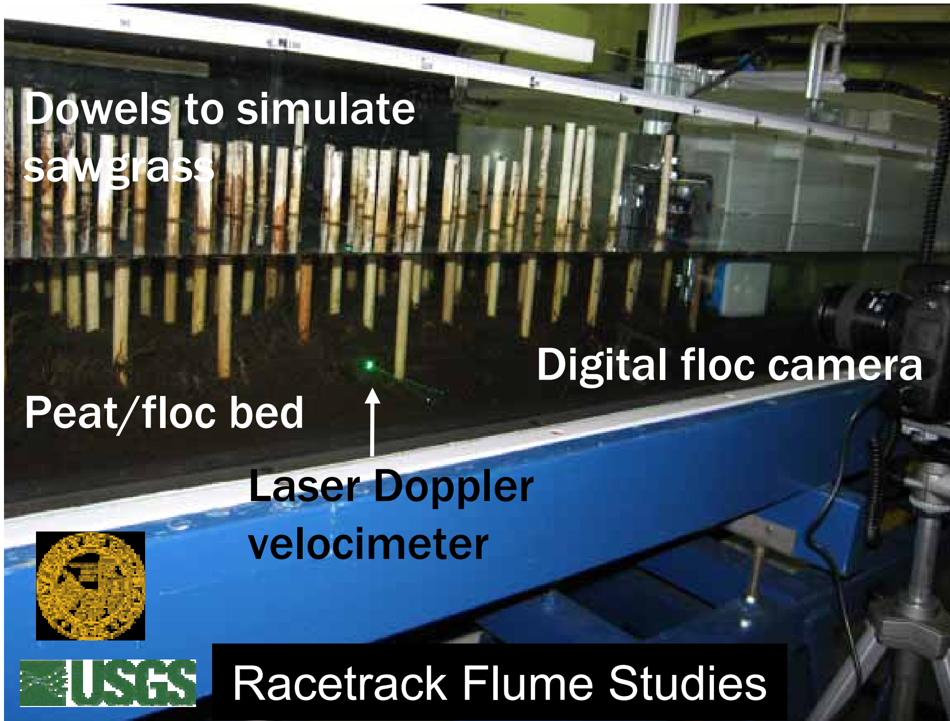
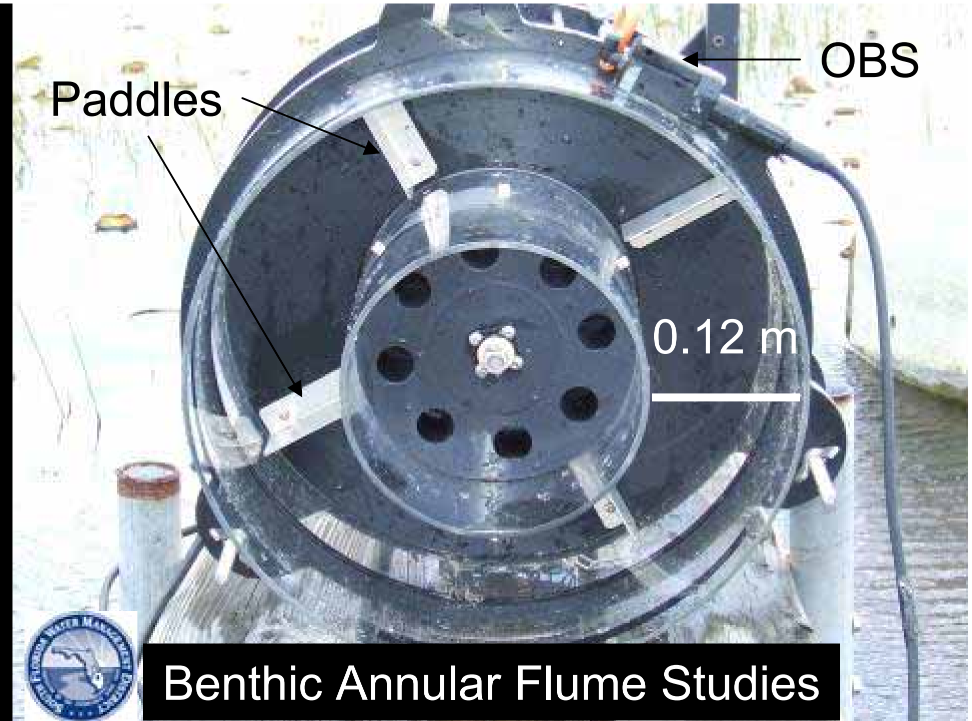
Sediment redistribution





Sediment redistribution

Entrainment threshold of floc seldom reached in present-day Everglades

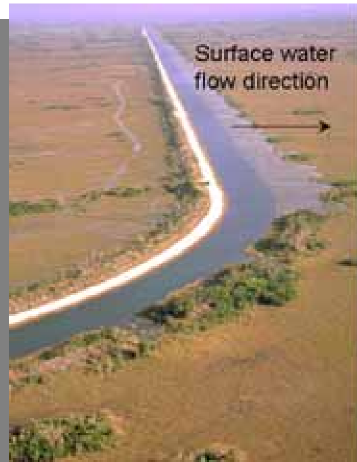
Critical entrainment threshold	**Sustained entrainment**	**Notes**	**Study**
0.01 Pascals bed shear stress (~2 cm s^{-1} in racetrack flume)	0.02 Pascals bed shear stress (~ 4 cm s^{-1} in racetrack flume)	Depth-averaged velocity associated with threshold bed shear stress varies with water surface slope,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

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.

Remain

- Durati
  interco
- Restoration timescales – re
  carbon and nutrient cycling (*tric*
- Surface-water slopes achievabl
  pulsed-flow management regim
- Required balance between flow
  and vegetation manipulation
- Particulate nutrient sources and sinks/role of fine particles



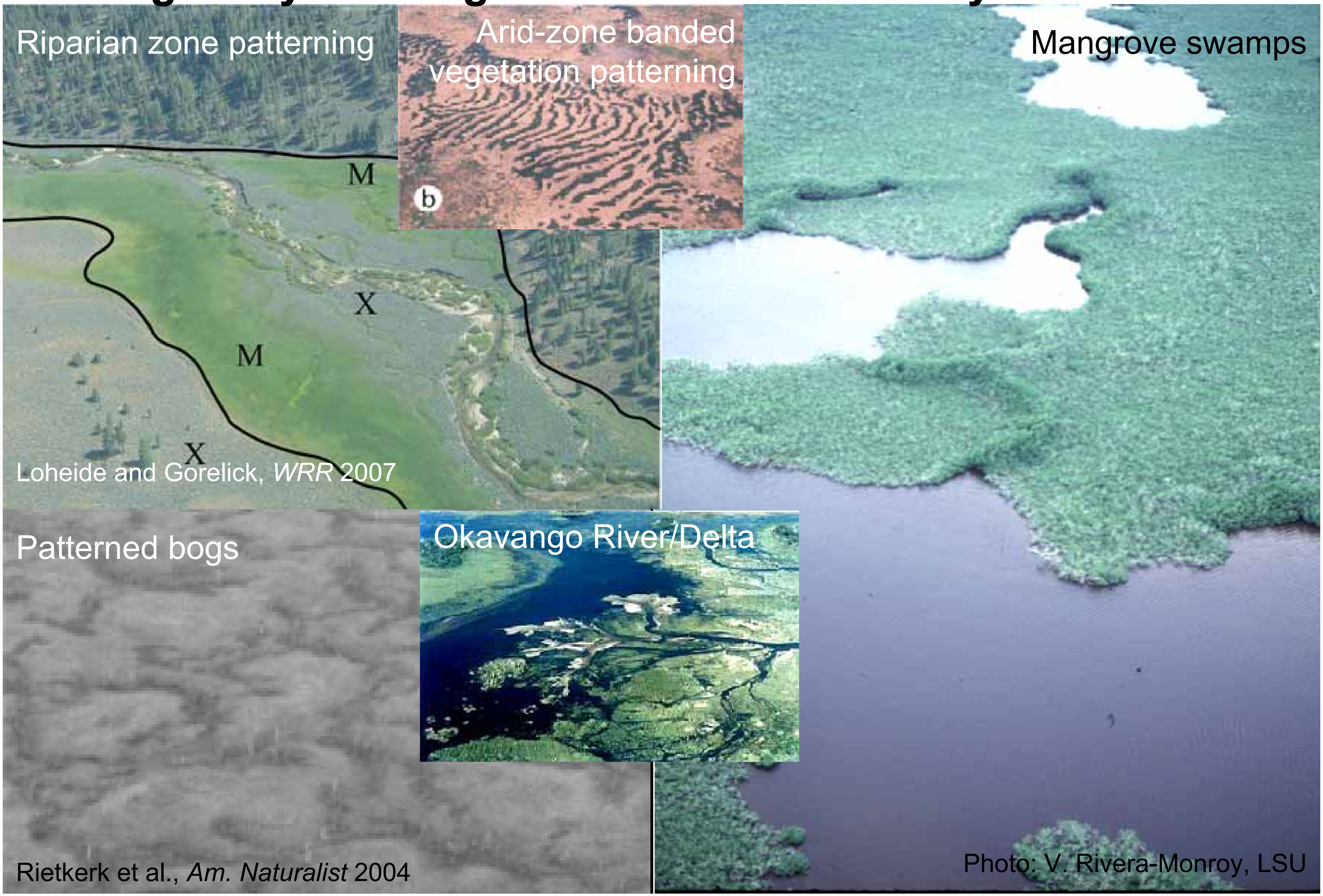
G. Noe

Large-scale field manipulations

Field/lab experiments

Modeling

Role of transport processes in maintaining vegetation heterogeneity in Everglades similar to other systems



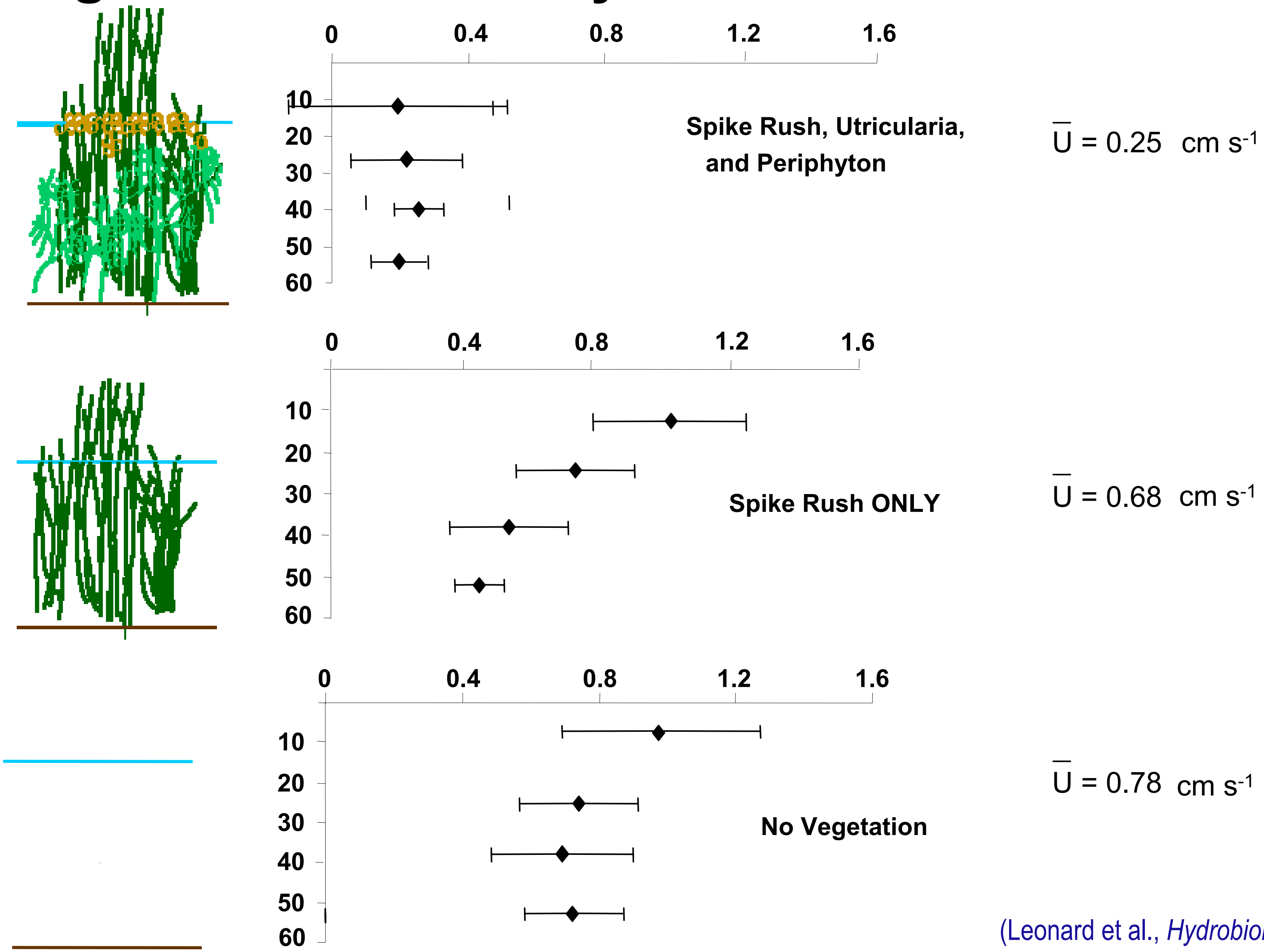
Status of Science Coordination Team (2003) Hypotheses

Hypothesis	Status	Working groups/ source
Sloughs formed by erosion, arising from “consequent drainage” on recently uplifted surface	Unlikely. The RSL was aggrading at the time of formation, and the landscape formed in a wetter environment than present	Bernhardt, Willard; Bernhardt et al., *USGS OFR* 2004, Willard et al., *Rev. Paleobot. Palynol.* 2001
Fire may have created initial patterning	Unlikely due to wet origin of landscape, its stability over millennia, and the pervasive occurrence of RSL patterning throughout Everglades	Bernhardt, Willard; Bernhardt et al., *USGS OFR* 2004, Willard et al., *Rev. Paleobot. Palynol.* 2001
RSL patterning reproduces underlying bedrock topography	Unlikely. Bedrock and surface topography are not correlated.	McVoy; Givnish et al. *Global Ecol. Biogeogr.* 2008

Status of Science Coordination Team (2003) Hypotheses

Hypothesis	Status	Working groups/ source
Sediment transport during high flows prevented net sedimentation in sloughs and caused ridges and tree islands to elongate	Likely explanation of longitudinal and lateral landscape features.	Engel, Hagerthey, Harvey, Larsen, Leonard, Noe, Nungesser
Altered hydroperiods (e.g., depths, duration) alone permit colonization of sloughs by emergent vegetation or cause changes in decomposition rates that induce flattening	Cannot explain degradation that has occurred in some areas with unaltered hydroperiods. However, in some places, may contribute to degradation	Givnish, Larsen, Saunders, Volin; SCT 2003
“Positive feedback” hypothesis: ridges and tree islands accrete peat more rapidly than sloughs and in response to nutrient and oxygen concentrations and water level	Likely explanation of vertical features/vertical stability of landscape. Role of flow in delivering nutrients and oxygen less well understood	Givnish, Larsen, Noe, Saunders, Troxler, Volin; Givnish et al. *Global Ecol. Biogeogr.* 2008; Larsen et al. *Ecol. Mon.* 2007

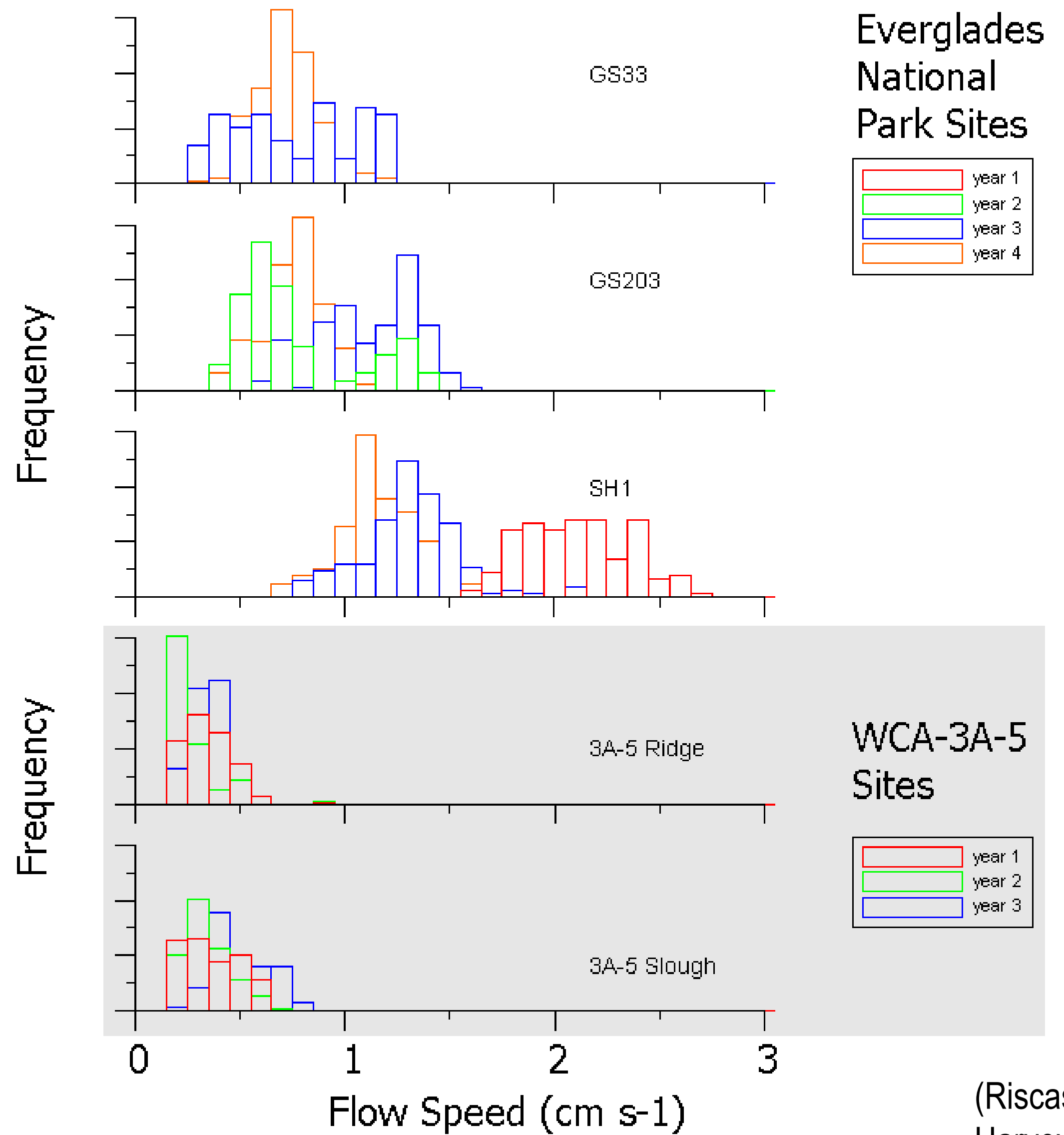
Velocity and bed shear stress affected by vegetation community



(Leonard et al., *Hydrobiologia* 2006)

Sediment redistribution

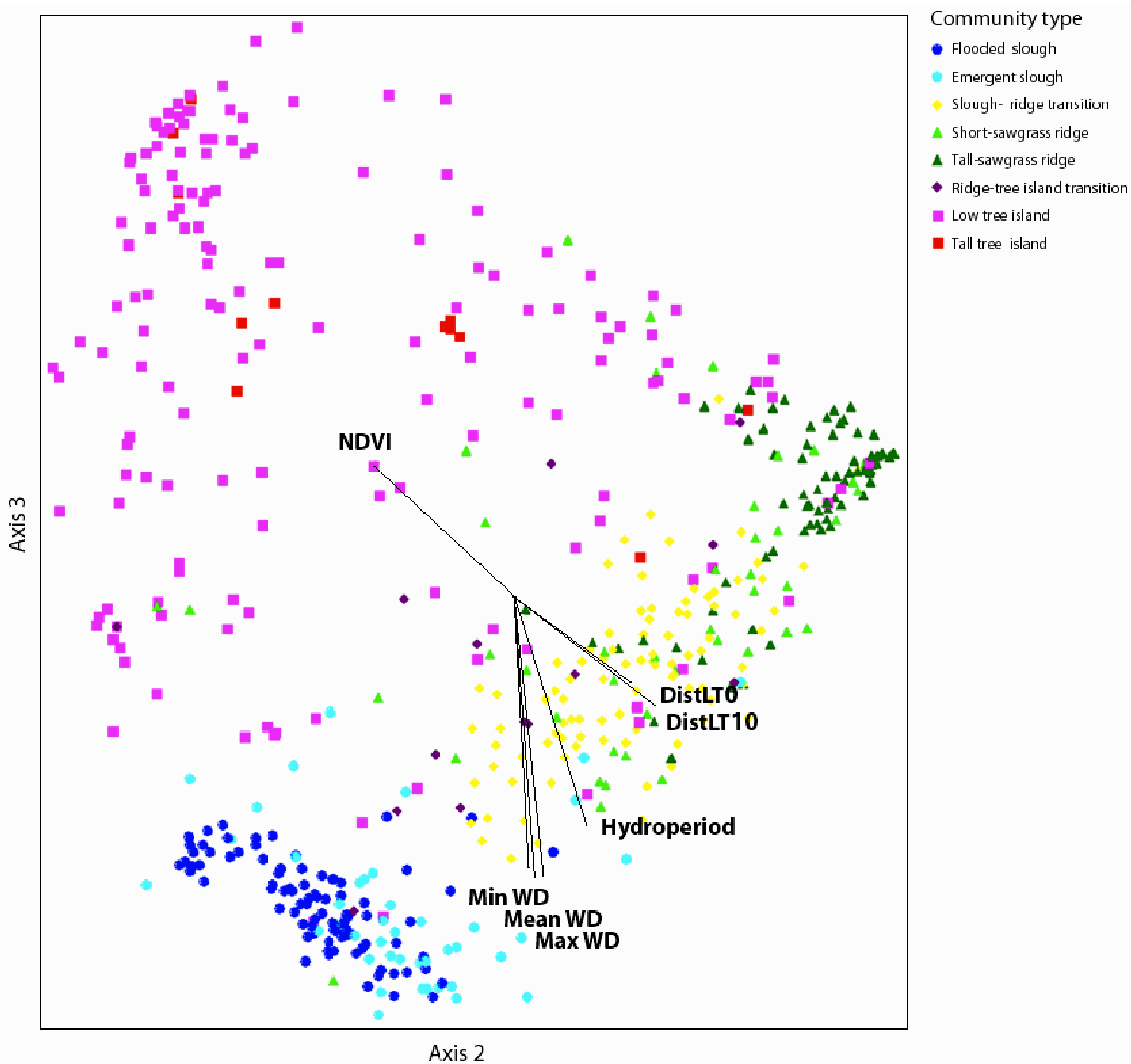
Flow speeds in “free-flowing” sites 3-5x higher than “confined” sites



(Riscassi and Schaffranek, 2004; Harvey et al., *in review*)

Sediment redistribution

NMS ordination: water depth highly significant to vegetation community composition



Axis 3 ≈ classic microtopographic gradient

Axis 2 ≈ proximity to tree islands gradient

Differential peat accretion

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