Interaction of pulse and press disturbances: evidence of the effects of sea level rise on the coastal forests of the lower Florida Keys, FL from 1990 to 2012

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Press (sea level rise) and pulse (hurricane storm surge) disturbances in south Florida in the 21st century

Press (Ramp): continual, leading to permanent change in species composition and/or abundance

Pulse: short-term, causing sudden change in species abundance and/or composition which will recover once disturbance ceases
Pine Rockland & Hardwood Hammock Forest Communities of the Lower Florida Keys

- Elevations range from 0.3 to 2.0 meters above mean sea level
- Provide habitat for many species / high biodiversity
- Disturbance-adapted communities
Effects to coastal forests during the 20th Century

Post Hurricane Wilma pine tree survival

Pine rockland extent on Upper Sugarloaf Key

Pine stump on Sugarloaf Key 2010
Florida Keys: Location and Geology

Fig. 5-1. Map showing the Florida Keys, their lithology, and location relative to mainland and reef tract. (Halley et al. 1993)
Conceptual Model of Freshwater Lens

- Precipitation
- Transpiration
- Well
- Water table
- Land surface
- Freshwater Lens
  - Fresh
  - Brackish
  - Ghyben-Herzberg Lens

Sea level
Sea water
Conceptual Model of Freshwater Lens

- Precipitation
- Transpiration
- Well
- Water table
- Land surface
- Fresh
- Ghyben-Herzberg Lens
- Freshwater
- Brackish
- Sea water

Current Sea level
Previous Sea Level
23cm of SLR at Key West Tide Gauge over 100 years

Mean rate of sea level rise = 2.3 mm yr\(^{-1}\)

Revised Local Reference (mm)

Year

Mean sea level

10 year moving average

5 cm

1990         22 yrs          2012
Research Questions

1) Has sea level rise of 5 cm increased groundwater salinity in coastal forests at locations inside and outside the boundaries of the freshwater lens?

2) Are changes in forest structure and species composition associated with the press disturbance (SLR) and/or the pulse disturbance (storm surge)?

3) Are changes in forest structure and composition present in all vegetation strata (canopy, high shrub, low shrub/herb)?
Study Area: Big Pine Key and Upper Sugarloaf Key

Hurricane Georges 1998

Hurricane Wilma 2005
### Sampling 1990s & 2010s

**Groundwater salinity monitoring**
- Wells sampled at periodic intervals
  - 2010s (2012 – 2013) every two months

### Statistical Analyses
- Mixed Linear Effects Modeling including random effects with post-hoc tests in R v. 3.1.2
- Nonmetric multidimensional scaling (NMDS) ordination and vector fitting to 3 environmental variables in DECODA v. 3.01

### Vegetation sampling
- Basal area calculated for all trees > 3cm dbh
- Percent cover estimated in high and low shrub strata in 5x5 m quadrats

<table>
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<th>Plot</th>
<th>Island</th>
<th>Habitat</th>
<th>Lens Location</th>
<th># of sub plots</th>
<th>Area (m²)</th>
<th>Distance to coast (m)</th>
<th>Ht (m) above LMSL</th>
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Deviation from 30-year average annual precipitation received at Key West International Airport (1984 – 2013)

Average Annual Precipitation = 102 cm

- Deviation from 30-year average annual precipitation received at Key West International Airport (1984–2013)


-30 -20 -10 0 10 20 30

- Deviation from 30-year average annual precipitation (cm)

- 1990s sample years
- 2010s sample years
Mean groundwater salinity (PPT) +/- SE in each sampling period

| Fixed Effects                  | Estimate (PPT) | Pr(>|t|) |
|-------------------------------|----------------|----------|
| Intercept                     | 9.77           | < 0.001  |
| Lens Location (Inside)        | -2.83          | < 0.01   |
| Period (2010s)                | 1.67           | 0.032    |
| 30 days precipitation         | -1.01          | 0.034    |
| LL(Inside) : Per(2010s)       | -1.87          | 0.065    |
| LL(Inside) : Precipitation    | -1.01          | 0.017    |
Percent Change in vegetation abundance in 3 strata

PR = Pine Rockland
HH = Hardwood Hammock

PR

HH

Percent Change in vegetation abundance in 3 strata:

- Basal area per hectare
- High shrub percent cover
- Low shrub percent cover

Plots inside lens boundary
Plots outside lens boundary
Tree stratum NMDS ordination

Inside Lens Pine
Inside Lens Hammock
Outside Lens Pine
Outside Lens Hammock

Groundwater salinity
Distance to coast
Height above local msl

Minimum stress: 0.14
Low shrub stratum NMDS ordination

- Height above local msl
- Groundwater salinity
- Distance to coast

- Inside Lens Pine
- Inside Lens Hammock
- Outside Lens Pine
- Outside Lens Hammock

Minimum stress: 0.13
Low shrub layer: Gain in species typical of coastal buttonwood forest

S4: Hardwood Hammock

S3: Pine rockland

Borrichia frutescens
Fimbristylis spadicea
Spartina spartinae
Sporobolus virginicus
Summary and Conclusions

• SLR increased groundwater salinity only at plots outside the FWL, while groundwater salinity at inside lens locations was dominated by amount of recent precipitation received.

• Pulse disturbance (storm surge) was primarily responsible for changes in structure and composition of the tree stratum, while press disturbance (SLR) or interaction of the disturbances was observed to change shrub strata along a trajectory of increasing groundwater salinity only in coastal forest plots outside the FWL.

• Changes in composition of low shrub stratum are an early indicator of effects of sea level rise on fresh water-requiring coastal forests.
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