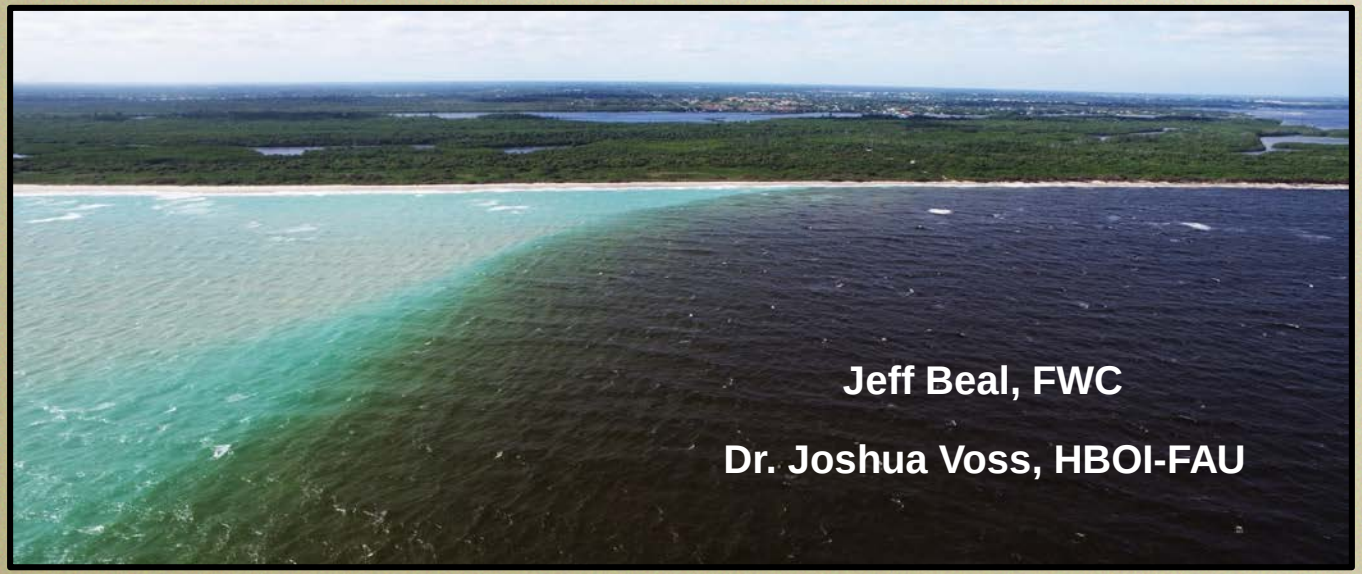
Black and Blue:

Informing Estuarine Restoration Performance Measures Using Assessments of Offshore Coral Communities



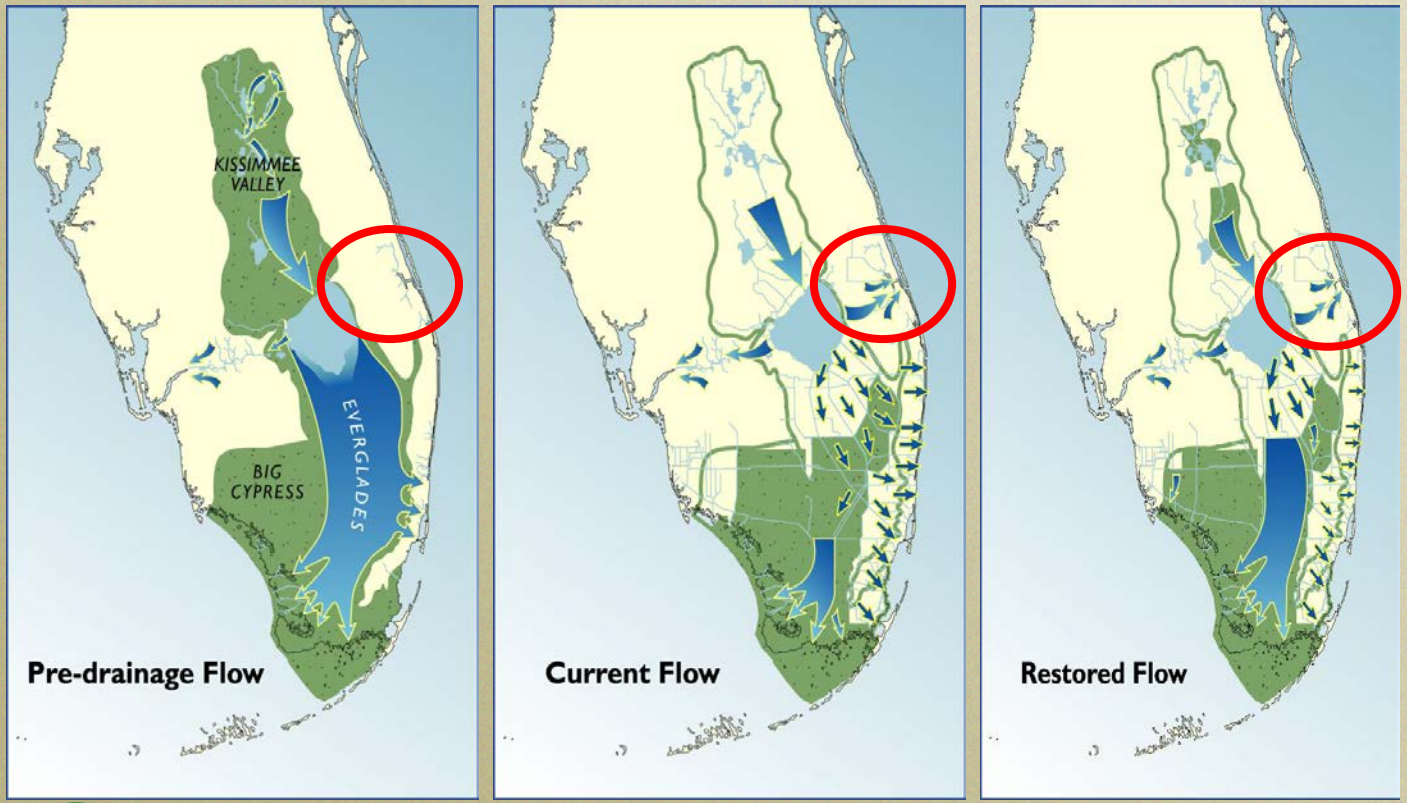
Alycia Shatters, Jennifer Polinski, Courtney Klepac, Sara Edge, Lisa Cohen, Danielle Dodge, Amanda Alker, Dennis Hanisak

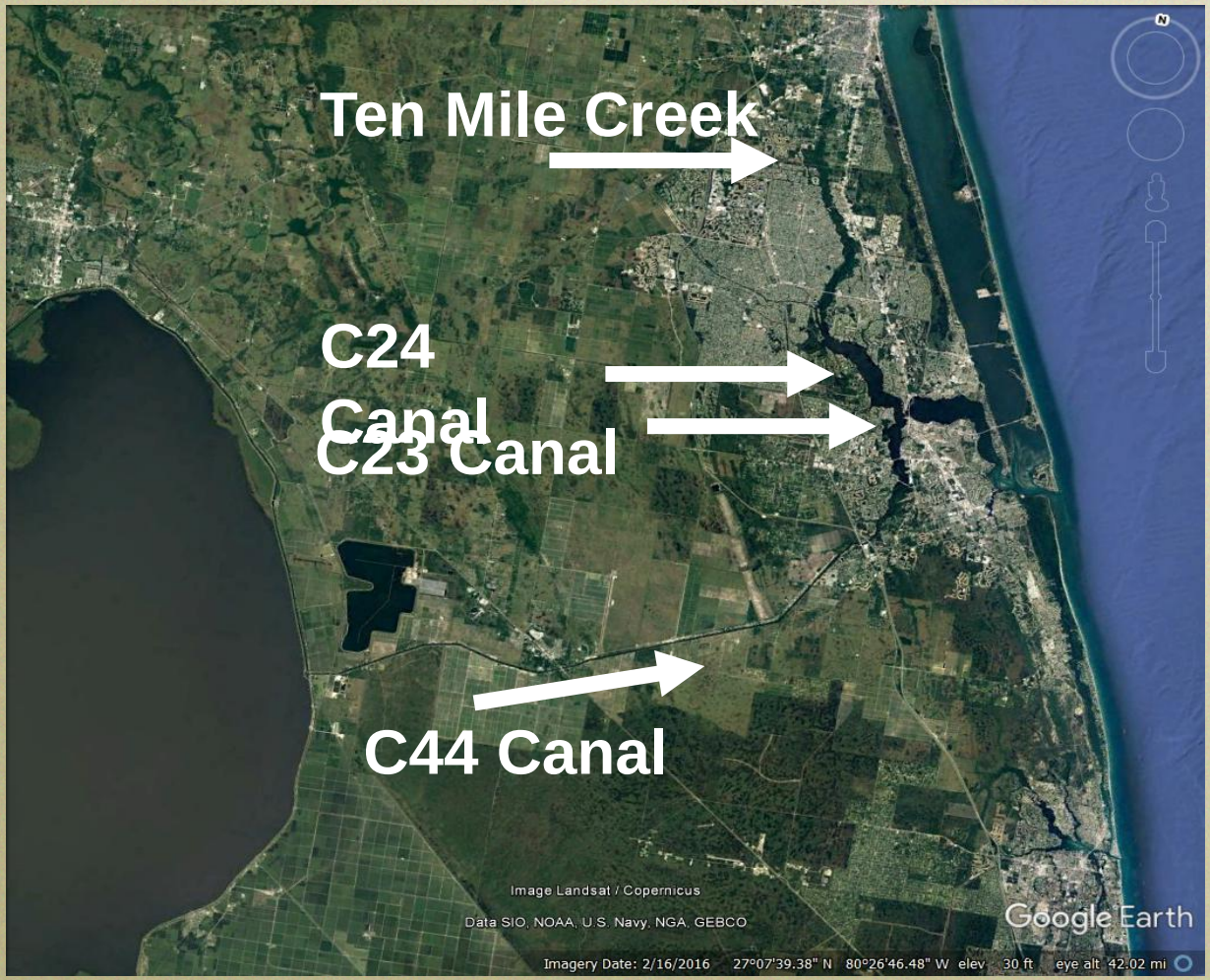
HARBOR BRANCH
FLORIDA ATLANTIC UNIVERSITY

Everglades Restoration

Performance Measures?

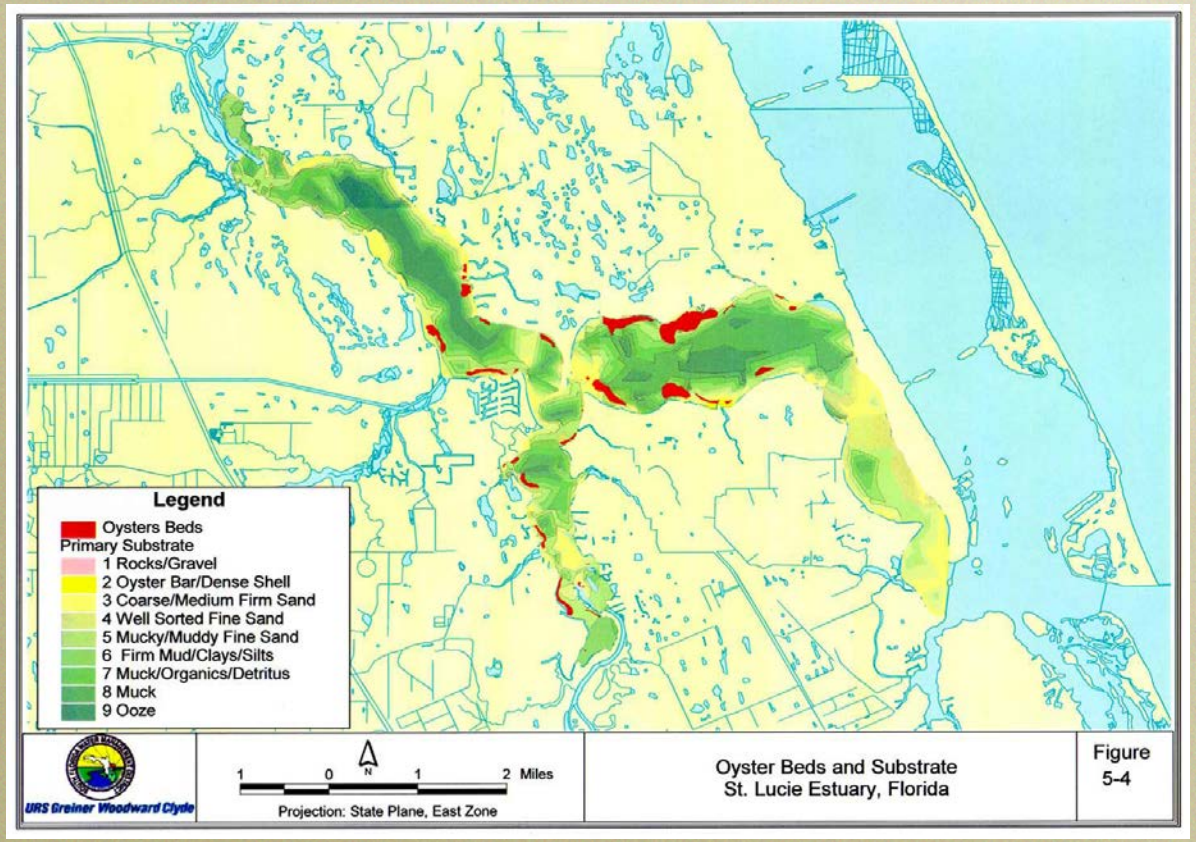
St. Lucie Estuary

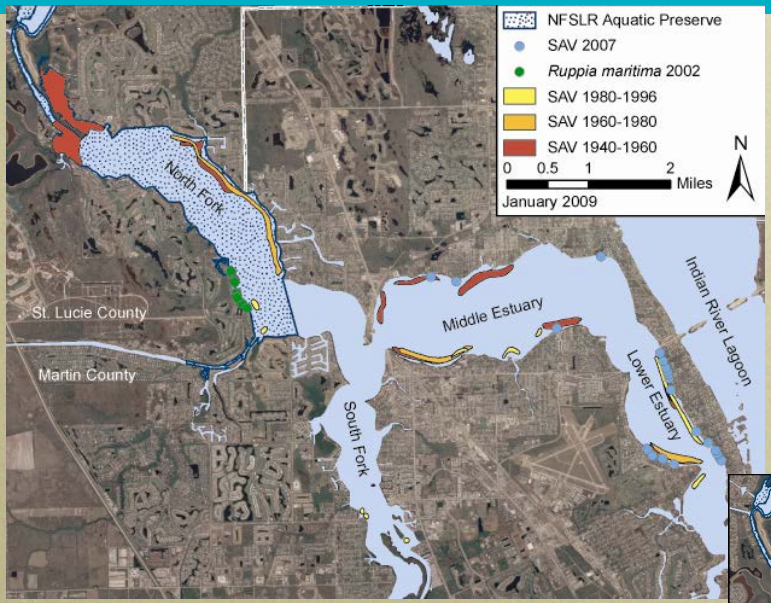


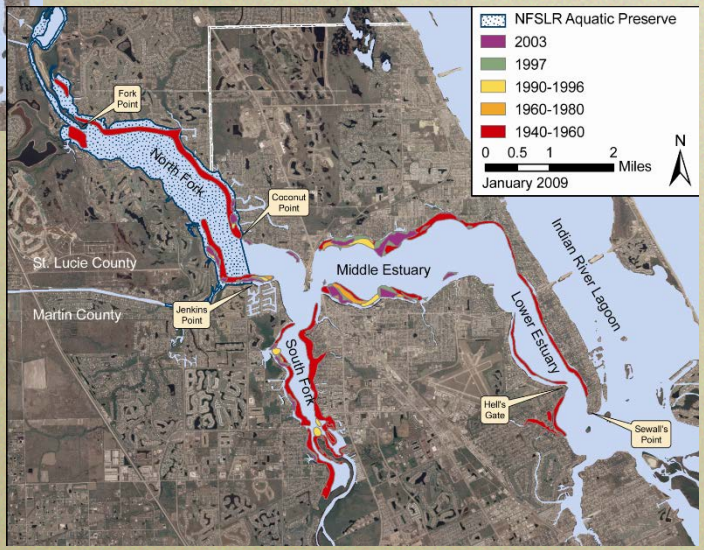

Ten Mile Creek
C24 Canal
C23 Canal
C44 Canal
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth
Imagery Date: 2/16/2016 27°07'39.38" N 80°26'46.48" W elev 30 ft eye alt 42.02 mi

Lake Okeechobee & St. Lucie Estuary Discharges

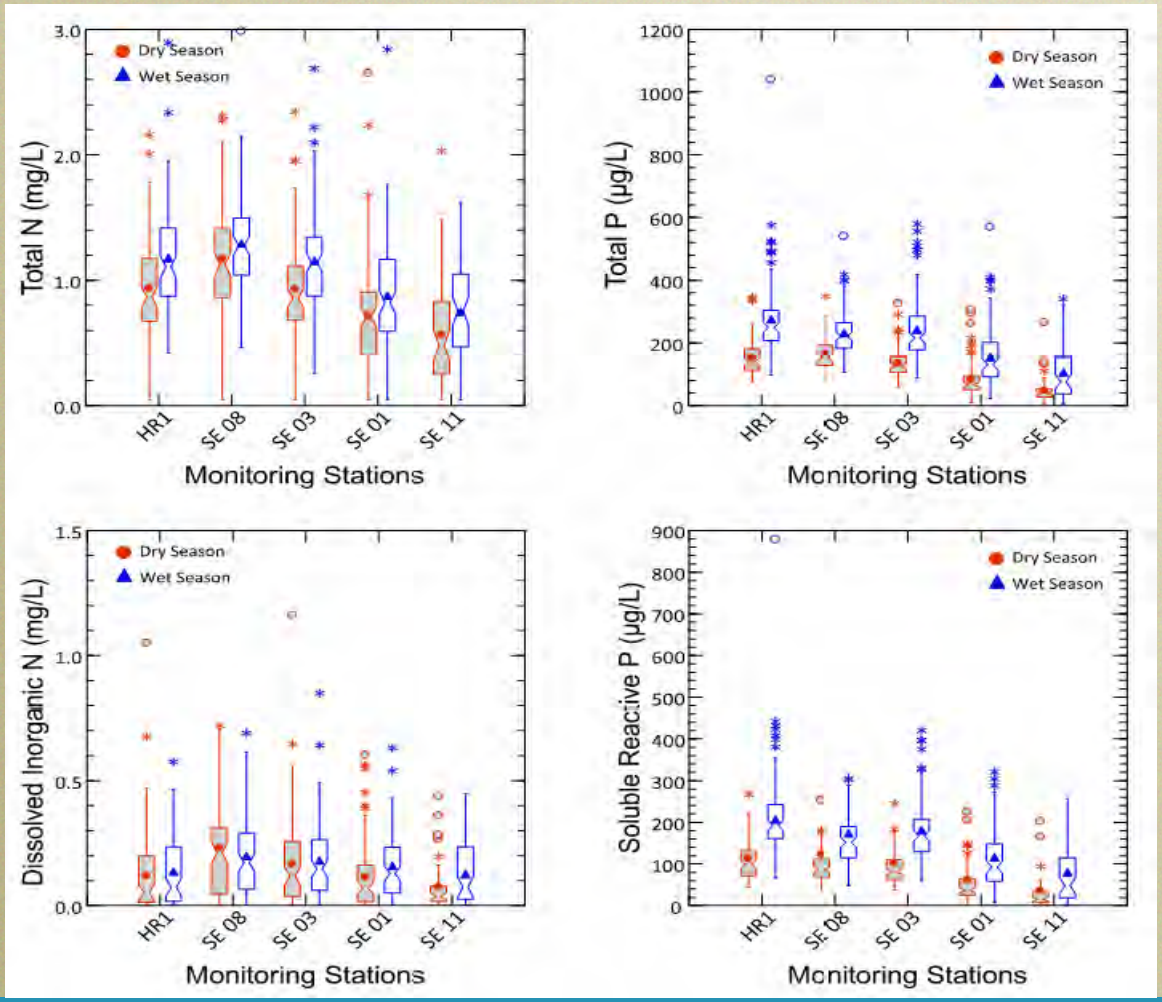
St. Lucie River Restoration Targets

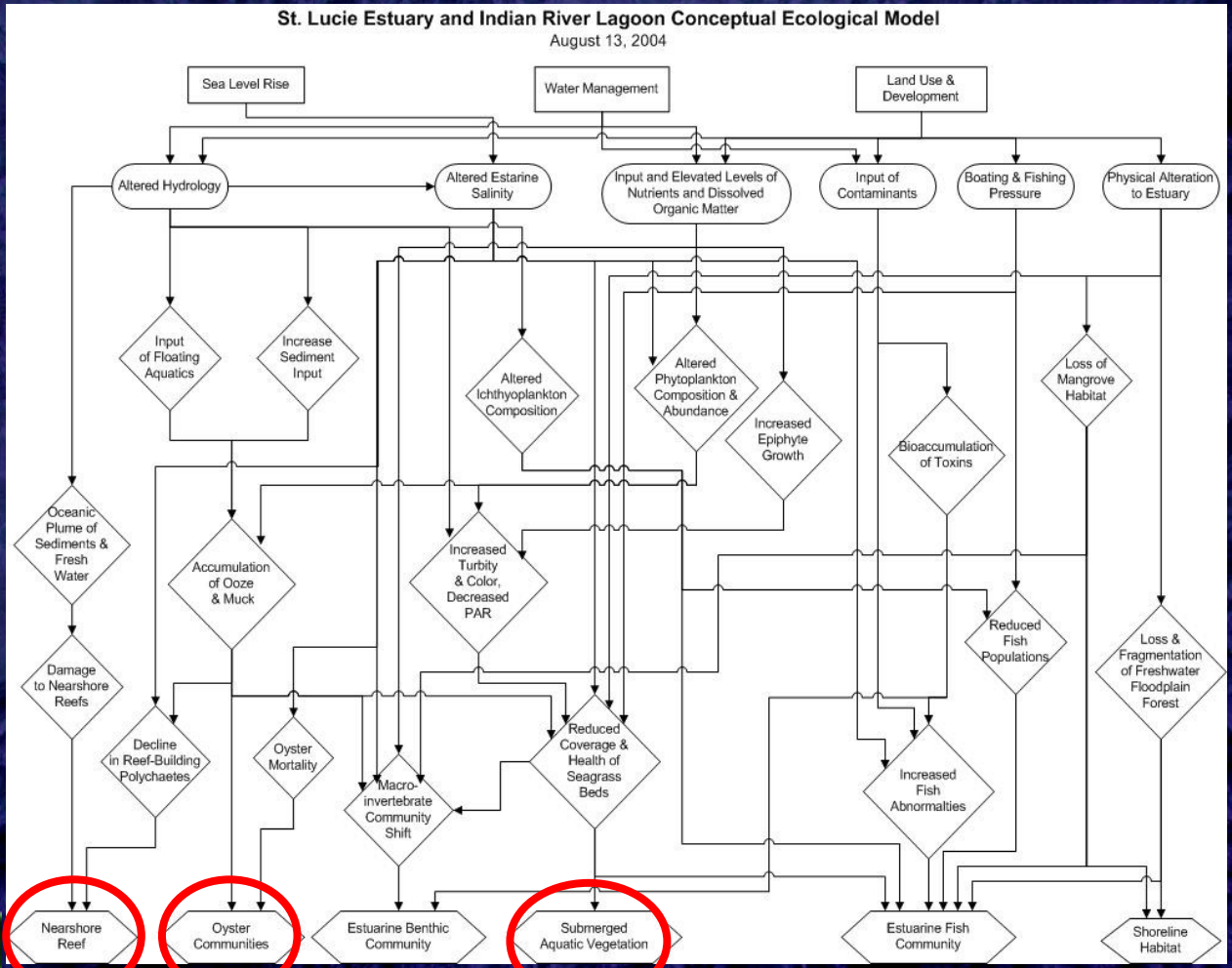






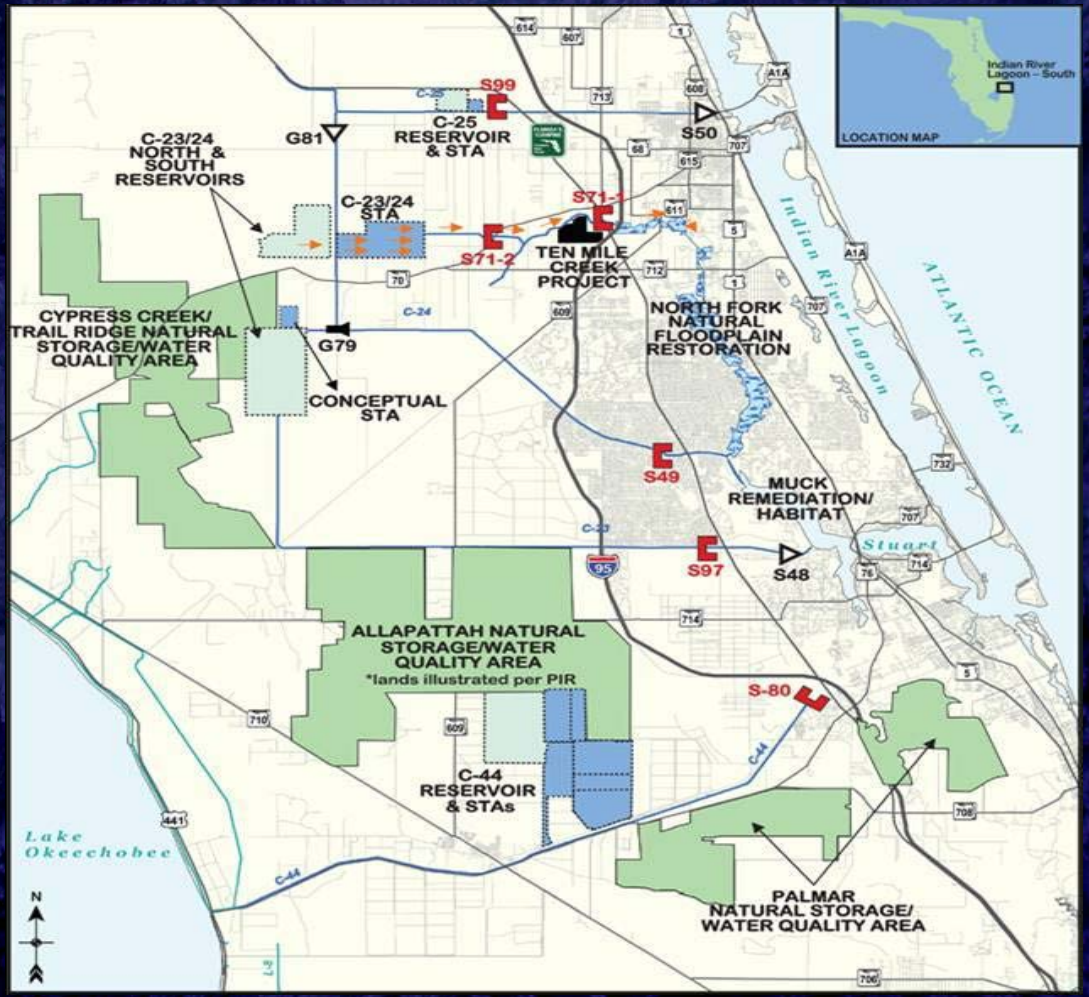
FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION


Total N (mg/L)
Dry Season
Wet Season
HR1
SE 08
SE 03
SE 01
SE 11
Monitoring Stations
Total P (µg/L)
Dissolved Inorganic N (mg/L)
Soluble Reactive P (µg/L)


St. Lucie Estuary and Indian River Lagoon Conceptual Ecological Model
August 13, 2004
Sea Level Rise
Water Management
Land Use & Development
Altered Hydrology
Altered Estarine Salinity
Input and Elevated Levels of Nutrients and Dissolved Organic Matter
Input of Contaminants
Boating & Fishing Pressure
Physical Alteration to Estuary
Input of Floating Aquatics
Increase Sediment Input
Altered Ichthyoplankton Composition
Altered Phytoplankton Composition & Abundance
Increased Epiphyte Growth
Bioaccumulation of Toxins
Loss of Mangrove Habitat
Oceanic Plume of Sediments & Fresh Water
Accumulation of Ooze & Muck
Increased Turbity & Color, Decreased PAR
Reduced Fish Populations
Loss & Fragmentation of Freshwater Floodplain Forest
Damage to Nearshore Reefs
Decline in Reef-Building Polychaetes
Oyster Mortality
Macro-invertebrate Community Shift
Reduced Coverage & Health of Seagrass Beds
Increased Fish Abnormalties
Nearshore Reef
Oyster Communities
Estuarine Benthic Community
Submerged Aquatic Vegetation
Estuarine Fish Community
Shoreline Habitat

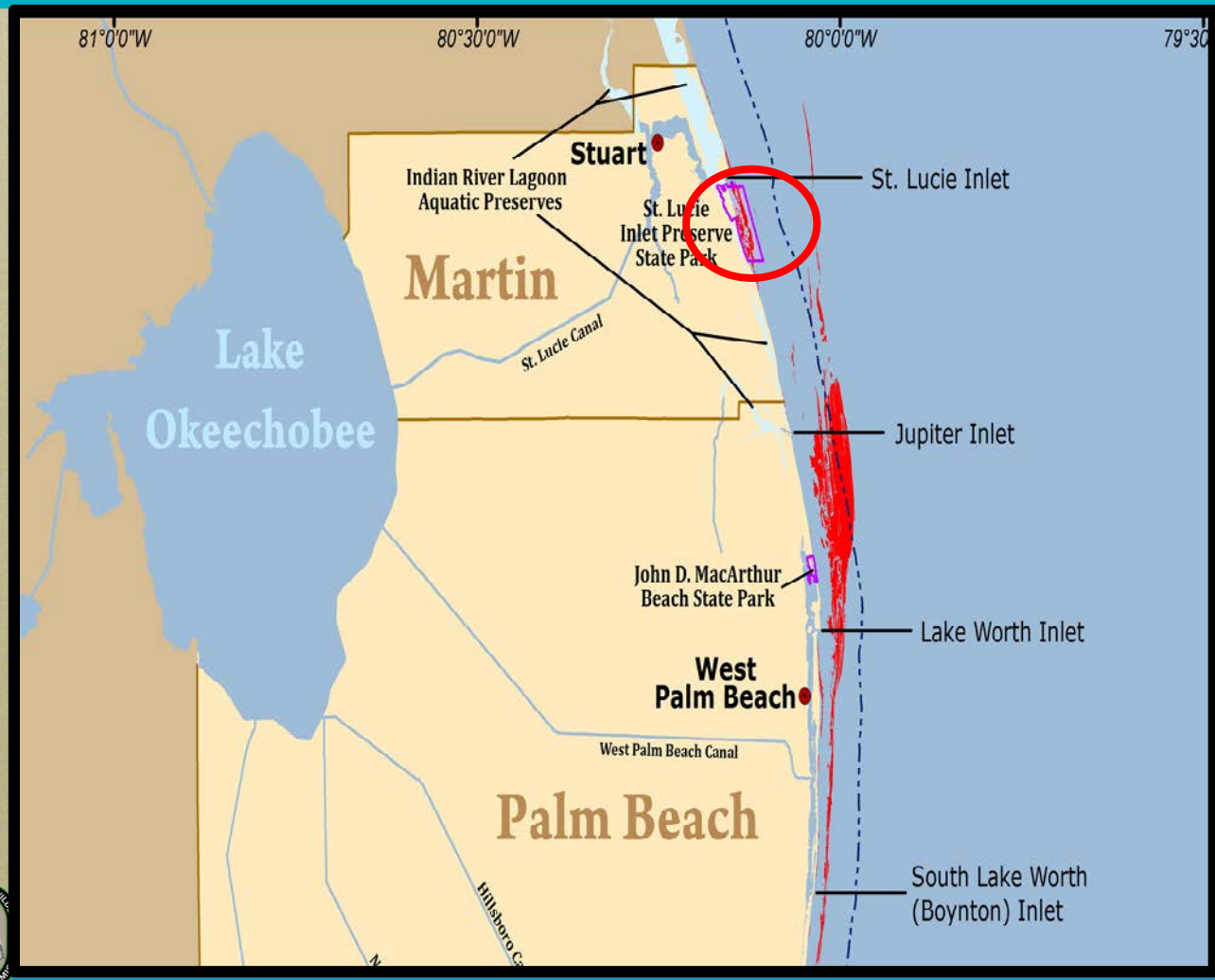
IRL South Plan

>$1B



Ecosystem Restoration?!

“Lost to Tide”


81°0'0"W
80°30'0"W
80°0'0"W
79°30
Stuart
Indian River Lagoon
Aquatic Preserves
St. Lucie Inlet
St. Lucie
Inlet Preserve
State Park
Martin
St. Lucie Canal
Lake
Okeechobee
Jupiter Inlet
John D. MacArthur
Beach State Park
Lake Worth Inlet
West
Palm Beach
West Palm Beach Canal
Palm Beach
South Lake Worth
(Boynton) Inlet

St. Lucie Reef coral reef inhabitants:

>250 species of fishes

21 species of sponges

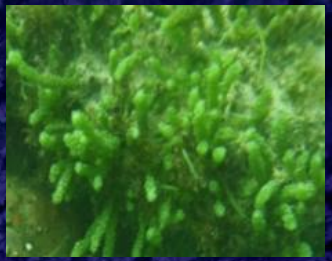
24 species of hard corals

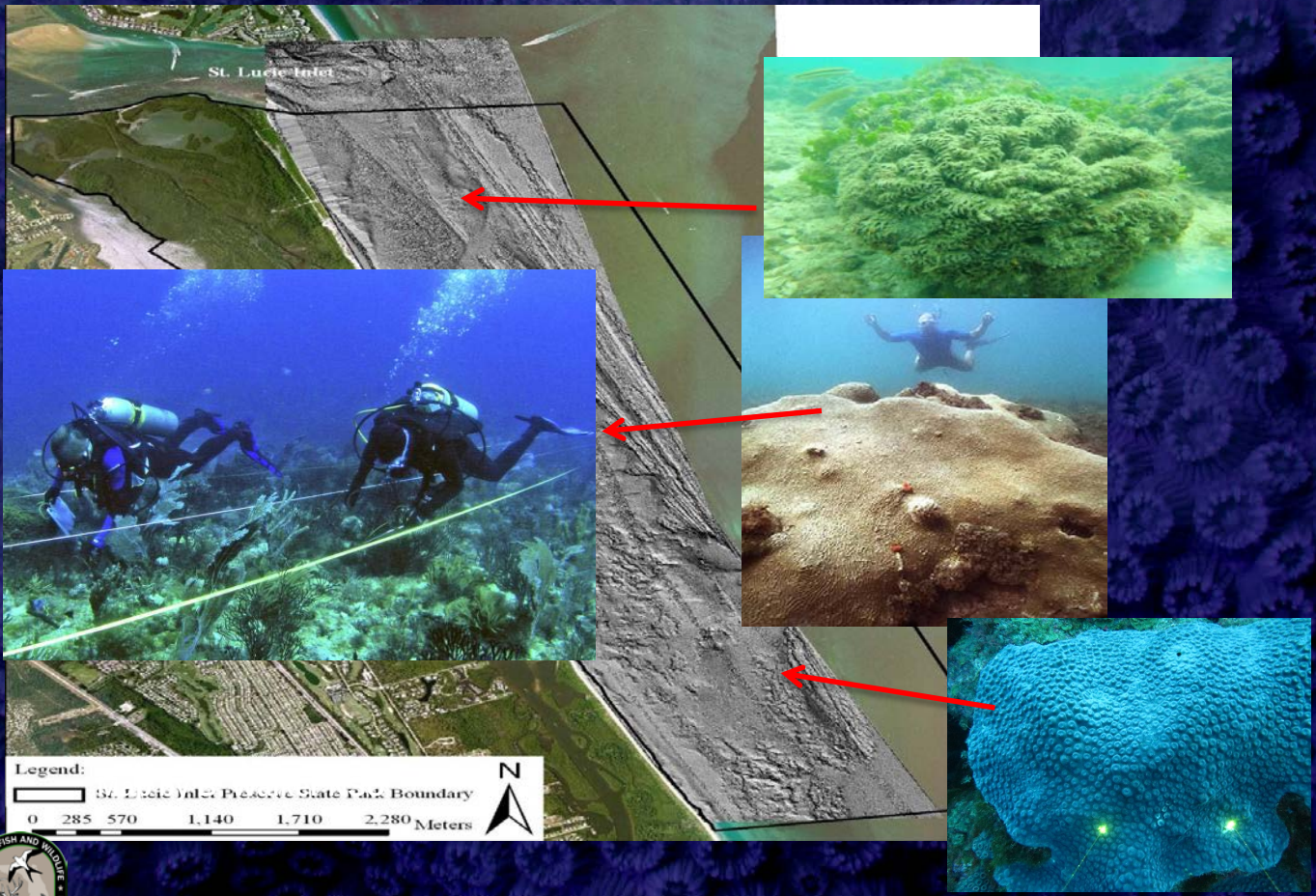
13 species of soft corals

17 species of crustaceans

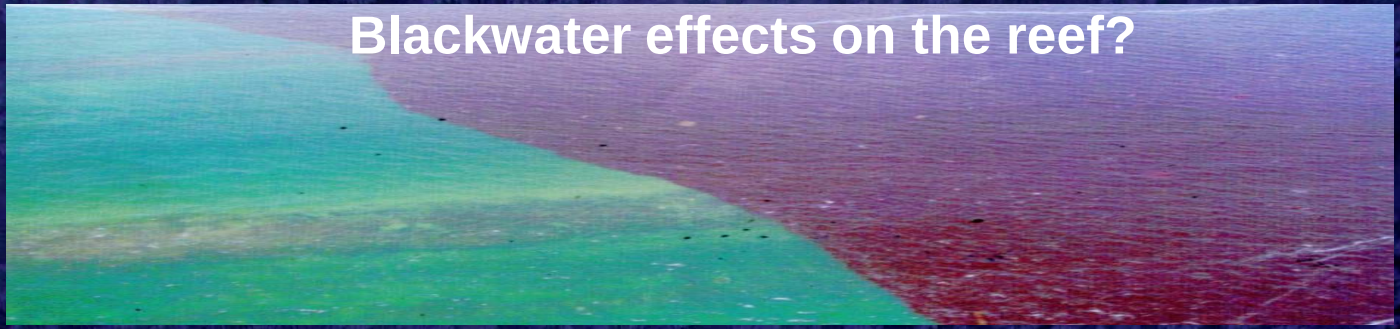
45 other inverts

23 species of algae



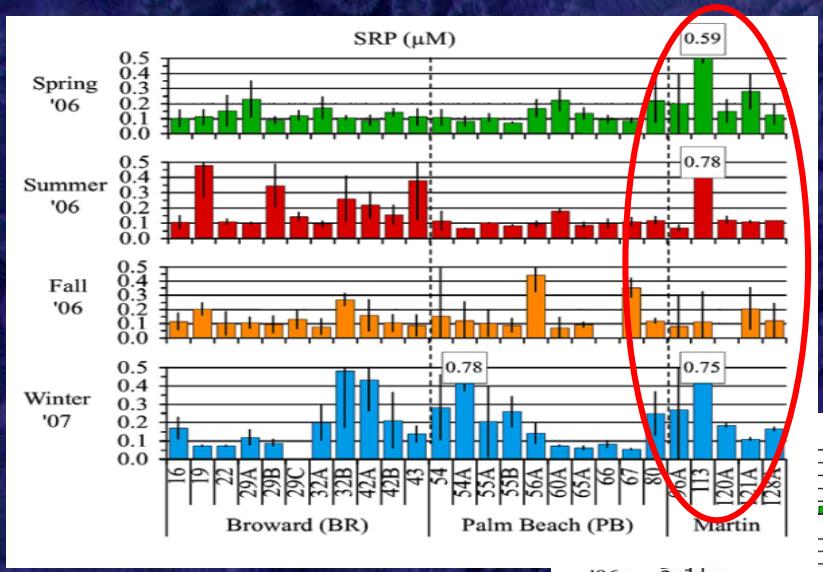

St. Lucie Inlet
Legend:
St. Lucie Inlet Preserve State Park Boundary
0 285 570 1,140 1,710 2,280 Meters
N

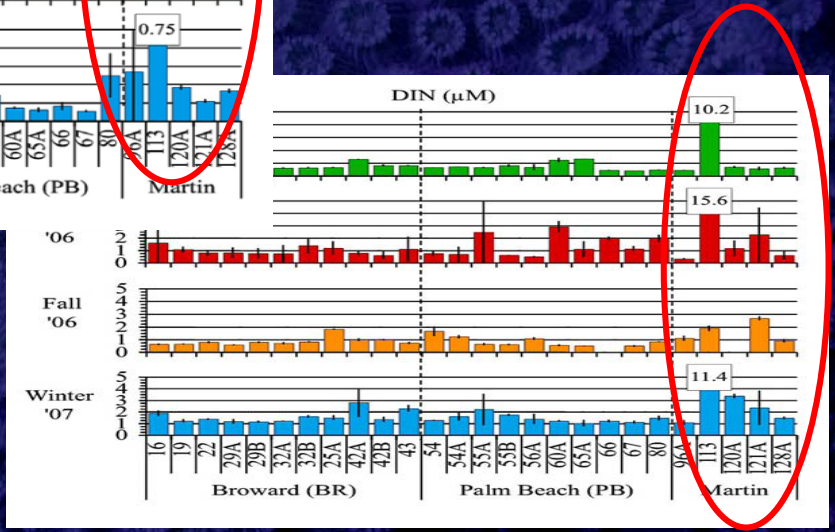
Blackwater effects on the reef?



- Temperature
- Reduction of light (PAR; color; turbidity; POM; CDOM)
- Osmotic shock (salinity; minerals)
- Excess nutrients (N; P; DOC; DO)
- Sedimentation
- Xenobiotics (microbes; metals; hydrocarbons; pesticides; herbicides)

Nutrient Input

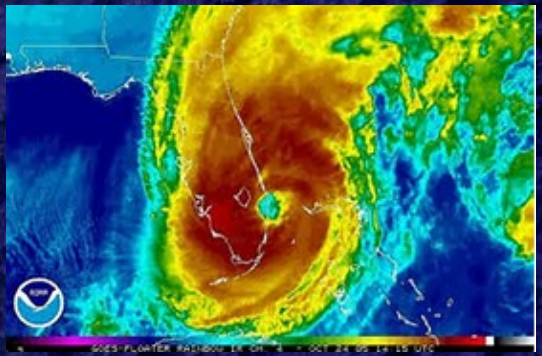




Comparative Ecology of Harmful Macroalgal Blooms in South Florida's Coastal Waters (CEHAB) (LaPointe 2007)

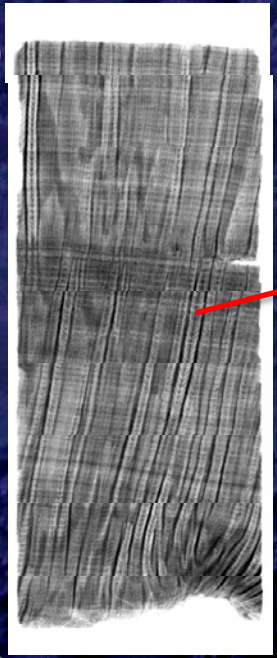
Coral Bleaching Event

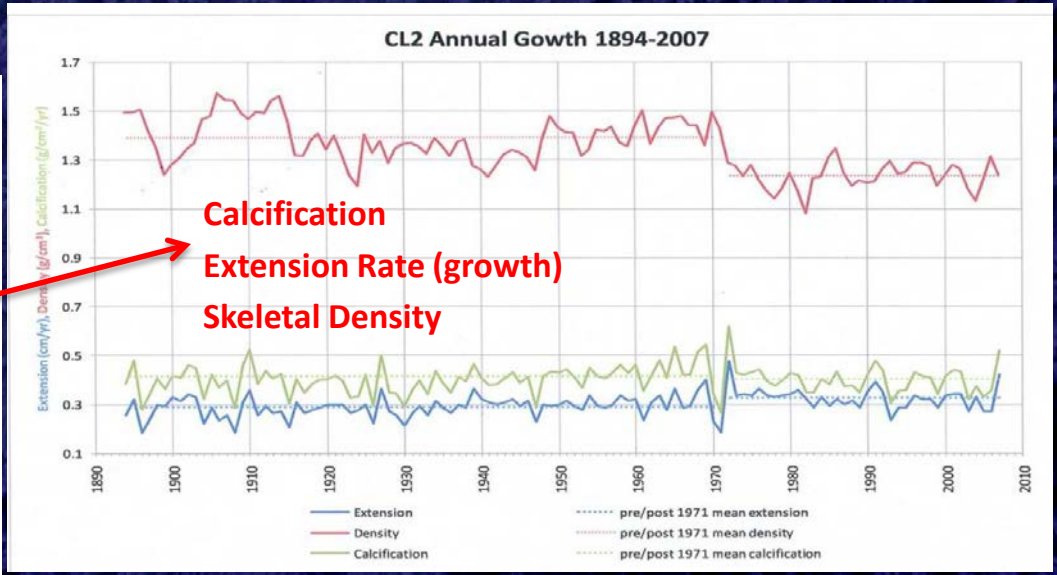
- **February 2006 following 3 ~11mths of Lake O releases**



Photos by L. Herren FDEP

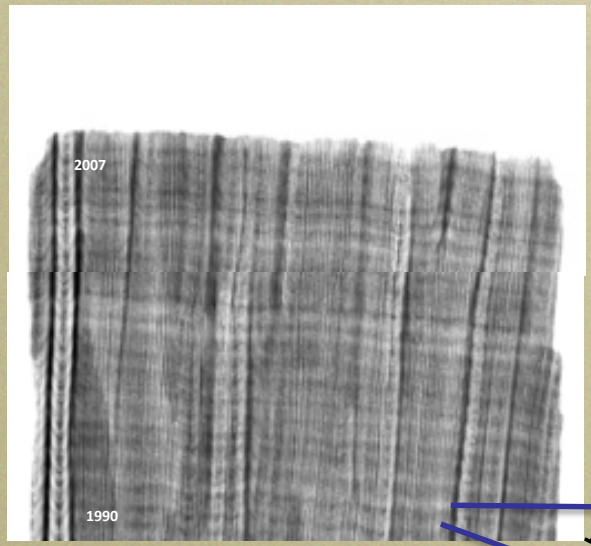
Pseudodiploria clivosa coring at St. Lucie Reef





B. Helmle NSU, unpublished data

1990-2007: complete flow record for SLE



1991 LD band

1991 HD band

Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

1990

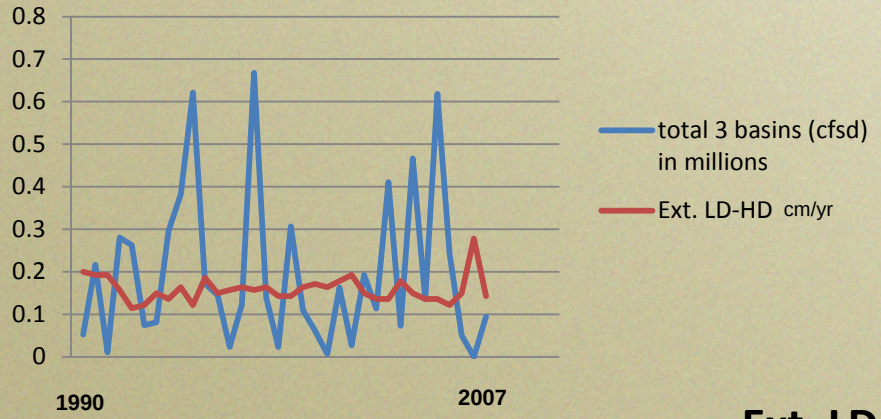
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

1991

Dry

Wet

Total SLE flow vs. extension by season (wet/dry) POR 1990-

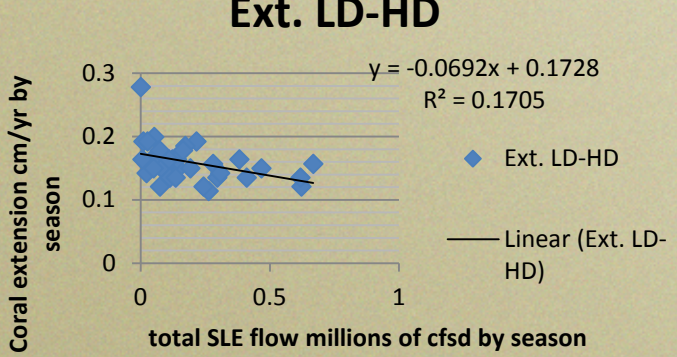


Spearman's Rank:

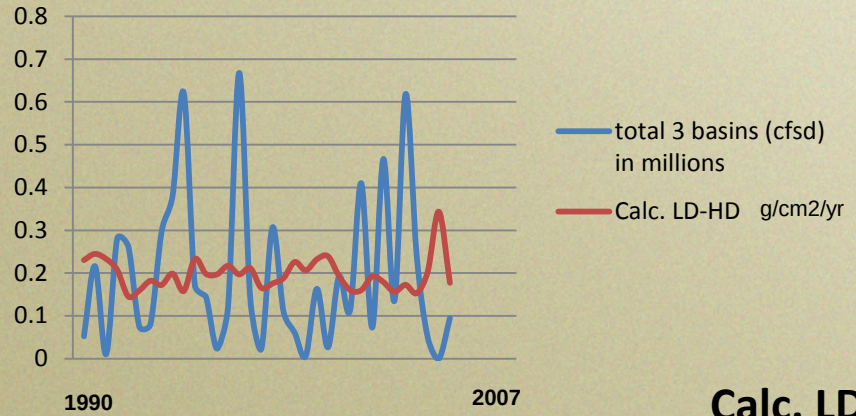
rho: -0.451

DF: 32

P-value: 0.00746*



Total SLE flow vs. calcification by season (wet/dry) POR 1990

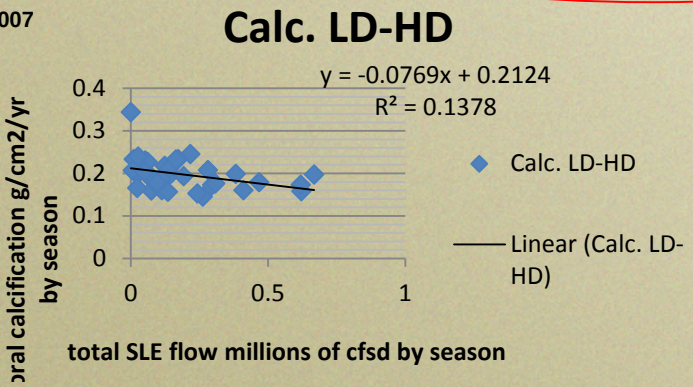


Spearman's Rank:

rho: -0.392

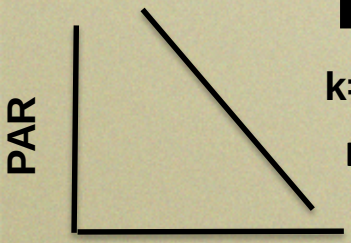
DF: 32

P-value: 0.0218*



Fragile coral skeletons

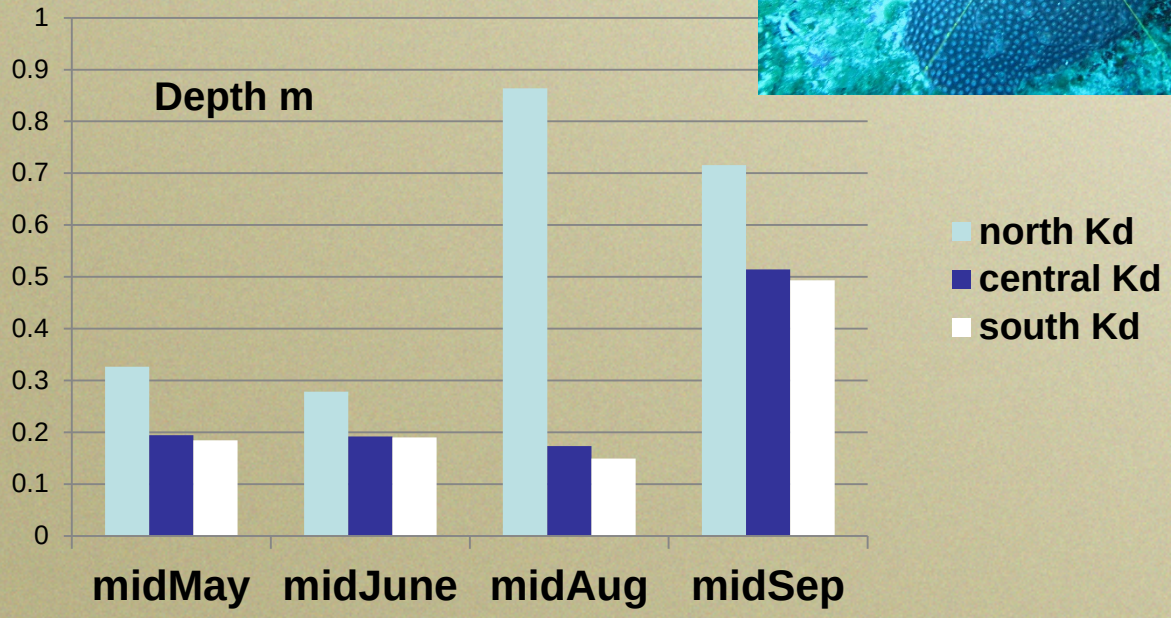
Light attenuation 2010



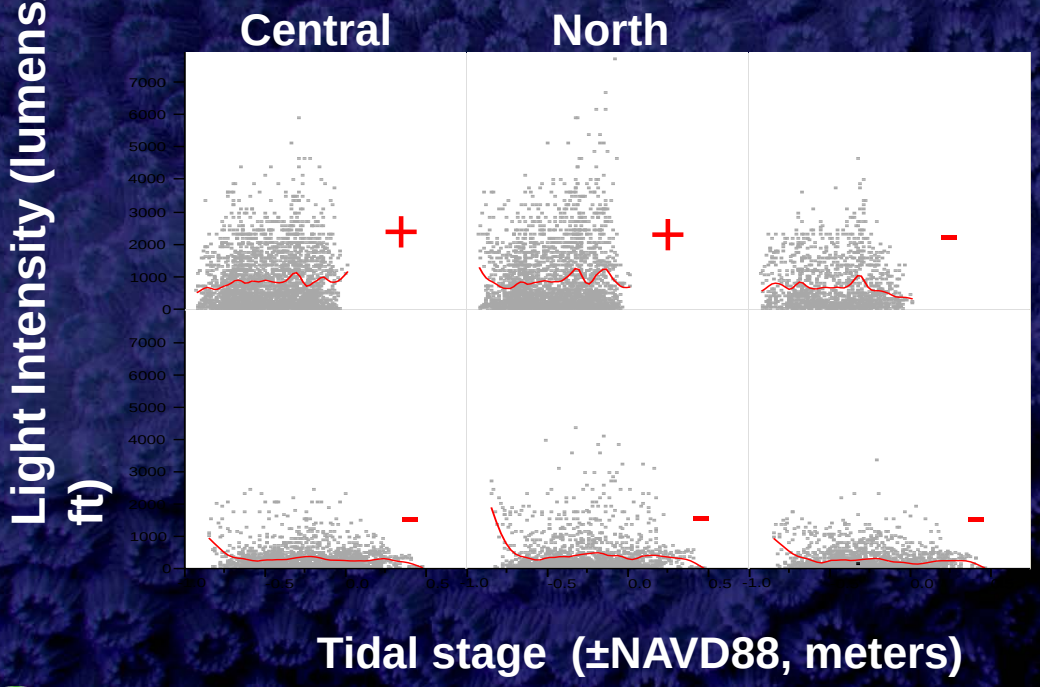
k=attenuation coefficient

Kd = (lnEz1 - ln Ez2)/(z2-z1)

Kd values at coral sites:



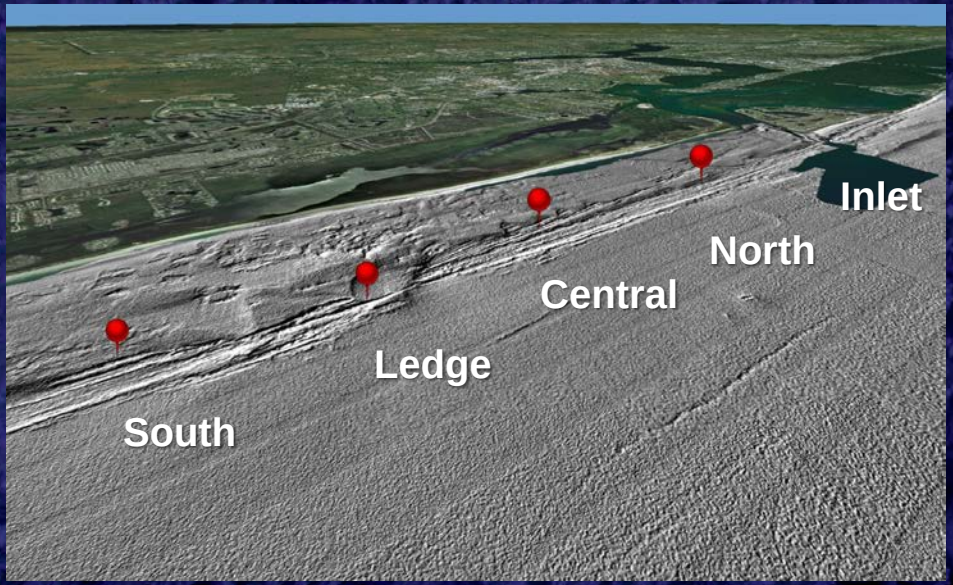
Tidal stage vs. light



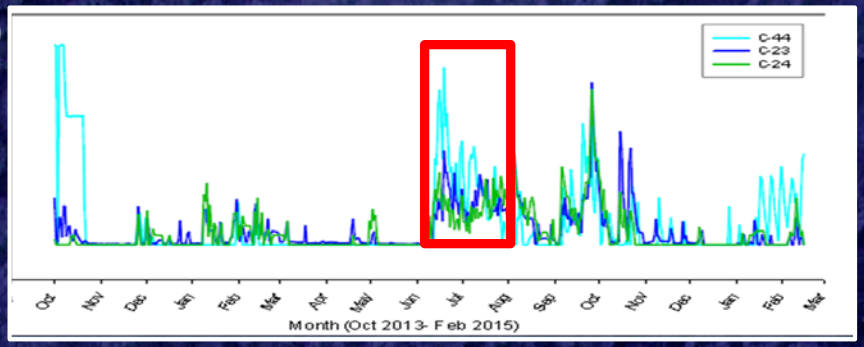
Early Summer
(May to early Aug 201

Late Summer
(mid Aug to Nov 2010)

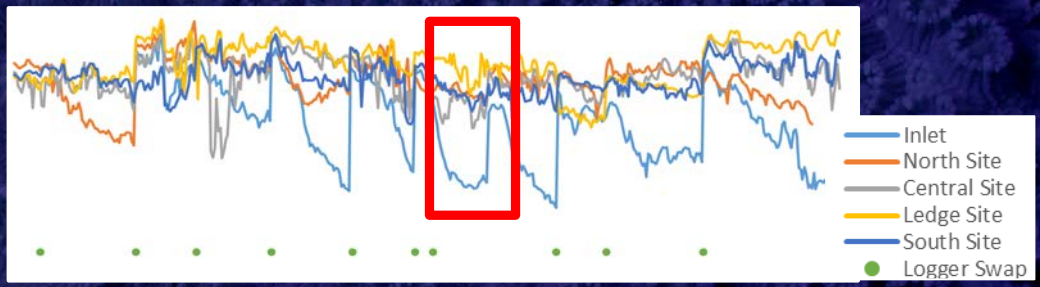
Tracking Freshwater Discharges Beyond the Inlet



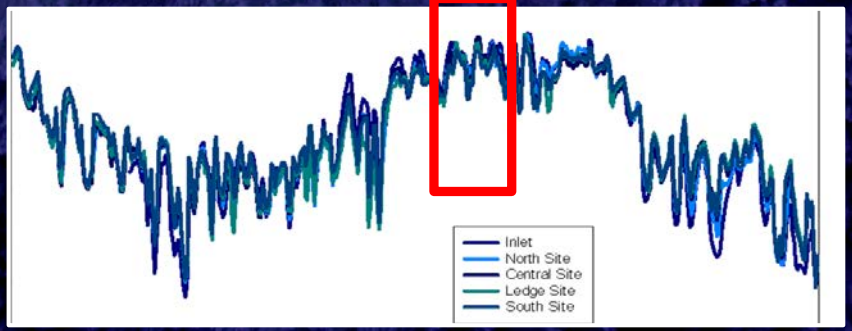
Discharge Rate (m^3s^{-1})
DBHYDRO database



Salinity(ppt)
Odyssey data loggers



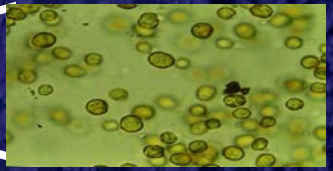
Temperature(°C)
Odyssey data loggers



The Coral Holobiont

coral colony

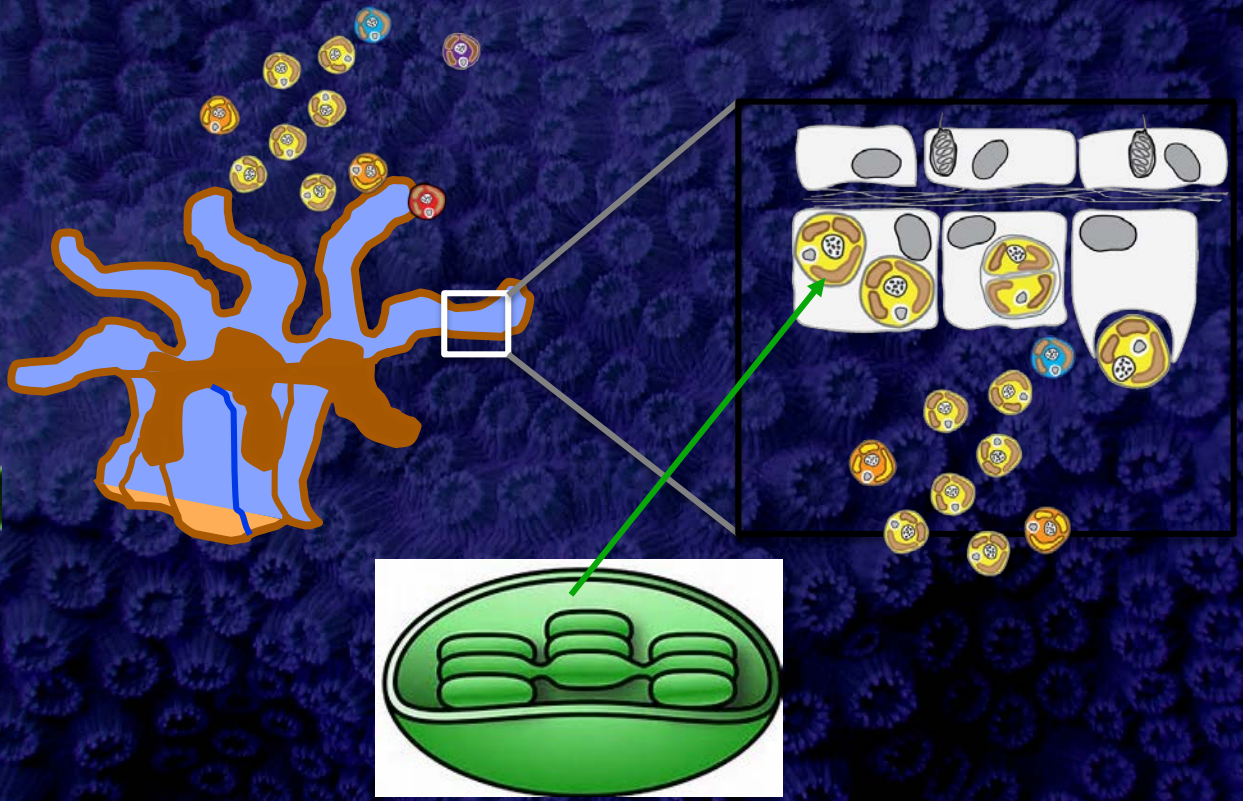
zooxanthellae



genetic information

bacteria

The Symbiosis



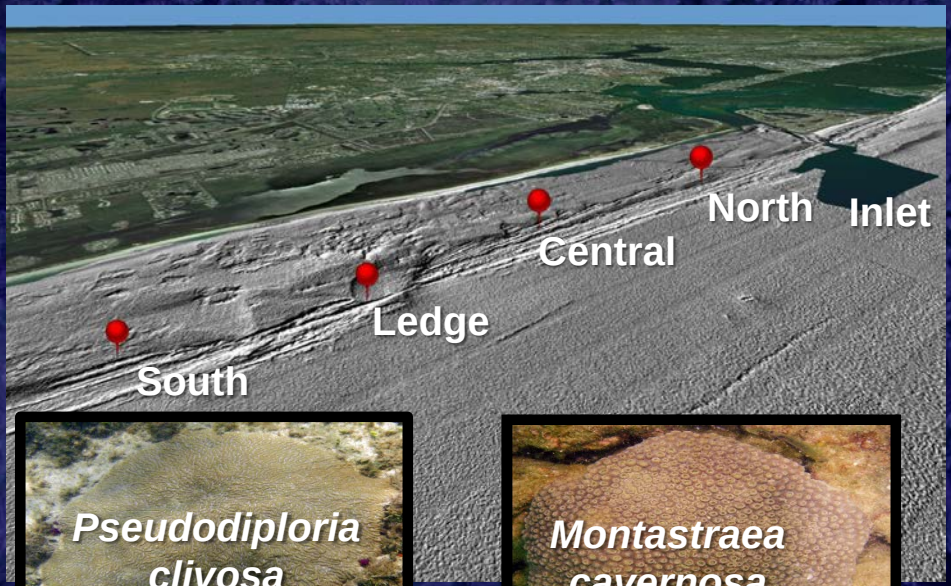
Coral stress

Resistance and Resiliency

Indicators of sub-lethal effects?

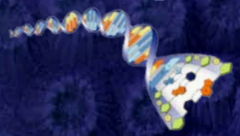
Inform upstream water management?

How do Discharges Impact Corals at SLR?

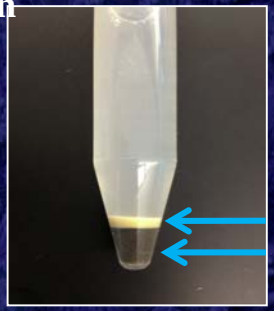


Using new technologies

Population Genetics
and Gene Expression

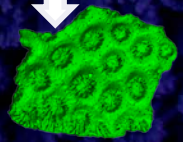


Zooxanthellae density



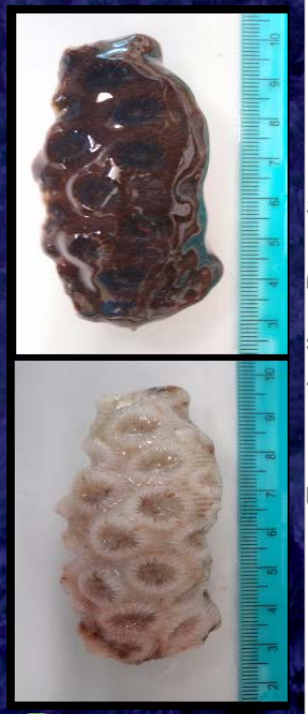
Chlorophyll

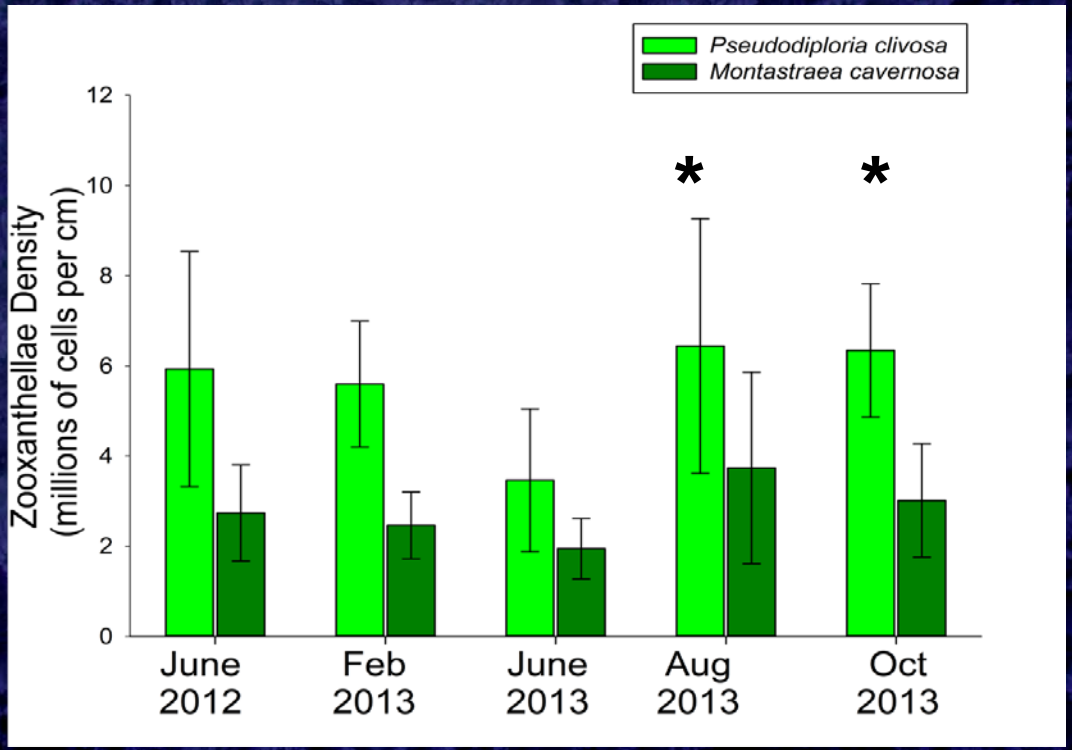
Zooxanthellae IDs via
next-gen sequencing



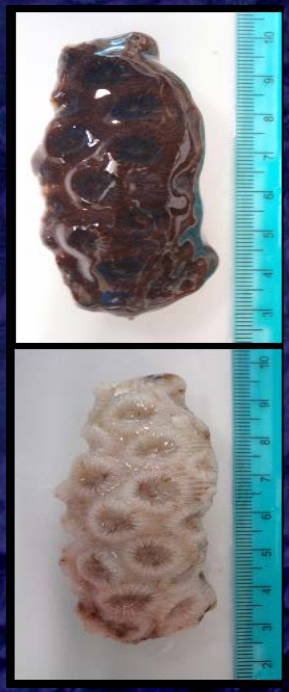
Surface area and
Morphometrics

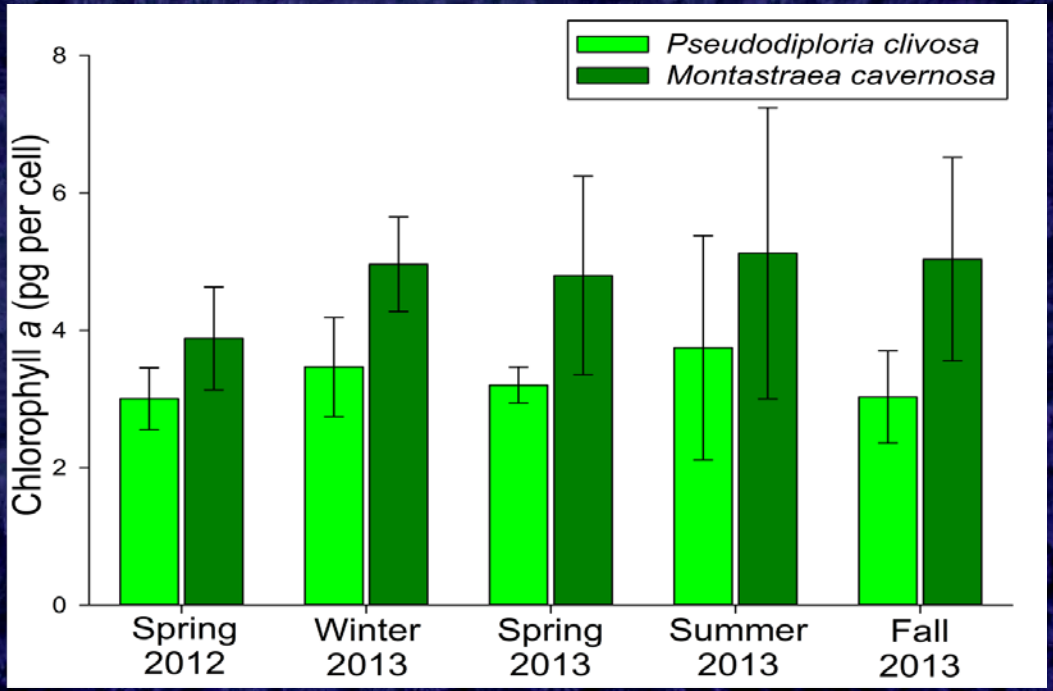
Zooxanthellae Density Differs Between Coral Species & Over Time



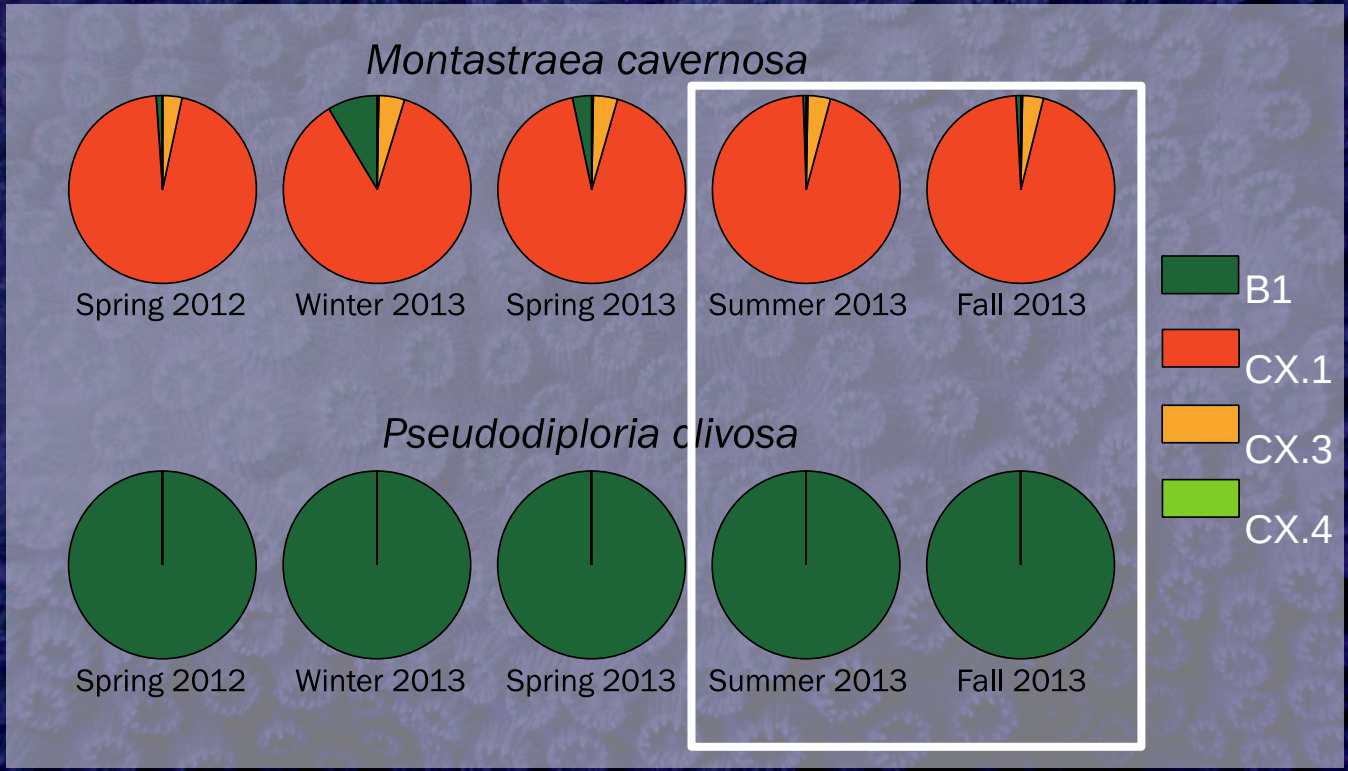


Chlorophyll per Zooxanthellae Cell

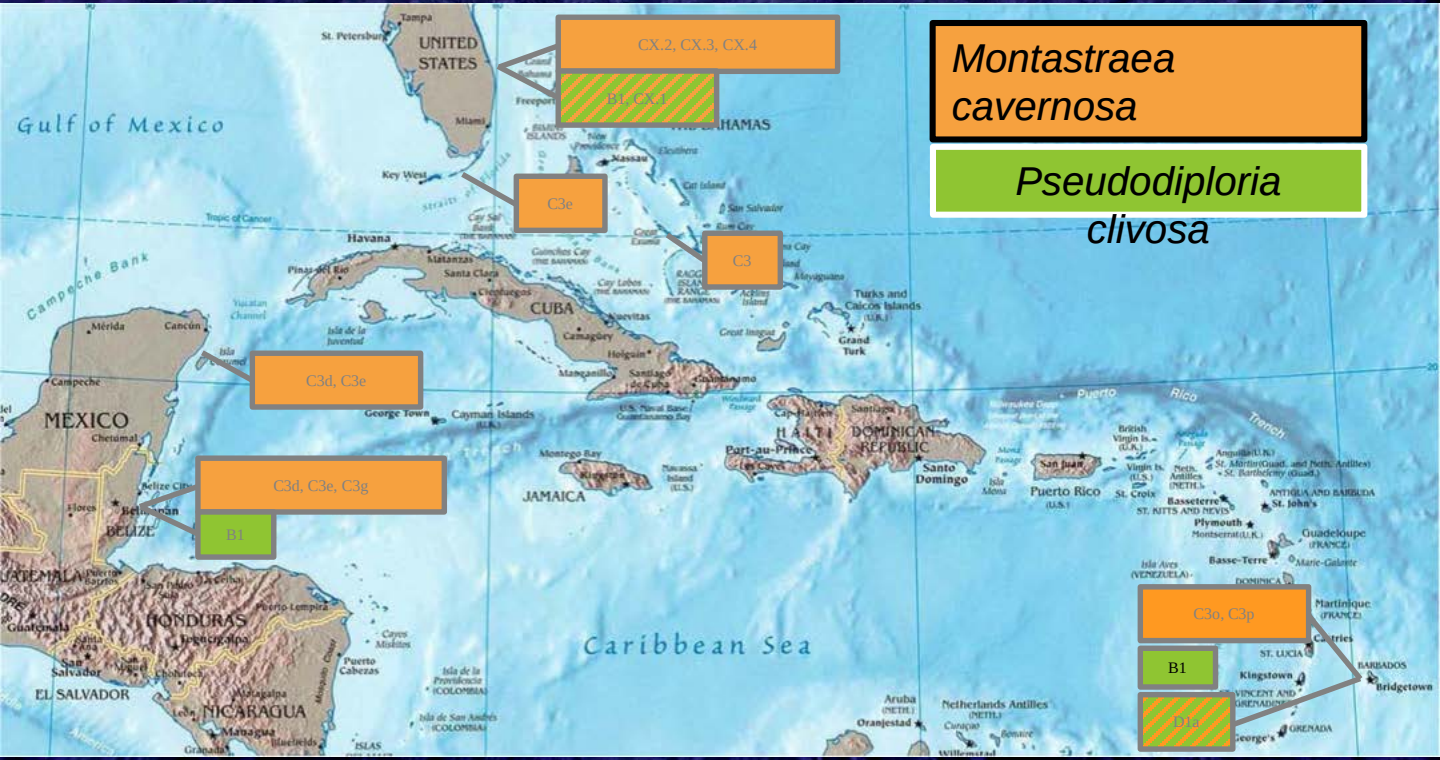




Zoox Types Over Time



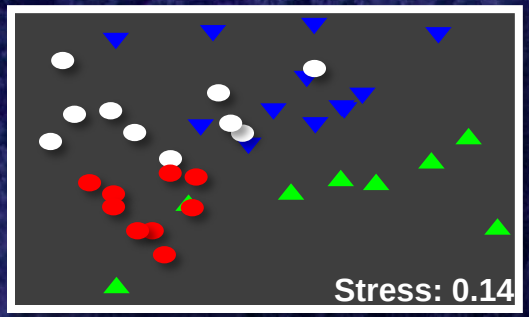
Zoox Diversity in the Wider Caribbean



Coral and Zooxanthellae Gene Expression

- Custom microarray
  - coral & zoox genes
- Expression of stress genes elevated during discharge events
  - Cell metabolism
  - Tissue repair
  - Osmotic stress-related
  - Reproduction

Coral Bacterial Community Profile Analysis



P. clivosa SLR, Fall

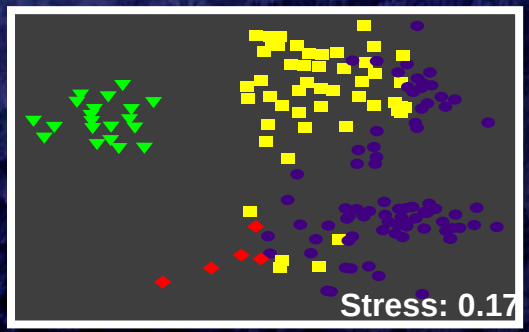
P. clivosa SLR, Summer

P. clivosa SLR, Winter

P. clivosa SLR, Spring

Time: R = 0.571, p < 0.005*

Site: R = 0.018, p = 0.415



SLR

FL Keys

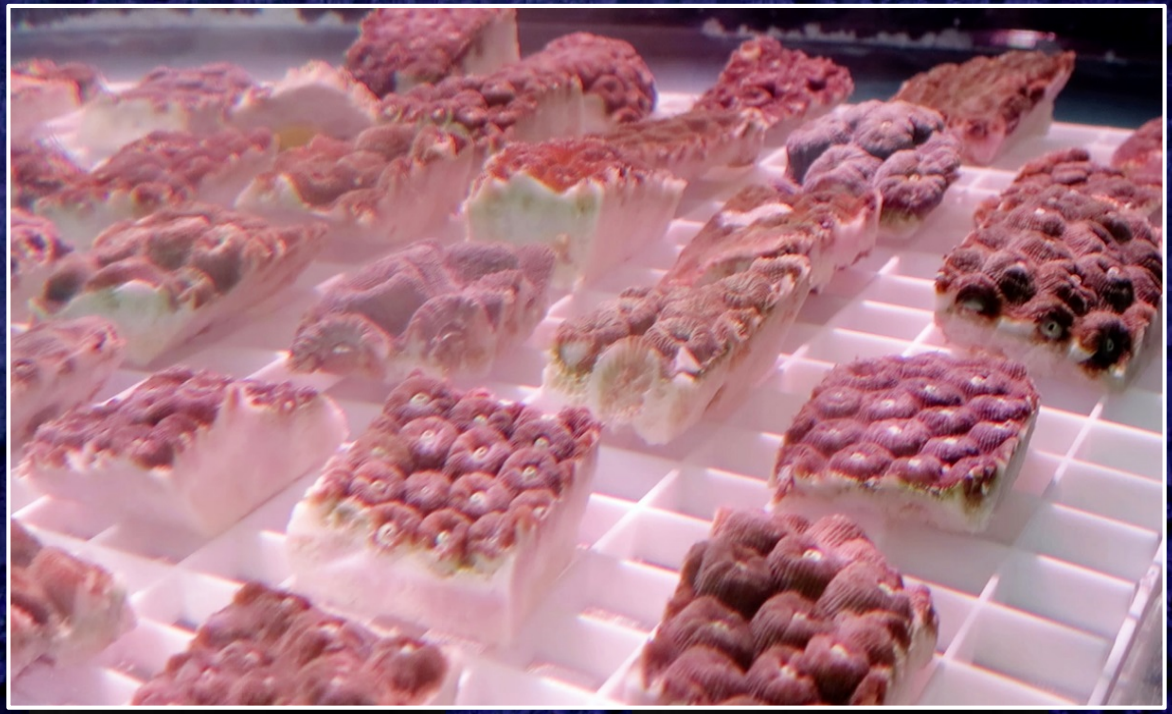
USVI

Bahamas

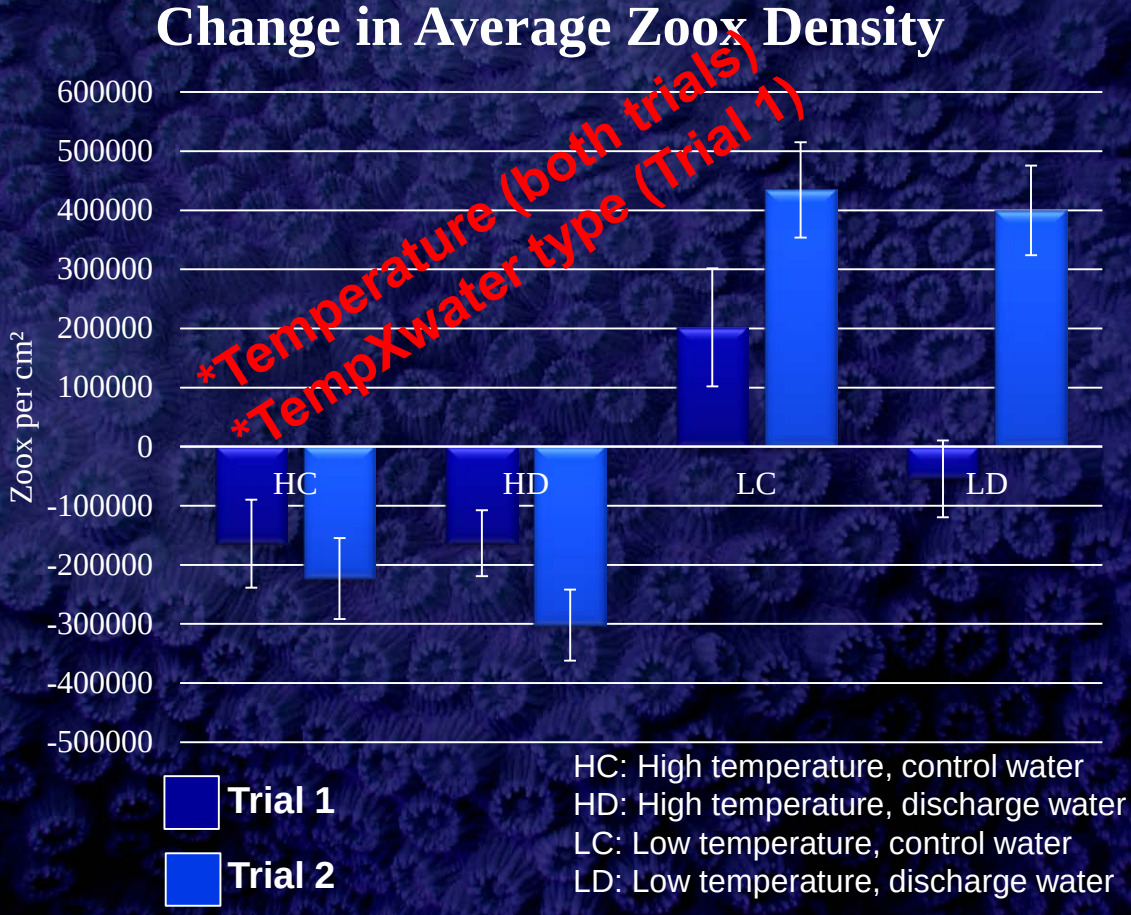
R = 0.535, p < 0.001

Ex-situ Experimental Design

- **Individual** and **combined** effects of discharge water and thermal stress
- 2 x 2 factorial design

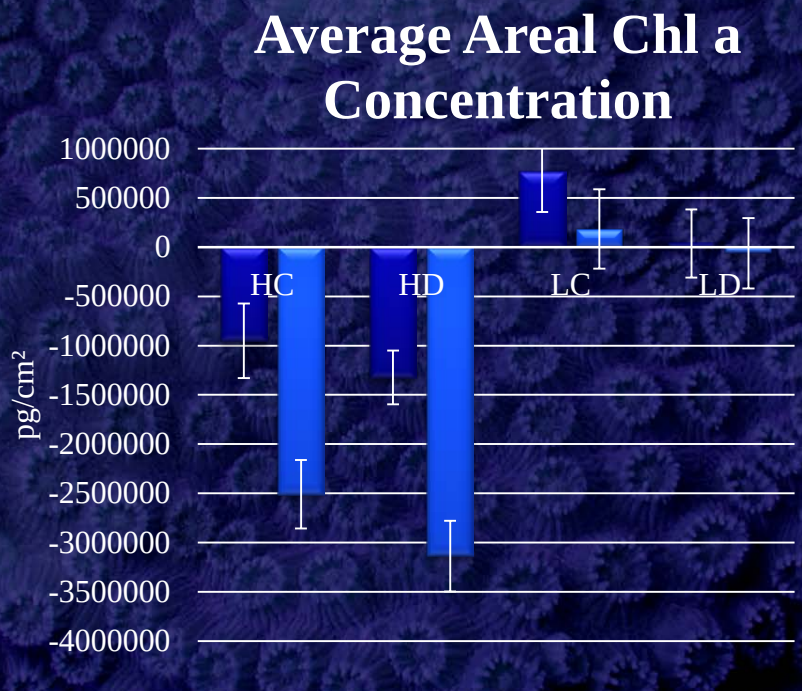


Zooxanthellae Density



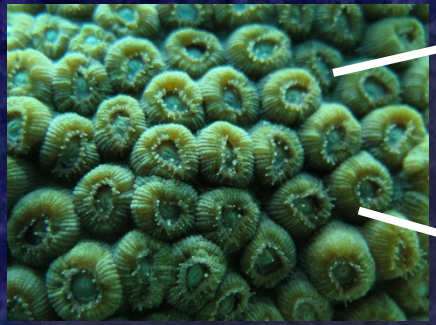
Areal Chlorophyll Concentration

HC: High temperature, control water
HD: High temperature, discharge water
LC: Low temperature, control water
LD: Low temperature, discharge water



***Temperature (both trials, Chlor a and c)**
***TempXwater type (Chlor a in Trial 1)**

Gene expression

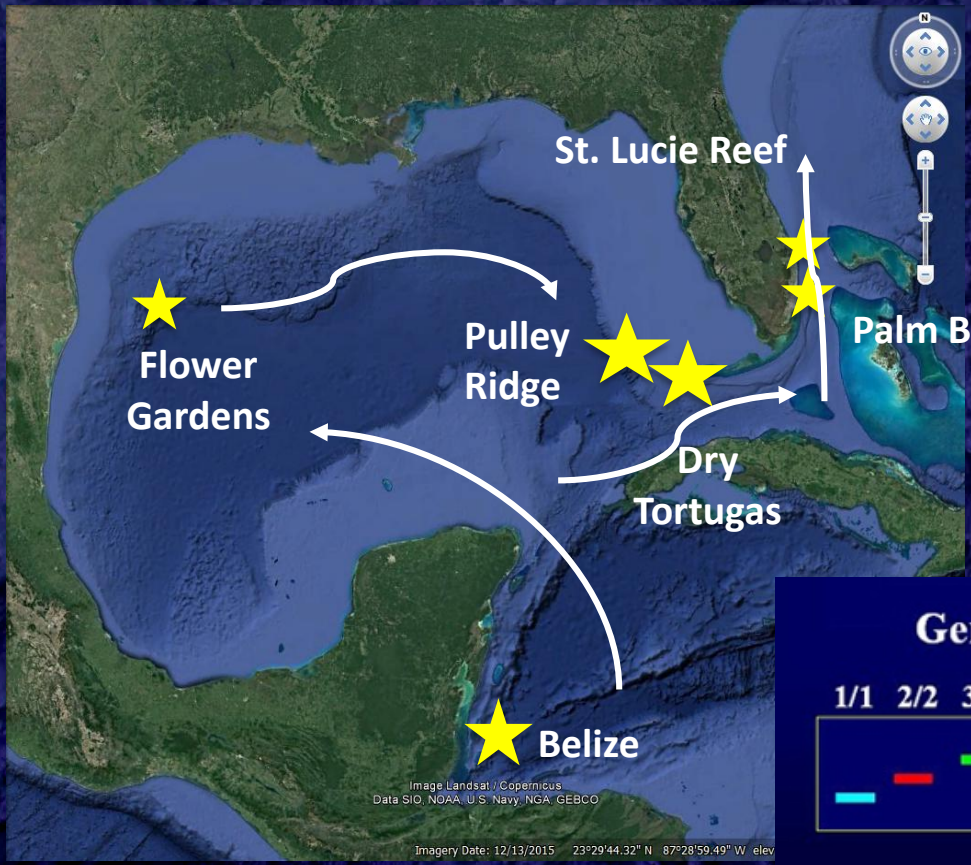


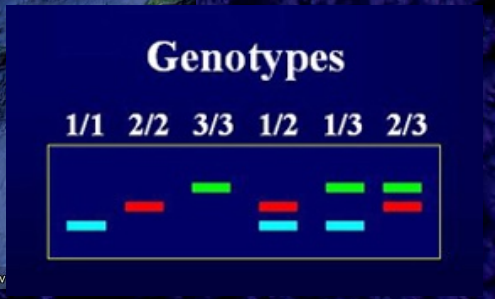
??

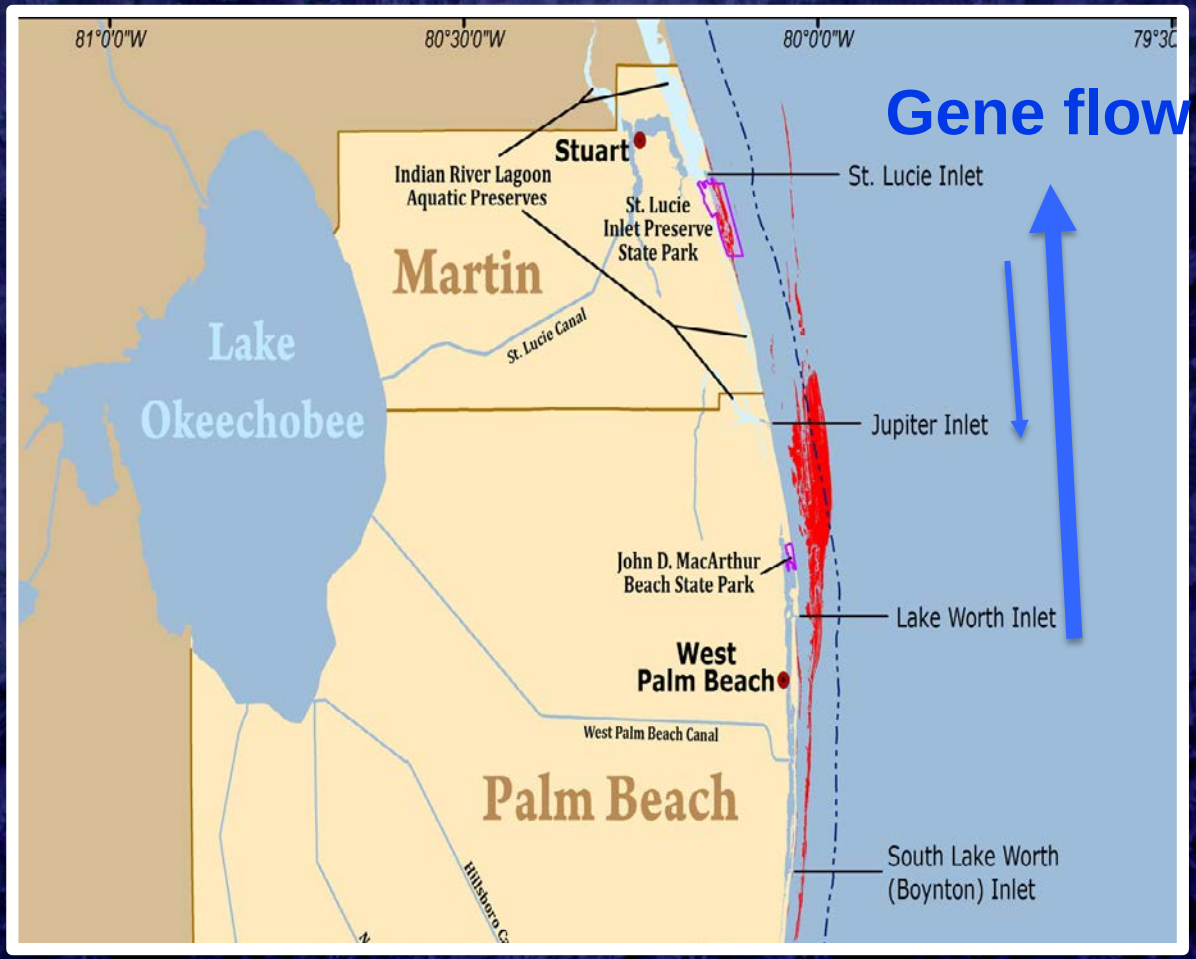
Conclusions

- Significant increases in coral stress gene expression during summer discharge events (RNAseq)
- St. Lucie corals harbor dynamic microbial and zoox assemblages that differ significantly from corals in other Caribbean regions
- Zooxanthellae density and chlorophyll concentration differ among coral species and in response to discharges (role of heterotrophy?)
- Temperature is a key factor in discharge effect (synergistic)
- Unique genotypes capable of withstanding great stress?

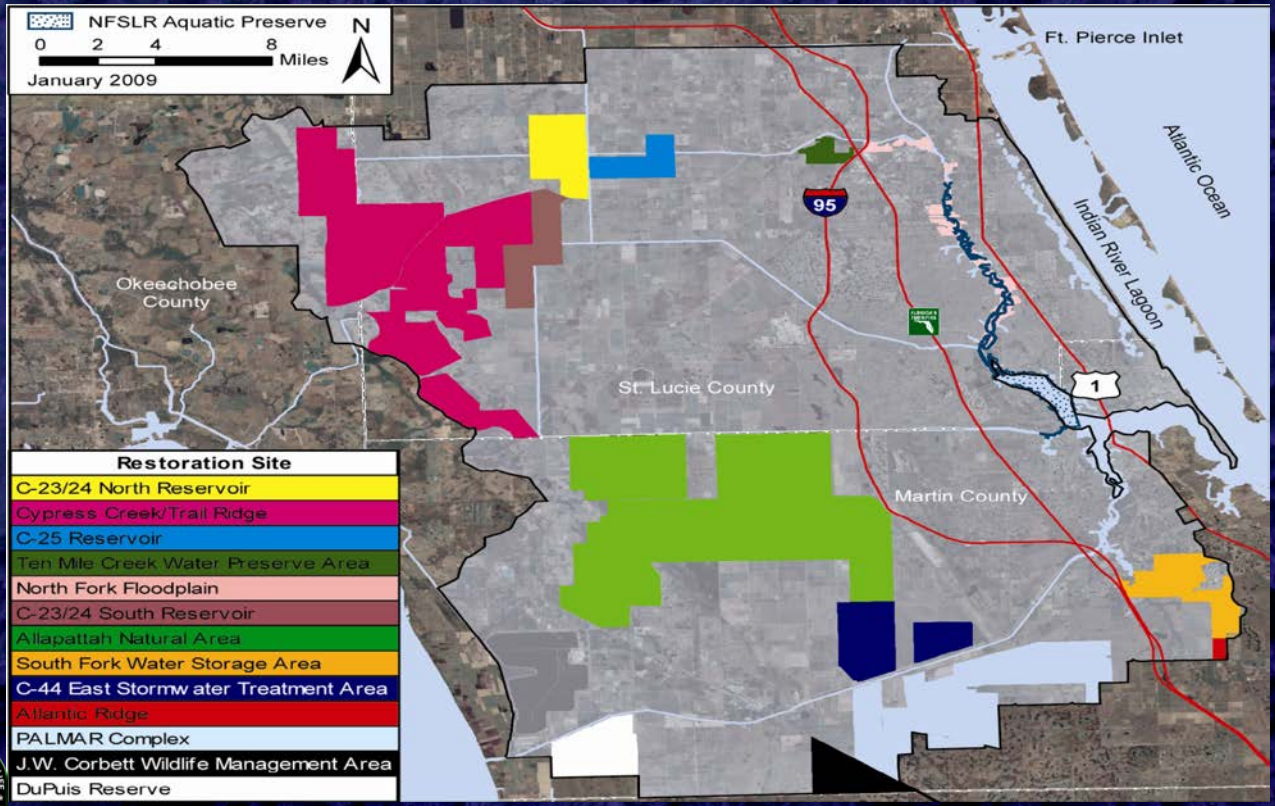
Assessing Connectivity Among Coral Populations



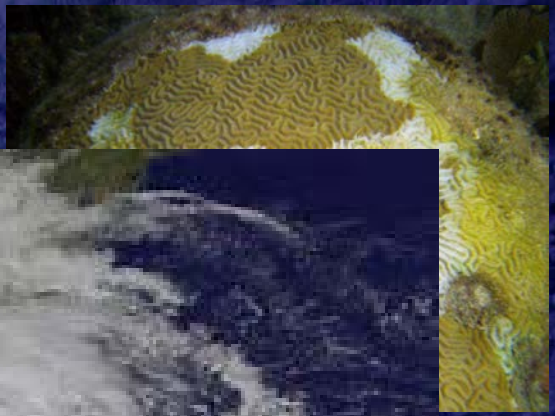


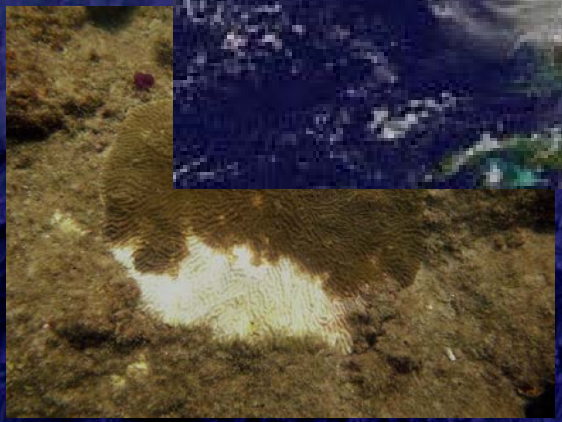
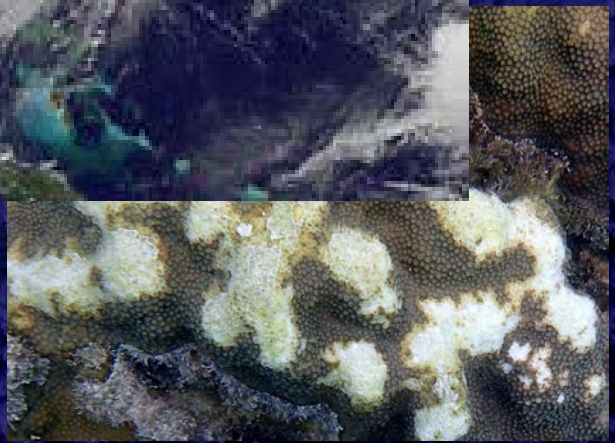

81°0'0"W
80°30'0"W
80°0'0"W
79°30
Gene flow
Stuart
Indian River Lagoon
Aquatic Preserves
St. Lucie Inlet
St. Lucie
Inlet Preserve
State Park
Martin
St. Lucie Canal
Lake
Okeechobee
Jupiter Inlet
John D. MacArthur
Beach State Park
Lake Worth Inlet
West
Palm Beach
West Palm Beach Canal
Palm Beach
South Lake Worth
(Boynton) Inlet

Comprehensive Everglades Restoration Plan
Indian River Lagoon – South Projects



Better data for effective restoration and adaptive management strategies!

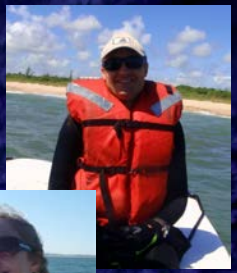



Thanks…









Dennis Hanisak
Maureen Williams
Sara Edge
Jennifer Polinski
Lisa Cohen
Michael Studivan
Clay Cook
Kristen Davis
Courtney Klepac
Amanda Alker
Jimmy Nelson
Susan Laramore
Ashley Sproles
Charles Jabaly
Will Krebs

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

RIVER·BRANCH FOUNDATION

FLORIDA C LIFE SAVE OUR SEAS

Sea Grant Florida

FLORIDA PARK SERVICE ENVIRONMENTAL PROTECTION

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION UNITED STATES DEPARTMENT OF COMMERCE

HARBOR BRANCH
FLORIDA ATLANTIC UNIVERSITY

Oyster Health: Natural and Restored Reefs

Jeff Beal, FWC MESS

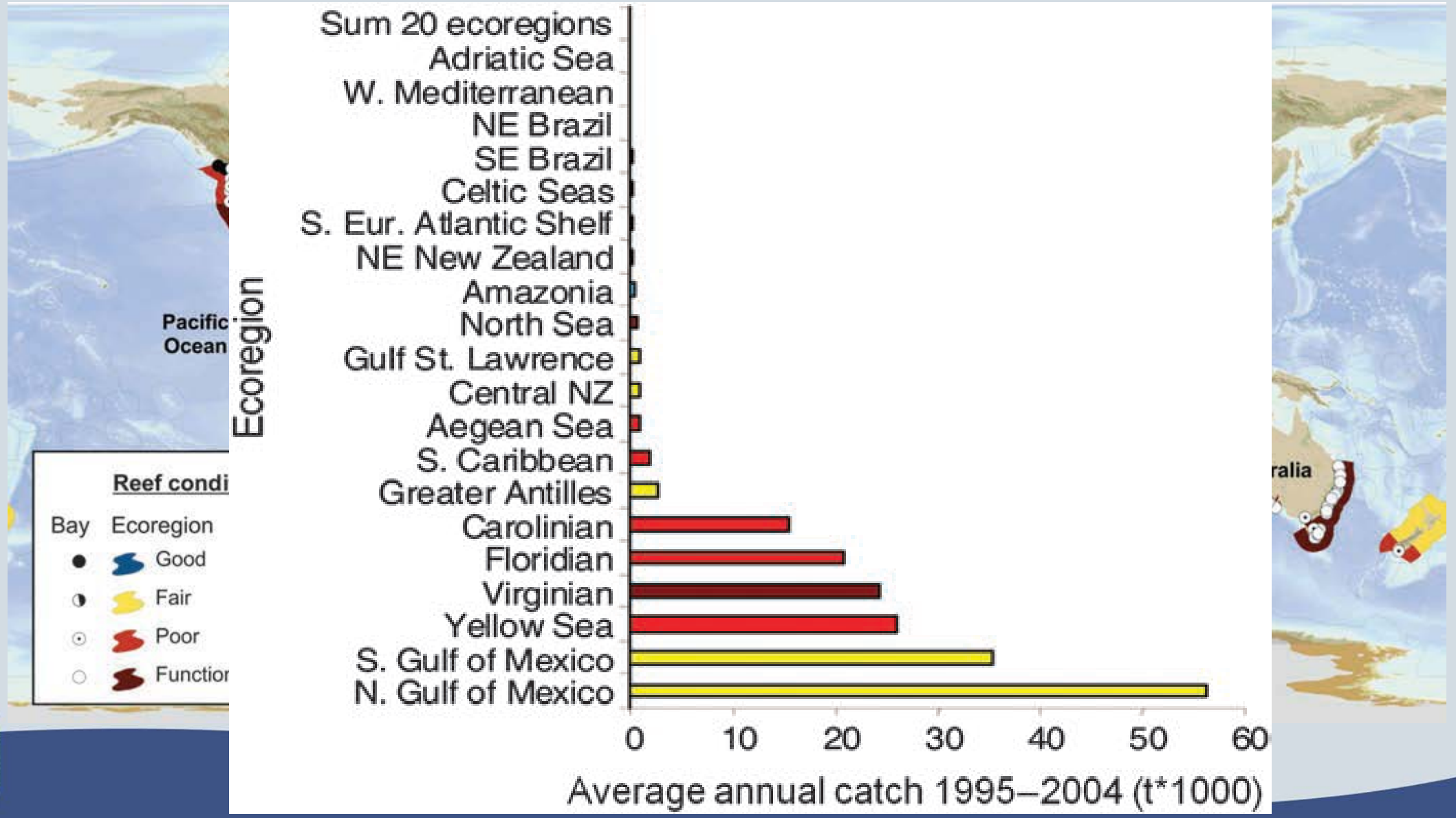
Emily Dark, FDEP

Reika Yu, Boston Univ.

Dr. Susan Laramore, FAU HBOI

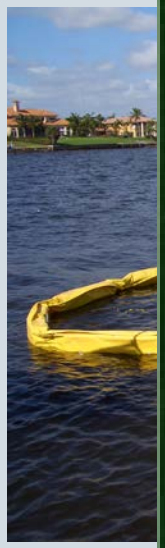
Elizabeth Urban, FAU HBOI

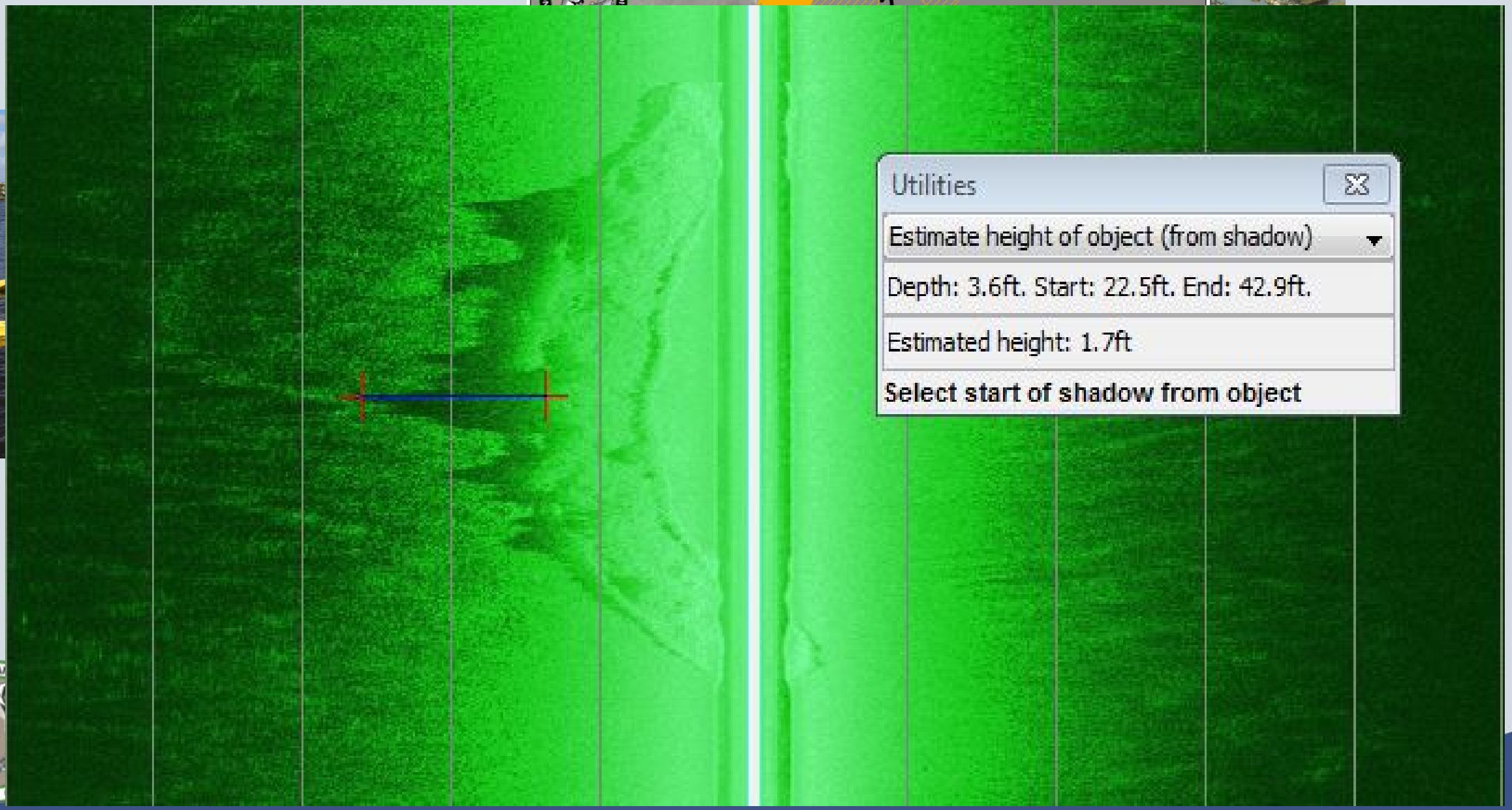
Pure Shellfishness

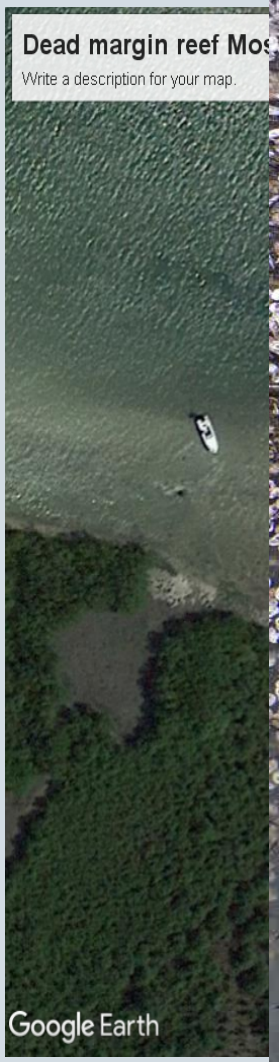


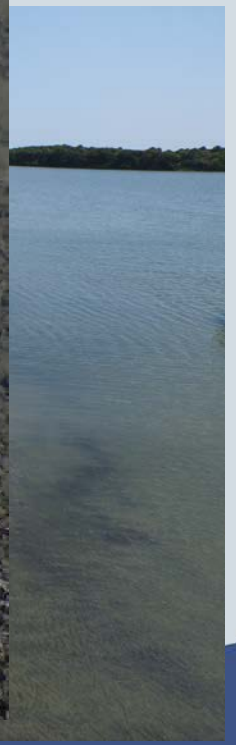
The Shellfish Cultchure

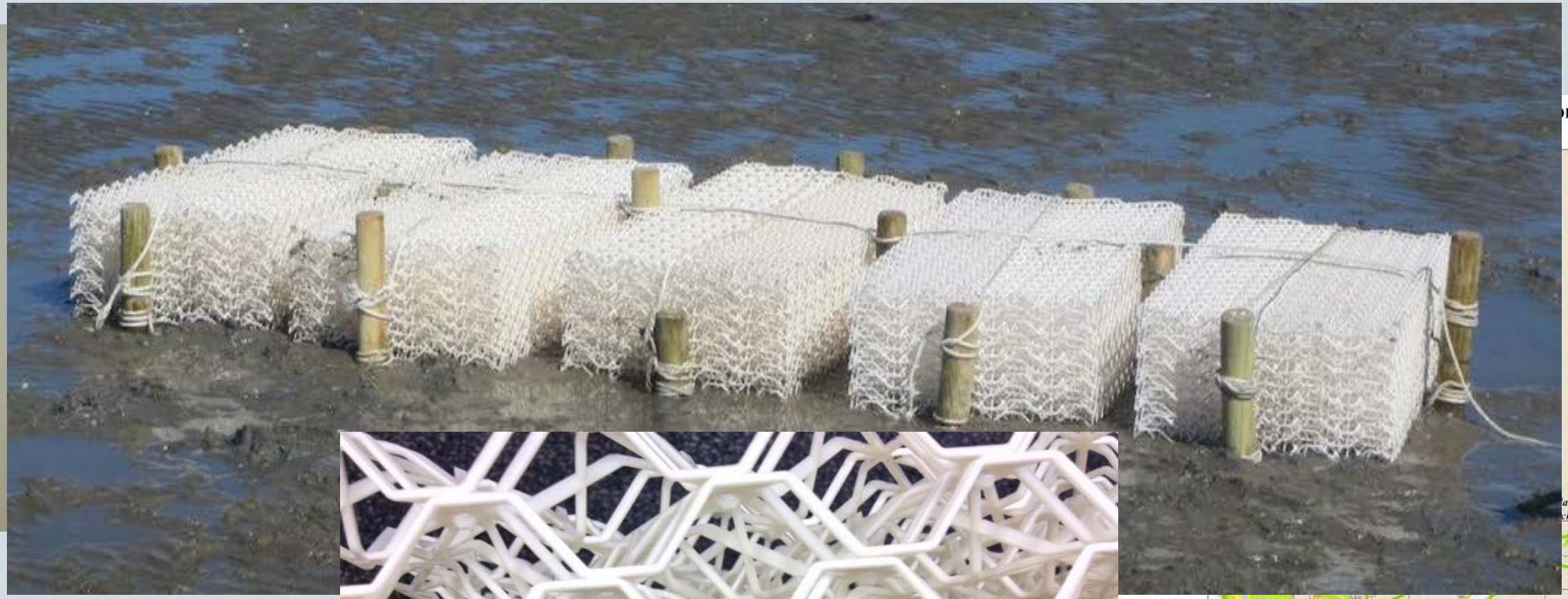
Florida Restoration

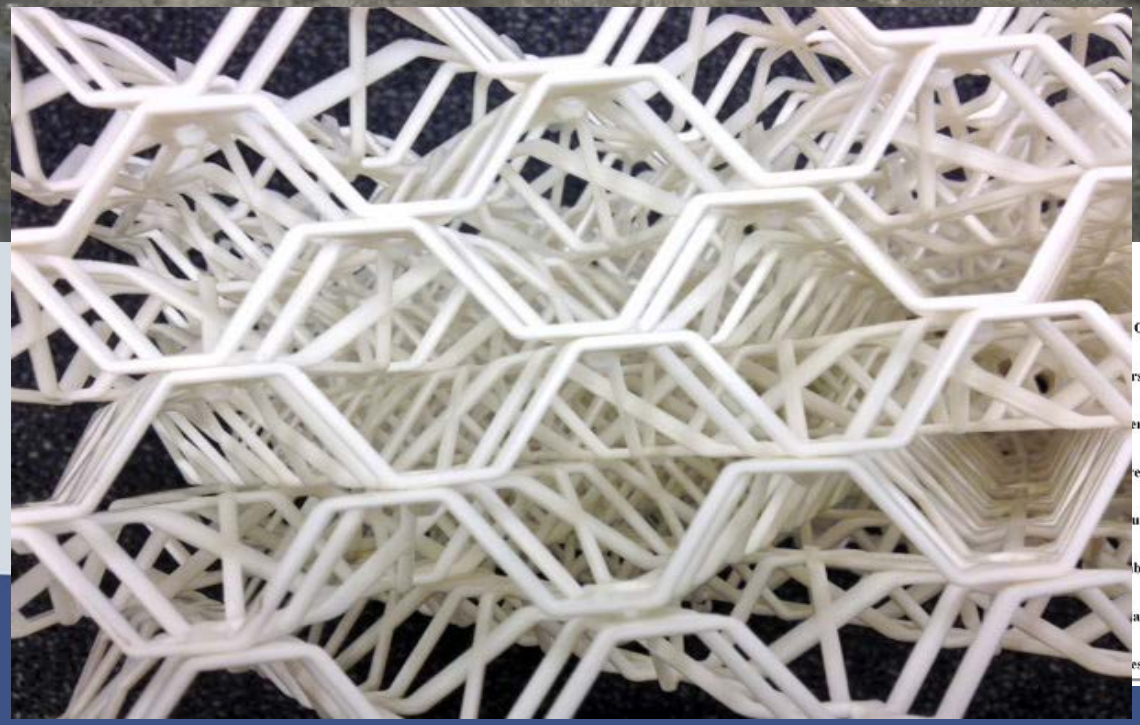




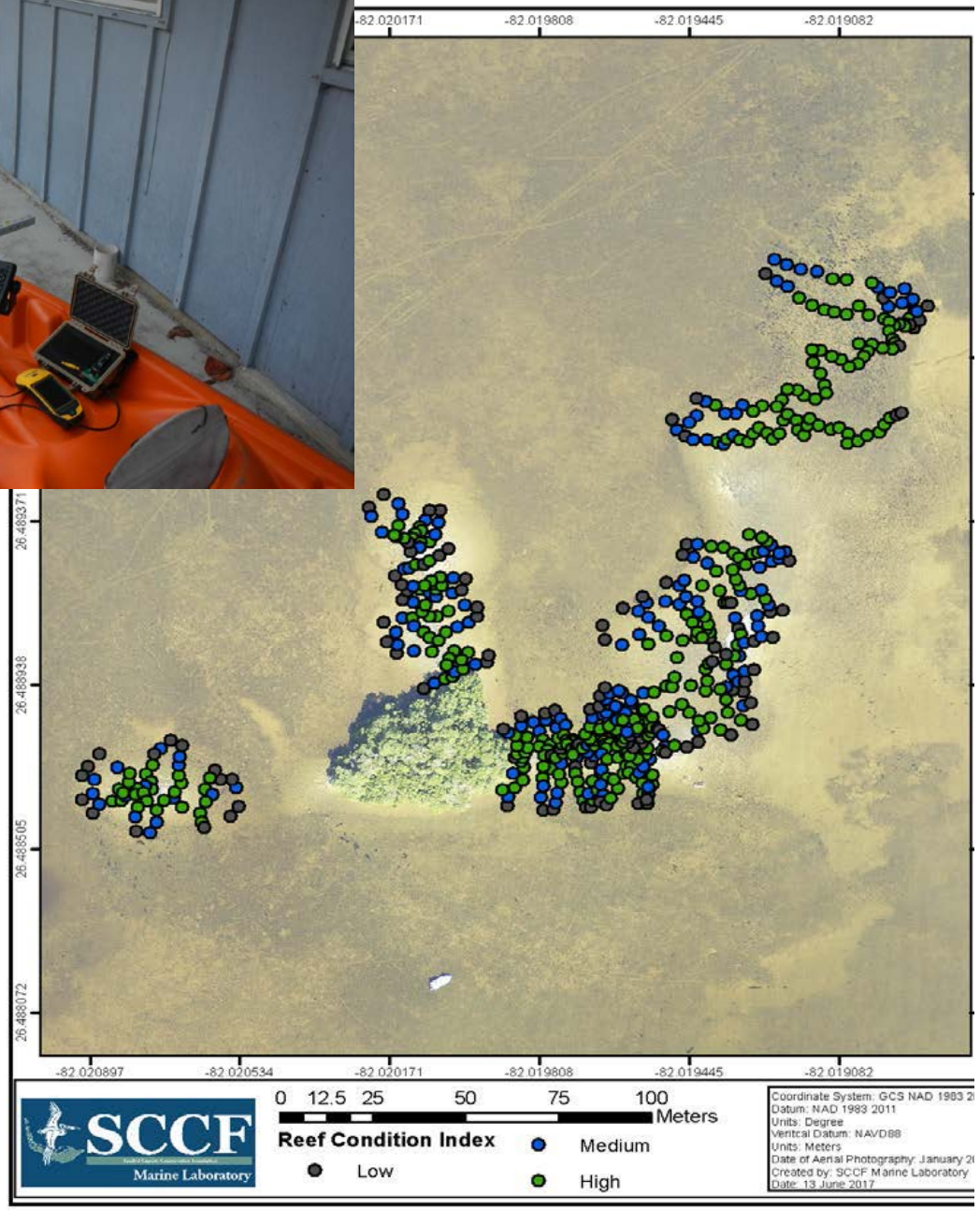

Dead margin reef Mos
Write a description for your map.
Google Earth

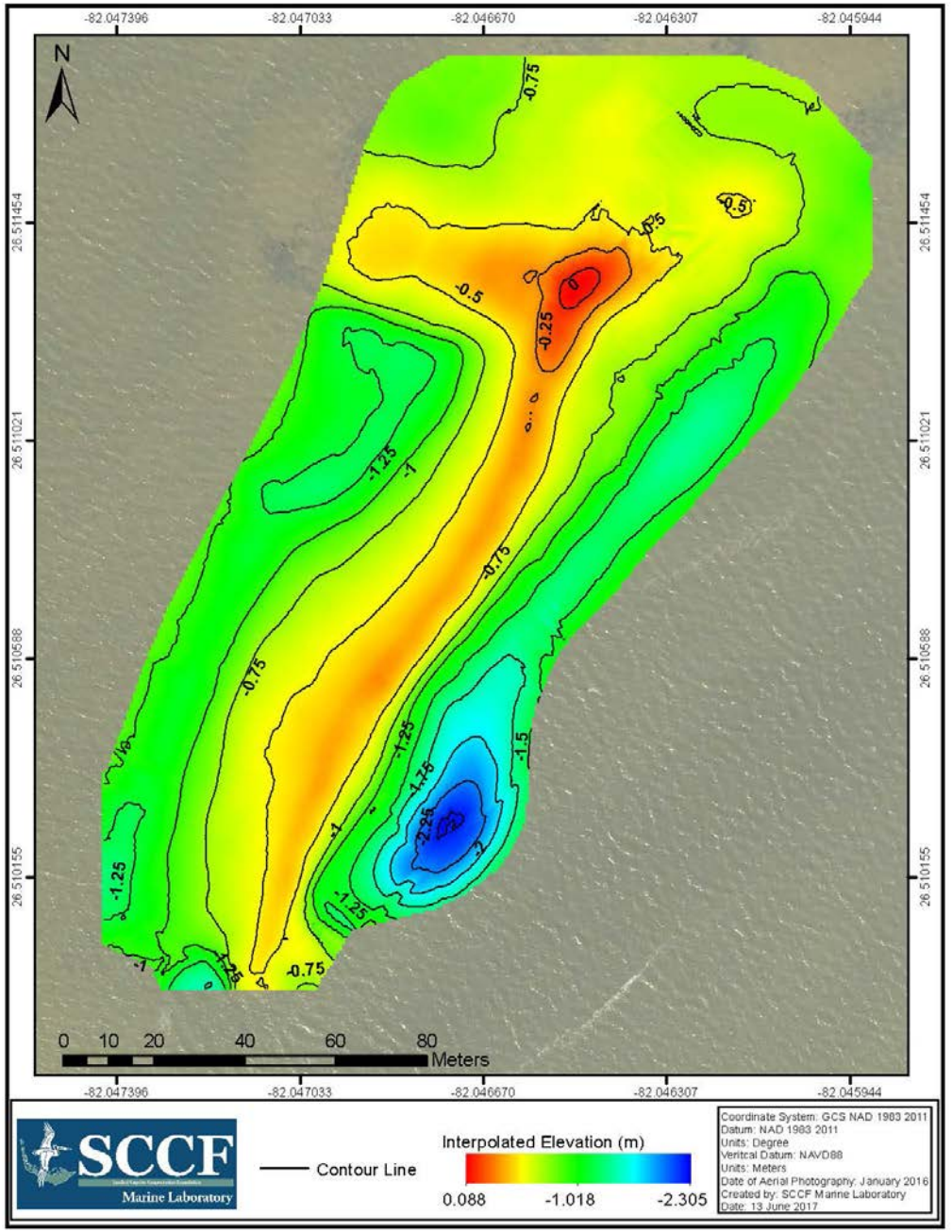







Oyster Restoration
Matlacha Pass
Pine Island Sound
San Carlos Bay
Estero Bay
CHARLOTTE HARBOR
Source: CHNEP, SWFRPC, FDACS & NOAA
Date: August 2012
N
Miles





FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

Vs.

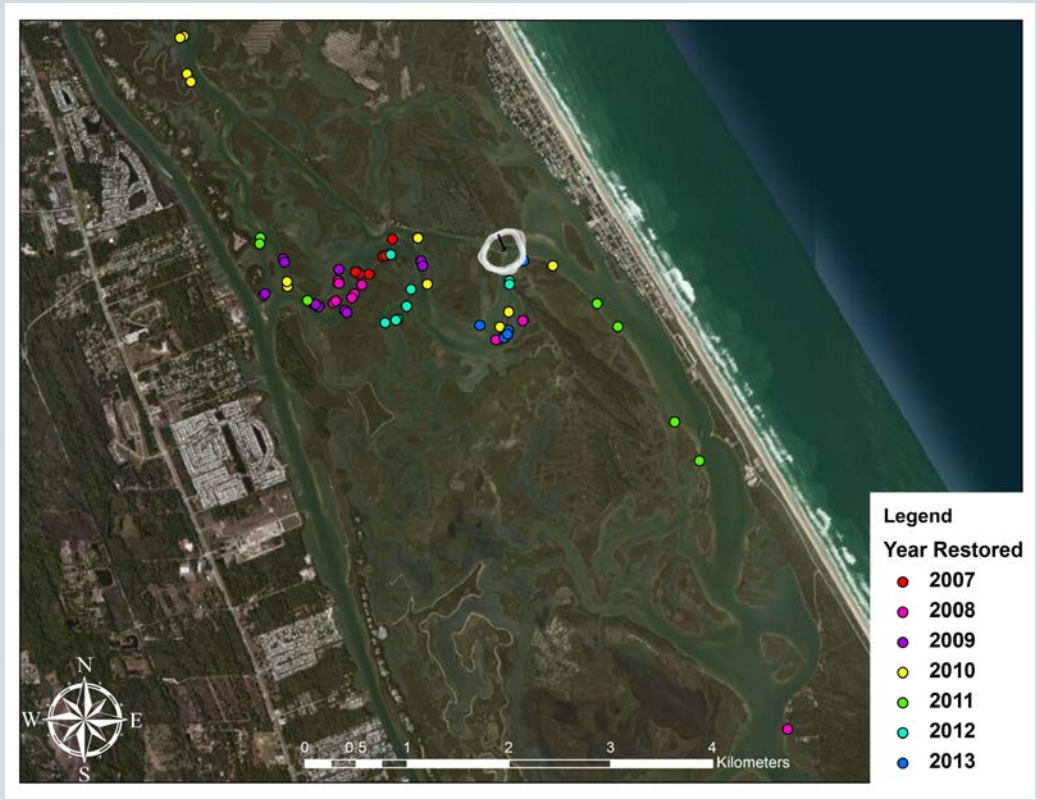
Goals and Objectives

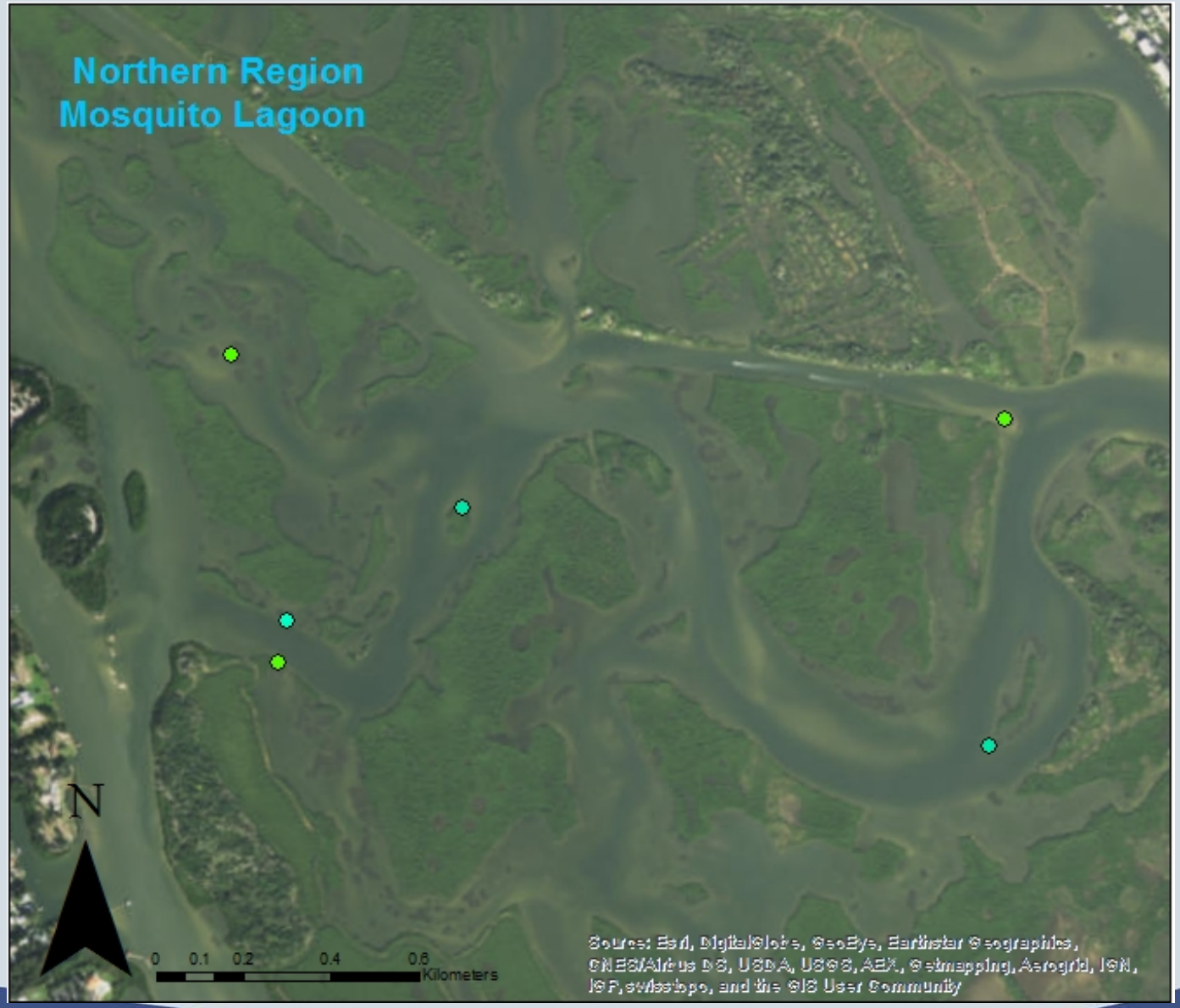
- Conduct the first lagoon-wide oyster (organismal) health survey
- Compare natural and restored reefs over latitude (three regions)
- Compare natural and restored reefs over seasons

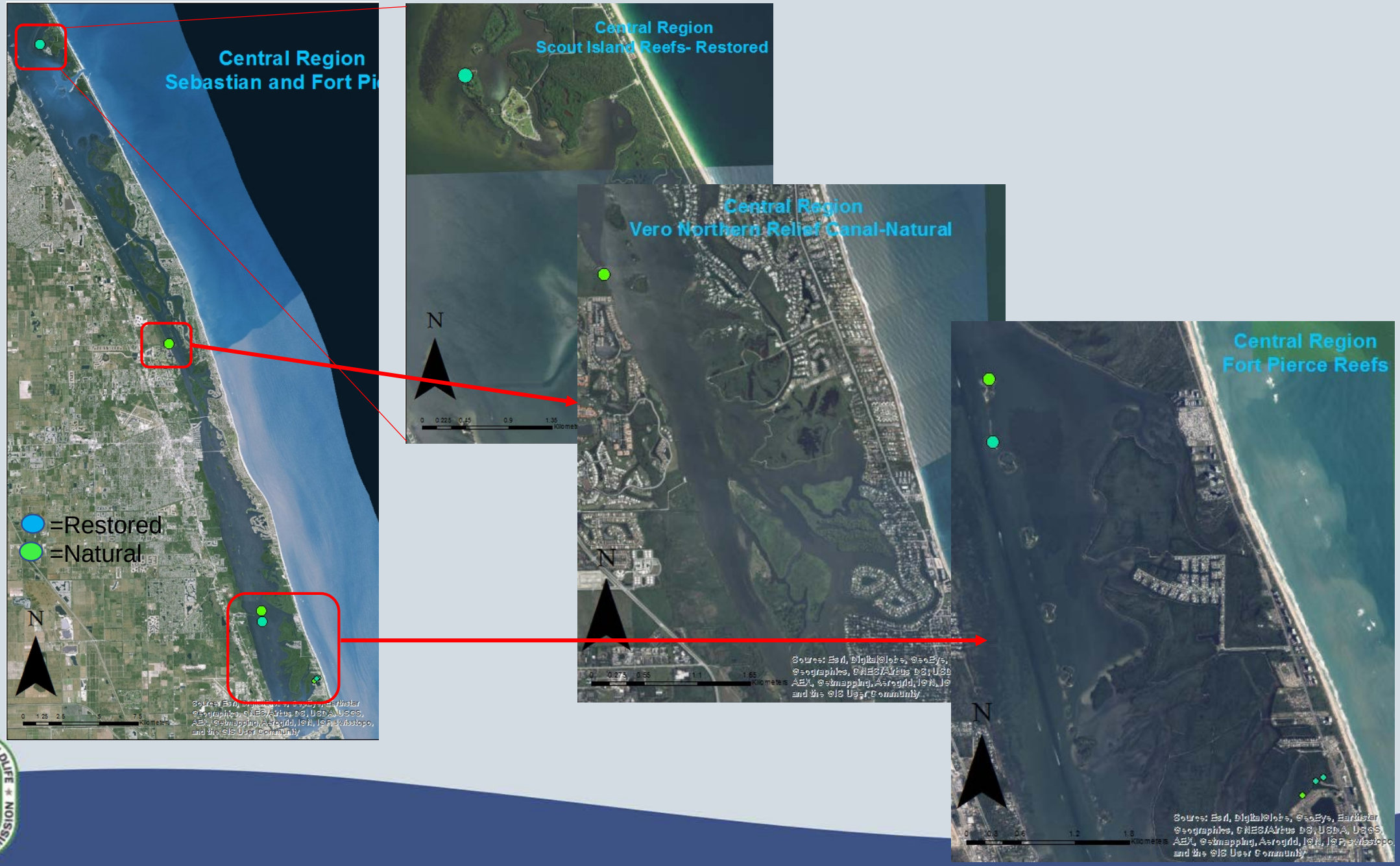
  Summer; Fall; Winter/Spring

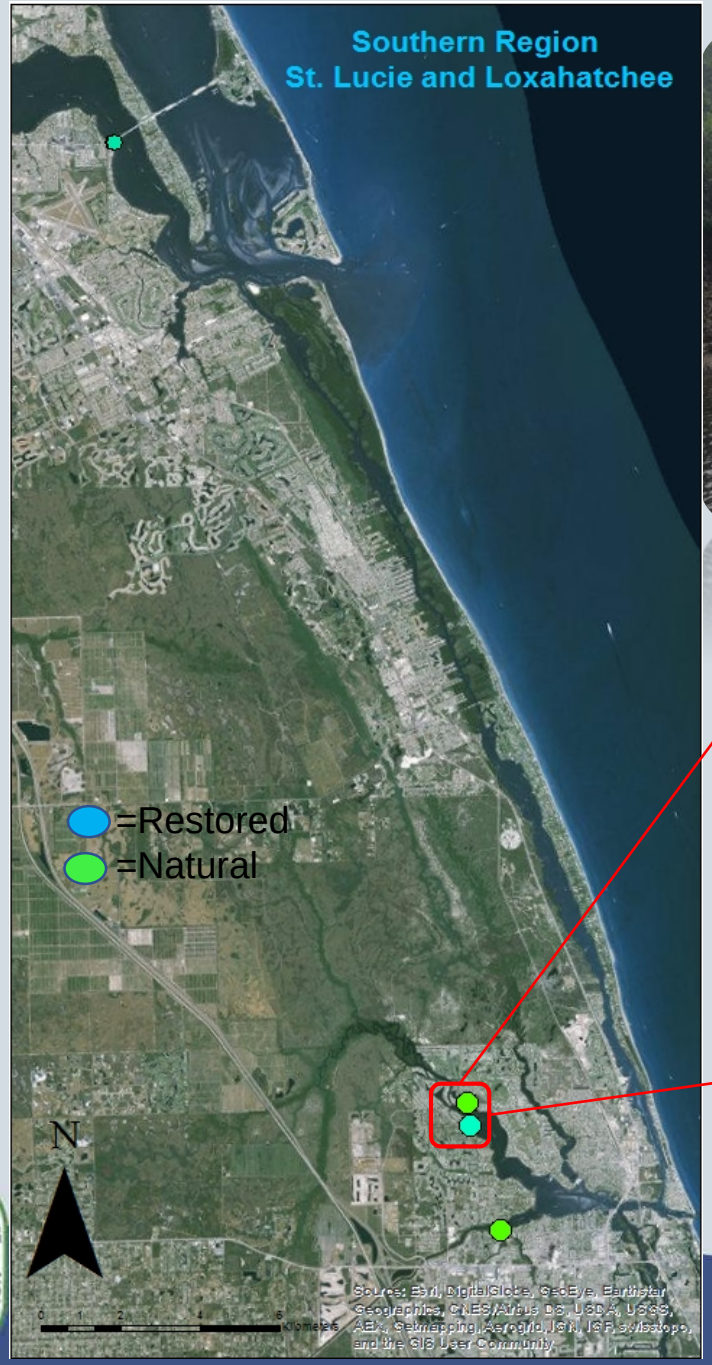
- Intertidal reefs only
- Collected 30 adult (>2in) oysters

Structural data


Legend
Year Restored
2007
2008
2009
2010
2011
2012
2013
N
W
E
S
0 0.5 1 2 3 4
Kilometers


Northern Region
Mosquito Lagoon
N
0 0.1 0.2 0.4 0.6
Kilometers
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Central Region
Sebastian and Fort Pi
=Restored
=Natural
N
Central Region
Scout Island Reefs- Restored
N
Central Region
Vero Northern Relief Canal-Natural
N
Central Region
Fort Pierce Reefs
N



FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

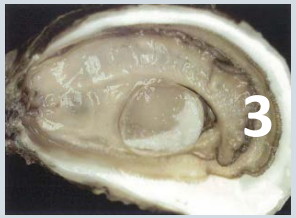
Methods

- Size measurements (length, height, width, shell weight, meat weight)
- Physiological condition (Howard et al. 2004)
- Health of digestive system
- Sex determination
- Presence of abnormalities, predators, pests/parasites

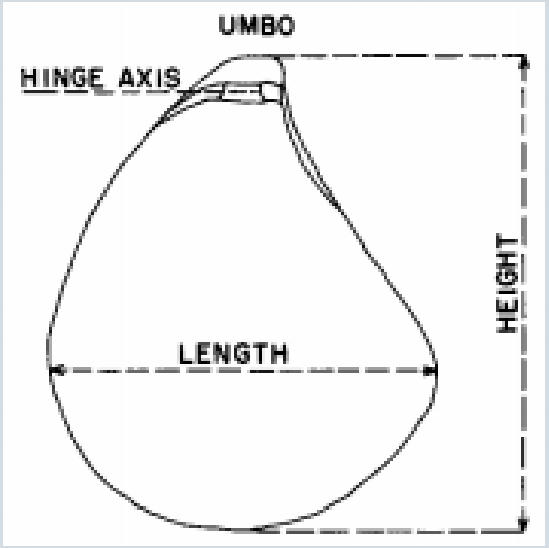
(mud blisters, pea crabs, boring sponge, *Nematopsis spp*., *Tylocephalum spp*., *Bucephalus spp*., trematodes)

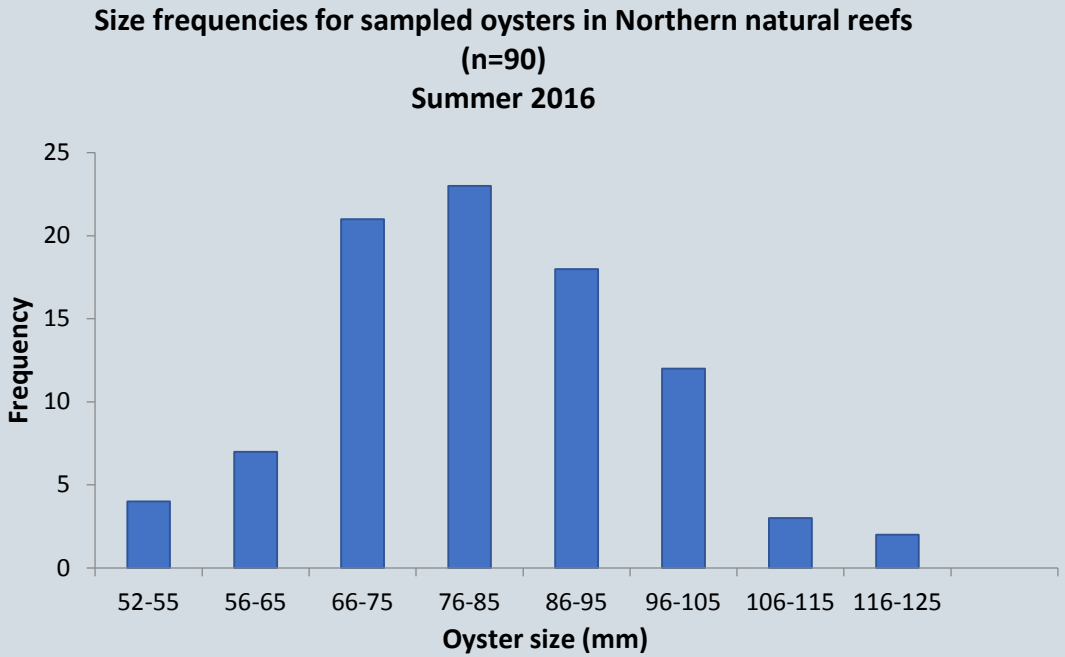
- Prevalence and intensity of *Perkinsus marinus* (Dermo)
- Presence of *Bonamia* sp.

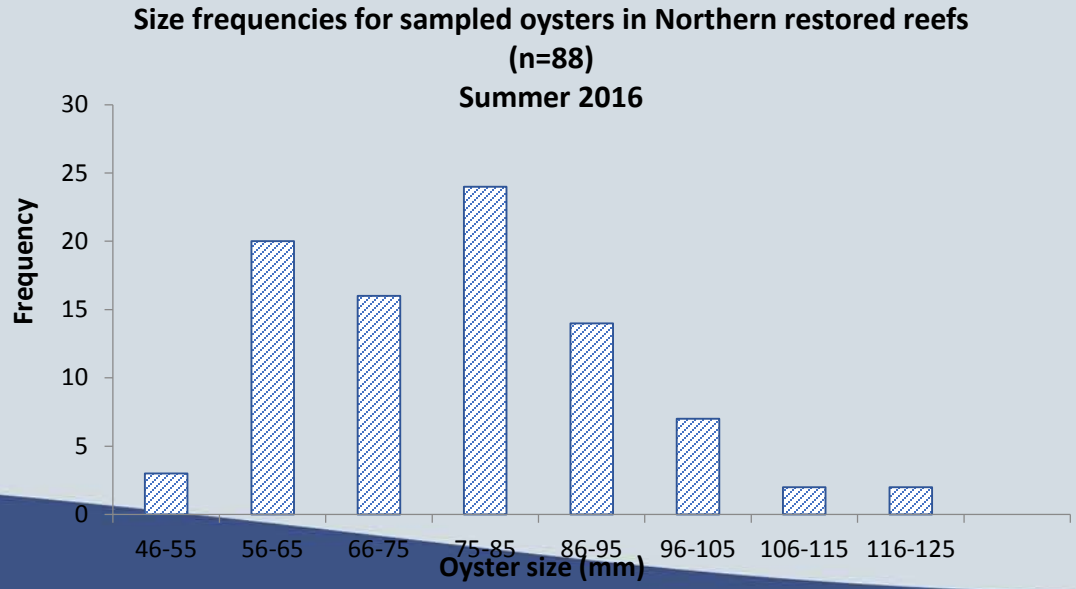
(Howard et al. 2004)



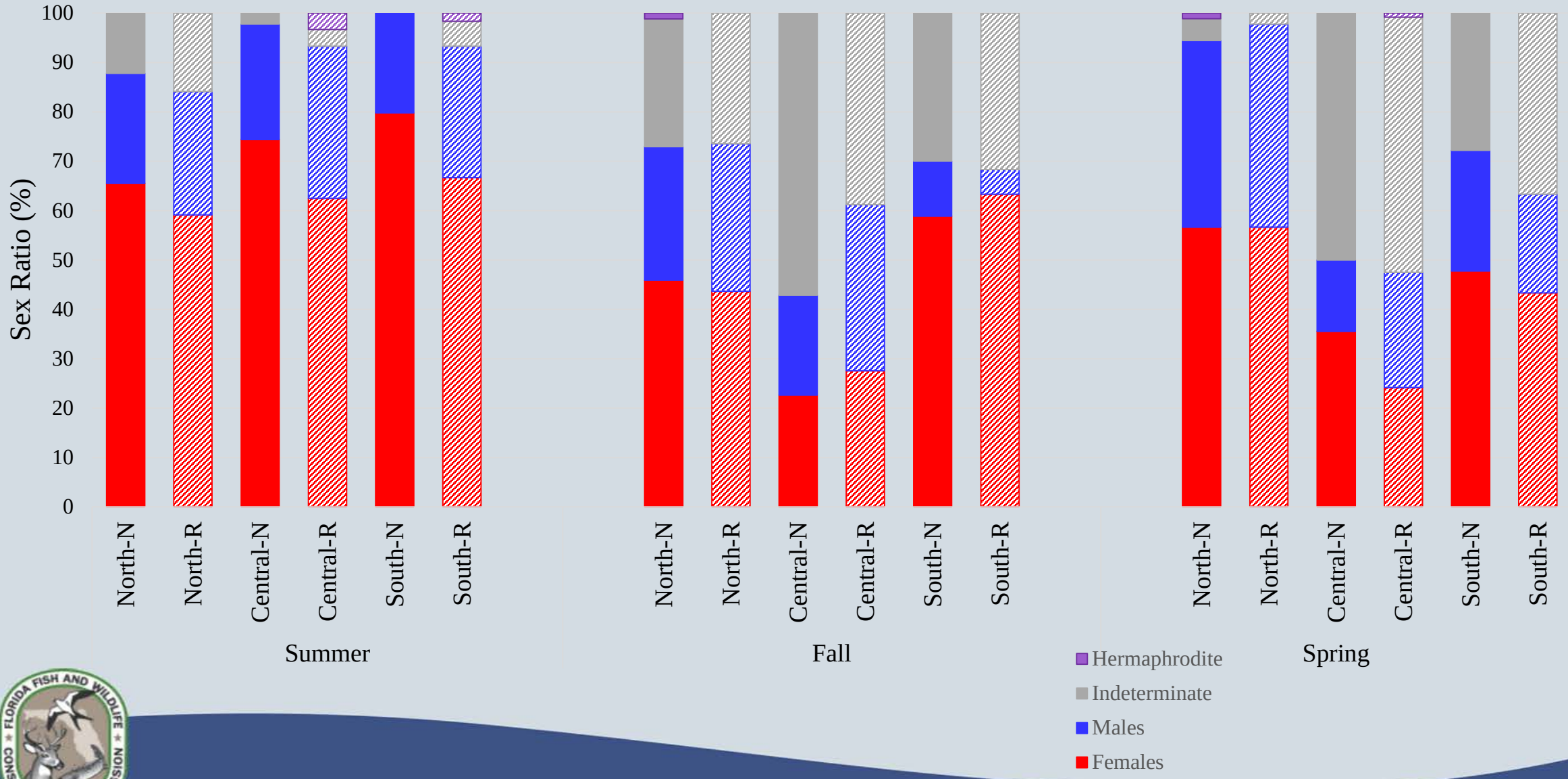
North:
Size Frequency





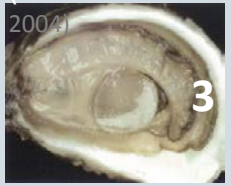


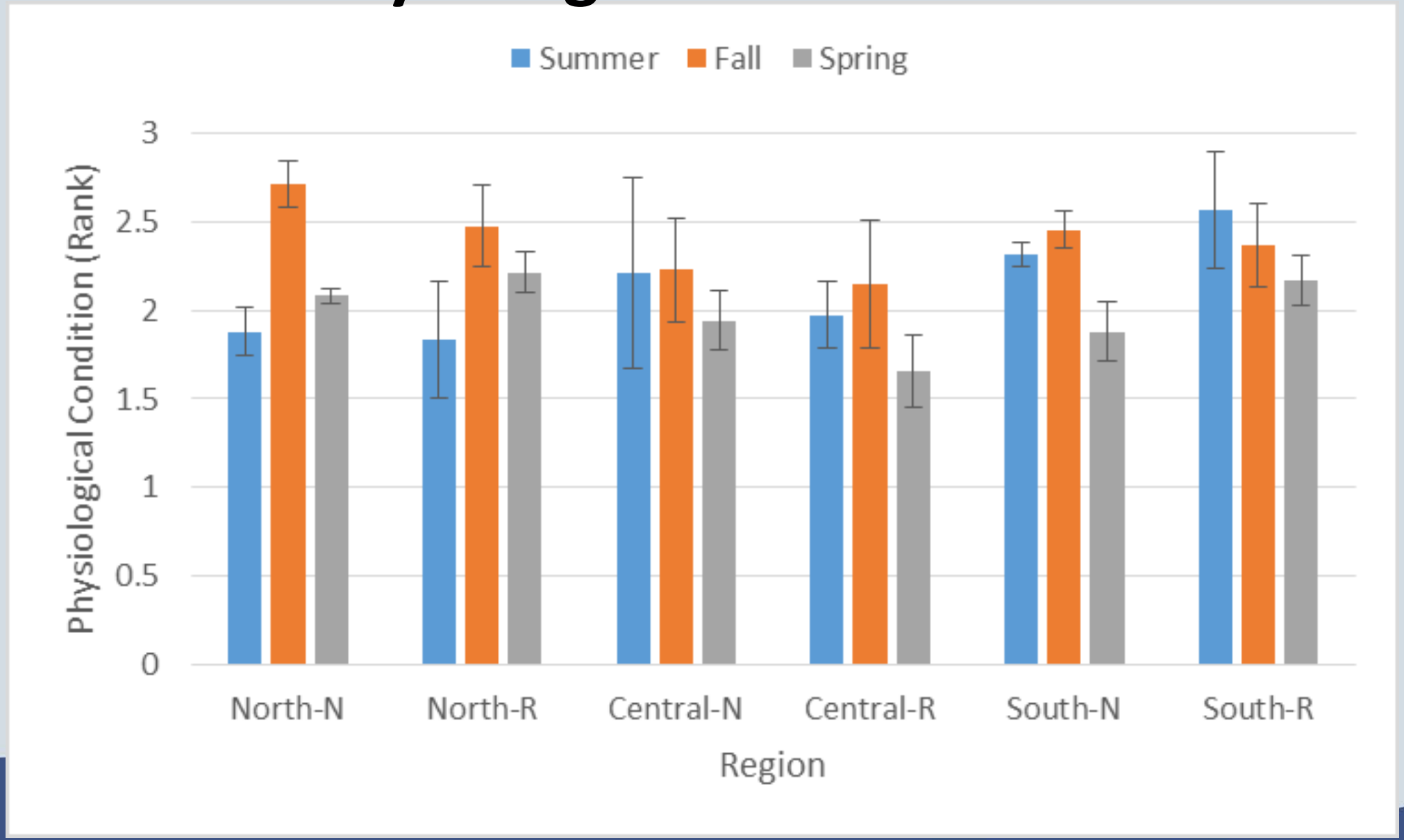
Seasonal Sex Ratios in C. virginica in the IRL



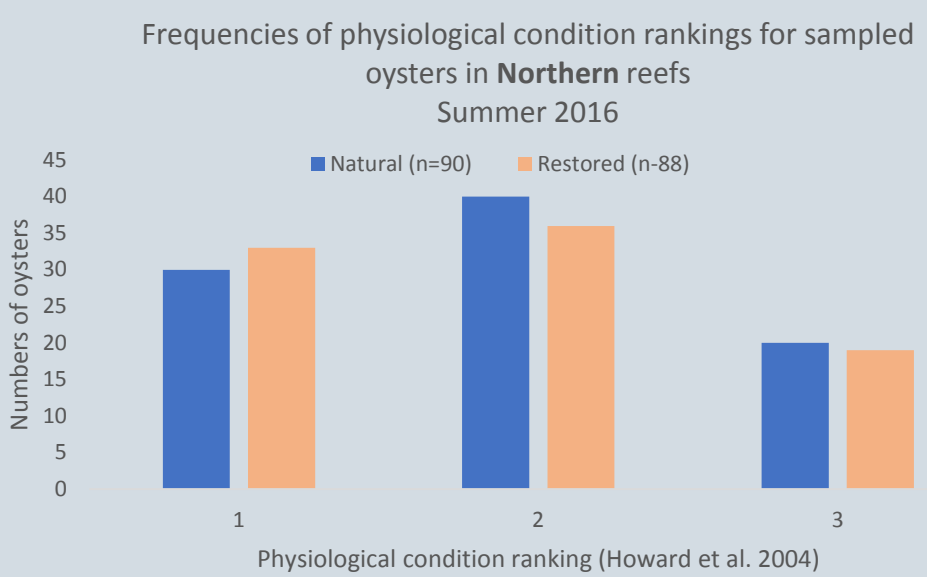
Physiological Condition

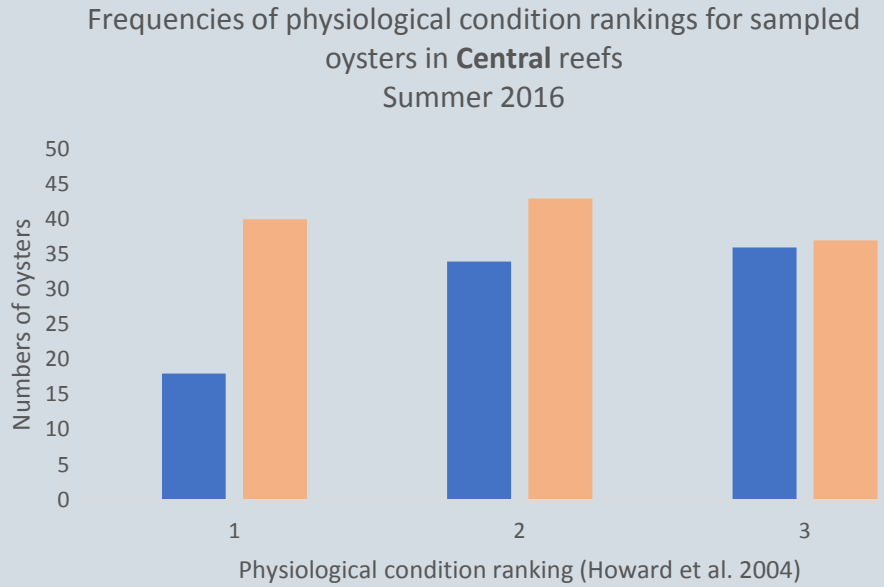
(Howard et al. 2004)

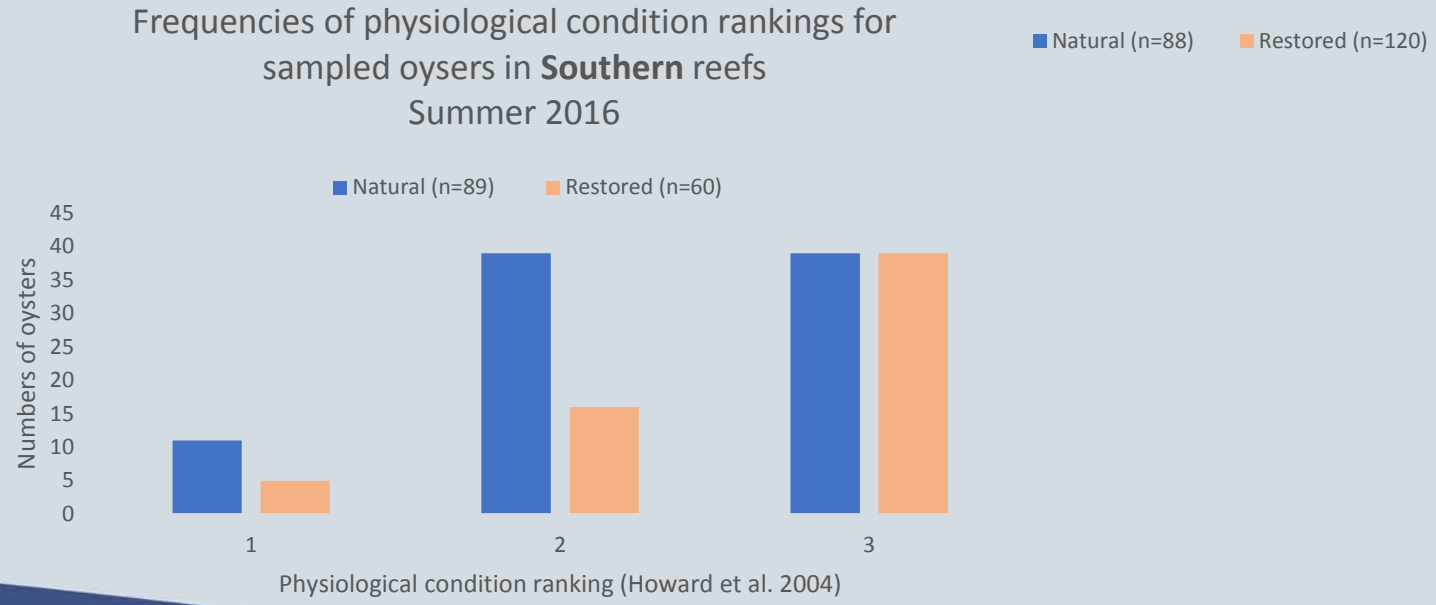




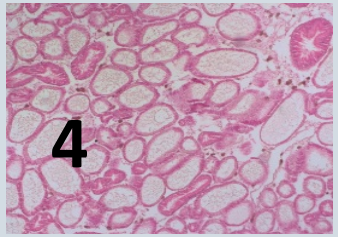
Physiological Condition: Summer

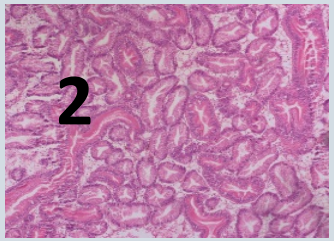


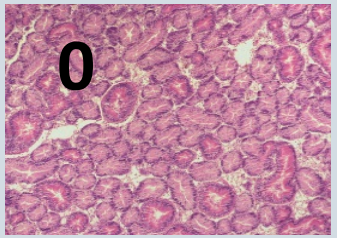


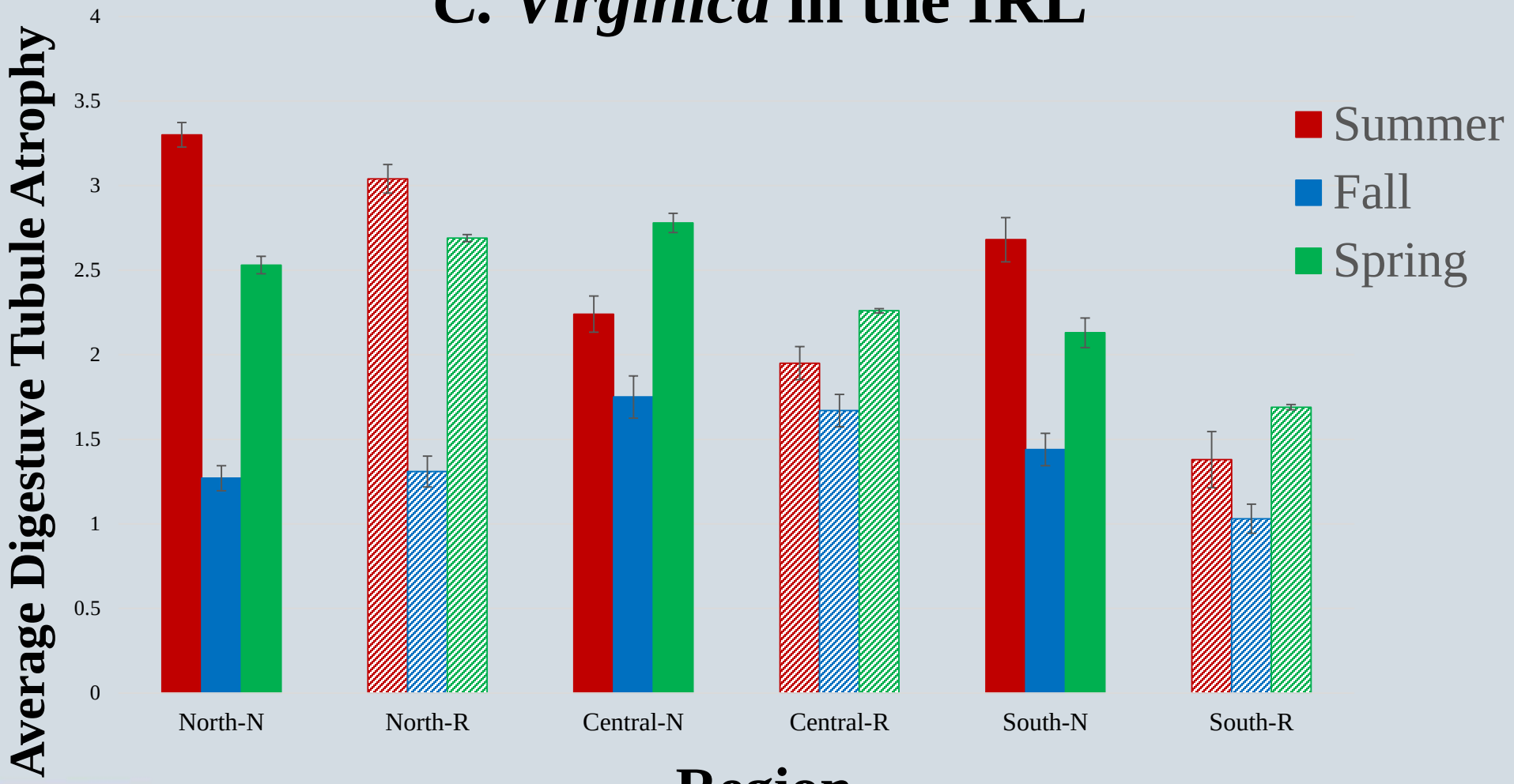


Seasonal Digestive Tubule Atrophy in *C. Virginica* in the IRL

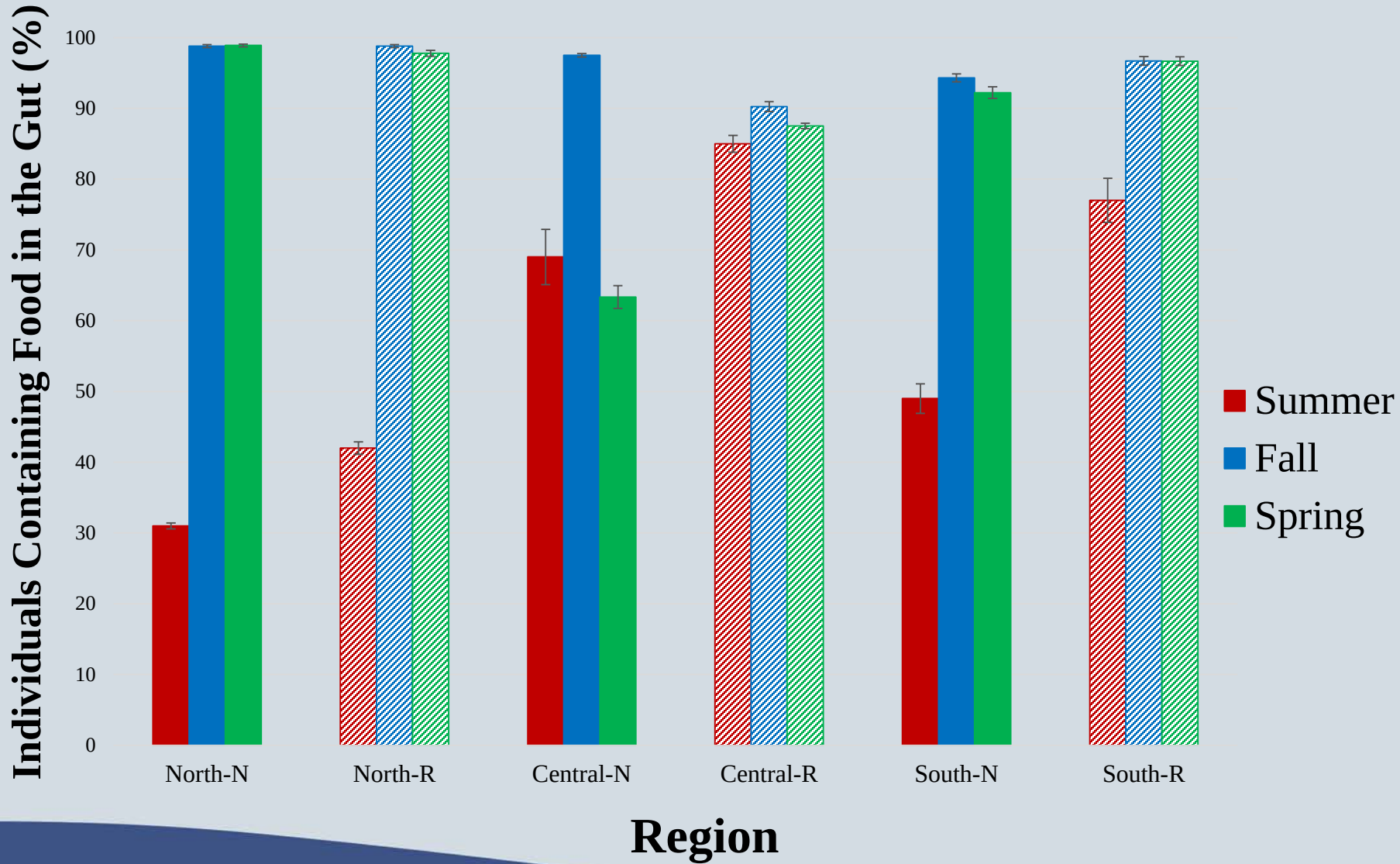




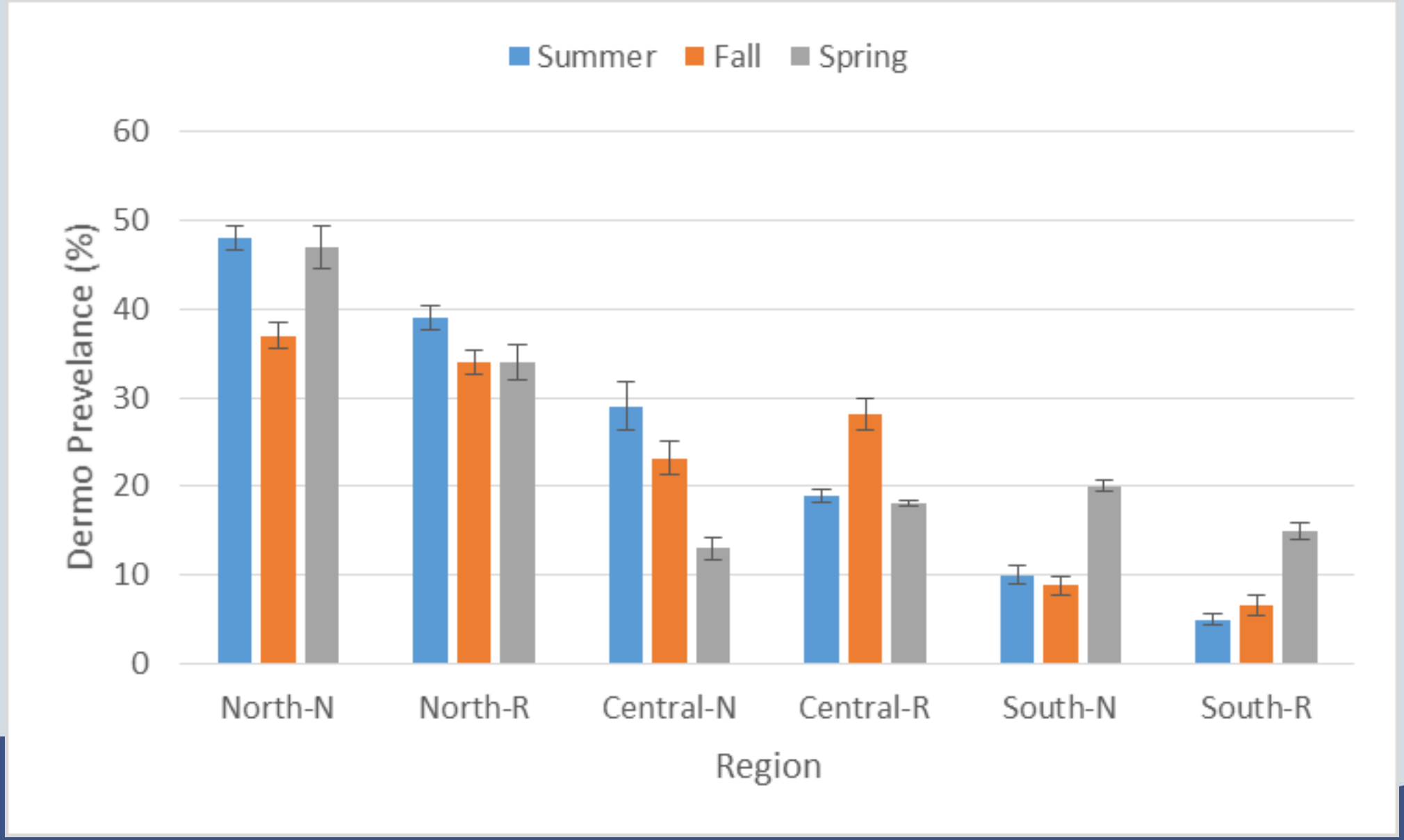




Seasonal Gut Contents of *C. virginica* in the IRL



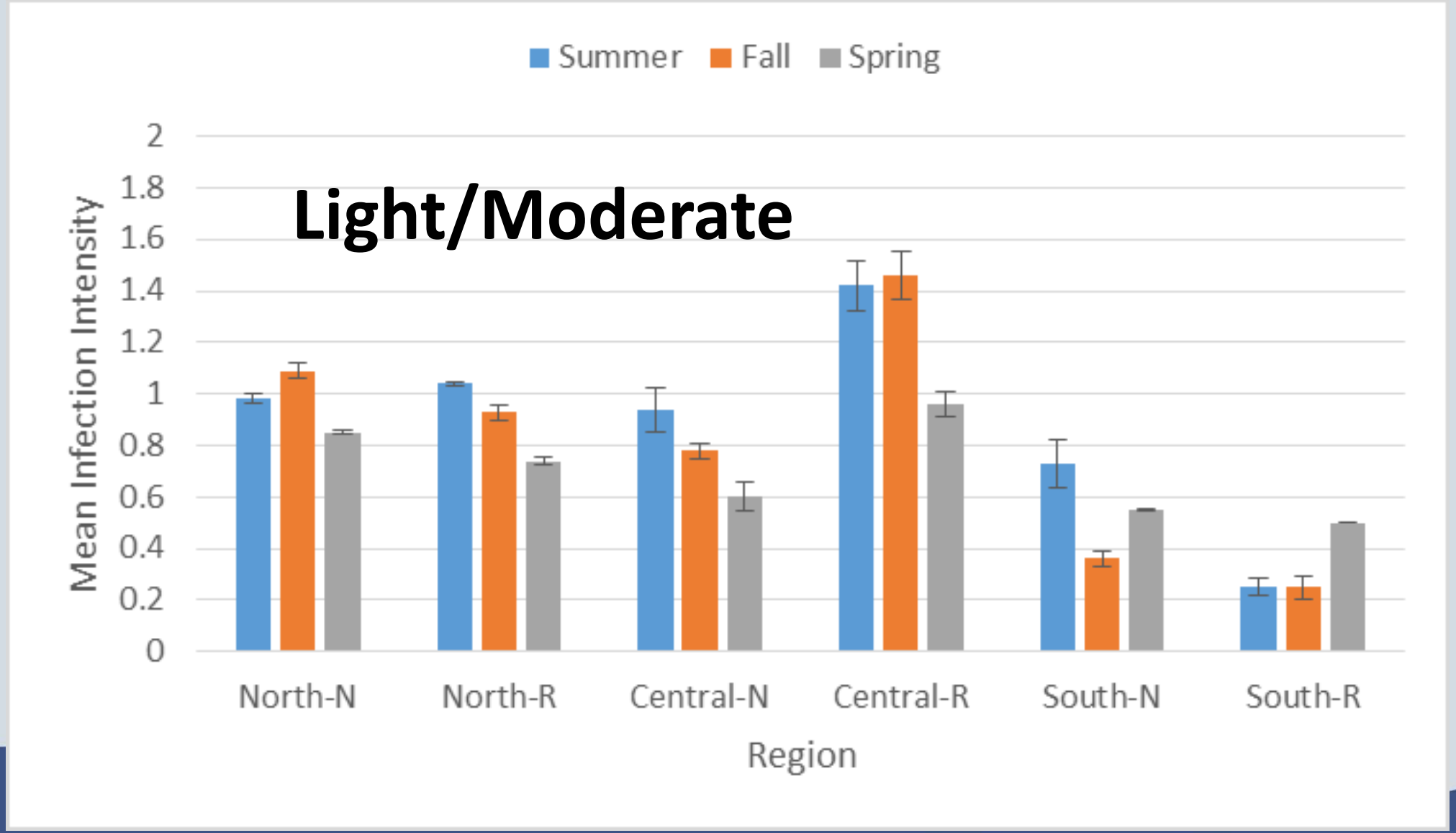
Dermo (*Perkinsus* sp.) Prevalence



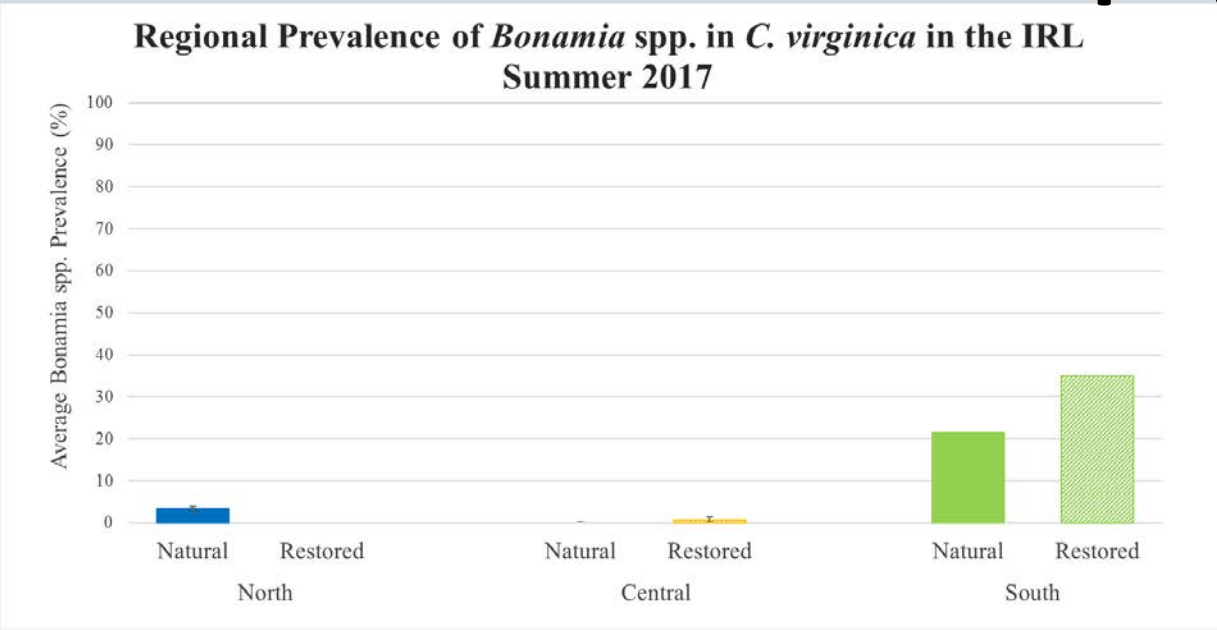
Dermo (*Perkinsus* sp.) Intensity

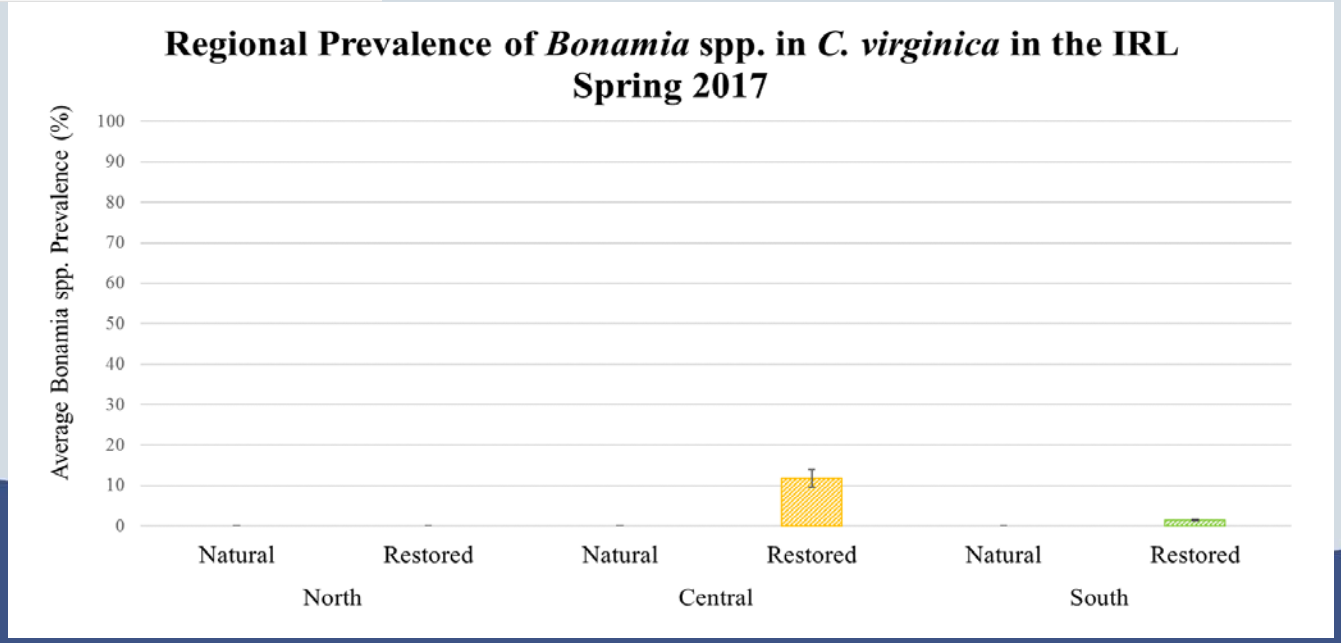
5

0

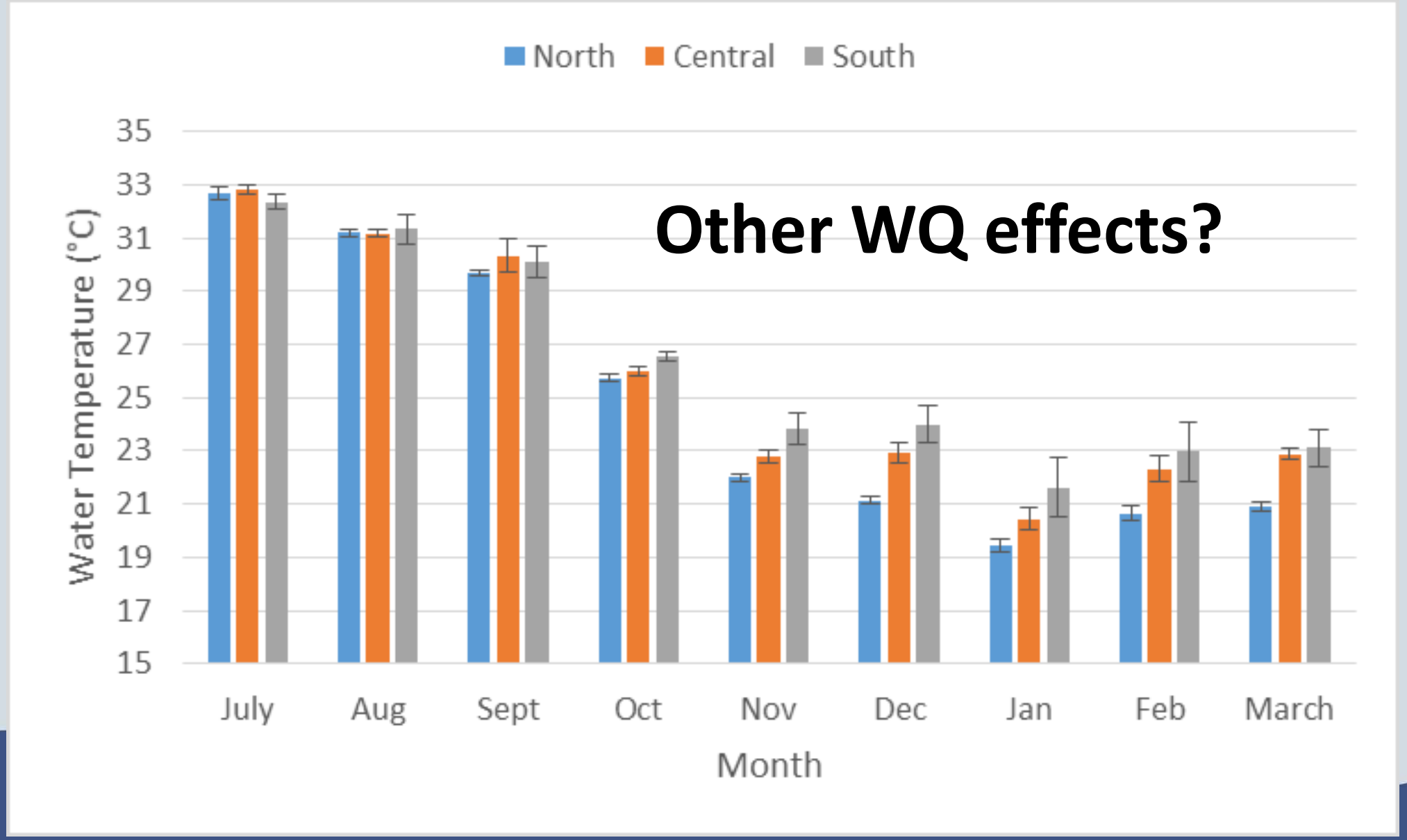


Bonamia sp. (Haplosporiid)



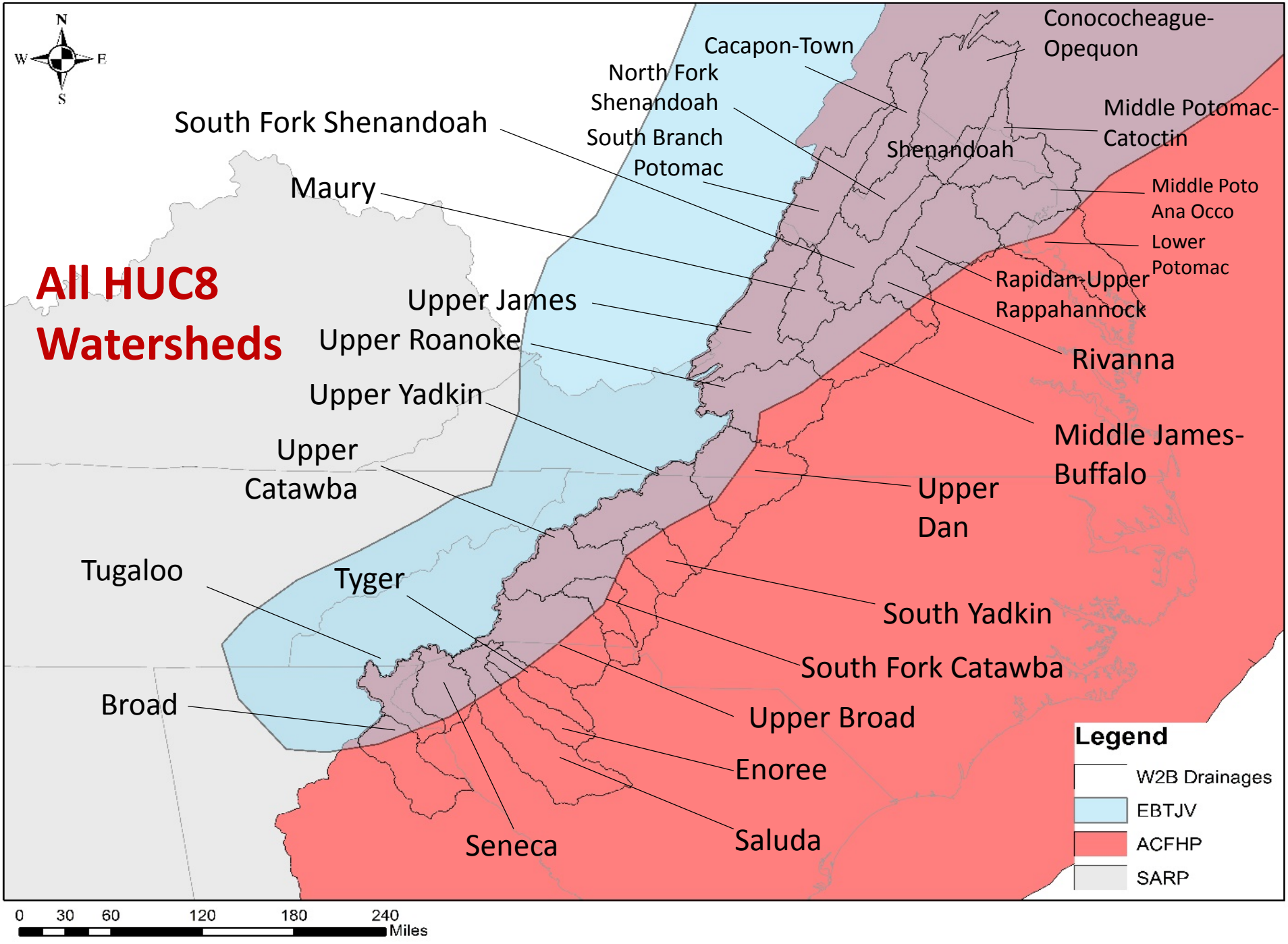


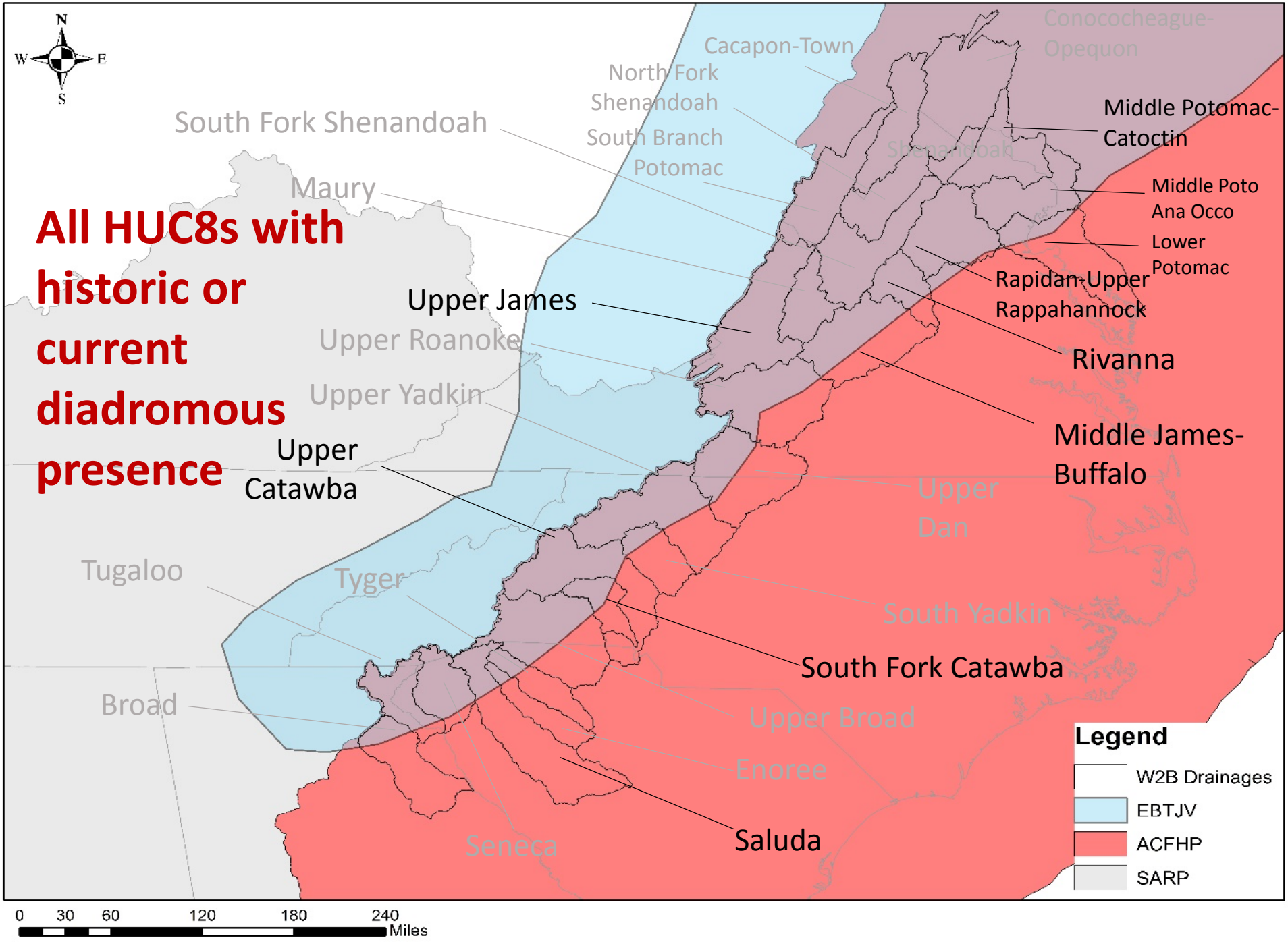
Reef Temperature

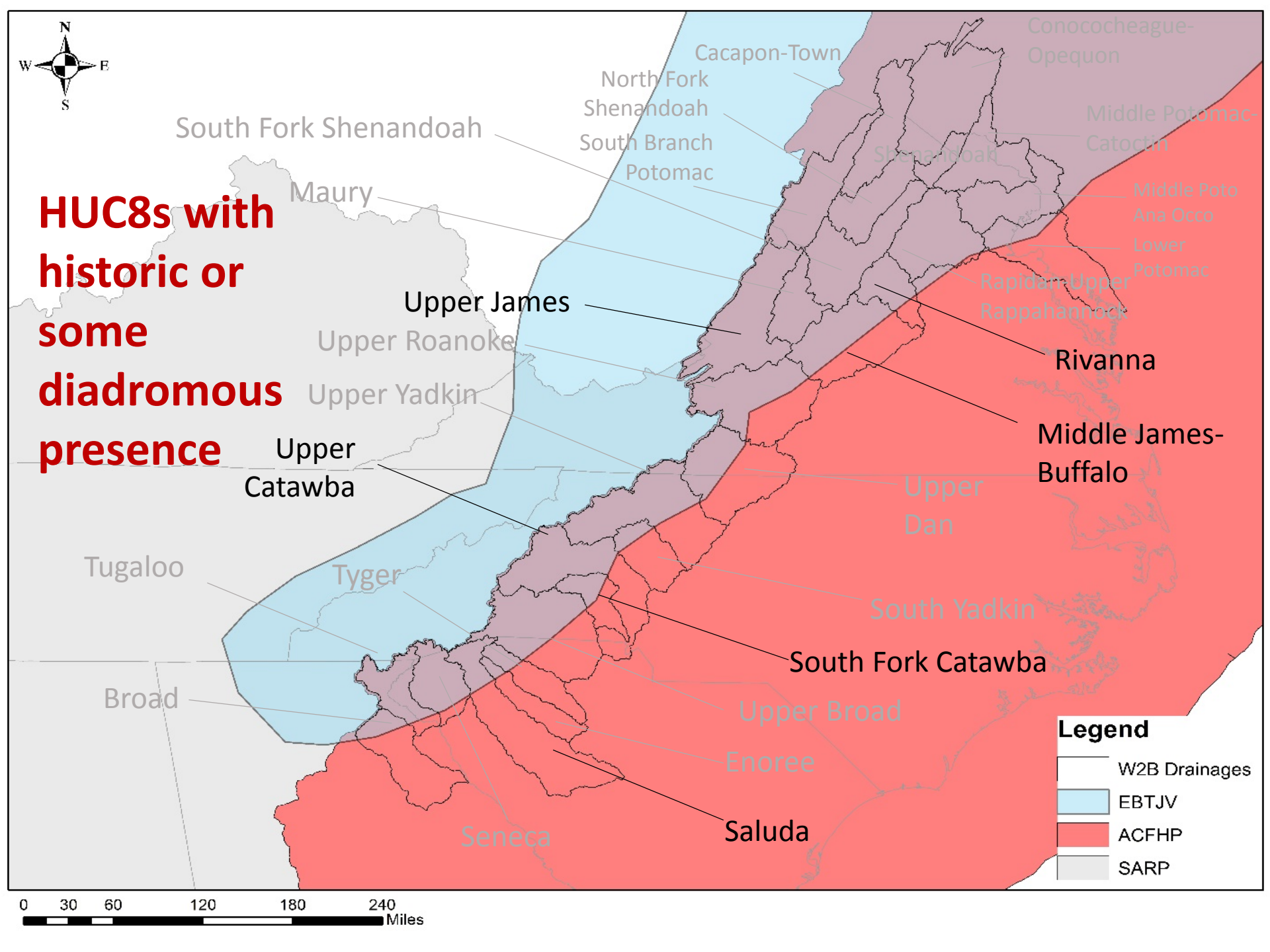


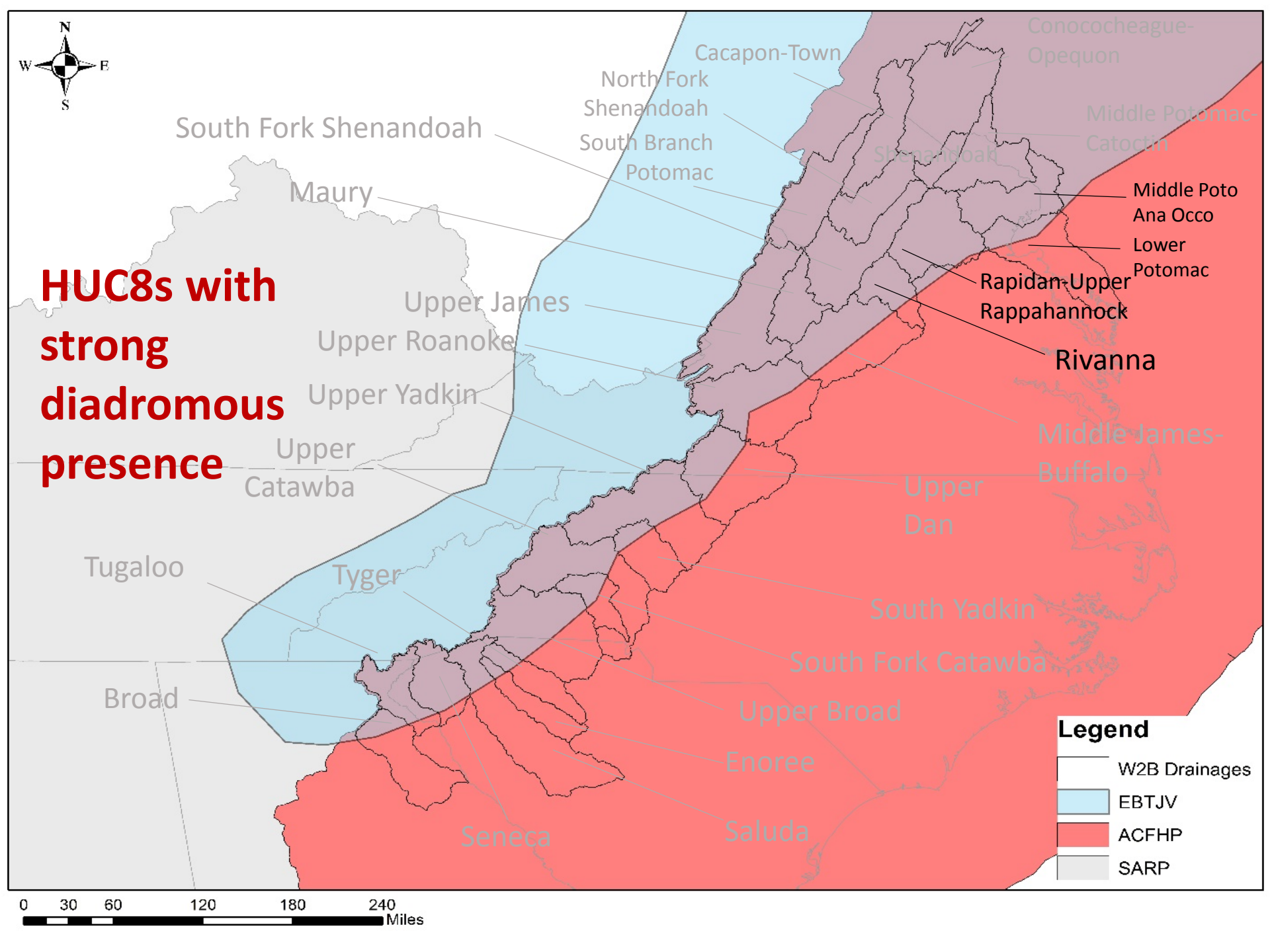
Preliminary Conclusions

- Seasonal and regional trends
- Positive signs regarding organismal health (gut, meat weight)
- Restored reefs generally similar to natural ones
- Low abundance of adults on restored reefs (reef age)
- Pest/parasite/disease moderate to high: N/S trend
- Baseline for lagoon oyster health


N
W
E
S
All HUC8 Watersheds
Conococheague-Opequon
Cacapon-Town
North Fork Shenandoah
South Branch Potomac
South Fork Shenandoah
Middle Potomac-Catoctin
Shenandoah
Maury
Middle Poto Ana Occo
Lower Potomac
Rapidan-Upper Rappahannock
Upper James
Upper Roanoke
Rivanna
Upper Yadkin
Middle James-Buffalo
Upper Catawba
Upper Dan
Tugaloo
Tyger
South Yadkin
South Fork Catawba
Broad
Upper Broad
Enoree
Saluda
Seneca
Legend
W2B Drainages
EBTJV
ACFHP
SARP
0 30 60 120 180 240
Miles


N
W
E
S
All HUC8s with historic or current diadromous presence
Cacapon-Town
North Fork Shenandoah
South Branch Potomac
Conococheague-Opequon
South Fork Shenandoah
Middle Potomac-Catoctin
Shenandoah
Maury
Middle Poto Ana Occo
Lower Potomac
Upper James
Rapidan-Upper Rappahannock
Upper Roanoke
Rivanna
Upper Yadkin
Middle James-Buffalo
Upper Catawba
Upper Dan
Tugaloo
Tyger
South Yadkin
South Fork Catawba
Broad
Upper Broad
Enoree
Saluda
Seneca
Legend
W2B Drainages
EBTJV
ACFHP
SARP
0 30 60 120 180 240
Miles


HUC8s with historic or some diadromous presence
N
W
E
S
Cacapon-Town
North Fork Shenandoah
South Branch Potomac
South Fork Shenandoah
Maury
Upper James
Upper Roanoke
Upper Yadkin
Upper Catawba
Tugaloo
Tyger
Broad
Saluda
Conococheague-Opequon
Middle Potomac-Catoctin
Middle Poto Ana Occo
Lower Potomac
Rapidan-Upper Rappahannock
Rivanna
Middle James-Buffalo
Upper Dan
South Yadkin
South Fork Catawba
Upper Broad
Enoree
Seneca
Legend
W2B Drainages
EBTJV
ACFHP
SARP
0 30 60 120 180 240
Miles


HUC8s with strong diadromous presence
Cacapon-Town
North Fork Shenandoah
South Branch Potomac
South Fork Shenandoah
Maury
Upper James
Upper Roanoke
Upper Yadkin
Upper Catawba
Tugaloo
Tyger
Broad
Conococheague-Opequon
Middle Potomac-Catoctin
Middle Poto Ana Occo
Lower Potomac
Rapidan-Upper Rappahannock
Rivanna
Middle James-Buffalo
Upper Dan
South Yadkin
South Fork Catawba
Upper Broad
Enoree
Saluda
Seneca
Legend
W2B Drainages
EBTJV
ACFHP
SARP
0 30 60 120 180 240
Miles

A	B	C	D	E	F	G
HUC 8 Name	State(s)	blueback	alewife	American shad	Atlantic sturgeon	American eel
Upper Yadkin	VA/NC	no	no	no	no	N/A
South Yadkin	NC	no	no	no	no	N/A
Upper Catawba	SC/NC	no	yes	no	no	N/A
South Fork Catawba	NC	no	yes	no	no	N/A
Upper Broad	SC/NC	no	no	no	no	N/A
Tyger	SC	no	no	no	no	N/A
Enoree	SC	no	no	no	no	N/A
Saluda	SC	no	no	no	no	yes a few
Seneca	SC/NC	no	no	no	no	N/A
Tugaloo	GA/SC	no	no	no	no	N/A
Broad	GA	no	no	no	no	N/A
South Branch Potomac	VA/WV	no	no	no	no	N/A
Cacapon-Town	VA/MD/PA	no	no	no	no	N/A
Conococheague-Opequon	VA/MD/PA	no	no	no	no	N/A
North Fork Shenandoah	VA/WV	no	no	no	no	N/A
South Fork Shenandoah	VA	no	no	no	no	N/A
Shenandoah	VA	no	no	no	no	N/A
Middle Potomac-Catoctin	VA/MD	no	no	no	yes	N/A
Middle Potomac-Anacostia-Occoquan	VA/MD/DC	yes	yes	yes	yes	N/A
Lower Potomac	VA/MD	yes	yes	yes	yes	N/A
Rapidan-Upper Rappahannock	VA	yes	yes	yes	no	N/A
Upper James	VA/WV	historic questionable	historic questionable	historical	no	N/A
Maury	VA	no	no	no	no	N/A
Middle James-Buffalo	VA	historic questionable	historic questionable	yes - potential	no	N/A
Rivanna	VA	yes	yes	yes - potential	no	N/A
Upper Roanoke	VA	no	no	no	no	N/A
Upper Dan	VA/NC	no	no	no	no	N/A
No brook trout (EBTJV)						
some priority ACFHP species						
many priority ACFHP species						