SOUTH FLORIDA WATER MANAGEMENT DISTRICT

WELCOME

Caloosahatchee River and Estuary Science Symposium

September 14-15, 2016

Introduction and Objectives

Caloosahatchee River and Estuary Science Symposium - Day 1
September 14, 2016

Don Medellin, Principal Scientist
Coastal Ecosystems Section
South Florida Water Management District

What is a Minimum Flow and Level (MFL) Waterbody?

- **MFLs are statutorily mandated pursuant to Chapter 373.042 and 373.0421, Florida Statutes**
- **MFLs are identified on a Priority List and Schedule and approved annually by the Governing Board and FDEP**
- **Water resource management tool to protect water resources from significant harm from withdrawals**
- **MFLs are integrated into other regulatory programs**
  - **Consumptive Use Permitting**
  - **Water Supply Planning**
  - **Water Shortage**

Caloosahatchee River Estuary

Conceptual Relationship among Harm, Significant Harm and Serious Harm

Water Levels/Flow Decreasing

Drought Severity Increasing

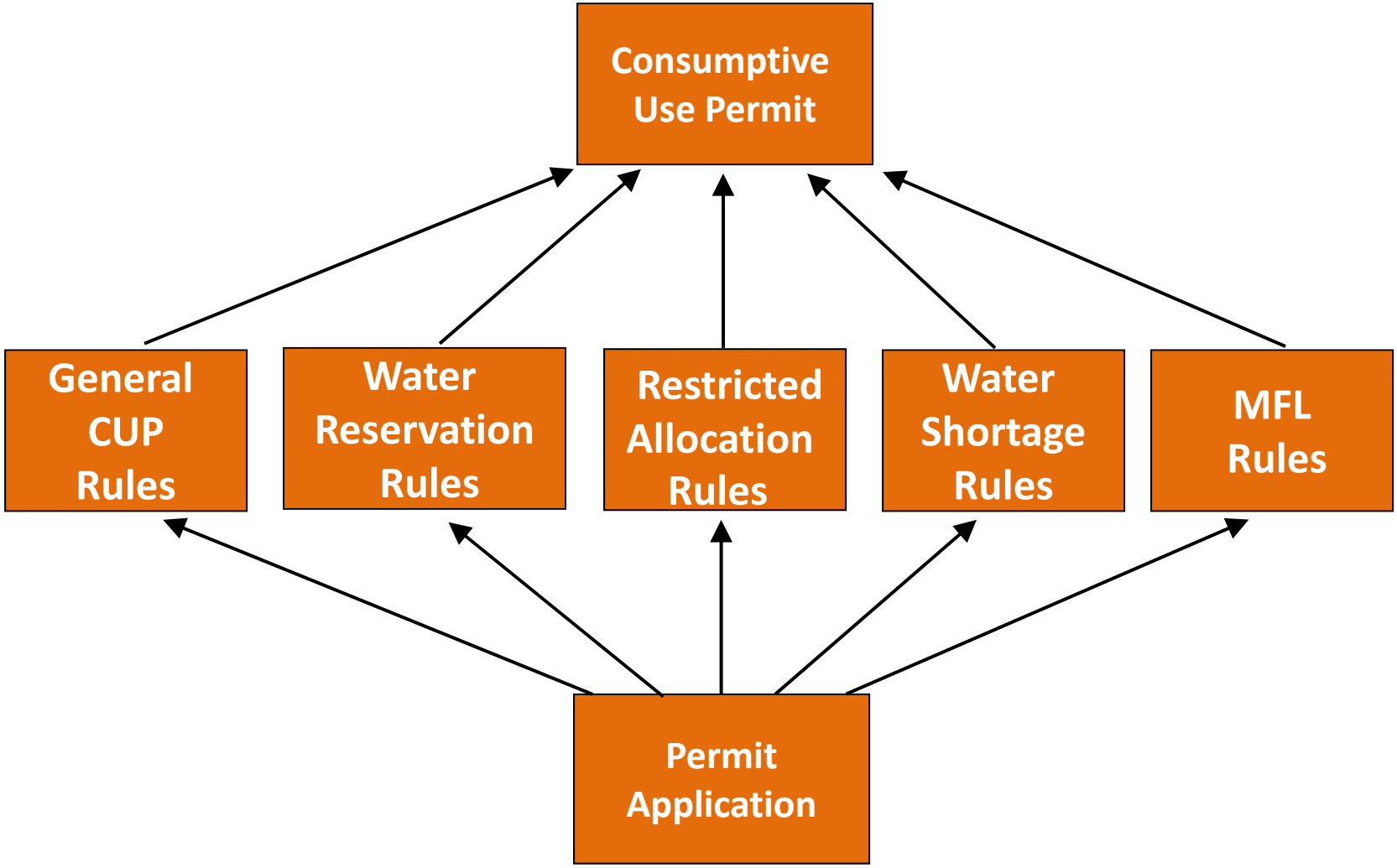
Water Resource Protection Tools	Water Resource Protection Standards	Observed Impacts
Permittable Water Reservation of Water	NO HARM (1-in-10 Level of Certainty*)	Normal Permitted Operations Environmental Restoration
Phase I Water Shortage Phase II Water Shortage	HARM	Temporary loss of water resource functions taking 1 to 2 years to recover
MINIMUM FLOWS & LEVELS		
Phase III Water Shortage	SIGNIFICANT HARM	Water resource functions require multiple years to recover (> 2 years)
Phase IV Water Shortage	SERIOUS HARM	Permanent or irreversible loss of water resource functions

** 1-in-10 Level of Certainty – Reasonable assurance that the proposed use will not harm water resources or ELUs up to a 1 in 10 year drought condition.*

What a MFL Does:

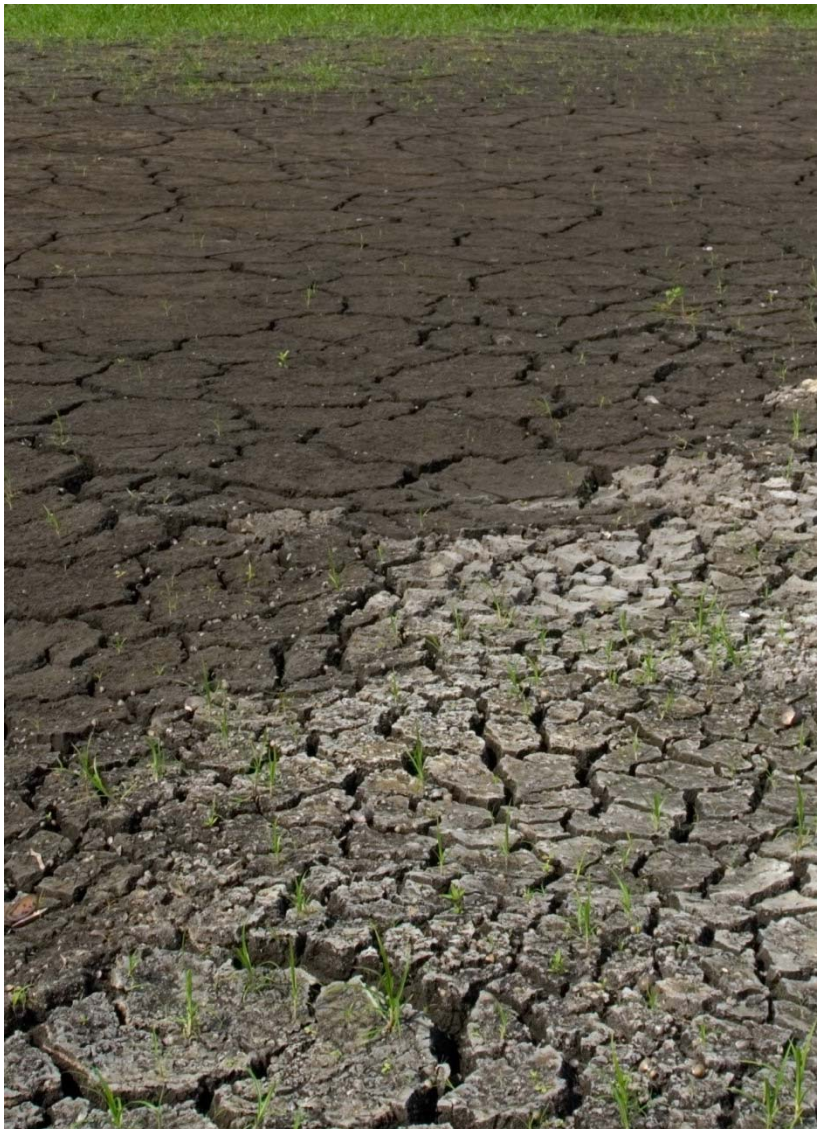
- **Protect water resources functions from further withdrawals that cause significant harm**
- **Links research and monitoring efforts to ensure that proposed MFL criteria are scientifically sound**
- **Based on technical documents using the "best available data"**
- **Include Recovery Plans or Prevention strategies that are adopted simultaneously with MFL rule**
- **Reevaluated periodically and revised as needed as hydrologic conditions change**

Water Resource Protection Tools are an Integral Part of Consumptive Use Permits

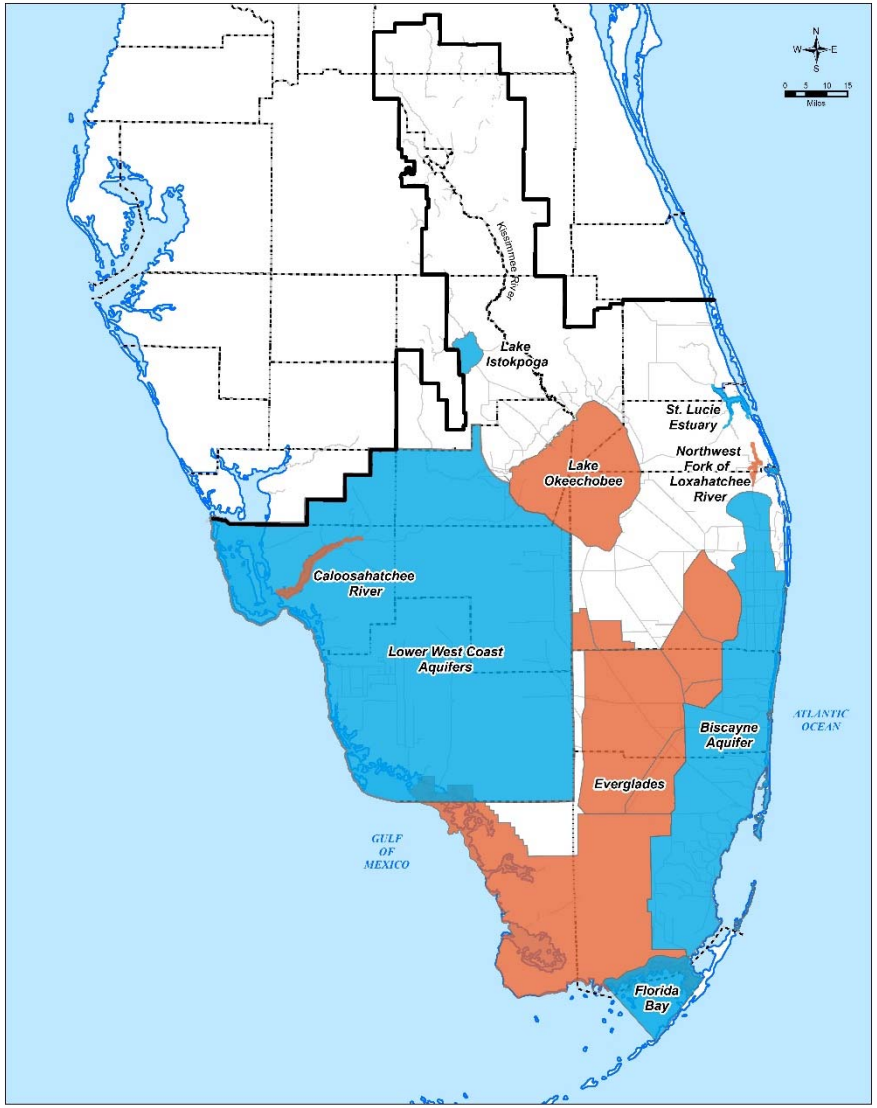


What a MFL Does Not Do:

- **Does not establish restoration criteria**
- **Does not drought proof the natural system**
- **Does not create additional or new water**
- **Does not prevent additional withdrawals if consistent with recovery or prevention plan**
- **Does not establish an operating regime by rule**



Existing MFL Water Bodies



MFL Prevention Waterbodies

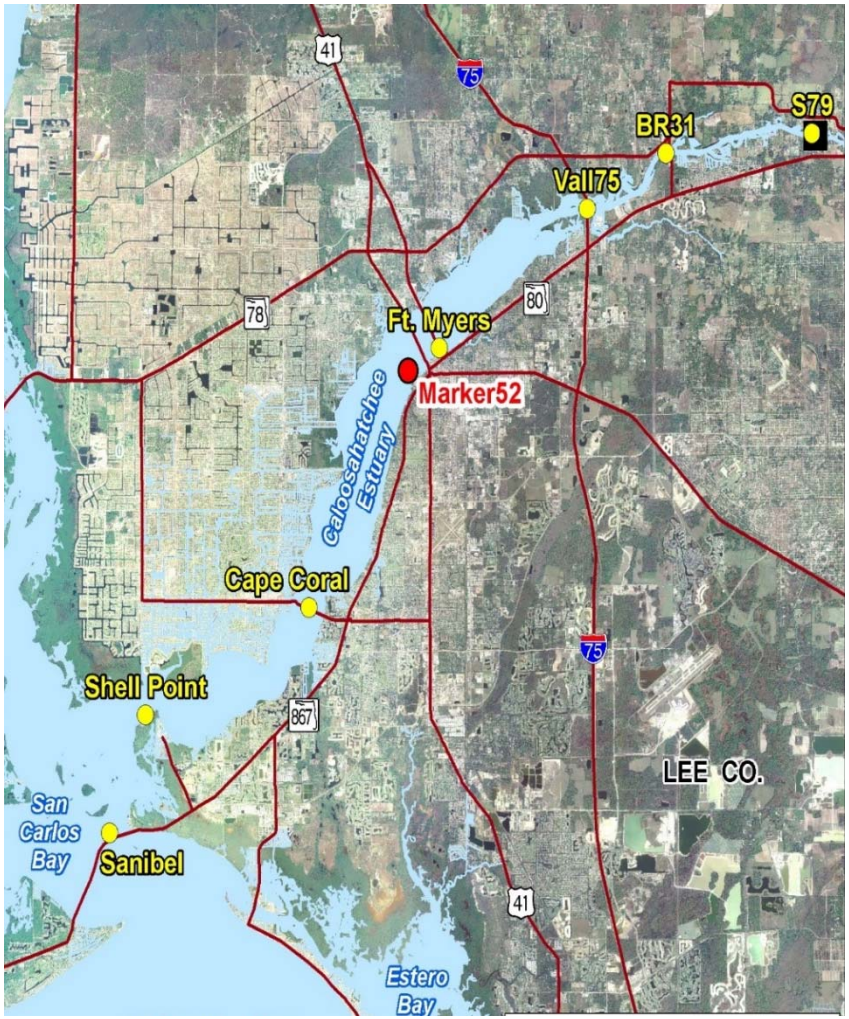
- Biscayne aquifer
- Lower West Coast aquifers
- St Lucie Estuary
- Lake Istokpoga
- Florida Bay

MFL Recovery Waterbodies

- Lake Okeechobee
- Everglades (5 MFL's)
- Caloosahatchee River
- Northwest Fork of Loxahatchee River

Caloosahatchee River MFL Background

- **Caloosahatchee River MFL was initially adopted in 2001**
  - **Recovery Strategy was adopted simultaneously**
- **Existing MFL criteria based on salinity tolerance of a single species**
  - **Vallisneria (Tape Grass)**
- **MFL Re-evaluated in 2003**
  - **No changes in criteria or recovery strategy**
- **Governing Board directed staff to implement MFL studies in 2010**
- **MFL is currently being reevaluated**



Existing Caloosahatchee MFL Criteria

A minimum mean monthly flow of 300 CFS is necessary to maintain sufficient salinities at S-79 in order to prevent a MFL exceedance.

A MFL exceedance occurs during a 365 day period, when:

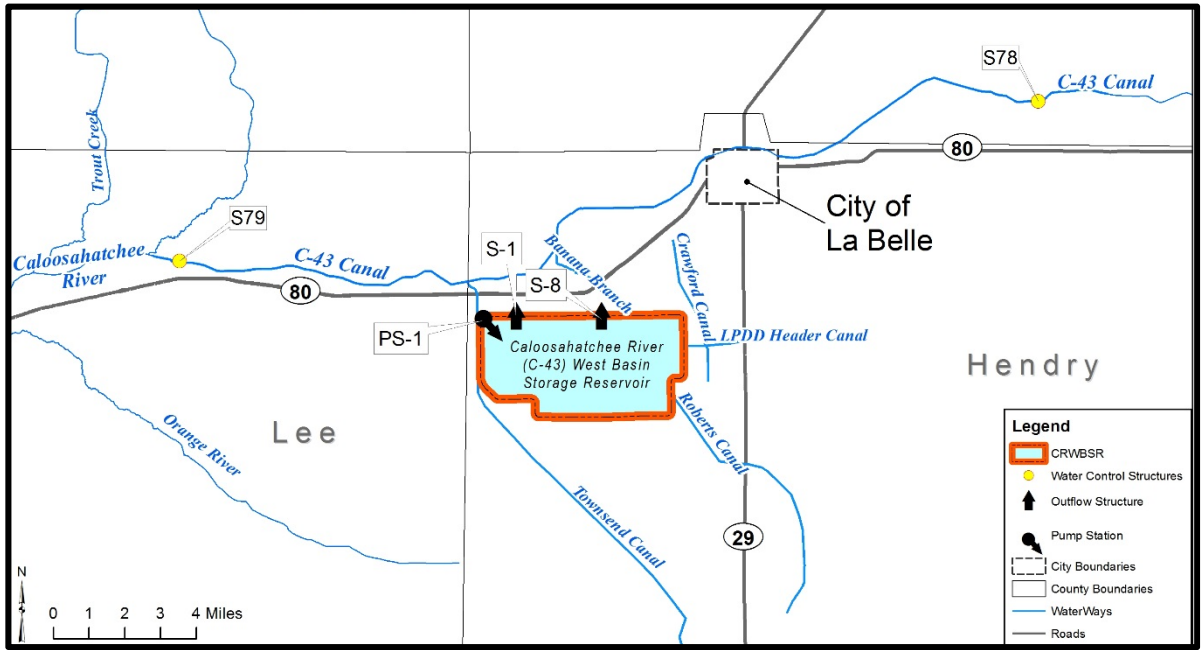
(a) A 30-day average salinity concentration exceeds 10 parts per thousand at the Ft. Myers salinity station - measured at 20% of the total river depth from the water surface…; or

(b) A single, daily average salinity exceeds a concentration of 20 parts per thousand at the Ft. Myers salinity station.

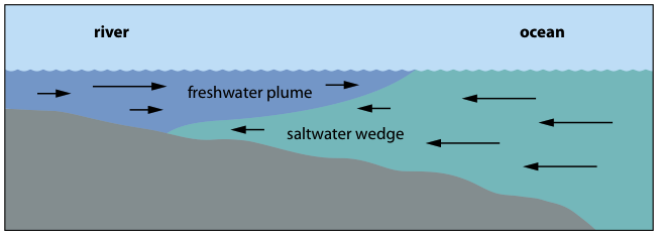
Exceedance of either paragraph (a) or (b), for two consecutive years is a violation of the MFL.

Existing Recovery Strategy for Caloosahatchee

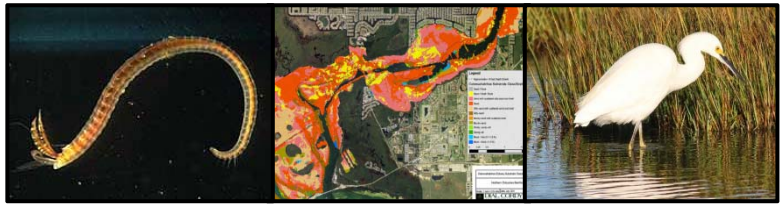
- **CERP Caloosahatchee River (C-43) West Basin Storage Reservoir**
- **Water Reservation for the CERP Caloosahatchee River (C-43) West Basin Storage Reservoir**
  - **Rule adopted in May 2014**
  - **Construction started November 2015**



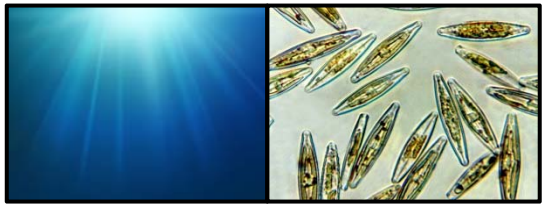
INDICATORS OF ESTUARINE RESPONSE TO LOW INFLOW



Changes in isohaline position with upstream encroachment of saltier water



Alter benthic community upon which many estuarine fauna are dependent

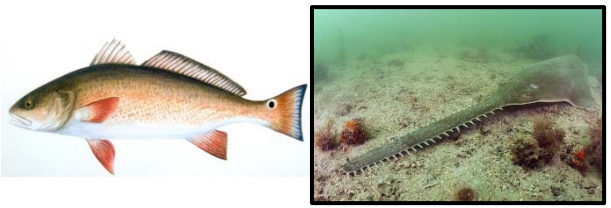


Reduced flushing and enhanced light can stimulate phytoplankton in upper estuary

Damaging to the freshwater *Vallisneria americana* (tape grass)

Impact physiology and habitat attributes of eastern oyster

Zooplankton and ichthyoplankton assemblages move upstream but can be impinged by structure



Affect coastal fish populations dependent upon estuaries as nurseries

Negatively impact harvests of important fisheries

Purpose and Objectives of Science Components

Purpose:

- **To provide a comprehensive assessment of the science for the Caloosahatchee River Estuary for the current Minimum Flows and Levels Re-evaluation**
  - **Science will provide a strong technical science foundation for the MFL technical document**

Objectives:

- **Compile and document information about dry season freshwater inflows and salinity patterns relative to multiple indicators**
- **Examine the responses of a suite of ecological indicators to dry season inflows**
- **Estimate the low inflows to which the indicator might respond negatively**

Science Approach

- **Explores new data since adoption of the MFL (2001), analyzes older data, uses updated statistical approaches and updated modeling**

- **Provides an evaluation of multiple indicators within the estuary including, zooplankton, icthyoplankton, submersed aquatic vegetation, oysters, benthic communities, blue crabs and sawfish**

- **Evaluates the effects of dry season freshwater inflow on the hydrology and ecology of the Caloosahatchee River Estuary**

SCIENCE COMPONENTS / STUDIES

	Component	Method
1	Hydrodynamics	Influence of alterations on hydrodynamics
2	Inflow vs. Salinity	Monthly freshwater-salinity relationships
3	Water Quality	Fine scale relationships between water quality and inflow
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7	*Vallisneria* data	Empirical relationships between tape grass, S, and inflow
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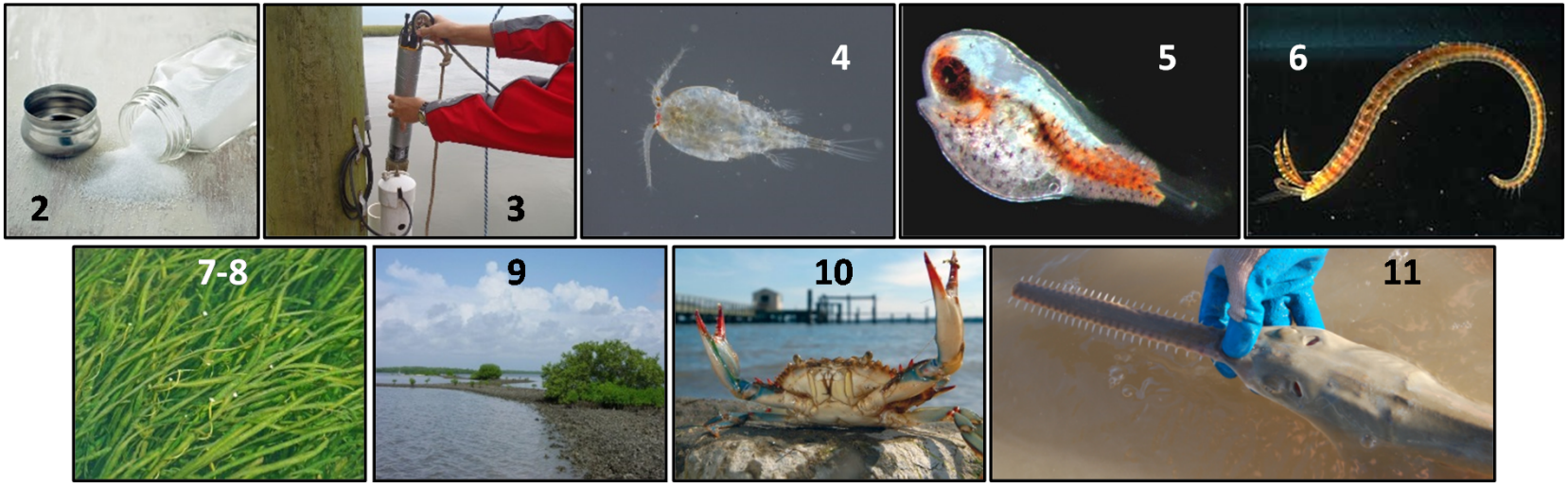
9	Oyster Habitat	Assess conditions for oyster survival and growth in lower CRE
10	Blue Crabs	Relationships between blue crab landings, rainfall, and inflow
11	Sawfish	Relationships between low inflow, salinity range, and depth



Goal and Objectives of Symposium

Goal: Keep comments focused on the science

Objectives:

- **Communicate with stakeholders to explain the scientific approach taken to evaluate all of the science information that was available**
- **Communicate with stakeholders to see if other data sets or analyses could add to this scientific body of knowledge**
- **Receive feedback on the science study during the 2-day science symposium and the 60-day public comment period**
- **Outline the process and specific steps for the MFL reevaluation**

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Overview of the Caloosahatchee River Estuary

Peter H. Doering, PhD

Section Administrator

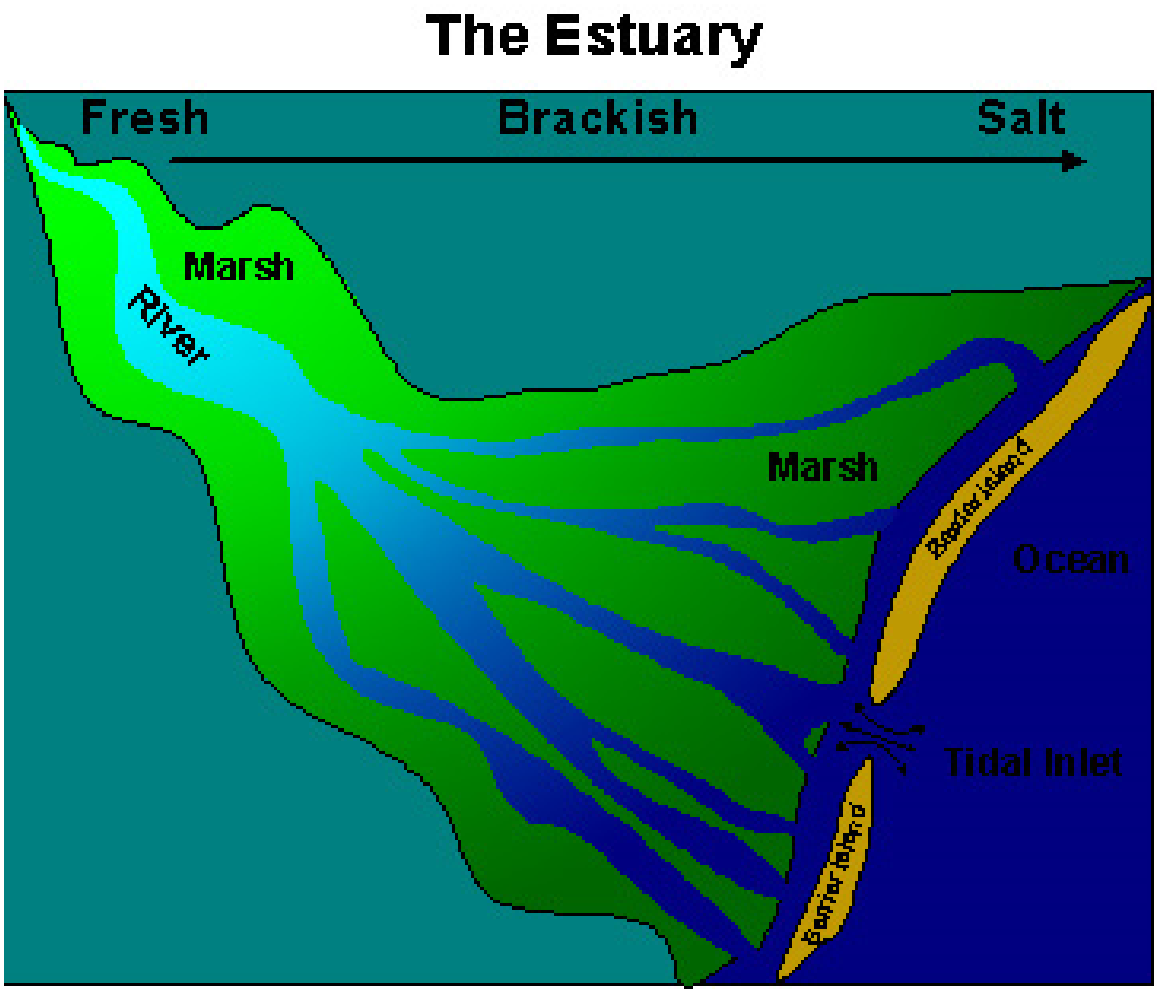
Coastal Ecosystems Section

South Florida Water Management District

What is an Estuary?

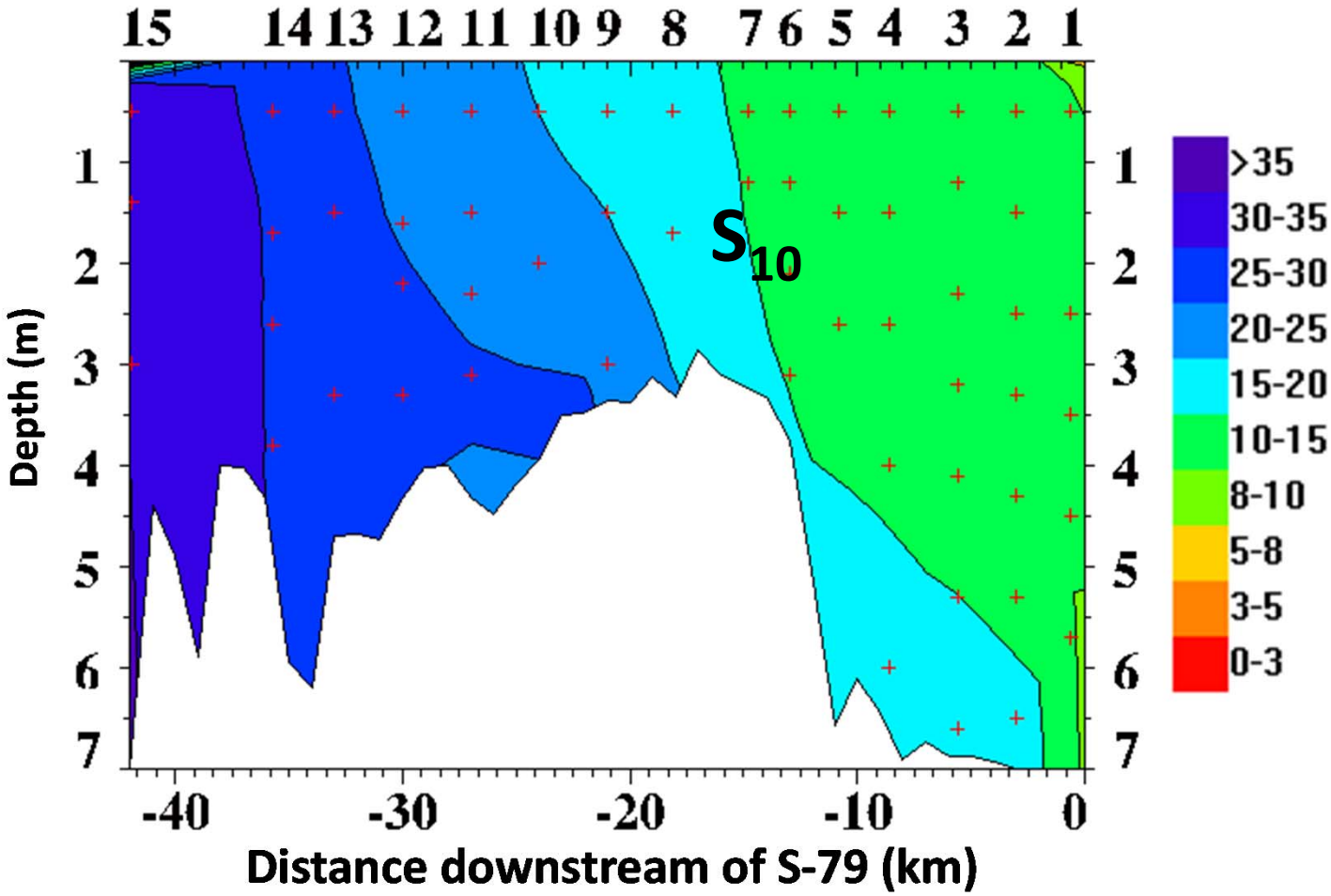
An estuary is a place where freshwater from the land mixes with salty water from the ocean

Estuarine Mixing



The mixing by river inflow, tides, and wind creates a spatial salinity gradient between fresh river water and salty ocean water

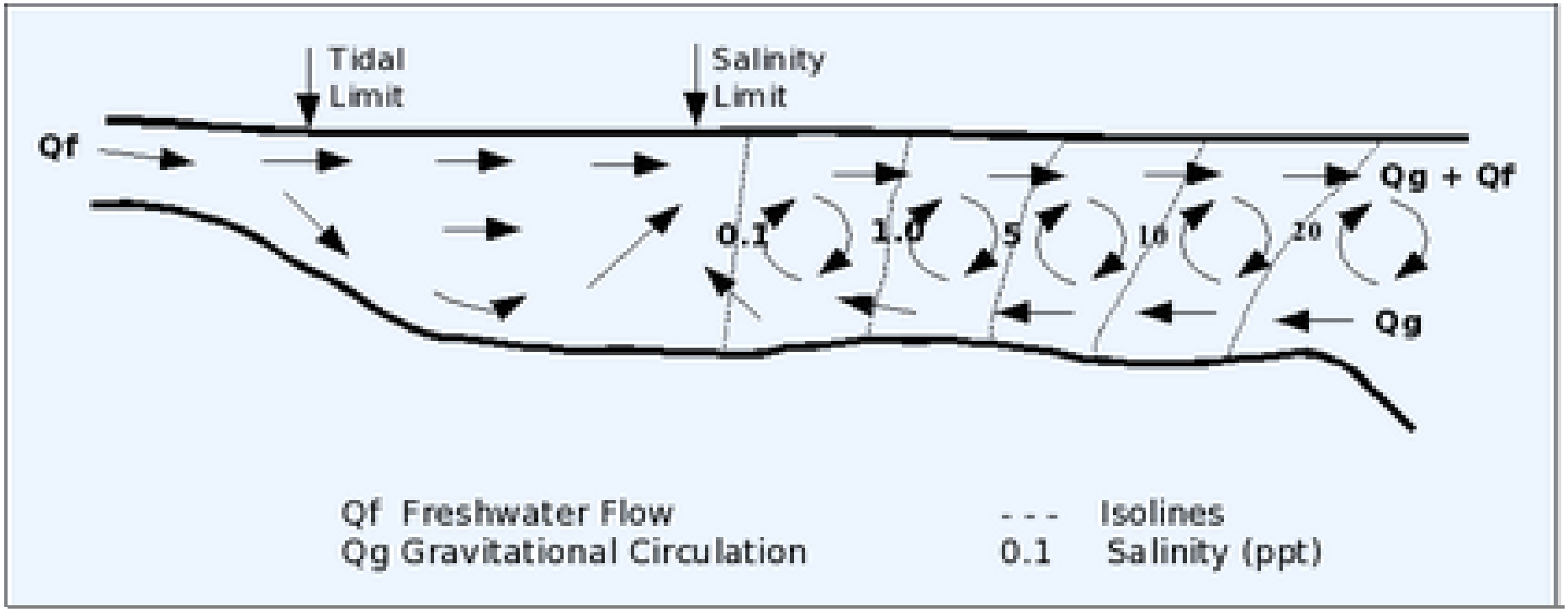
Isohalines – Lines of Equal Salinity



Can plot the vertical and horizontal extent of isohalines as in this 2D representation of depth vs. distance

Modeling Estuary Salinity Gradient

Can predict the spatial and temporal variations in salinity as a function of tide, wind, estuary geomorphology, and freshwater inflow



Freshwater Inflow & Estuaries

Freshwater Inflow
- Quantity
  - Timing
  - Frequency
  - Duration
  - Extent
- Quality
- Tidal connections

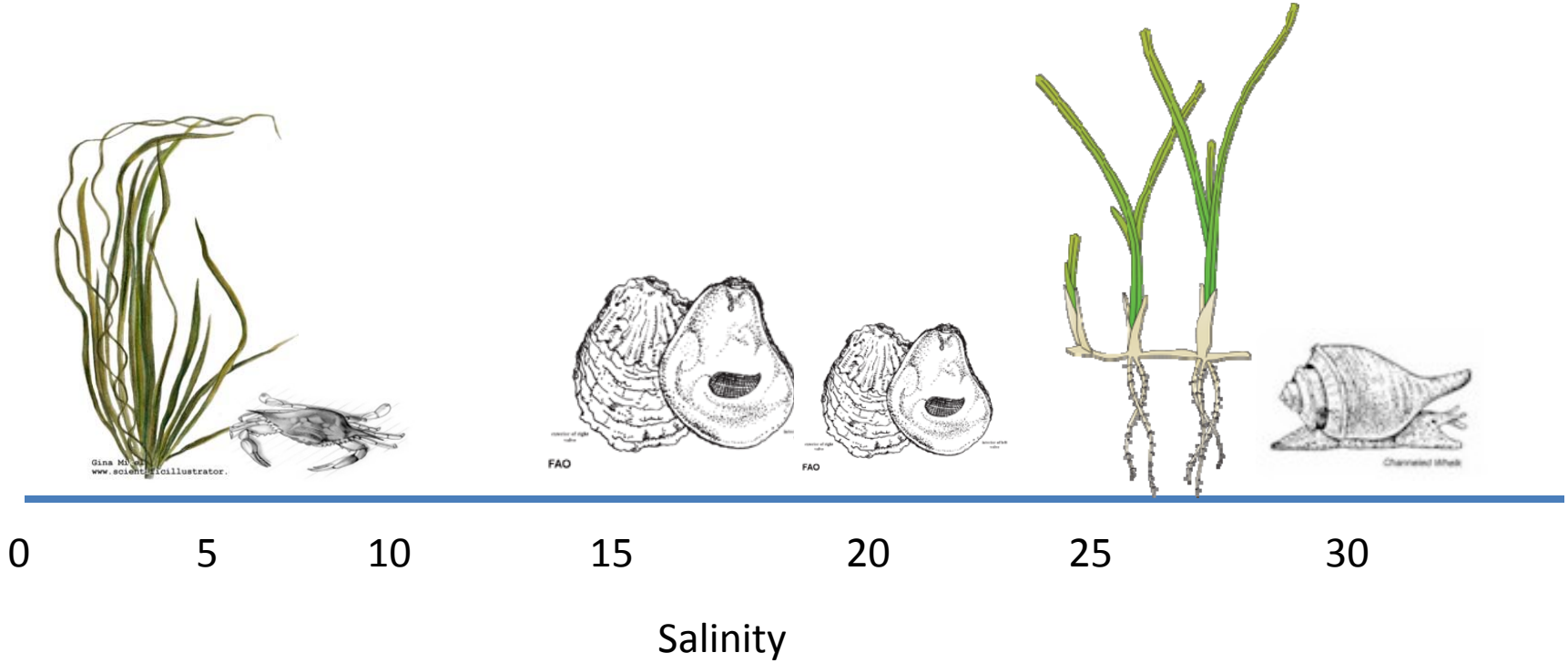
Estuarine Conditions
- Salinity
- Sediment
- Dissolved material
- Particulate material

Estuarine Resources
- Integrity
  - Species composition
  - Abundance
  - Biomass
  - Diversity
- Function
  - Primary production
  - Secondary production
  - Nutrient recycling
- Sustainability
  - Habitats
  - Valued resources
  - Ecosystem services

Estuarine Biota & Salinity Gradient

Prefer Low Salinity

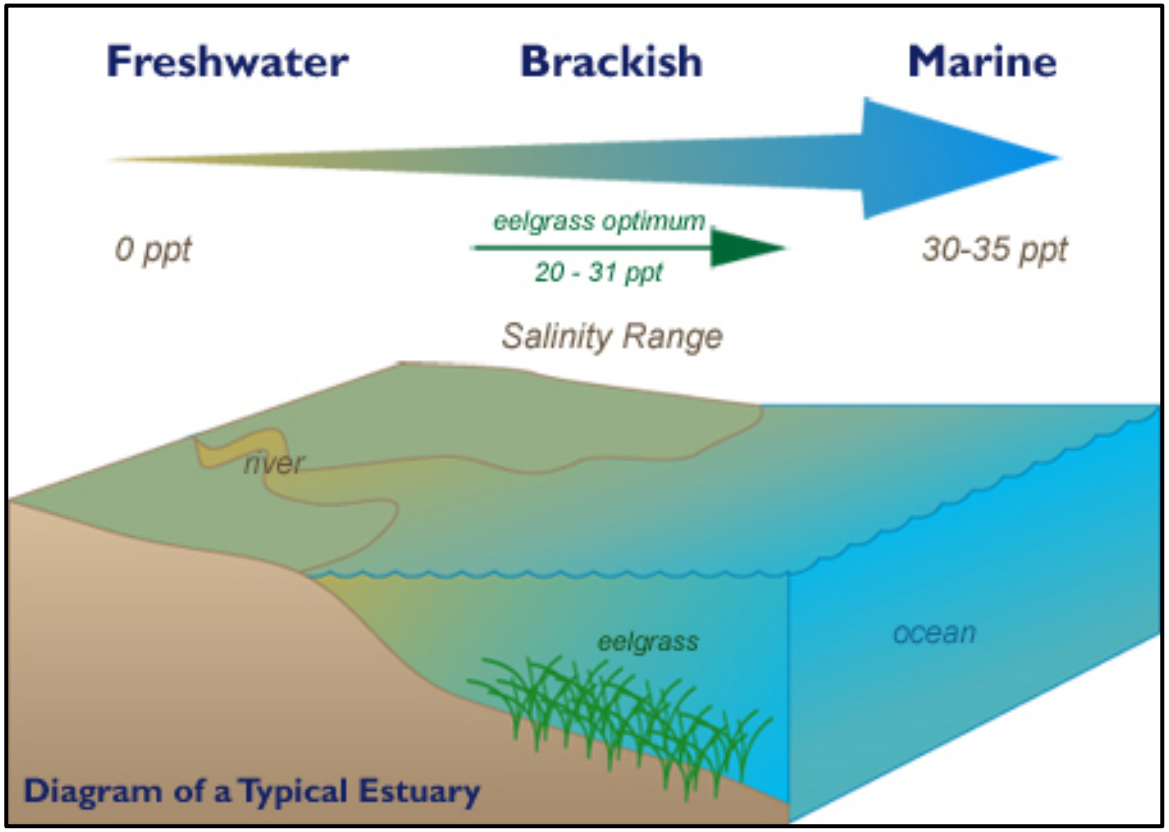
Prefer Higher Salinity



Different organisms occupy different portions of the estuarine salinity gradient

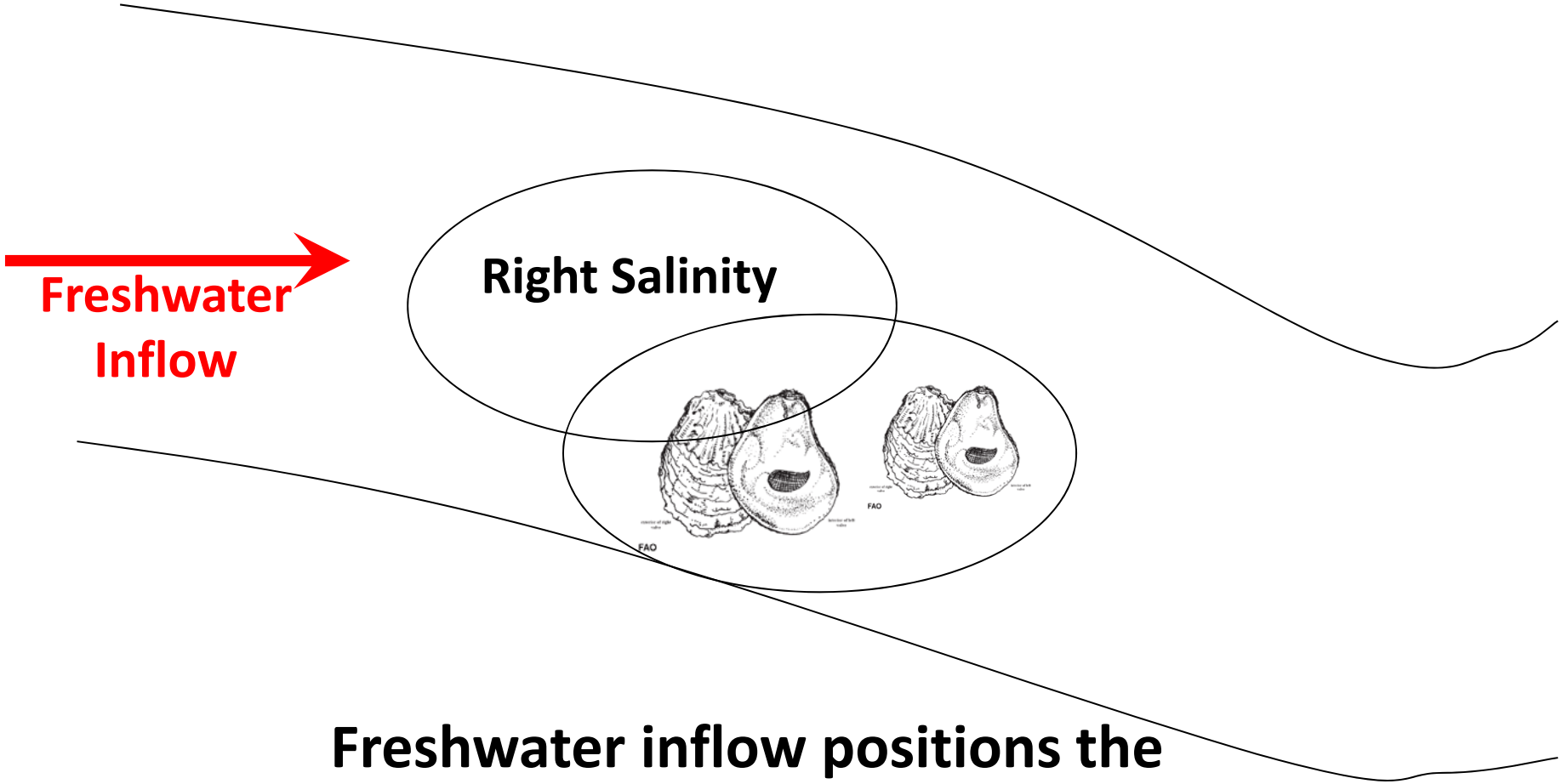
Estuarine Biota & Salinity Gradient

To persist in a given region of an estuary the biota must be able to tolerate the salinity at that location



<u>Habitat Overlap</u>: the dynamic or moveable habitat (salinity) and the stationary habitat (region of the estuary) where the organism is ordinarily found are coincident

Habitat Overlap

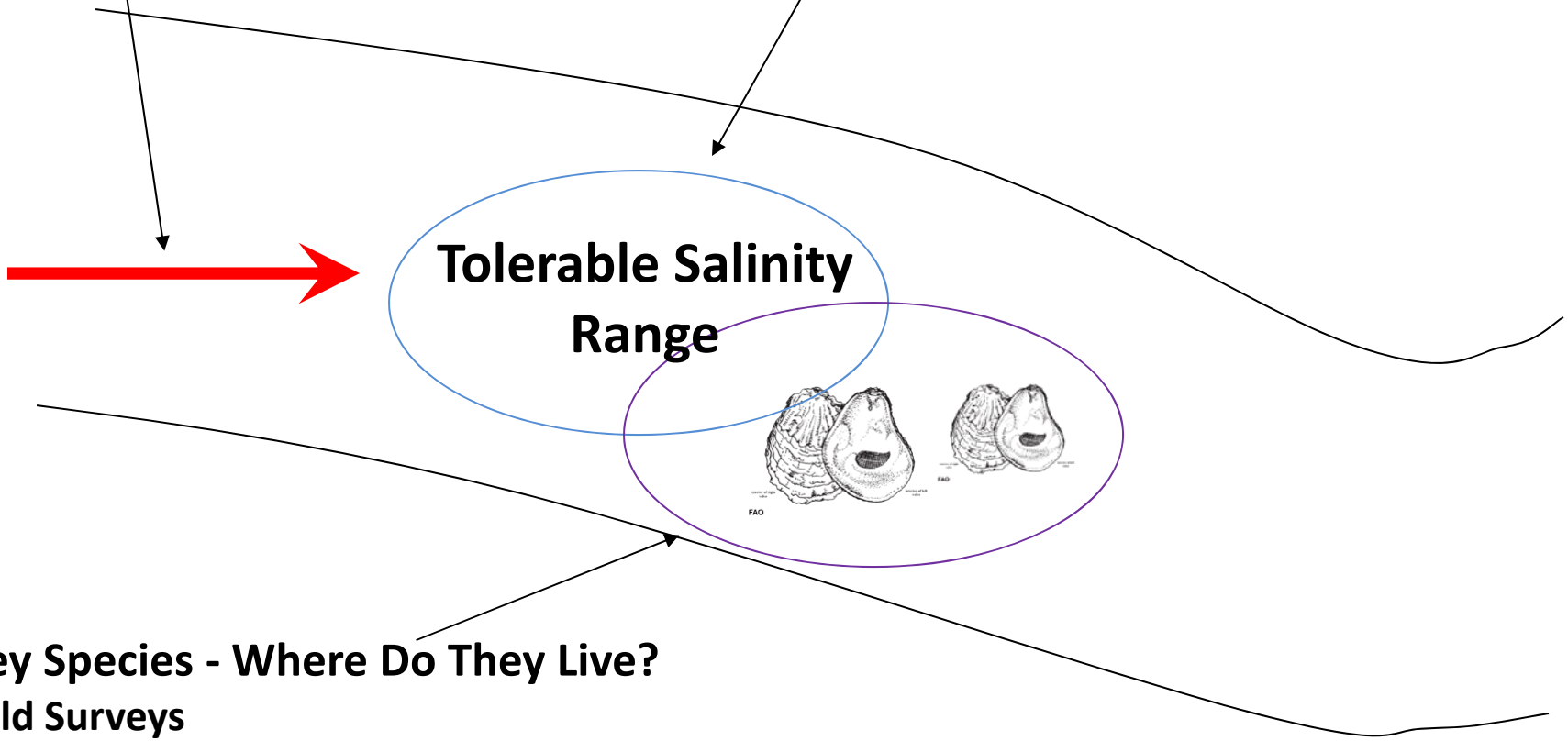


Freshwater inflow positions the right salinity over the oyster bed

Habitat Overlap

III. How much freshwater?
- **a) Model**
- **b) Data**

II. What is the "right" salinity?
- **a) Monitoring in the Field**
- **b) Lab Salinity Tolerance Experiments**
- **c) Literature Review**

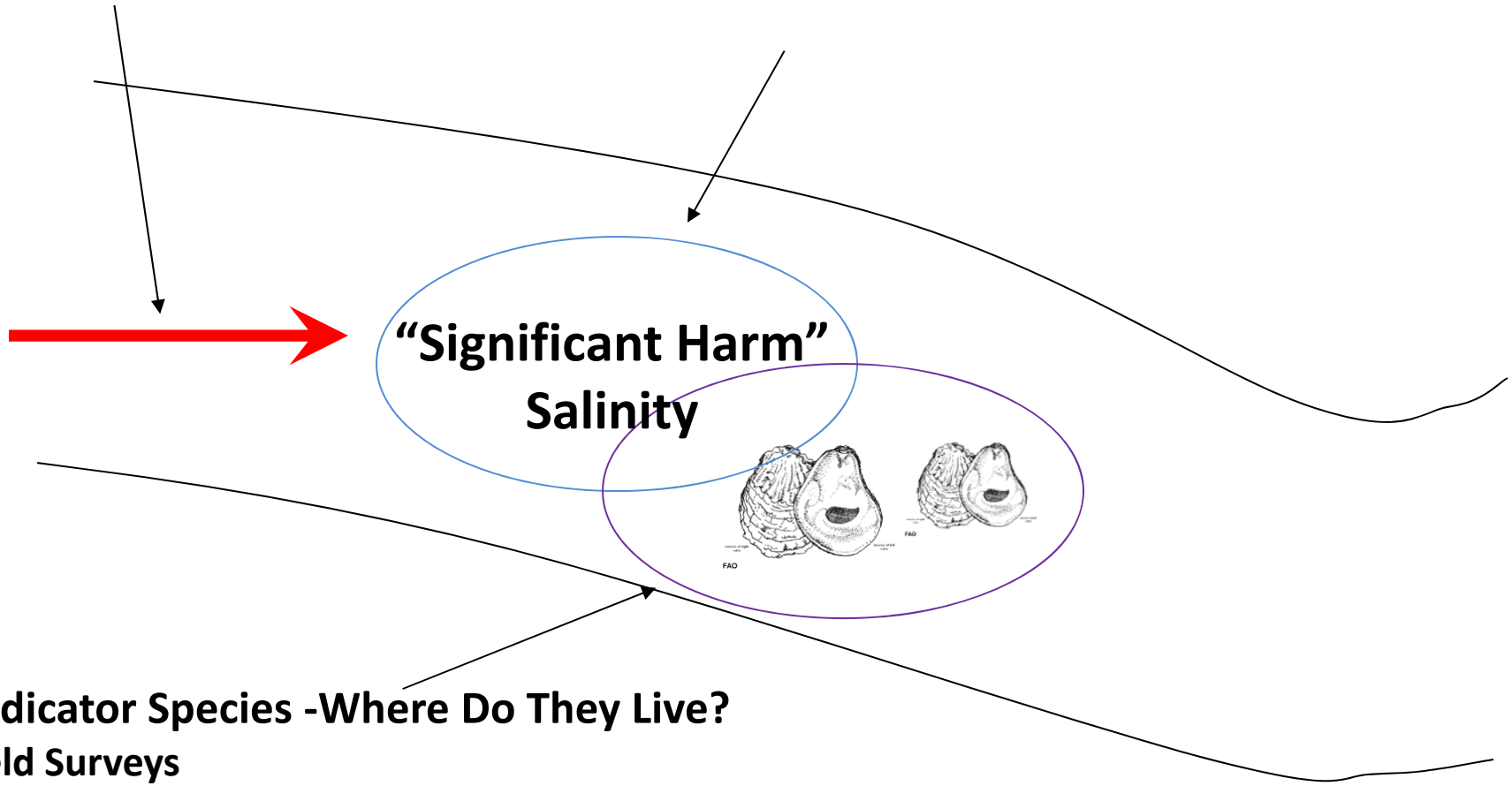


I. Key Species - Where Do They Live?
- **a) Field Surveys**
- **b) Monitoring**

Habitat Overlap & MFL's

III. What are the freshwater inflows associated with the Significant Harm salinity?

II. What is the salinity associated with Significant Harm to the indicator?

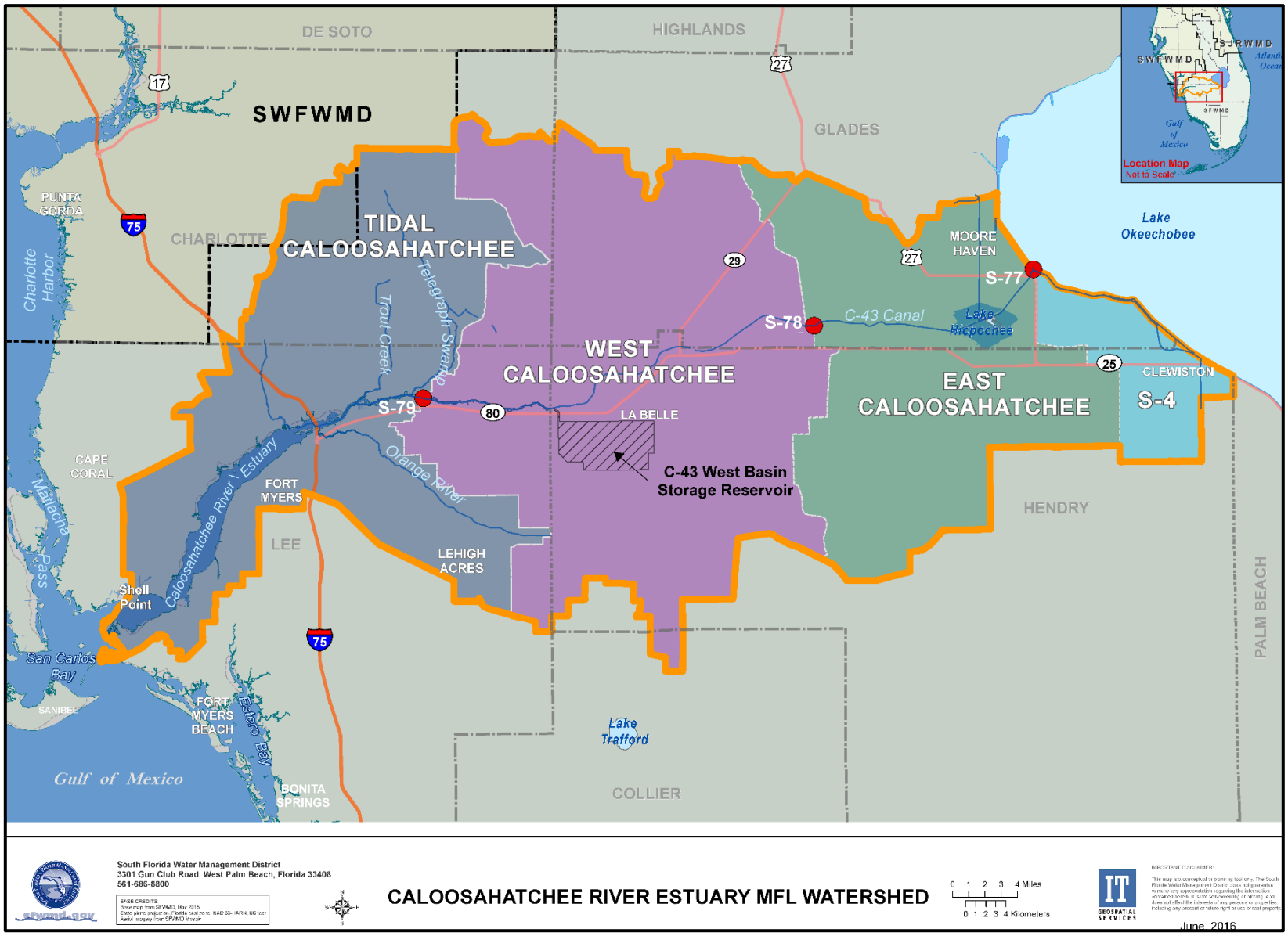


I. Indicator Species -Where Do They Live?

a) Field Surveys

b) Monitoring

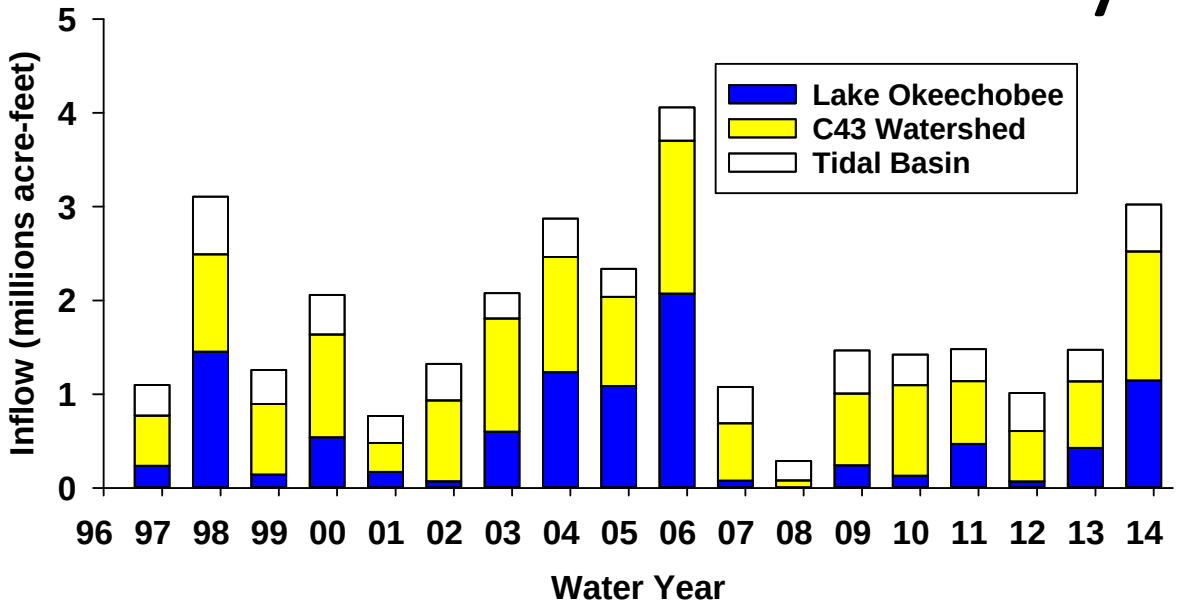
Caloosahatchee River Estuary MFL Watershed

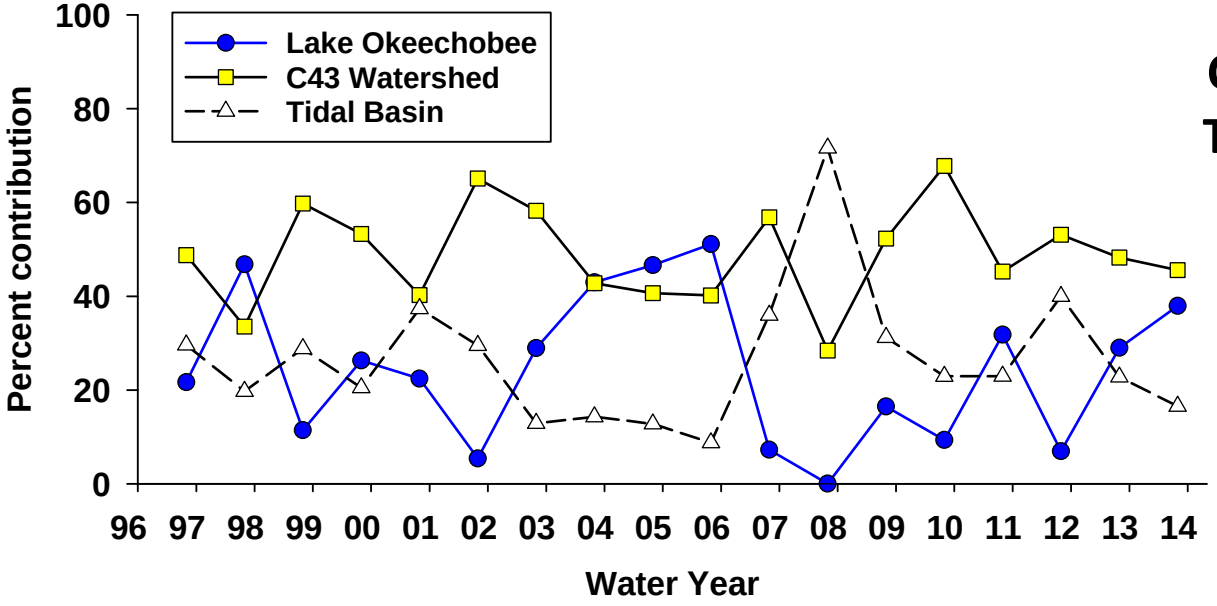


Caloosahatchee River Estuary MFL Watershed

- **Modern Watershed**
  - **S-79 completed in 1965**
  - **C-43 Canal spans 70 km from S-77 to S-79**
  - **Watershed size = 865,488 acres;**
  - **2012 Land Use: Agriculture = 42%; Urban & Built Up = 18%; Wetlands = 15%**
  - **4 sub-watersheds connected by a network of secondary and tertiary canals**
    - **S-4 Basin adjacent to Lake Okeechobee**
    - **East and West Caloosahatchee Basins**
    - **Tidal Basin downstream of S-79**

Caloosahatchee River Estuary Inflows





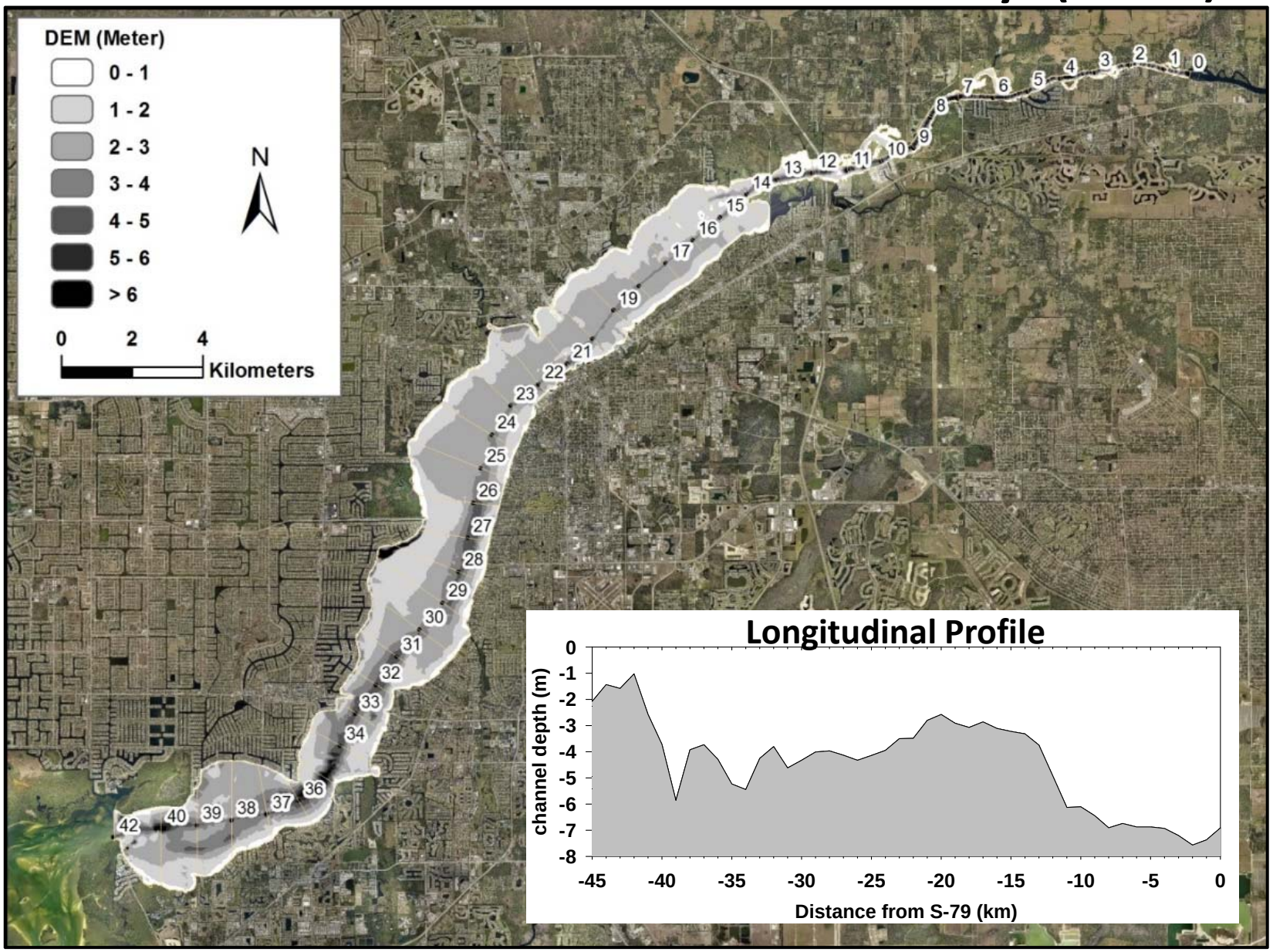
Averages

Lake O = 32%

C-43 Basin = 47%

Tidal Basin= 21 %

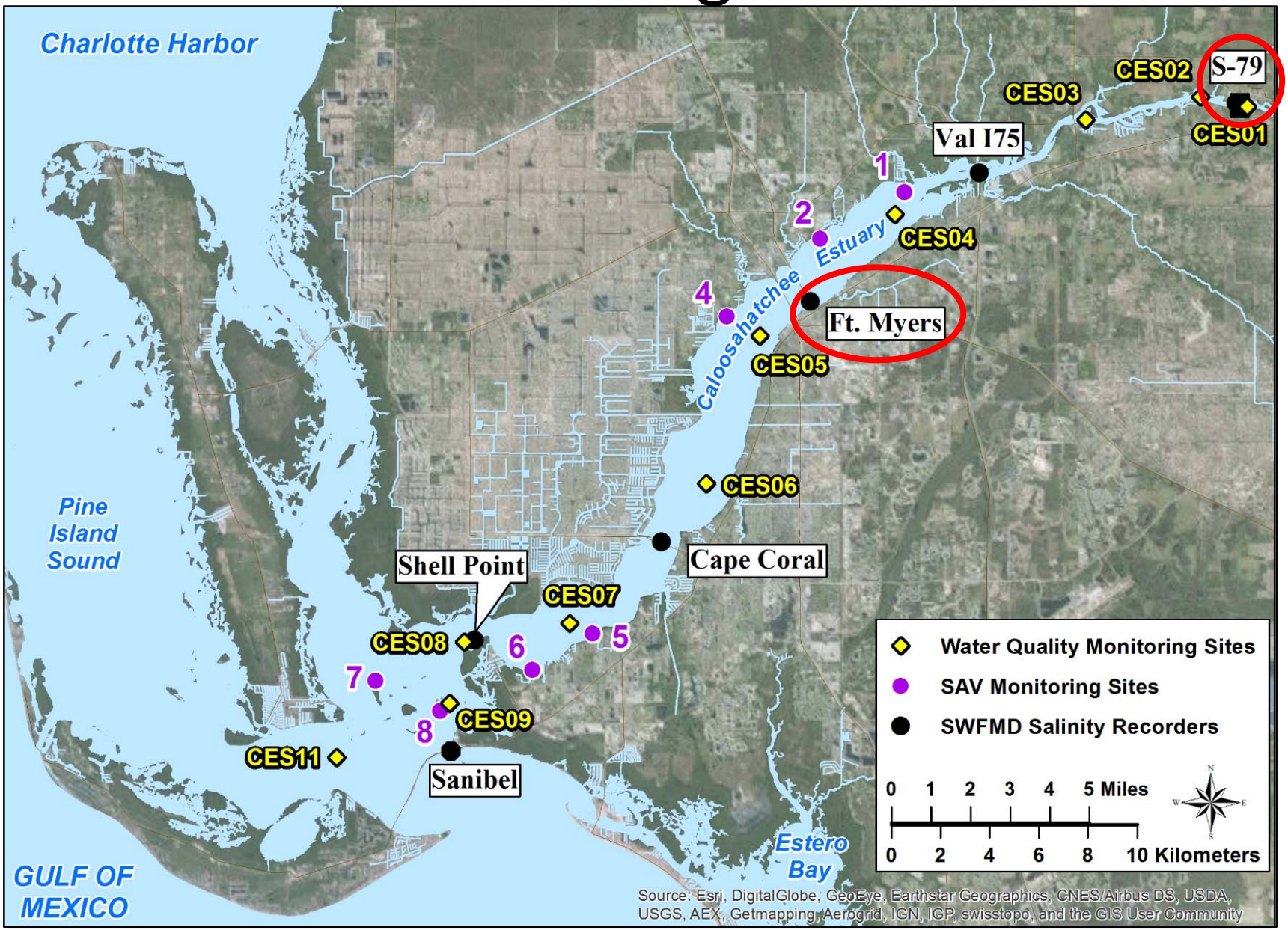
Caloosahatchee River Estuary (CRE)



Caloosahatchee River Estuary (CRE)

Attribute	Unit	Value
Length	km	42
Area	10^6 m^2	56
Depth (avg)	m	2.4
Volume	10^6 m^3	140
Flushing Time	days	3 to 90 (Avg ~30 d)
<u>Hypsometry</u>		
0 to 1 m	%	58.5
1-2 m	%	26.5
2-4 m	%	14.0
>4 m	%	1.0

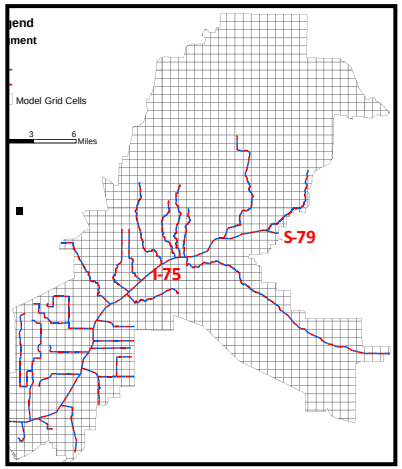
CRE Monitoring Stations



Modeling for the CRE

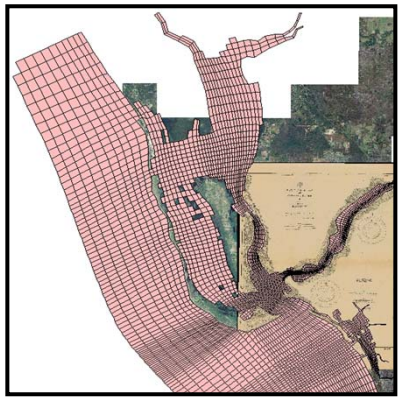
Tidal Basin Model

- Ungauged tidal basin downstream of S-79
- Urban, suburban, and agricultural land use
- Tributaries and submarine groundwater discharge
- Stage and flow data at 7 locations 10/2008 to 3/2013



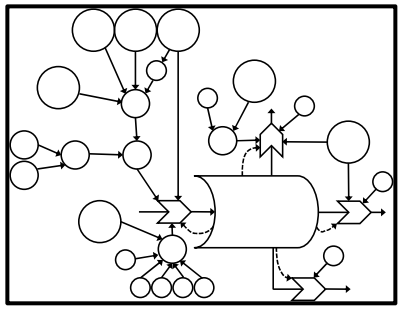
Curvilinear 3-D Hydrodynamic Model (CH3D)

- Simulates salinity, water level, and circulation
- Grid includes Charlotte Harbor, CRE, Estero Bay
- Calibrated with data collected from 1992-2012
- Simulations span 1/1/2000 to 12/31/2010



Ecological Models

- Water quality (chlorophyll, nutrients, submarine light)
- *Vallisneria americana* (tape grass)
- Oyster beds (*Crassostrea virginica*)



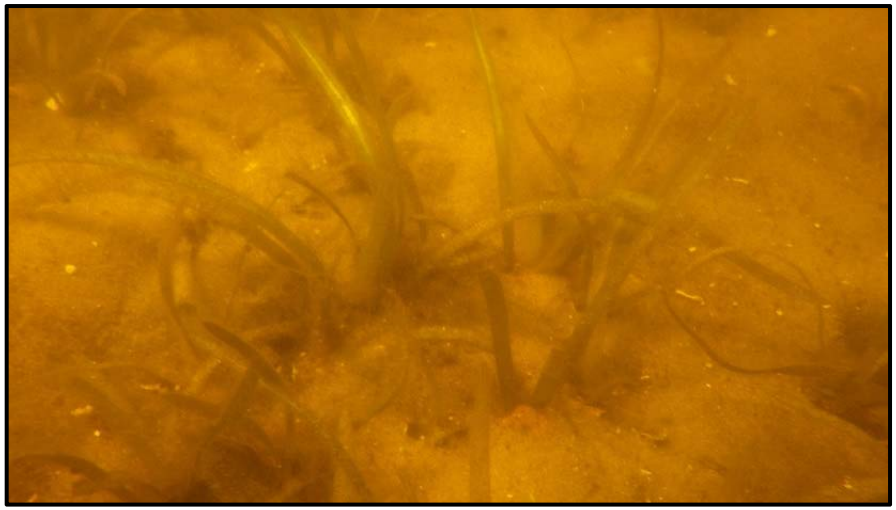
Caloosahatchee MFL

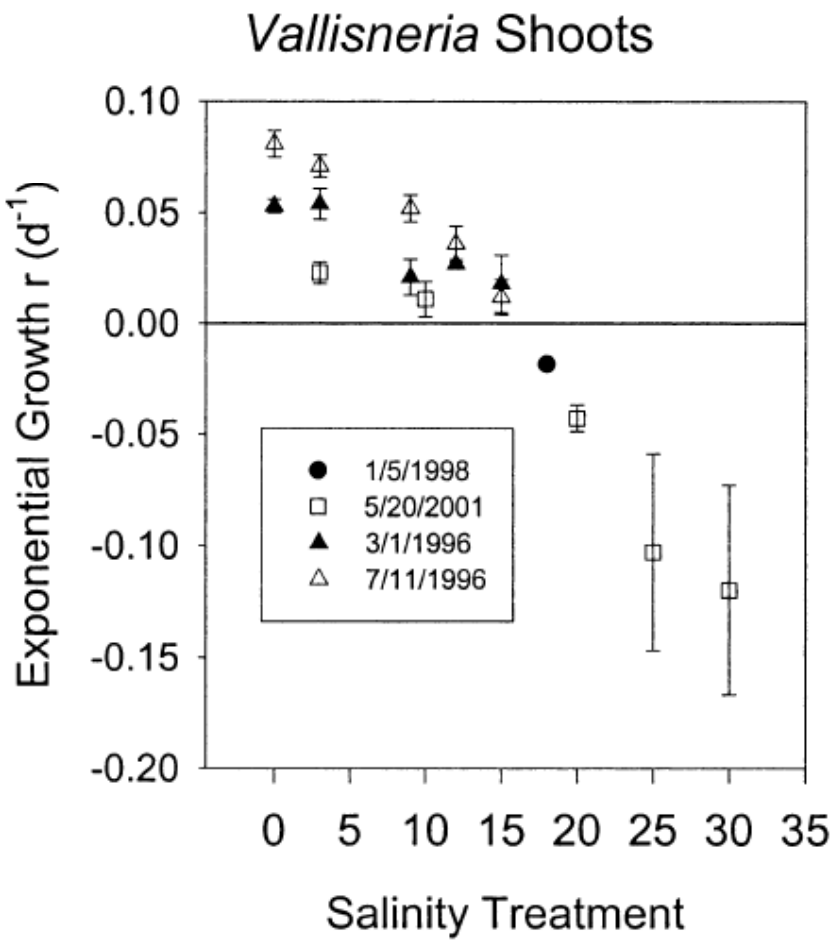
Estuaries Vol. 25, No. 6B, p. 1343–1354 December 2002

Using Submerged Aquatic Vegetation to Establish Minimum and Maximum Freshwater Inflows to the Caloosahatchee Estuary, Florida

PETER H. DOERING*, ROBERT H. CHAMBERLAIN, and DANIEL E. HAUNERT

South Florida Water Management District, 3301 Gun Club Road, West Palm Beach, Florida 33406





The original Caloosahatchee MFL (2001) was based primarily on the salinity tolerance of Tape Grass, *Vallisneria americana*

SCIENCE COMPONENTS / STUDIES

	Component	Method
1	Hydrodynamics	Influence of alterations on hydrodynamics
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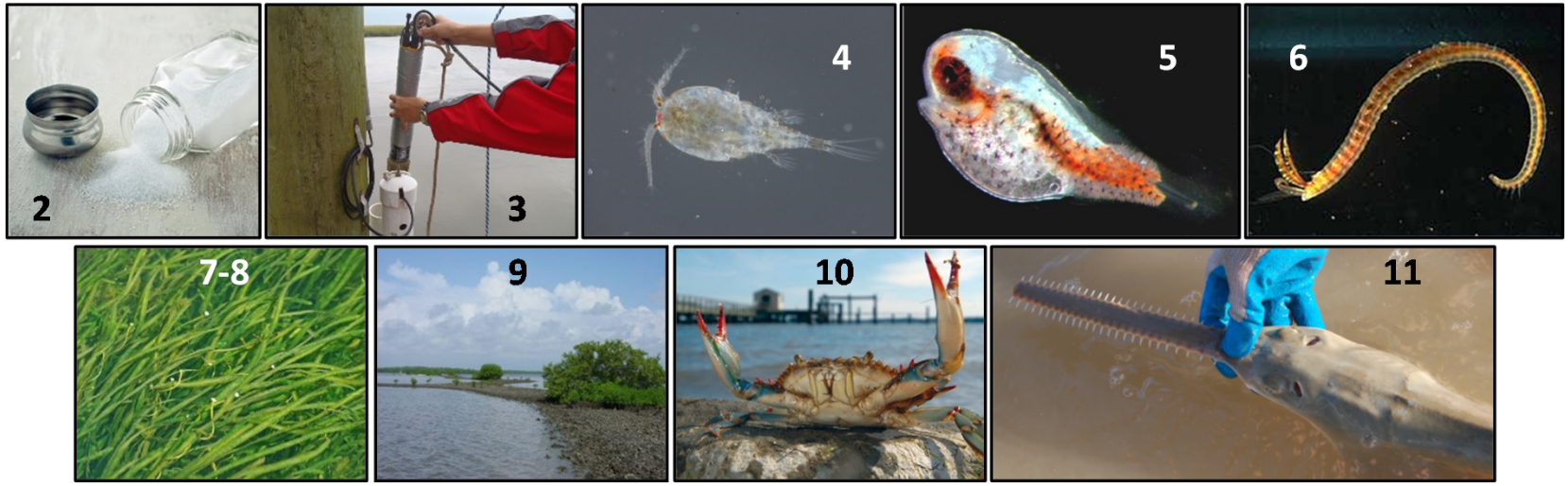

Alterations to the CRE

Component Study 1: Three Dimensional Model Evaluation of Physical Alterations to the Caloosahatchee River Estuary: Impact on Salt Transport

Detong Sun, Ph.D and Yongshan Wan, Ph.D , PE

Coastal Ecosystems Section

South Florida Water Management District

SCIENCE COMPONENTS / STUDIES

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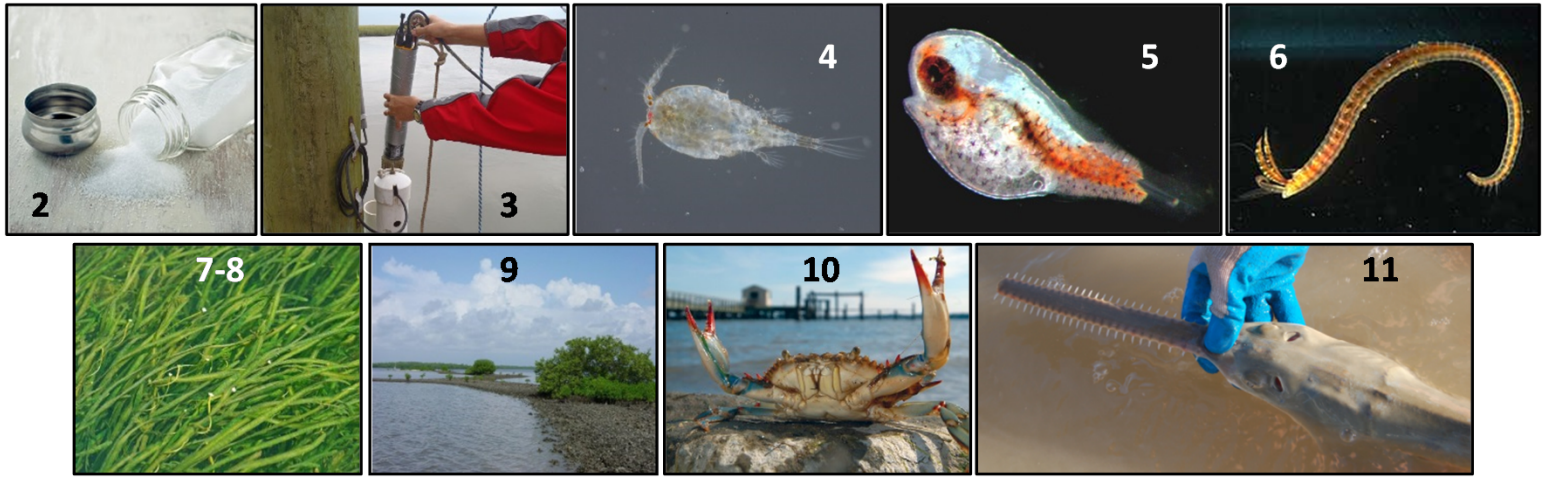
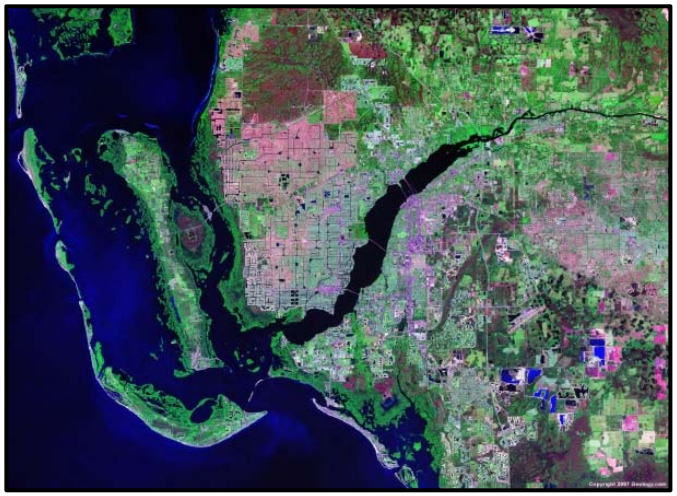
11	Sawfish	Dry season inflow, hydrodynamics, and habitat extent

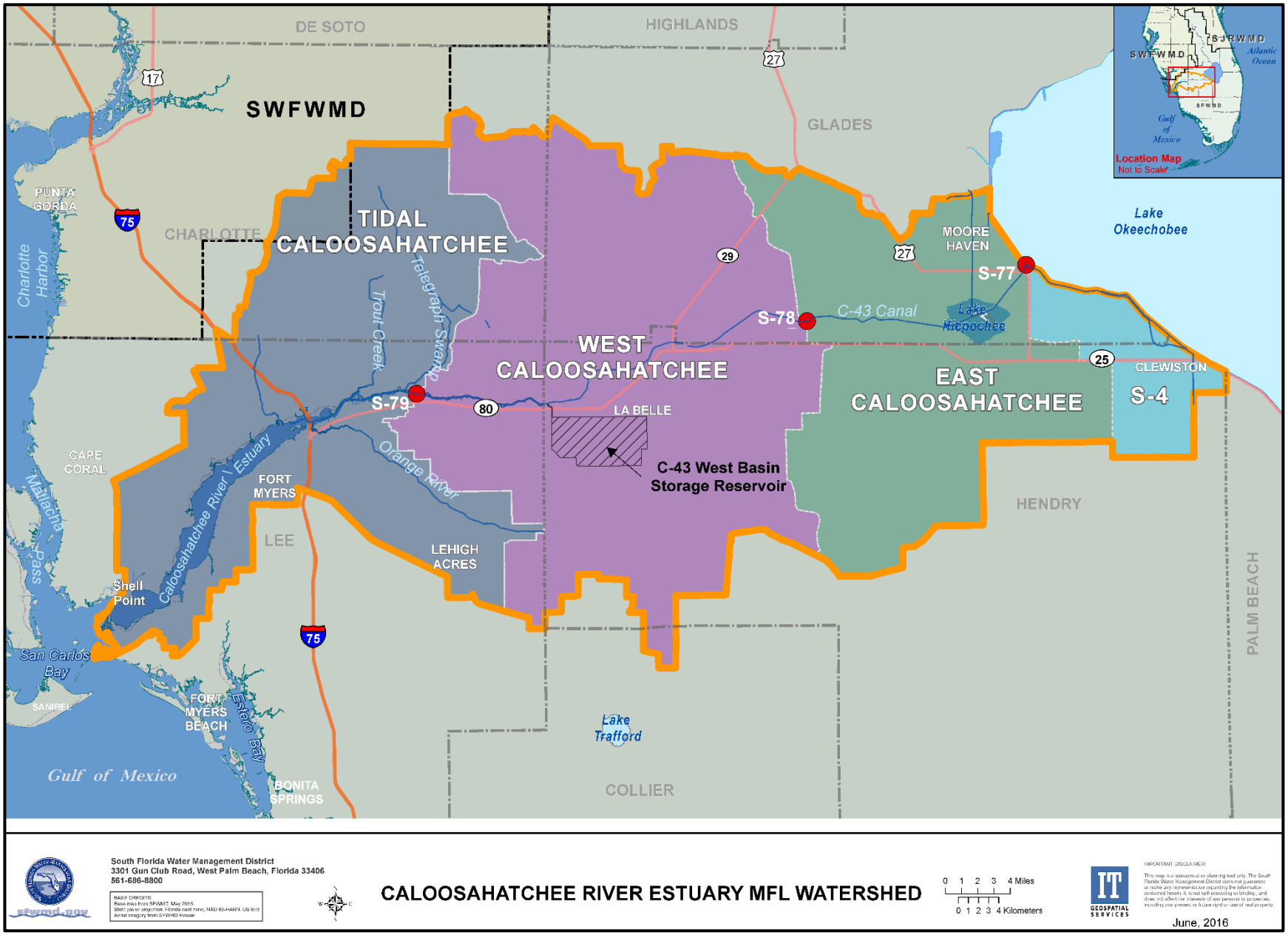


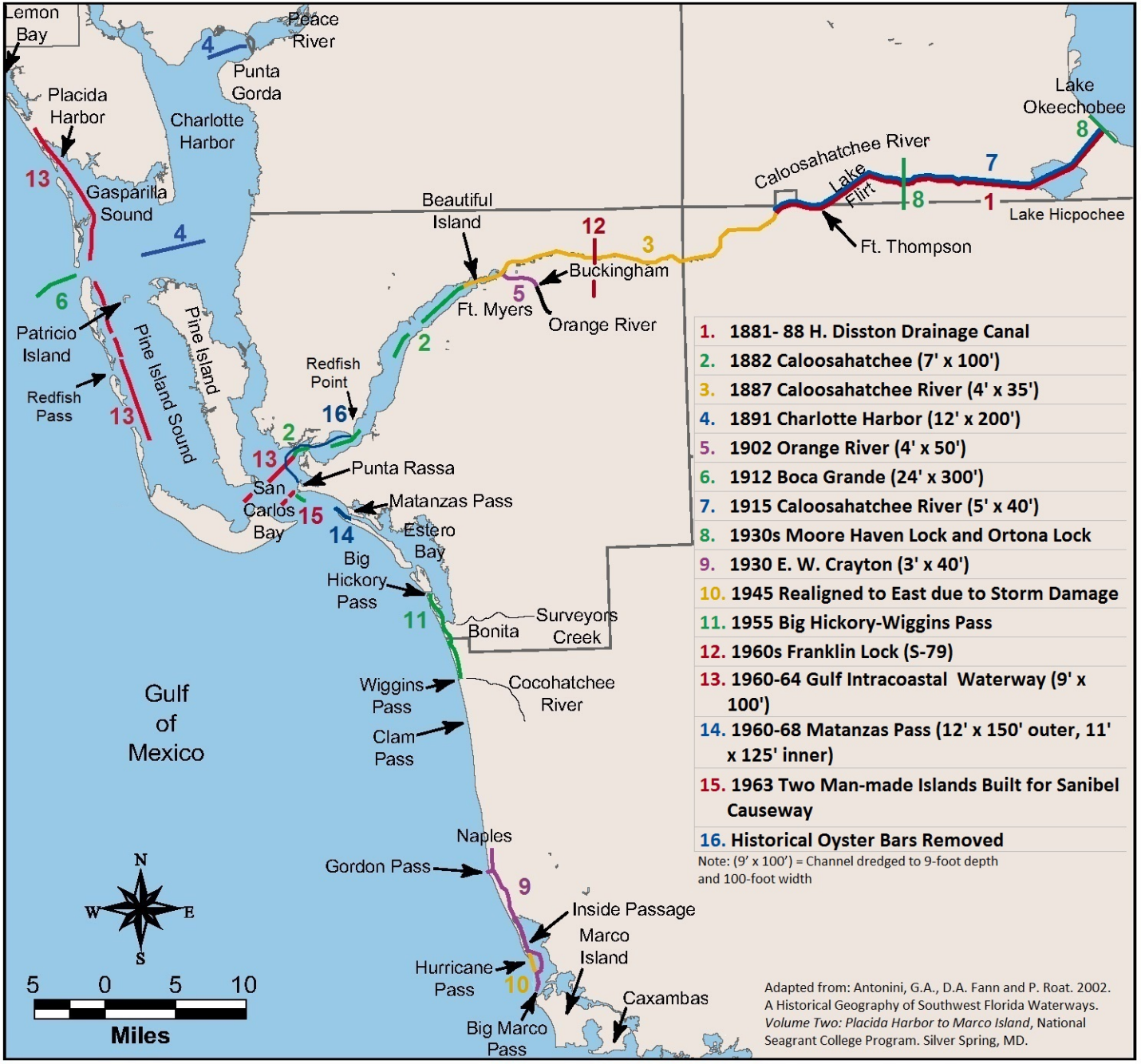
STUDY RATIONALE

- **Impacts of physical alterations noted worldwide, many irreversible**
- **What are salinity patterns without alterations**
- **Quantitatively evaluate the impact on salt transport**
- **Identify which alteration is primarily responsible for salinity increase**
- **Potential implications for developing environmental flow targets**



Caloosahatchee River Estuary MFL Watershed

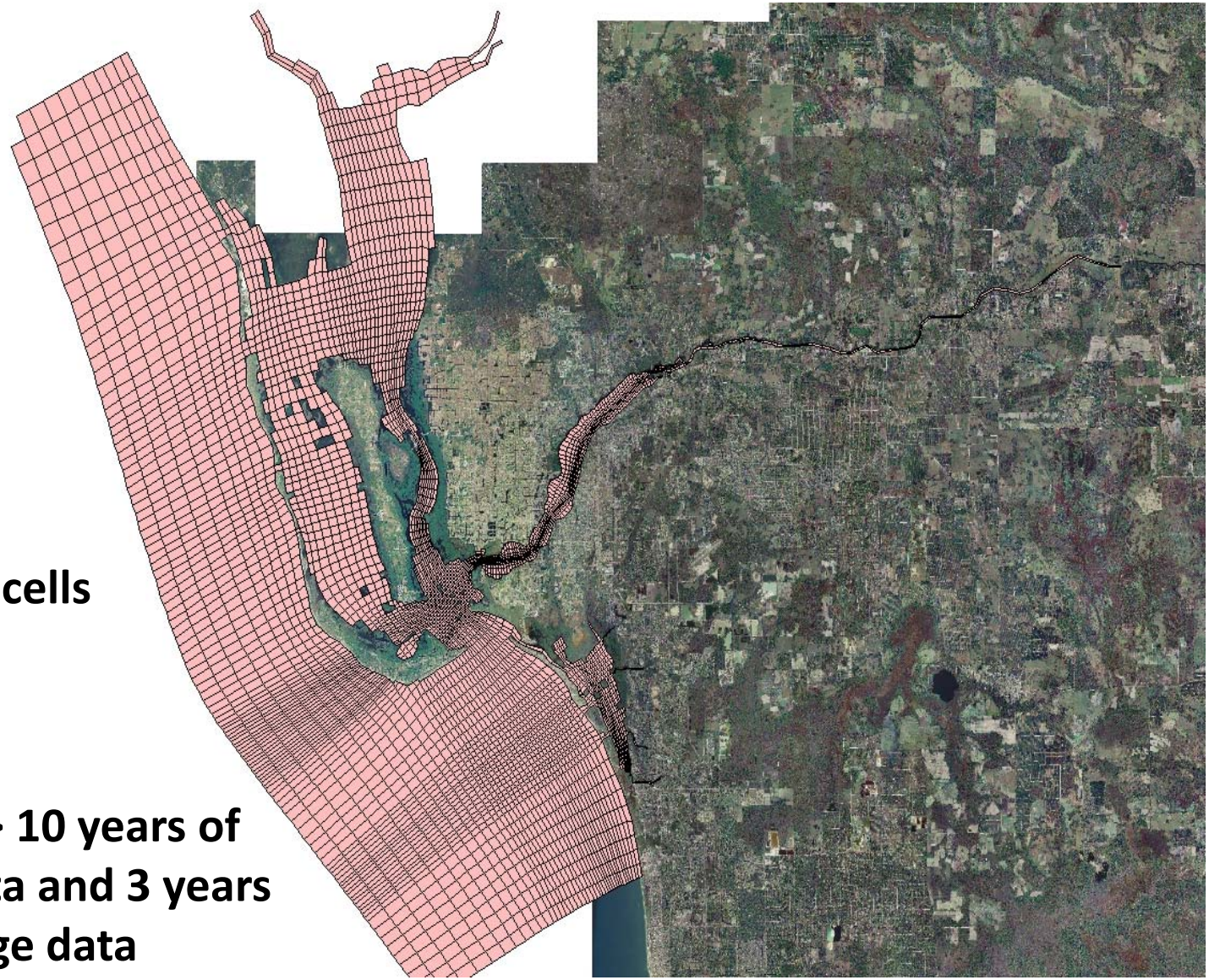



Lemon Bay
Peace River
Punta Gorda
Placida Harbor
Charlotte Harbor
Gasparilla Sound
Beautiful Island
Buckingham
Ft. Myers
Orange River
Caloosahatchee River
Lake Flirt
Lake Okeechobee
Lake Hicpochee
Ft. Thompson
Patricio Island
Pine Island Sound
Pine Island
Redfish Pass
Redfish Point
Punta Rassa
San Carlos Bay
Matanzas Pass
Estero Bay
Big Hickory Pass
Bonita
Surveyors Creek
Wiggins Pass
Cocohatchee River
Clam Pass
Gulf of Mexico
Naples
Gordon Pass
Inside Passage
Marco Island
Hurricane Pass
Big Marco Pass
Caxambas
N
W
E
S
5 0 5 10
Miles
1. 1881- 88 H. Disston Drainage Canal
2. 1882 Caloosahatchee (7' x 100')
3. 1887 Caloosahatchee River (4' x 35')
4. 1891 Charlotte Harbor (12' x 200')
5. 1902 Orange River (4' x 50')
6. 1912 Boca Grande (24' x 300')
7. 1915 Caloosahatchee River (5' x 40')
8. 1930s Moore Haven Lock and Ortona Lock
9. 1930 E. W. Crayton (3' x 40')
10. 1945 Realigned to East due to Storm Damage
11. 1955 Big Hickory-Wiggins Pass
12. 1960s Franklin Lock (S-79)
13. 1960-64 Gulf Intracoastal Waterway (9' x 100')
14. 1960-68 Matanzas Pass (12' x 150' outer, 11' x 125' inner)
15. 1963 Two Man-made Islands Built for Sanibel Causeway
16. Historical Oyster Bars Removed
Note: (9' x 100') = Channel dredged to 9-foot depth and 100-foot width
Adapted from: Antonini, G.A., D.A. Fann and P. Roat. 2002. A Historical Geography of Southwest Florida Waterways. Volume Two: Placida Harbor to Marco Island, National Seagrant College Program. Silver Spring, MD.

STUDY METHODS

- **Evaluate impact of physical alterations using hydrodynamic model (CH3D)**
- **Model the existing condition (model validation)**
- **Alterations relative to existing condition by modifying grid and depth**
- **Forcing conditions at boundaries (wind, tide etc.) maintained**
- **Compare salinities**
- **Five independent scenarios done separately to isolate the effects:**
  1. **Removal of the S-79 water control structure**
  2. **Removal of the downstream Sanibel Causeway**
  3. **Backfill of the oyster bar near the estuary month**
  4. **Backfill of the navigation channel**
  5. **Re-establish pre-development bathymetry**

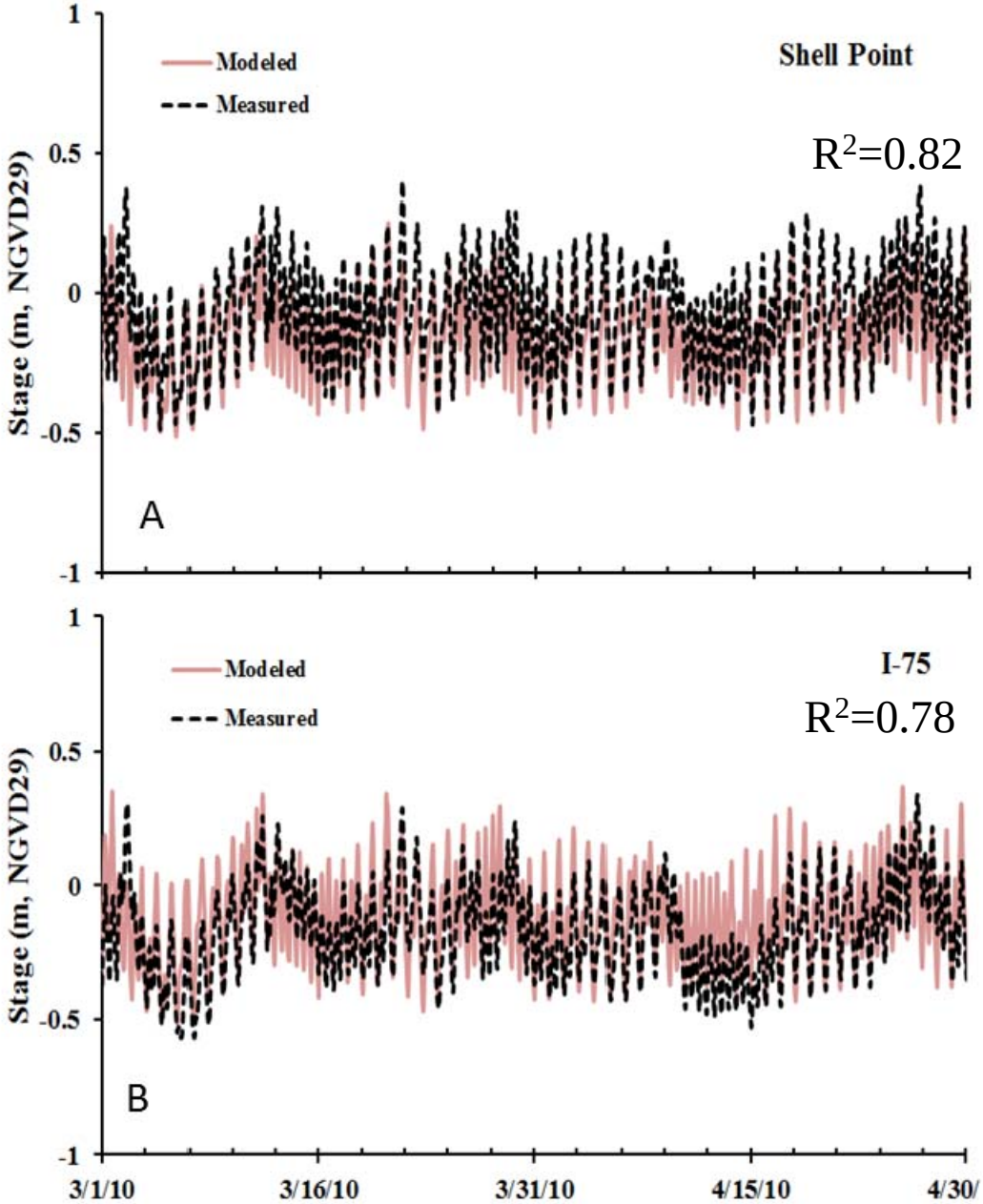
CH3D MODEL GRID



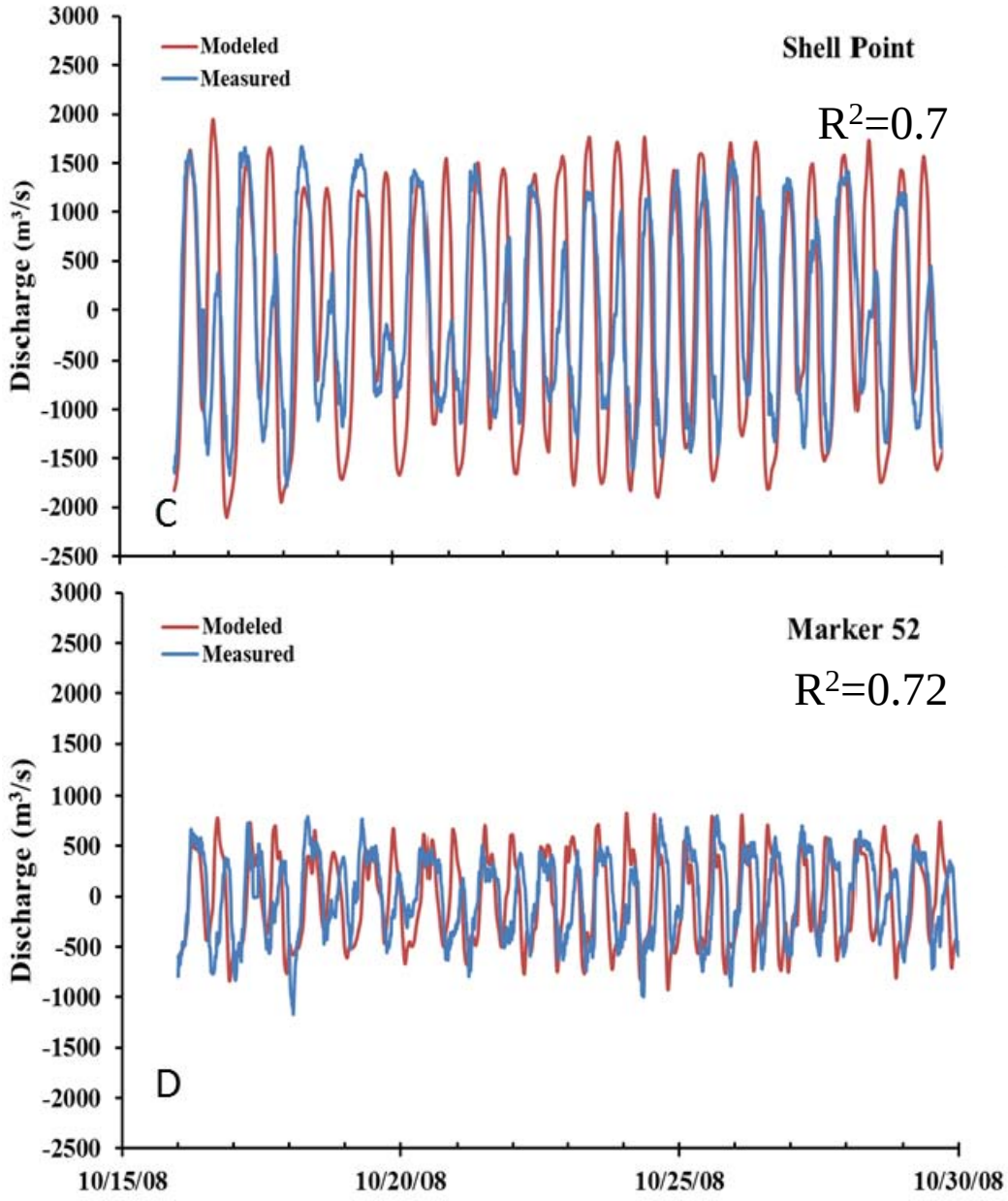
- **5300 horizontal cells**
- **5 vertical layers**
- **Validated with > 10 years of tide, salinity data and 3 years of tidal discharge data**

CRE MONITORING LOCATIONS

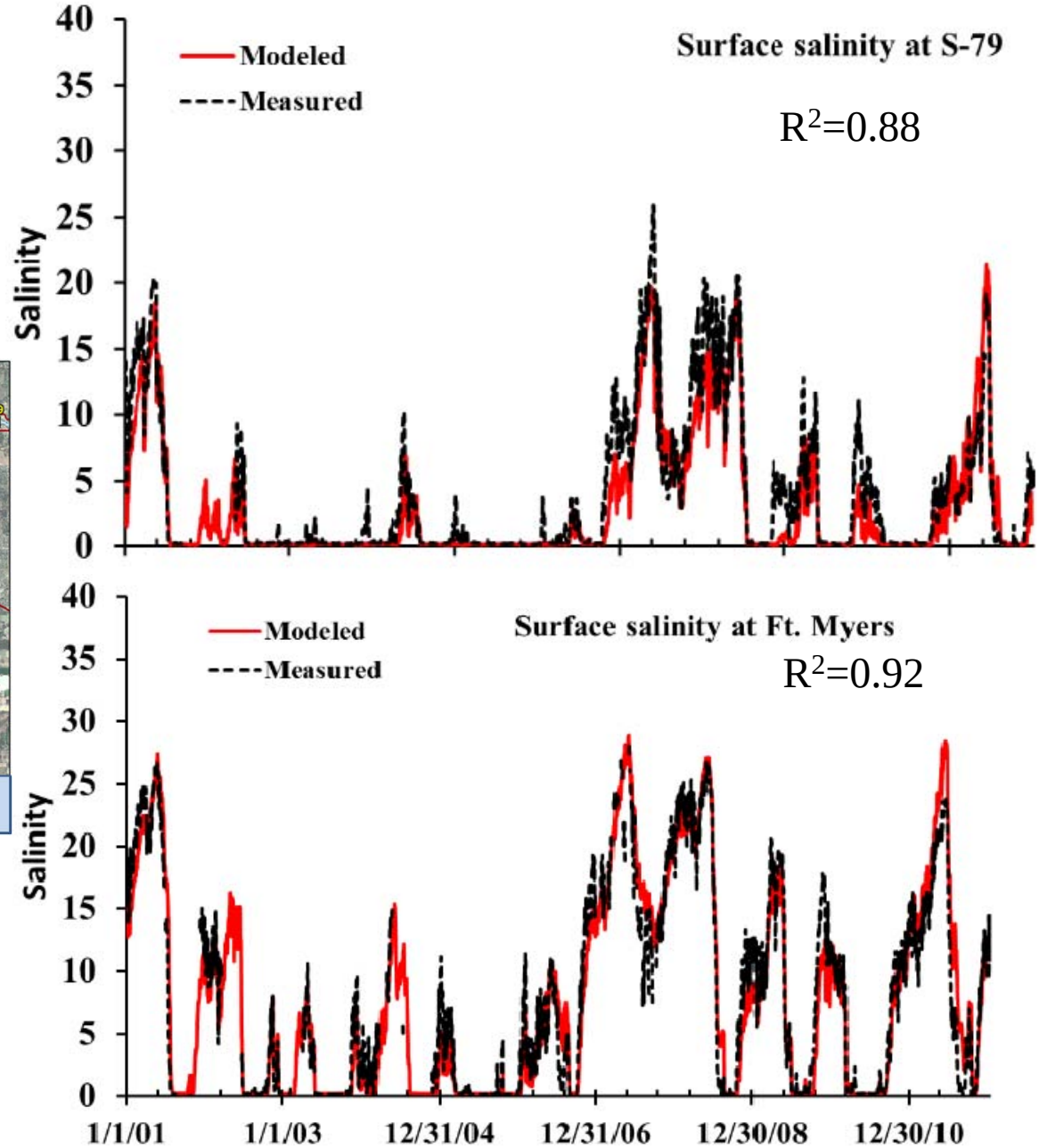
HYDRODYNAMIC MODEL VALIDATION - STAGE



HYDRODYNAMIC MODEL VALIDATION - DISCHARGE

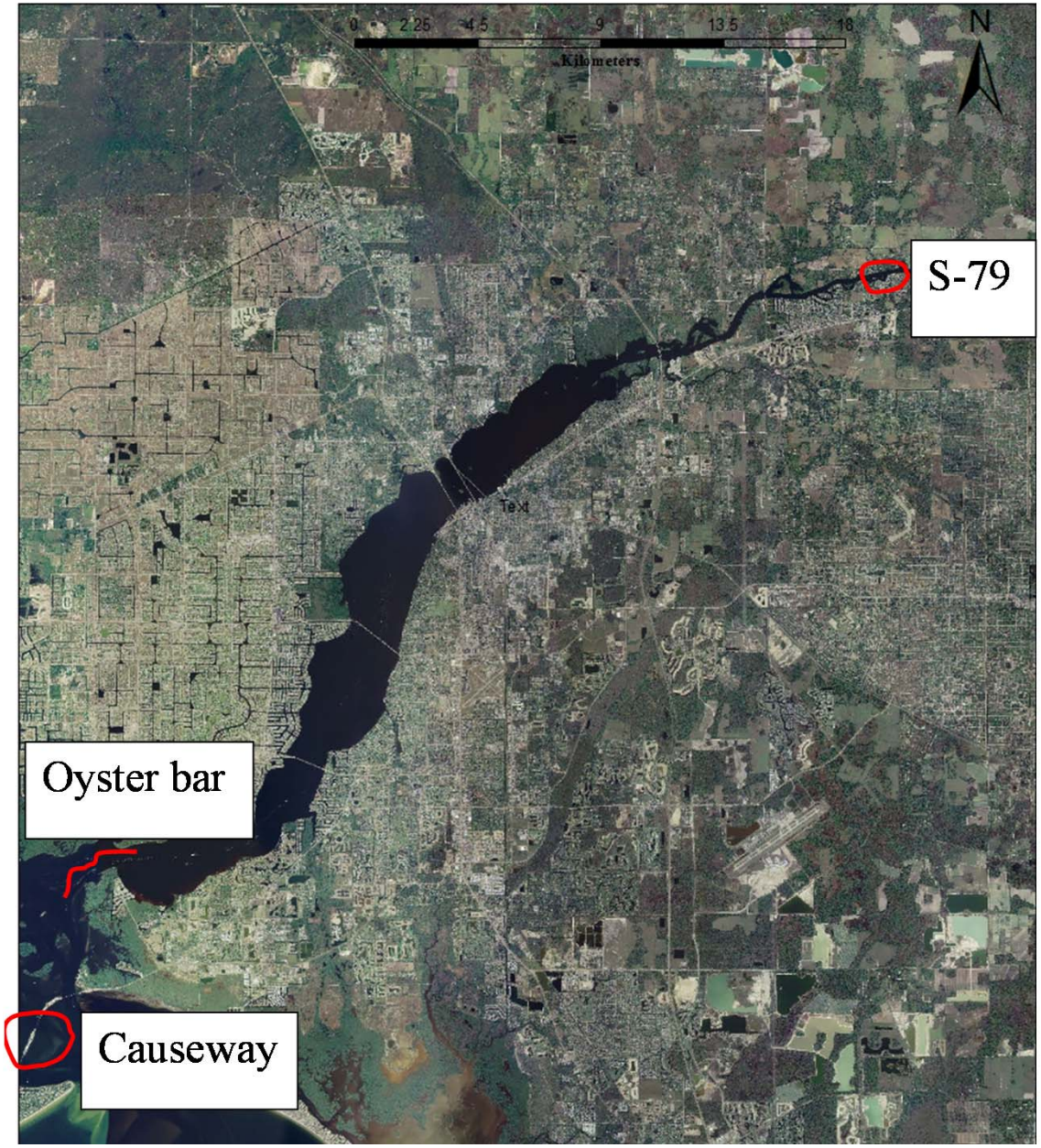


HYDRODYNAMIC MODEL VALIDATION - SALINITY

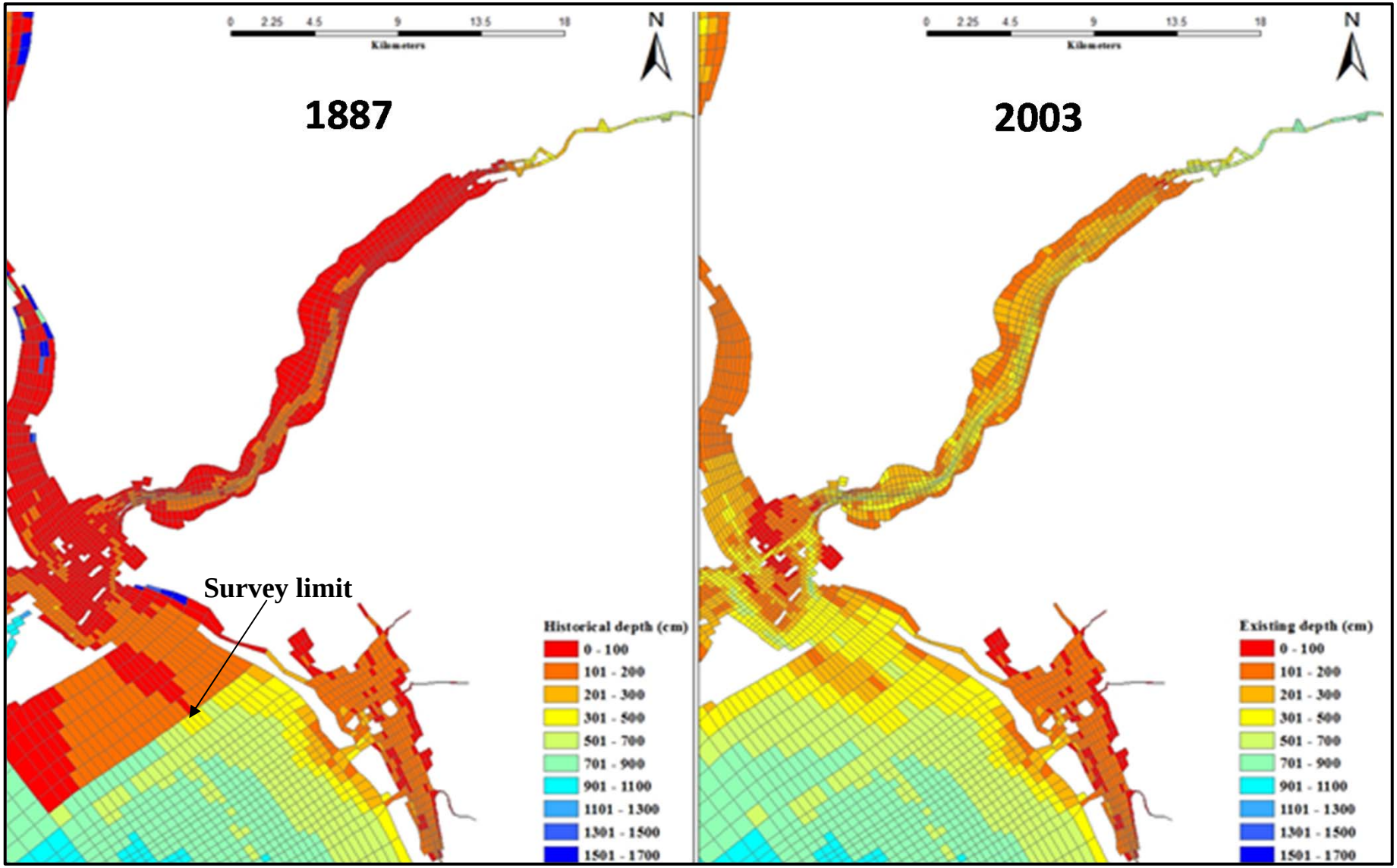


PHYSICAL ALTERATIONS

1. **S-79 removal**
2. **Removal of Sanibel Causeway**
3. **Backfill of Oyster Bar**
4. **Refill of navigation channel (ICW)**

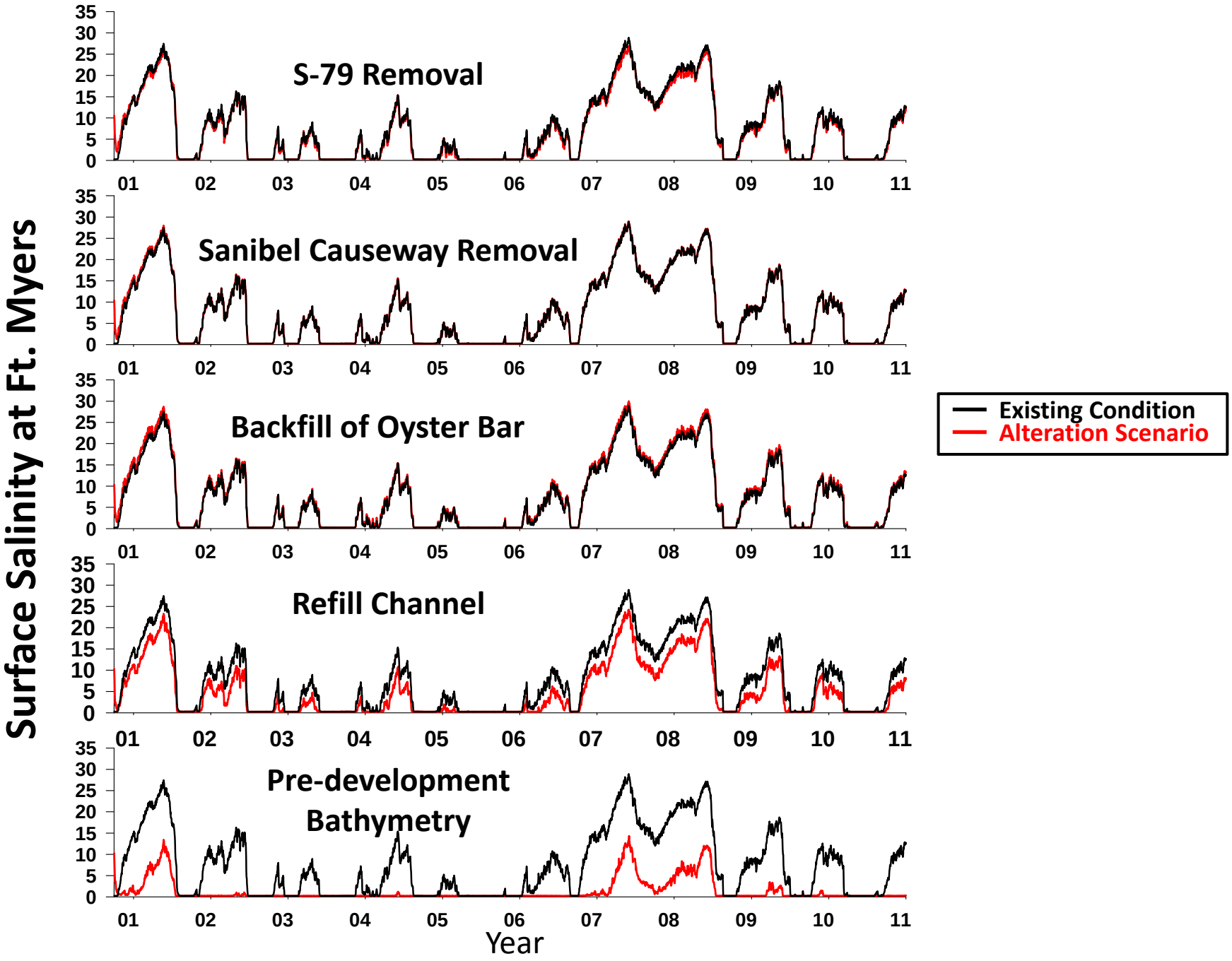


PHYSICAL ALTERATIONS - BATHYMETRY

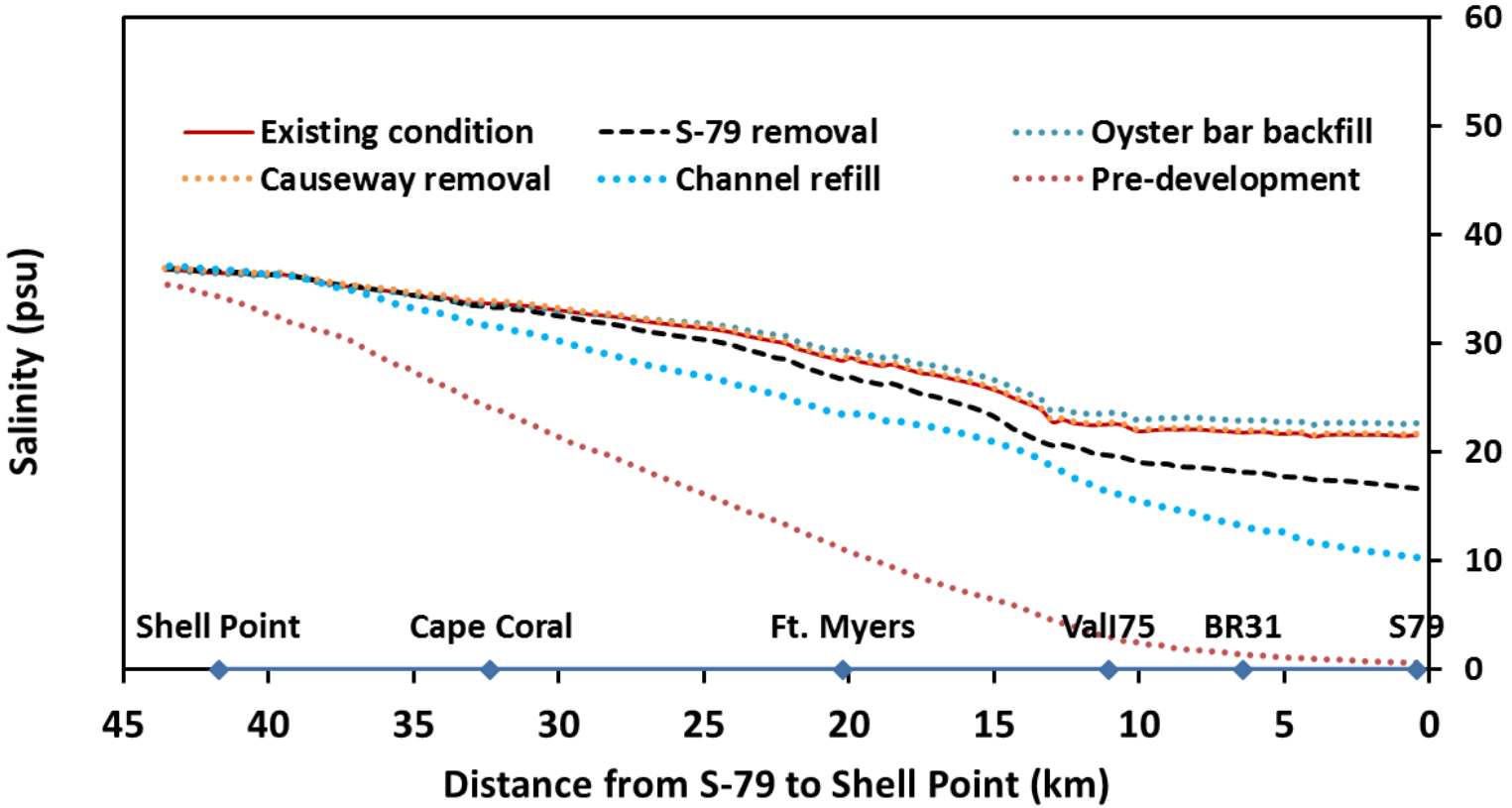


Pre-development

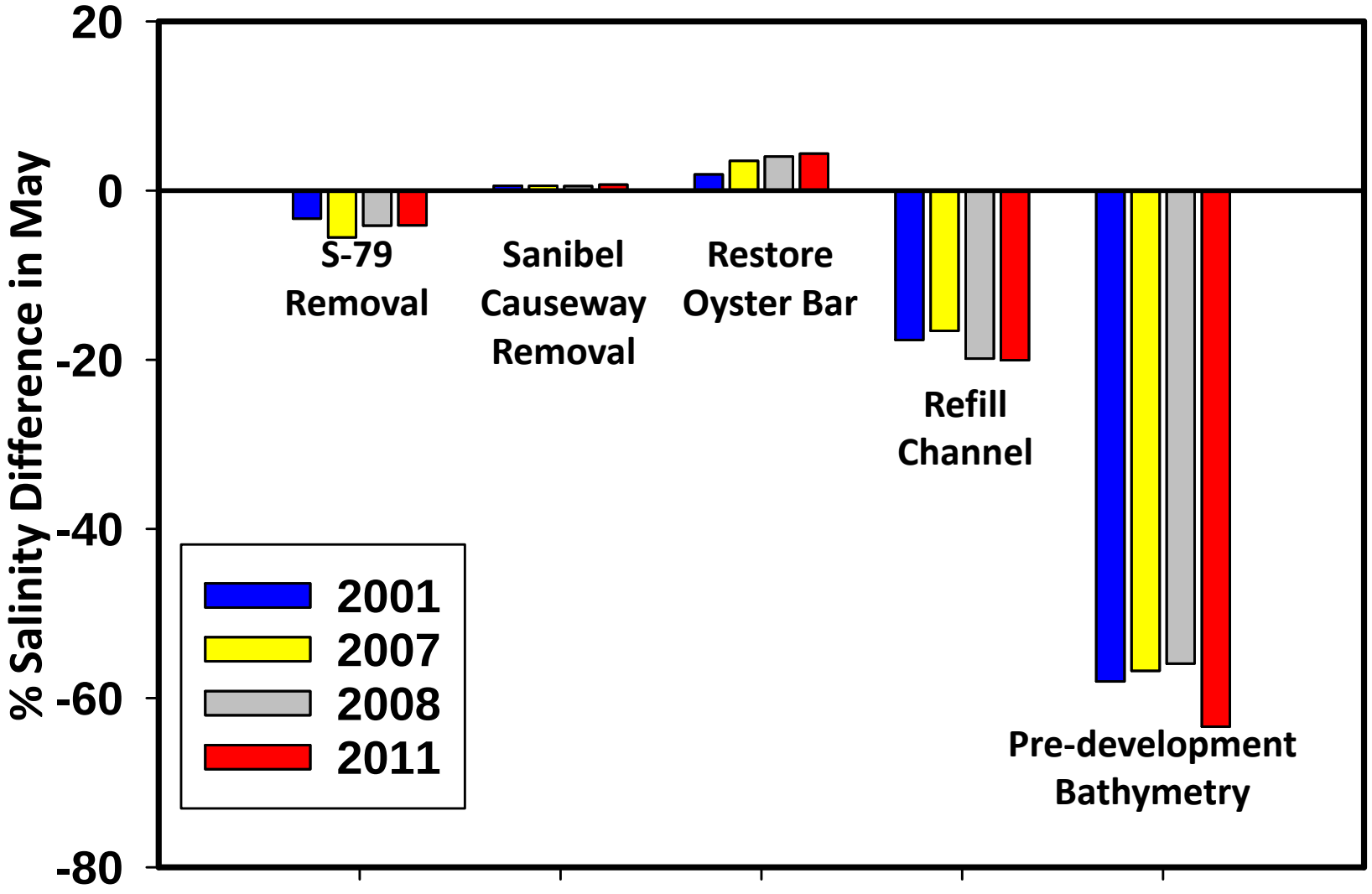
Existing Condition


Surface Salinity at Ft. Myers
S-79 Removal
Sanibel Causeway Removal
Backfill of Oyster Bar
Refill Channel
Pre-development Bathymetry
Existing Condition
Alteration Scenario
Year
0
5
10
15
20
25
30
35
01
02
03
04
05
06
07
08
09
10
11

COMPARISON OF SALINITY GRADIENT – 5/2001

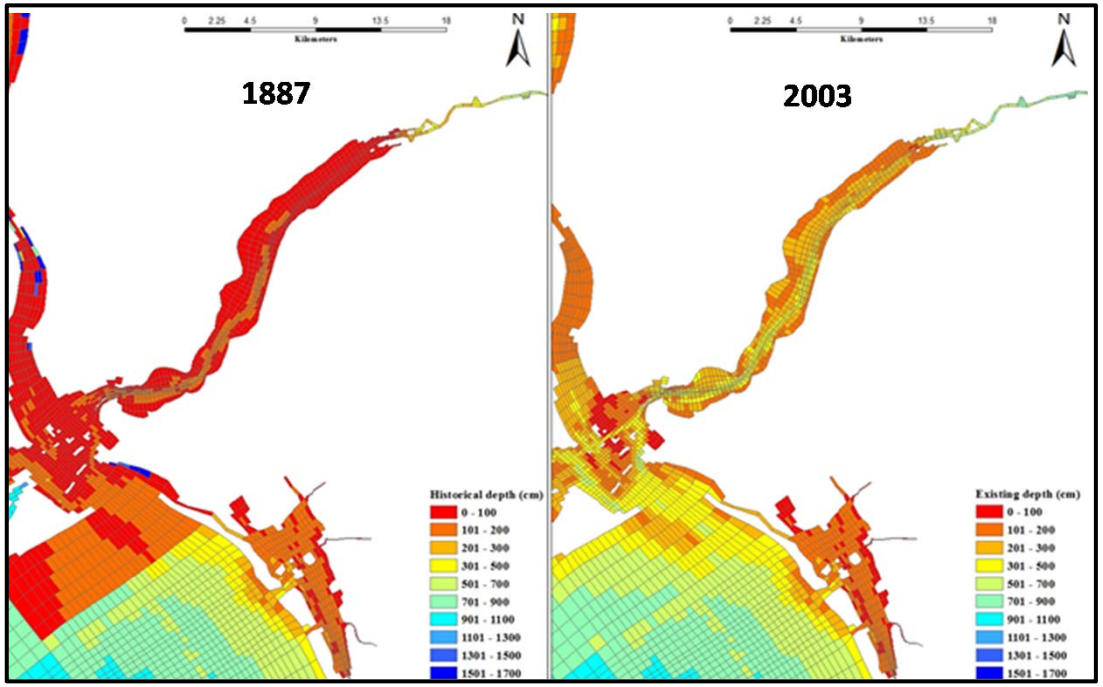


SALINITY DIFFERENCE AT FT. MYERS



STUDY SUMMARY

- **Physical alterations likely had significant impacts on salt intrusion**
- **Dredging and deepening are the primary cause of salinity increase**
- **Largely irreversible physical alterations should be considered in the development of freshwater inflow targets**



SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Component Study 2: Analysis of the Relationship Between Freshwater Inflow at S-79 and Salinity in the Caloosahatchee River Estuary 1993-2013

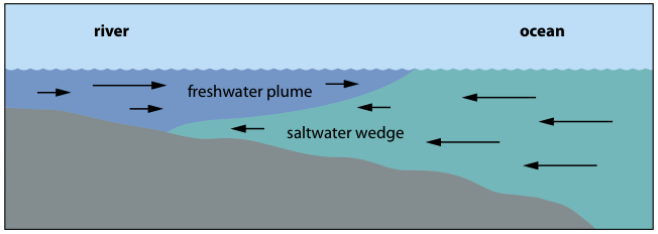
Christopher Buzzelli, PhD

Lead Scientist

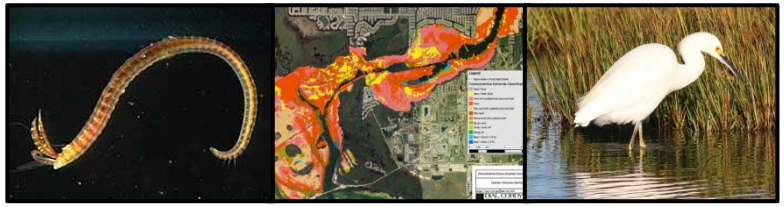
Coastal Ecosystems Section

South Florida Water Management District

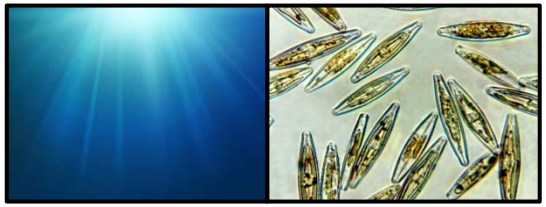
INDICATORS OF ESTUARINE RESPONSE TO LOW INFLOW



Changes in isohaline position with upstream encroachment of saltier water



Alter benthic community upon which many estuarine fauna are dependent



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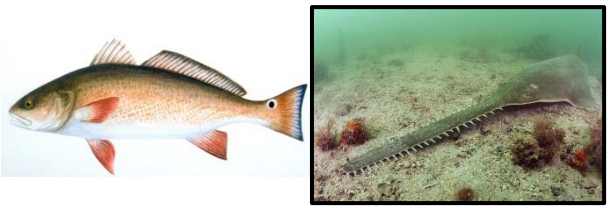

Affect coastal fish populations dependent upon estuaries as nurseries

Negatively impact harvests of important fisheries

SCIENCE COMPONENTS / STUDIES

	Component	Method
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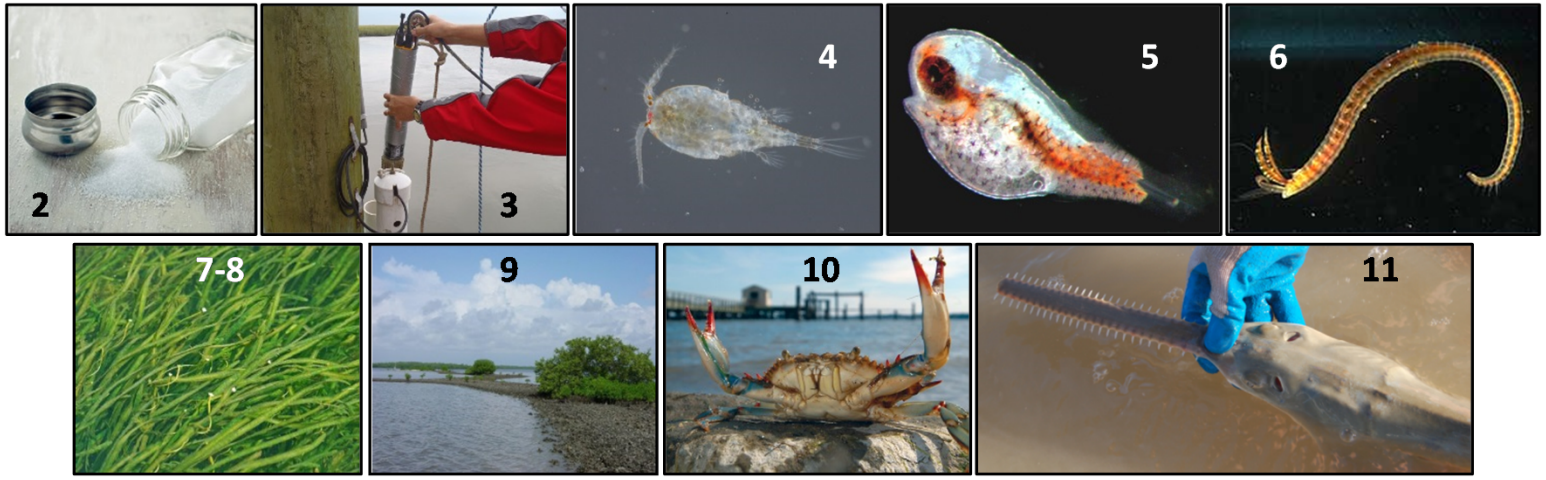
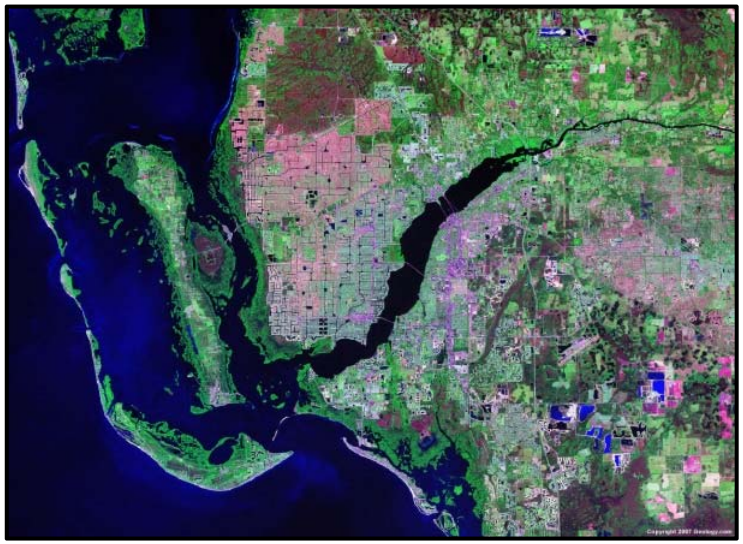
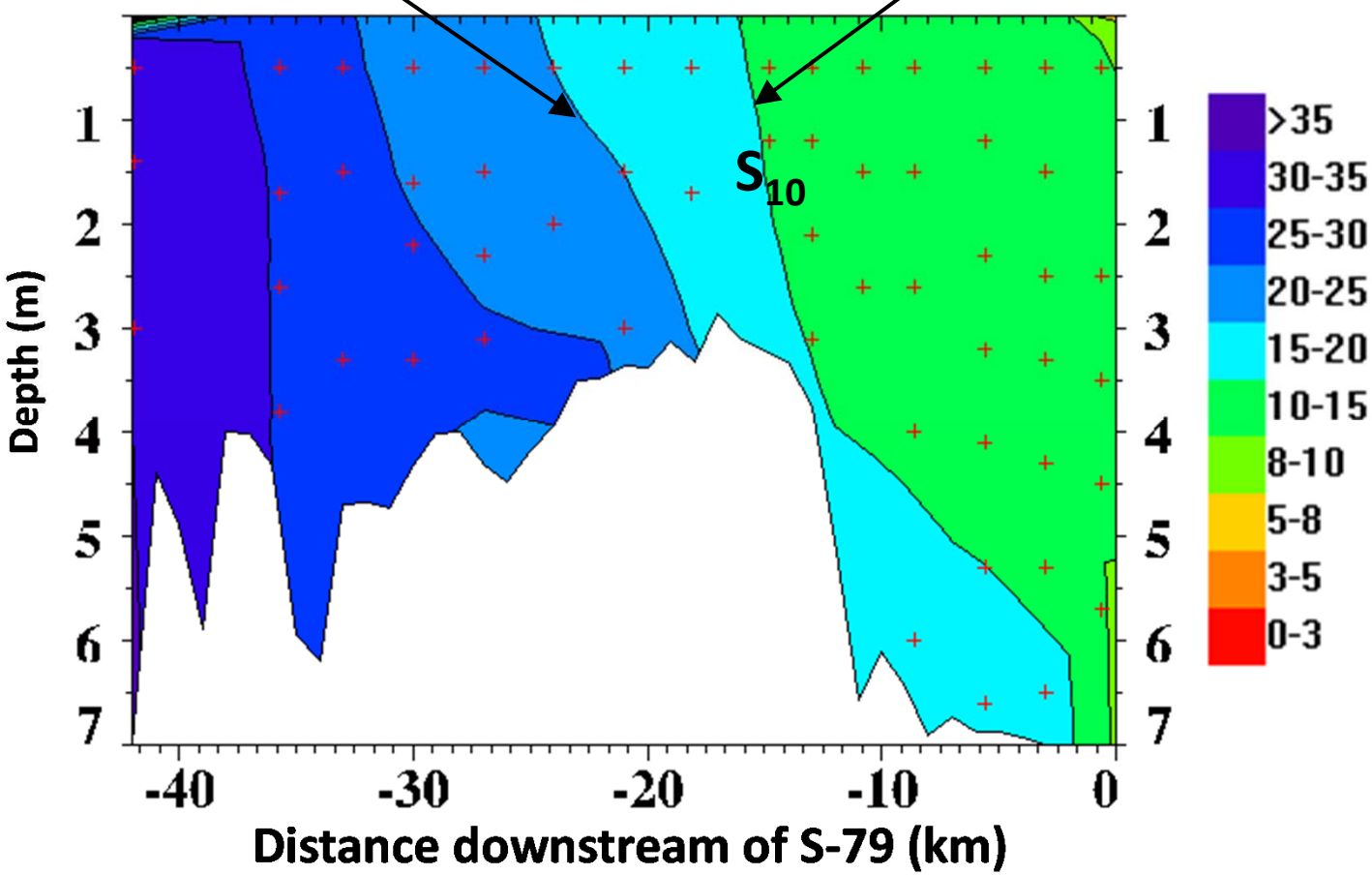


STUDY RATIONALE

- **Life histories of estuarine organisms depend on salinity gradients**
- **Salinity gradients can be quantified using isohalines (i.e. S = 10)**
- **Isohaline locations fluctuate with freshwater inflow, tide, and wind**
- **Longitudinal shifts in isohaline position can narrow the habitat or transport organisms away from their optimal location**
- **Isohaline position can indicate ecological conditions at the ecosystem scale**



Isohalines = lines of equal salinity



Low Freshwater Inflow

- Upstream migration of isohalines
- Increased salinity throughout estuary
- Increased flushing time (>> 30 d)

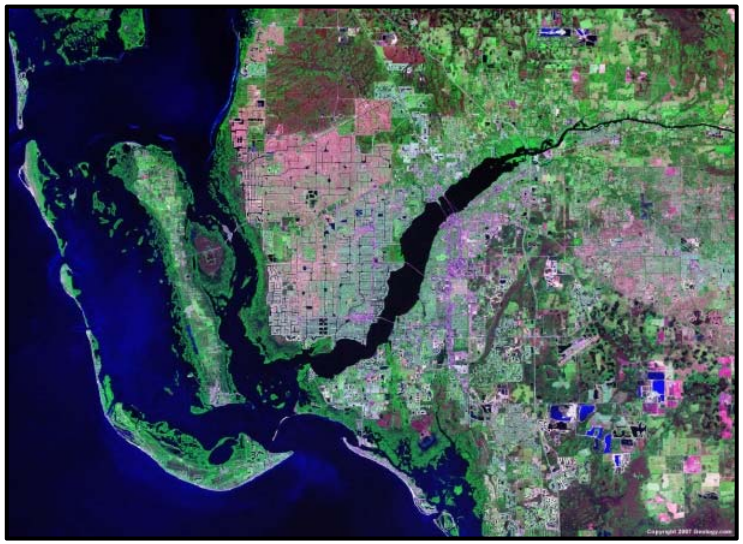
RESEARCH COMPONENT RATIONALE

- **Salinity $\leq$10 (S_{10}) at Ft. Myers is beneficial for upper CRE in the dry season**
  - **Promotes growth of *Vallisneria americana* (tape grass)**
  - **Creates favorable salinity gradients for variety of biota in estuary**

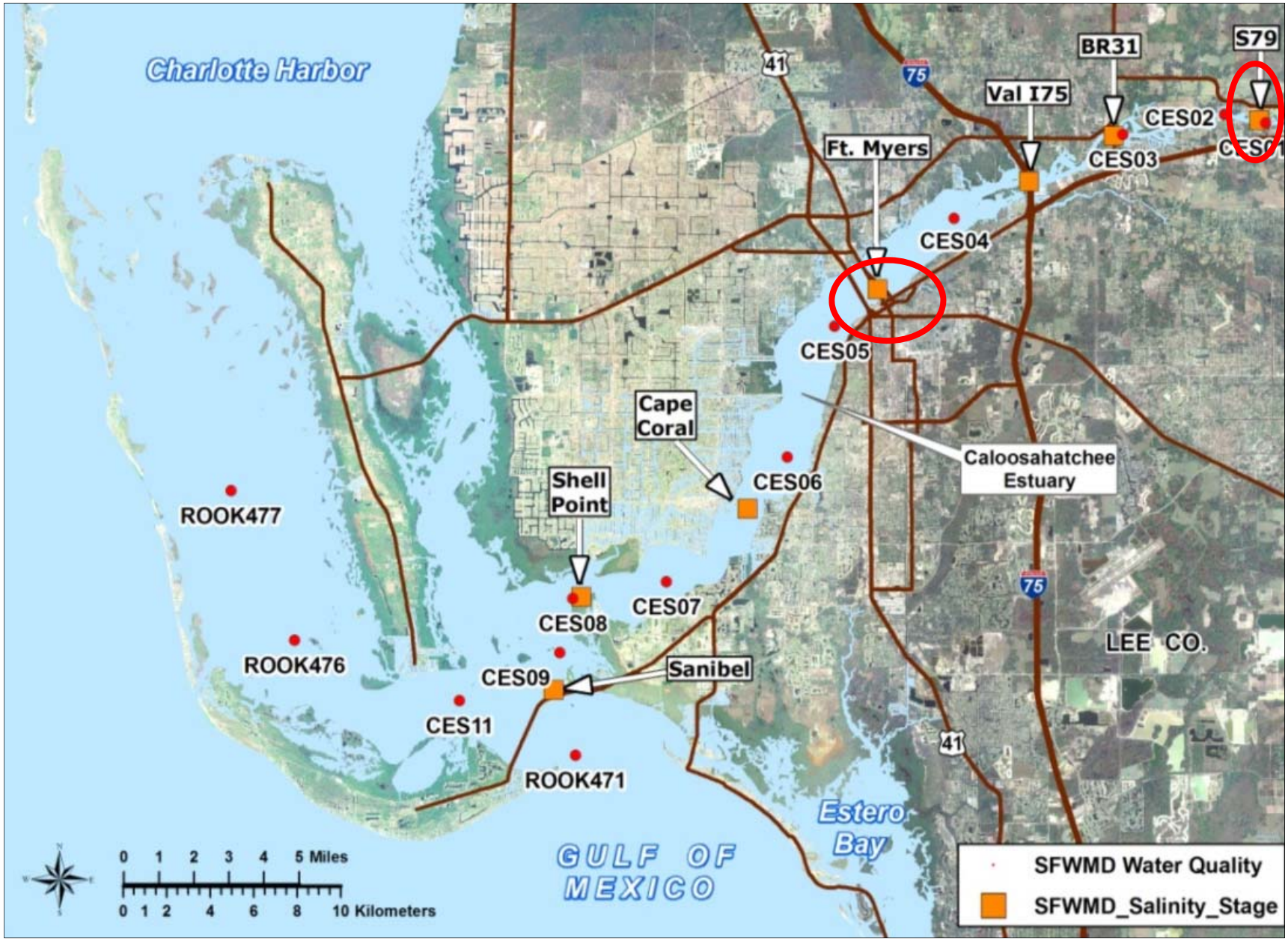
- **Inverse relationship between S-79 inflow and salinity at Ft. Myers**

- **What S-79 inflow is associated with S_{10} at Ft. Myers?**

- **Does the magnitude of this calculated inflow vary inter-annually?**



CRE MONITORING LOCATIONS



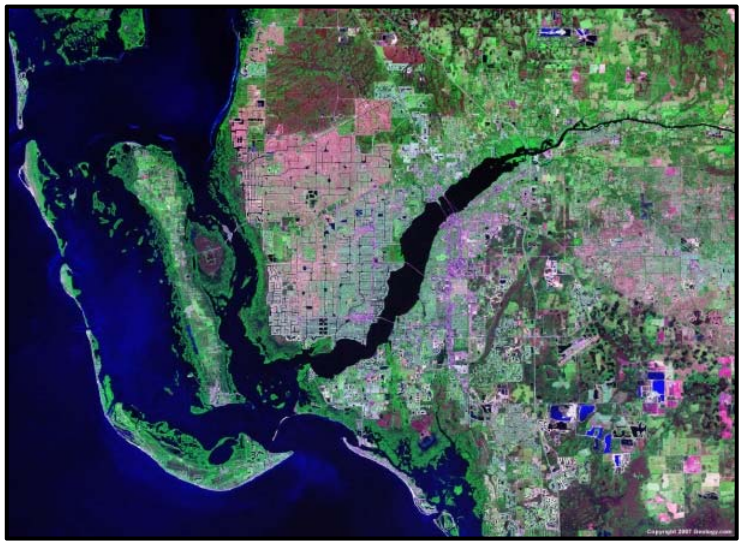
STUDY METHODS

- **SFWMD DBHydro**

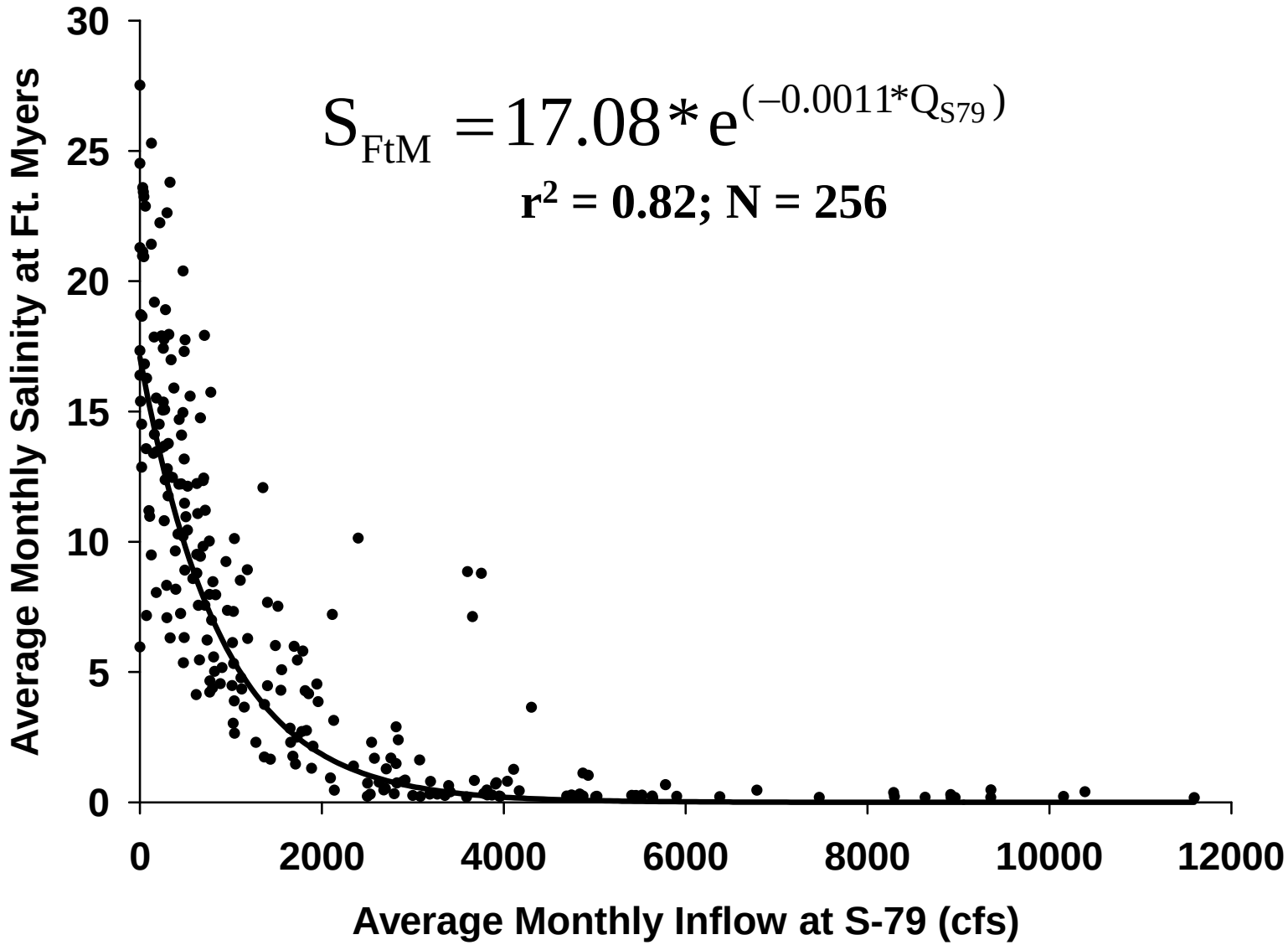
  (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu)

- **WY1993-2013 (WY = 5/1 to 4/30; includes both wet and dry seasons)**
  - **S-79 inflow rate (Q; cfs)**
  - **Salinity at Ft. Myers**

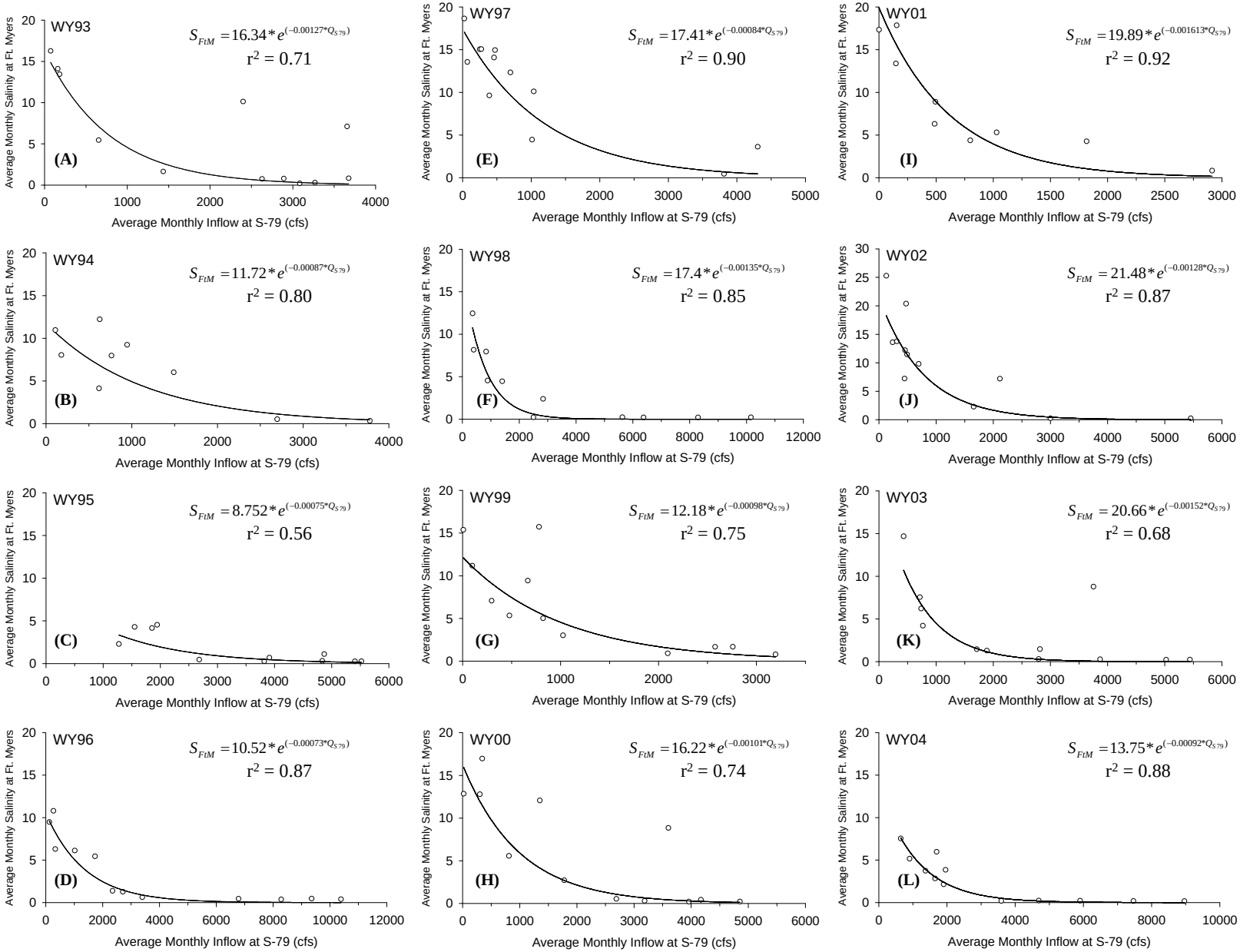
- **Average monthly inflow and Ft. Myers salinity for each WY (5/1 to 4/30)**
  - **Inverse exponential relationship between inflow and salinity for each year**
  - **Solve equation to calculate Q with S_{10} at Ft. Myers (Q_{calc})**
  - **Evaluate variations in Q_{calc} from WY1993-2013**



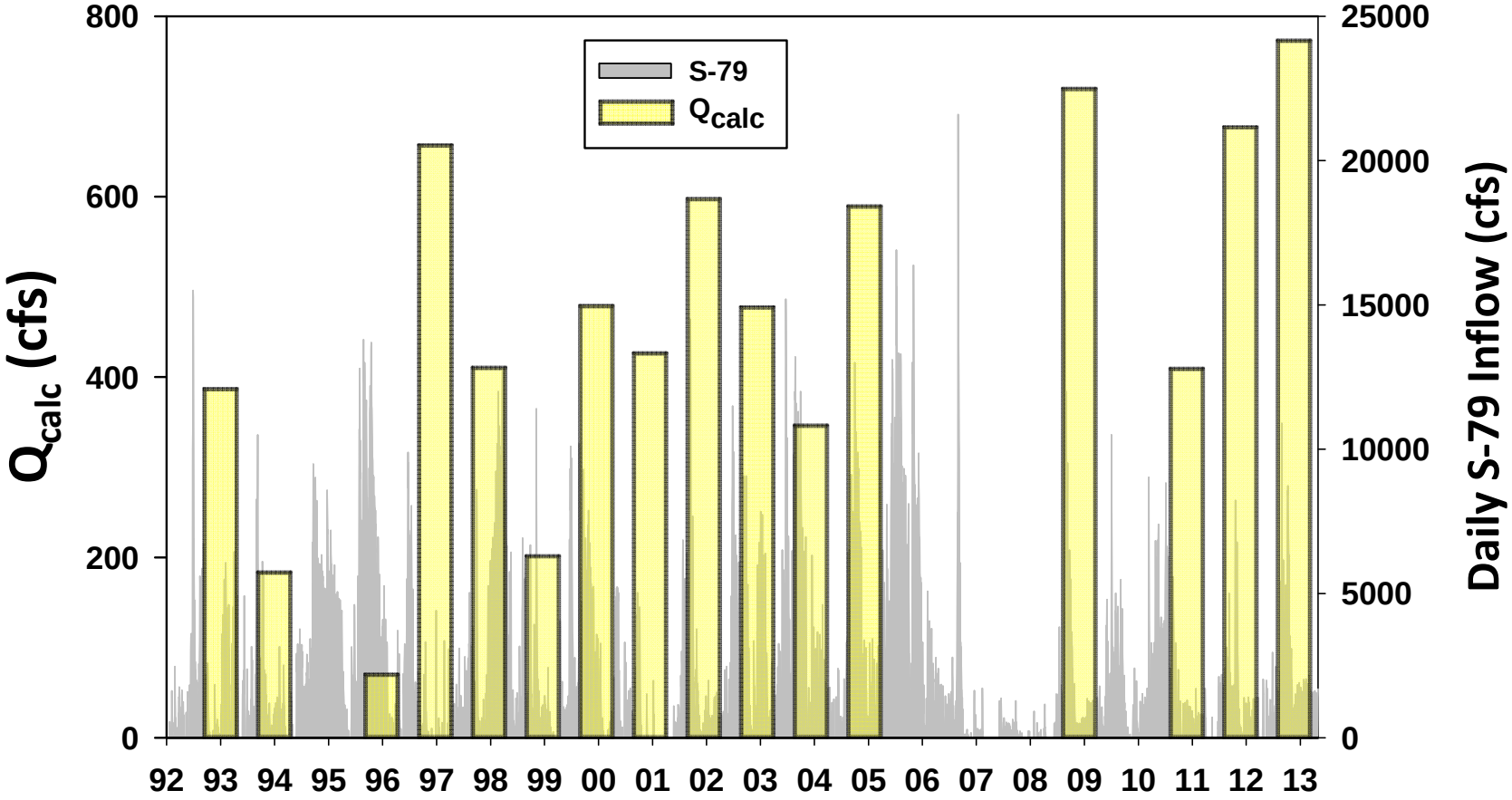
INFLOW-SALINITY RELATIONSHIP – ALL MONTHS



INFLOW-SALINITY RELATIONSHIPS BY WY



INFLOW-SALINITY RELATIONSHIPS BY WY



- No Q-S relationship in 1995, 2006-2008; missing data in 2010
- r^2 ranged from 0.71 (1993) to 0.96 (2011)
- For each water year solve for Q_{calc} with salinity of 10 (S_{10})
- Inter-annual variations in the magnitude of Q_{calc}
- Min = 70 cfs (1996); Max = 773 cfs (2013); Mean = 445±218 cfs
- Different amounts of S-79 inflow required for S_{10}

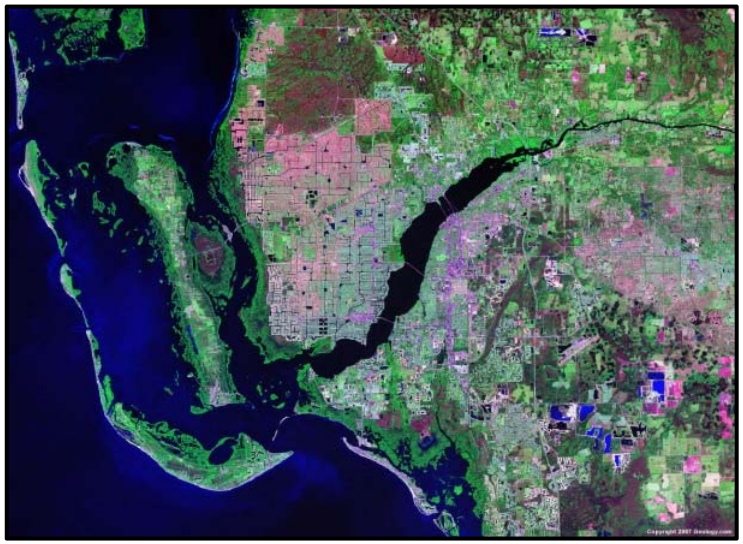
STUDY SUMMARY

- **Ft. Myers salinity values ≤10 are desirable in the dry season**

- **Q_{calc} for S_{10} varied from 70-773 cfs with an average±SD of 445±218 cfs**

- **Magnitude of inflow associated with S_{10} varied inter-annually**

- **Factors to explain variations in Q_{calc}**
  - **Over all months, S-79 inflow explained ~82% of variability in salinity at Ft. Myers**
  - **Inflow from the ungauged tidal basin downstream of S-79 can be important**
  - **Can have significant effects of wind and tide on water level and salinity gradients**



SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Component Study 3: Relationships Between Freshwater Inflows and Water Quality Attributes During The Dry Season in Caloosahatchee River Estuary

Christopher Buzzelli, Peter Doering, Teresa Coley, Zhiqiang Chen

Coastal Ecosystems Section

South Florida Water Management District

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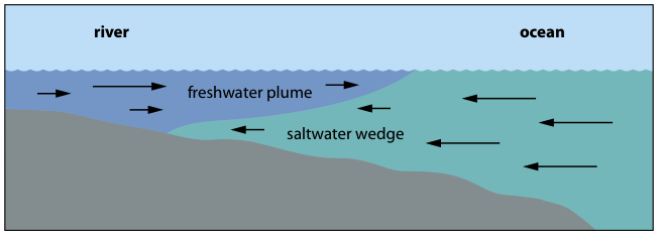

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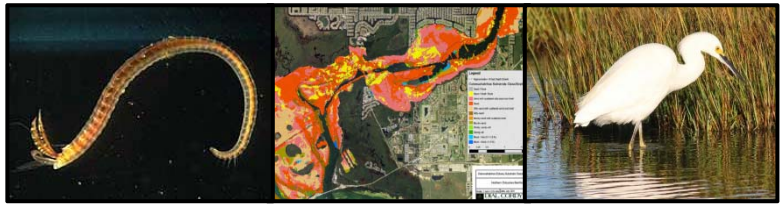

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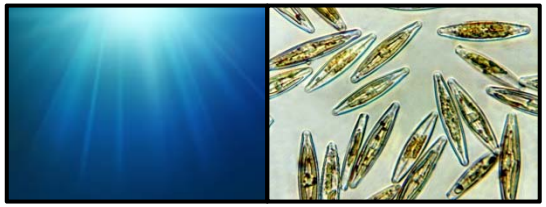

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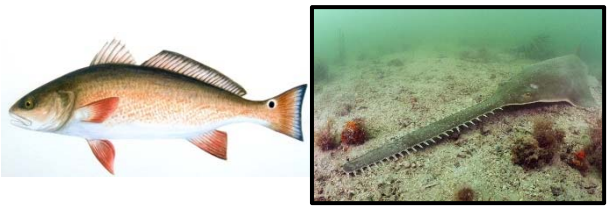

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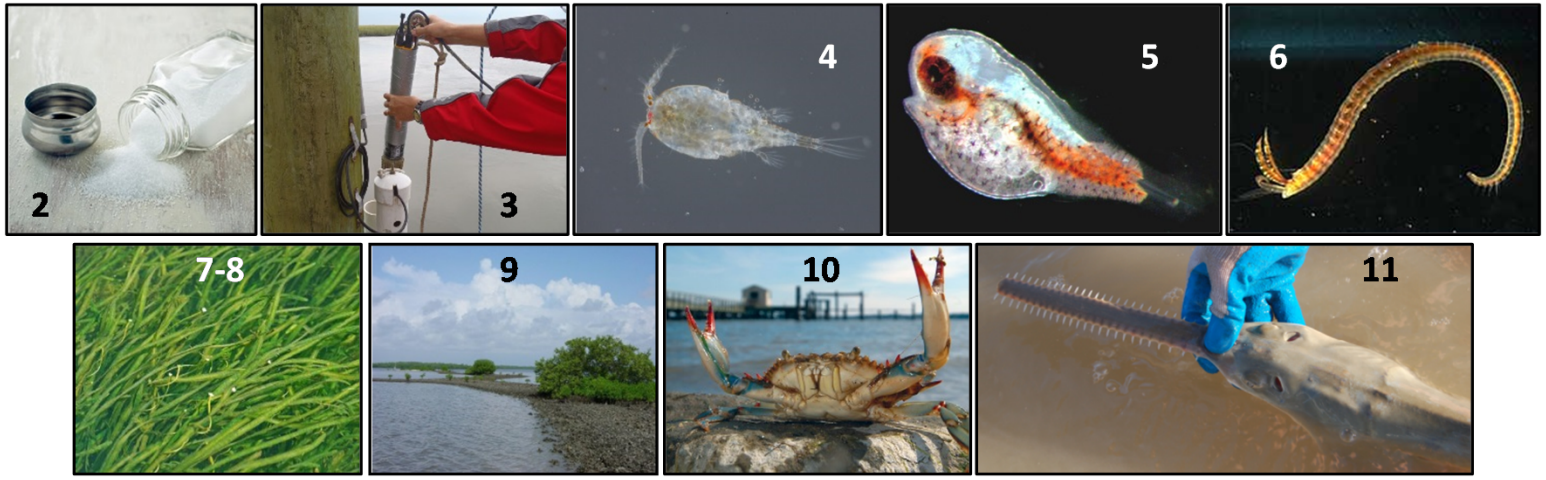
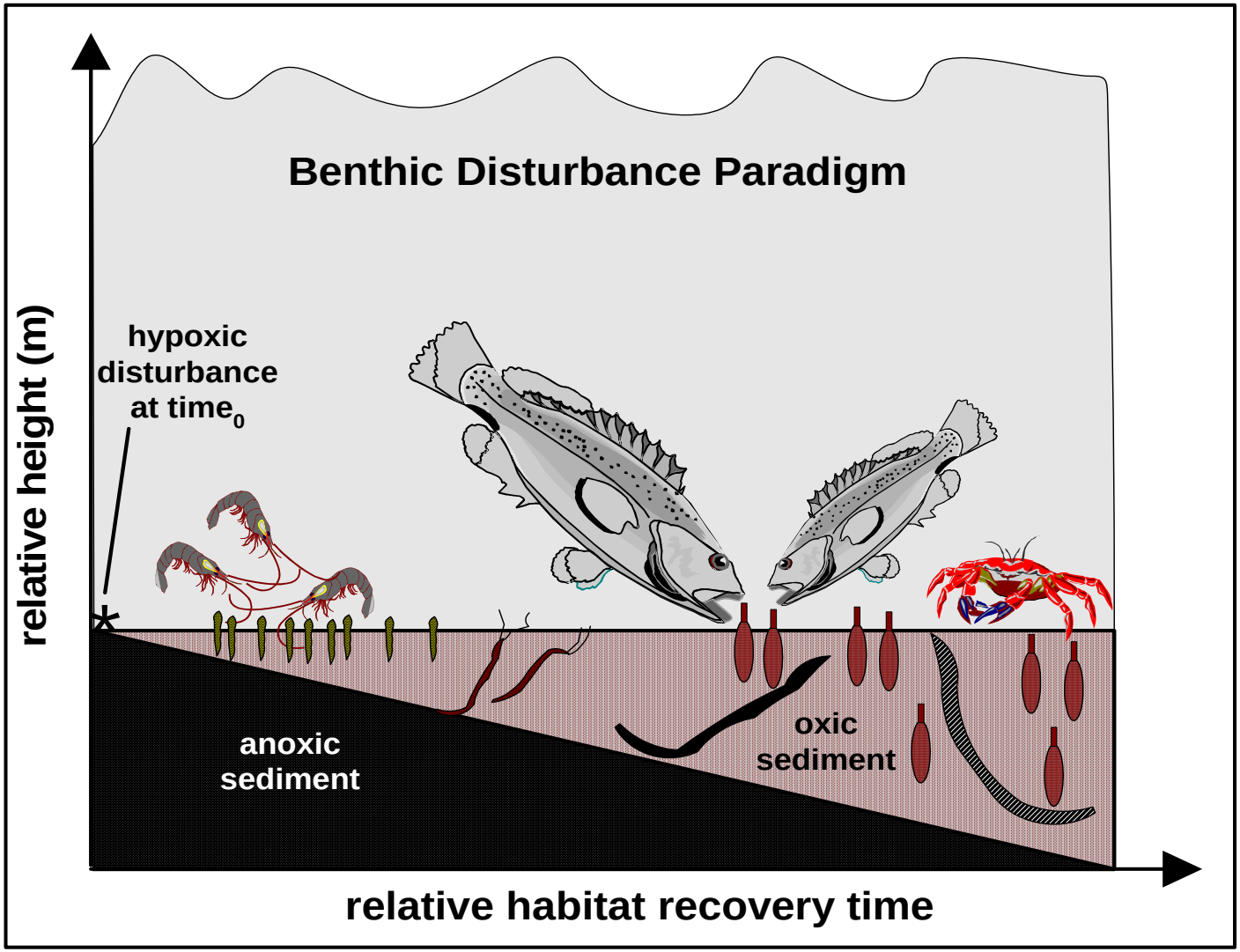




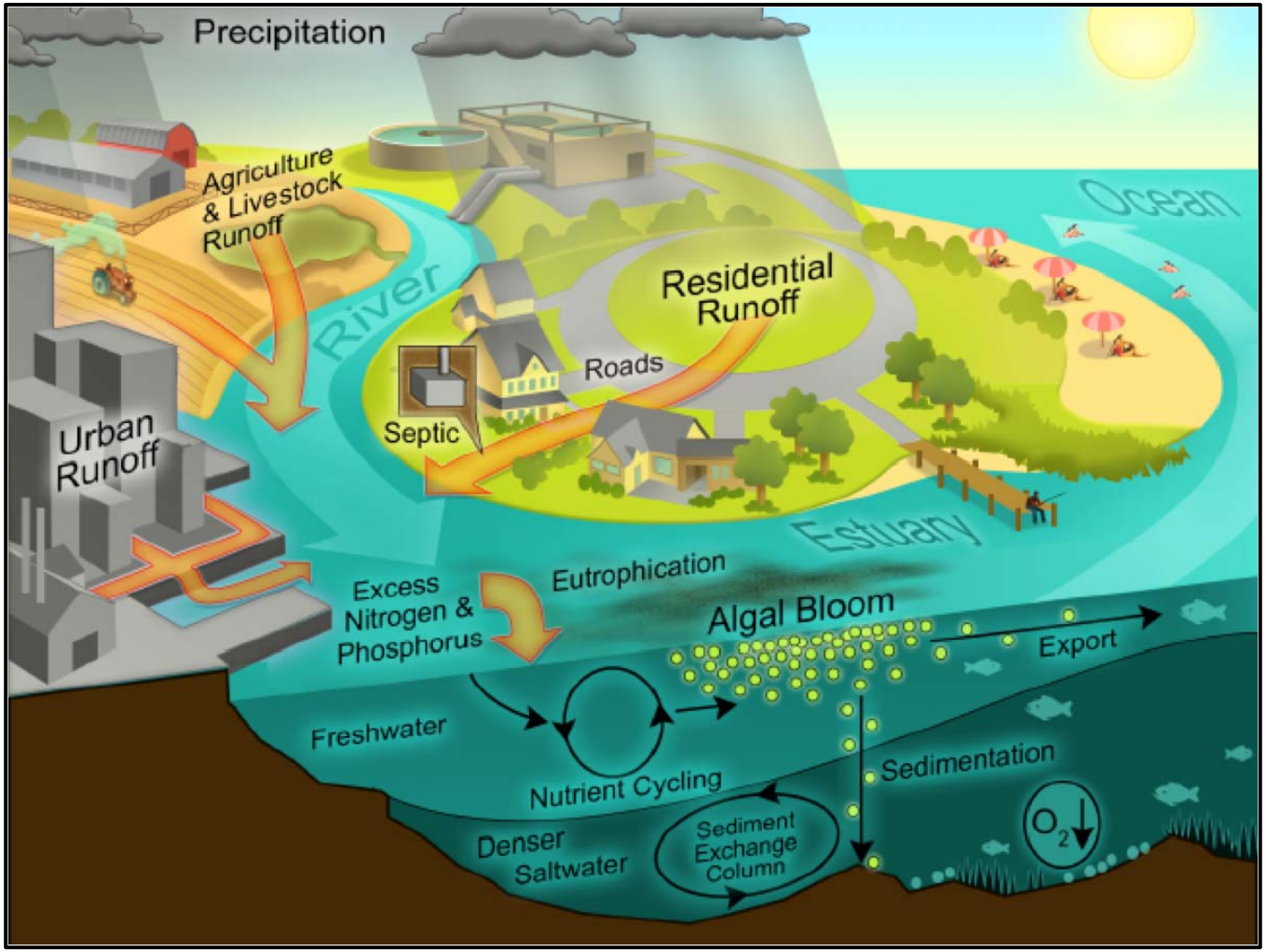
ESTUARINE HYPOXIA

Bottom water hypoxia (DO $\leq$ 3 mg L^{-1}) is a problem for many estuaries

Hypoxia negatively impacts

- Benthic fauna (meio-, macro-, infauna)
- Fish population dynamics & harvest
- Ecosystem energy flow

ESTUARINE HYPOXIA



The potential for hypoxia is related to phytoplankton blooms

- **Biomass production in excess of grazing + transport**
- **Vertical sinking and deposition of phytodetritus**
- **Increased sediment organic content and bottom water DO consumption**

STUDY RATIONALE

- **Phytoplankton dynamics at the event-scale can be particularly acute in small estuaries with sub-tropical climate and managed freshwater inflows**

- **Low inflow in the dry season to micro-tidal Gulf of Mexico (GOM) estuaries**
  - **Reduced flushing and increased vertical salinity stratification**
  - **Phytoplankton growth in excess of loss (transport & grazing)**
  - **Upstream migration of the chlorophyll *a* maximum (CHL_{max})**
  - **Deposition of phytodetritus**
  - **Potential for bottom water hypoxia**

- **There is limited information on the effects of low inflows on CRE water quality**

STUDY OBJECTIVES

QUESTION

Does low dry season inflow enhance phytoplankton biomass (CHL) and hypoxic conditions in the bottom waters?

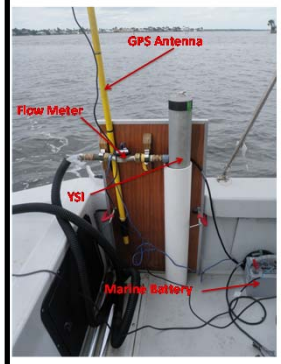
OBJECTIVES

1. To use long-term monitoring data to evaluate the inflow conditions associated with potential for increased CHL in the dry season

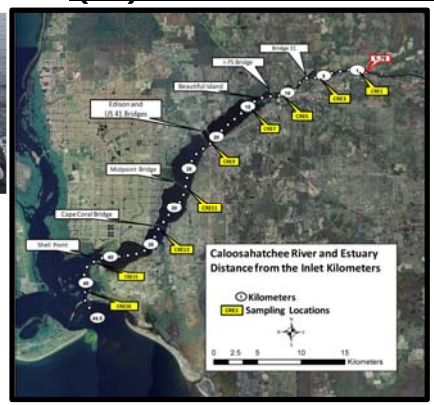
2. To use a water quality simulation model to examine CHL in the upper CRE associated with low dry season inflows (<500 cfs)

3. To assess water quality gradients and potential for bottom water hypoxia at the event scale in the dry season

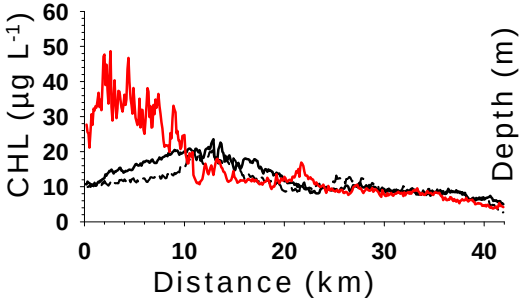
(3) EVENT SCALE STUDY



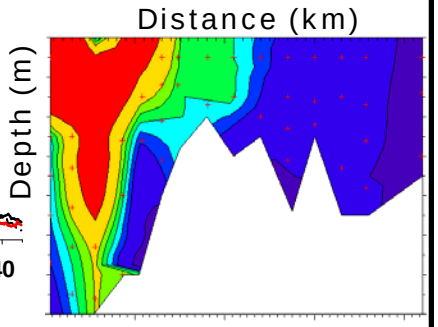
Flow-through sampling & vertical profiles



Entire CRE in hours

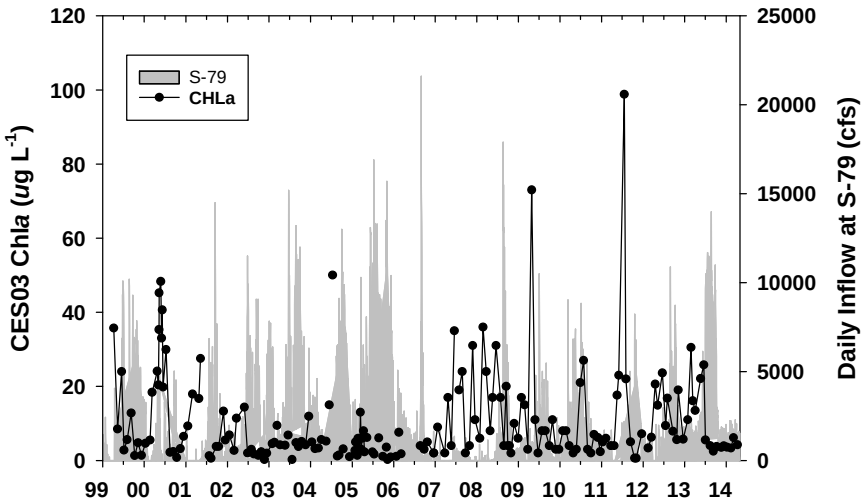


Longitudinal gradients

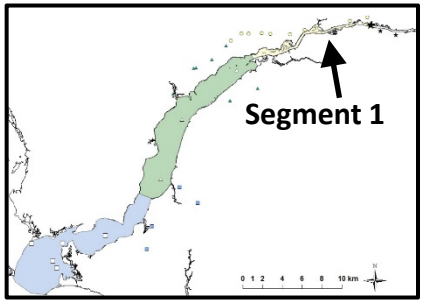


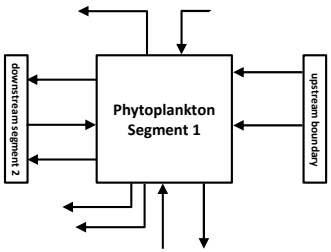
Contours interpolated from profiles

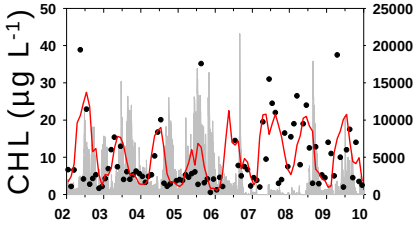
(1) LONG-TERM DATA

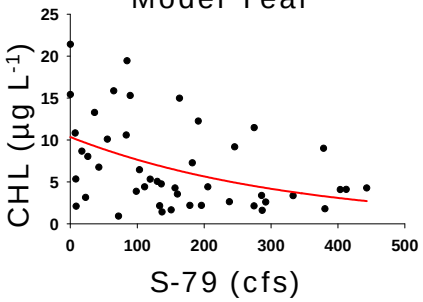


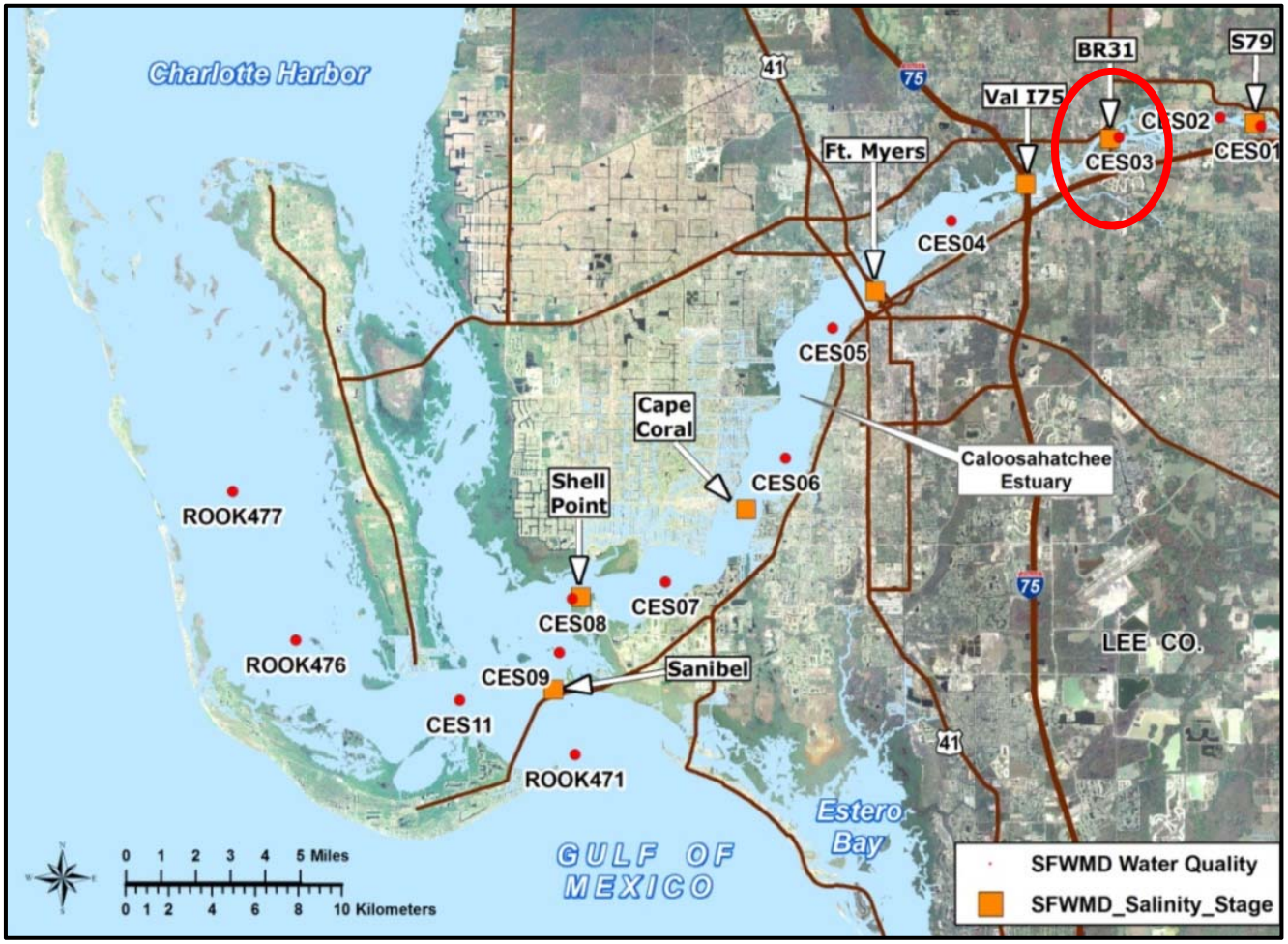
(2) WQ MODELING

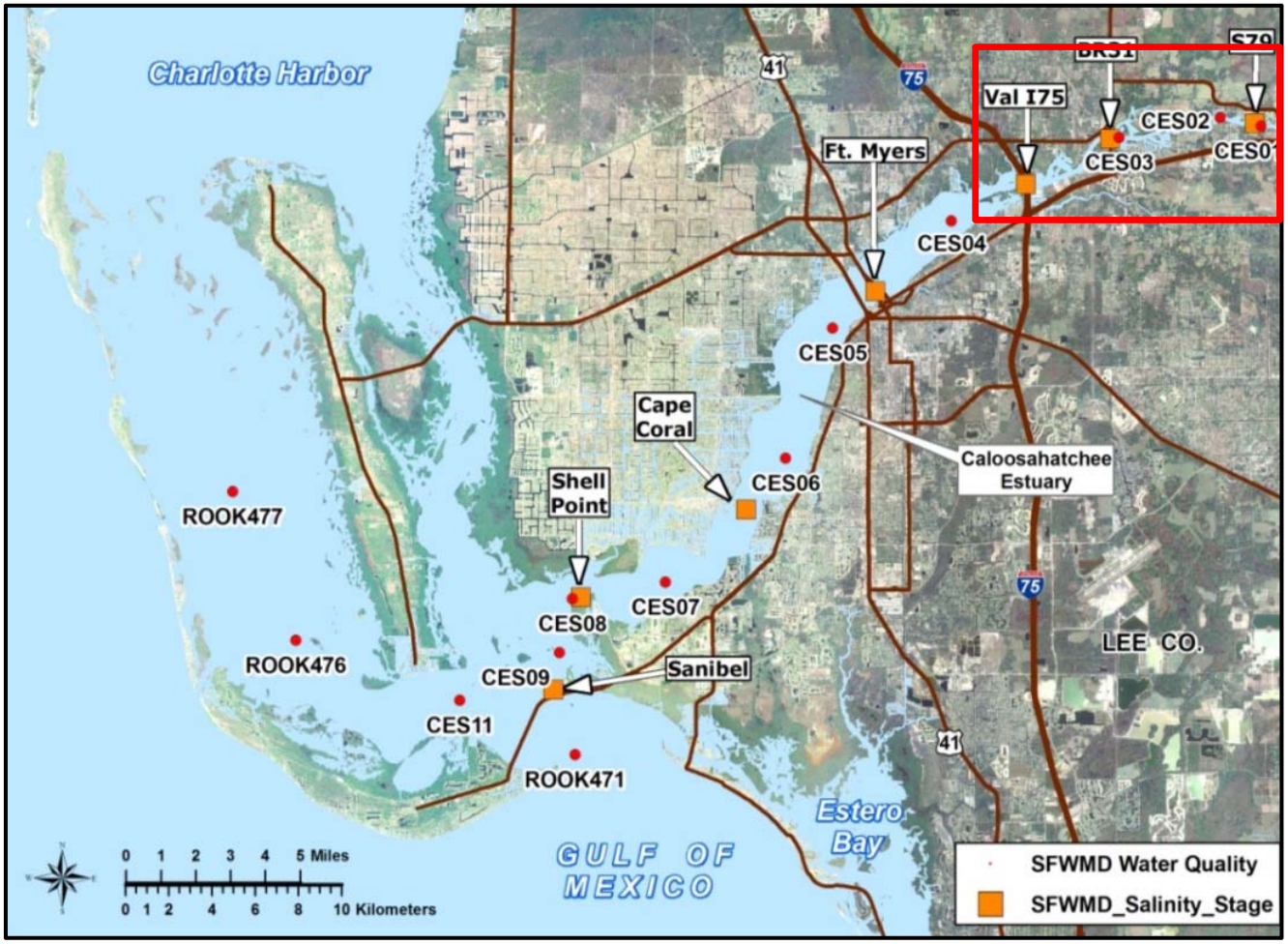


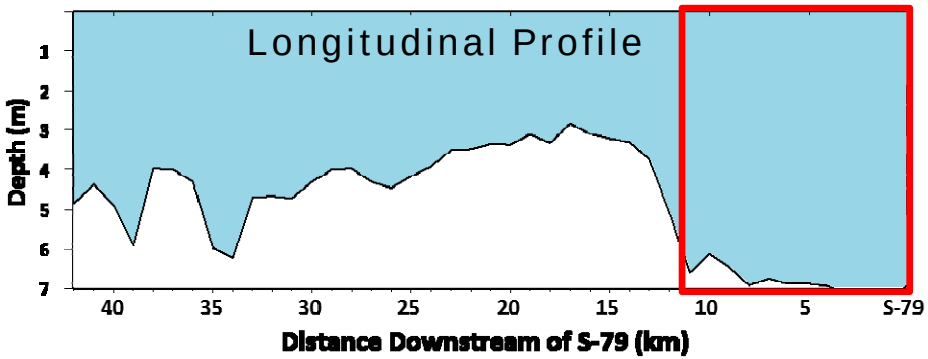







Charlotte Harbor
BR31
S79
Val I75
CES02
CES01
CES03
Ft. Myers
CES04
CES05
Cape Coral
Caloosahatchee Estuary
Shell Point
CES06
ROOK477
CES08
CES07
LEE CO.
ROOK476
CES09
Sanibel
CES11
ROOK471
Estero Bay
GULF OF MEXICO
0 1 2 3 4 5 Miles
0 1 2 4 6 8 10 Kilometers
SFWMD Water Quality
SFWMD_Salinity_Stage

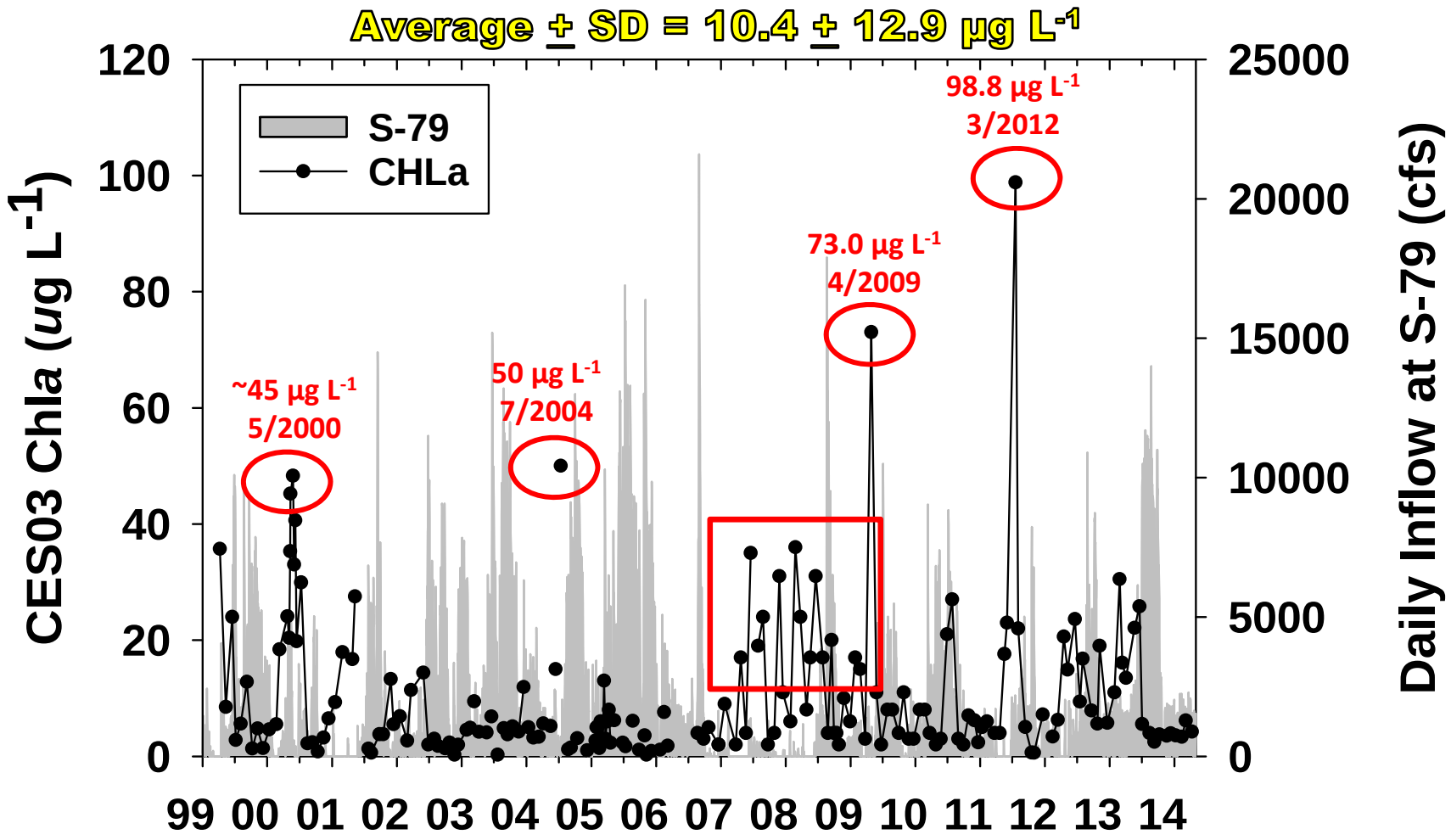

Charlotte Harbor
41
75
Val I75
BRS1
S79
CES02
CES03
CES01
Ft. Myers
CES04
CES05
Cape Coral
Caloosahatchee Estuary
CES06
Shell Point
ROOK477
CES08
CES07
ROOK476
CES09
Sanibel
CES11
ROOK471
LEE CO.
Estero Bay
GULF OF MEXICO
0 1 2 3 4 5 Miles
0 1 2 4 6 8 10 Kilometers
SFWMD Water Quality
SFWMD_Salinity_Stage


Longitudinal Profile
Depth (m)
1
2
3
4
5
6
7
40
35
30
25
20
15
10
5
S-79
Distance Downstream of S-79 (km)

LONG-TERM WATER QUALITY DATA

- **Water concentrations monitored monthly at multiple locations in the CRE**
- **Data available DBHydro at the SFWMD (http://www.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu)**
- **CHL concentrations at CES03 in the upper CRE from 4/1999 to 4/2014**
- **Combined CHL-inflow data set queried for freshwater inflows associated with the Impaired Waters Rule (Chapter 62-303, FAC) CHL concentration $\geq$ 11 µg L^{-1}**

FRESHWATER INFLOW & CHLOROPHYLL



Greatest CHL*a* concentrations when inflow was reduced

STUDY OBJECTIVES

QUESTION

Does low dry season inflow enhance phytoplankton biomass (CHL) and hypoxic conditions in the bottom waters?

OBJECTIVES

1. To use long-term monitoring data to evaluate the inflow conditions associated with potential for increased CHL in the dry season

2. **To use a water quality simulation model to examine CHL in the upper CRE associated with low dry season inflows (<500 cfs)**

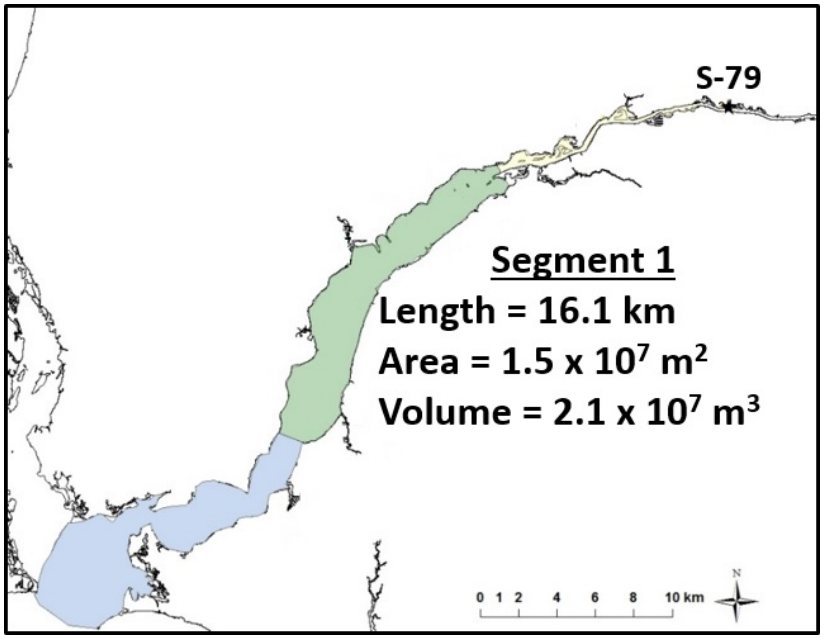
3. To assess water quality gradients and potential for bottom water hypoxia at the event scale in the dry season

CRE WATER QUALITY MODEL

- **Model attributes**
  - **3 homogeneous segments; no vertical resolution; upper Segment 1 for this study**
  - **Box model for transport (advection/dispersion)**
  - **External inputs (freshwater; dissolved and particulate materials)**
  - **Forcing functions (salinity, temperature, light)**
  - **Biogeochemical equations and coefficients**
  - **Simulations = 2922 d from 2002-2009**

- **Each segment with biogeochemical model**
  - **Phytoplankton carbon**
  - **Organic nitrogen and phosphorus**
  - **Inorganic nitrogen and phosphorus**
  - **Sediment microalgae**

- **Analyses**
  - **Dry seasons (Nov-Apr)**
  - **Select days where S-79 $\leq$ 500 cfs**
  - **Evaluate CHL concentrations**



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Estuarine, Coastal and Shelf Science

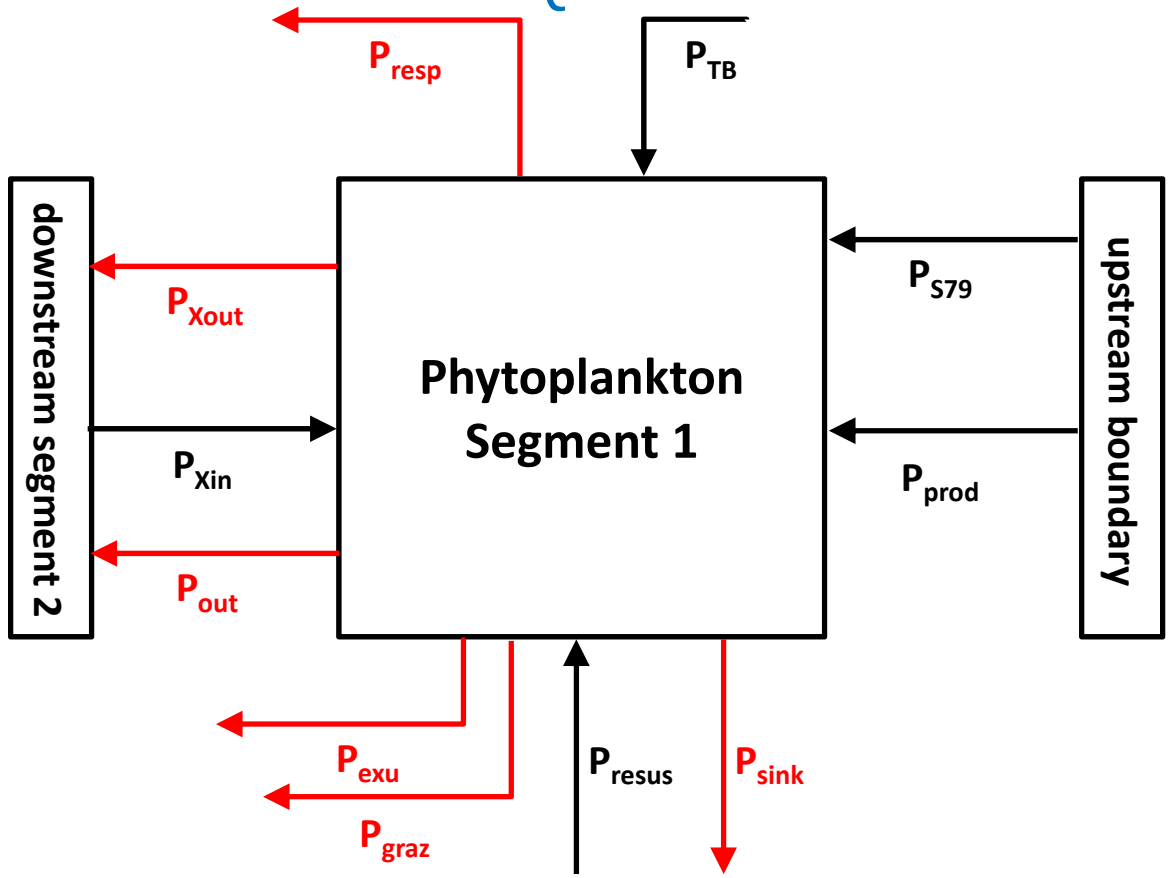
journal homepage: www.elsevier.com/locate/ecss

Modeling ecosystem processes with variable freshwater inflow to the Caloosahatchee River Estuary, southwest Florida. I. Model development

Christopher Buzzelli [a,*], Peter H. Doering [a], Yongshan Wan [a], Detong Sun [a], David Fugate [b]

[a] Coastal Ecosystems Section, South Florida Water Management District, 3301 Gun Club Rd., West Palm Beach, FL 33406, USA
[b] Department of Marine and Ecological Sciences, Florida Gulf Coast University, 10501 FGCU Blvd. South, Fort Myers, FL 33965, USA

CRE WATER QUALITY MODEL



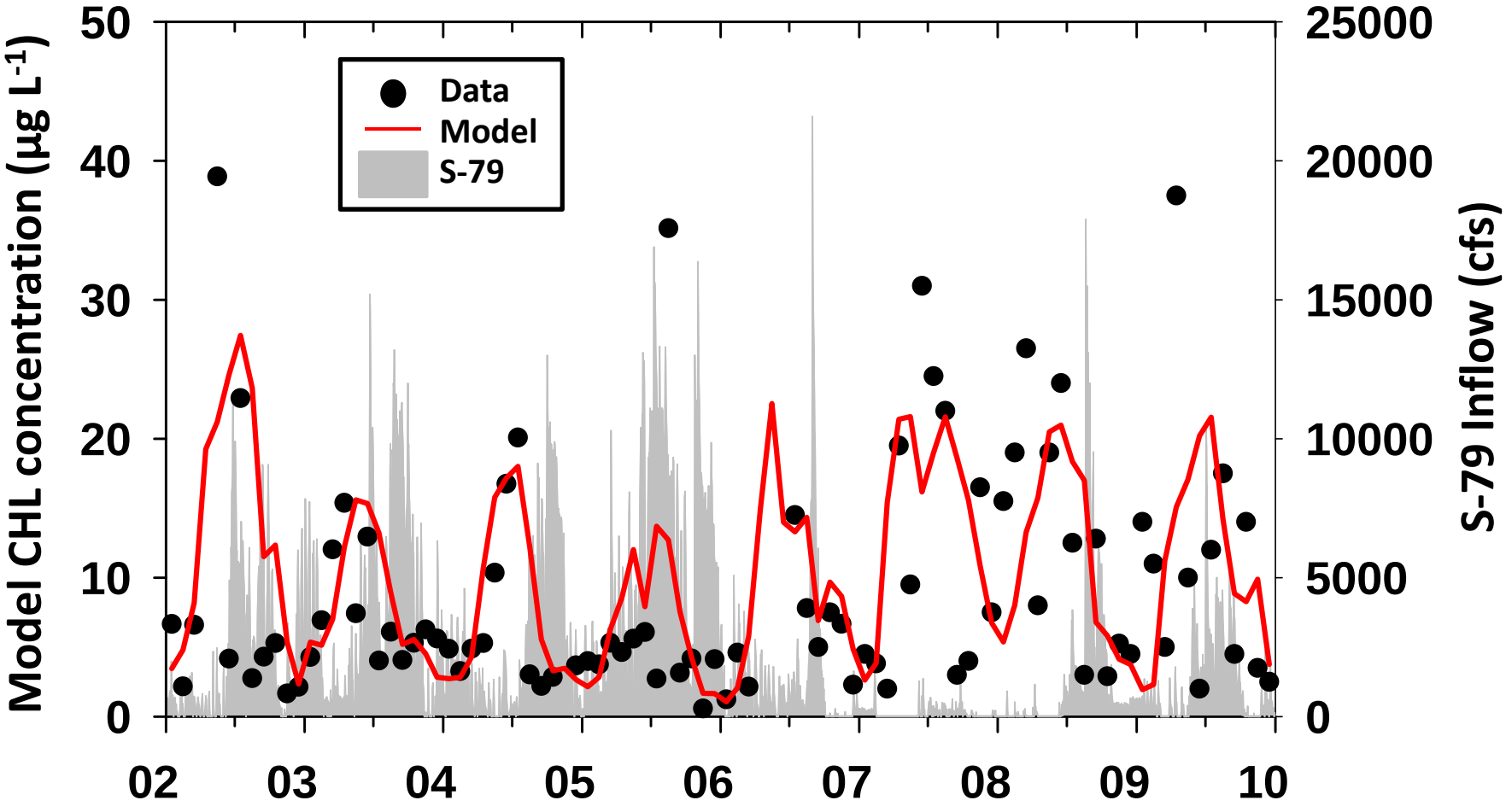
SINKS

P_{out} = Downstream transport
P_{Xout} = Downstream non-tidal exchange
P_{resp} = Respiration
P_{graz} = Loss to grazing
P_{exu} = Loss to exudation
P_{sink} = Sinking from water column

SOURCES

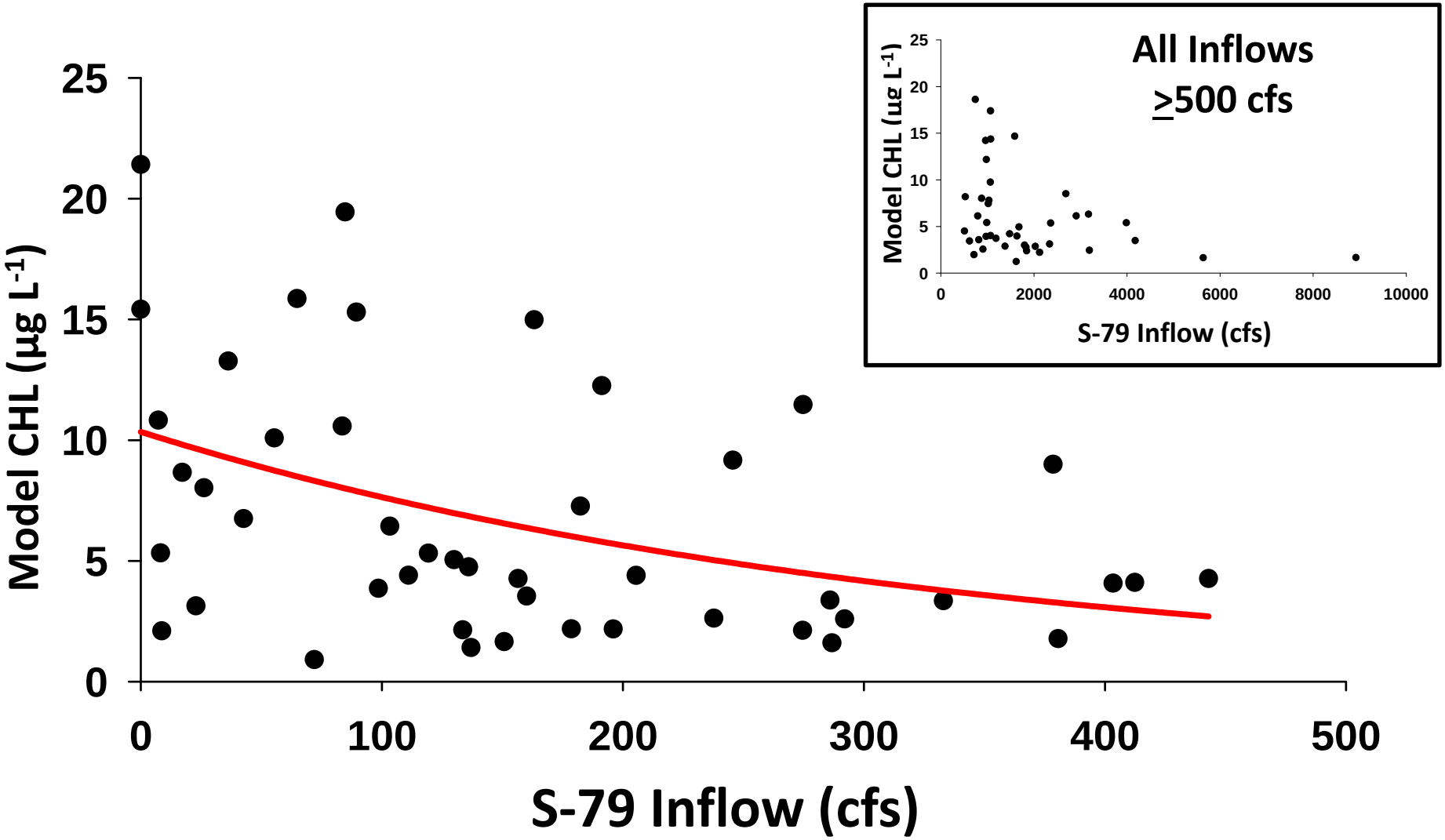
P_{S79} = Input from S79
P_{Xin} = Upstream non-tidal exchange
P_{prod} = Gross production
P_{TB} = Input from the tidal basin
P_{resus} = Resuspension from bottom

CRE WATER QUALITY MODEL



Season	Data	Model	r
Dry	7.4±4.5	6.8±2.3	0.61
Wet	9.4±3.9	14.2±4.0	0.76

CRE WATER QUALITY MODEL

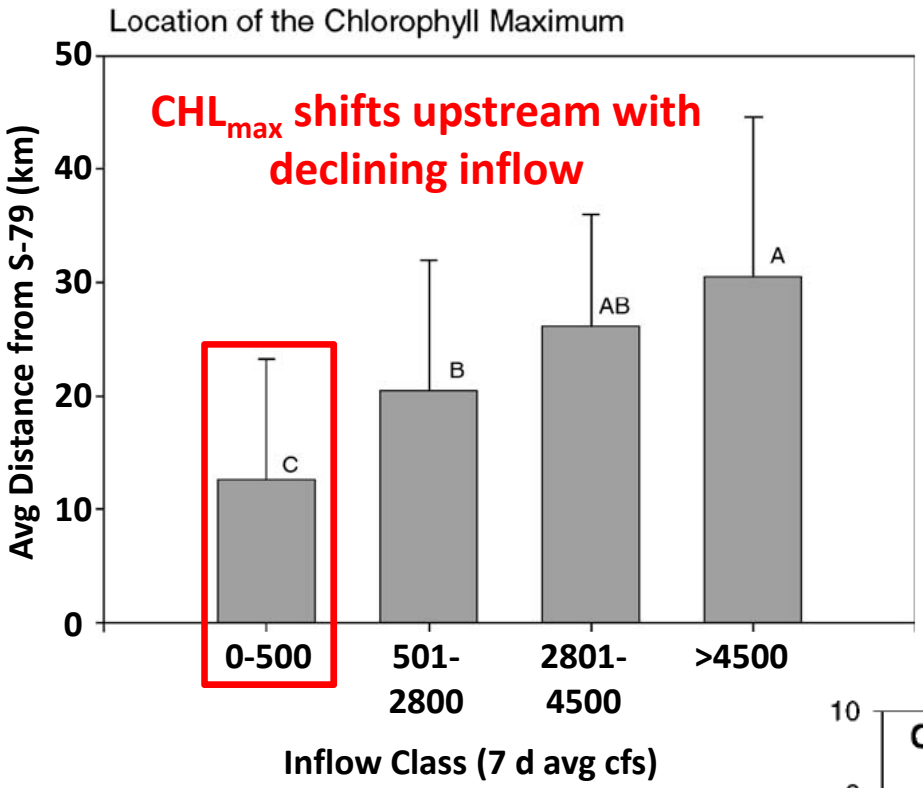


Increased CHL predicted when S79 inflow was ≤ 500 cfs

CRE DATA & MODEL RESULTS

Table X. Results of queries of CHL values from monitoring data and the simulation model. Provided are the number and percentage of CHL values that were ≥11 µg L^{-1}, the average and standard deviation of those values, and the average and standard deviation of S-79 inflows on days with CHL ≥11 µg L^{-1}.

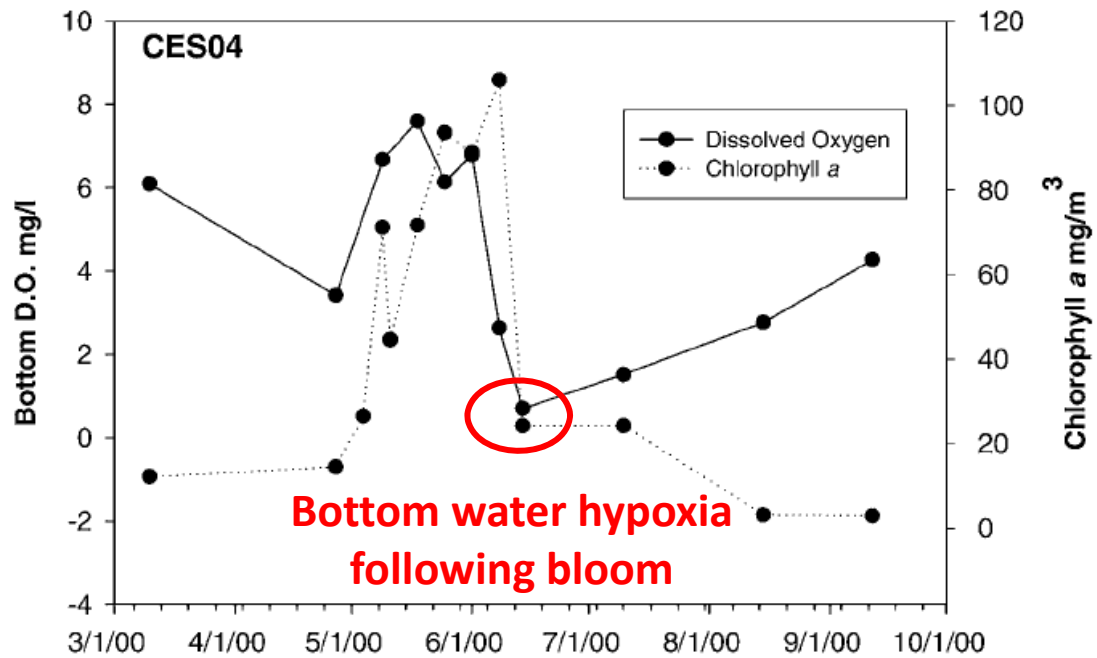
Source	Number (% ≥11 µg L^{-1})	CHL ≥11 µg L^{-1} Avg±SD	Q_{S79} (cfs) Avg±SD
Data	24 (19.5%)	31.8±51.4	469±689
Model	265 (18.3%)	16.1±3.8	269±493



CHLOROPHYLL *A* AND ITS USE AS AN INDICATOR OF EUTROPHICATION IN THE CALOOSAHATCHEE ESTUARY, FLORIDA

PETER H. DOERING[1], ROBERT H. CHAMBERLAIN[1], AND KATHLEEN M. HAUNERT[1]

[1]Coastal Ecosystems Division, South Florida Water Management District, West Palm Beach, Florida 33406



STUDY OBJECTIVES

QUESTION

Does low dry season inflow enhance phytoplankton biomass (CHL) and hypoxic conditions in the bottom waters?

OBJECTIVES

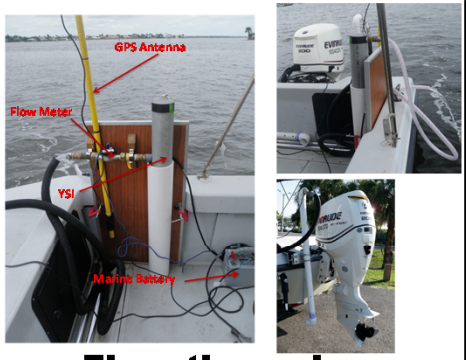
1. To use long-term monitoring data to evaluate the inflow conditions associated with potential for increased CHL in the dry season

2. To use a water quality simulation model to examine CHL in the upper CRE associated with low dry season inflows (<500 cfs)

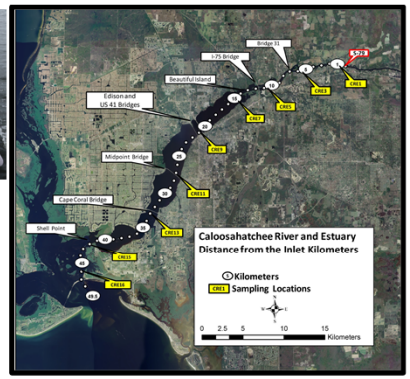
3. **To assess water quality gradients and potential for bottom water hypoxia at the event scale in the dry season**

EVENT SCALE STUDY

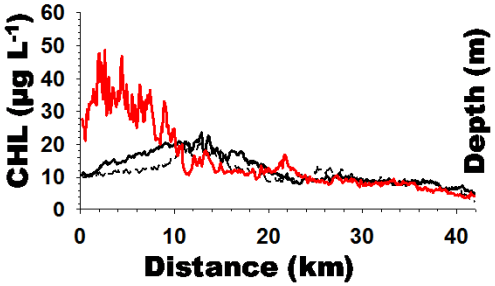
- **A total of 23 cruises in dry seasons 2012-2014**
  - **Flow-through surface water data acquisition system**
  - **42 km from S-79 to San Carlos Bay**
  - **7–8 hours travel time; 15–26 m between recordings; ~2200/cruise**
- **Data used to assess longitudinal gradients**
  - **Isohalines (salinity gradient)**
  - **CHL_{max} (location of maximum CHL concentration)**
- **2D patterns (depth vs. distance from S-79)**
  - **16 mid-channel hydrographic vertical profiles**
  - **Profiles for S, CHL, and DO interpolated in 2D**
  - **March 8, March 21, and April 12 2012 for this study**



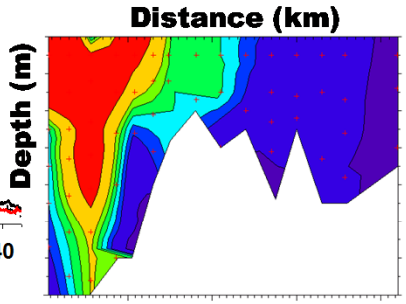
Flow-through sampling & vertical profiles



Entire CRE in hours

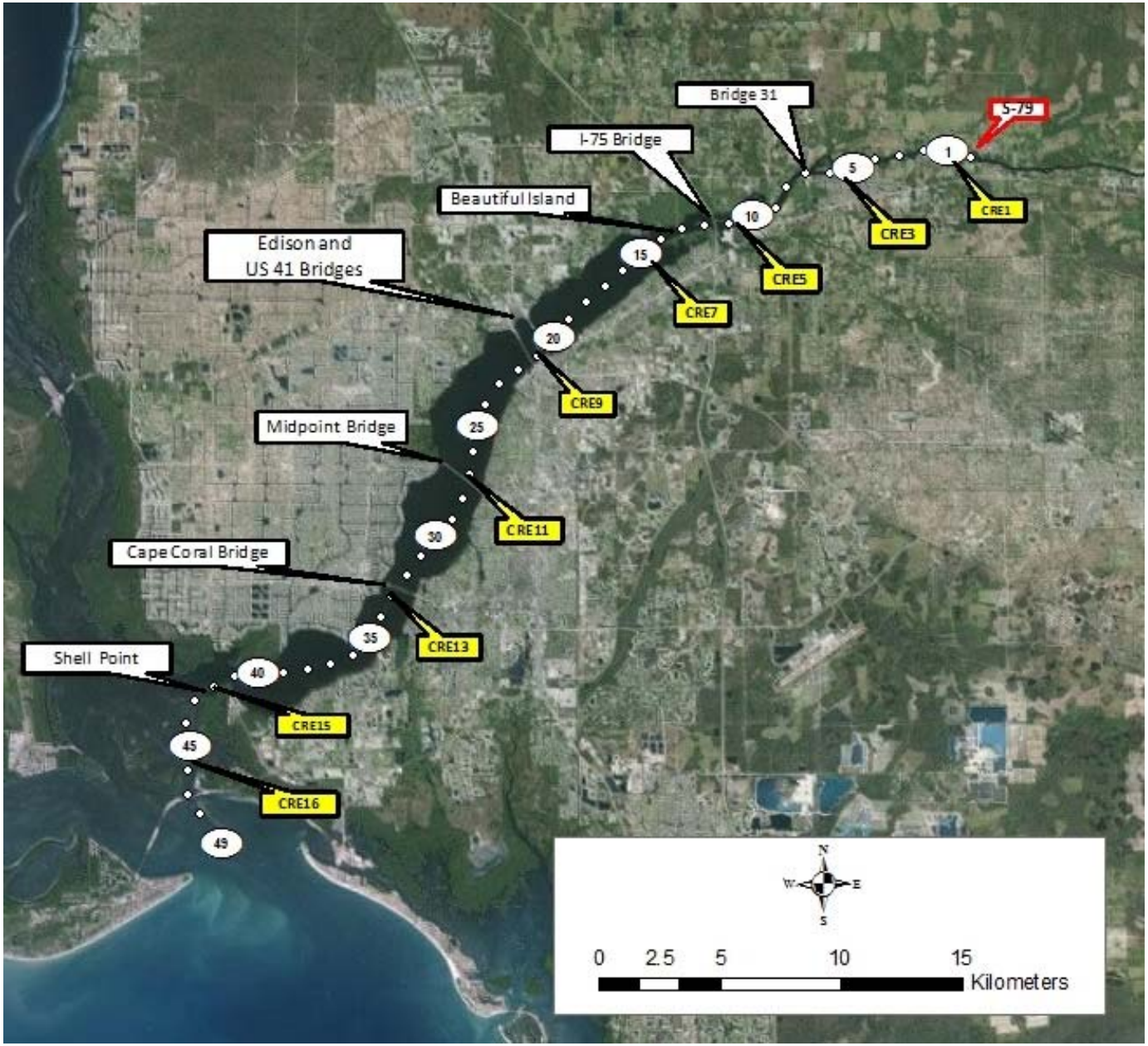


Longitudinal gradients

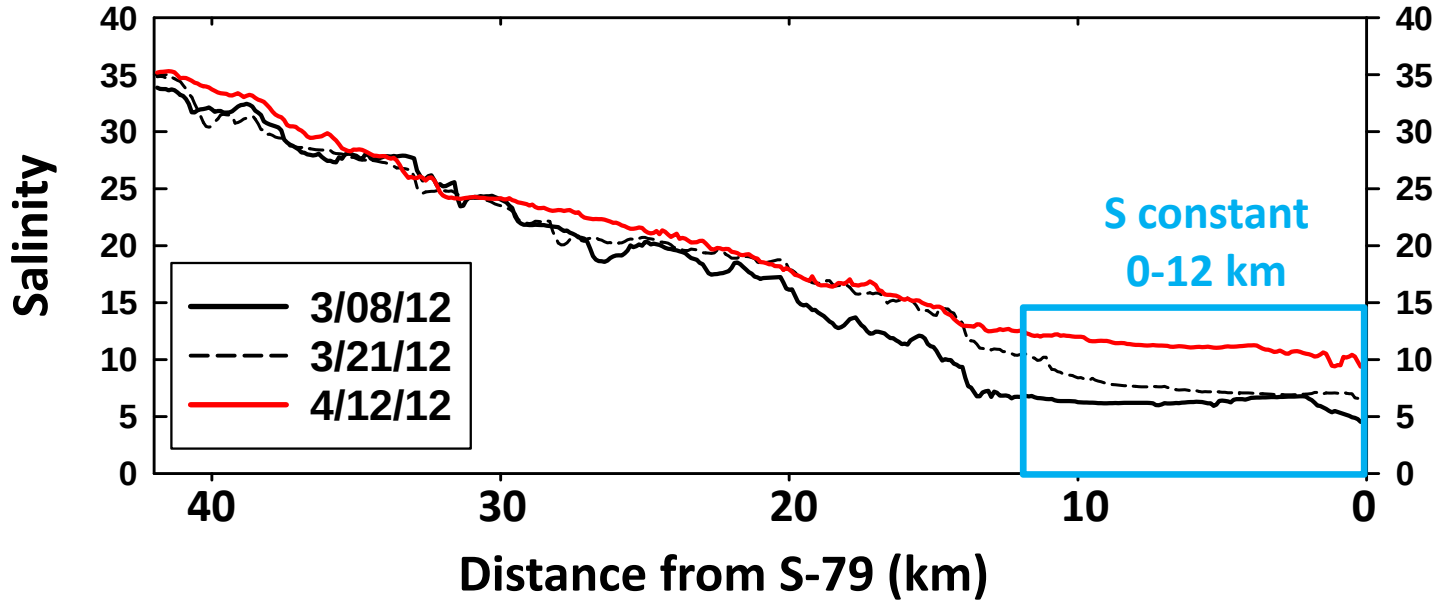


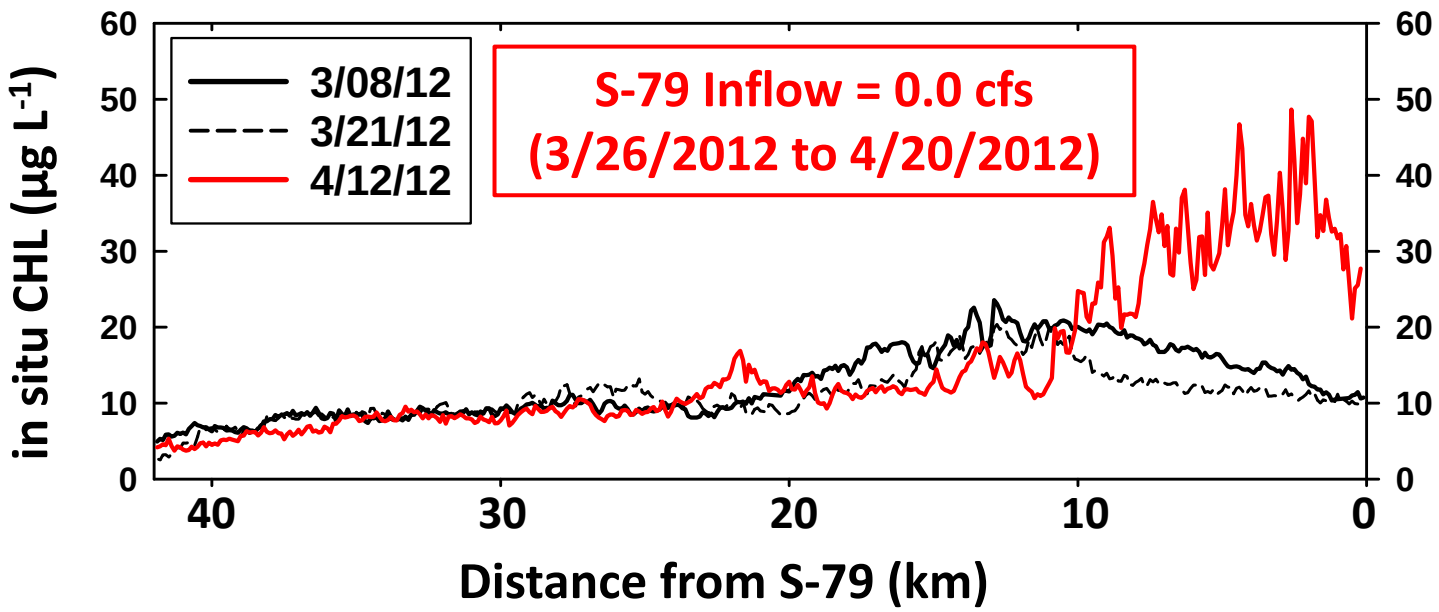
Contours interpolated from profiles

EVENT SCALE STUDY

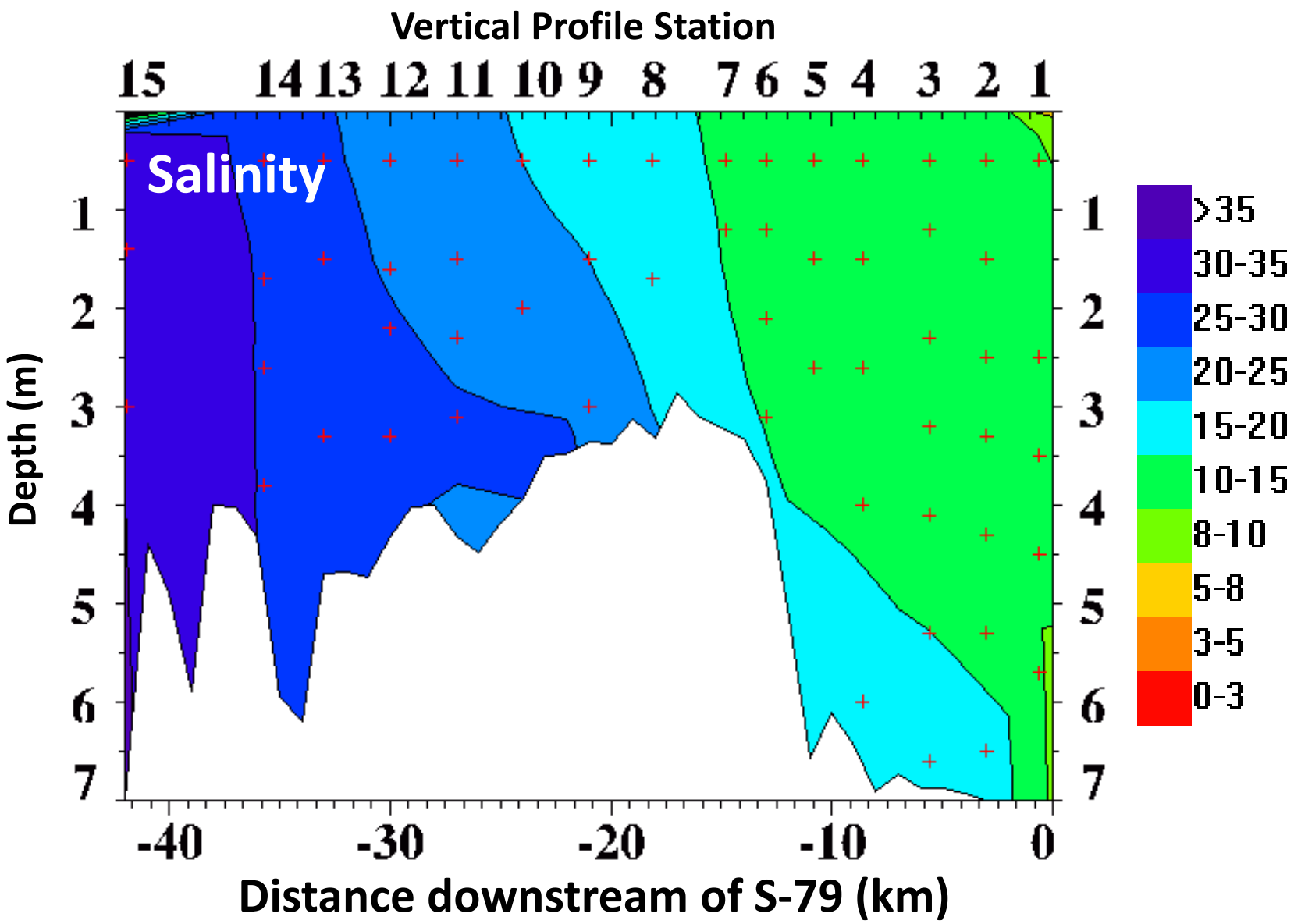


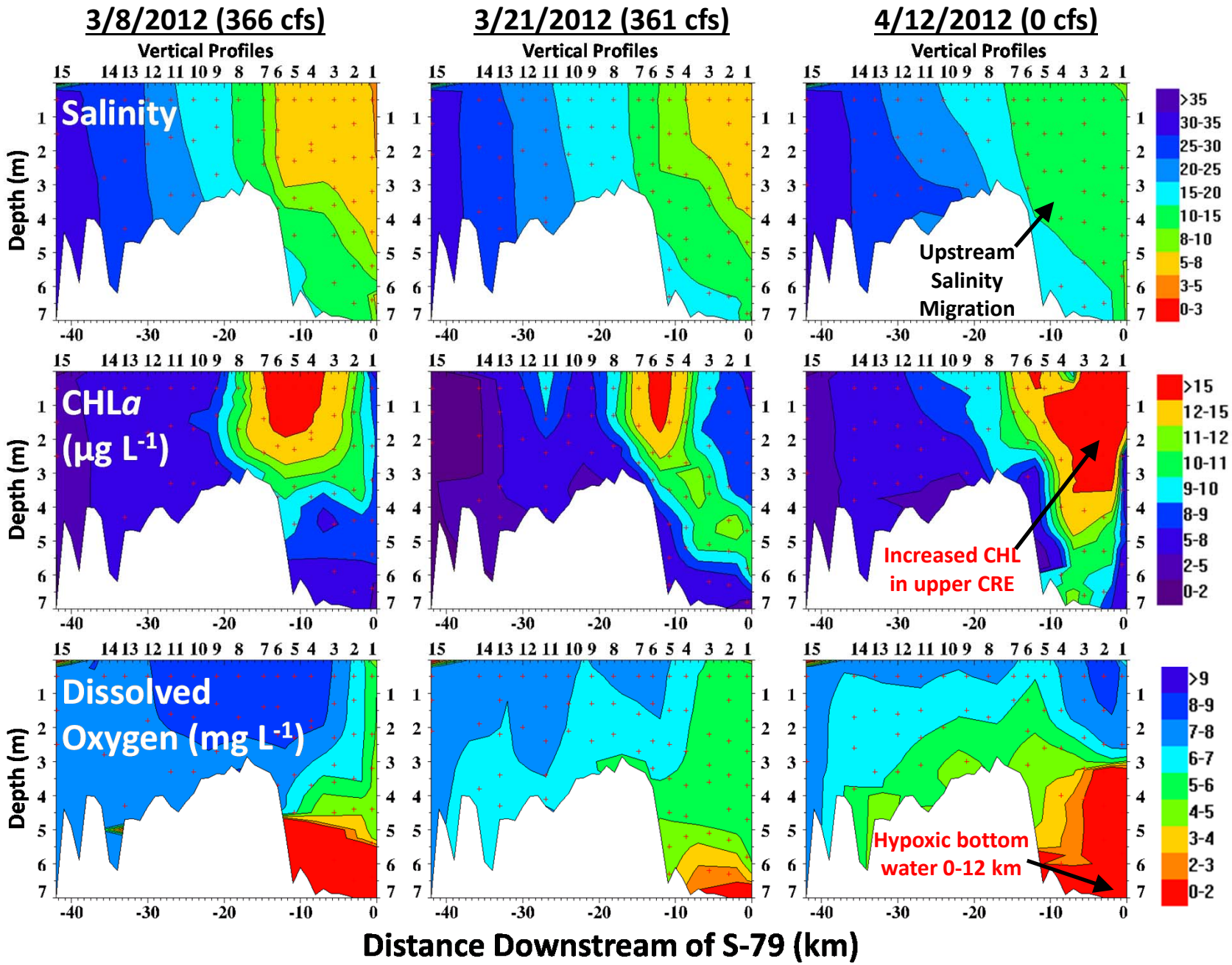
EVENT SCALE STUDY – SURFACE WATER





FINE SCALE STUDY – 2D CONTOURS




3/8/2012 (366 cfs)
3/21/2012 (361 cfs)
4/12/2012 (0 cfs)
Vertical Profiles
Salinity
CHLa (µg L-1)
Dissolved Oxygen (mg L-1)
Depth (m)
Upstream Salinity Migration
Increased CHL in upper CRE
Hypoxic bottom water 0-12 km
>35
30-35
25-30
20-25
15-20
10-15
8-10
5-8
3-5
0-3
>15
12-15
11-12
10-11
9-10
8-9
5-8
2-5
0-2
>9
8-9
7-8
6-7
5-6
4-5
3-4
2-3
0-2
Distance Downstream of S-79 (km)

SUMMARY

- **Caloosahatchee River Estuary experiences low freshwater inflow**
  - **Agricultural, urban/residential, environmental demands for freshwater**
  - **Wet/dry climatic cycles (~3-6 y); Dry season (Nov-Apr)**
  - **Increased flushing time (30-90 d)**

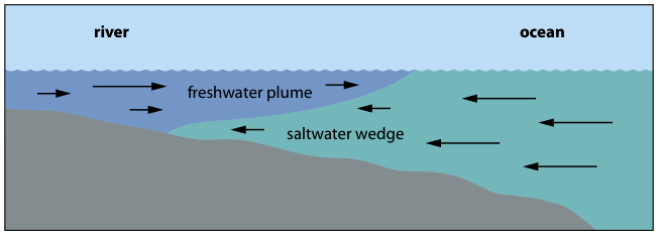
- **CRE in the dry season**
  - **S-79 inflows <500 cfs**
    - **Increased concentration of CHL**
    - **Locates the CHL_{max} $\leq$12 km from S-79 over deeper channel (~ 7 m)**
    - **Bottom water DO $\leq$ 3 mg L^{-1}**
  - **Late season effects (May-June)**
    - **Increased temperature**
    - **Increased potential for blooms with reduced inflow**

- **Further studies for improved freshwater management in the dry season**
  - **Increase spatial resolution of model (i.e. more boxes)**
  - **Need more surveys at inflows < 500 cfs**
  - **Estimate inflows to mitigate potential for bottom water hypoxia**
  - **Other indicators (*Vallisneria*, benthos, plankton, oyster, sawfish)**

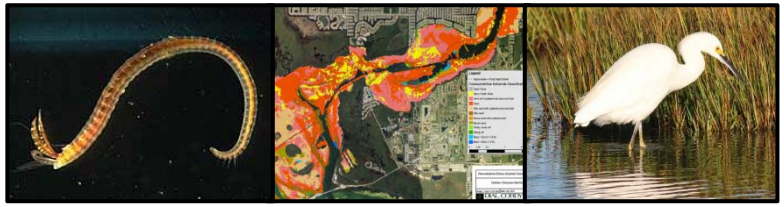
Component Study 4: Zooplankton Response to Freshwater Inflow in the Caloosahatchee River Estuary

Peter H. Doering, PhD
Section Administrator
Coastal Ecosystems Section
South Florida Water Management District

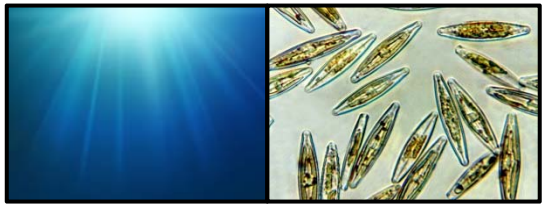
INDICATORS OF ESTUARINE RESPONSE TO LOW INFLOW



Changes in isohaline position with upstream encroachment of saltier water



Alter benthic community upon which many estuarine fauna are dependent

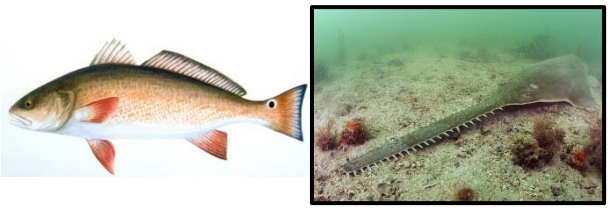


Reduced flushing and enhanced light can stimulate phytoplankton in upper estuary

Damaging to the freshwater *Vallisneria americana* (tape grass)

Impact physiology and habitat attributes of eastern oyster

Zooplankton and ichthyoplankton assemblages move upstream but can be impinged by structure

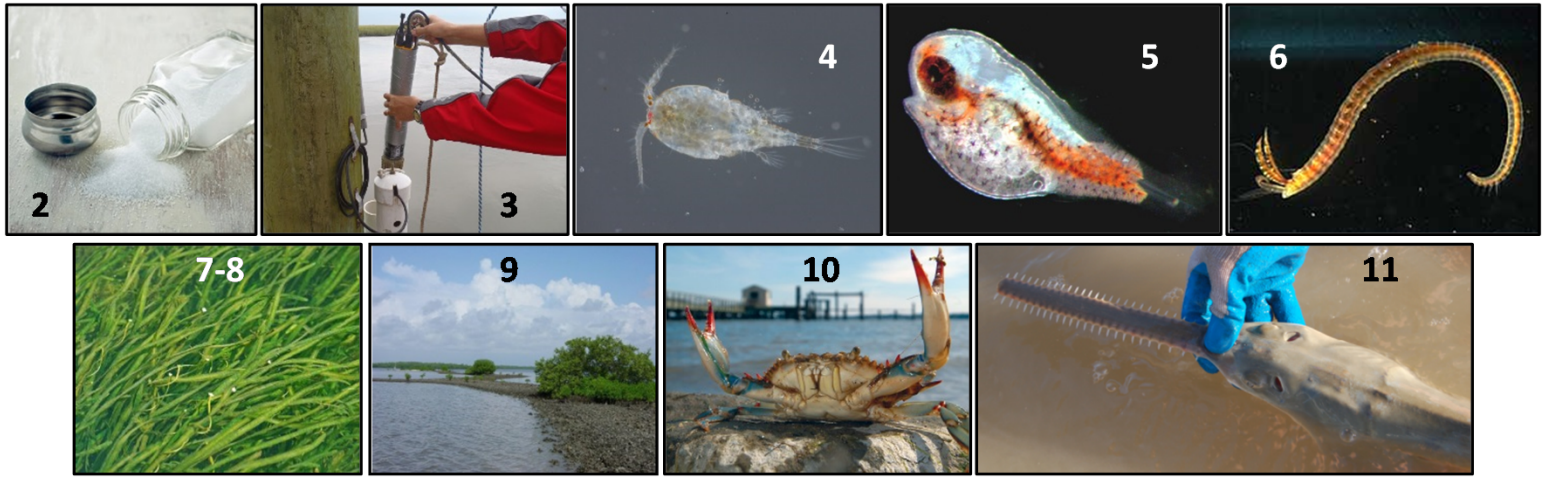


Affect coastal fish populations dependent upon estuaries as nurseries

Negatively impact harvests of important fisheries

SCIENCE COMPONENTS / STUDIES

	Component	Method
1	Hydrodynamics	Influence of alterations on hydrodynamics
2	Inflow vs. Salinity	Monthly freshwater-salinity relationships
3	Water Quality	Relationships between inflow, salinity, and water quality
4	Zooplankton	Inflow, zooplankton and habitat compression
5	Ichthyoplankton	Relationships between ichthyoplankton and inflow
6	Benthic Fauna	Macrofauna-salinity patterns relative to inflow
7	*Vallisneria* data	Empirical relationships between tape grass, S, and inflow
8	*Vallisneria* model	Model exploration of tape grass, S, light, and inflow
9	Oyster Habitat	Salinity patterns for oyster habitat in lower CRE
10	Blue Crabs	Relationships between blue crab landings, rainfall, and inflow
11	Sawfish	Dry season inflow, hydrodynamics, and habitat extent



WHY USE ZOOPLANKTON AS AN INDICATOR?

Zooplankton

Include early life stages of commercially and recreationally important fish and shell fish, food items for these species

Estuaries

Nurseries for these early life stages

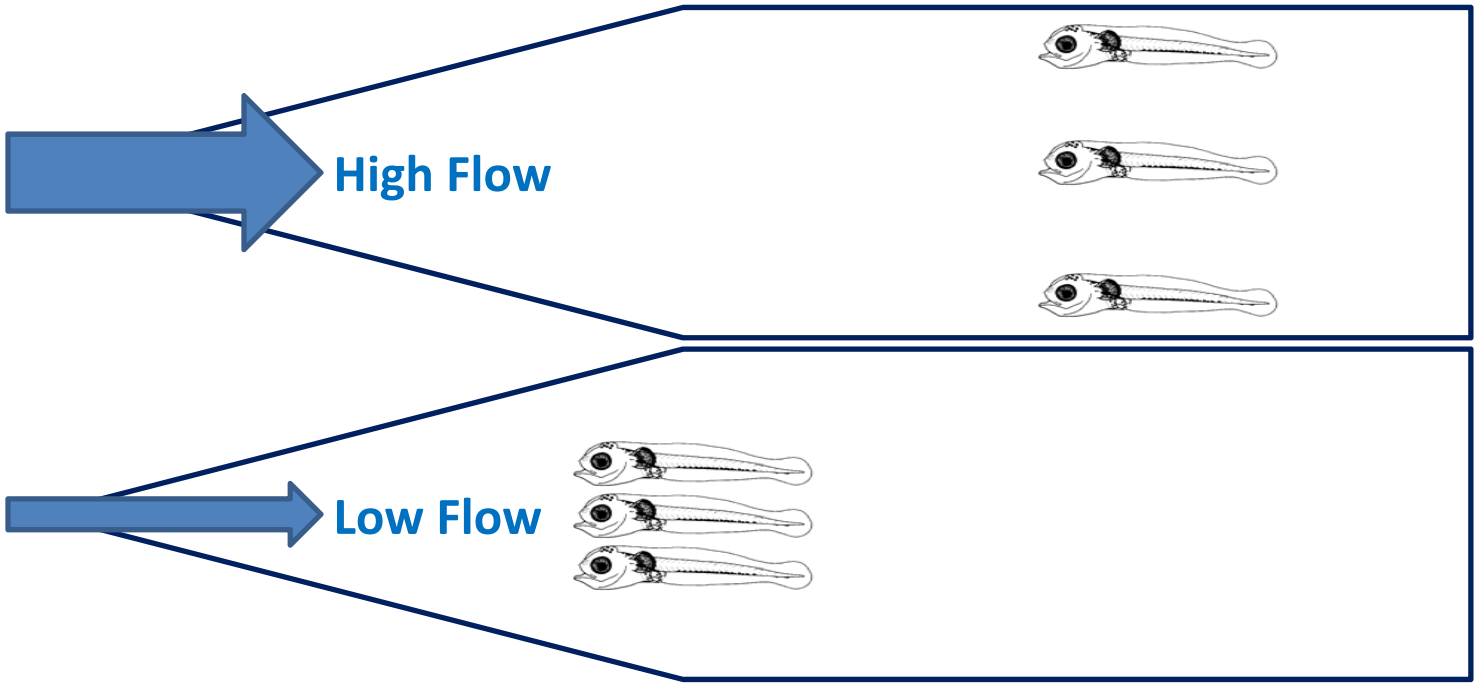
Freshwater Inflow

Nutrients - source to support food web

Salinity - many species require low salinity to develop into adults

Flushing / Residence Time - controls retention within an estuary

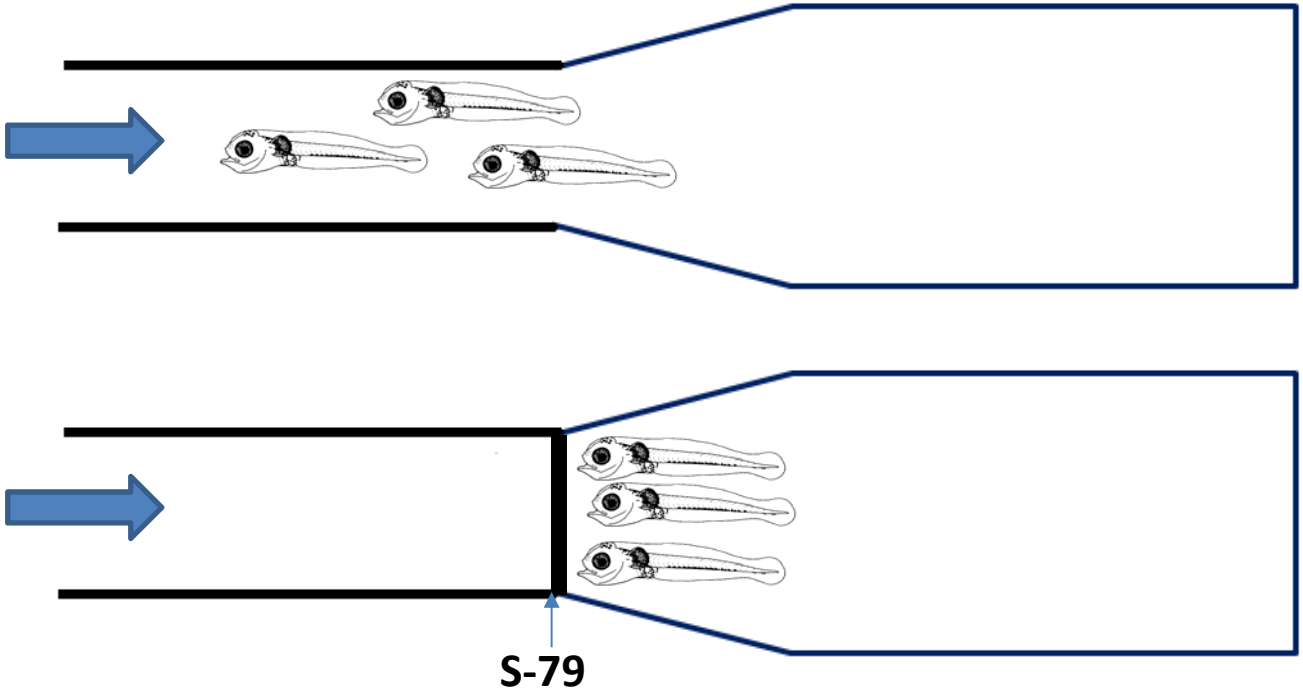
ZOOPLANKTON & FRESHWATER INFLOW



Habitat Compression

- Many planktonic organisms move upstream and downstream as inflow changes
- Riverine estuaries are funnel shaped
- As organisms move upstream they must fit into a smaller and smaller volume
- More intense competition for food, habitat, and increased risk of predation

ZOOPLANKTON & FRESHWATER INFLOW

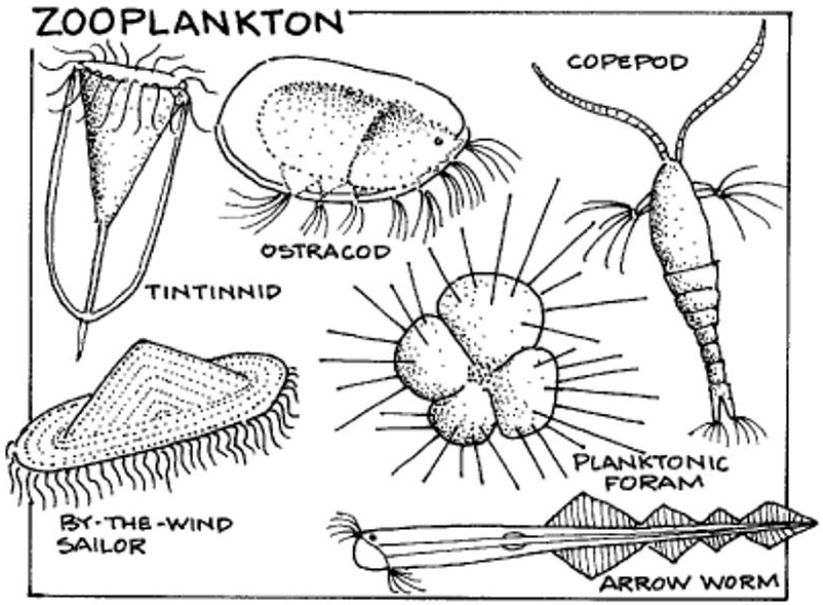


Impingement

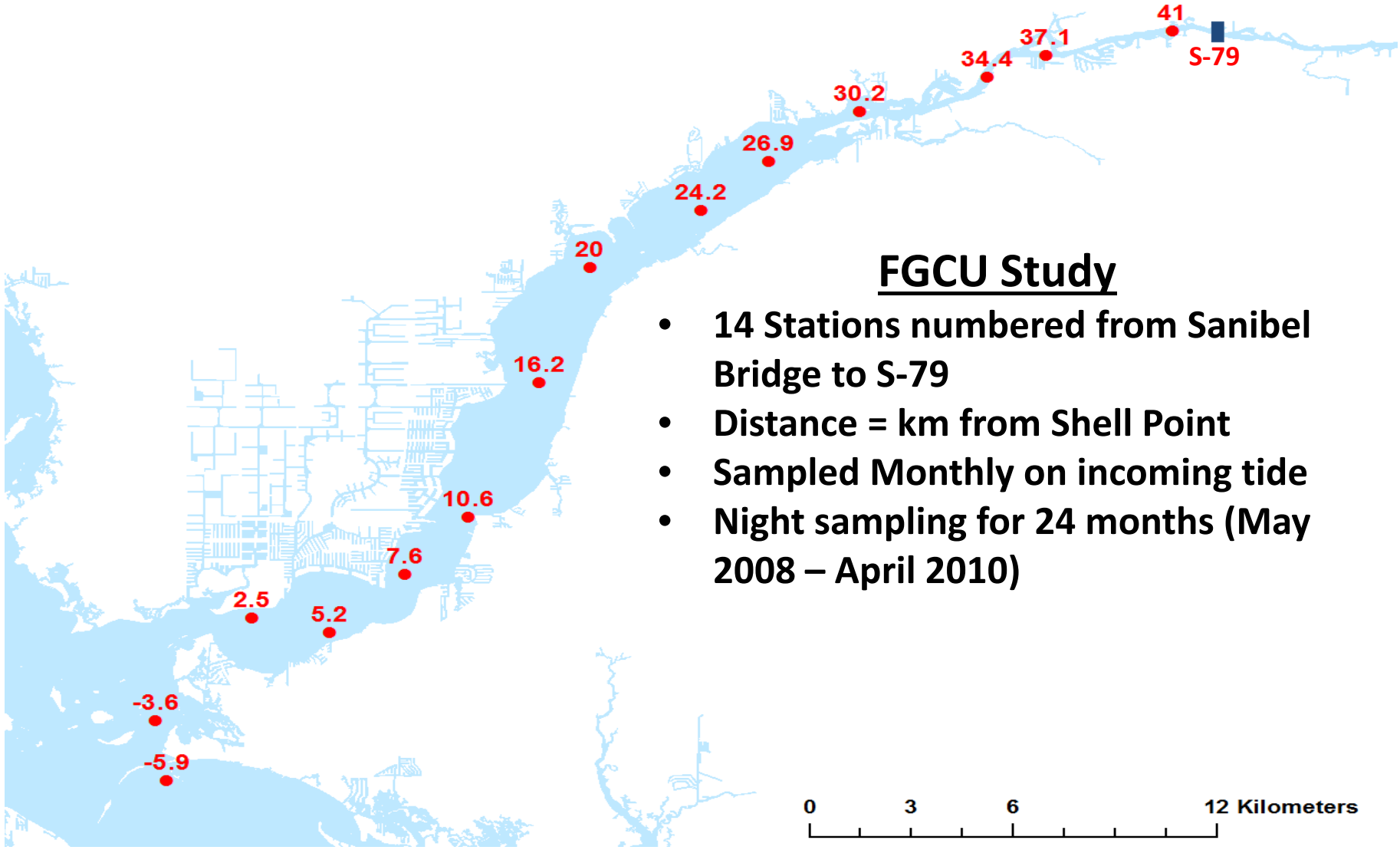
- In free flowing river there will always be somewhere to retreat
- However, dam blocks further upstream migration as inflow decreases
- More intense competition for resources along with increased risk of predation
- Potential loss of dynamic water column habitat

STUDY OBJECTIVES

- **To demonstrate compression of the zooplankton community with upstream migration under reduced freshwater inflow**
- **To quantify the impingement of zooplankton against S-79**
- **To determine the discharges at S-79 that promote habitat compression and impingement**



ZOOPLANKTON STUDY METHODS

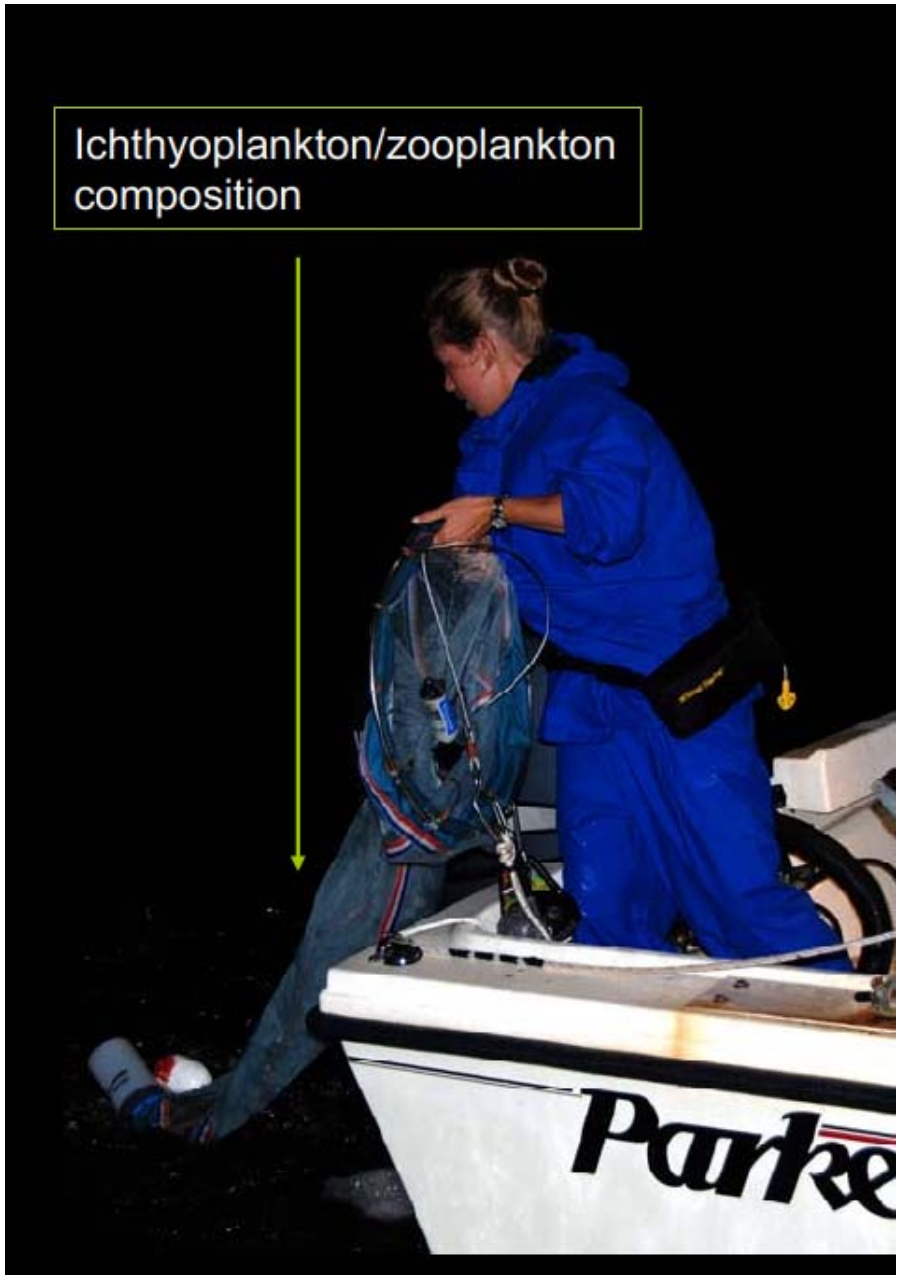


FGCU Study

- 14 Stations numbered from Sanibel Bridge to S-79
- Distance = km from Shell Point
- Sampled Monthly on incoming tide
- Night sampling for 24 months (May 2008 – April 2010)

Tolley, S. G., D. Fugate, M. L. Parsons, S. E. Burghart and E. B. Peebles 2010. The responses of turbidity, CDOM, benthic microalgae, phytoplankton and zooplankton to variation in seasonal freshwater inflow to the Caloosahatchee Estuary. Final report to the South Florida Water Management District.

ZOOPLANKTON STUDY METHODS



Zooplankton Sampling

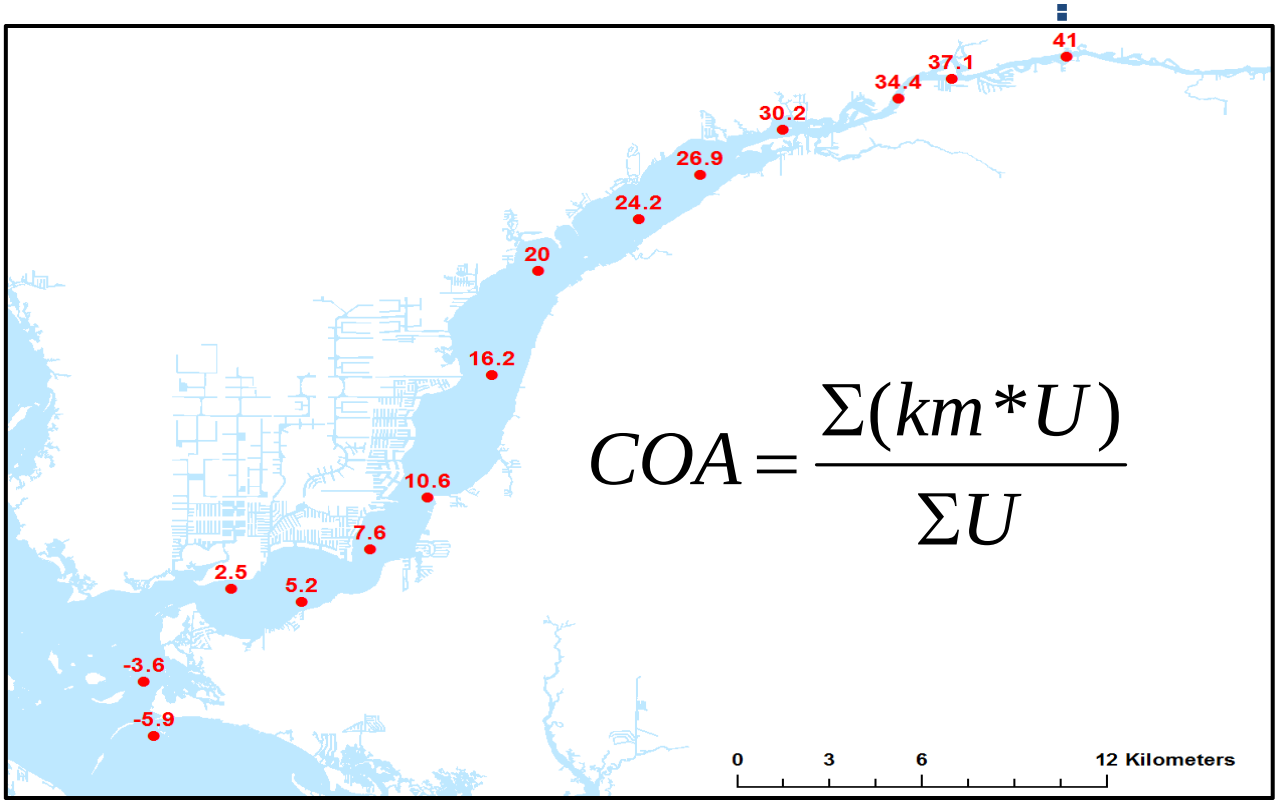
- **Night sampling**
- **0.5 meter net**
- **500 μm mesh nitex net**
- **5 minute oblique tow**
- **Flow meter for volume**

Zooplankton Processing

- **Enumerated and identified to lowest practical taxon**

ZOOPLANKTON – DATA ANALYSIS

- **Calculate the Center of Abundance (COA) for a variety of zooplankton taxa**
- **COA= Average location of capture, weighted by organism density**
- **U = organism density at a station (#/m^3)**
- **km = distance upstream from Shell Point**

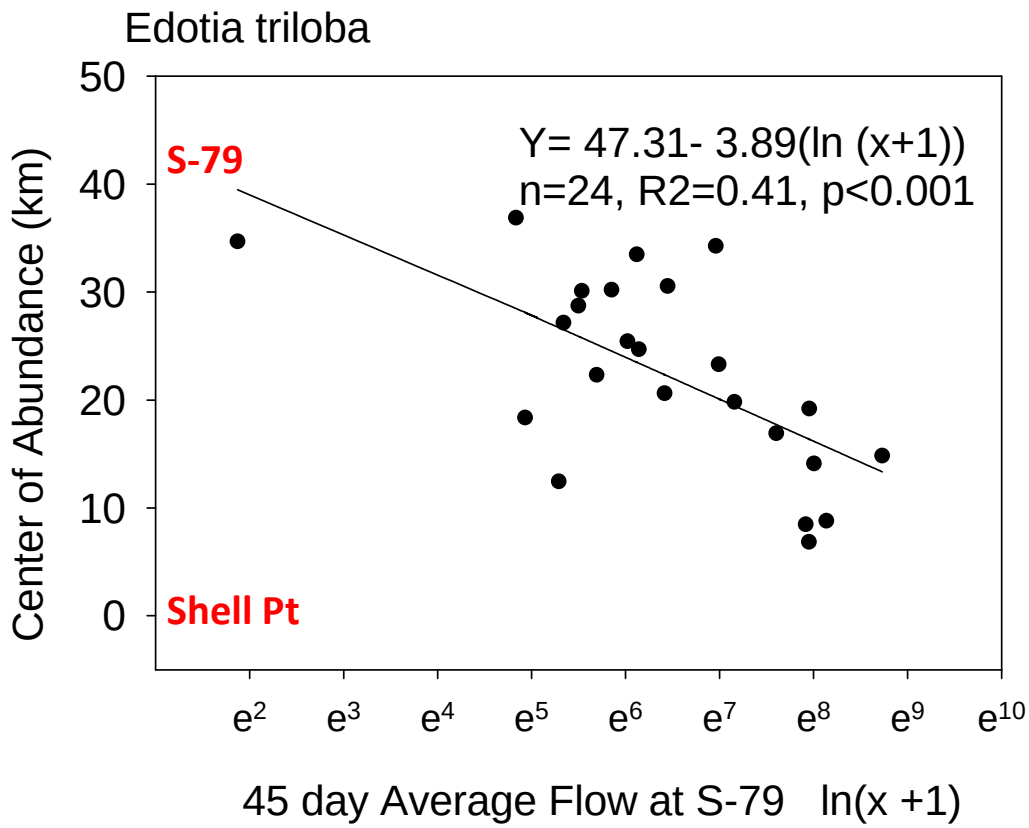


$$COA = \frac{\Sigma(km * U)}{\Sigma U}$$

ZOOPLANKTON – DATA ANALYSIS

- **COA was correlated to transformed freshwater inflow at S-79 (ln (Q_{S79}+1)) averaged over 0, 3, 7, 14, 18, 20, 21, 30, 45, and 60 days prior to sampling**

- **Linear regression of COA vs. the transformed freshwater inflow computed for lagged inflow with highest correlation coefficient**



Flow Range:
6.5 cfs- 6188 cfs

ZOOPLANKTON – DATA ANALYSIS

Taxon	Type
Clytia spp.	jellyfish
Lironeca spp.	isopod
Edotia triloba	isopod
Bowmaniella brasilliensis	mysid
Americamysis almyra-adults	mysid
Americamysis spp. juveniles	mysid
Psuedodiaptomus pelgicus	copepod
Gobiosoma spp. post flexion larvae	fish
Menidia spp. preflexion larvae	fish
Gobiidae preflexion larvae	fish
Microgobius spp. post flexion larvae	fish
Anchoa mitchilli adult	fish
Anchoa mitchilli juveniles	fish

- **11 marine taxa with intercepts occurring furthest upstream (COA when Q_{S79} = 0.0 cfs) were evaluated for impingement and habitat compression**
- **Because of high relative abundance and importance in food web, adult and juvenile anchovies were included (*Anchoa mitchilli* and *Anchoa* sp.).**

ZOOPLANKTON – HABITAT COMPRESSION

Habitat Compression assessed in two ways:

1. **Position of the center of abundance (COA)**

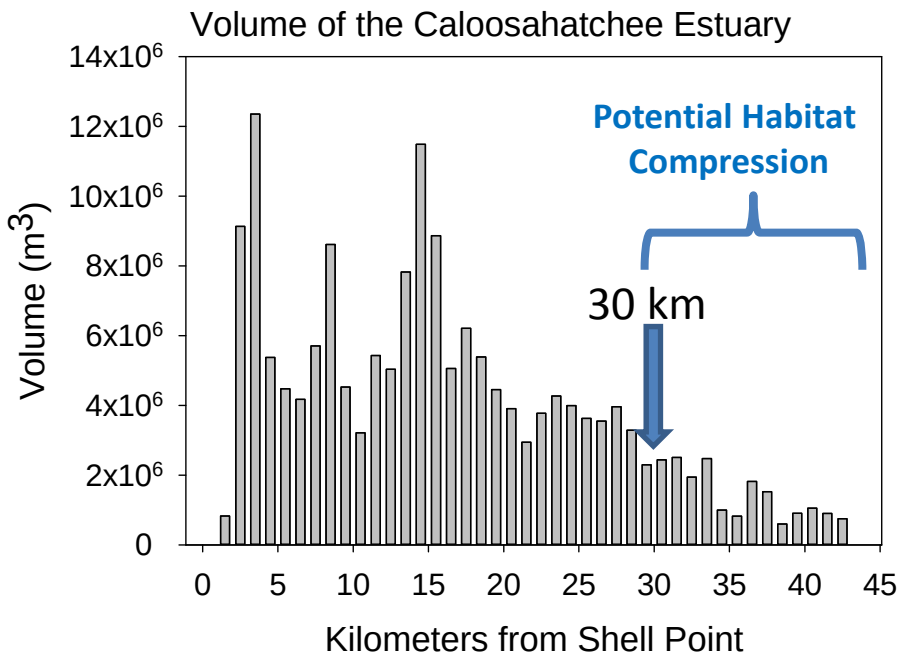
2. **Spatial abundance quantiles (Peebles and Greenwood 2009)**

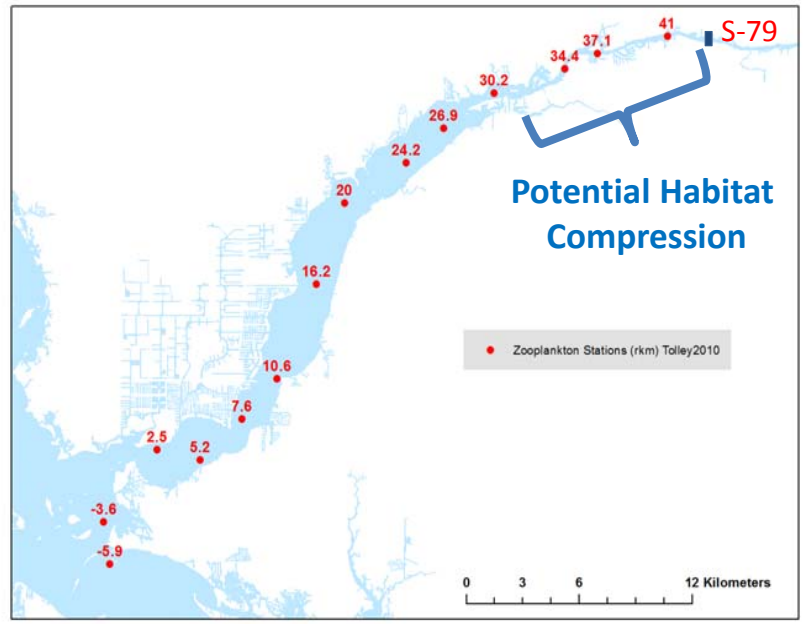
   a) **Utilizes the locations of the 10th and 90th deciles of cumulative abundance to assess compression**

   b) ***Compression* - As the center of abundance translates upstream with decreasing flow, the distance between the 10th and 90th deciles remains constant or decreases and habitat volume shrinks**

   c) ***Compensation* - As the center of abundance translates upstream with decreasing flow, the distance between the 10th and 90th deciles increases and habitat volume remains constant or increases**

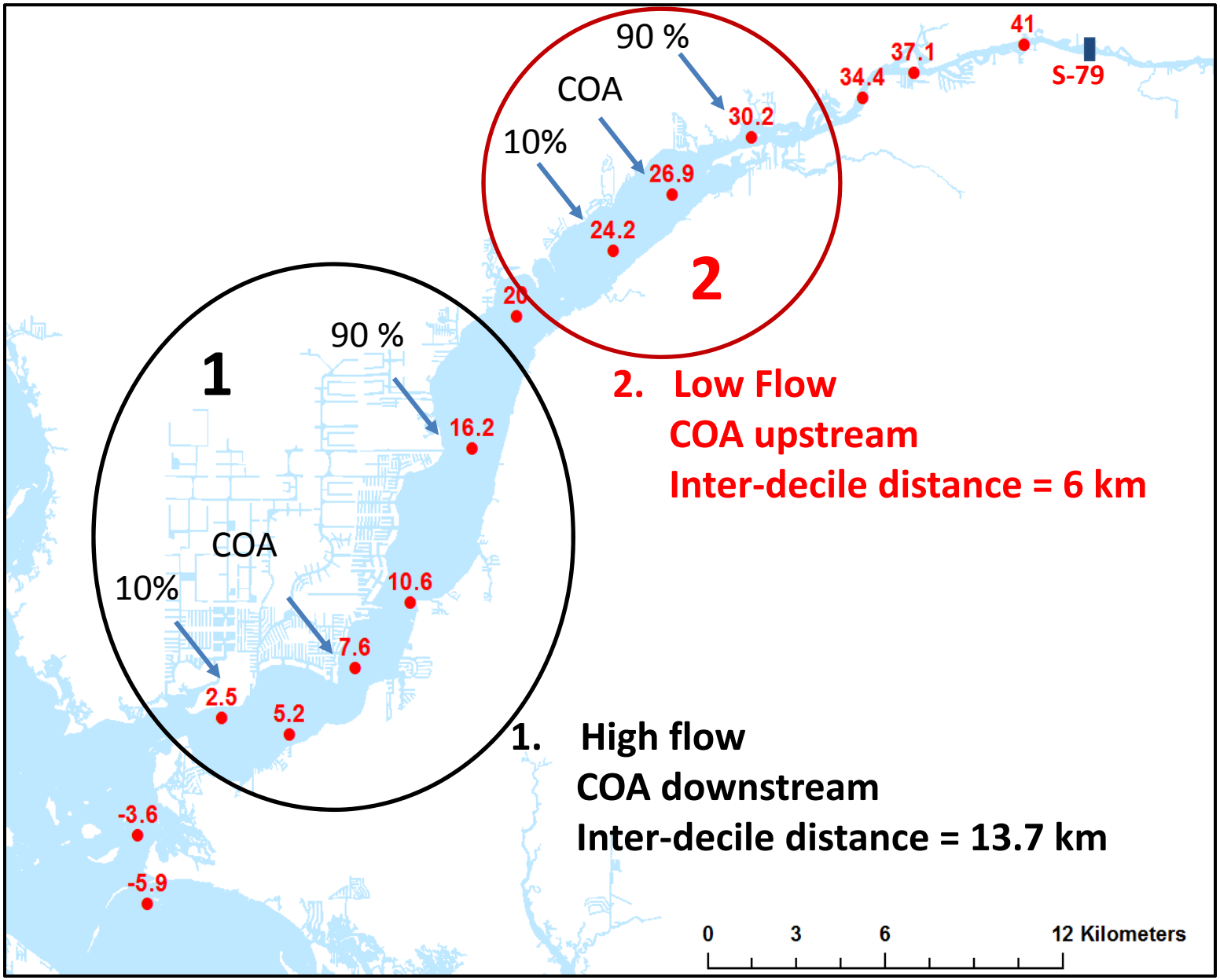
ZOOPLANKTON – CENTER OF ABUNDANCE



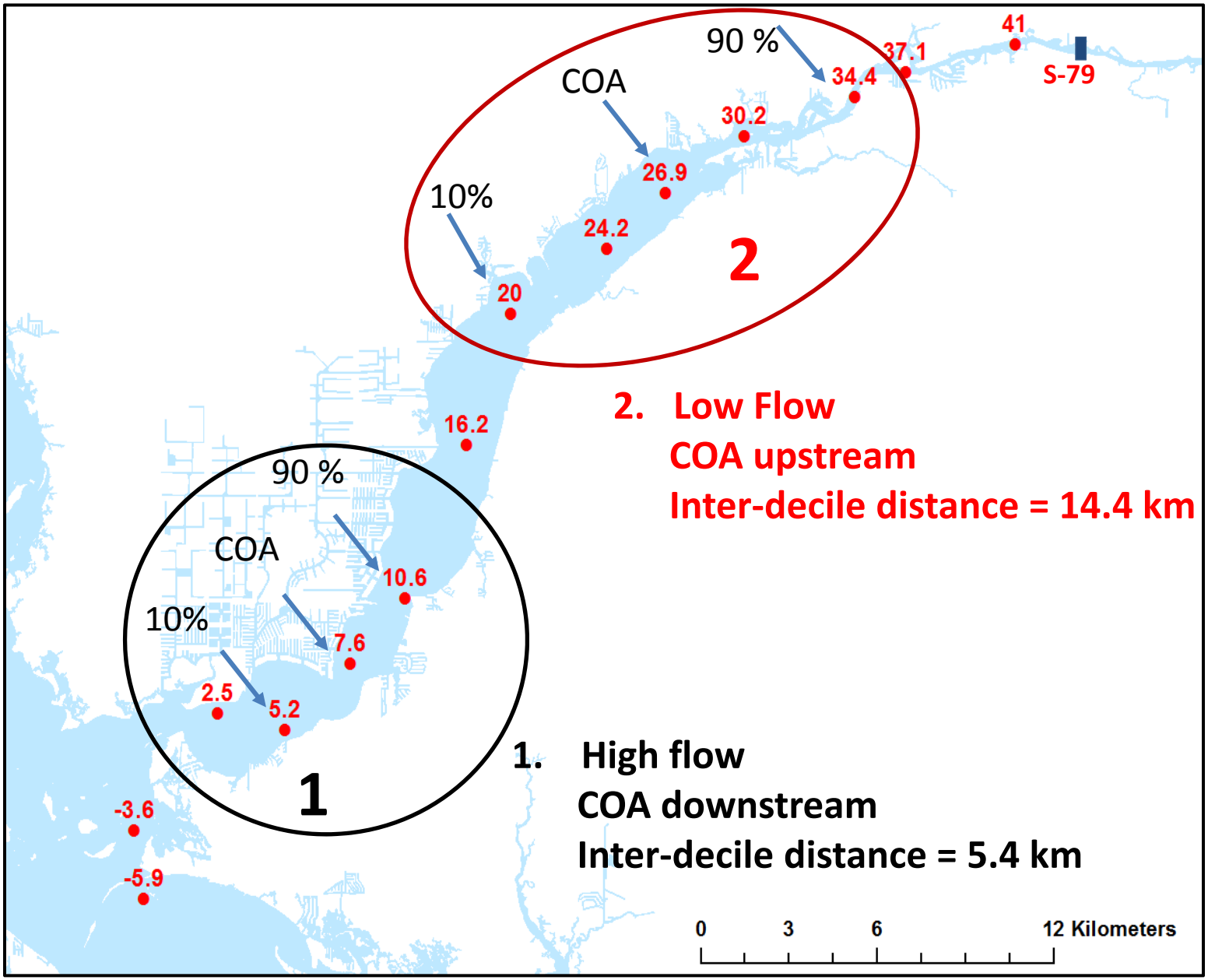


- **Segment volume decreases ~30 km upstream of Shell Point**
- **Decreased volume = potential for habitat compression upstream of this location**
- **Thus, the inflows which position the COA ≥30 km upstream of Shell Point could compress (reduce volume) water column habitat for zooplankton**

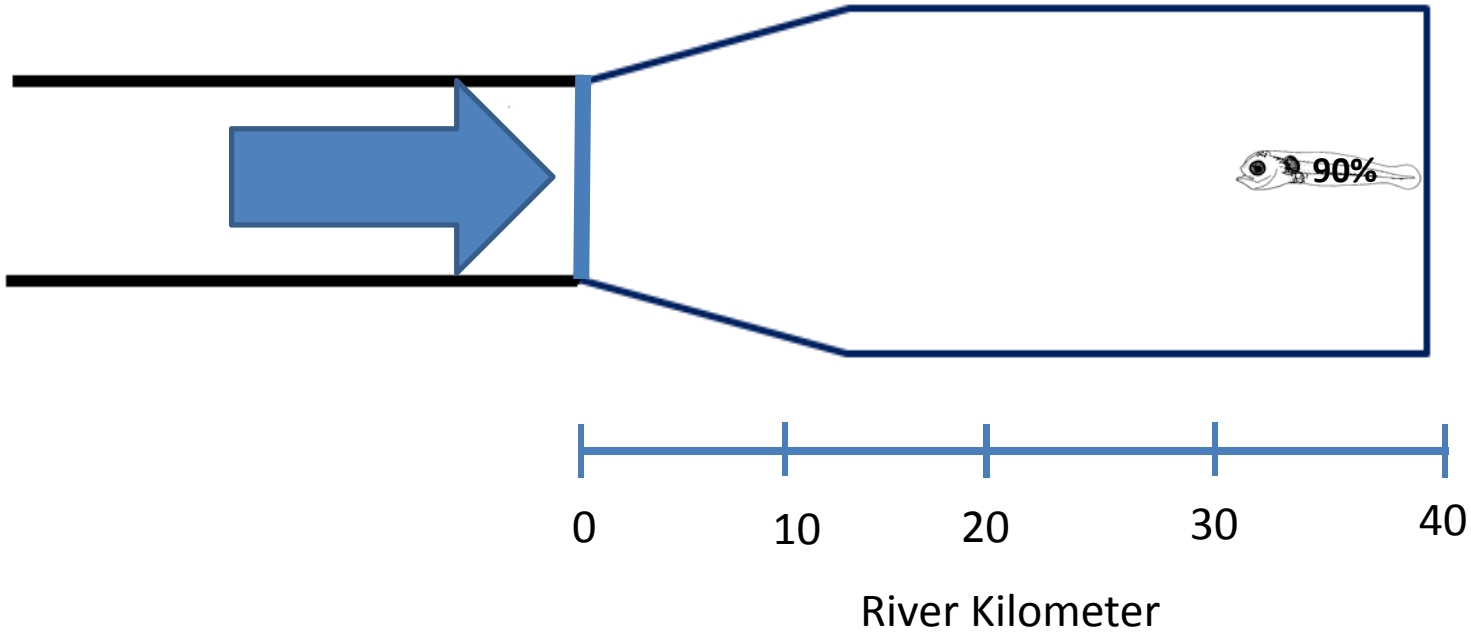
SPATIAL ABUNDANCE – COMPRESSION



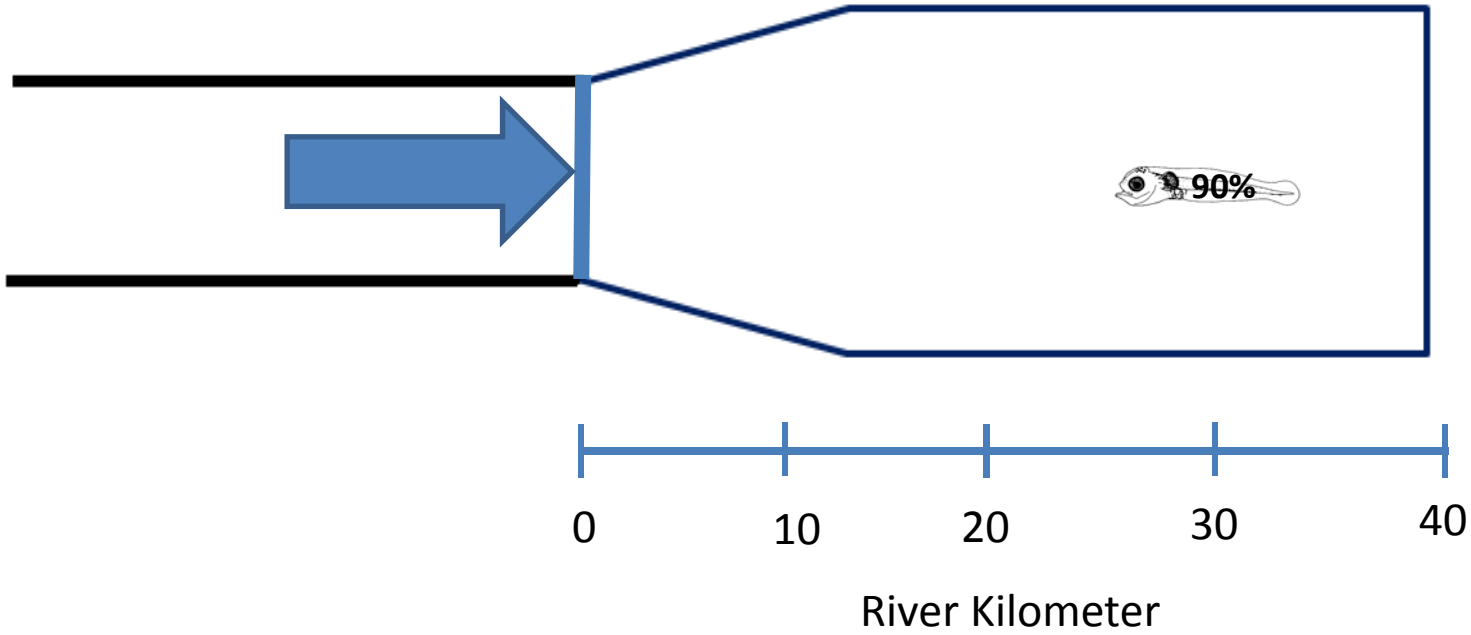
SPATIAL ABUNDANCE – COMPENSATION



ZOOPLANKTON IMPINGEMENT



ZOOPLANKTON IMPINGEMENT



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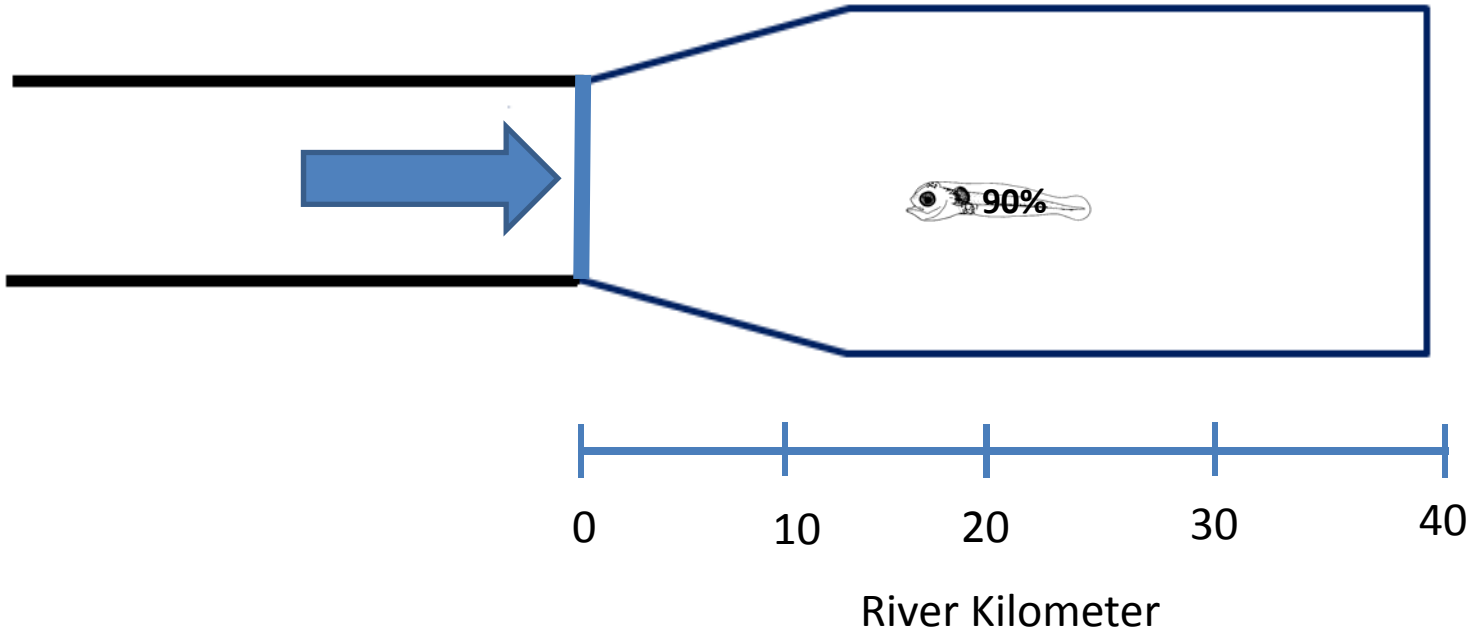

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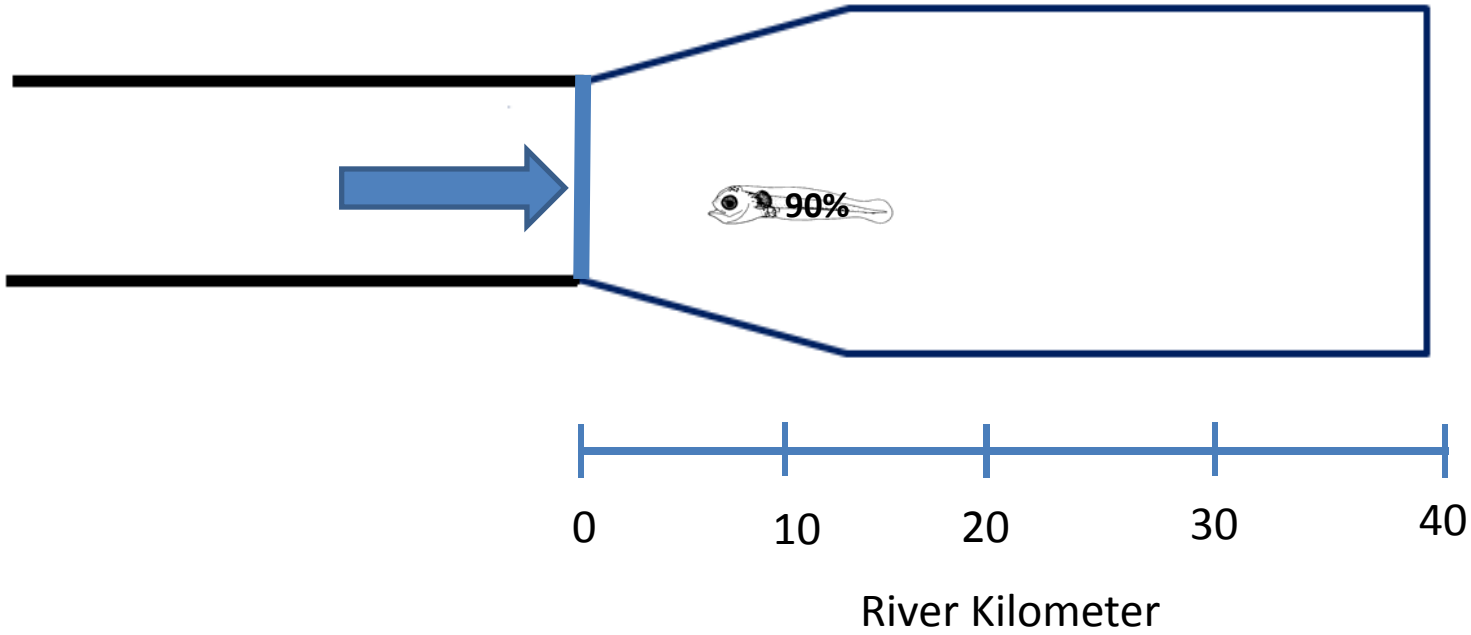
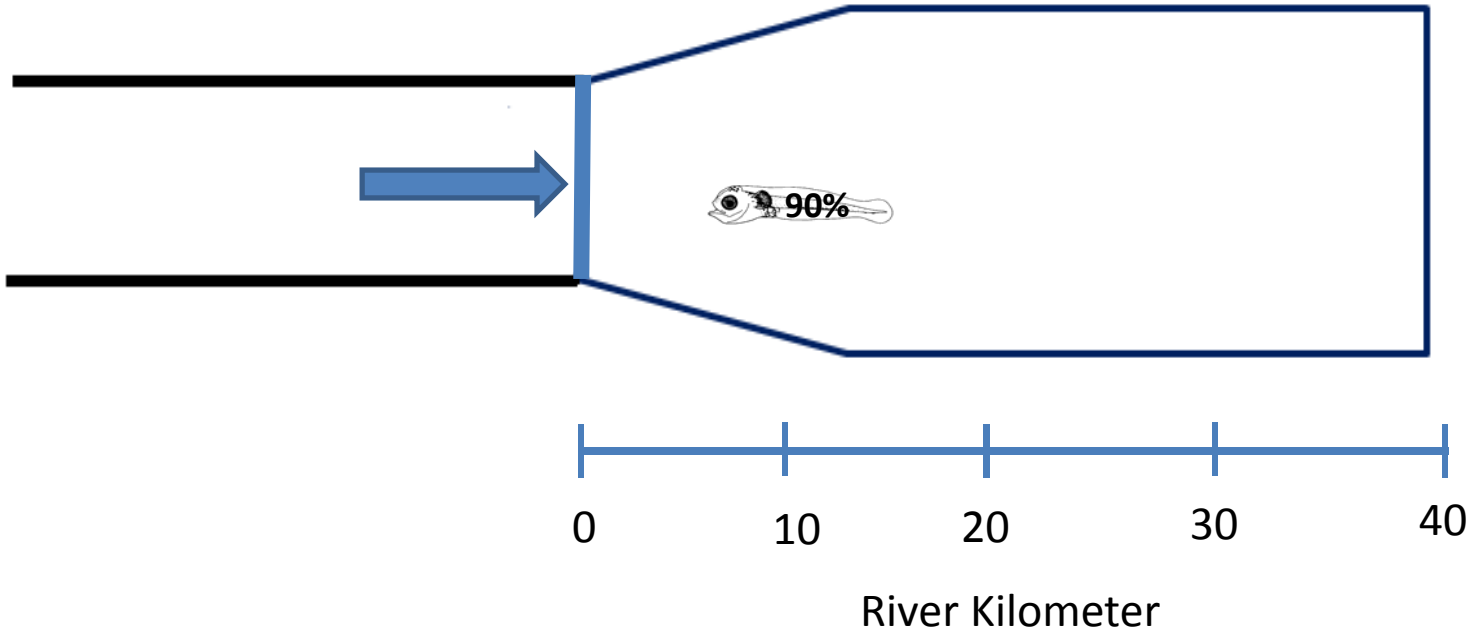
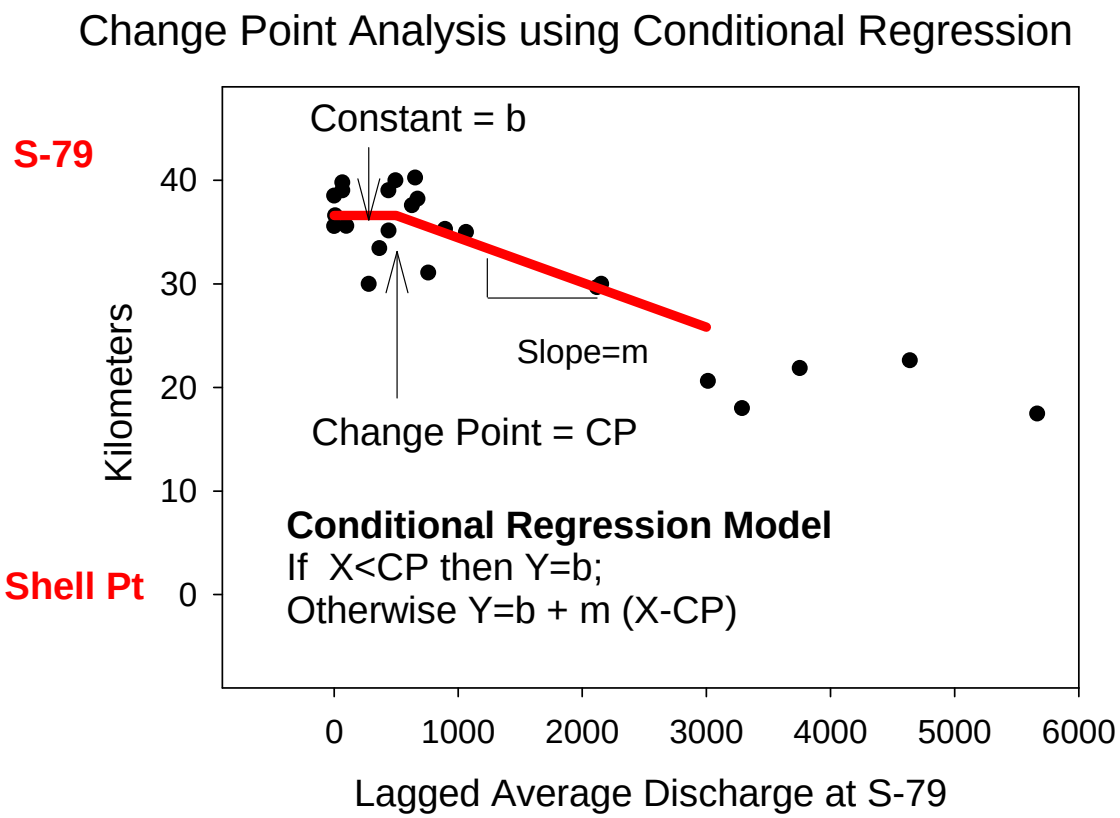


ZOOPLANKTON IMPINGEMENT



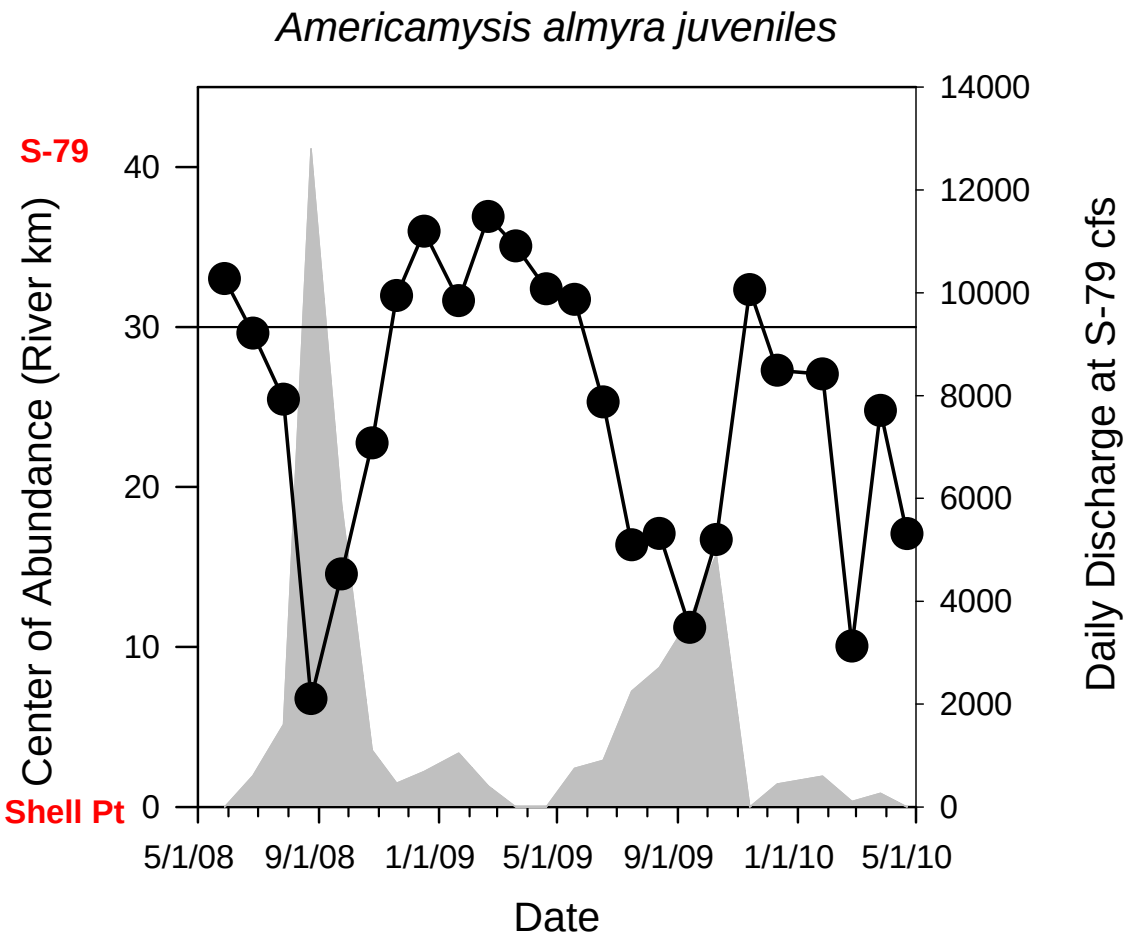
ZOOPLANKTON IMPINGEMENT



- **Position of 90% abundance decile as function of discharge at S-79**
- **Impingement when position of the 90% abundance decile stops moving upstream as flow decreases**
- **Inflow at which decile stops moving upstream is inflow which initializes impingement**
- **This can be determined by change point analysis using conditional regression**

ZOOPLANKTON – HABITAT COMPRESSION

Position of COA



Center of abundance for all but one taxon was located upstream of 30 km at least sometime during the study period

ZOOPLANKTON – HABITAT COMPRESSION

Position of COA

Taxon	n	a	b	p	R^2	Days	30 km (CFS)
Clytia spp.	8	81.77	-10.55	0.021	0.56	60	**134.2**
Lironeca spp.	24	36.73	-3.31	0.001	0.43	14	**6.6**
Edotia triloba	24	47.31	-3.89	0.001	0.41	45	**85.0**
Bowmaniensis brasilliensis	24	44.76	-4.31	0.002	0.36	45	**29.7**
Americamysis almyra -adults	24	49.90	-3.51	0.002	0.35	45	**288.9**
Americamysis spp. - juveniles	24	46.72	-3.44	0.004	0.32	45	**128.1**
Psuedodiapotomus pelagicus	22	44.10	-5.37	0.001	0.46	60	**12.8**
Gobiosoma spp. postflexion larvae	20	51.85	-5.91	0.008	0.33	60	**39.4**
Microgobius spp. postflexion larvae	17	71.82	-7.88	0.001	0.54	60	**200.8**
Gobiidae preflexion larvae	24	45.72	-5.21	0.001	0.36	60	**19.5**
Menidia spp. preflexion larvae	17	76.31	-7.36	0.005	0.38	60	**540.8**
Anchoa mitchilli - adults *	24	3.50	-0.0002	0.002	0.34	14	**518.4**
Anchoa spp. - juveniles**	24	31.88	-0.00013	0.065	0.15	3	**1362.3**

30 km

Mean: 259 cfs

Stdev: 378 cfs

Median: 128 cfs

25th %: 29.7 cfs

75th%: 289 cfs

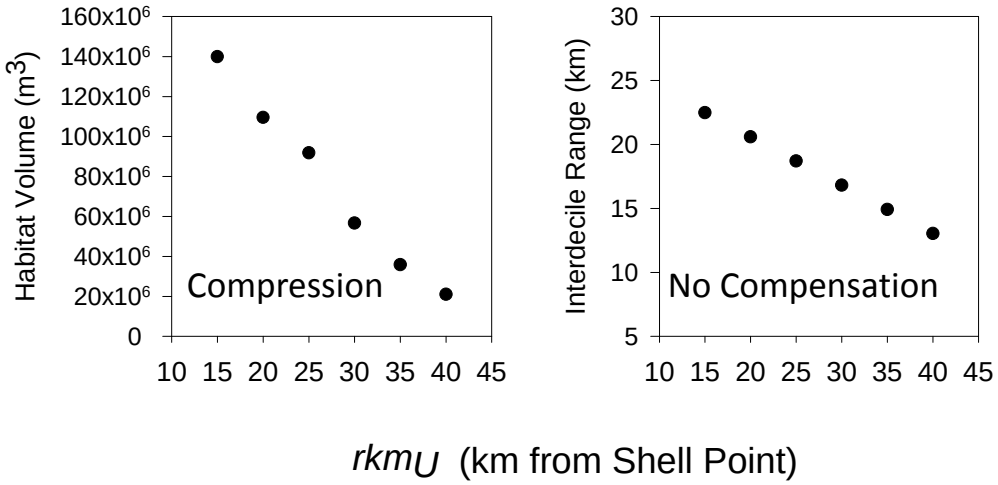
*** ln(*COA*)=a-b(Q)**

*****COA*=a-b(Q)**

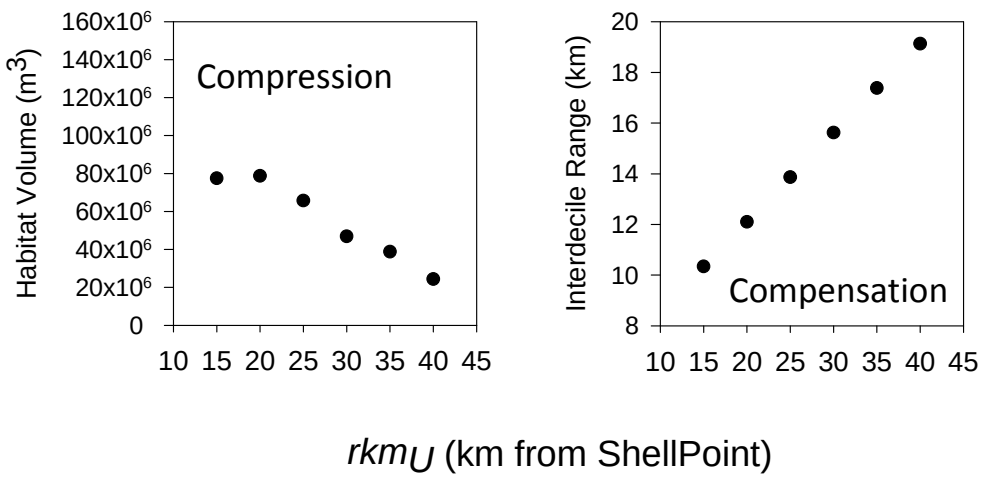
ZOOPLANKTON – HABITAT COMPRESSION

Volume **Inter-Decile Range**

Americamysis sp. (juveniles)



Edotia triloba

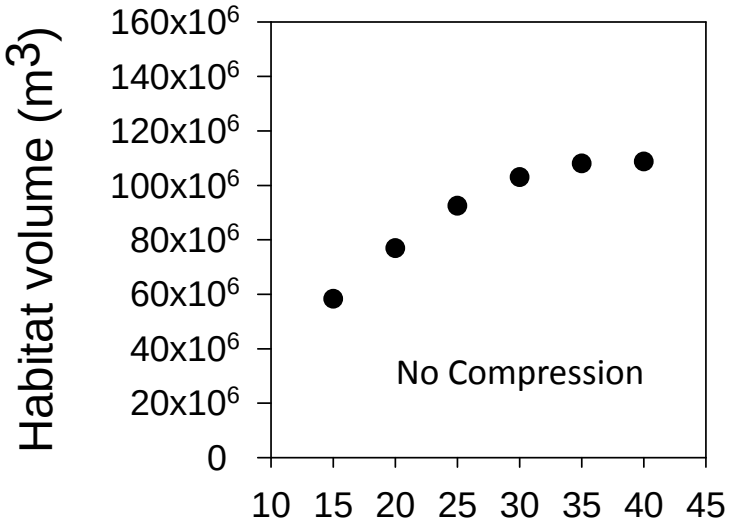


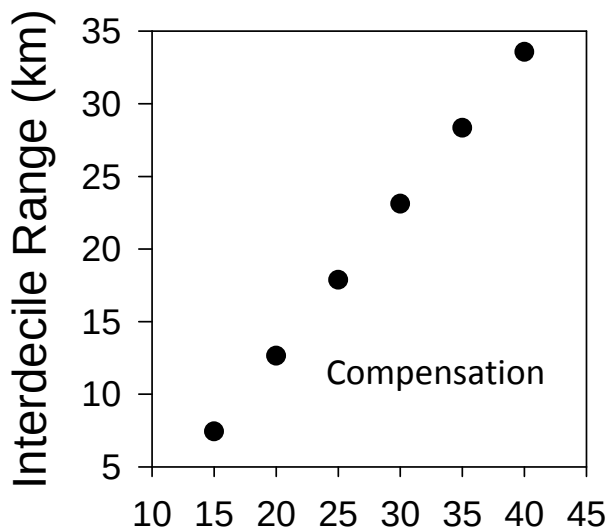
All taxa exhibited habitat compression as the COA translated upstream except one (*Menidia*)

ZOOPLANKTON – HABITAT COMPRESSION

Volume **Inter-Decile Range**

Menidia spp. preflexion larvae

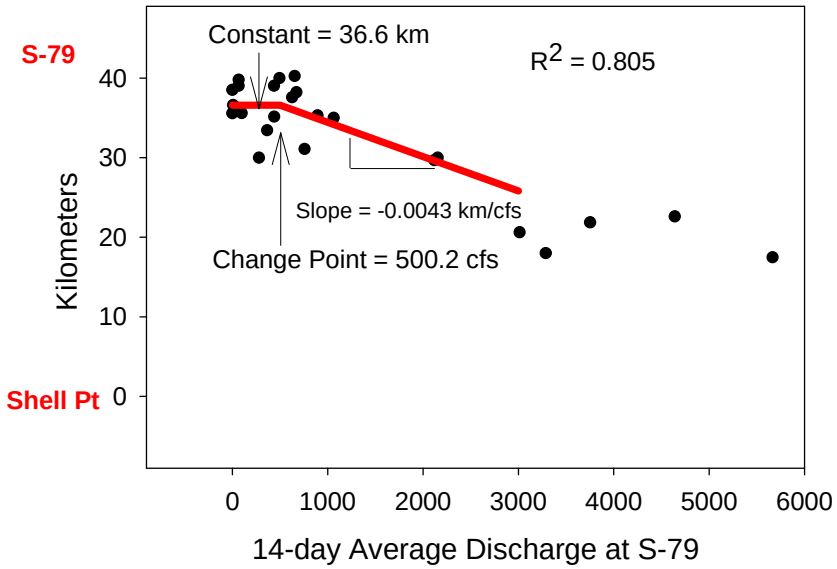




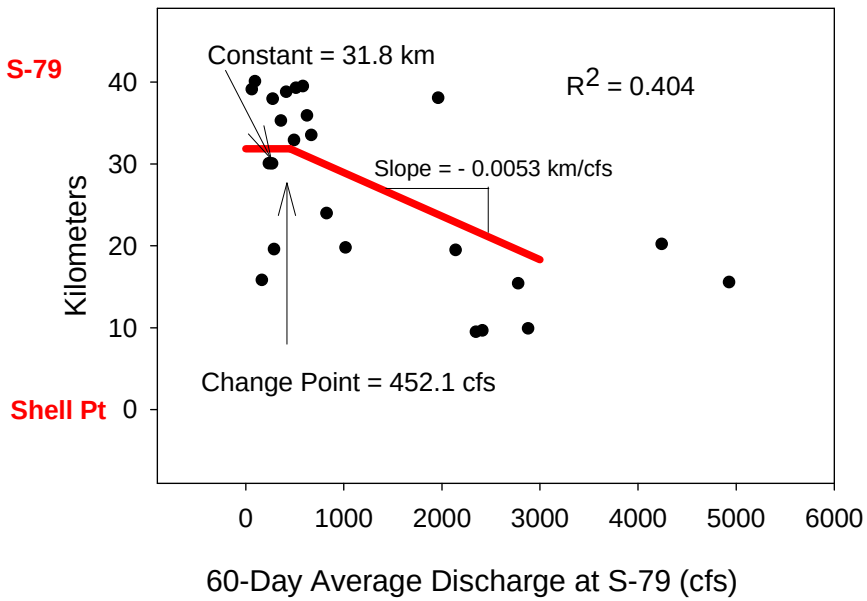
rkmU (km from ShellPoint)

ZOOPLANKTON IMPINGEMENT (2 EXAMPLES)

Americamysis almyra (Adults, position of the 90 th percentile)



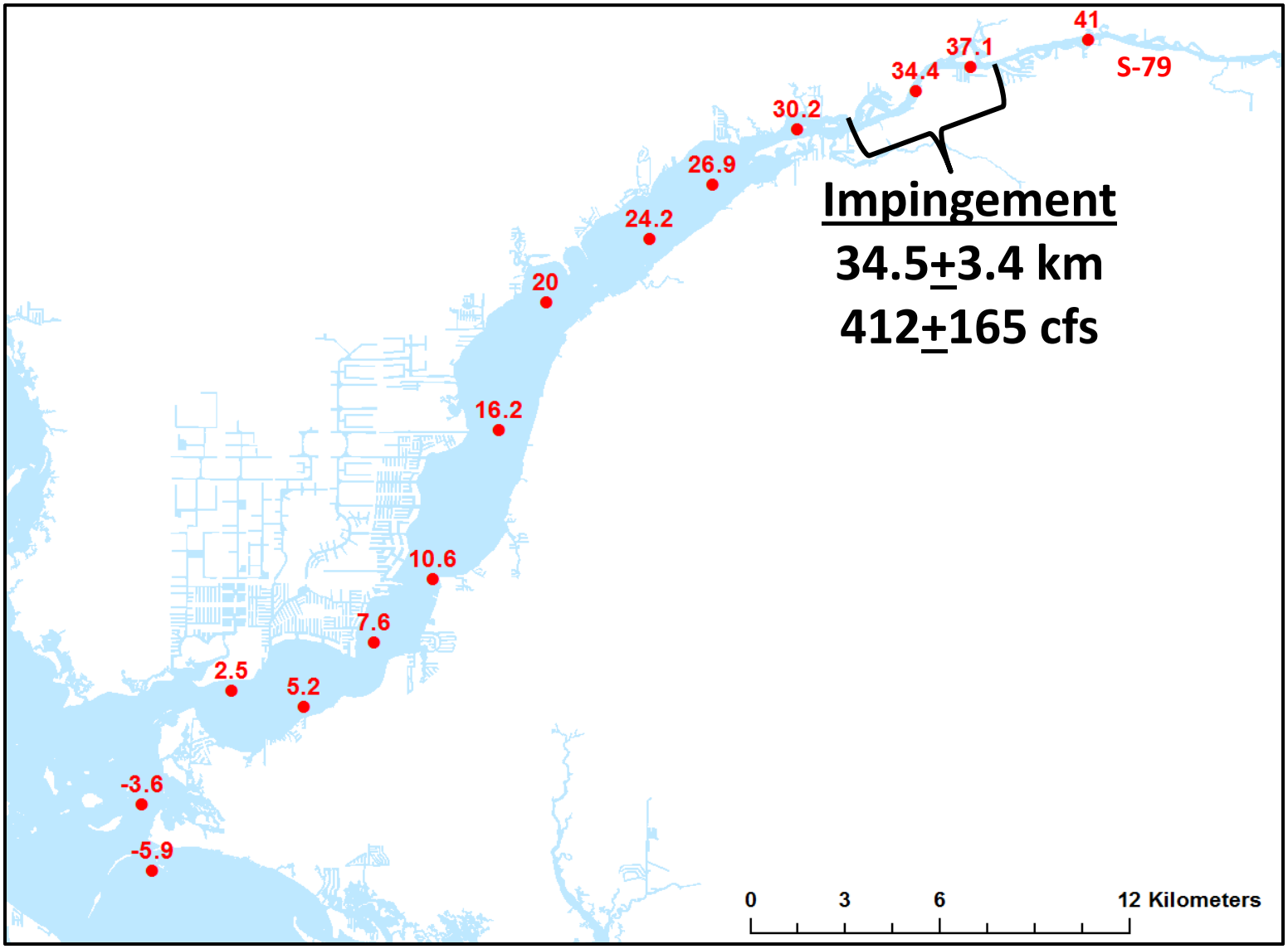
Edotia triloba (position of the 90 th percentile)



ZOOPLANKTON IMPINGEMENT

Taxon	n	Days	Const (km)	95%L	95%U		CP (cfs)	95%L	95%U	
Psuedodiaptomus	20									
Clytia spp.	3									
Menidia spp.	4									
Anchoa mitchilli adults (ln)	17	18	35.51	33.44	37.71		4277.0	4178	4377	
Anchoa mitchilli juveniles	19	7	37.79	36.1	39.5		3826.5	-1167	8820	
Gobiidae Preflexion Larvae	15	30	33.36	30.4	36.35		2219.7	-180	4620	
Lironeca spp.	16	3	32.18	24.5	39.86		476.3	-1323	2275	
Edotia triloba	24	60	31.8	25.7	38		452.1	-1286	2190	
Bowmaniella brasilliensis	23	14	29.13	23.3	34.91		512.2	-1041	2065	
Americamysis almyra-adults	24	14	36.6	34.5	38.7		500.2	-322	1322	
Americamysis juveniles	24	14	36	33.5	38.5		565.6	-423	1554	
Gobiosoma Post Flexion Larvae	10	45	37.6	23	52.2		97.9	-2615	2811	
Microgobius postflexion	6	20	38.1	28.6	47.6		280.2	-1763	2323	

ZOOPLANKTON IMPINGEMENT



STUDY SUMMARY

- **COA's for the 13 taxa migrated downstream and upstream as discharge at S-79 increased and decreased, respectively**
- **Discharge at S-79 explained from 15-50% of the variability in location of the COA's of the various taxa.**
- **Most taxa responded to inflows averaged over 45 or 60 days**

Habitat Compression

- **All species, except *Menidia*, showed habitat compression as the COA translated upstream**
- **Flows positioning COA at 30 km averaged 259 ± 378 cfs at S-79**

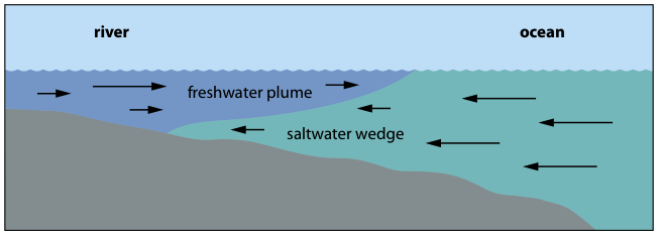
Impingement

- **Impingement could be demonstrated for 7 of the 13 taxa**
- **Flows at which impingement began averaged 412 ± 165 cfs at S-79**

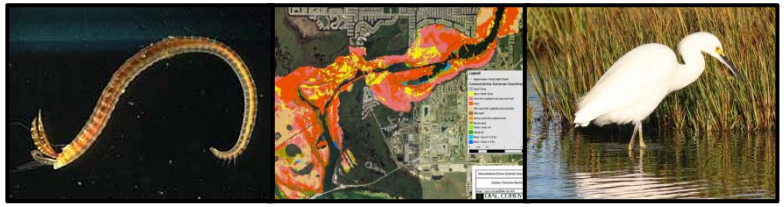
Component Study 5: Relationships between ichthyoplankton and inflow

Cassondra Thomas, PhD
Senior Scientist
Coastal Ecosystems Section
South Florida Water Management District

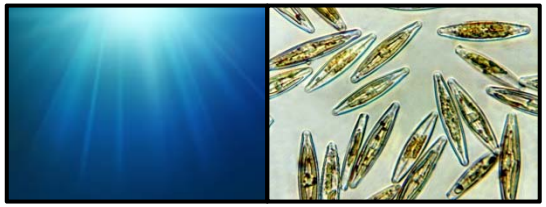
INDICATORS OF ESTUARINE RESPONSE TO LOW INFLOW



Changes in isohaline position with upstream encroachment of saltier water



Alter benthic community upon which many estuarine fauna are dependent

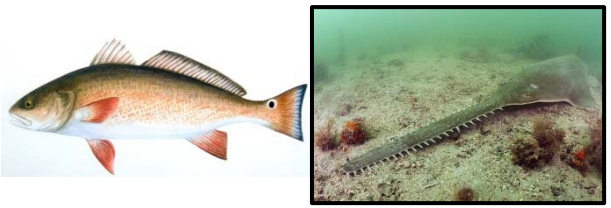


Reduced flushing and enhanced light can stimulate phytoplankton in upper estuary

Damaging to the freshwater *Vallisneria americana* (tape grass)

Impact physiology and habitat attributes of eastern oyster

Zooplankton and ichthyoplankton assemblages move upstream but can be impinged by structure

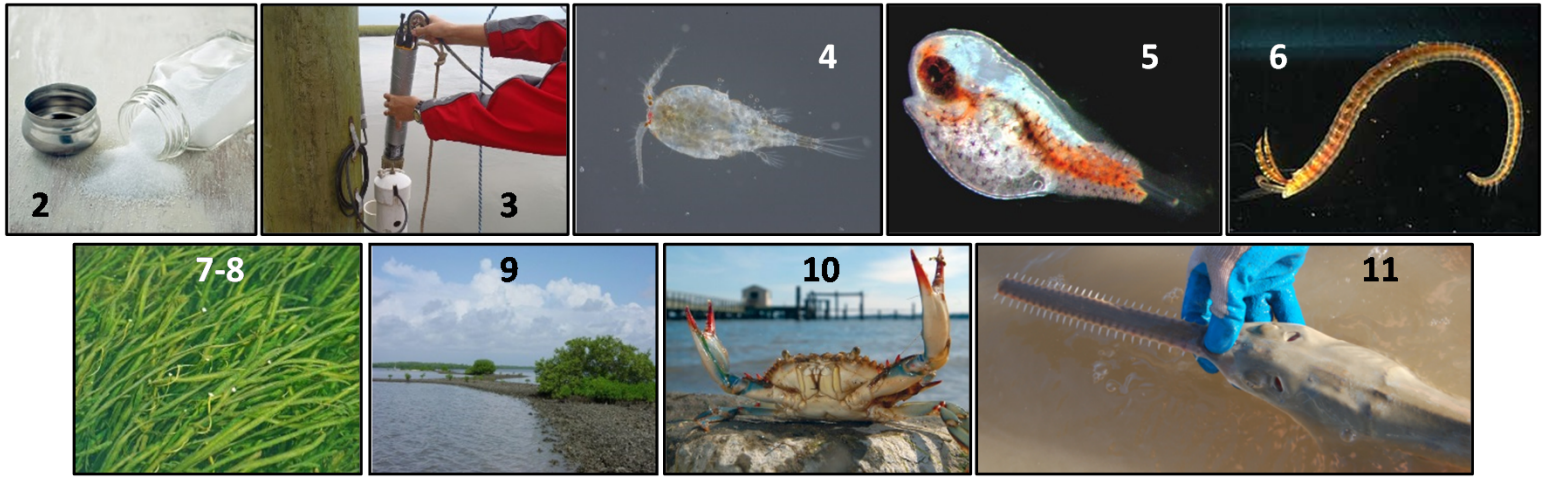


Affect coastal fish populations dependent upon estuaries as nurseries

Negatively impact harvests of important fisheries

SCIENCE COMPONENTS / STUDIES

	Component	Method
1	Hydrodynamics	Influence of alterations on hydrodynamics
2	Inflow vs. Salinity	Monthly freshwater-salinity relationships
3	Water Quality	Relationships between inflow, salinity, and water quality
4	Zooplankton	Inflow, zooplankton and habitat compression
5	Ichthyoplankton	Relationships between ichthyoplankton and inflow
6	Benthic Fauna	Macrofauna-salinity patterns relative to inflow
7	*Vallisneria* data	Empirical relationships between tape grass, S, and inflow
8	*Vallisneria* model	Model exploration of tape grass, S, light, and inflow
9	Oyster Habitat	Salinity patterns for oyster habitat in lower CRE
10	Blue Crabs	Relationships between blue crab landings, rainfall, and inflow
11	Sawfish	Dry season inflow, hydrodynamics, and habitat extent



Intro to Ichthyo: What are they and why do we care?

Ichthyoplankton: A component of zooplankton, fish of different life stages that are generally between 153 µm and 5 mm

Life Stages

- Egg
- Yolk sac larva
- Post yolk sac larva
- Juvenile
- Adult

Food web

- They eat phytoplankton, detritus, zooplankton
- Are eaten by zooplankton, jelly fish and ctenophores, decapods, larger fish

Ecological Indicator

- status, abundance, and reproductive potential of adult fish populations

Primary Objective

- Composition and location of assemblages may fluctuate with inflow

STUDY OBJECTIVE

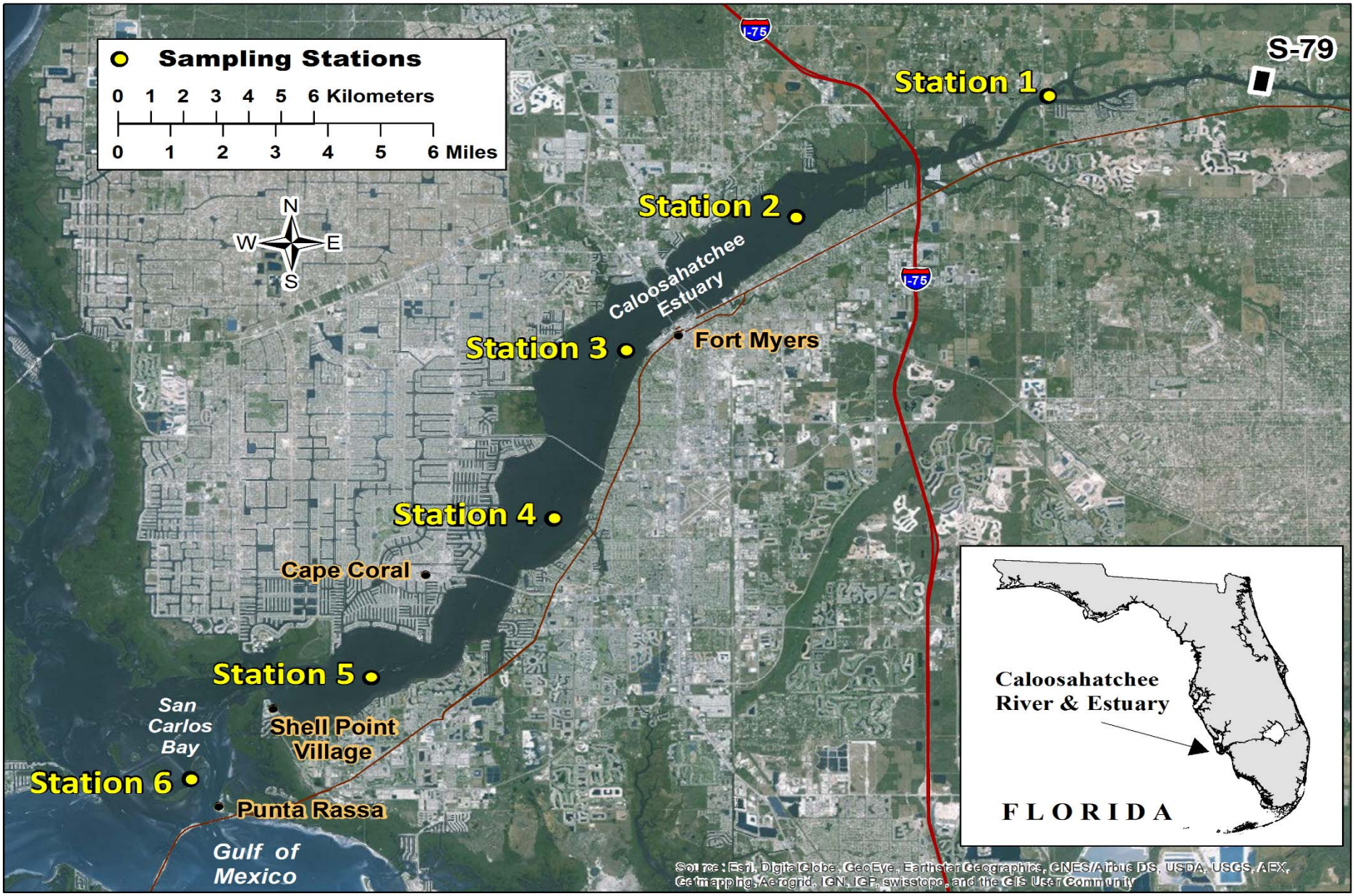
To assess the associations between freshwater inflow, salinity, and ichthyoplankton community attributes

1. **Do ichthyoplankton assemblages change location with variable inflow?**
2. **How is abundance affected by freshwater inflow?**

SAMPLING METHODS

- Nocturnal samples monthly from 1986 to 1989 at six stations (S79 to San Carlos Bay; R. Chamberlain et al, 2003)
- Paired 0.5 m conical zooplankton nets
  - 505 µm mesh
  - Towed obliquely
  - Flow meter (m s^{-1}) to measure the volume sampled (m^3 s^{-1})
- Samples sorted to the lowest possible taxonomic level and counted
- Classifications
  - Total abundance (# m^{-3})
  - Age class groups
    - Eggs
    - Post-yolk sac larval
    - Juvenile

SAMPLING LOCATIONS



STUDY METHODS

- **Freshwater inflow volume measured daily at S-79**

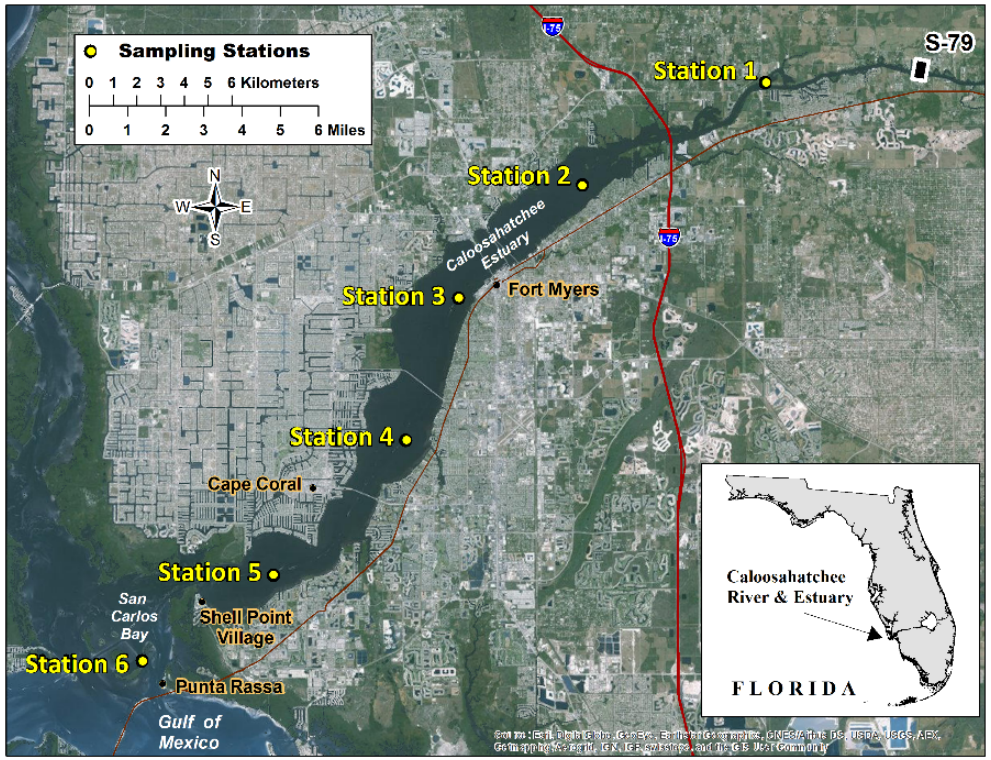
- **Salinity at each station predicted using an auto-regressive approach (Qiu and Wan 2013)**

- **S-79 Inflow and salinities averaged over 1 d, 5 d, 7 d, 14 d, 21 d, and 30 d periods prior to the day of sampling**

- **Inflow was grouped into categories based in 1980's study (Chamberlain et al, 2003):**
  1) 0-150 cfs
  2&3) 151-600 cfs
  4) 601-1200 cfs
  5) 1201-2500 cfs
  6) > 2500 cfs

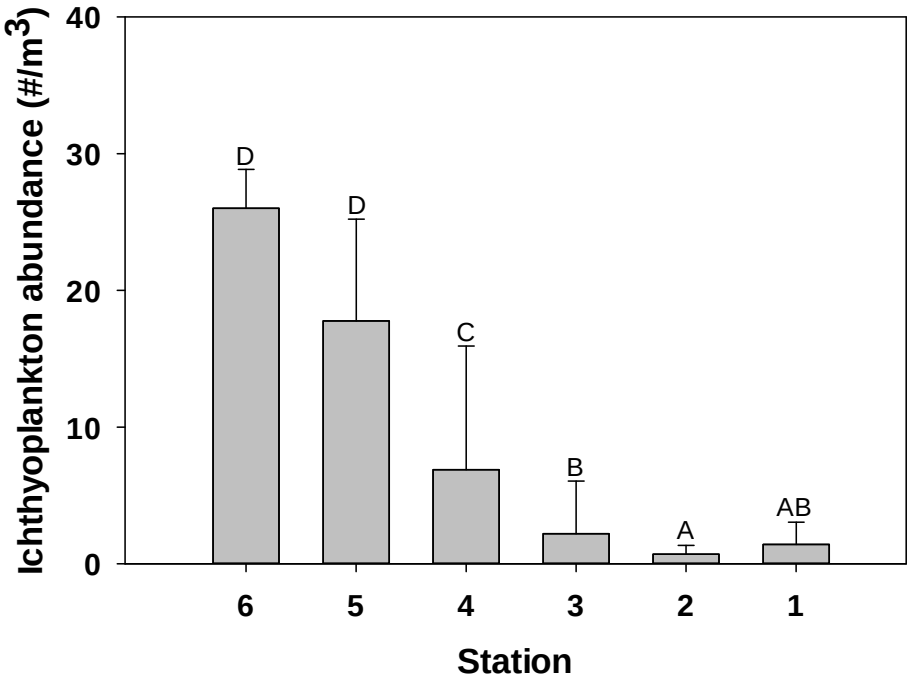
ICTHYOPLANKTON – DATA ANALYSIS

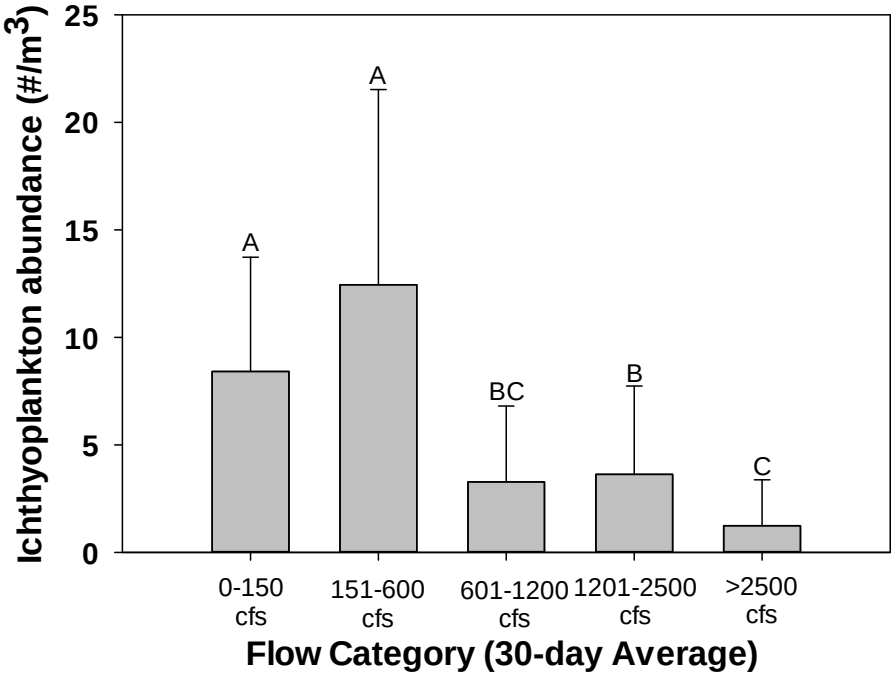
- **Calculate the Center of Abundance (COA) for a variety of taxa**
- **COA= Average organism density weighted by distance downstream from S-79**
- **U = organism density at a station (#/m^3) for each sampling date**
- **Km = distance downstream from S-79**



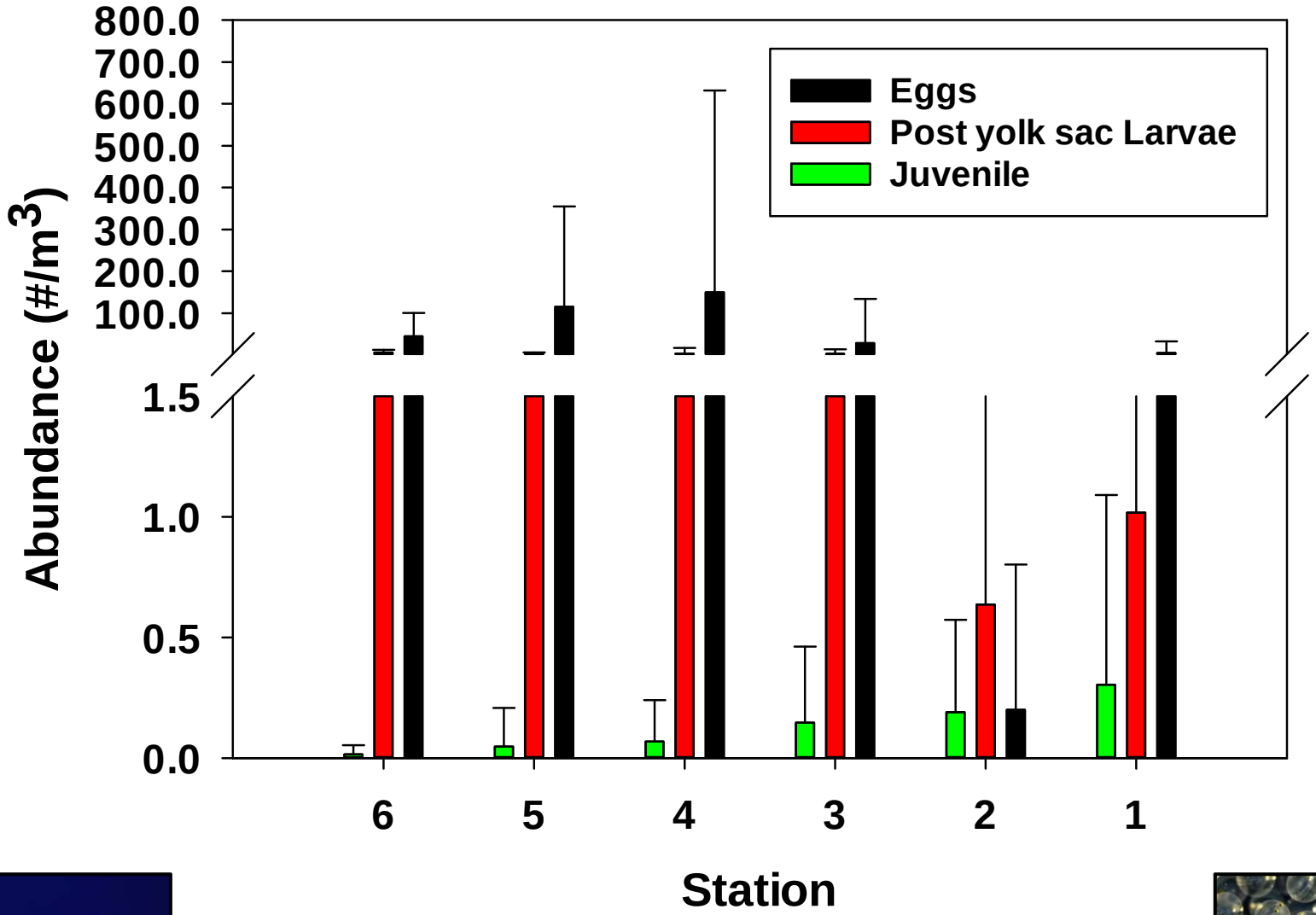
$$COA = \frac{\Sigma(km * U)}{\Sigma U}$$

ICHTHYOPLANKTON ABUNDANCES BY STATION AND FLOW

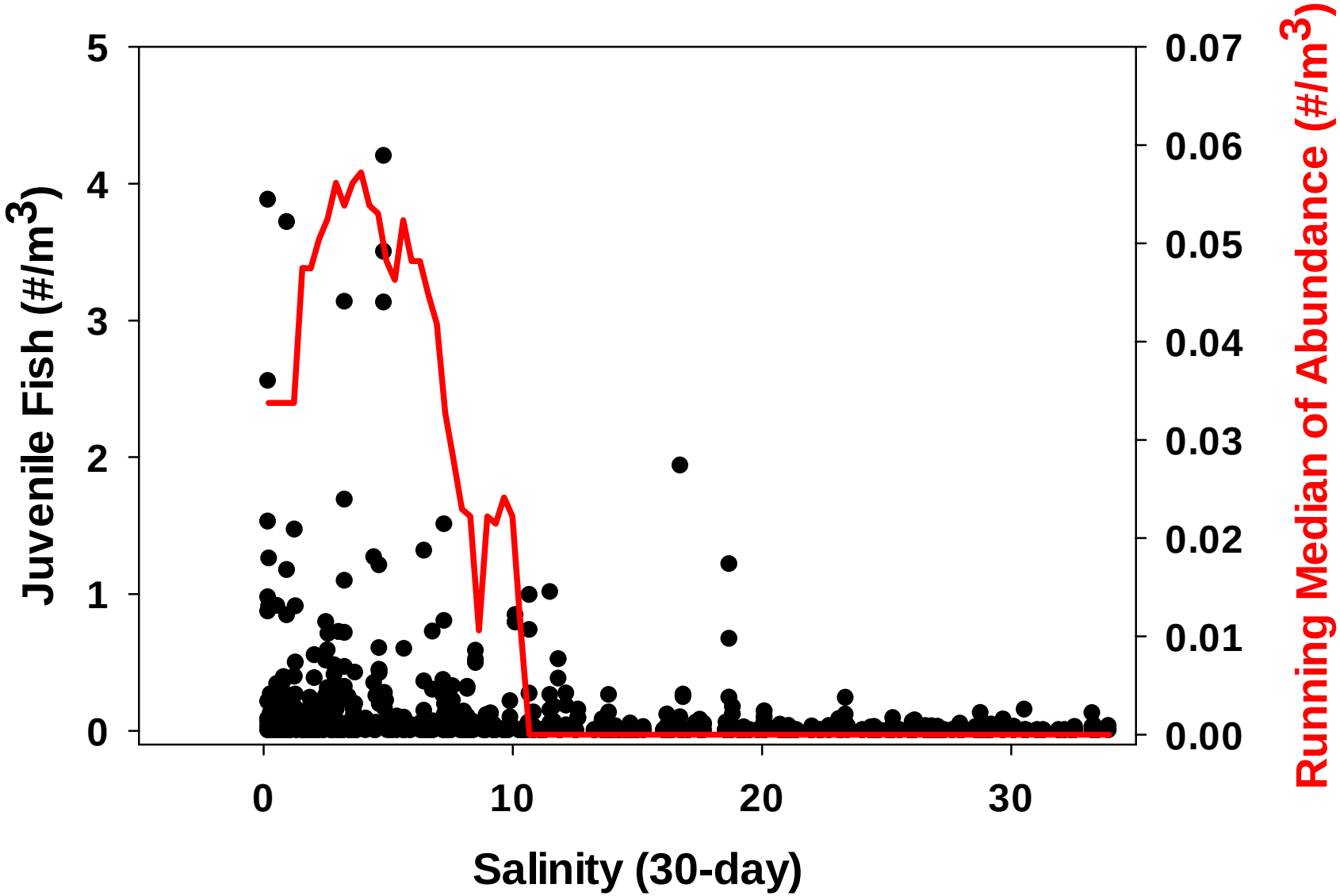




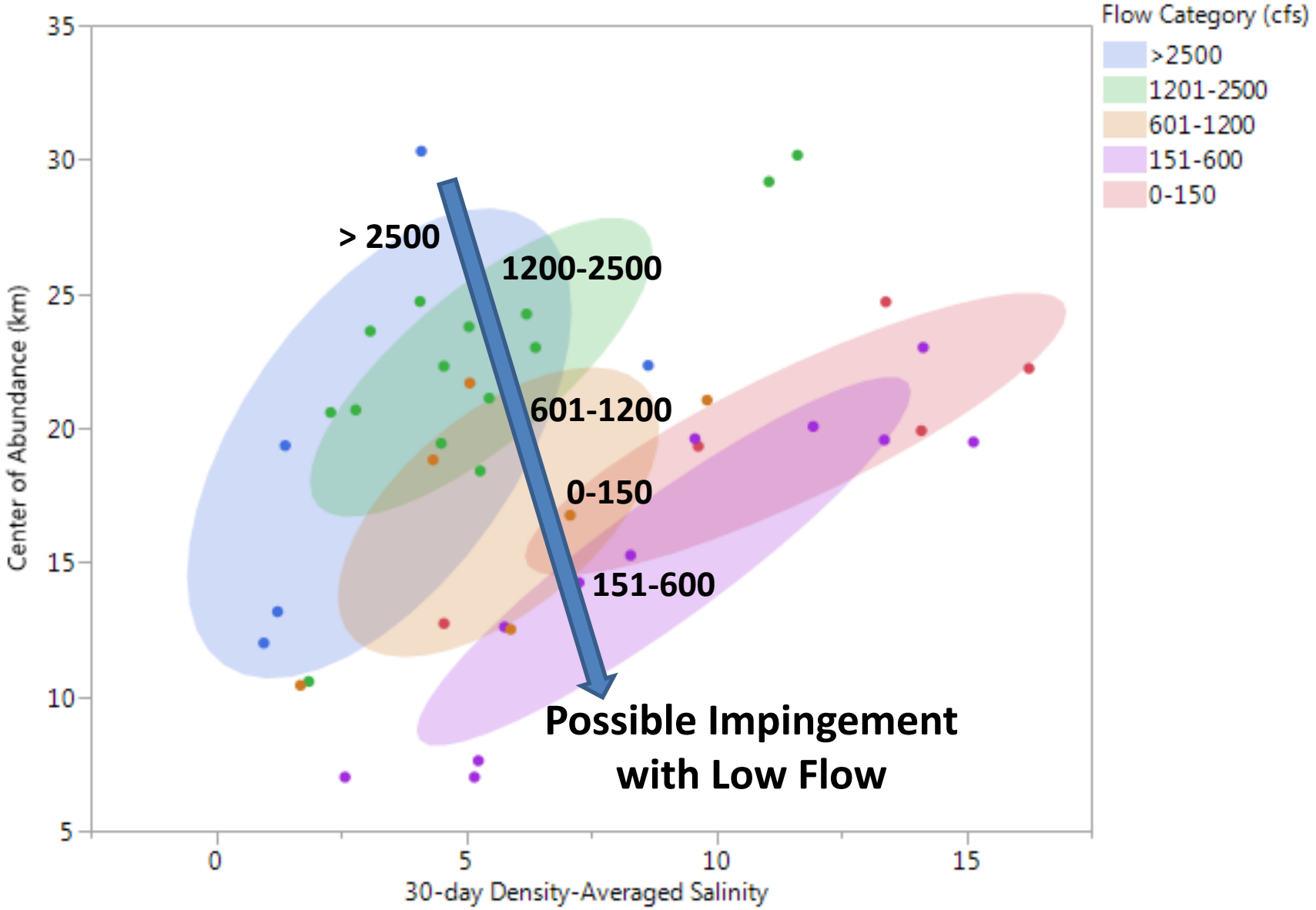
ICTHYOPLANKTON ABUNDANCE - GROUPS



JUVENILE FISH AND SALINITY



JUVENILE FISH LOCATION



STUDY SUMMARY

- **Ichthyoplankton abundance tended to be greater in the lower estuary under most inflow conditions**
- **Eggs and larvae were the main components of the ichthyoplankton assemblages with the community location influenced freshwater inflow**
- **Increased inflow tended to push ichthyoplankton out of the estuary**
- **Juvenile fish were capable of seeking out preferable habitat with a majority of juvenile fish located in the middle and upper estuary**

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

PUBLIC INPUT

Question and Answer Session

Science Workshop-Day 1