BEFORE THE GHOSTS APPEAR: IDENTIFYING THE EFFECTS OF CHRONIC SALTWATER INTRUSION ON COASTAL FLOODPLAIN SWAMPS USING REMOTE SENSING

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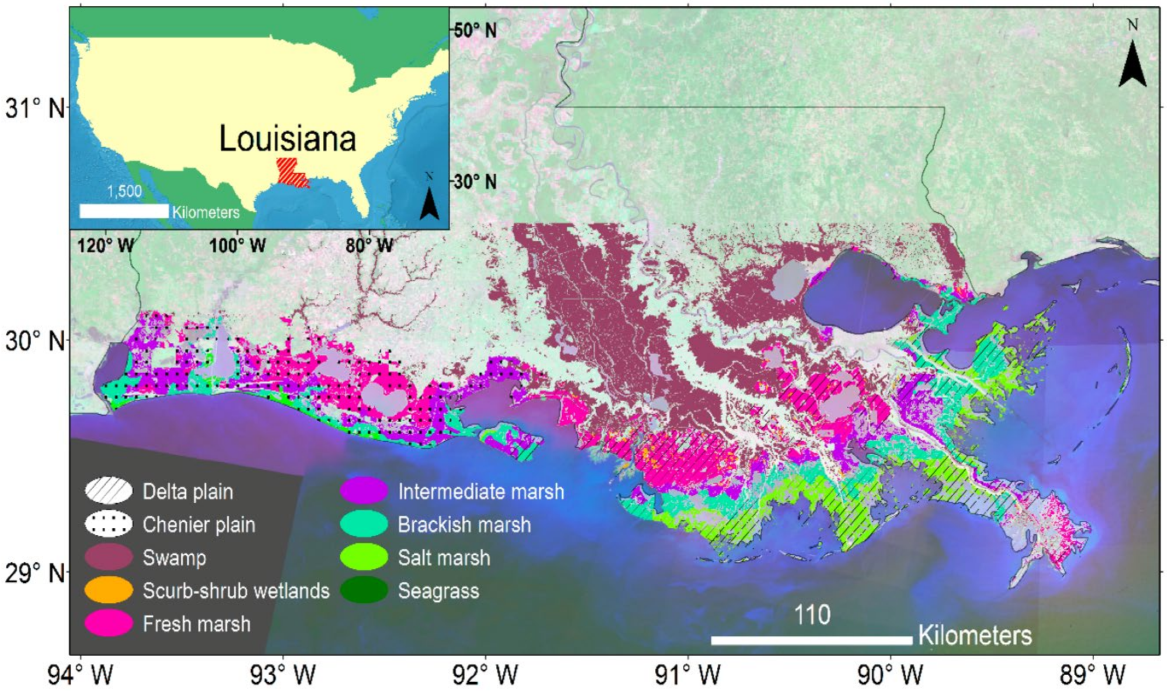
The Take-Home Message

- Remote-sensing (RS) data can be used to identify saltwater-stressed coastal floodplain swamps...
- **Outcomes** easier to detect than **process**
- RS can be used for monitoring and exploration...coupled with local knowledge

The Coastal Wetland Mosaic

- Coastal margins are inhabited by a mosaic of different wetland types
- Abiotic gradients strongly drive ecosystem structure and function
  - Hydroperiod, salinity, nutrients



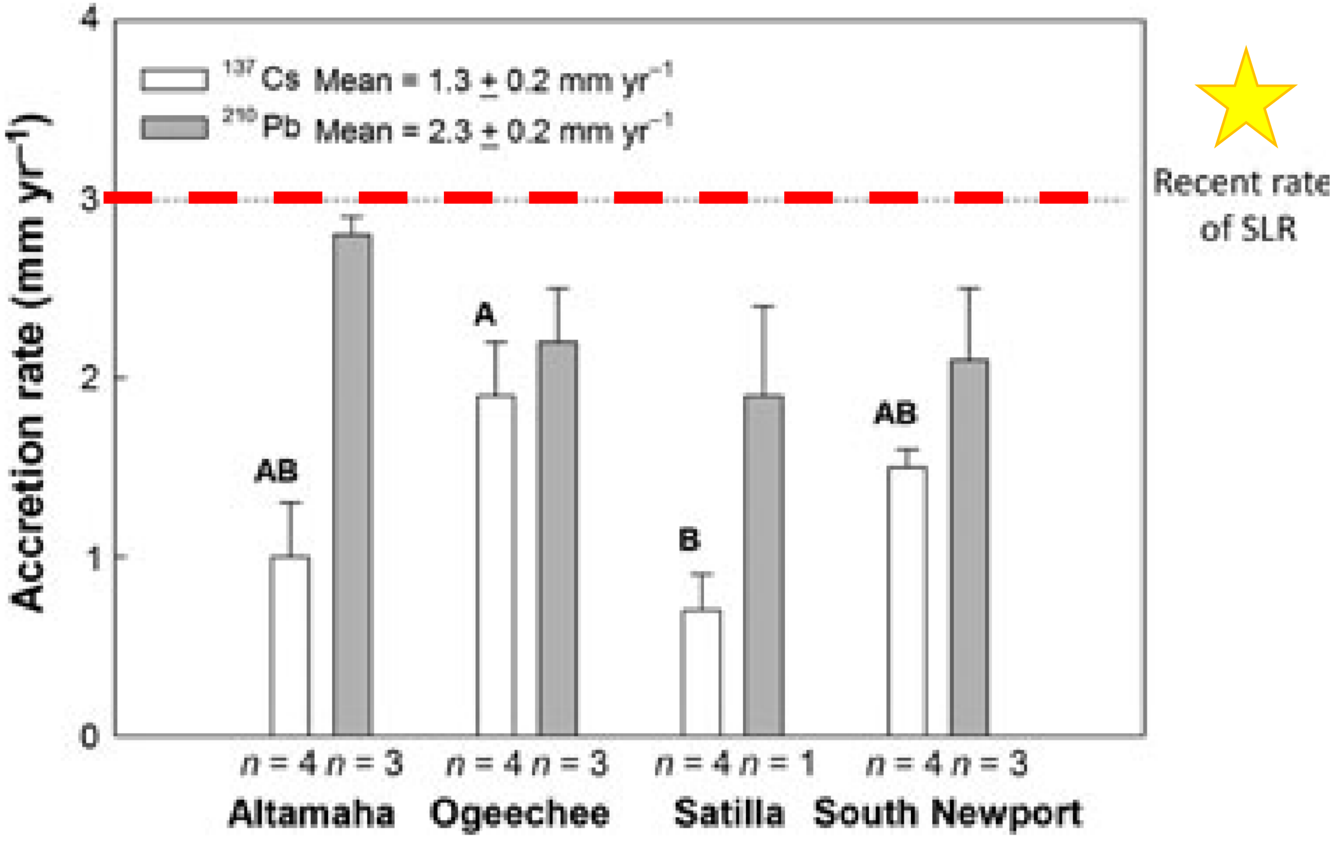
(Oliver-Cabrera and Wdowinski 2016)

Coastal Floodplain Swamps (CFS)

- Coastal floodplain swamps (CFS) prevalent coastal ecosystem in SE USA
- CFS provide \$25,681 ha^{-1} yr^{-1} worth of ecosystem services (Costanza 2014;)
  - Nutrient removal, storm surge attenuation, and carbon sequestration (Blair et al. 2015)
- Landscape position → vulnerable to saltwater intrusion (SWI) (Krauss et al. 2009)

Sea Level Rise and Saltwater Intrusion

- Sea level rise represents a significant stressor to CFS
- Current rates of SLR outpace CFS soil accretion (Craft 2012)
- Saltwater intrusion is a well documented threat to CFS (Middleton et al. 2015)



(Craft 2012)

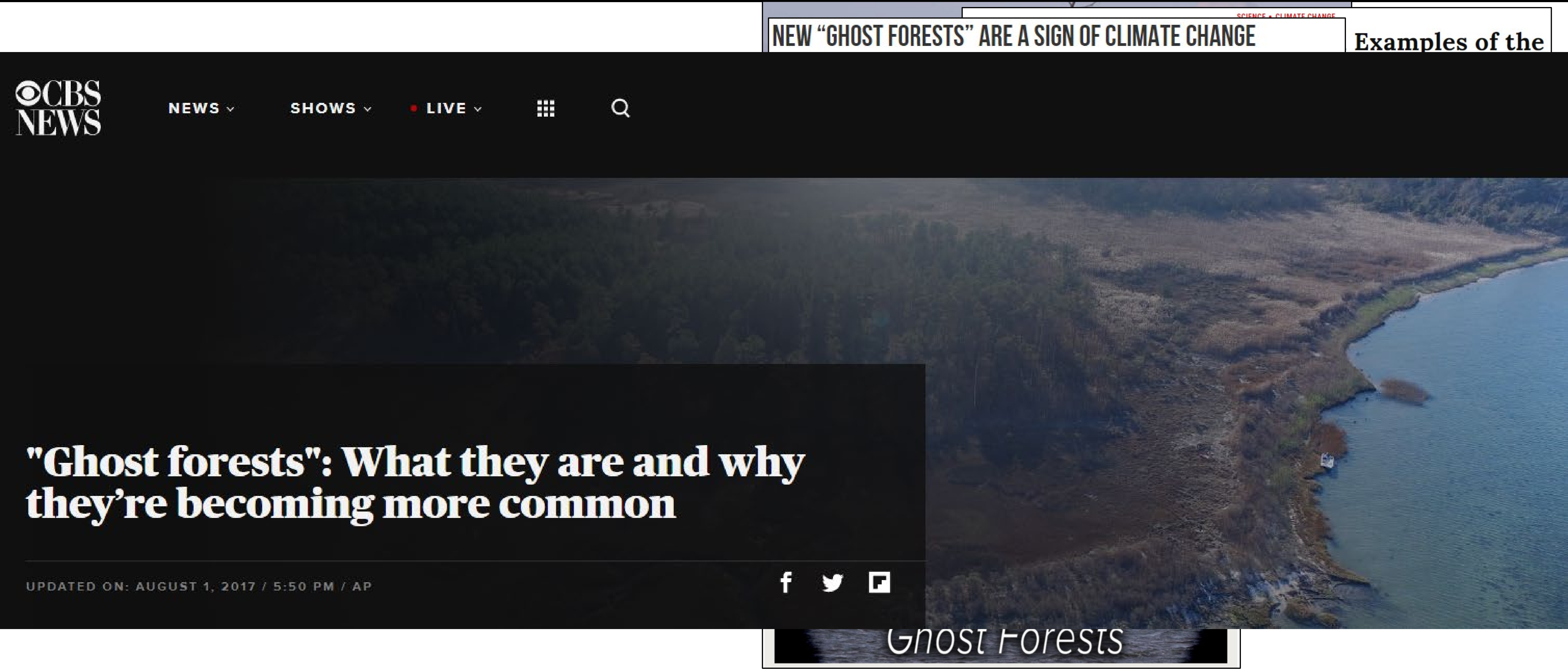
Coastal Floodplain Swamps and Salinization



Increasing Salinity

- CFS species have limited tolerance to salinity (Pezeshki et al. 1987)
- Chronic SWI can lead to a shift in community structure and function (White and Kaplan 2017)
- CFS will be converted to salt marsh or open water in the long-term (Brinson et al. 1995)
- Need for a region-wide approach to understand the effects of SWI on CFS ecology

Mainstream Attention to “Ghost Forests”



Body of Work on CFS and Salinization

Response of baldcypress (*Taxodium distichum* L. var.*Distichum*) to increases in flooding salinity in Louisiana's Mississippi River deltaic plain

Authors   Authors and affiliations

S. R. Pezeshki, R. D. Delaune, W. H. Patrick

GROWTH AND NUTRITION OF BALDCYPRESS FAMILIES PLANTED UNDER VARYING SALINITY REGIMES IN LOUISIANA, USA

Ken W. Krauss, Jim L. Chambers, James A. Allen, David M. Soileau Jr., Antoinette S. DeBosier

Identification of salt tolerant baldcypress (*Taxodium distichum* (L.) Rich) for planting in coastal areas

Authors   Authors and affiliations

William H. Conner, L. Wayne Inabinette

Interaction of flooding and salinity stress on baldcypress (*Taxodium distichum*) FREE

James A. Allen, S. Reza Pezeshki, Jim L. Chambers

Selection for Salt Tolerance in Tidal Freshwater Swamp Species: Advances Using Baldcypress as a Model for Restoration

Authors   Authors and affiliations

Ken W. Krauss, Jim L. Chambers, David Creech

Tidal Freshwater Swamps of the Southeastern United States: Effects of Land Use, Hurricanes, Sea-level Rise, and Climate Change

Authors   Authors and affiliations

Thomas W. Doyle, Calvin P. O'Neil, Marcus P.V. Melder, Andrew S. From, Monica M. Palta

Degradation of Baldcypress–Water Tupelo Swamp to Marsh and Open Water in Southeastern Louisiana, U.S.A.: An Irreversible Trajectory?

Gary P. Shaffer[†], William B. Wood[†], Susanne S. Hoeppner[‡], Thais E. Perkins[†], Jason Zoller[†], and Demetra Kandalepas[§]

SEASONAL PATTERNS OF RIVER CONNECTIVITY AND SALTWATER INTRUSION IN TIDAL FRESHWATER FORESTED WETLANDS

Christopher J. Anderson, B. Graeme Lockaby

Flooding and saltwater intrusion: Potential effects on survival and productivity of wetland forests along the U.S. Gulf Coast

S.R. Pezeshki, R.D. Delaune, W.H. Patrick Jr.

Disentangling the effects of drought, salinity, and sulfate on baldcypress growth in a coastal plain restored wetland

Amanda S. Powell, Lonnie Jackson, Marcelo Ardón

Groundwater salinity in a floodplain forest impacted by saltwater intrusion

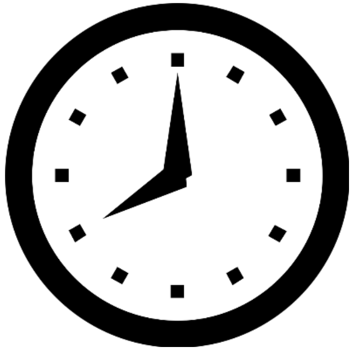
David A. Kaplan [a], Rafael Muñoz-Carpena [b]

Effects of Hurricane Katrina on the forest structure of *Taxodium distichum* swamps of the Gulf Coast, USA

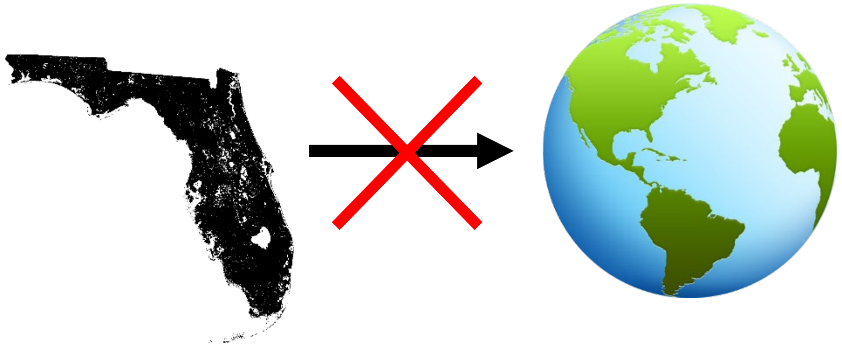
Authors   Authors and affiliations

Beth A. Middleton

Challenges of Traditional/Field Methods



Interest



(Strayer et al 1986, Franklin 1989, Lovett et al. 2007)

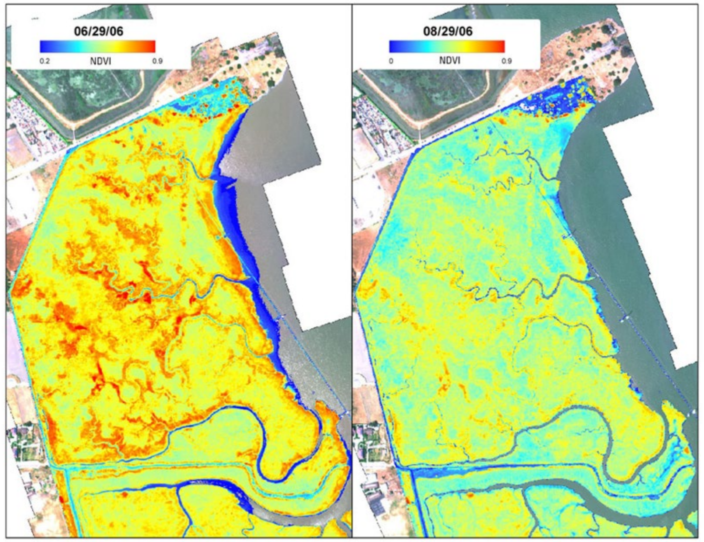
Detecting Vegetative Change Using Remote Sensing

- Can detect changes to vegetative structure, composition, and distribution (Duchemin et al. 1999, Wang et al. 2005, Douglas et al. 2018)
- **Enhanced vegetation index (EVI)**
  - Sensitive to high biomass (Huete et al. 2002)
  - Corrects for aerosol scattering and background soil
- Variety of RS tools available: Google Earth Engine (GEE) is fast, free, and user-friendly.

Google Earth Engine ArcGIS ENVI

NDVI TVI VARI EVI SAVI NDWI

$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L)}$$



Overarching Research Question

Can remote sensing data be used to track the long-term impacts of saltwater intrusion on coastal floodplain swamps?

Welcome to the Swamp, We Got Mud and Knees

- Mixture of **needle** and **broadleaf** canopy
  - *Taxodium distichum, Nyssa spp., Fraxinus spp.* (Brinson et al. 1980)
- Characterized by **yearly leaf senescence**
  - Varies with abiotic factors (i.e. flooding, temperature, salinity stress)
- Groundcover vegetation is **rare**, and **sparse** when present (Huenneke and Sharitz 1986)
- Canopy species have limited salinity tolerance

Idealized Difference In CFS Health

Summer Canopy

Upstream

Downstream

Idealized Difference In CFS Health

Summer Canopy

Summer Understory

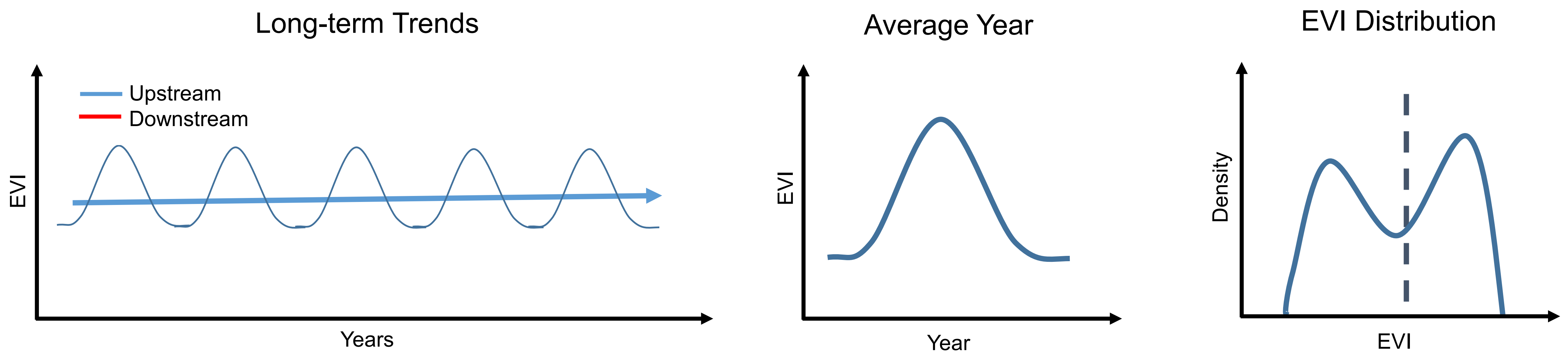
Upstream

Downstream

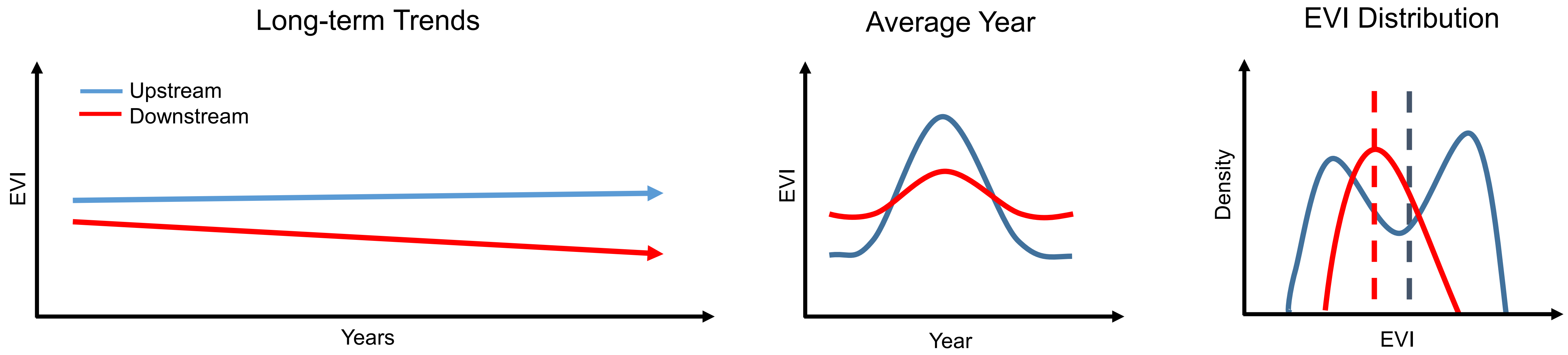
Idealized Difference In CFS Health

	Summer Canopy	Summer Understory	Winter Understory
Upstream			
Downstream			

Expected Differences in EVI



Expected Differences in EVI

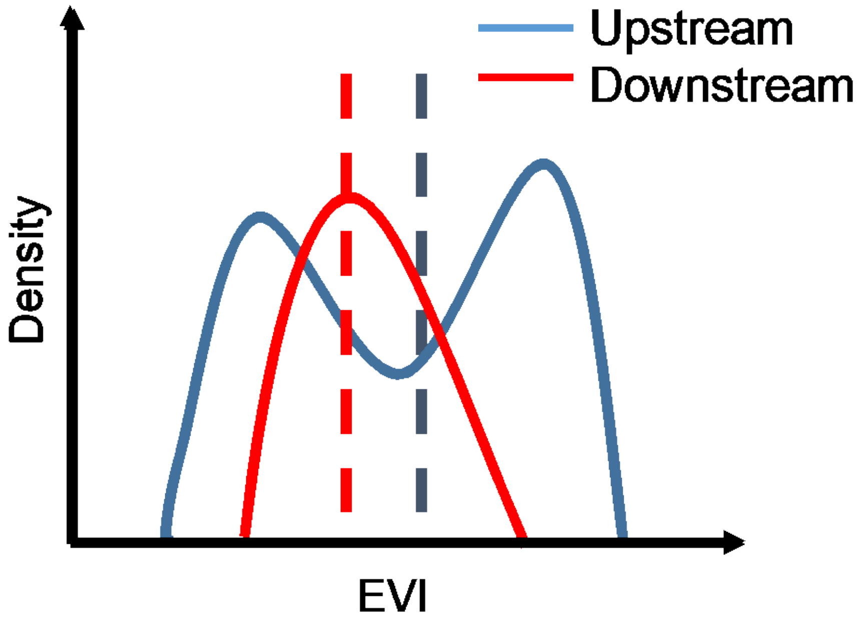


Hypotheses – H_1: Magnitude and Distribution

Table 1. A suite of hypothesis developed to help identify the effects of SWI on CFS using remote sensing

Hypothesis	Rationale	Test
H_{1A}: $\tilde{X}\ EVI_{salt} < EVI_{fresh}$	Lower EVI at SWI sites may indicate the presence of a stressor	MWU
H_{1B}: $X\sim EVI_{salt} \neq EVI_{fresh}$	Differences in distribution imply changes to phenological patterns	KS

The symbols X̃ and X~ represent median and standard deviation, respectively. Statistical techniques and test used in this study are abbreviated as follows: Mann-Whitney U (MWU), Kolmogorov-Smirnov (KS), Linear Regression (LR), and Mann-Kendall (MK).

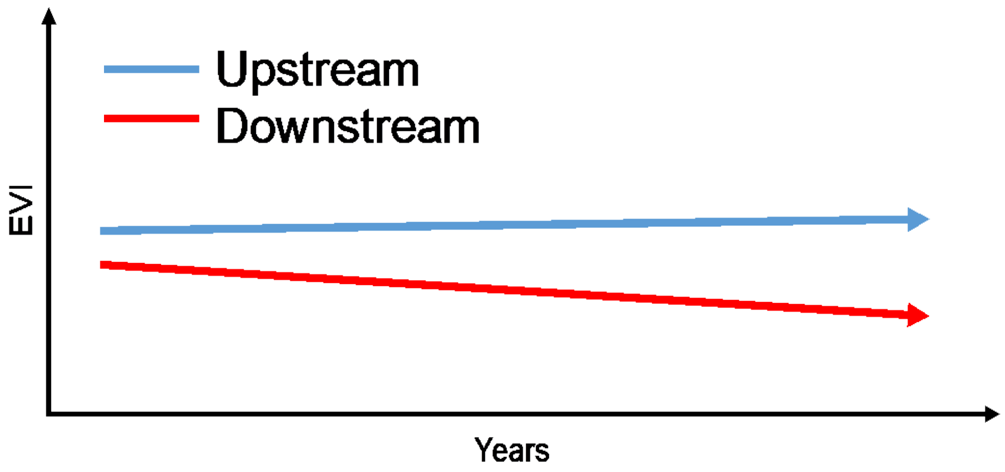


Hypotheses – H_2: Long-term Trends

Table 1. A suite of hypothesis developed to help identify the effects of SWI on CFS using remote sensing

Hypothesis	Rationale	Test
H_{2A}: Slope $EVI_{salt} < 0$	Negative slope at stressed sites likely driven by SWI induced stress	LR, MK
H_{2C}: Slope $EVI_{Trend,S} < 0$	A declining trend indicates a long-term change in EVI	LR, MK
H_{2B}: Slope $EVI_{D:U} < 0$	The ratio accounts for shared regional stressors, meaning a declining slope indicates local stressor is affecting the stressed site	LR, MK

The symbols X̃ and X~ represent median and standard deviation, respectively. Statistical techniques and test used in this study are abbreviated as follows: Mann-Whitney U (MWU), Kolmogorov-Smirnov (KS), Linear Regression (LR), and Mann-Kendall (MK).

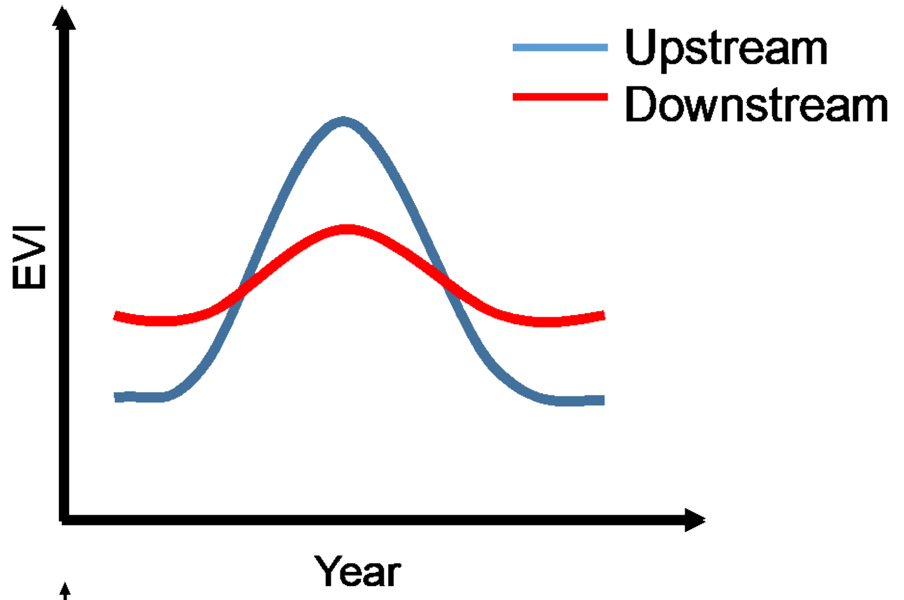


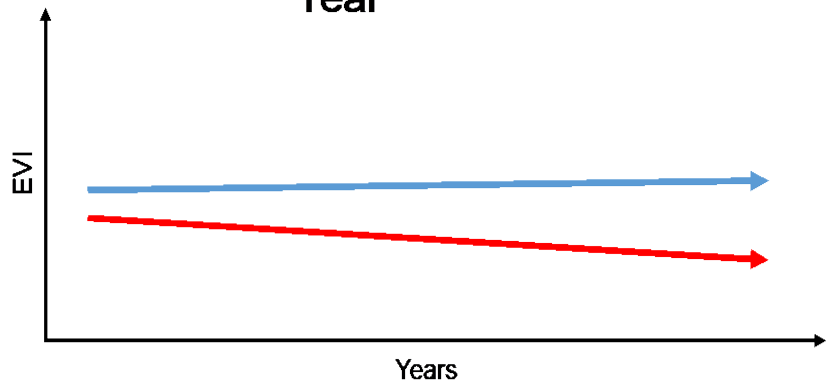
Hypotheses – H_3: Seasonal Attributes

Table 1. A suite of hypothesis developed to help identify the effects of SWI on CFS using remote sensing

Hypothesis	Rationale	Test
H_{3A}: $\tilde{X}\ EVI_{G,S} < EVI_{G,F}$	Lower growing season EVI can indicate effect of SWI stress on peak biomass/productivity	MWU
H_{3B}: $\tilde{X}\ EVI_{D,S} > EVI_{D,F}$	Higher dormant seasons EVI may indicate the presence of salt-tolerant canopy and herbaceous species (Succession)	MWU
H_{3C}: $\tilde{X}\ EVI_{G:D,S} < EVI_{G:D,F}$	Lower G:D ratio implies a decrease in seasonal variation (Phenological change)	MWU
H_{3D}: Slope $EVI_{G:D,S} < 0$	A declining slope indicates a chronic stressor is present	LR, MK

The symbols $\tilde{X}$ and X~ represent median and standard deviation, respectively. Statistical techniques and test used in this study are abbreviated as follows: Mann-Whitney U (MWU), Kolmogorov-Smirnov (KS), Linear Regression (LR), and Mann-Kendall (MK).

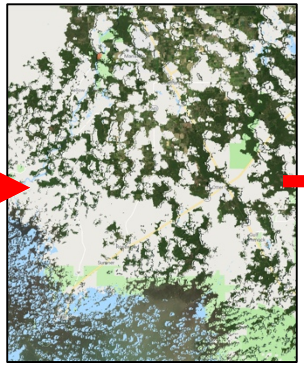


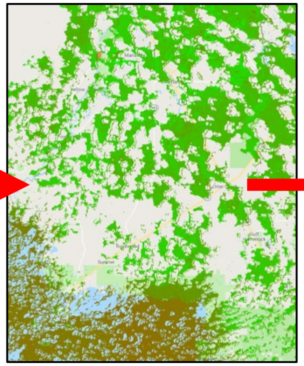


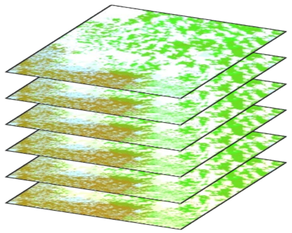
Site Selection – Long-term Salinity/Veg Monitoring

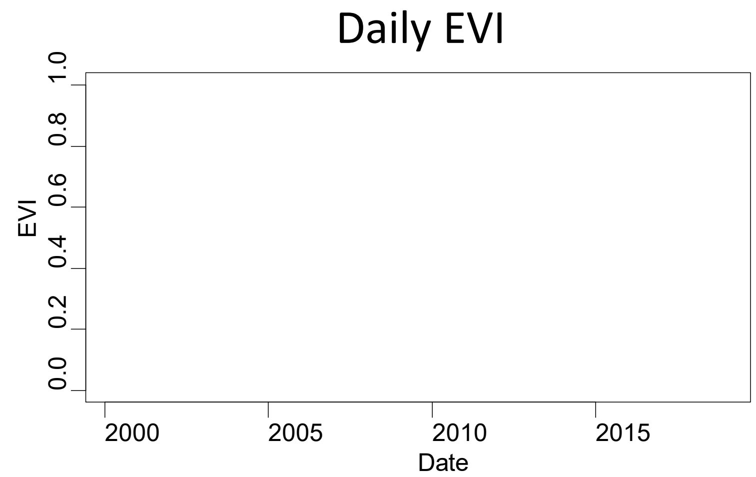
Remote Sensing Workflow

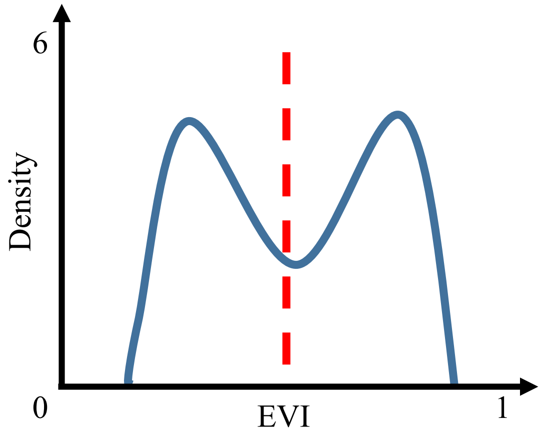
RS Data	Masking	Calculations
MODIS Terra 500m Surface Reflectance	Clouds, cloud shadows, and incomplete pixels	EVI is calculated per pixel and averaged across the ROI











Were the Hypotheses Supported?

- 52.8% support across all sites
- Support varied across regions
  - Suwannee and Big Bend >50%
  - SE Louisiana and Neches <50%
- Subset of "best-performing" hypotheses more supported across all regions

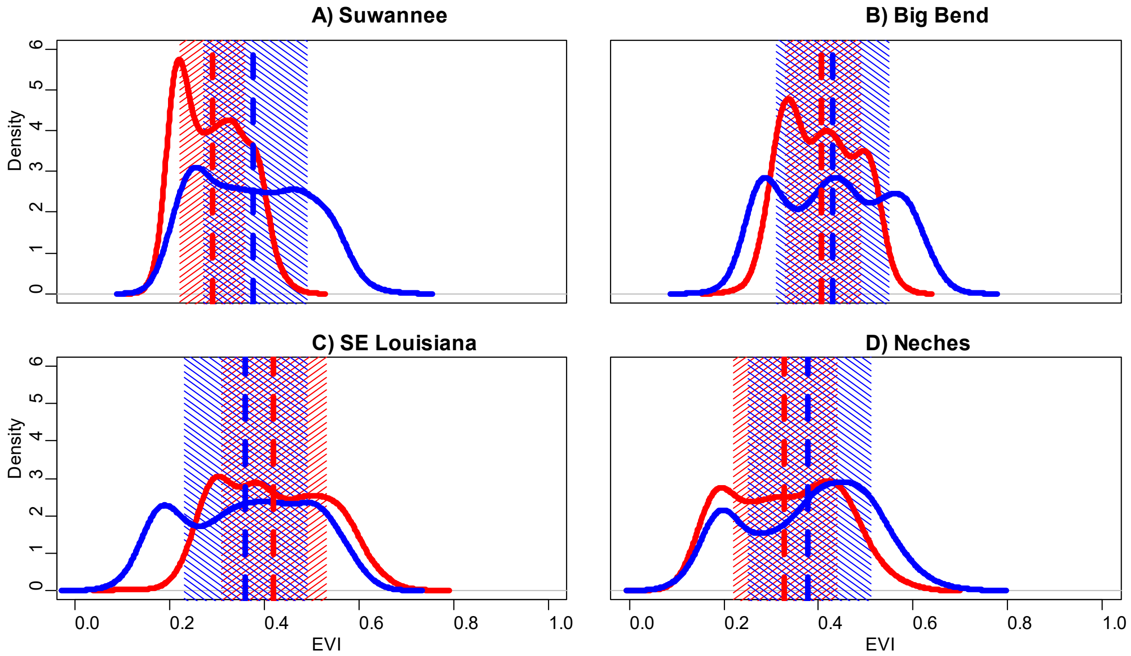
Table 3. Results of hypothesis testing in each region

Hypothesis	Suwannee	Big Bend	SE Louisiana	Neches	Correct (%)
H_{1A}: $\tilde{X}\ EVI_{salt} < EVI_{fresh}$	True	True	False	True	75*
H_{1B}: $X\sim EVI_{salt} \neq EVI_{fresh}$	True	True	True	True	100*
H_{2A}: Slope $EVI_{salt} < 0$	True	False	False	False	25
H_{2B}: Slope $EVI_{Trend,S} < 0$	True	False	False	False	25
H_{2C}: Slope $EVI_{D:U} < 0$	True	False	False	True	50
H_{3A}: $\tilde{X}\ EVI_{G,S} < EVI_{G,F}$	True	True	False	True	75*
H_{3B}: $\tilde{X}\ EVI_{D,S} > EVI_{D,F}$	False	True	True	False	50
H_{3C}: $\tilde{X}\ EVI_{G:D,S} < EVI_{G:D,F}$	True	True	True	False	75*
H_{3D}: Slope $EVI_{G:D,S} < 0$	False	False	False	False	0
All Correct (%)	78	56	33	44	52.8
Best Performing (%)	100	100	50	75	81.3

Best performing hypotheses (*) were supported ≥ 75% across sites

Why Were Certain Hypotheses Supported?

- Best-performing hypotheses relied on differences in **summary statistics**



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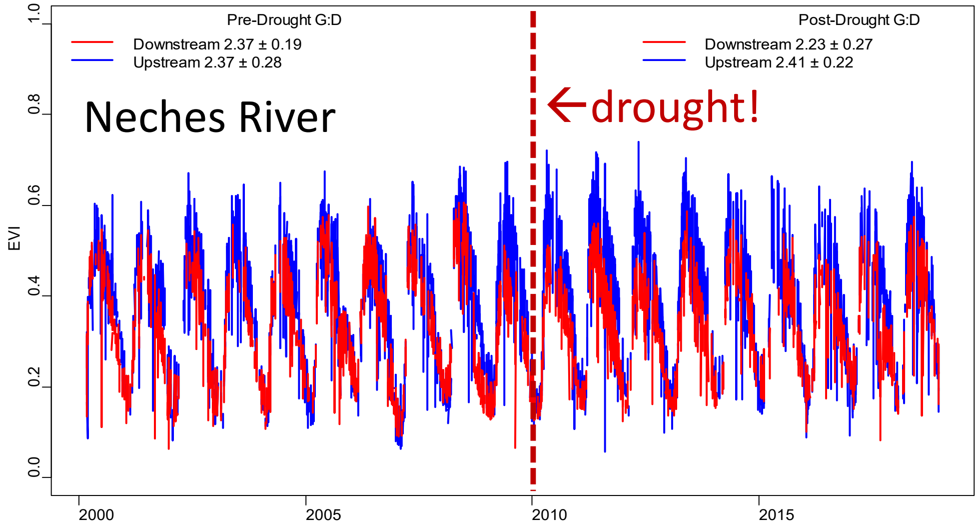
Why Were Certain Hypotheses Supported?

- Best-performing hypotheses relied on differences in **summary statistics**
- 5 of 9 hypotheses had low support
  - Slow pace of change and interannual variation challenges detection



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H_{2C}: Slope $EVI_{D:U} < 0$	True	False	False	True	50
H_{3B}: $\tilde{X}\ EVI_{D,S} > EVI_{D,F}$	False	True	True	False	50
H_{3D}: Slope $EVI_{G:D,S} < 0$	False	False	False	False	0
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Why Were Certain Hypotheses Supported?

- Best-performing hypotheses relied on differences in **summary statistics**
- 5 of 9 hypotheses had low support
  - Slow pace of change and interannual variation challenges detection
- Detecting process vs. outcome?

time, increasing salinity

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H_{2C}: Slope $EVI_{D:U} < 0$	True	False	False	True	50
H_{3B}: $\tilde{X}\ EVI_{D,S} > EVI_{D,F}$	False	True	True	False	50
H_{3D}: Slope $EVI_{G:D,S} < 0$	False	False	False	False	0
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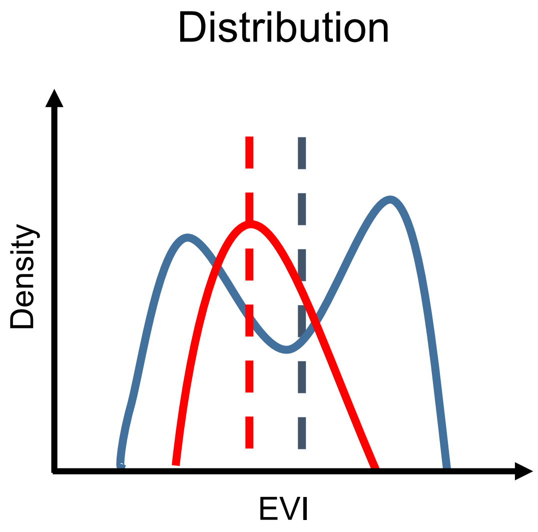
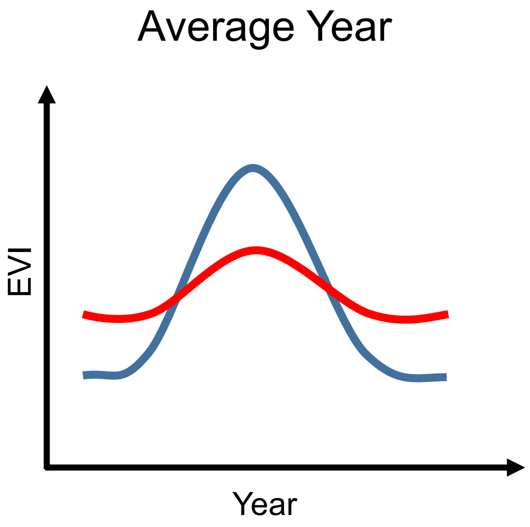
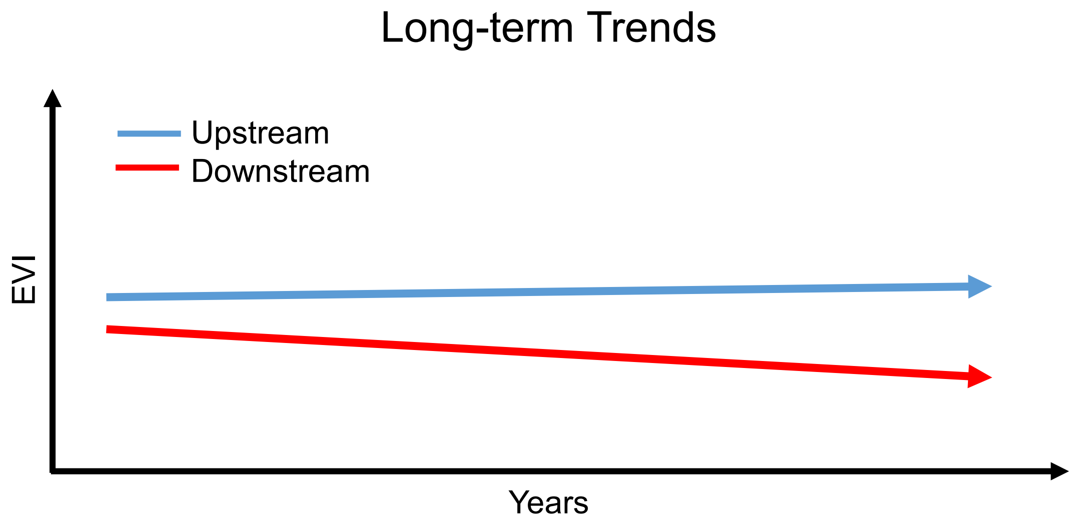
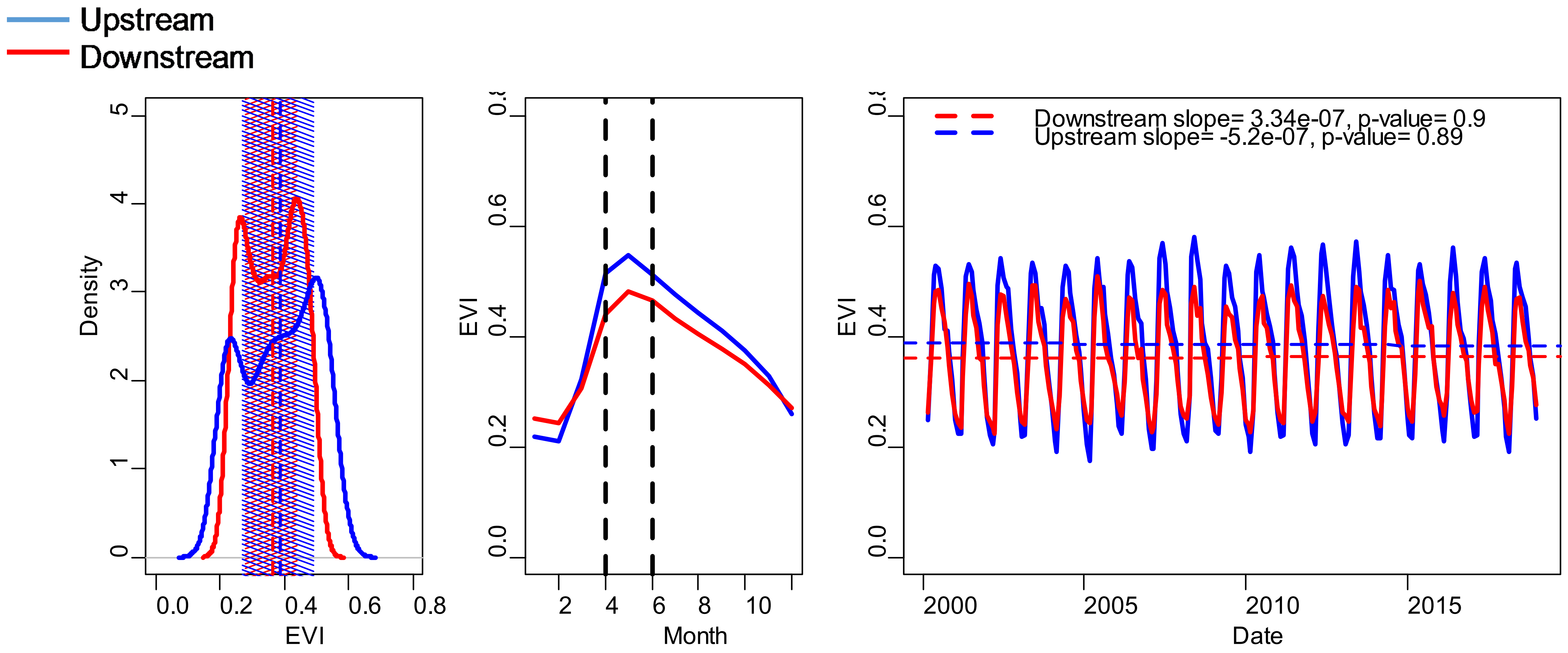
Recall: Expected Differences in EVI







Observed Differences in EVI Across All Sites



Technical and Methodological Considerations

- Sampling rate
  - MODIS period of record too short?
  - Landsat temporal resolution too low?
- Smaller pixel size would help capture smaller sites
- Local knowledge needed to contextualize results

Specifications	Landsat	MODIS
Spectral resolution	7 bands	36 bands
Pixel size	30 m	250, 500 or 1000 m
Scene width	185 km	2330 km
Image frequency	16 days	Twice daily
Corrections	None	Surface reflectance

Take Home Messages

- RS data can be used to identify chronic, low level SWI-stress in CFS
- Ecologically motivated hypotheses: some ”work” better...
- SWI **outcomes** easier to detect than **process**

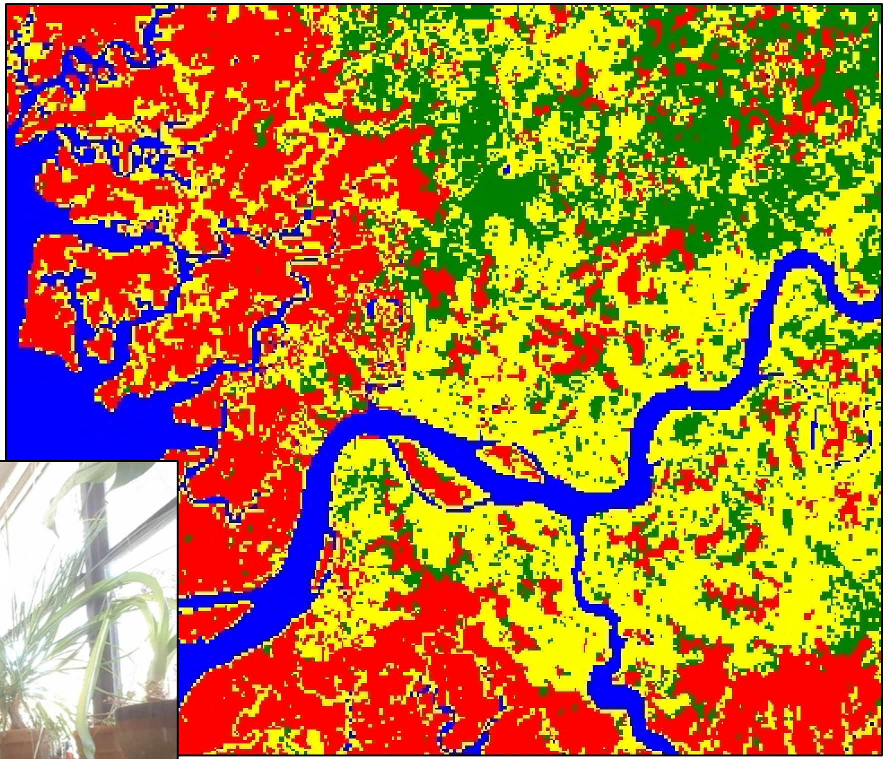





Next Steps – Supervised Classification

- Map extent/health of CFS across the Northern Gulf of Mexico and the South Atlantic Coast
  - Preliminary results using supervised classification
  - Challenges arise from the lack of uniformity at stressed sites

Lower Suwannee River
- Water
- Marsh
- Unhealthy CFS
- Healthy CFS



Thank you! Questions?

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H_{1A}: Compares Median EVI Value

- Reduction in primary production via SWI is well-documented
  - (Conner et al. 1997, Krauss et al. 2009, Cormier et al. 2012)
- Chronic stress will lead to consistent lower production/biomass
- EVI value will/do reflect that trend
- Lack of Support in SE Louisiana
  - Proliferation of *Triadica sebifera*
  - Highly hydrologically altered

Table 3. Results of hypothesis testing in each region

Hypothesis	Suwannee	Big Bend	SE Louisiana	Neches	Correct (%)
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H_{1B}: $X\sim EVI_{salt} \neq EVI_{fresh}$	True	True	True	True	100*
H_{3A}: μ $EVI_{G,S} < EVI_{G,F}$	True	True	False	True	75*
H_{3C}: μ $EVI_{G:D,S} < EVI_{G:D,F}$	True	True	True	False	75*
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*Best performing hypotheses ($\geq$ 75%)

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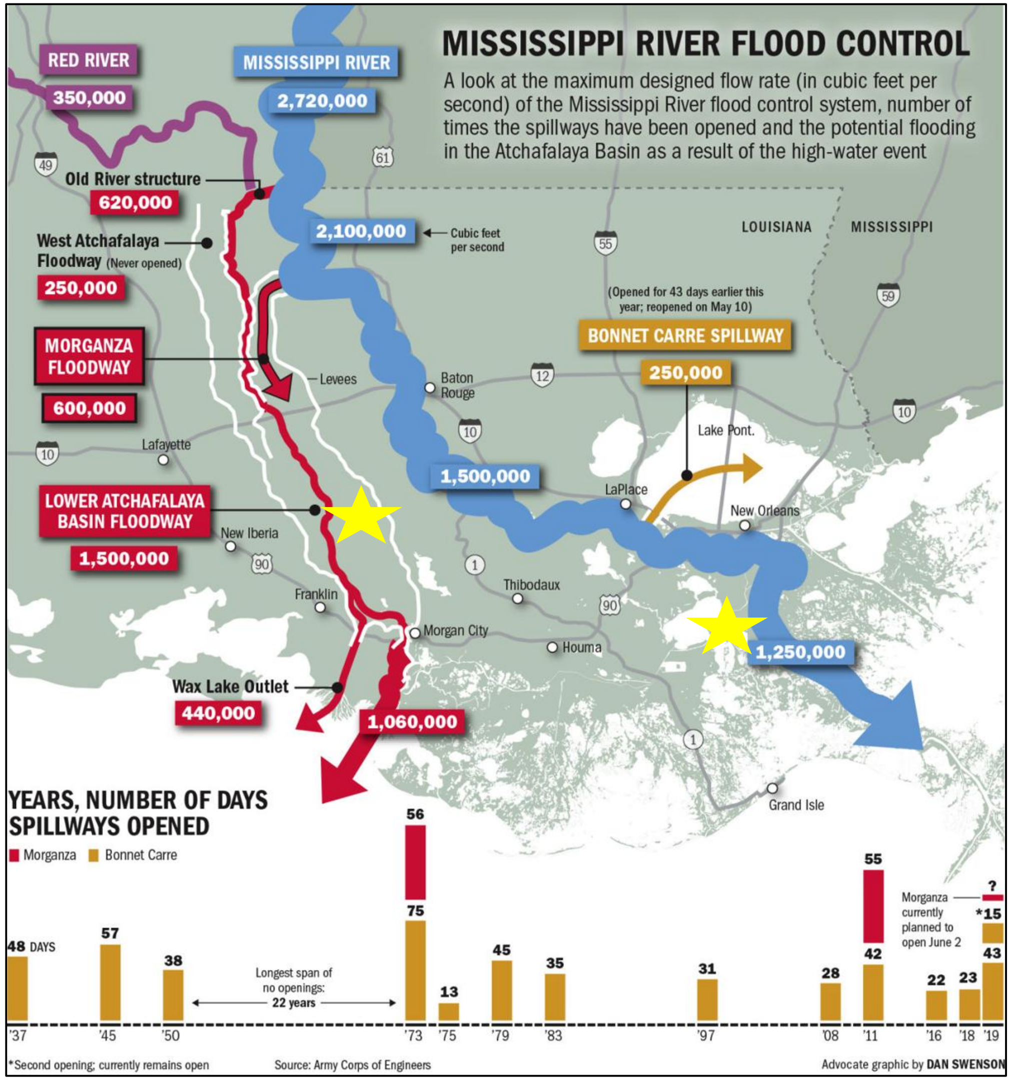

H_{1B}: Compares EVI Distributions

- Demonstrates long-term changes to seasonal patterns
- Over time, stressed CFS will lose bimodality from:
  - Decreased growing season productivity
  - Increased understory biomass during the dormant season
  - Leaf emergence and senescence can shift due to SWI (Brinson et al. 1985, Pezeshki et al. 1988)

Table 3. Results of hypothesis testing in each region

Hypothesis	Suwannee	Big Bend	SE Louisiana	Neches	Correct (%)
H_{1A}: μ $EVI_{salt} < EVI_{fresh}$	True	True	False	True	75*
H_{1B}: X~ $EVI_{salt} \neq EVI_{fresh}$	True	True	True	True	100*
H_{3A}: μ $EVI_{G,S} < EVI_{G,F}$	True	True	False	True	75*
H_{3C}: μ $EVI_{G:D,S} < EVI_{G:D,F}$	True	True	True	False	75*
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*Best performing hypotheses (≥ 75%)

H_{1B}: Compares EVI Distributions

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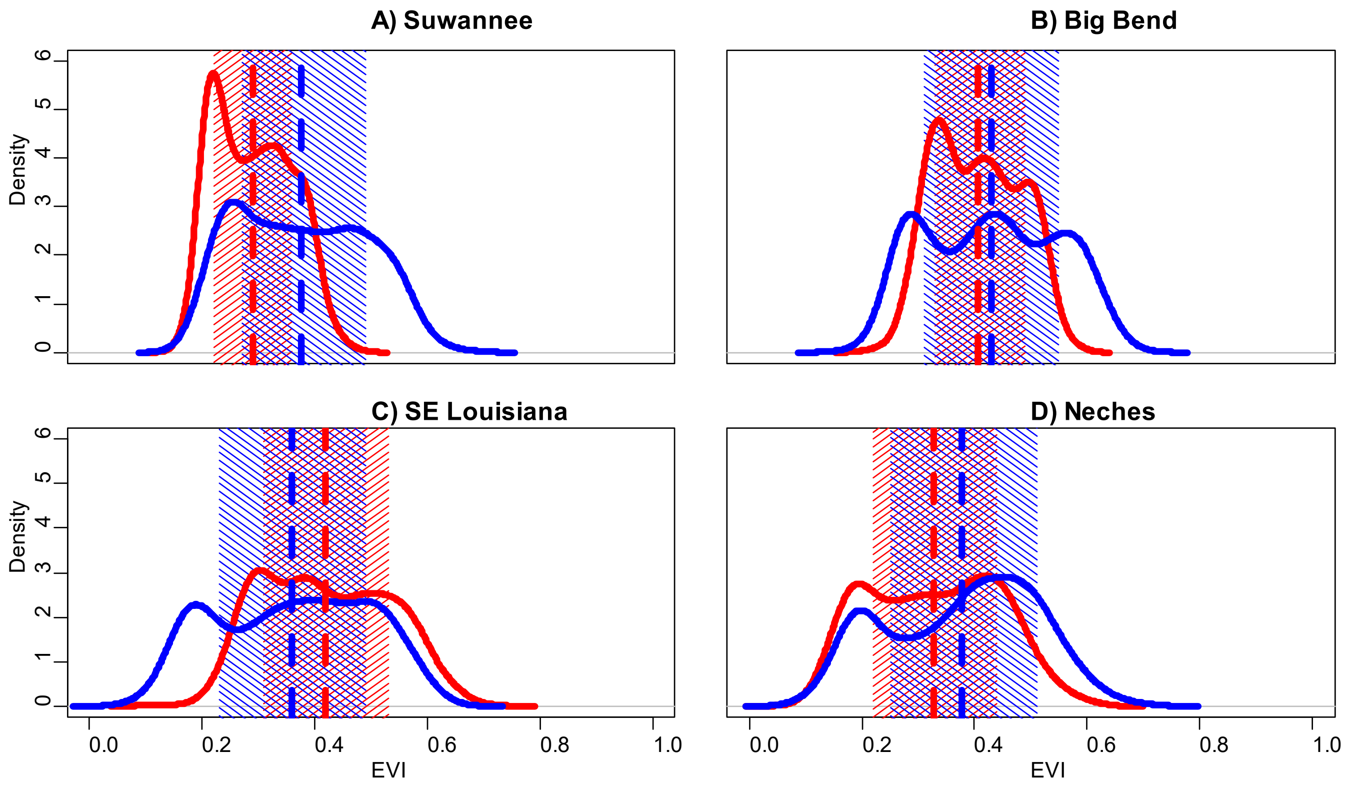

H_{3A}: Compares Peak Growing Season Median EVI

- Highlights the effect of chronic SWI on peak primary production
- Stressed sites have consistently lower peak biomass
- Lack of support in SE Louisiana

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All Correct (%)	78	56	33	44	52.8\52.8
Best Performing (%)	100	100	50	75	81.3

*Best performing hypotheses ($\geq 75\%$)

H_{3C}: Compares Median Growing:Dormant Season EVI Ratio

- Shows consistent changes to seasonal dynamics
- Lack of Support in Neches
  - Historic drought in 2010 to 2011 (Nielsen-Gammon 2012)

Table 3. Results of hypothesis testing in each region

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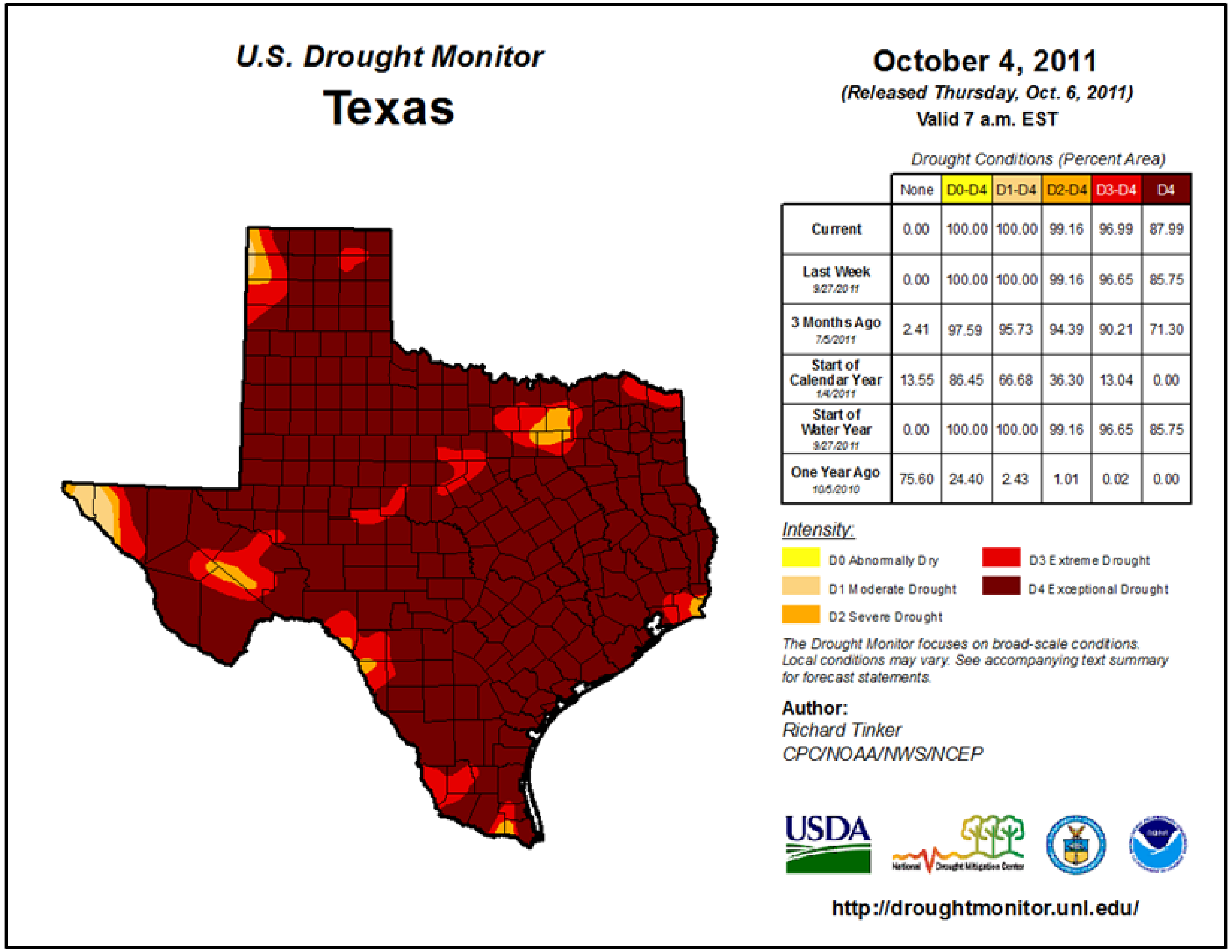
H_{1A}: μ $EVI_{salt} < EVI_{fresh}$	True	True	False	True	75*
H_{1B}: $X\sim EVI_{salt} \neq EVI_{fresh}$	True	True	True	True	100*
H_{3A}: μ $EVI_{G,S} < EVI_{G,F}$	True	True	False	True	75*
H_{3C}: μ $EVI_{G:D,S} < EVI_{G:D,F}$	True	True	True	False	75*
All Correct (%)	78	56	33	44	52.8\52.8
Best Performing (%)	100	100	50	75	81.3

*Best performing hypotheses ($\geq$ 75%)

H_{3C}: Compares Median Growing:Dormant Season EVI Ratio

- Shows consistent changes to seasonal dynamics
- Lack of Support in Neches
  - Historic drought in 2010 to 2011 (Nielsen-Gammon 2012)



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