# Land Use Change & Freshwater Inflow

## Exploring Effects on Blue Crabs

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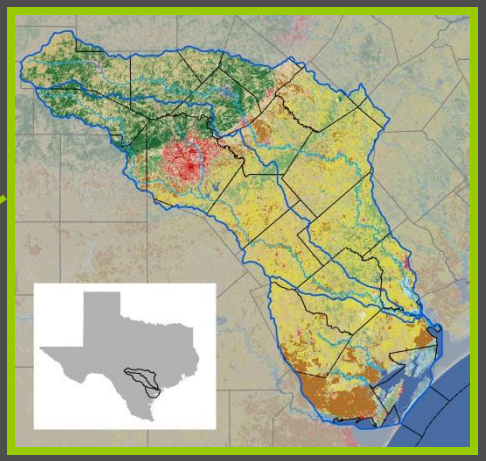
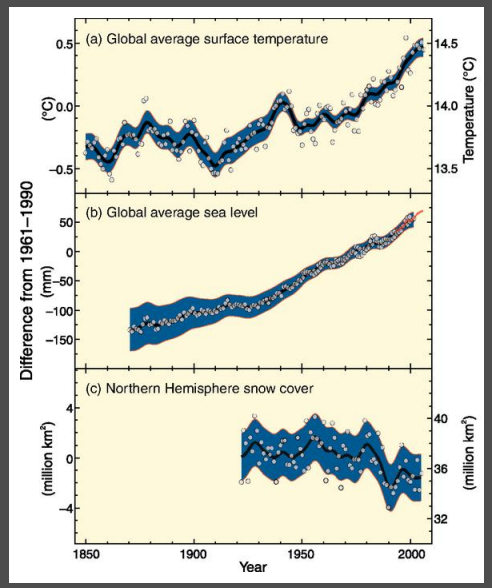
# Background






(a) Global average surface temperature
(°C)
Temperature (°C)
0.5
0.0
−0.5
14.5
14.0
13.5
(b) Global average sea level
Difference from 1961–1990
(mm)
50
0
−50
−100
−150
(c) Northern Hemisphere snow cover
(million km²)
4
0
−4
40
36
32
1850
1900
1950
2000
Year

# Goal



## Use decision support tools to compare multiple "scenarios" and . . .

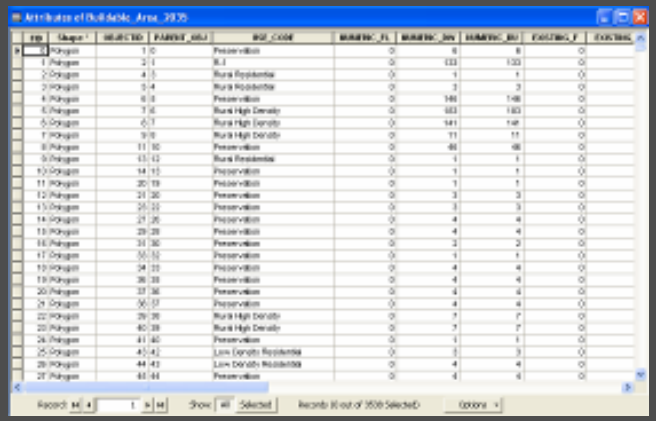
- Examine the effect of land use change on water usage and runoff . . .
- Explore the effect of freshwater inflow changes on blue crabs . . .
- Improve management decisions

# GIS

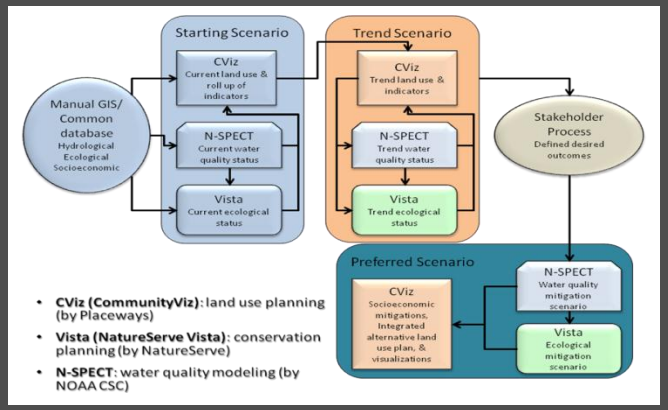


## *GIS = Geographic Information System*

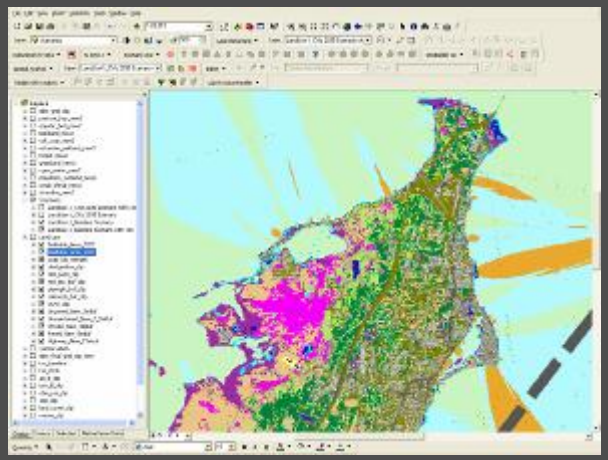
*Integrates hardware, software, and data . . .*



*Store Data*




*Model Data*



*Map Data*

# Water Consumption



community viz®

## Analyze

GIS-based analysis of growth and development

## Visualize

Interactive 3D models and other visuals of places as they are, and as they could be

## Communicate

Wide variety of tools for public participation, expression, and communication

placeways

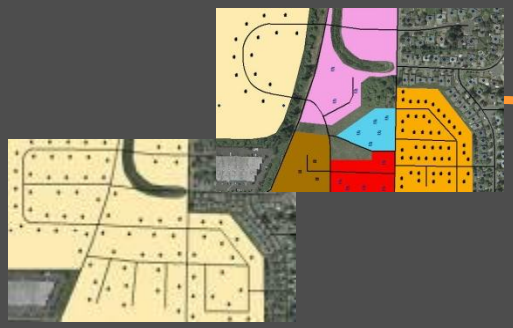
ORTON FAMILY FOUNDATION

# Water Consumption

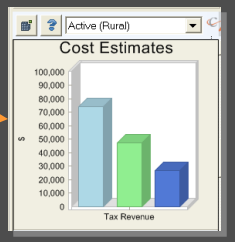


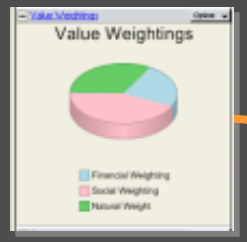
communityviz®

Create land use scenarios



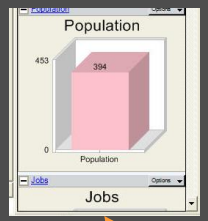
Create indicators measuring impacts (economic, social, environmental)

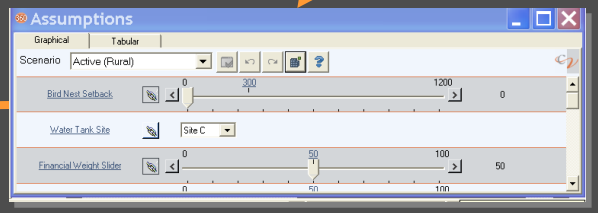



Create 3D visual models

Project impacts into the future

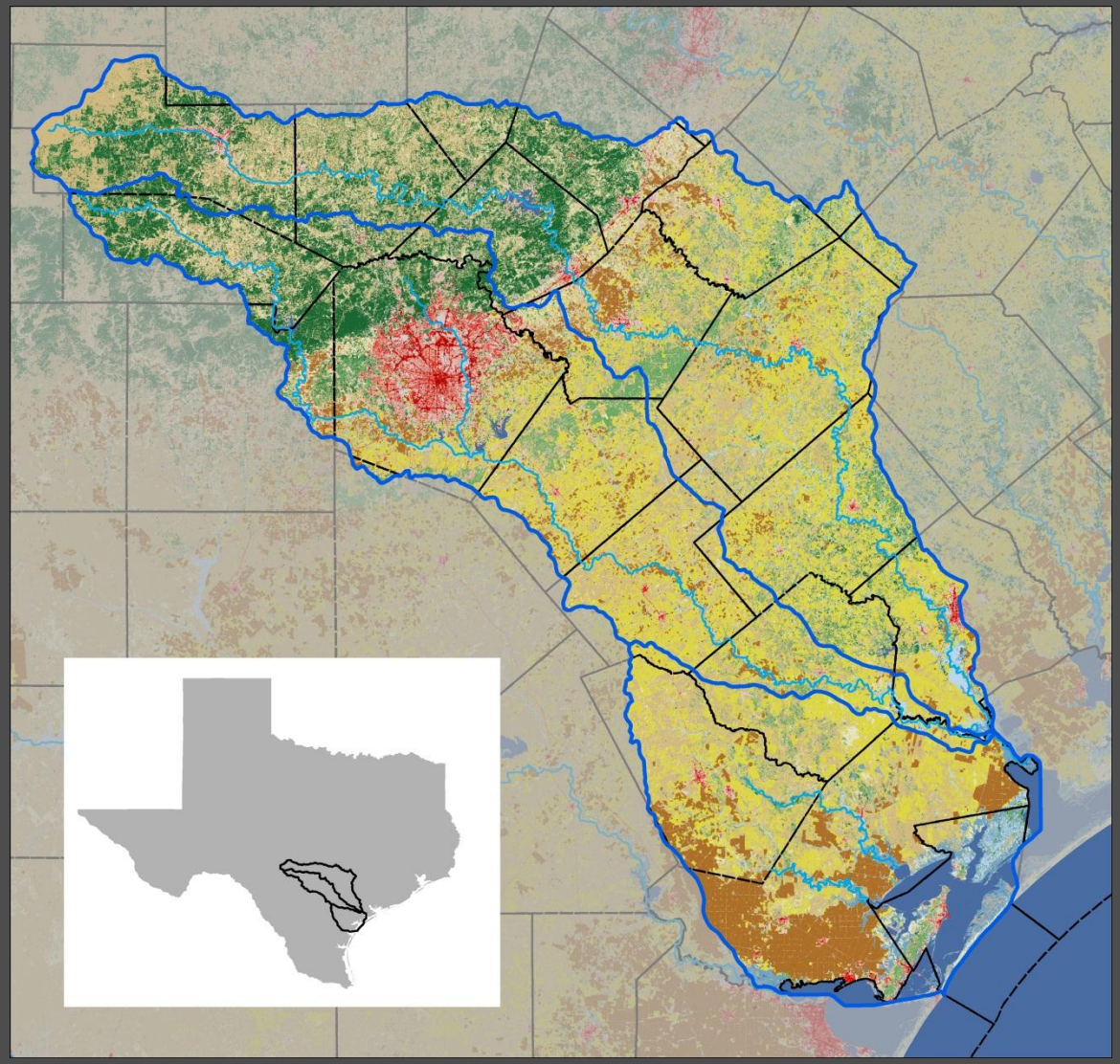

Experiment interactively and see changes

# Land Use - Baseline



**Land Use/Land Cover**

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Herbaceous
- Hay/Pasture
- Cultivated Crops
- Woody Wetlands
- Emergent Herbaceous Wetlands



# City



## *Kerrville - Baseline*

**Land Use/Land Cover**

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensit
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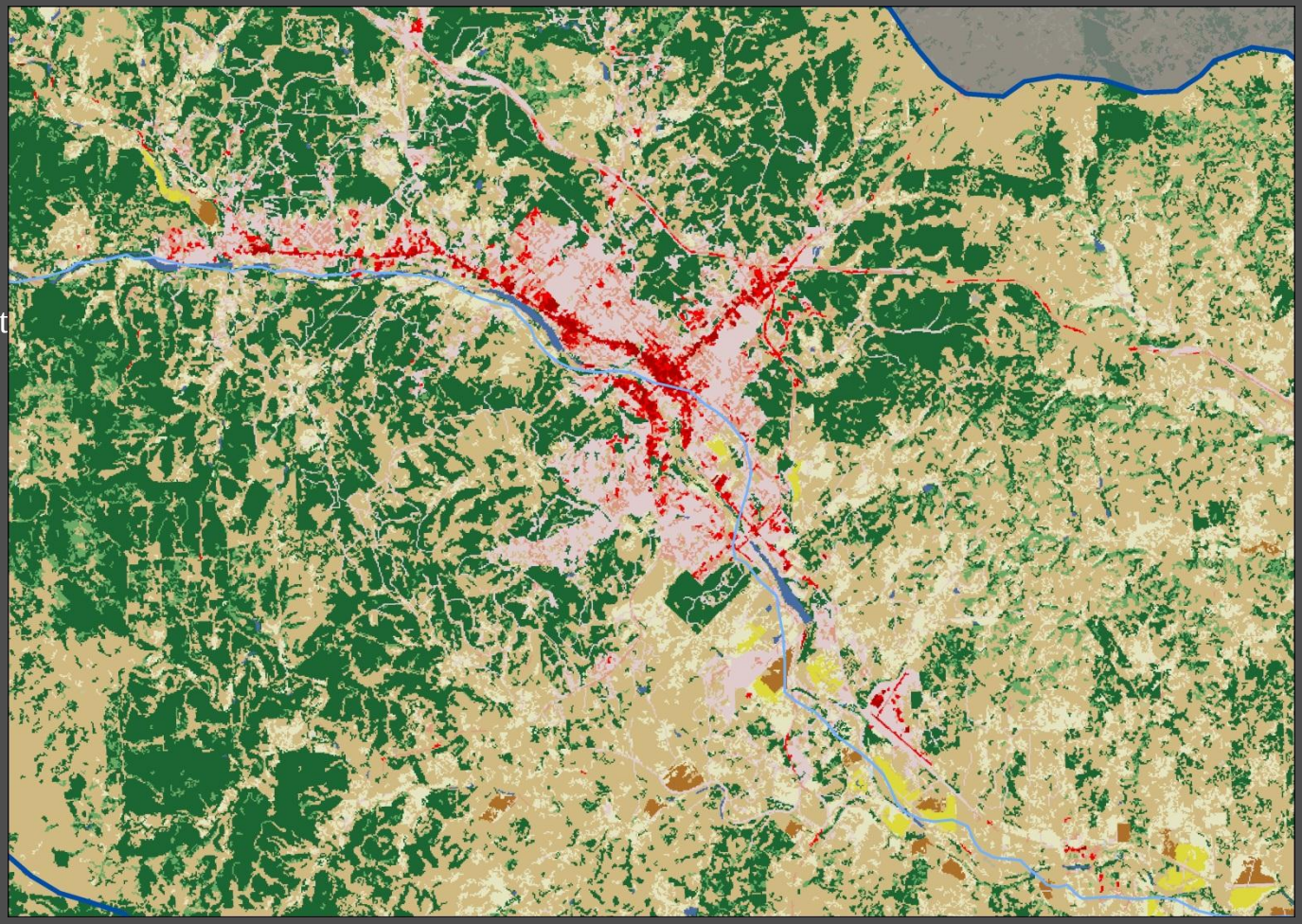

# City



## *Kerrville - Future*

**Land Use/Land Cover**

- Open Water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensit
- Developed, High Intensity
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- Evergreen Forest
- Mixed Forest
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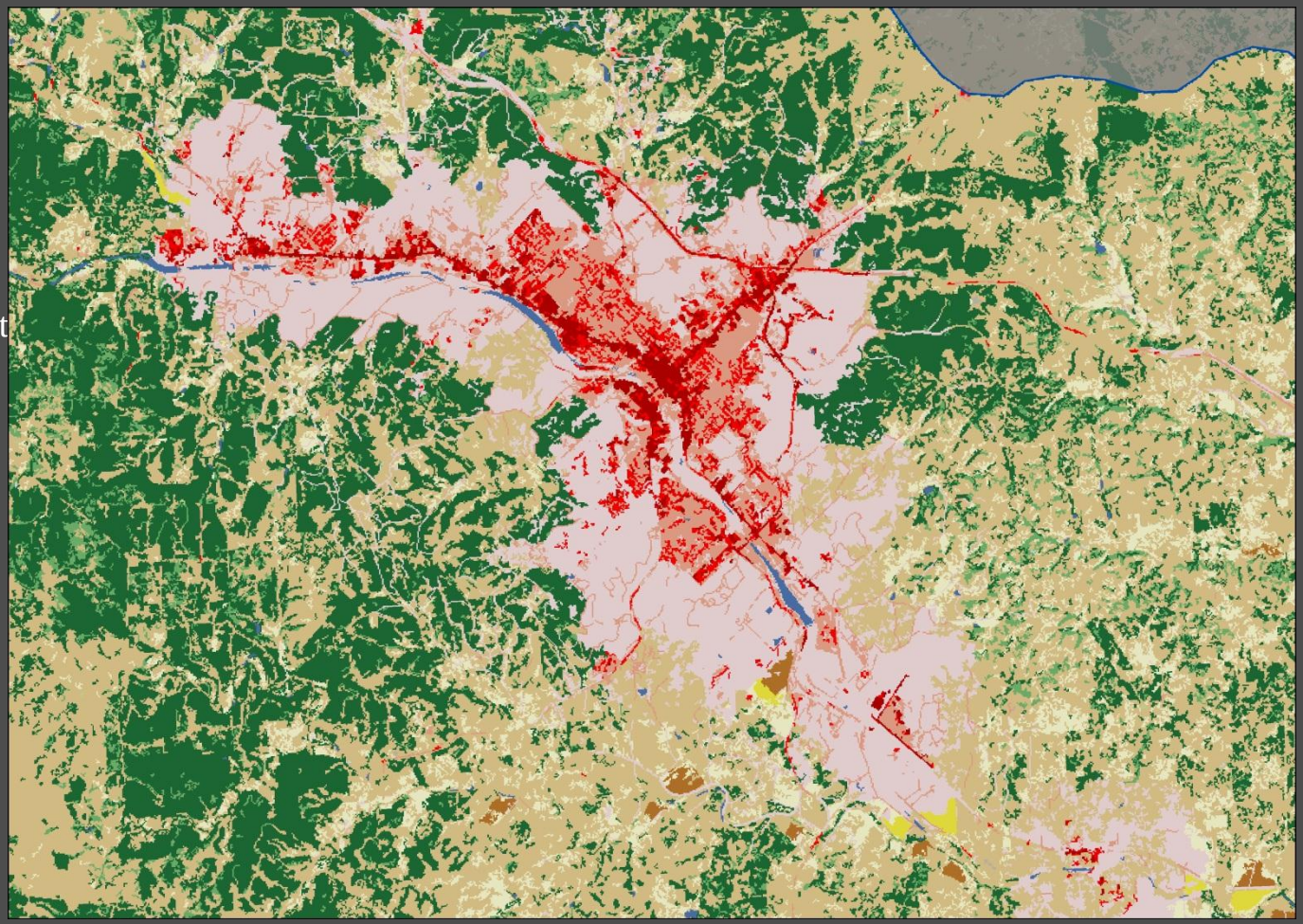


# Buildout Analysis



1. **Numeric Buildout:**
   Mathematical calculation based on area and density rules.

   OUTPUT = number

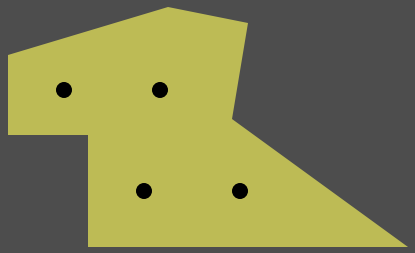
Area = 5 acres

Density = 1 DU/acre

Numeric DUs = 5

2. **Spatial Buildout:**
   Creates map layer with points or polygons

   OUTPUT = points on map

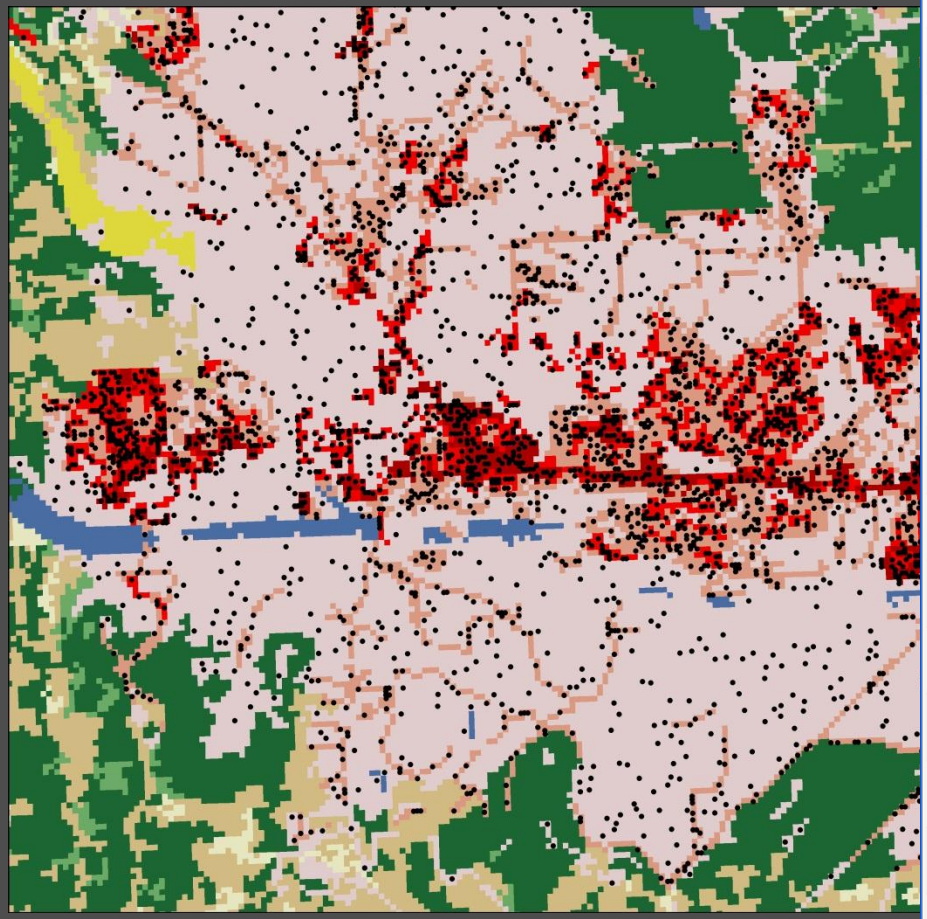


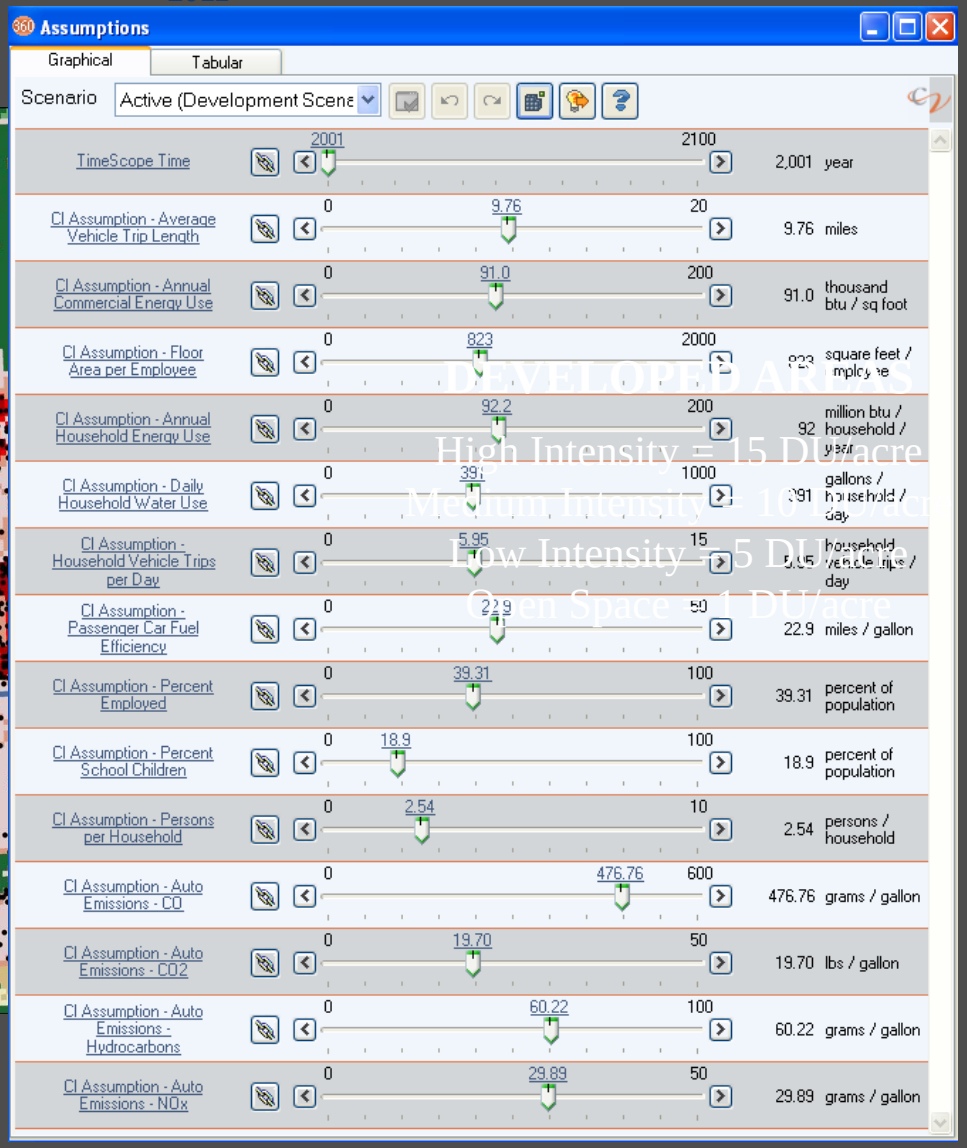
Physical shape restricts development.

Spatial DUs = 4

# Buildings - Baseline

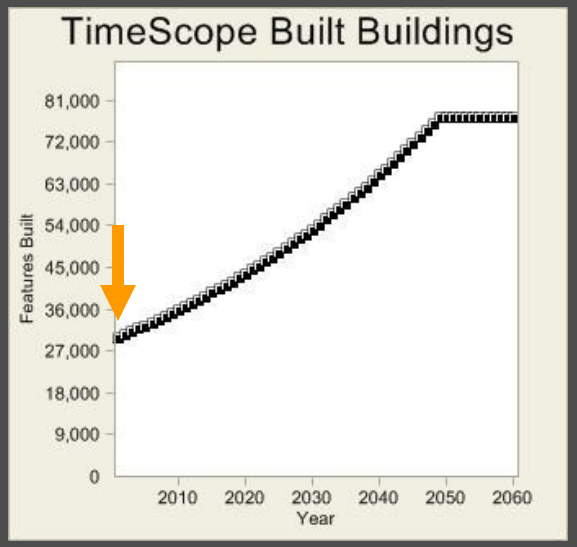


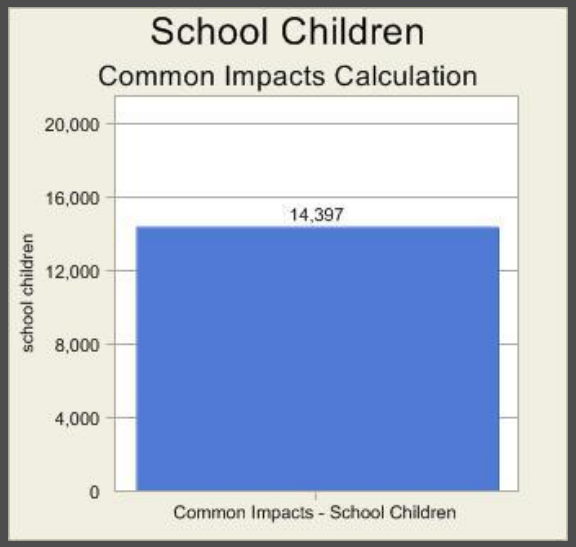


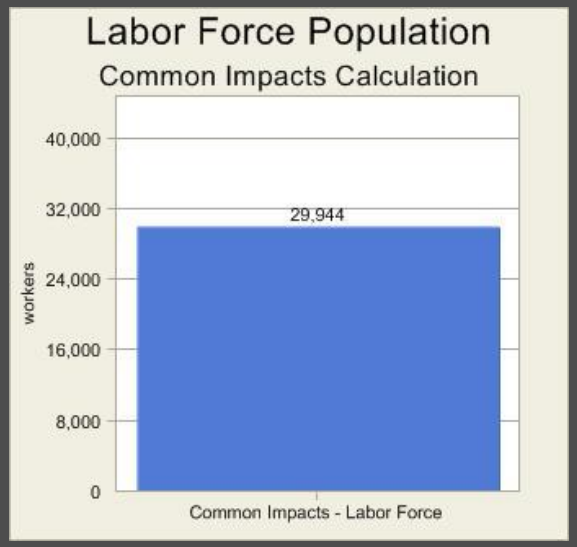


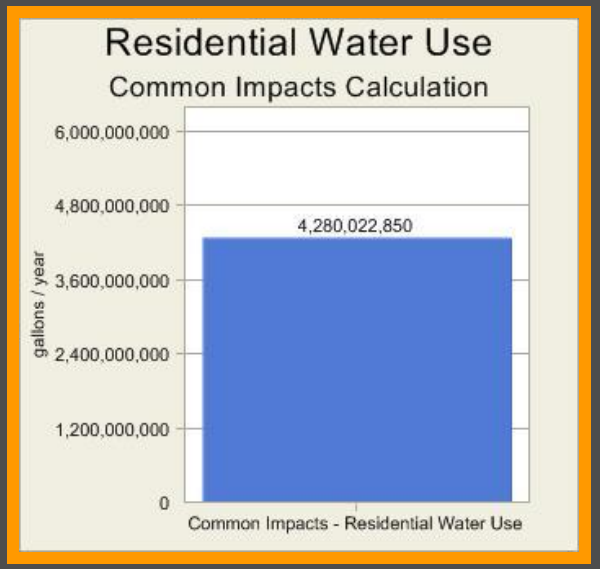
# Impacts - Baseline

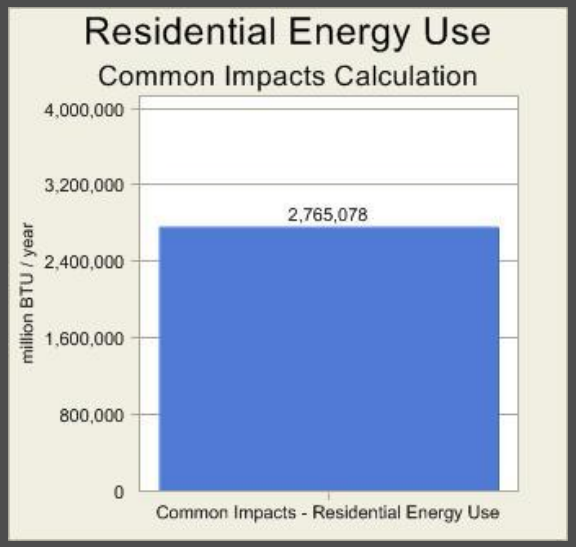


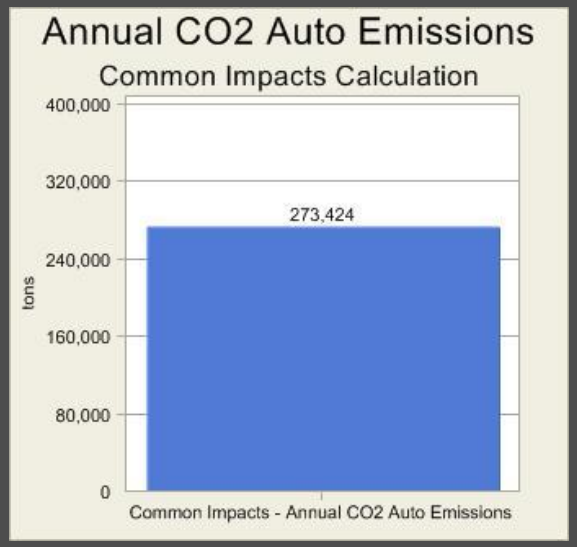


# Revised Assumptions



**FACT SHEET**

United States | Texas | Kerr County

## Kerr County, Texas

city/town, county, or zip: kerr
state: Texas GO
search by address »

2005-2009 | 2000

**2005-2009 American Community Survey 5-Year Estimates - what's this?** Narrative Profile | Reference Map

**Data Profile Highlights:**

**Note:** The following links are to data from the American Community Survey and the Population Estimates Program.

**NOTE:** Although the American Community Survey (ACS) produces population, demographic and housing unit estimates, it is the Census Bureau's Population Estimates Program that produces and disseminates the official estimates of the population for the nation, states, counties, cities and towns and estimates of housing units for states and counties.

| Social Characteristics - show more >> | Estimate | Percent | U.S. | Margin of Error | |
|---|---|---|---|---|---|
| Average household size | 2.42 | (X) | 2.60 | +/-0.05 | map |
| Average family size | 2.80 | (X) | 3.19 | +/-0.08 | |
| Population 25 years and over | 33,131 | | | +/-93 | |
| High school graduate or higher | (X) | 84.5 | 84.6% | (X) | map |
| Bachelor's degree or higher | (X) | 25.7 | 27.5% | (X) | map |
| Civilian veterans (civilian population 18 years and over) | 6,449 | 17.4 | 10.1% | +/-407 | map |
| With a Disability | (X) | (X) | (X) | (X) | |
| Foreign born | 2,846 | 6.0 | 12.4% | +/-397 | map |
| Male, Now married, except separated (population 15 years and over) | 11,404 | 62.0 | 52.3% | +/-491 | |
| Female, Now married, except separated (population 15 years and over) | 11,049 | 53.7 | 48.4% | +/-541 | |
| Speak a language other than English at home (population 5 years and over) | 7,658 | 17.2 | 19.6% | +/-467 | map |
| Household population | 45,157 | | | +/-479 | |
| Group quarters population | (X) | (X) | (X) | (X) | |

| Economic Characteristics - show more >> | Estimate | Percent | U.S. | Margin of Error | |
|---|---|---|---|---|---|
| In labor force (population 16 years and over) | 20,717 | 54.0 | 65.0% | +/-701 | map |
| Mean travel time to work in minutes (workers 16 years and over) | 17.9 | (X) | 25.2 | +/-1.0 | map |
| Median household income (in 2009 inflation-adjusted dollars) | 43,371 | (X) | 51,425 | +/-2,376 | map |
| Median family income (in 2009 inflation-adjusted dollars) | 50,697 | (X) | 62,363 | +/-3,509 | map |
| Per capita income (in 2009 inflation-adjusted dollars) | 24,529 | (X) | 27,041 | +/-1,216 | |
| Families below poverty level | (X) | 9.6 | 9.9% | +/-1.9 | |
| Individuals below poverty level | (X) | 13.6 | 13.5% | +/-2.1 | map |

**Assumptions**

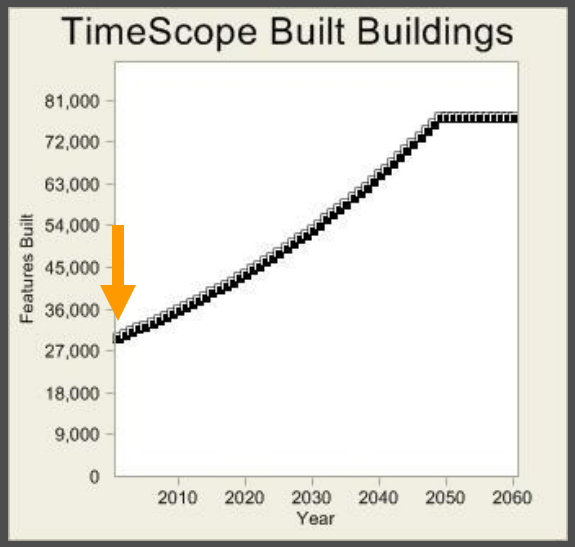
Graphical | Tabular

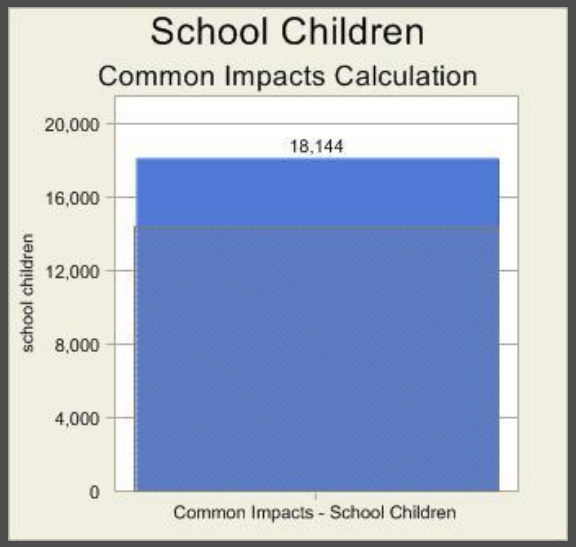
Scenario: Development Scenario

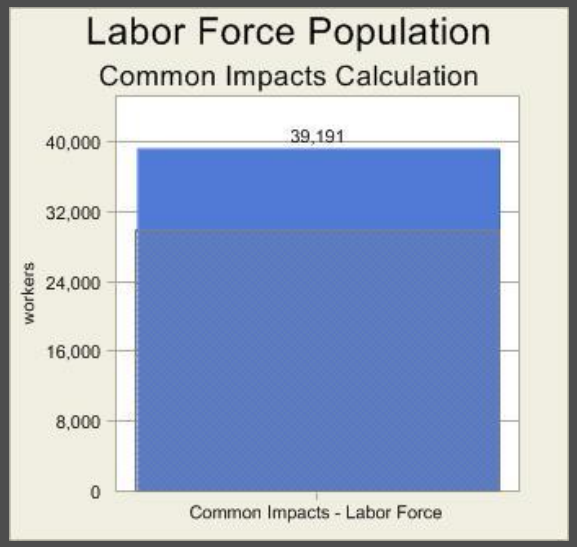
| | Min | Value | Max | Current | |
|---|---|---|---|---|---|
| TimeScope Time | 2001 | | 2100 | 2,001 | year |
| CI Assumption - Average Vehicle Trip Length | 0 | 9.76 | 20 | 15.00 | miles |
| CI Assumption - Annual Commercial Energy Use | 0 | 91.0 | 200 | 91.0 | thousand btu / sq foot |
| CI Assumption - Floor Area per Employee | 0 | 823 | 2000 | 823 | square feet / employee |
| CI Assumption - Annual Household Energy Use | 0 | 92.2 | 200 | 92 | million btu / household / year |
| CI Assumption - Daily Household Water Use | 0 | 391 | 1000 | 275 | gallons / household / day |
| CI Assumption - Household Vehicle Trips per Day | 0 | 5.95 | 15 | 4.50 | household vehicle trips / day |
| CI Assumption - Passenger Car Fuel Efficiency | 0 | 22.9 | 50 | 18.0 | miles / gallon |
| CI Assumption - Percent Employed | 0 | 39.31 | 100 | 54.00 | percent of population |
| CI Assumption - Percent School Children | 0 | 18.9 | 100 | 25.0 | percent of population |
| CI Assumption - Persons per Household | 0 | 2.54 | 10 | 2.42 | persons / household |
| CI Assumption - Auto Emissions - CO | 0 | 476.76 | 600 | 476.76 | grams / gallon |
| CI Assumption - Auto Emissions - CO2 | 0 | 19.70 | 50 | 19.70 | lbs / gallon |
| CI Assumption - Auto Emissions - Hydrocarbons | 0 | 60.22 | 100 | 60.22 | grams / gallon |
| CI Assumption - Auto Emissions - NOx | 0 | 29.89 | 50 | 29.89 | grams / gallon |

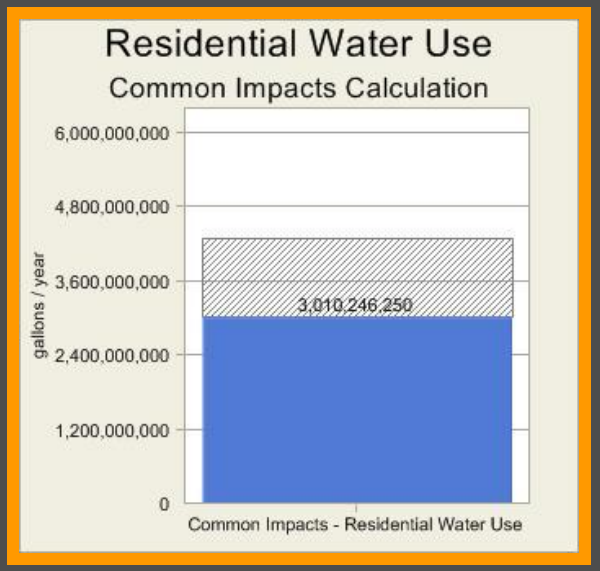
# Revised impacts - Baseline

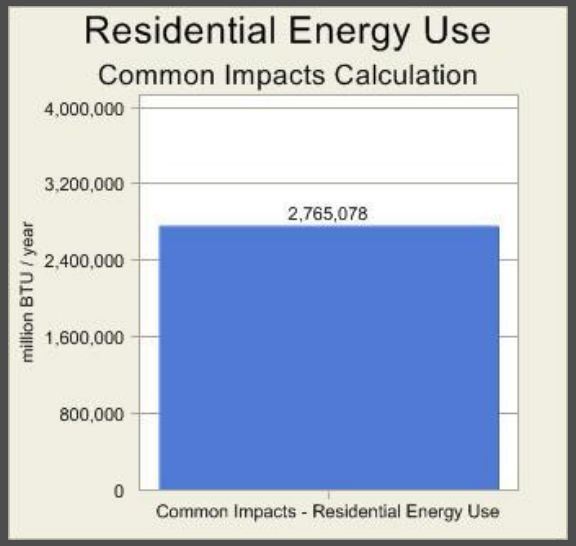


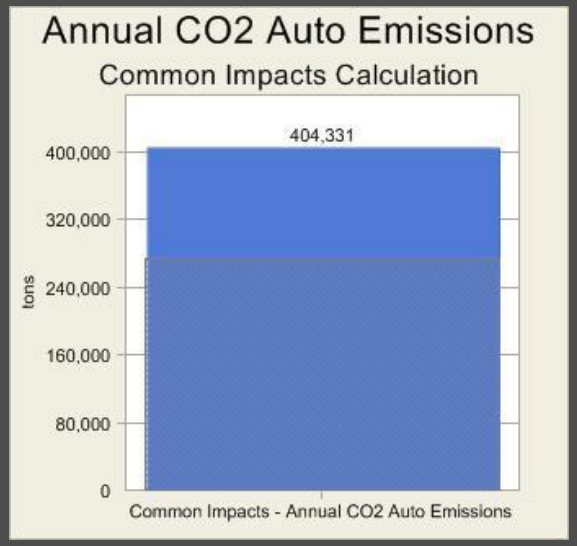


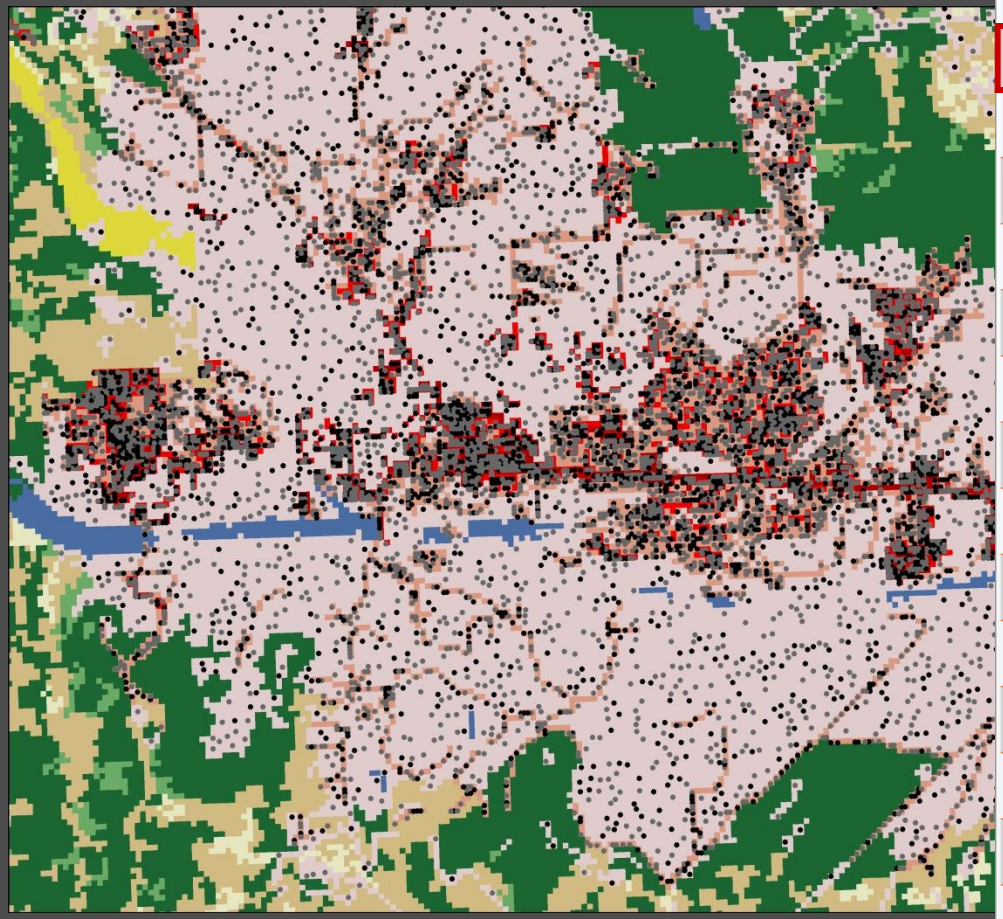



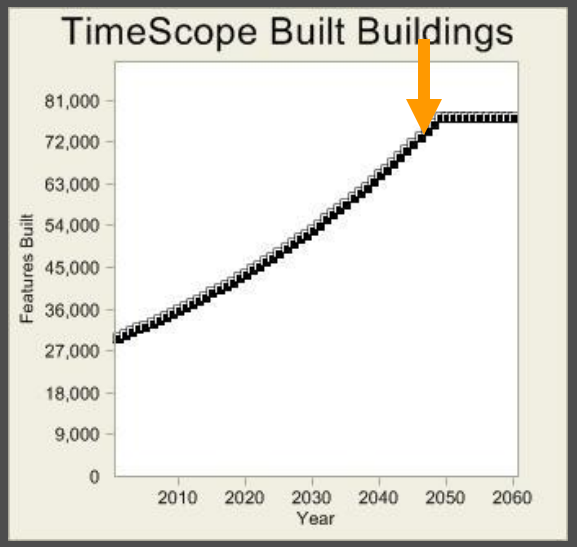
# Buildings - 2050

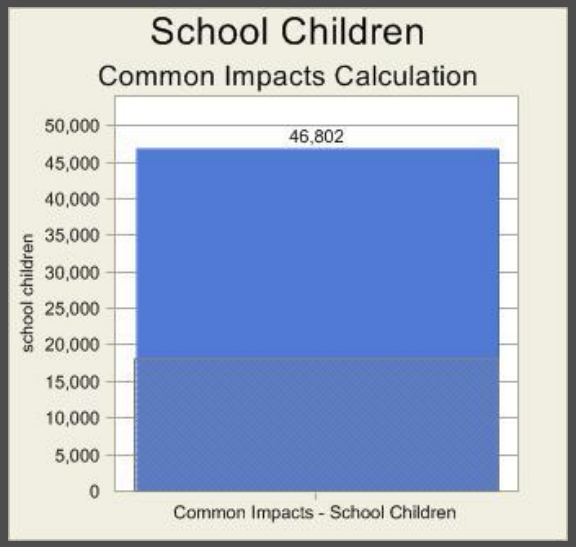


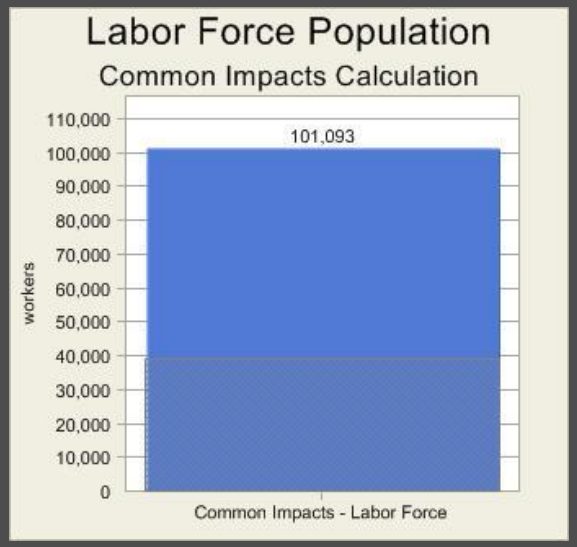


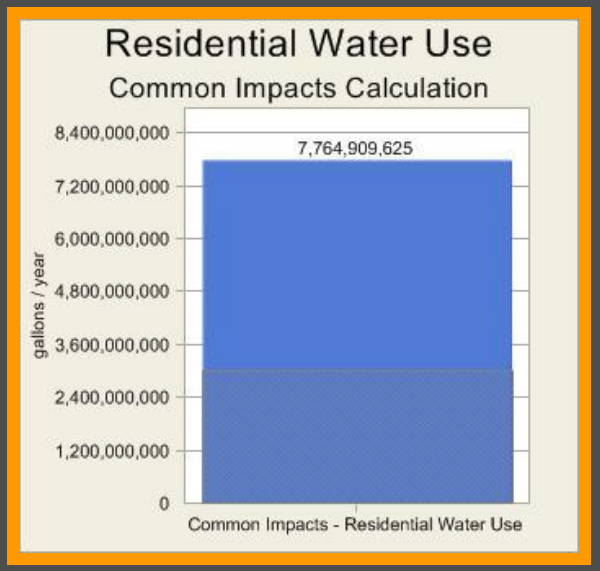
# Impacts - 2050

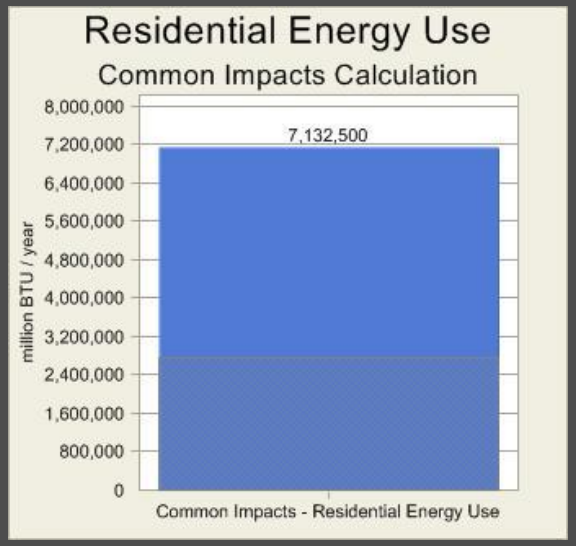


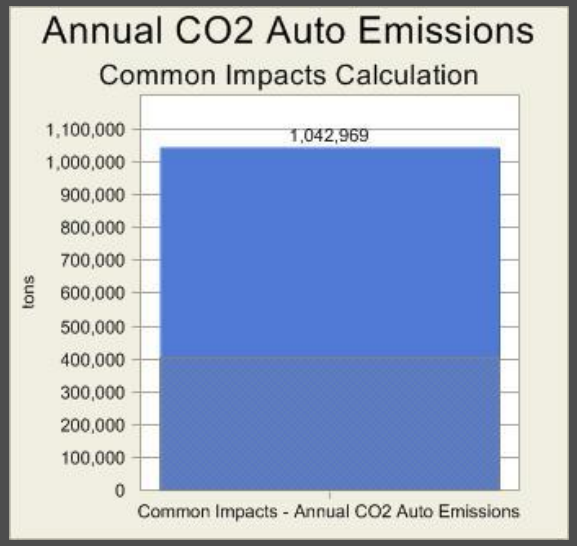


# Runoff



## Nonpoint-Source Pollution & Erosion Comparison Tool

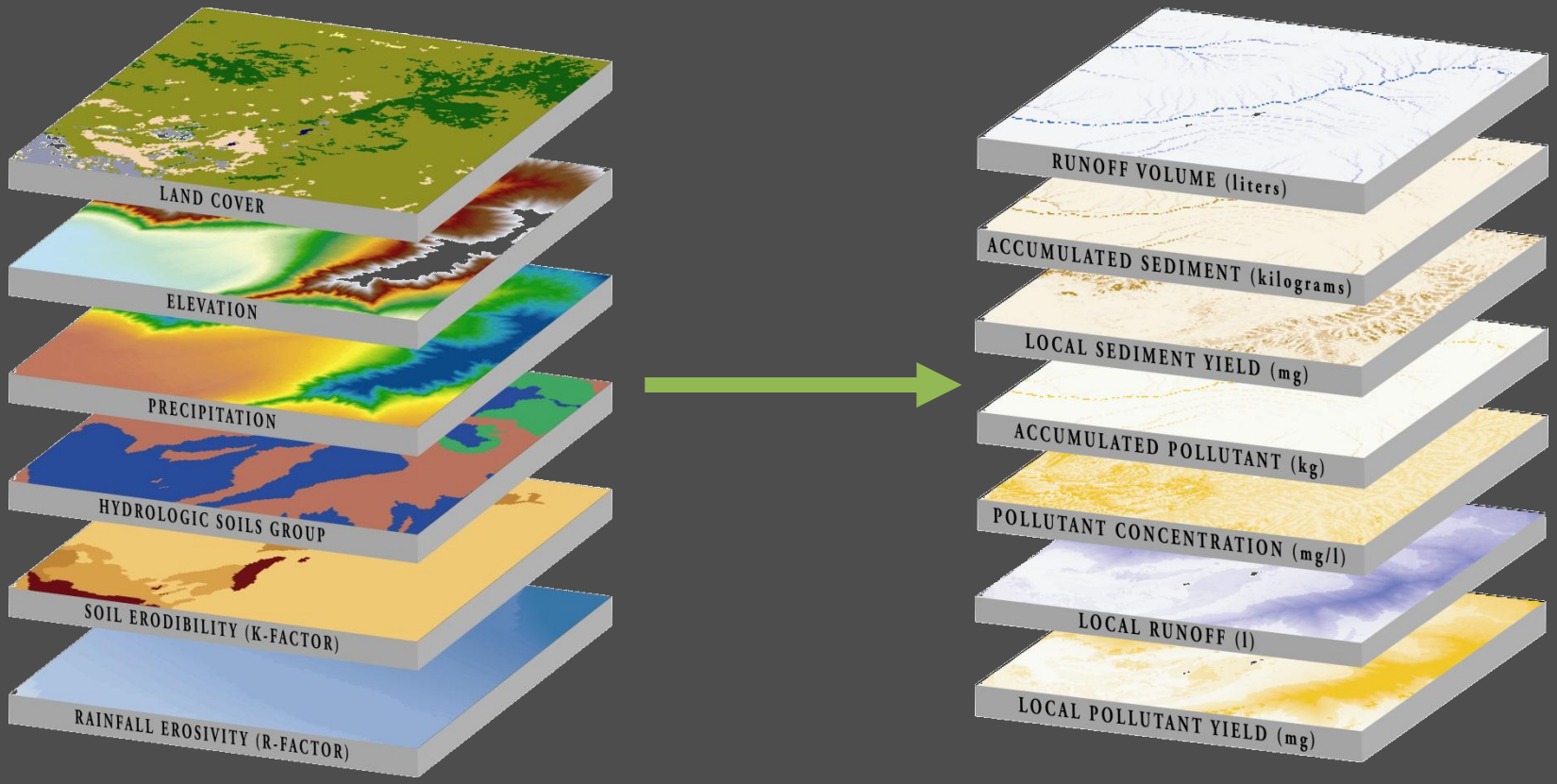
NOAA Coastal Services Center
LINKING PEOPLE, INFORMATION, AND TECHNOLOGY

- Water quality screening tool
- Spatially distributed (raster-based) pollutant and sediment yield model
- Compares the effects of different land cover and land use scenarios on total yields
- User friendly graphical interface within a GIS environment

# Runoff



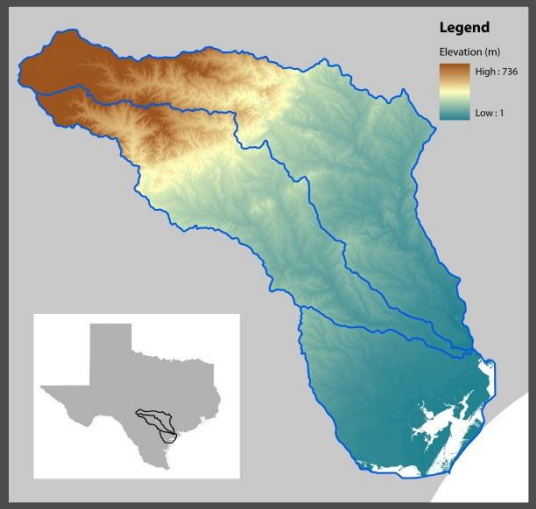
## Nonpoint-Source Pollution & Erosion Comparison Tool



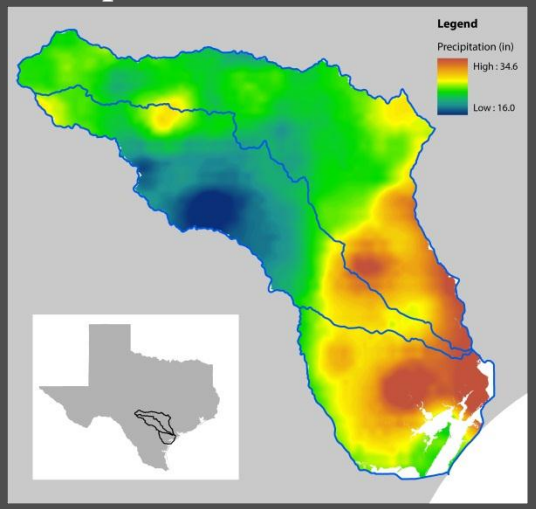
# Data



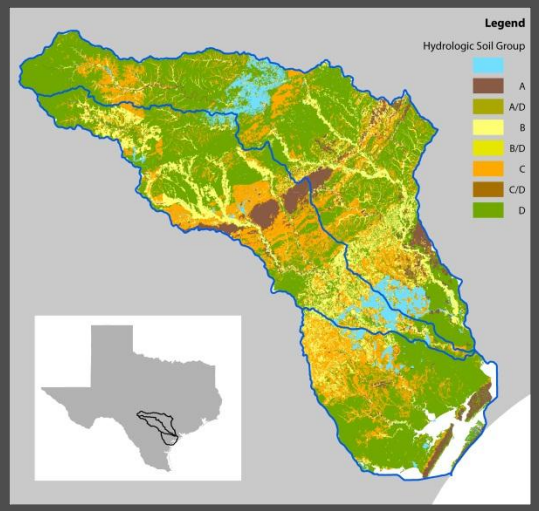
*Elevation*




*Precipitation*



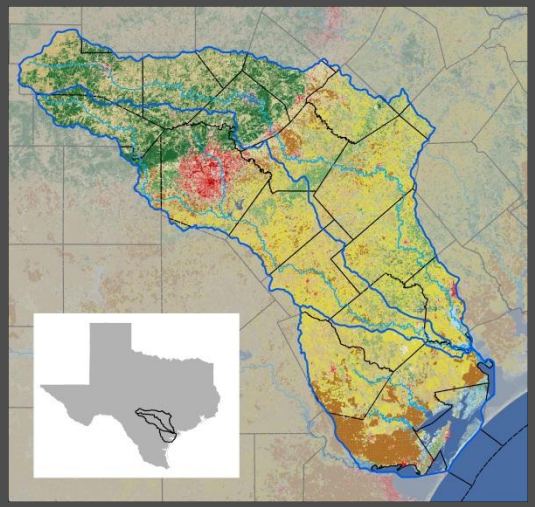

*Soils*




*Land Use/Land Cover Coefficients*

| Land Use/Land Cover | 1 | 2 | 3 | 4 | 5 | Wet |
|---|---|---|---|---|---|---|
| Developed, High Intensity | 0.89 | 0.92 | 0.94 | 0.95 | 0 | No |
| Woody Wetland | 0 | 0 | 0 | 0 | 0 | Yes |

*Land Use/Land Cover*



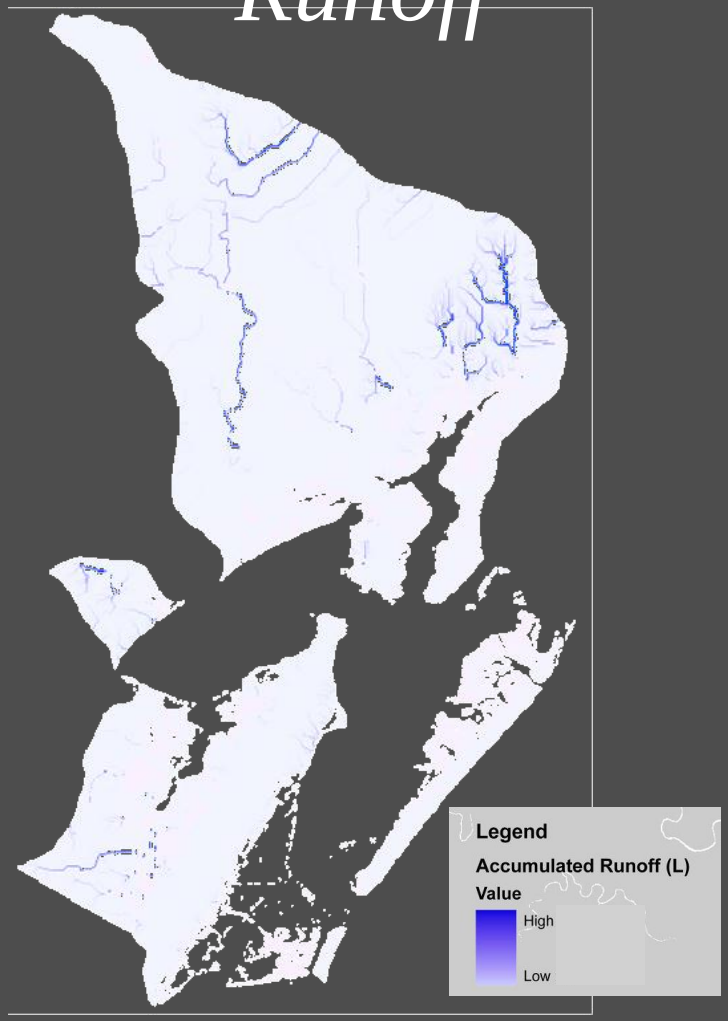
*Pollutant Coefficients - Nitrogen*

| Land Use/Land Cover | Nitrogen | TSS | Phosphorus |
|---|---|---|---|
| Developed, High Intensity | 2.22 | 71 | 0.47 |
| Woody Wetland | 1.1 | 19 | 0.2 |

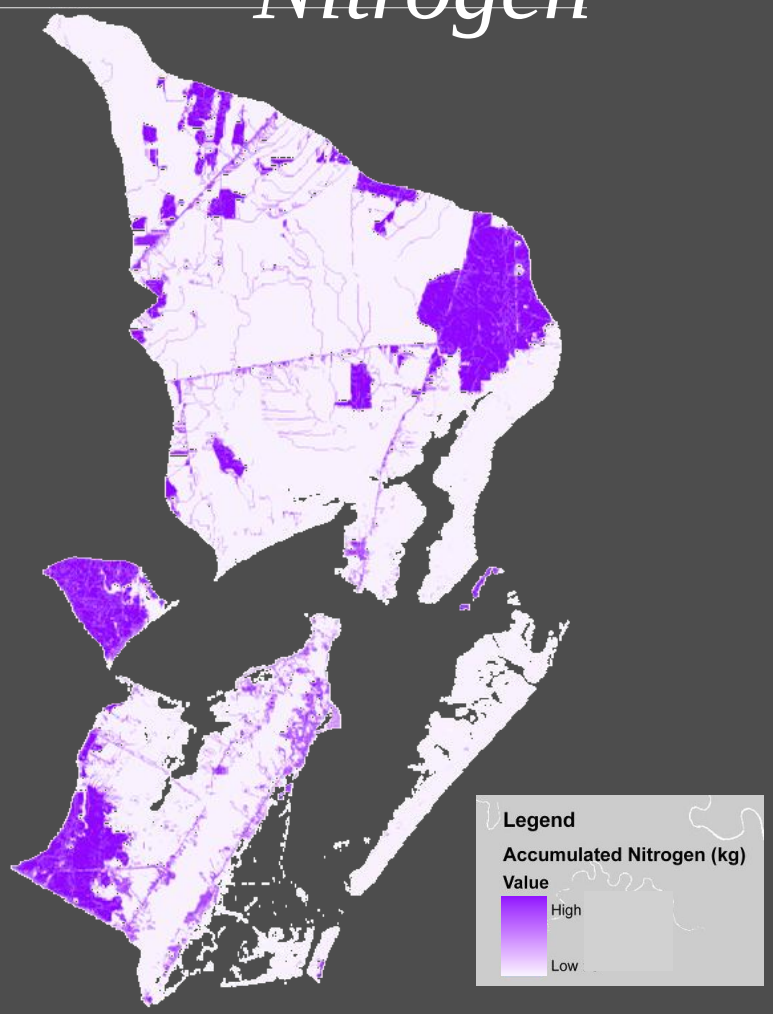
# Results - Current LULC



*Runoff*




*Nitrogen*

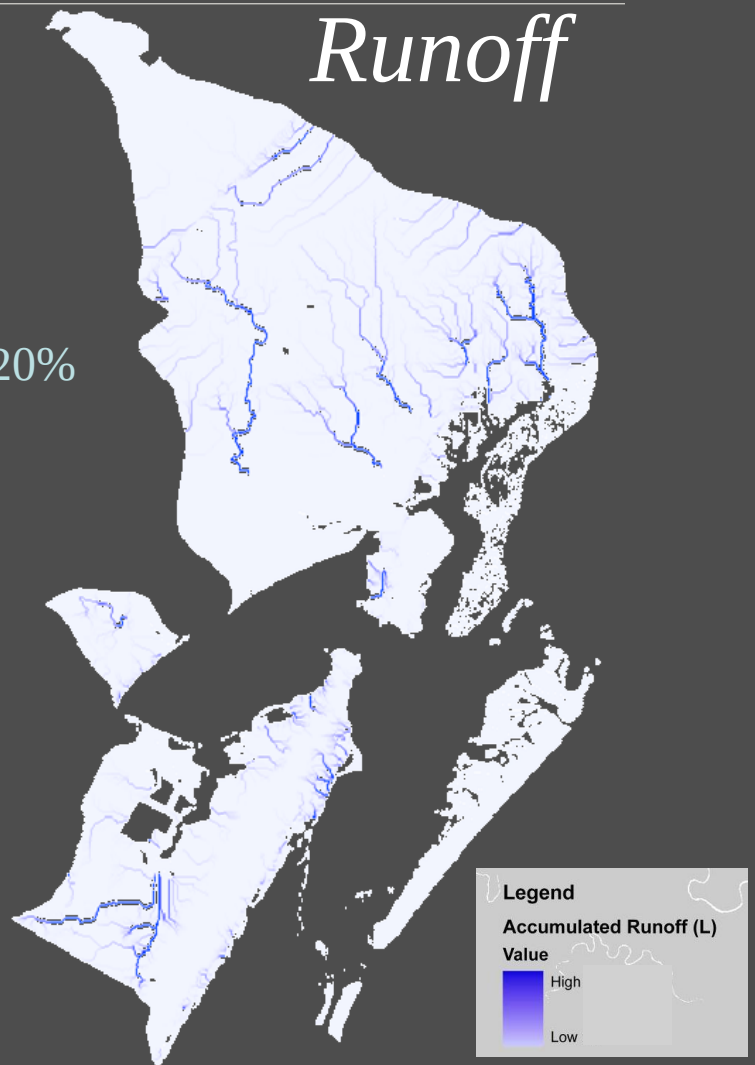


# Results - Future LULC



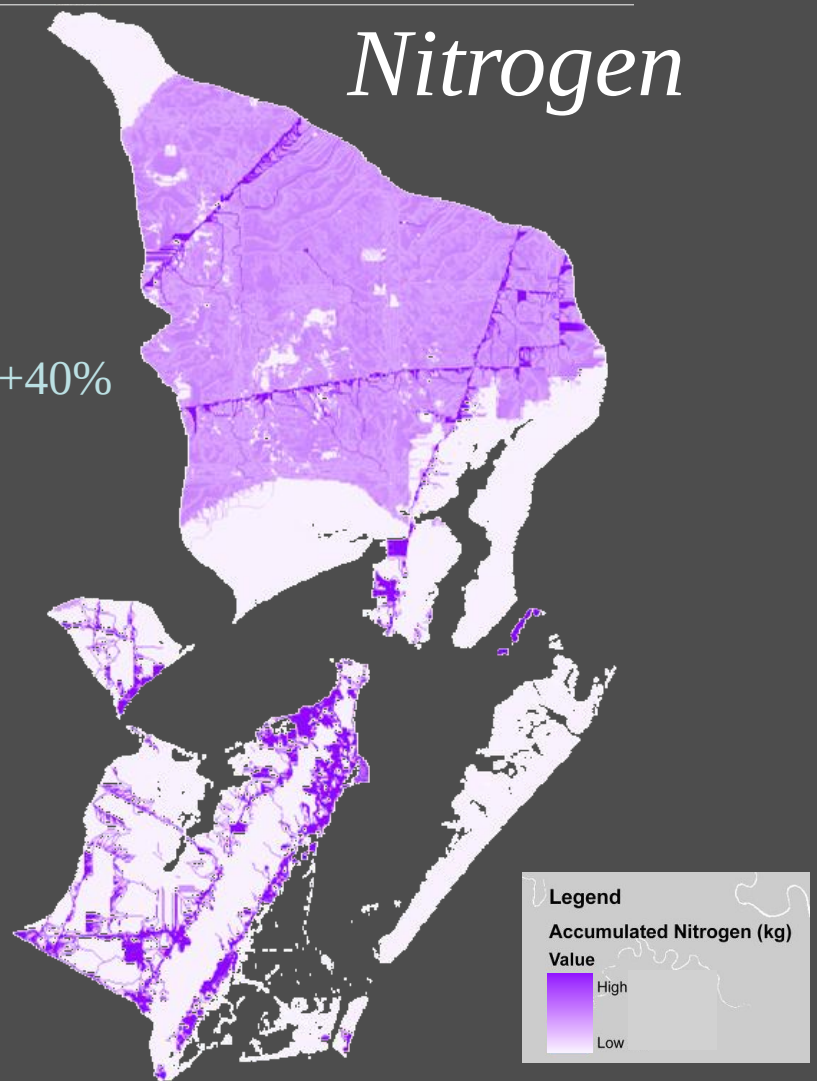
## *Runoff*

+20%




## *Nitrogen*

+40%



# Blue Crabs



NatureServe VISTA

**Mission:** facilitate biodiversity conservation planning by all those making decisions that affect biodiversity.

- Provide a conservation framework tool…
- that integrates conservation with other sectors: land use, resource management , infrastructure…
- by supporting both expert knowledge integration and end-user conservation application…
- in a full process from data input to monitoring and adaptive management (in a toolkit approach)

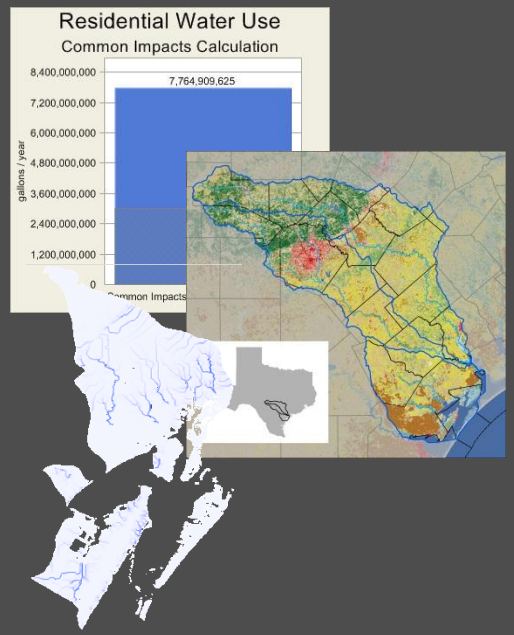
# Blue Crabs



Things you care about: Elements

Information about your elements

What will happen to the things you care about?



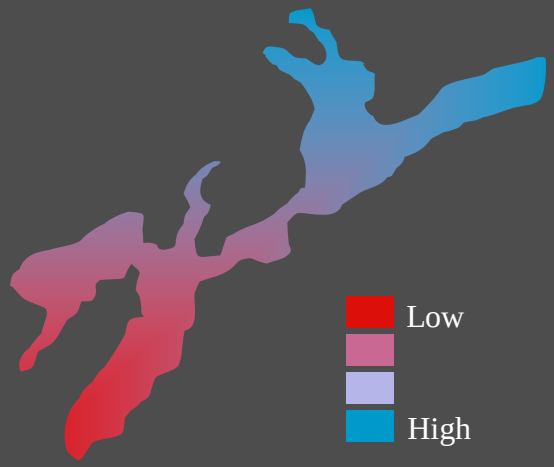

What should you do to help meet multiple objectives?

Things that affect your elements: Scenarios

# Condition Model



+

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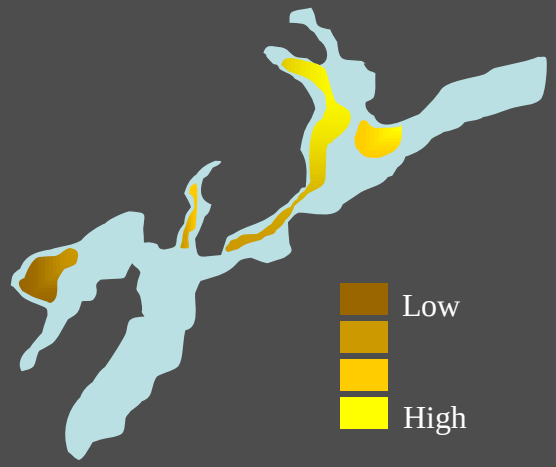



Blue Crab Distribution

Landscape Condition

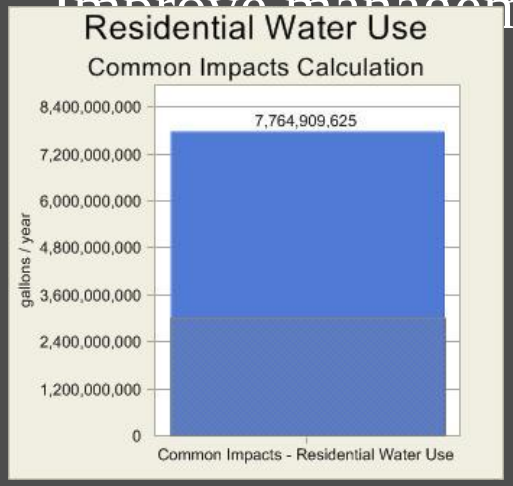
Salinity
Pollutants
Habitat type
Fishing pressure

Modified Distribution

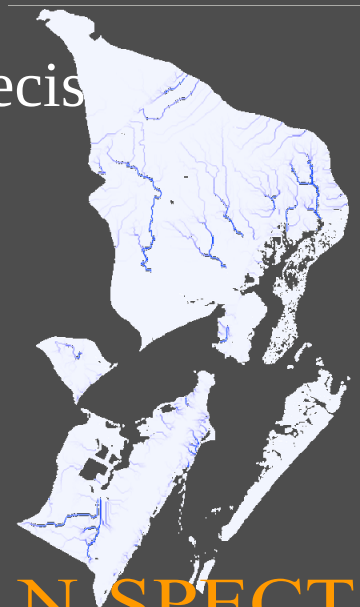
# Conclusions



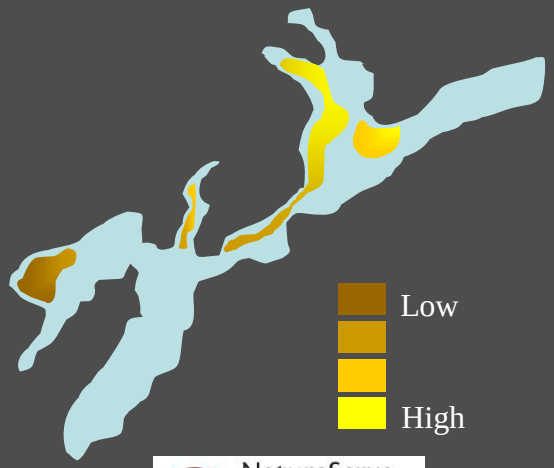
- Examine the effect of land use change on water usage and runoff . . .
- Explore the effect of freshwater inflow changes on blue crabs . . .
- Improve management decis




communityviz®



N-SPECT




NatureServe VISTA

# Questions??



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# Blue crab population dynamics and fisheries management

**David B. Eggleston**

**Nathalie Reyns, Lisa Etherington, Gayle Plaia, Eric Johnson, Christina Durham, Geoff Bell, Rom Lipcius, Tuck Hines**

# Key Points

- Fishery-independent data is crucial (unbiased)
  - Status of stock
  - Life history bottlenecks
- Dynamic salinity = dynamic movement
  - Influences catch efficiency
  - Influences population size
- Protection of spawning stock is crucial
  - Supplies recruits
  - Catch limits/Catch shares
  - No-take sanctuaries
  - Stock enhancement

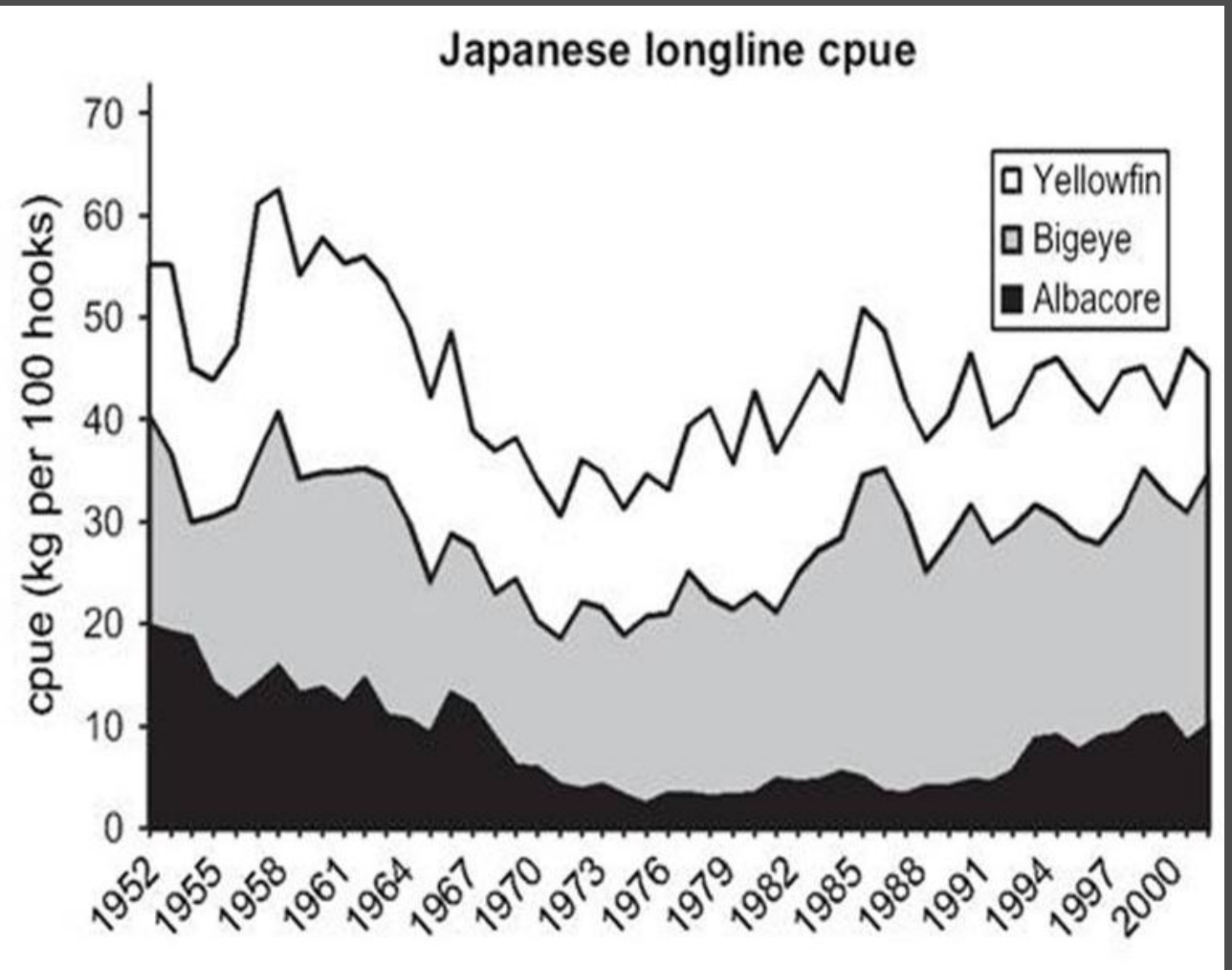
# Outline

1. Background
    1. CPUE
    2. Catchability
    3. Stock-recruit
    4. Landings and life history
    5. Data Sources

2. Research questions
    1. indices of SSB
    2. Stock-recruit
    3. Storms, salinity, movement, catchability
    4. Fisheries management

# Effective fisheries management

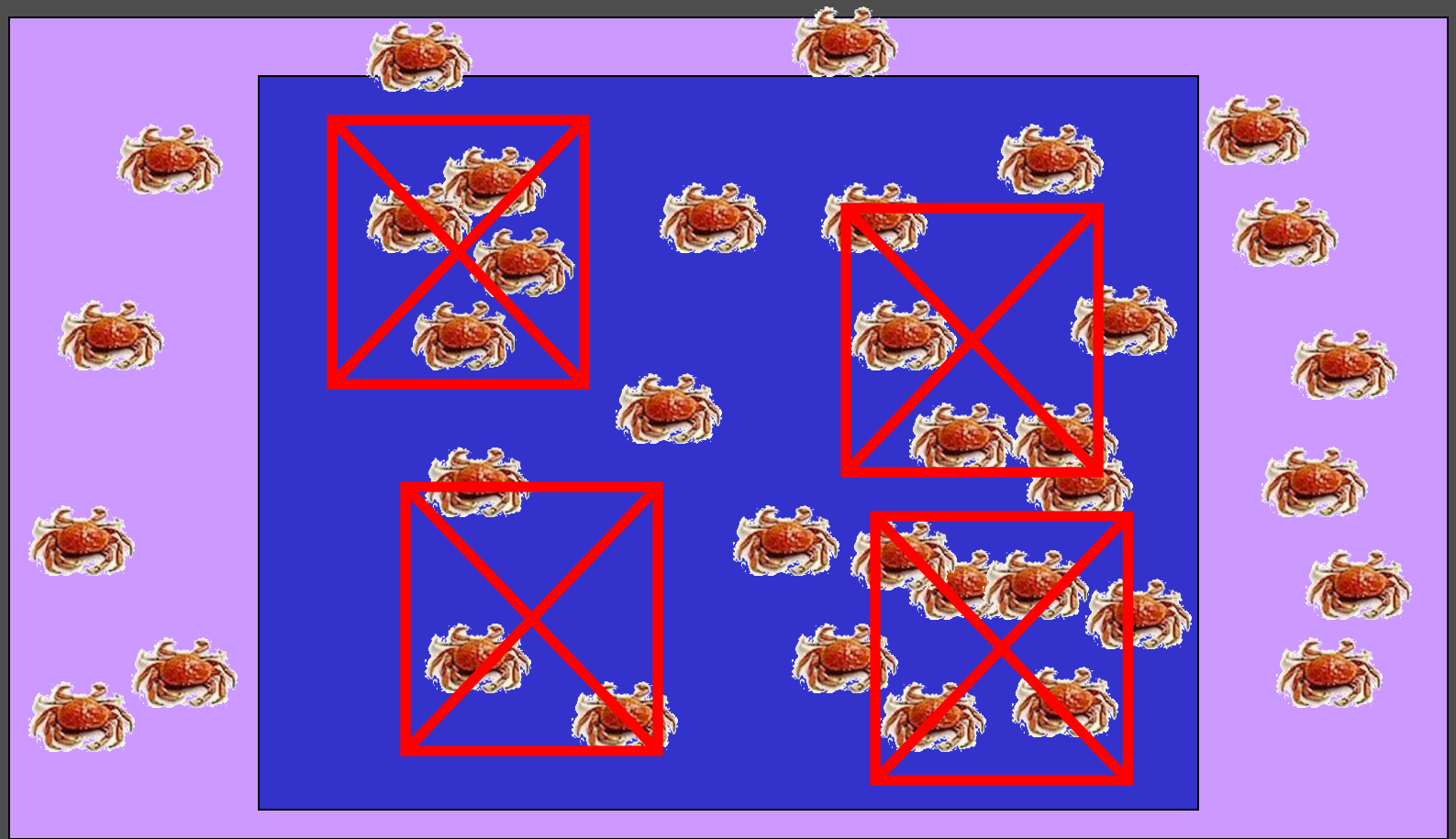
- Begins with an estimate of population size over time
- Common index: mean catch-per-unit-effort (CPUE)




- Effective if CPUE proportional to total abundance
- Proportionality requires constant catchability

# What is catchability?

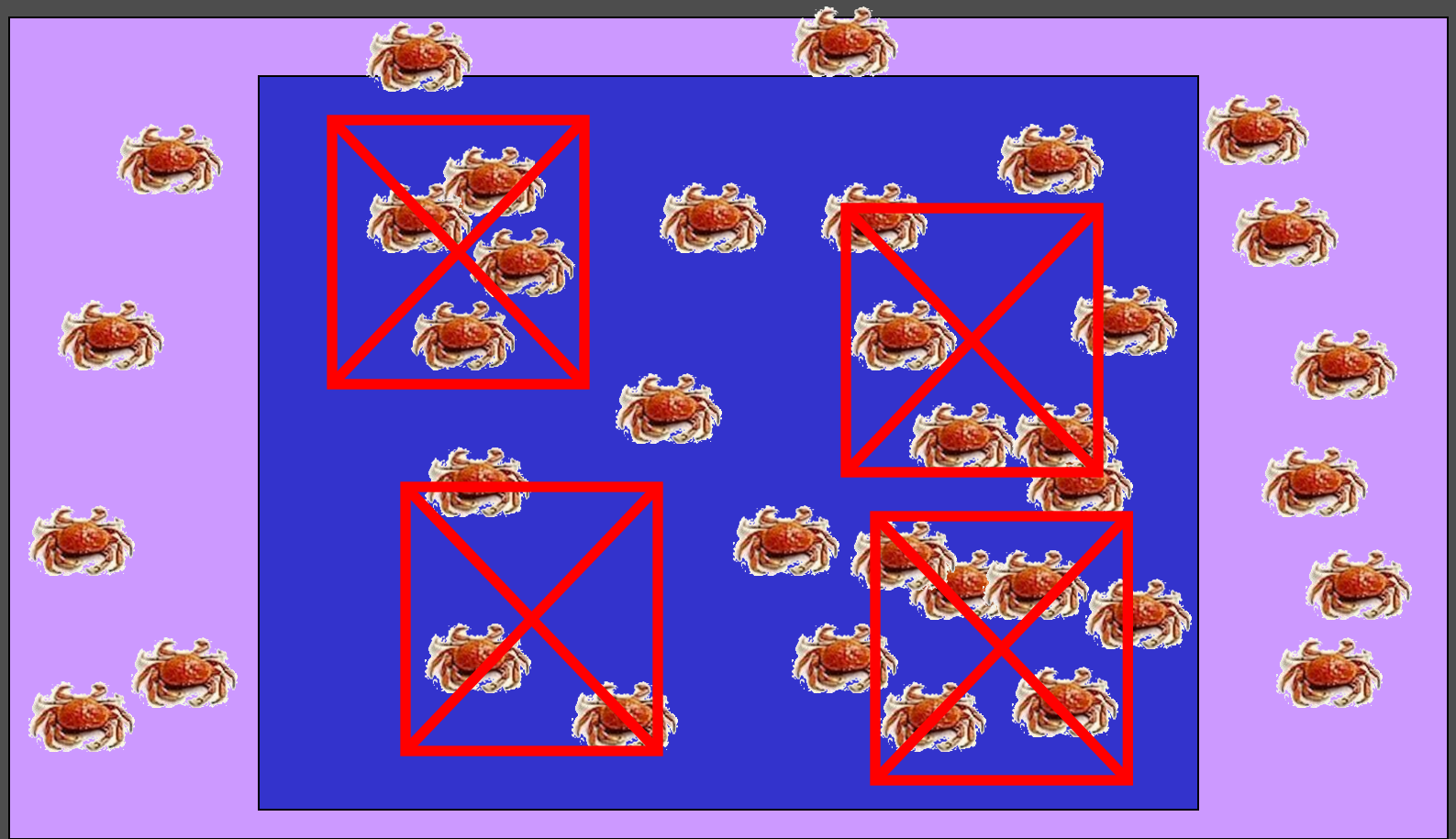
- Average proportion of stock taken per unit effort



# What is catchability?

- A function of proportion of population in the survey area

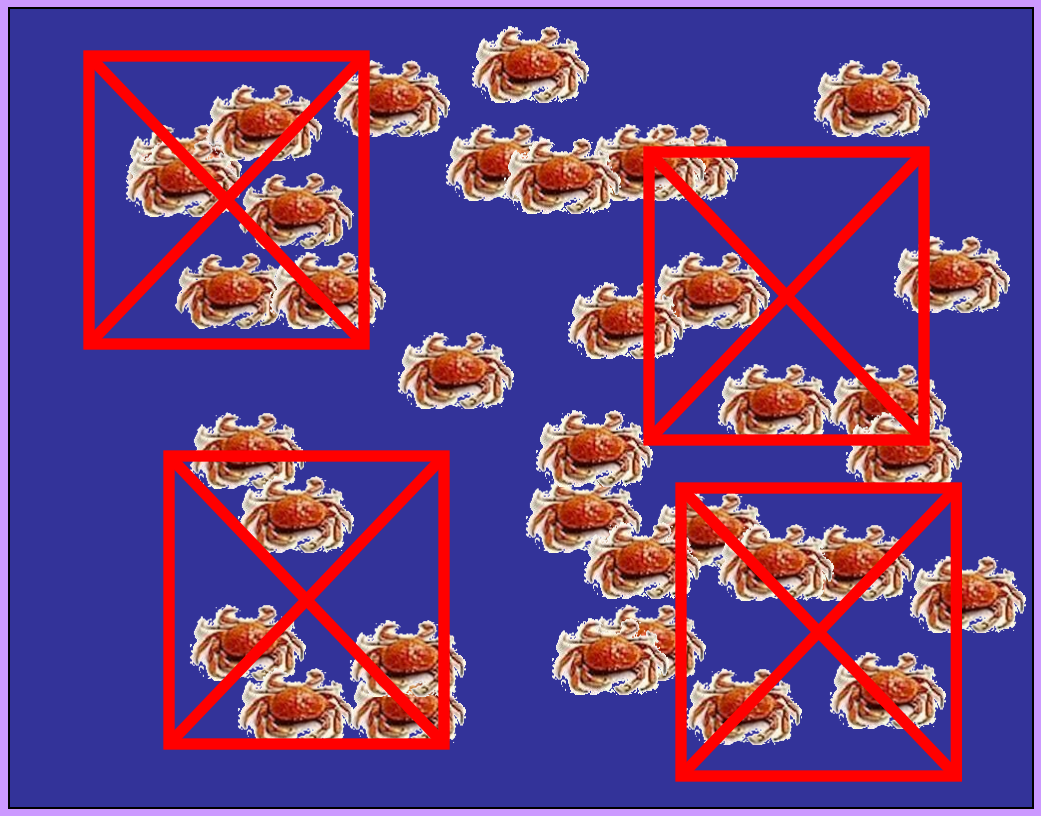
$$\text{CPUE} = \frac{17 \text{ crab}}{4 \text{ effort units}} = 4.25$$



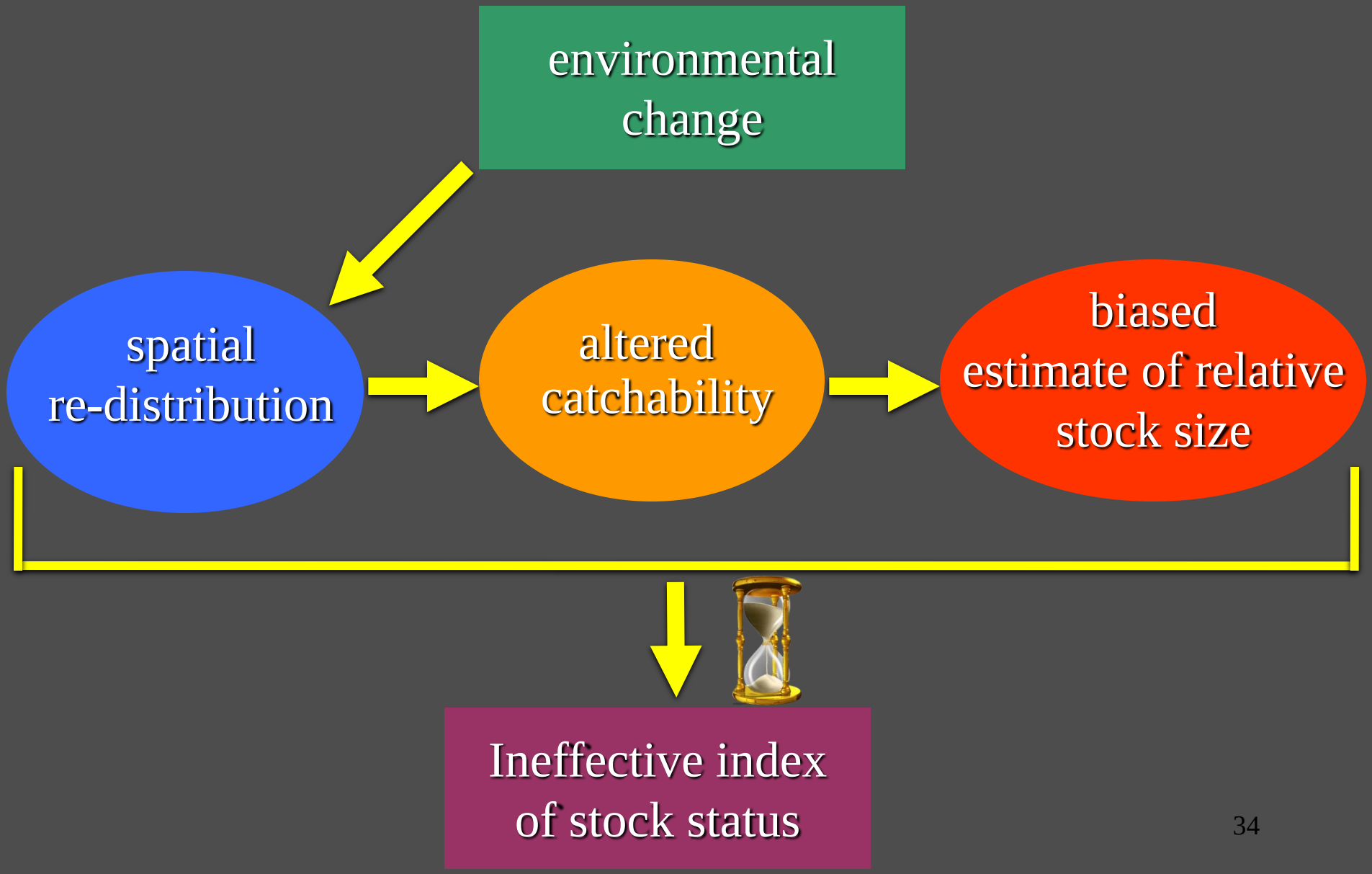
# What is catchability?

- A function of the population proportion in the surveyed area

$$\text{CPUE} = \frac{11 \text{ crab}}{4 \text{ effort units}} = 2.75$$



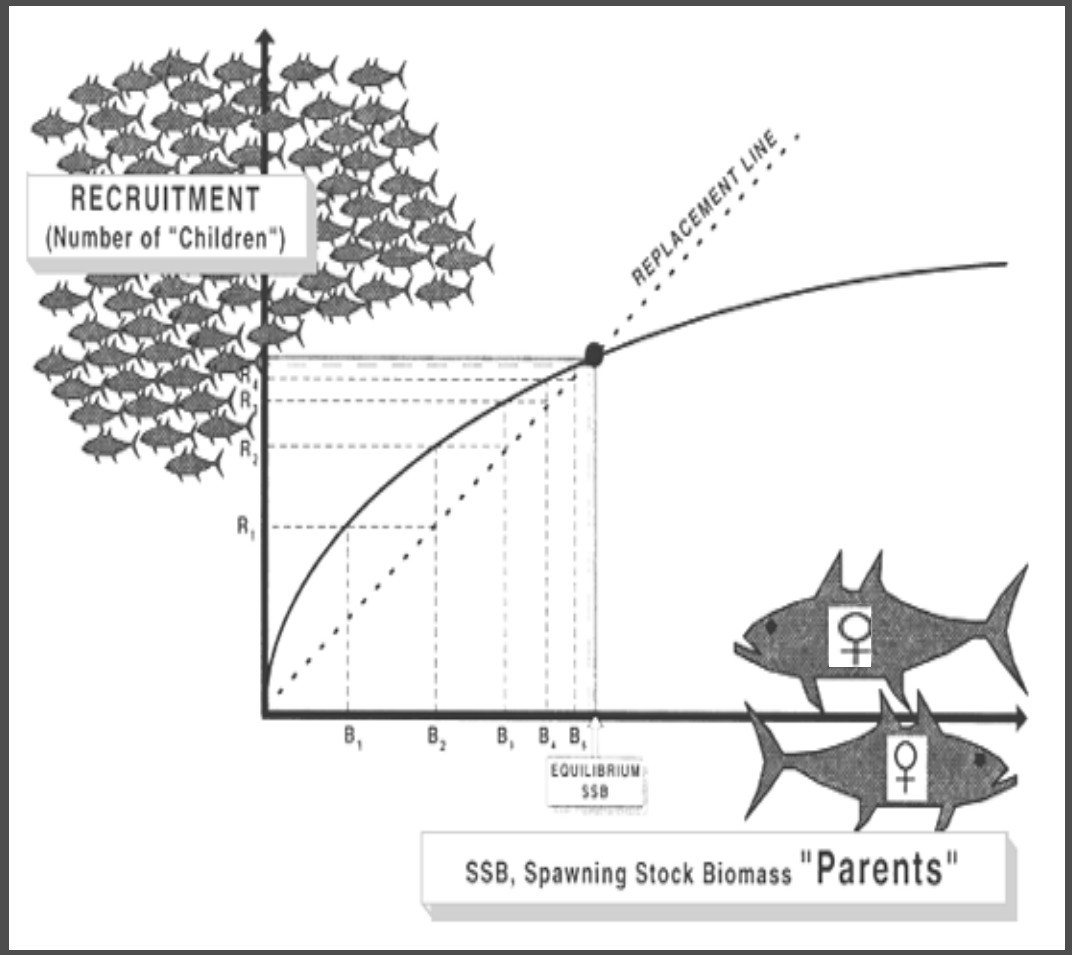
# Index of SSB biased by environmental change



Indices of population size MUST account for biases in catchability

# Spawning stock-recruit relationship

- Mature females comprise spawning stock population
- Larger spawning stock
  - = more recruits
  - = increased population size



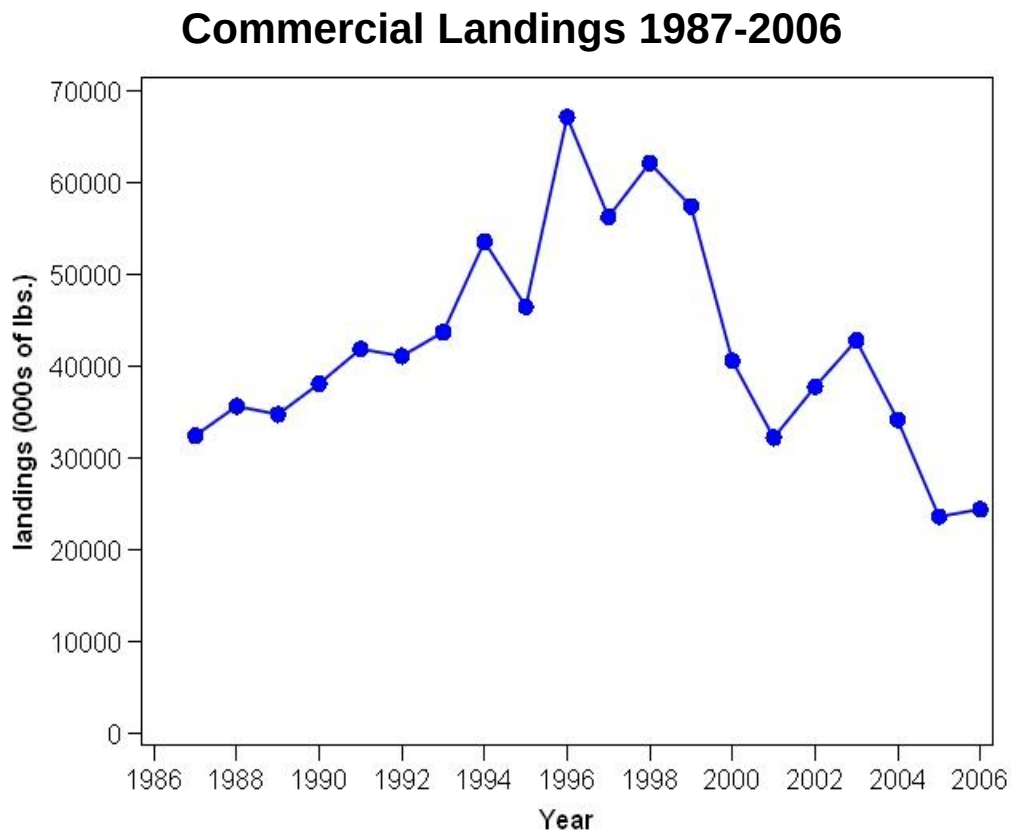

** S/R key to understanding recruitment variation

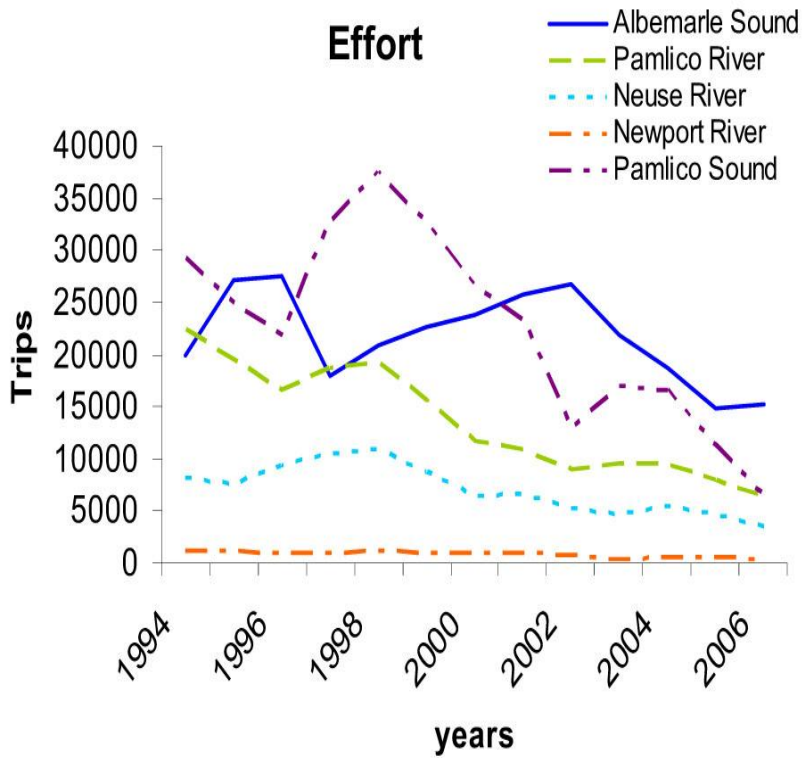
# Why blue crab?

- Ecologically important
- NC's most profitable fishery

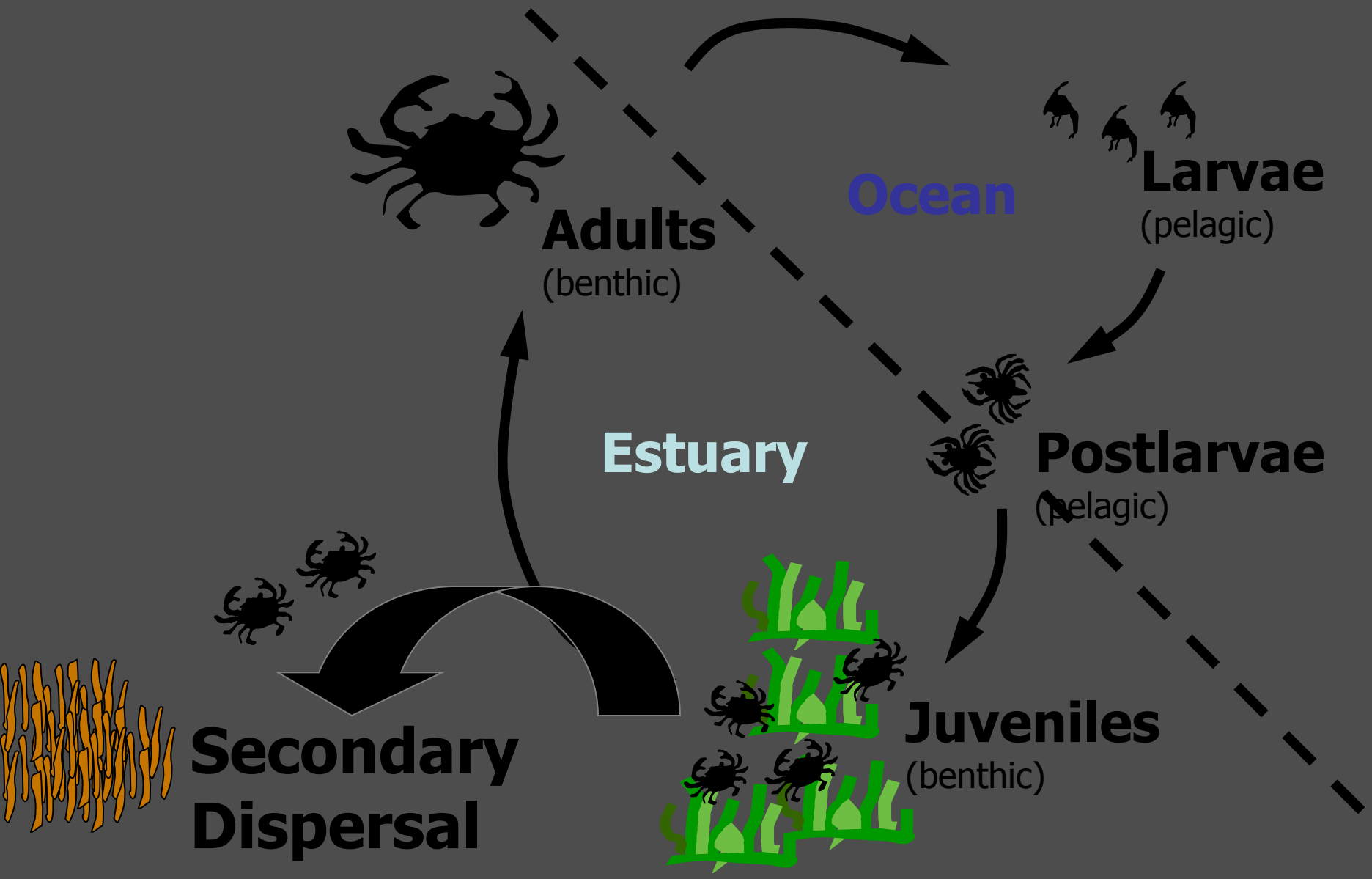
**Appears to be in decline;**

landings & effort down since 2000



# Complex Life Cycle



# Why Pamlico Sound?

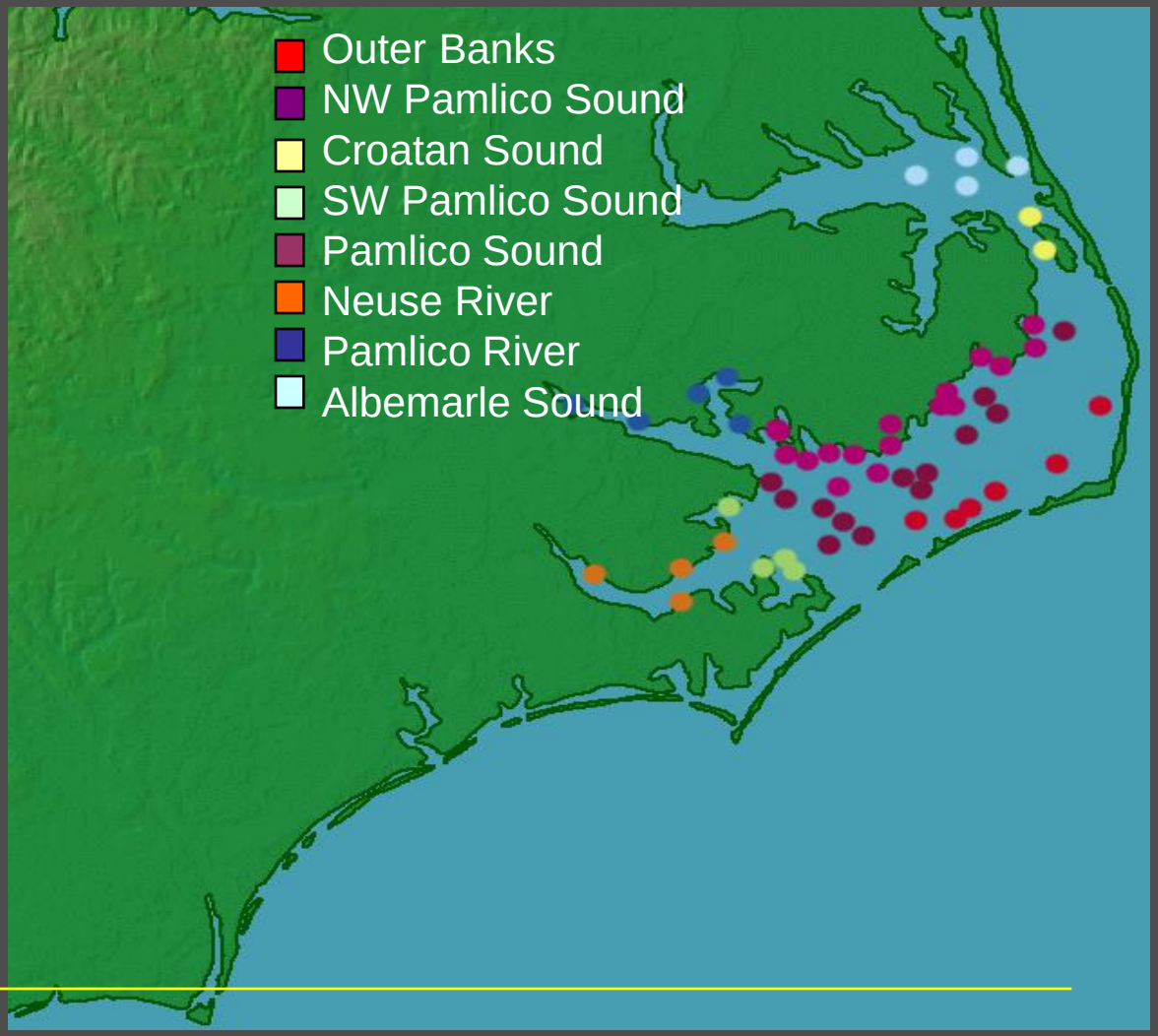
(Croatan, Albemarle, Pamlico Estuarine System)


- 2nd largest estuary in U.S., largest lagoonal estuary in U.S.
- Circulation primarily wind-driven
- Tidal influence around inlets
- Experiences large # tropical cyclones
- Water levels respond to strong forcing events

# Data Sources--Spawning Stock
# NC DMF Sampling Stations

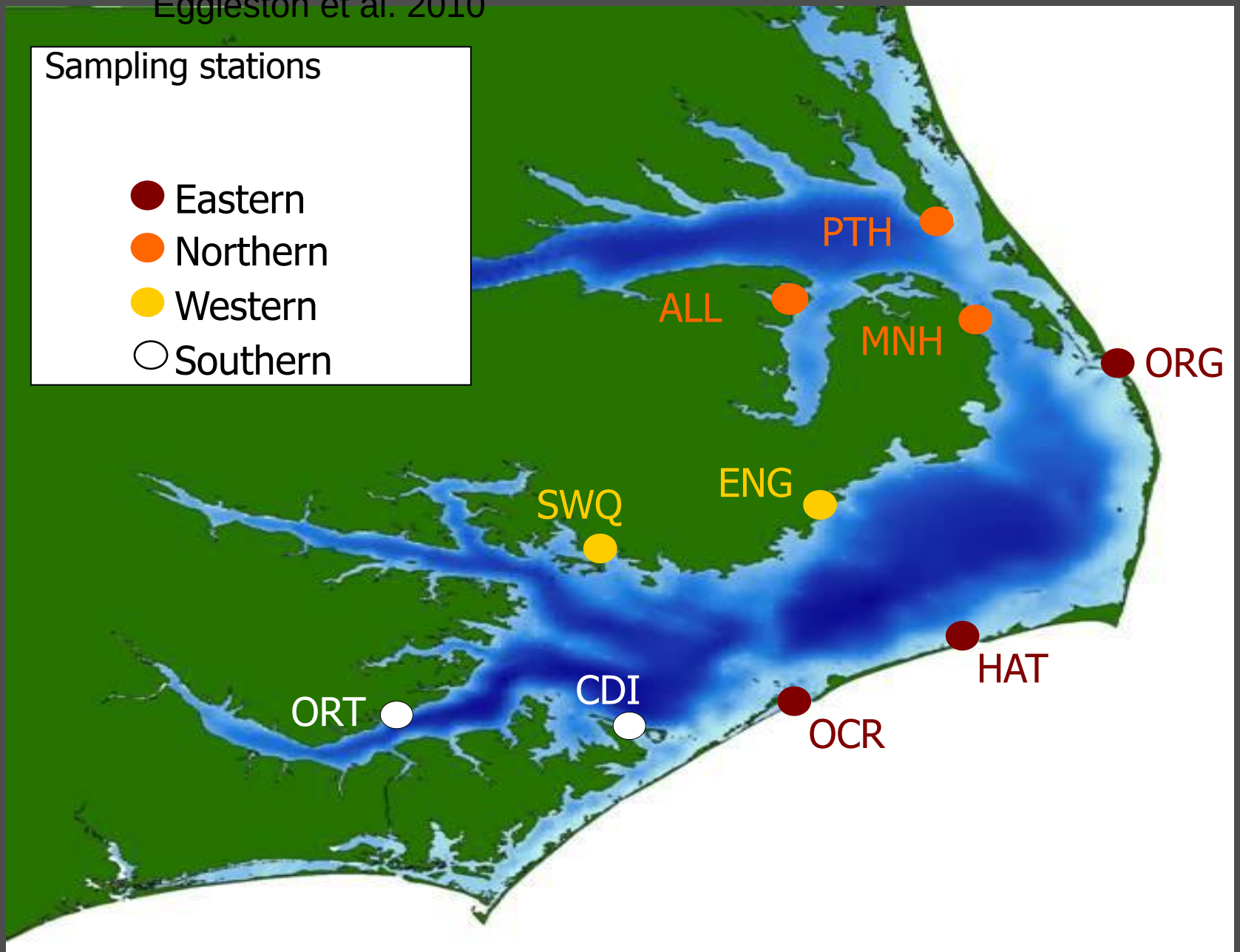
Program 195 Adults

- Stratified, random trawl survey
- 54 stations each June & Sept
- 1987-Pres



# Data Sources--Megalopal settlement

Eggleston et al. 2010



# Megalopal settlement—Artificial Substrates

Daily, Aug. 1- Oct. 31, 4-10 sites

1996-2005

Grades 5-12

93 students, 19 teachers

Lectures, lesson plans, web-site

http://www4.ncsu.edu/~dbeggles/

# Questions

1. Are there biases in index of SSB?  Why?

2. Is there a Stock-Recruit relationship?

3. What is role of storms on recruitment variation?

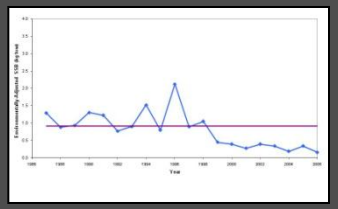
4. How do episodic events interact w/ fishing?

5. What are some management options for SSB

# 1. Are there biases in index of SSB? <u>Addressed w/ 3 statistical models</u>

Examine Pamlico Sound salinity patterns under different conditions

Examine spatial distribution of blue crab SSB; locate potential high density areas

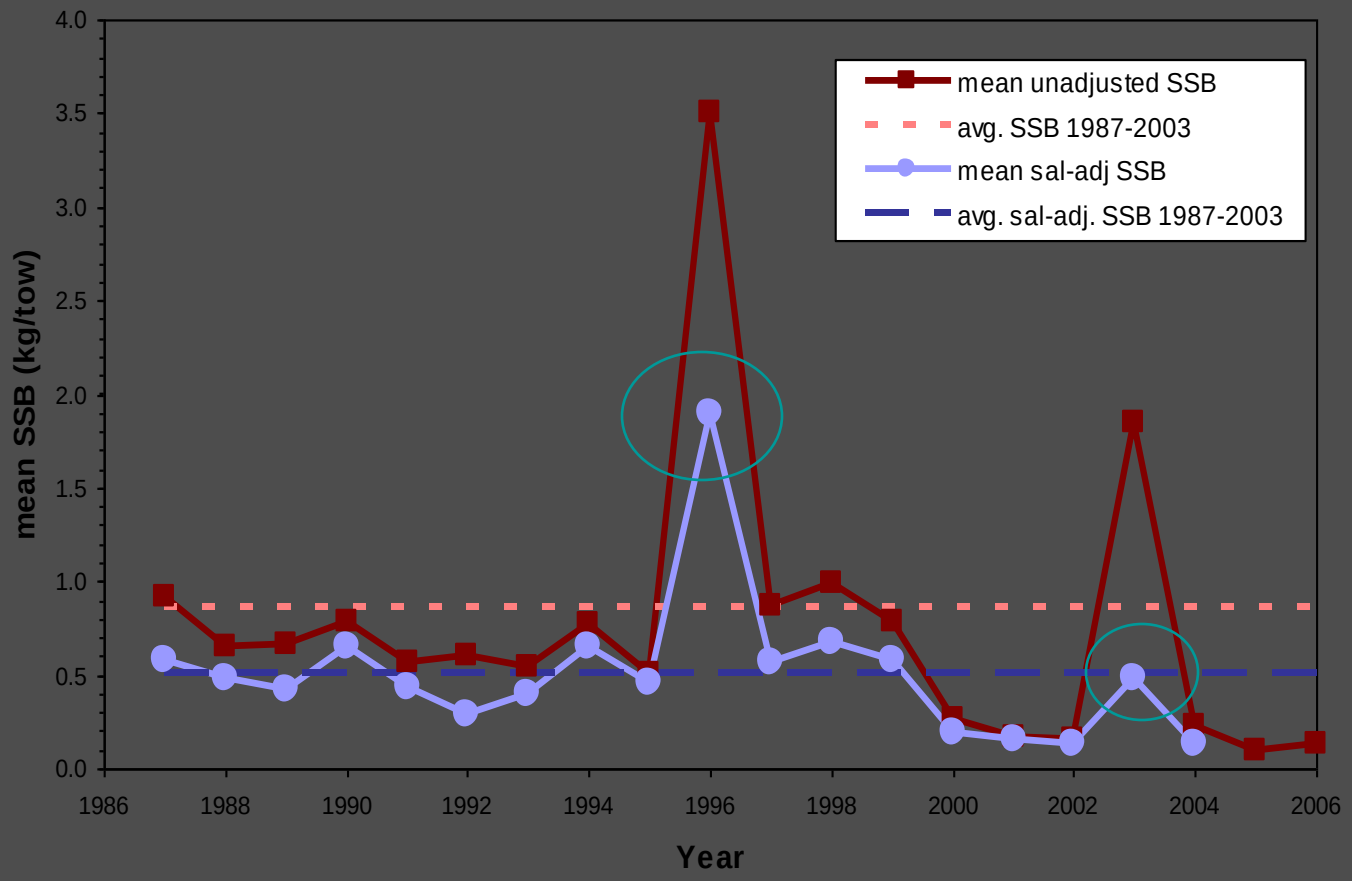


Adjust annual mean SSB by accounting for environmental variability

# 1. Are there biases in index of SSB?

Yes!

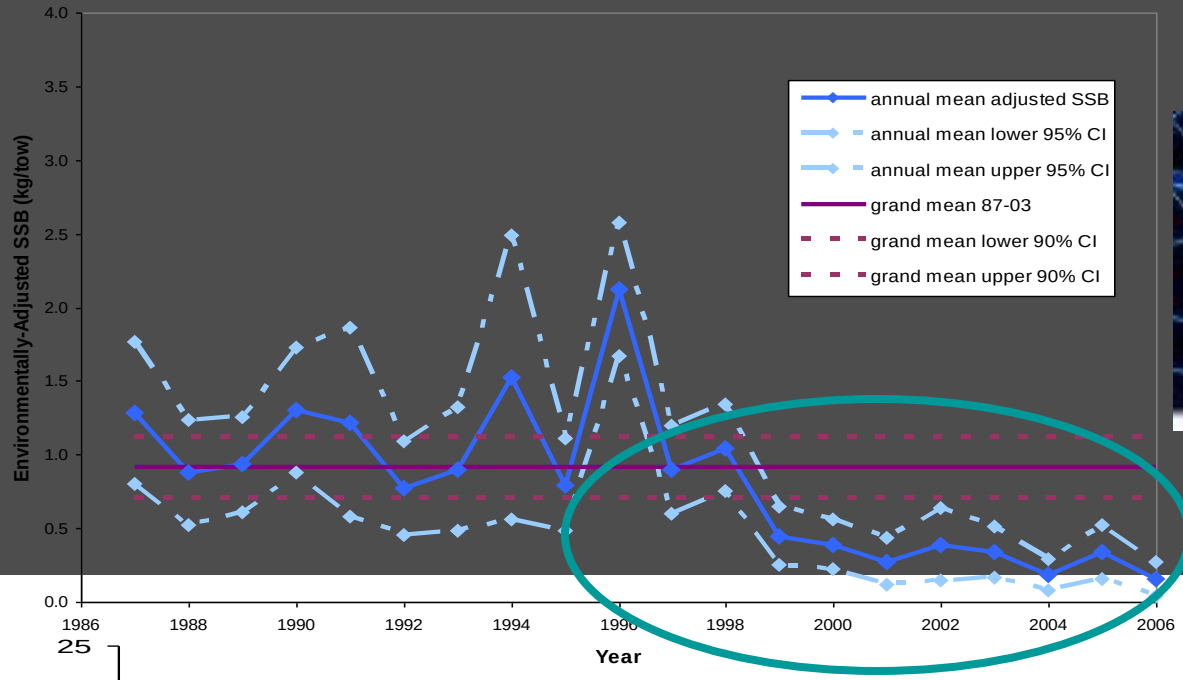
## Environmentally-adjusted vs. Unadjusted SSB



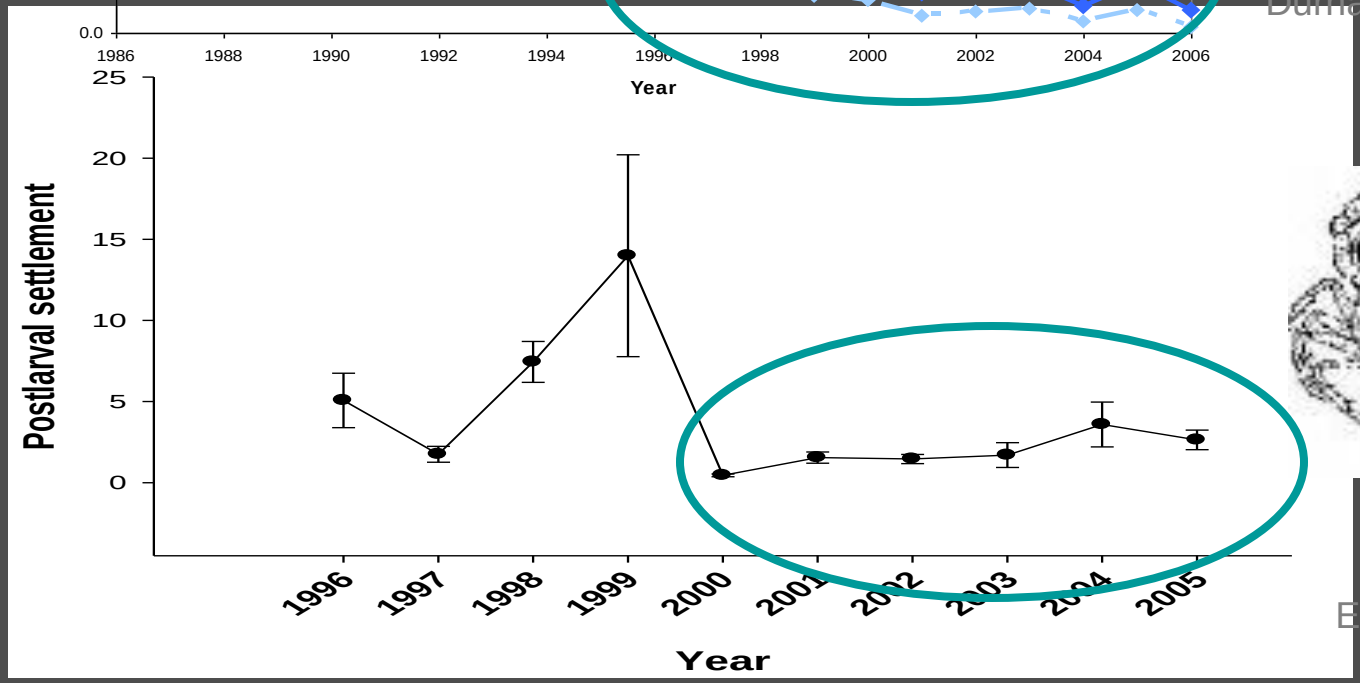

- Adjustment smaller range, brought down both large peaks

## 2. Is there a S/R relationship?

## Both annual SSB & settlement at low levels



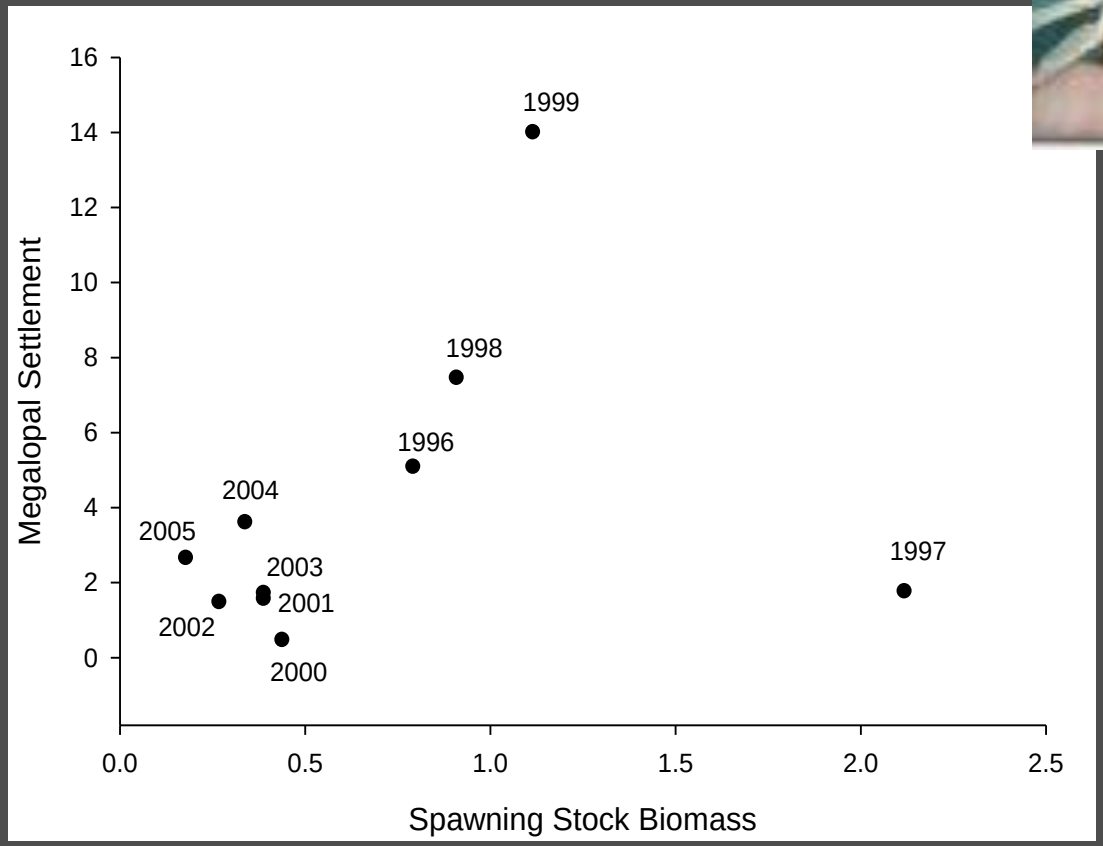

Durham & Eggleston 2010




Eggleston et al. 2010

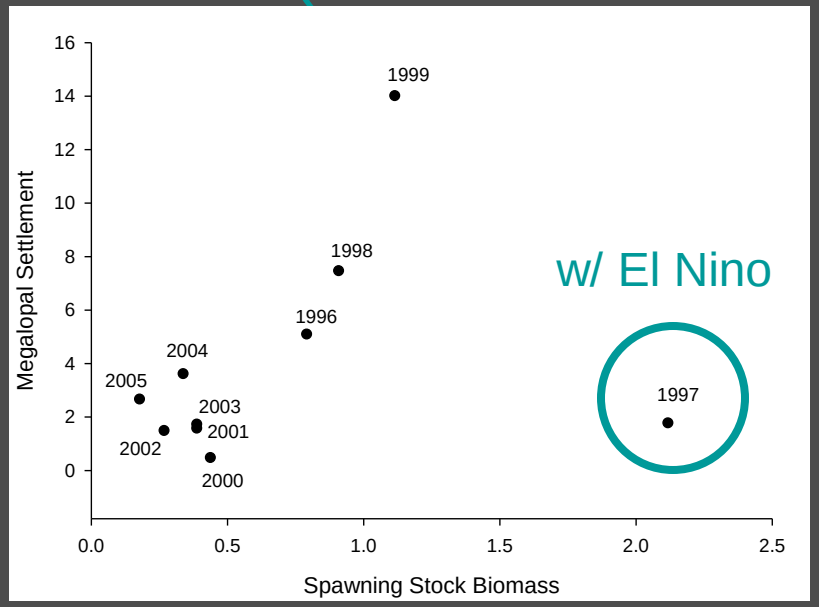
# 2. Is there a S/R relationship?

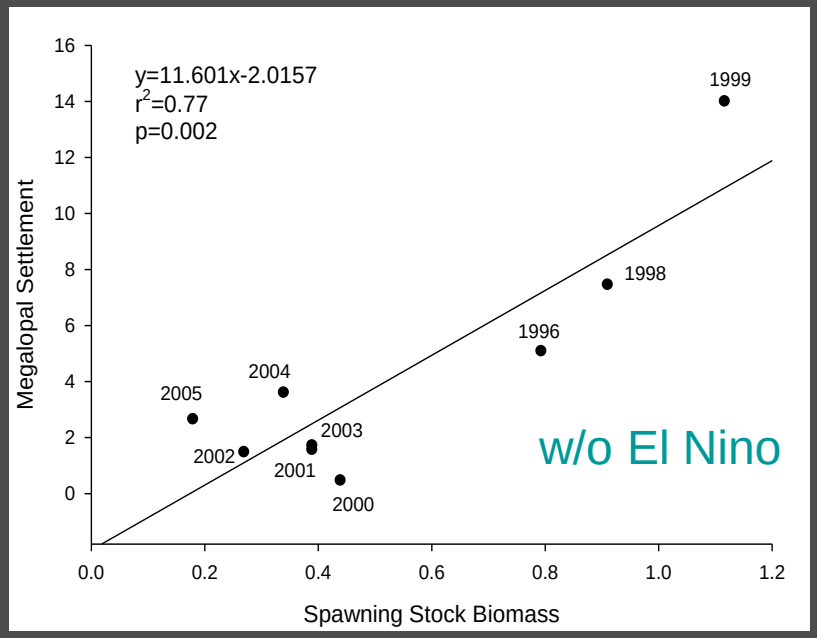
- No



# 2. Is there a S/R relationship?

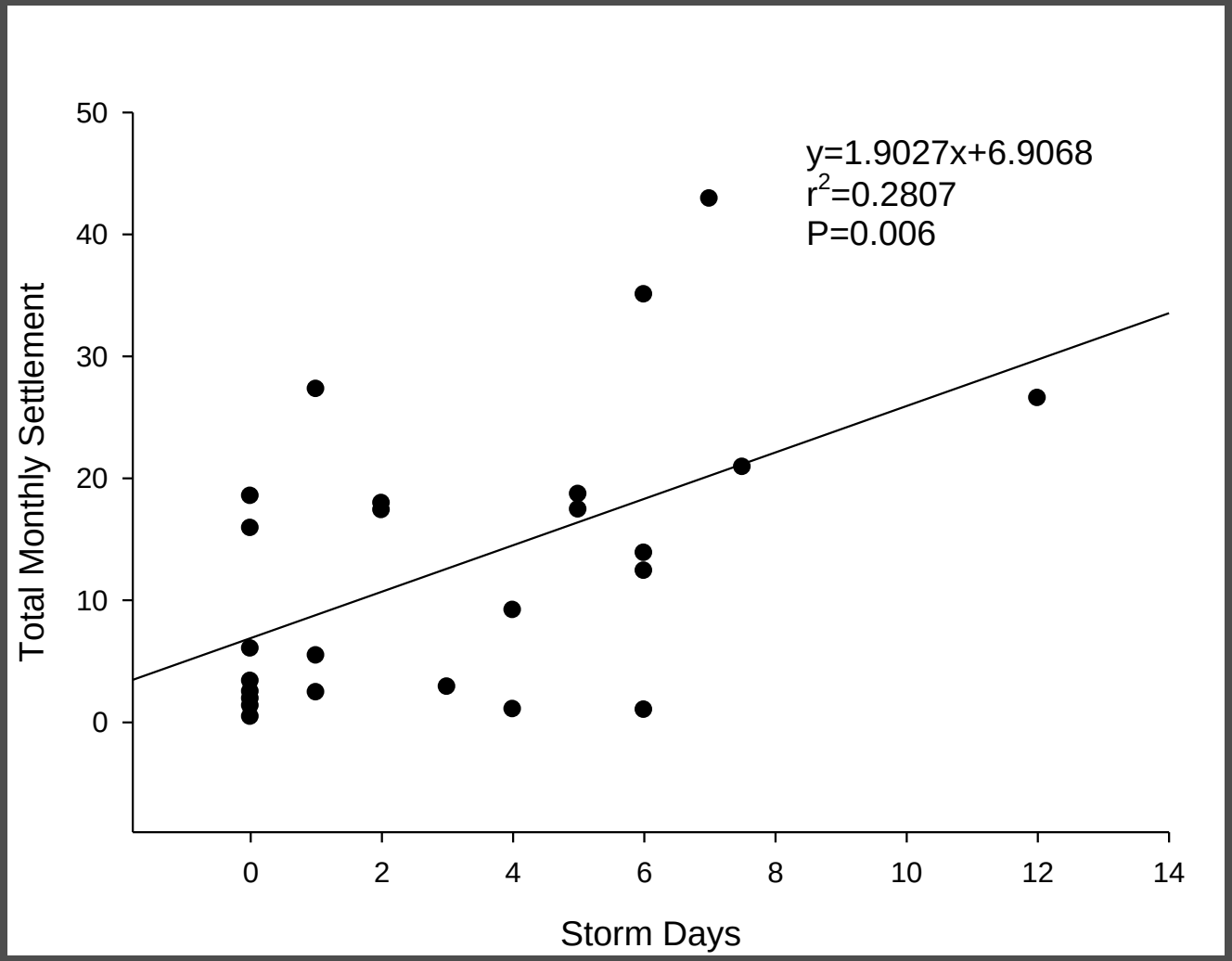
- No & Yes (77% of variation)



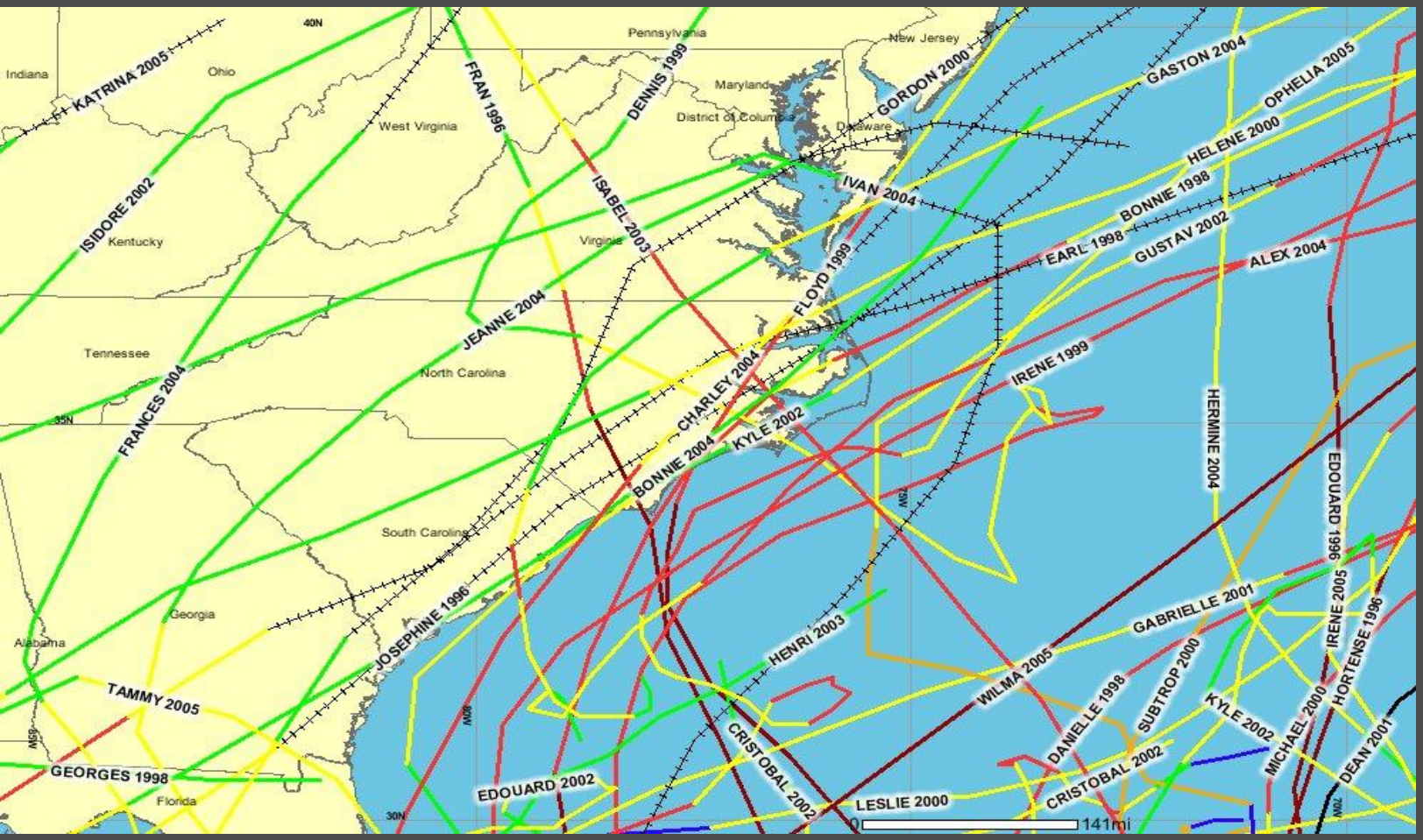




3. What is the role of storms on recruitment variation?

- Do storm days explain monthly variation in settlement?
  - Yes (28% of variation)

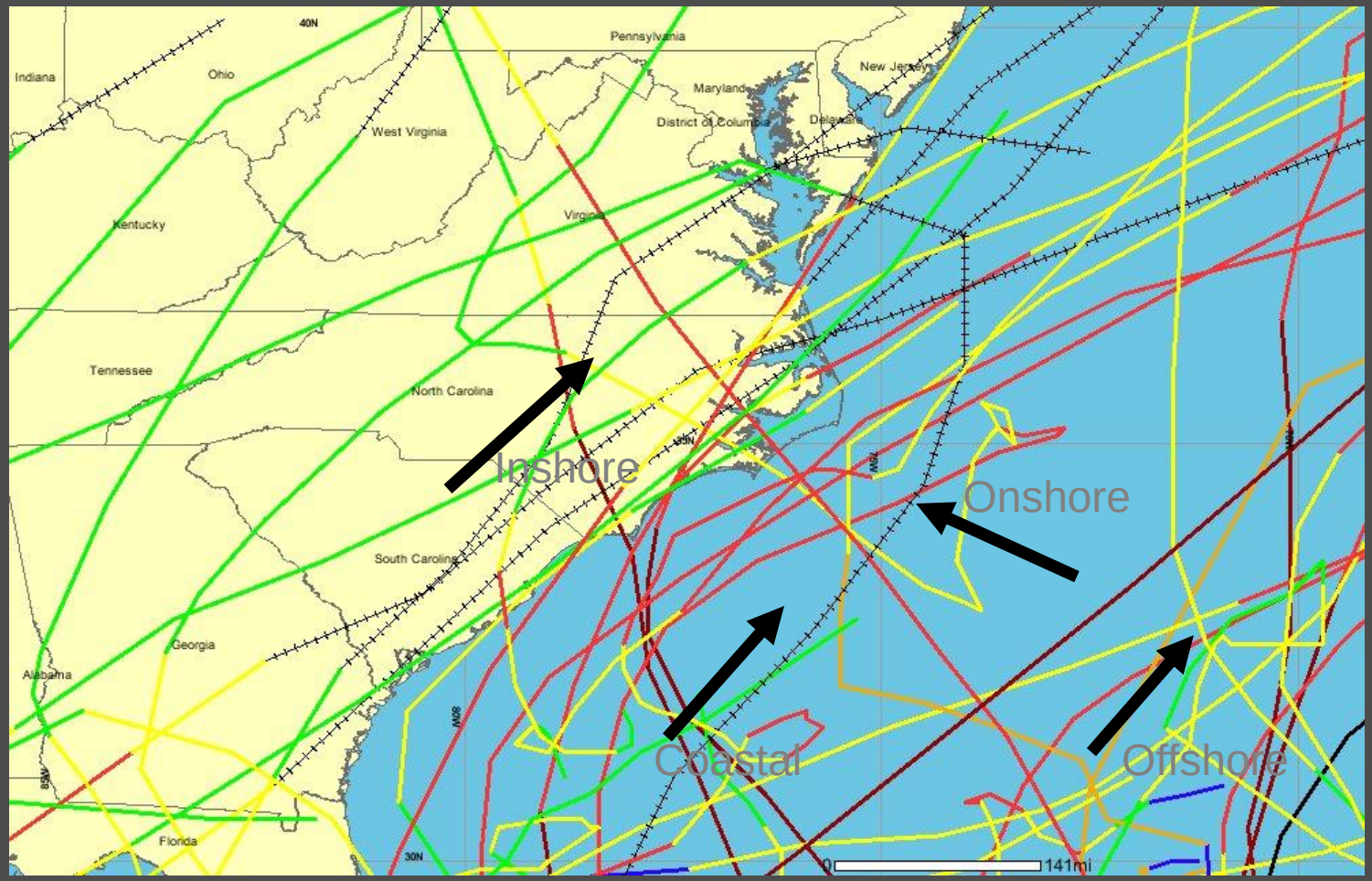


# Are some storms better for recruitment than others?

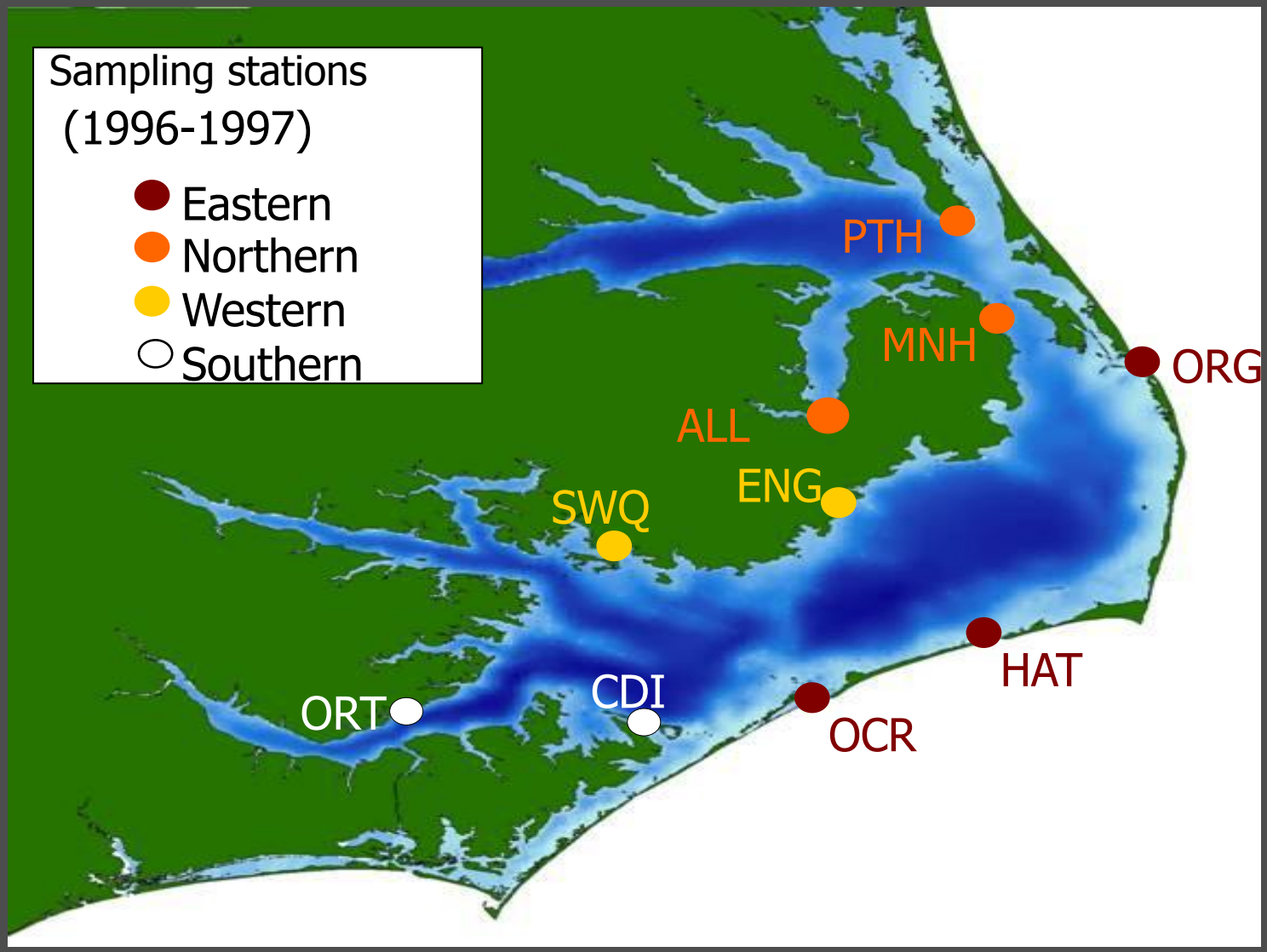



- 1996-2005
- 35 Tropical Storms & Hurricanes (28)

# Classified according to storm track

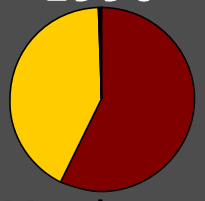



- Inshore = onshore > coastal >> inland > offshore
- Inlets = coastal > offshore >> inland > onshore




**% settlement**

1996



4 Hurricanes 1996

1997

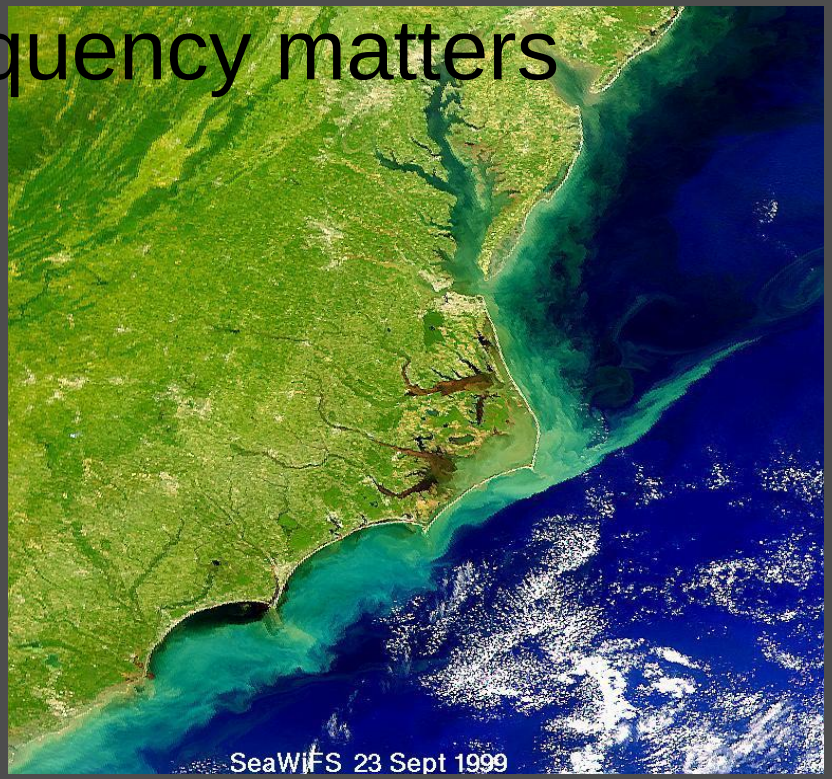
El Nino 1997

- **Recruitment limitation in W region in absence of storms**
- **Recruitment limitation in N & S regions**

Eggleston et al. 2010

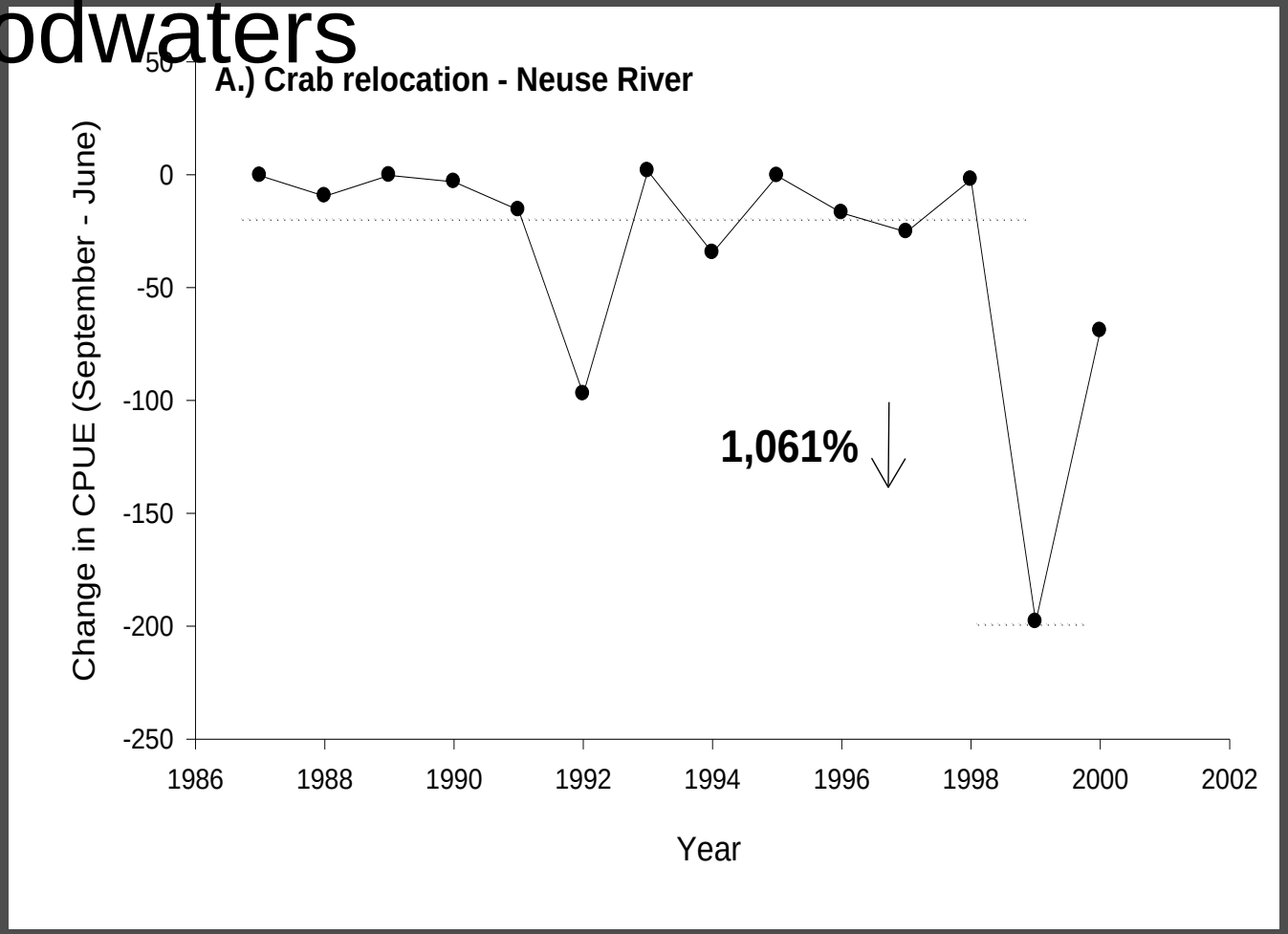
# 4. How do episodic events & fishing interact?

## Hurricane intensity & frequency matters



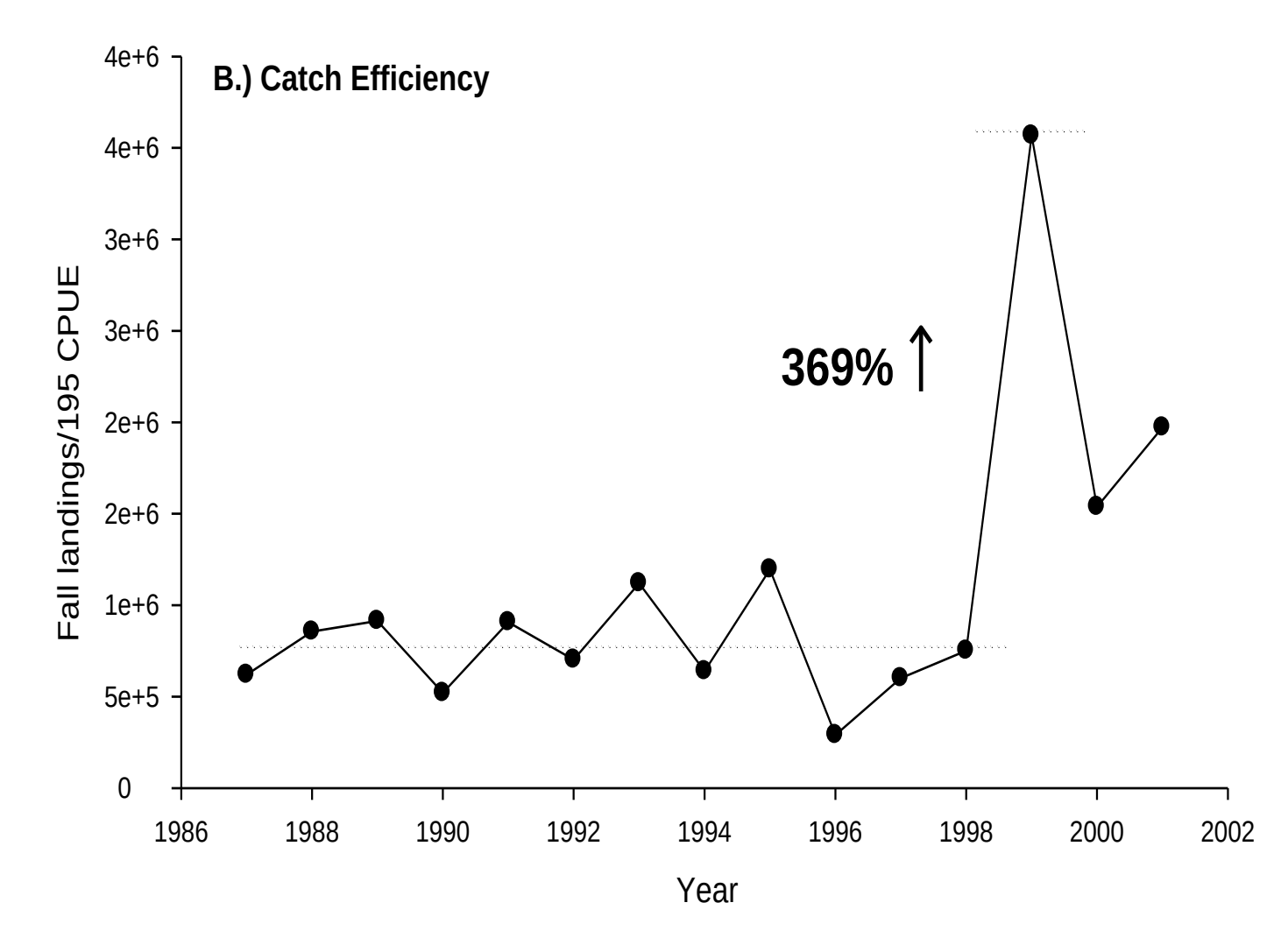

- Perturbation #1
- 3 sequential hurricanes in Sept.-Oct. 1999
- 50- to 500-yr flooding

# Crab behavioral response to floodwaters




* Mass migration of crabs downstream
* Hyper-aggregation of crabs in Pamlico Sound

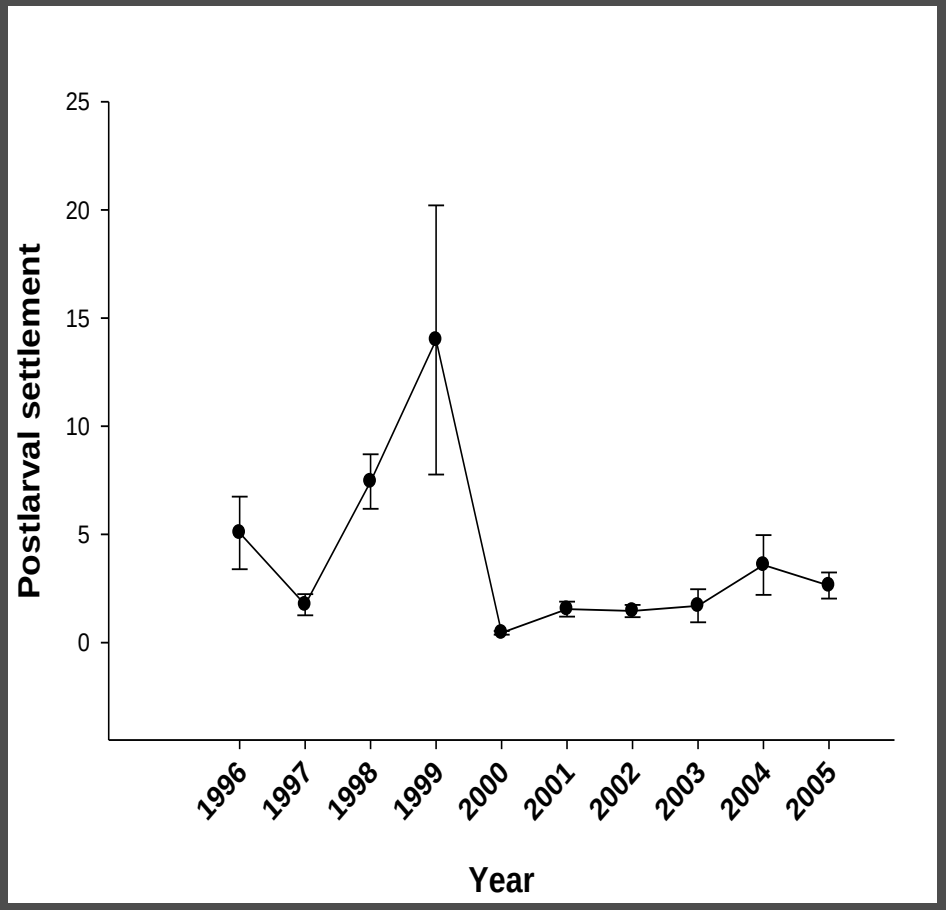
# Perturbation #2

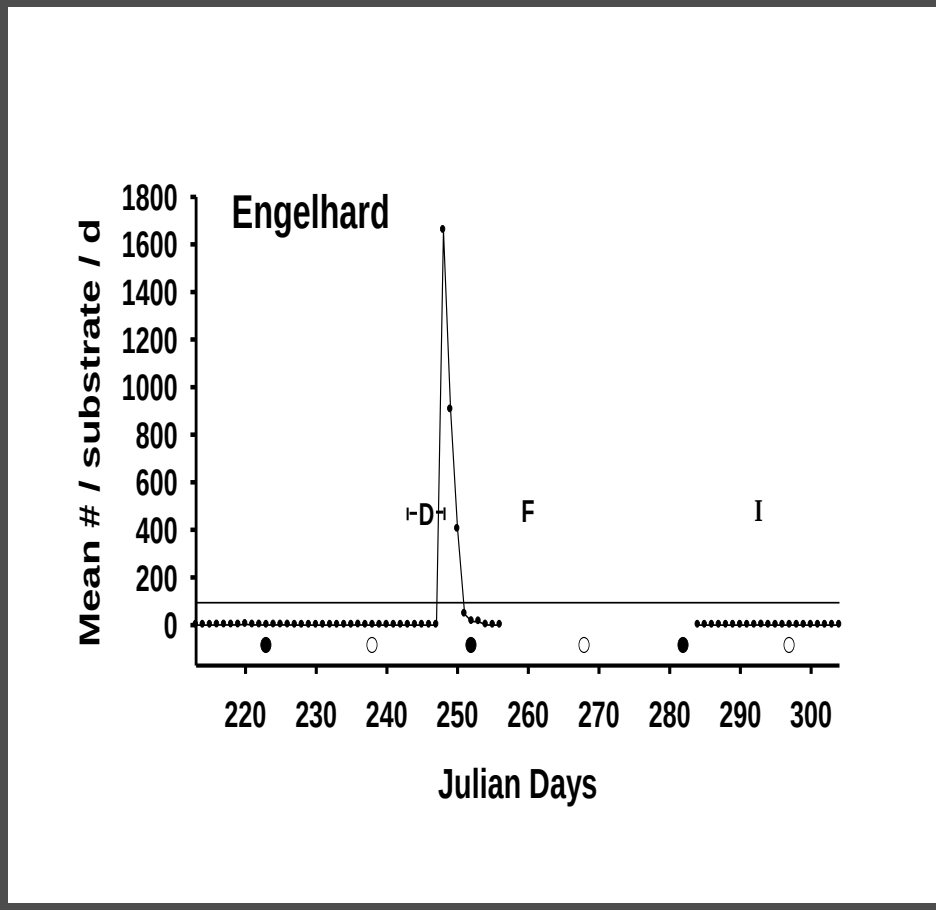



* Intense exploitation of hyper-aggregations

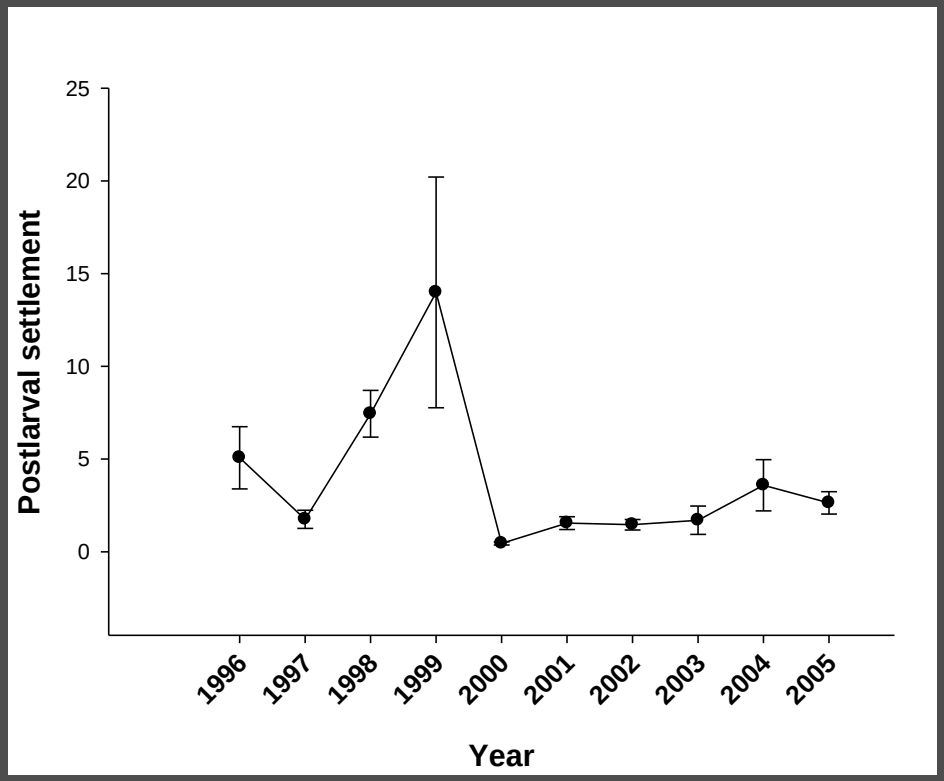
# Recruitment to the rescue?

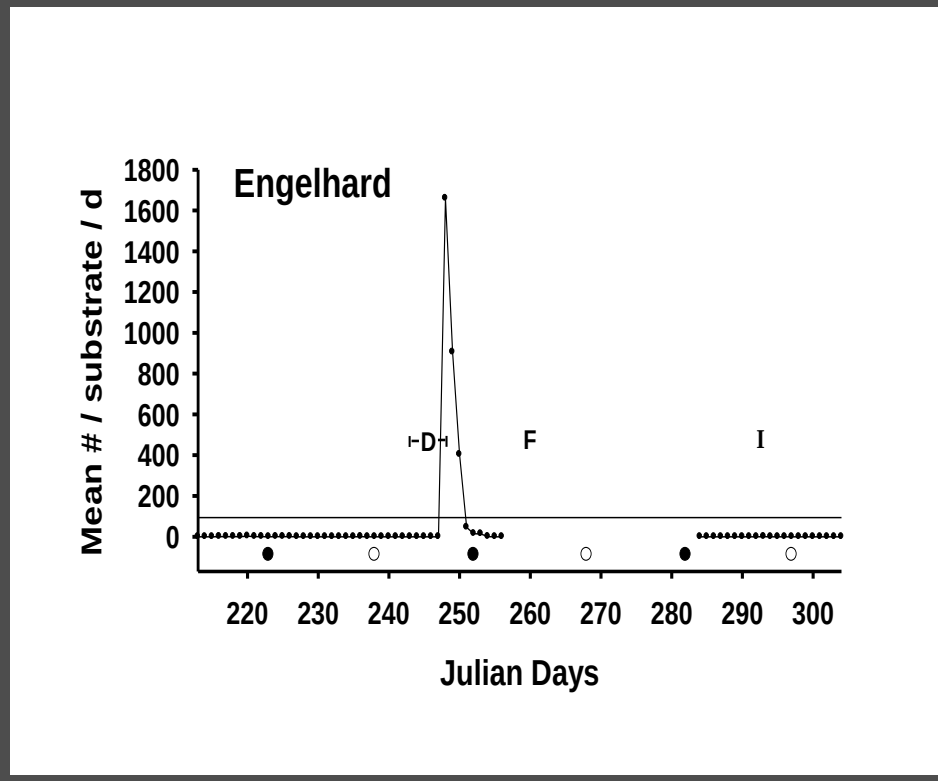
## Highest postlarval supply in Fall 1999



# Highest postlarval supply in Fall 1999

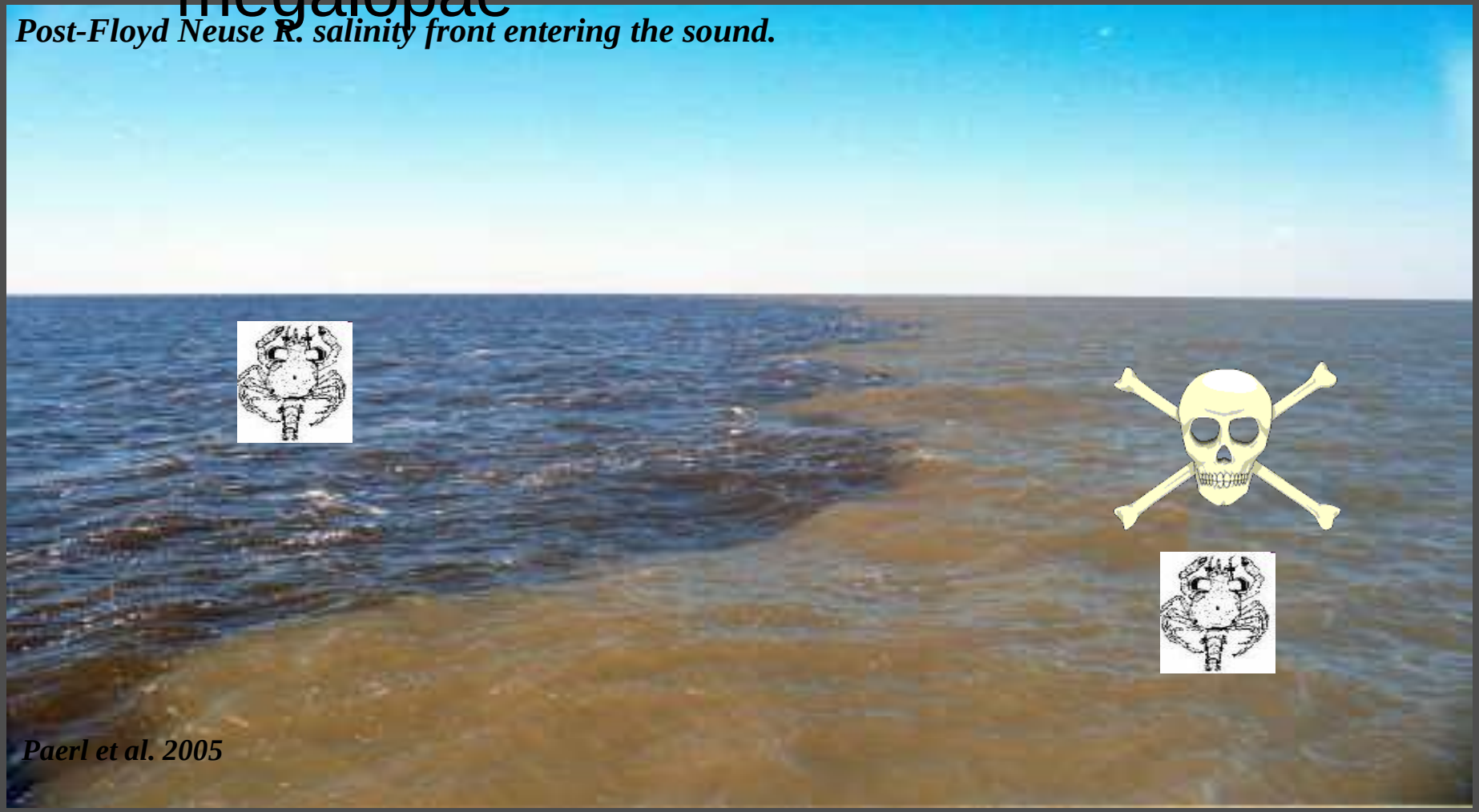



- High settlement did NOT lead to high juvenile or adult abundances (Eggleston et al. 2004; Durham & Eggleston 2010).

- Why?

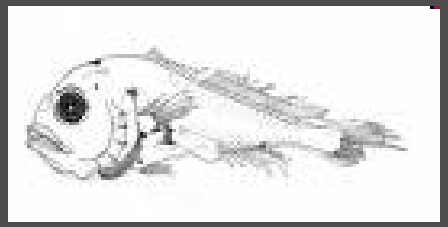
# Extreme FW events kill megalopae




Salinities = 5 ppt (Burkholder et al. 2004)
Megalopae die < 12 ppt (Eggleston & Plaia, unpubl.)

# Future Climate in Western Atlantic?

- Prevalence of El Nino-like conditions
  - (Federov et al. 2010. Nature)
- Decreasing frequency of moderate tropical cyclones (Cat. I-III)
  - (Knutson et al. 2008. Nat. Geoscience).
- Doubling of intense tropical cyclones (Cat. IV-V)
  - (Bender et al. 2010. Science).
- Little known consequences for recruitment dynamics



# Implications

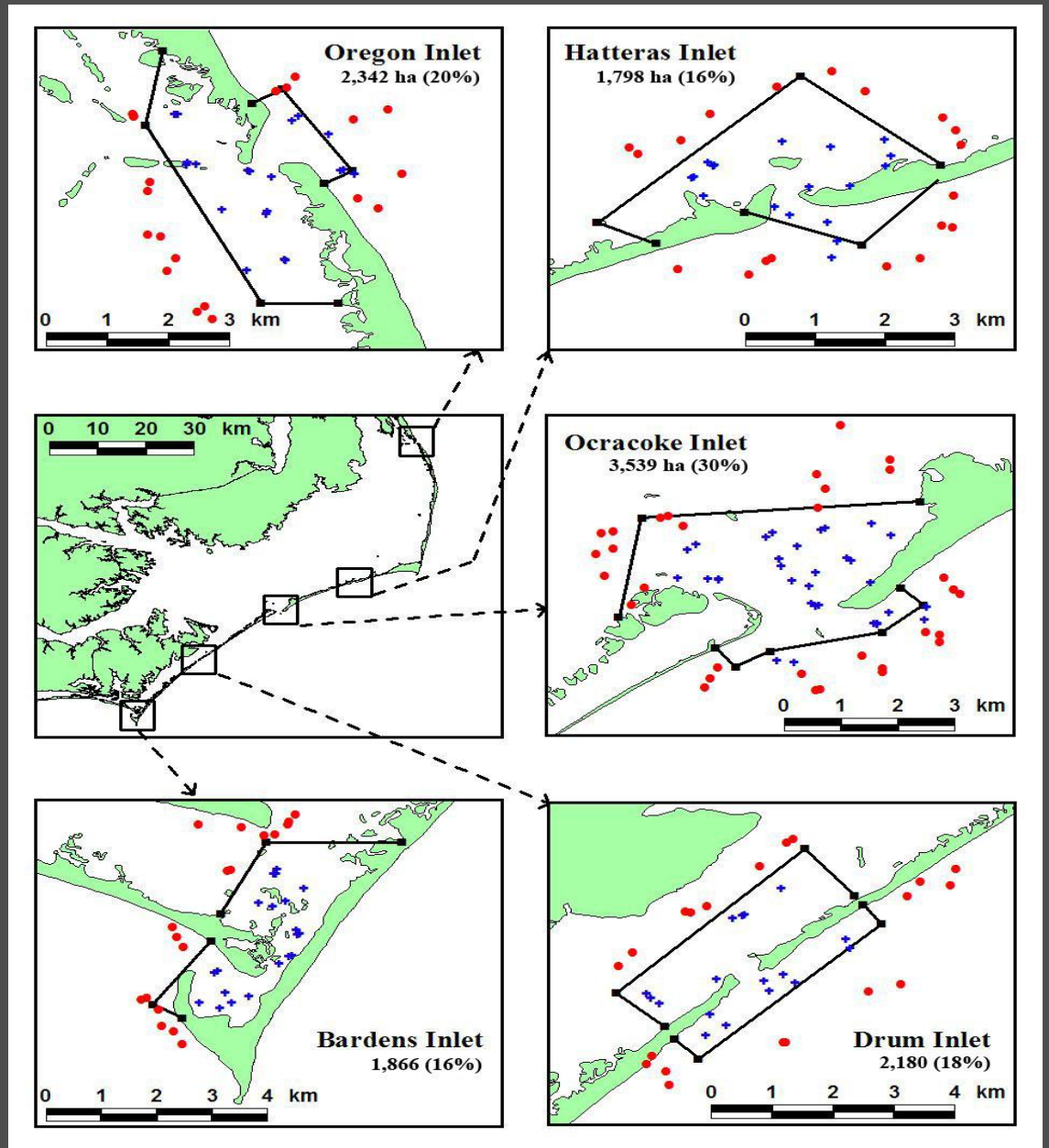
- Successful recruitment requires SSB AND the "right" storms
- Pros: Moderate storms key to estuarine recruitment
- Cons: Extreme FW events will likely kill megalopae delivered by Cat IV-V storms
- The Future?
  - Low recruitment due to:
  - Low SSB
  - Decreasing frequency of moderate storms
  - Increasing frequency of Cat IV-V hurricanes
- Management implications:
  - Must conserve spawning stock
  - Protect inlet nursery areas and settlement hot-spots

# 5. What are some management options for SSB?

- Catch limits vs Catch Shares
  - Limits = fish hard before allowable catch reached
  - Shares = divide allowable catch among users
- No-take sanctuaries
  - May work in concert with catch shares
- Stock enhancement
  - May work, but expensive

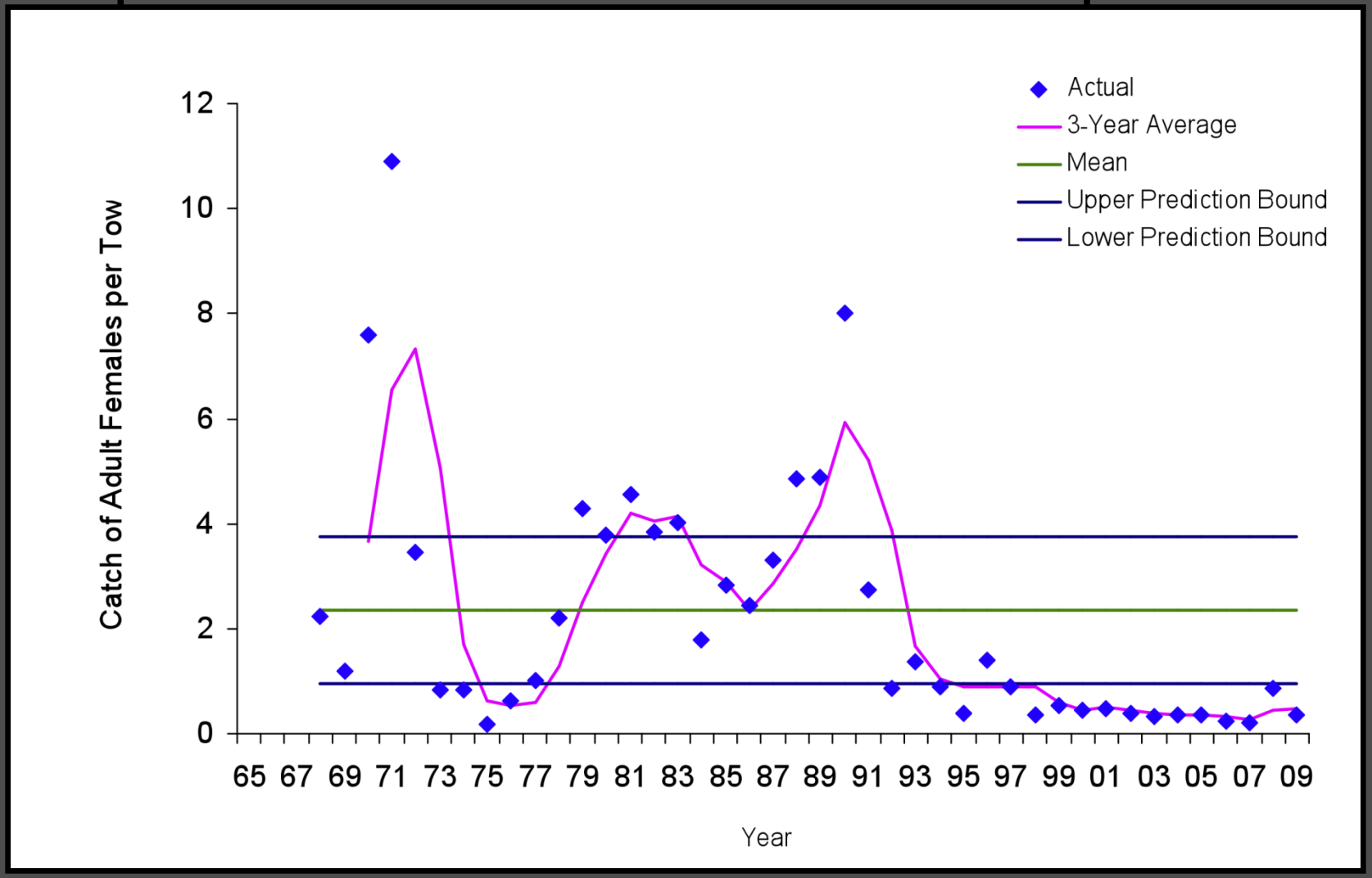
# No-Take Sanctuaries - NC

Eggleston et al. 2009




- Only protect <1% of SSB
- 85% mortality of mature females
- Deeper-water sources of SSB?
- SEAMAP trawls surveys off NC show high cpue
- Gelpi et al. 2009 found high SSB > 20km off LA coast
- Mone 1969 found high SSB in surfzone offshore of Galveston, TX

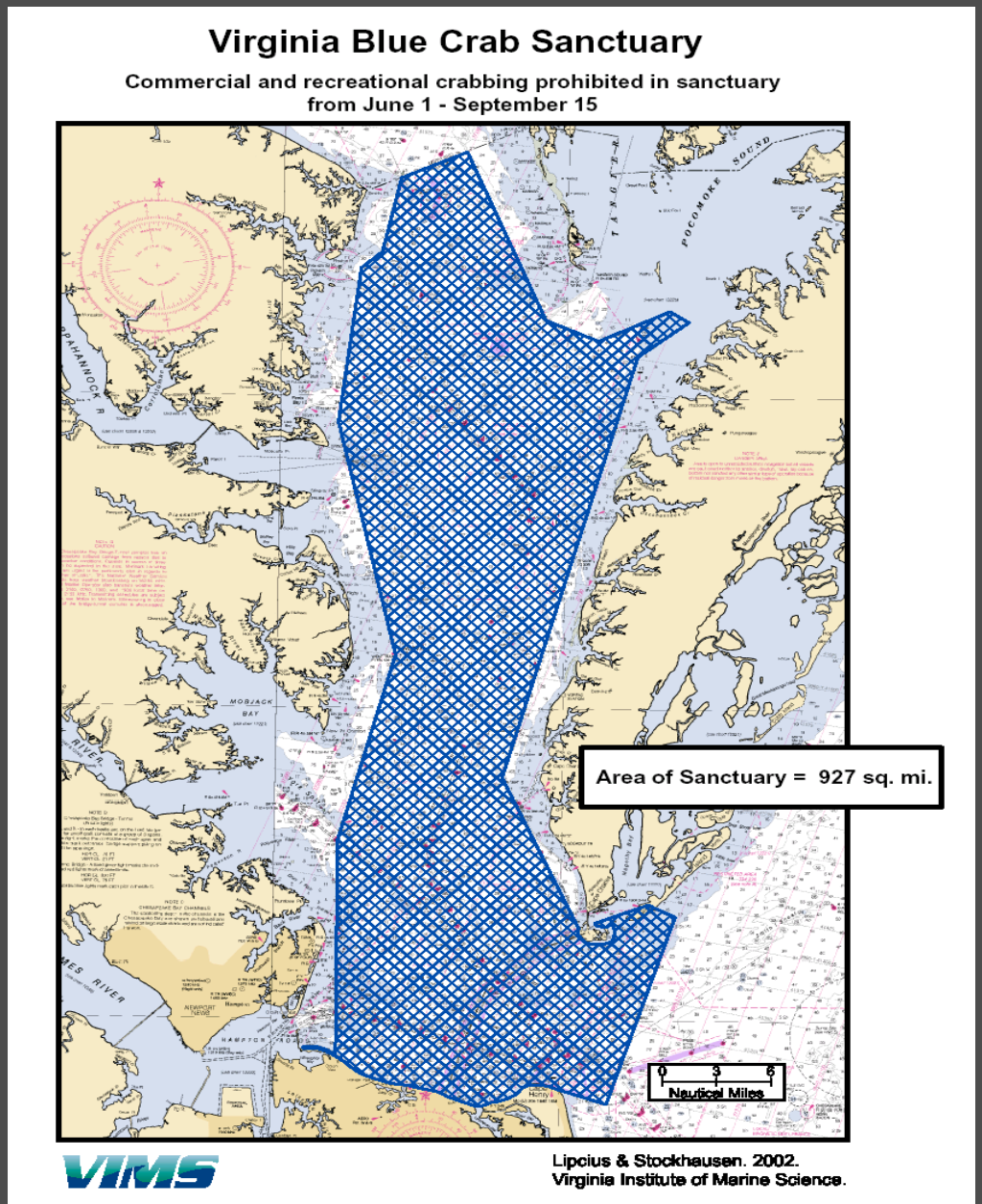
# No-Take Sanctuaries – CB
# Population decline in lower Chesapeake Bay



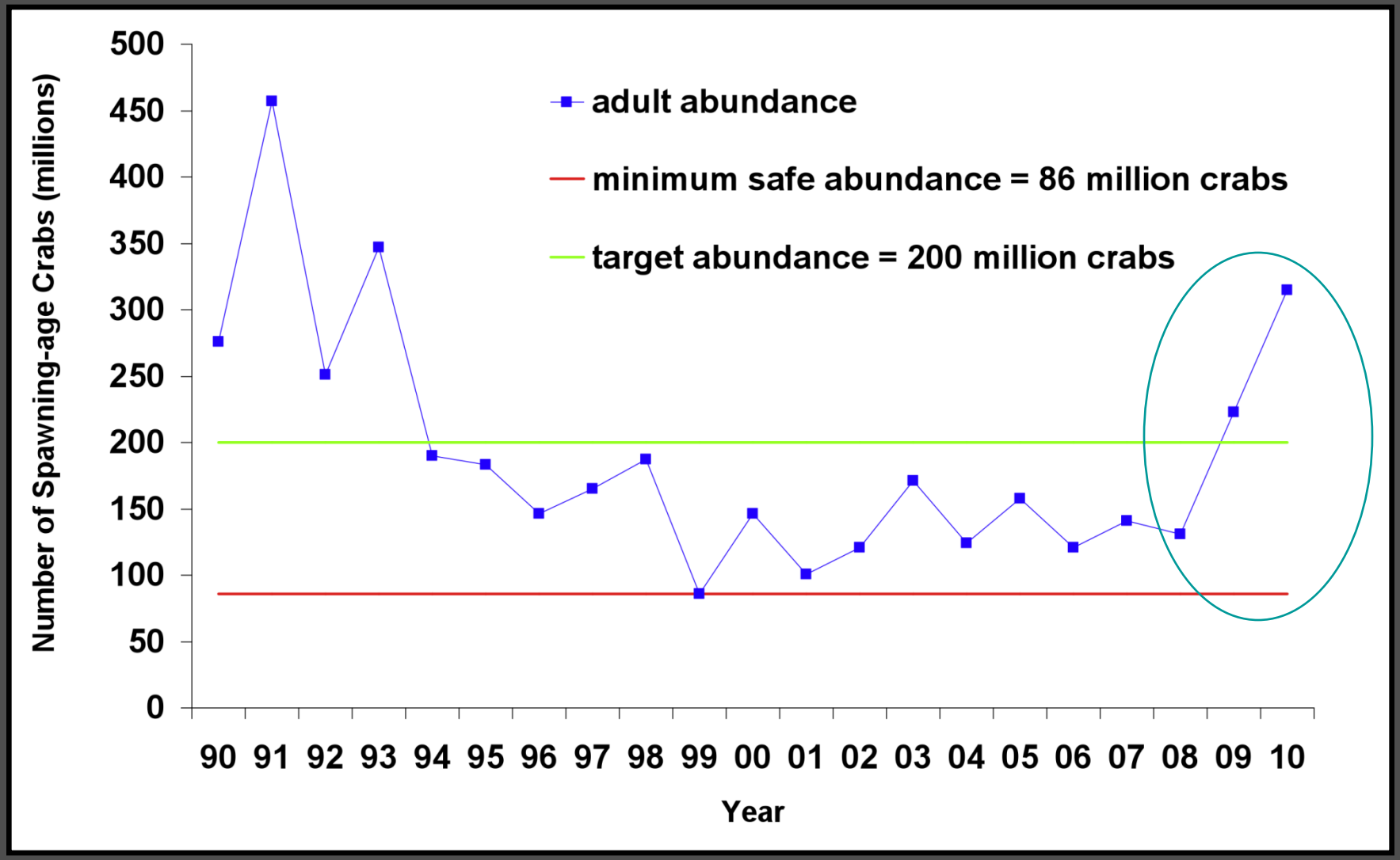

R. Lipcius, VIMS

# No-take sanctuaries- CB

- Expanded to 775 $km^2$ in 2002
- Protects 70% of SSB
- Increased catch limits in 2008



# No-take Sanctuaries

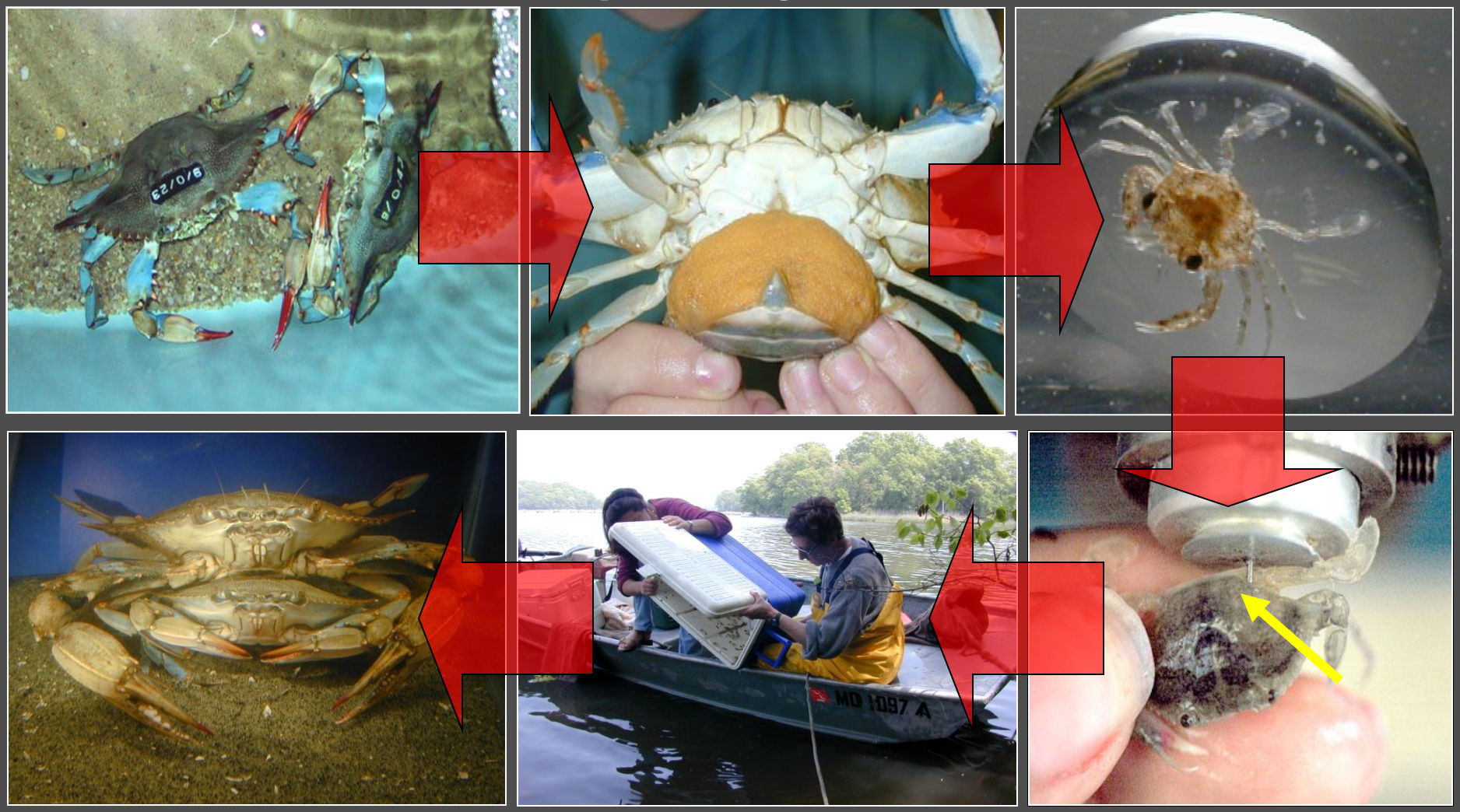



- Spawning stock & juveniles increasing

R. Lipcius, VIMS

# Hatchery-based restocking strategy

A. Hines & E. Johnson SERC; Y. Zohar & O. Zmora, UMD/COMB



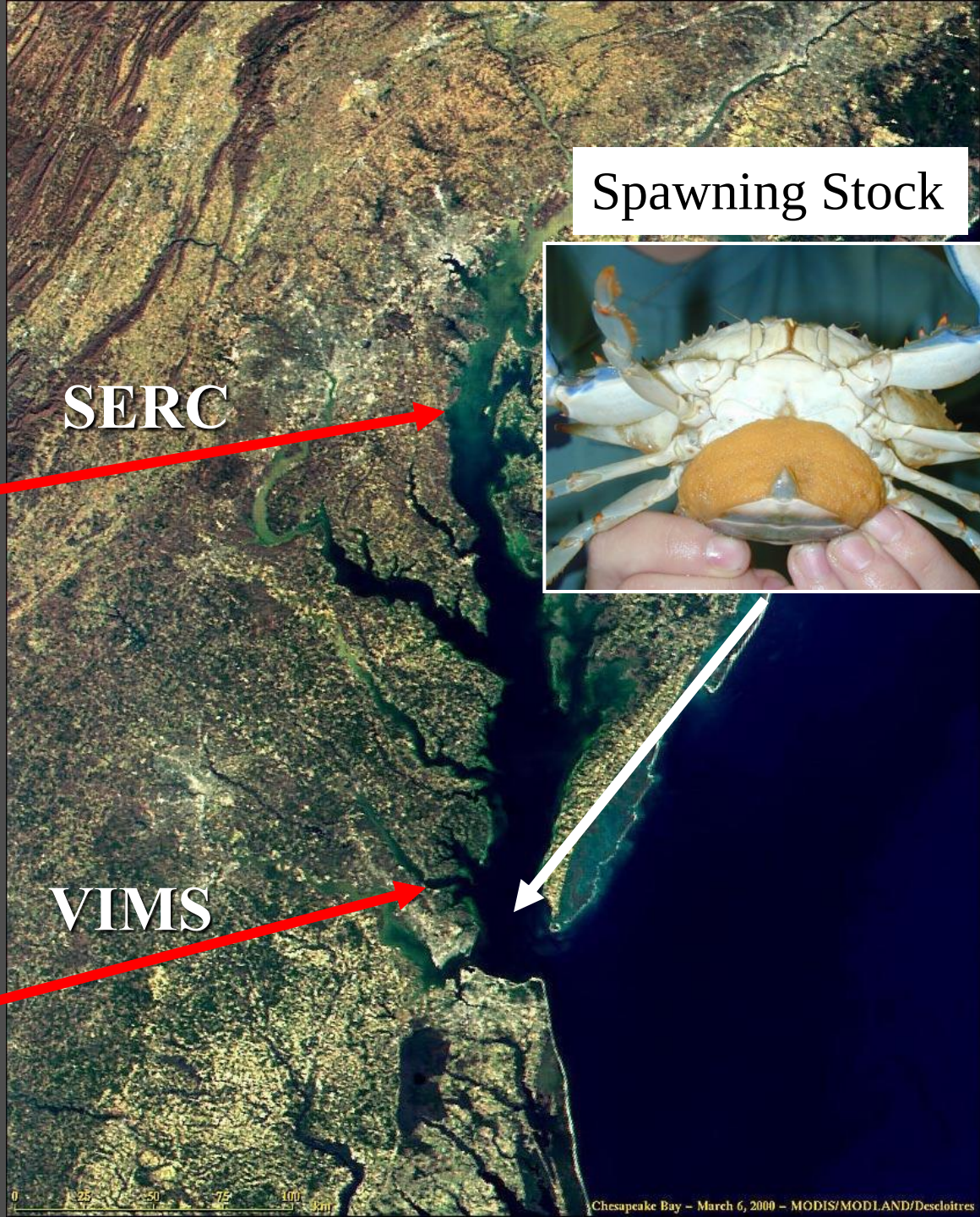
**Chesapeake Stock Enhancement concept**

Under-used nurseries linked by migration corridors to spawning sanctuary

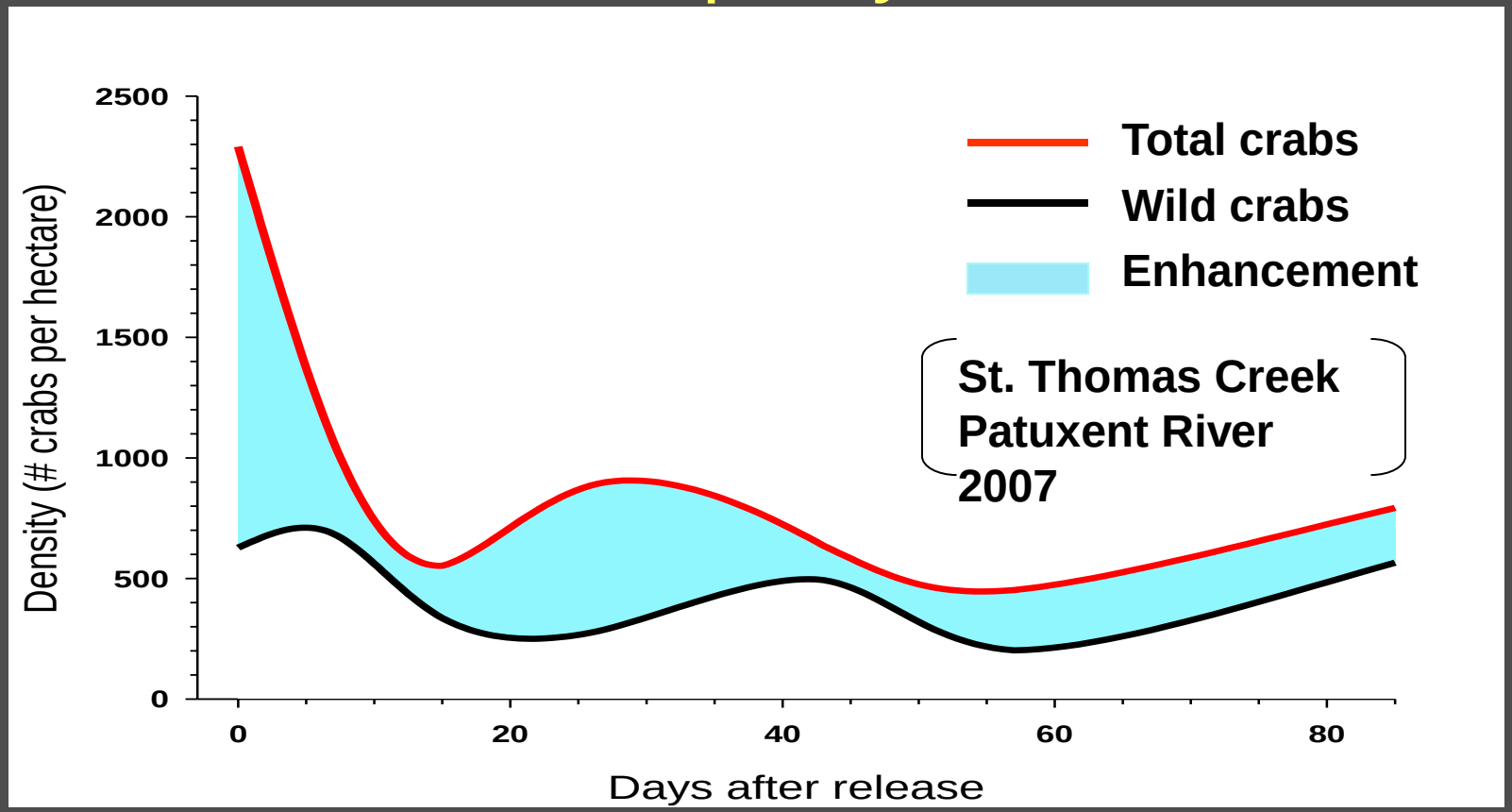
# Experimental stock enhancement: 2002-2008

Upper Bay: 390,000
60 cohorts
1,000-20,000
juveniles/release

Lower Bay: 312,000
25 cohorts
2,000-28,000
juveniles/release



# Stock Enhancement Expts – Testing Carrying Capacity




- 25-150% local enhancement
- Production 100-600 crabs/ha
- HR females mated and migrated to spawning sanctuary
- Expensive: $0.15-0.30/juvenile ($18-36/doz mature females)

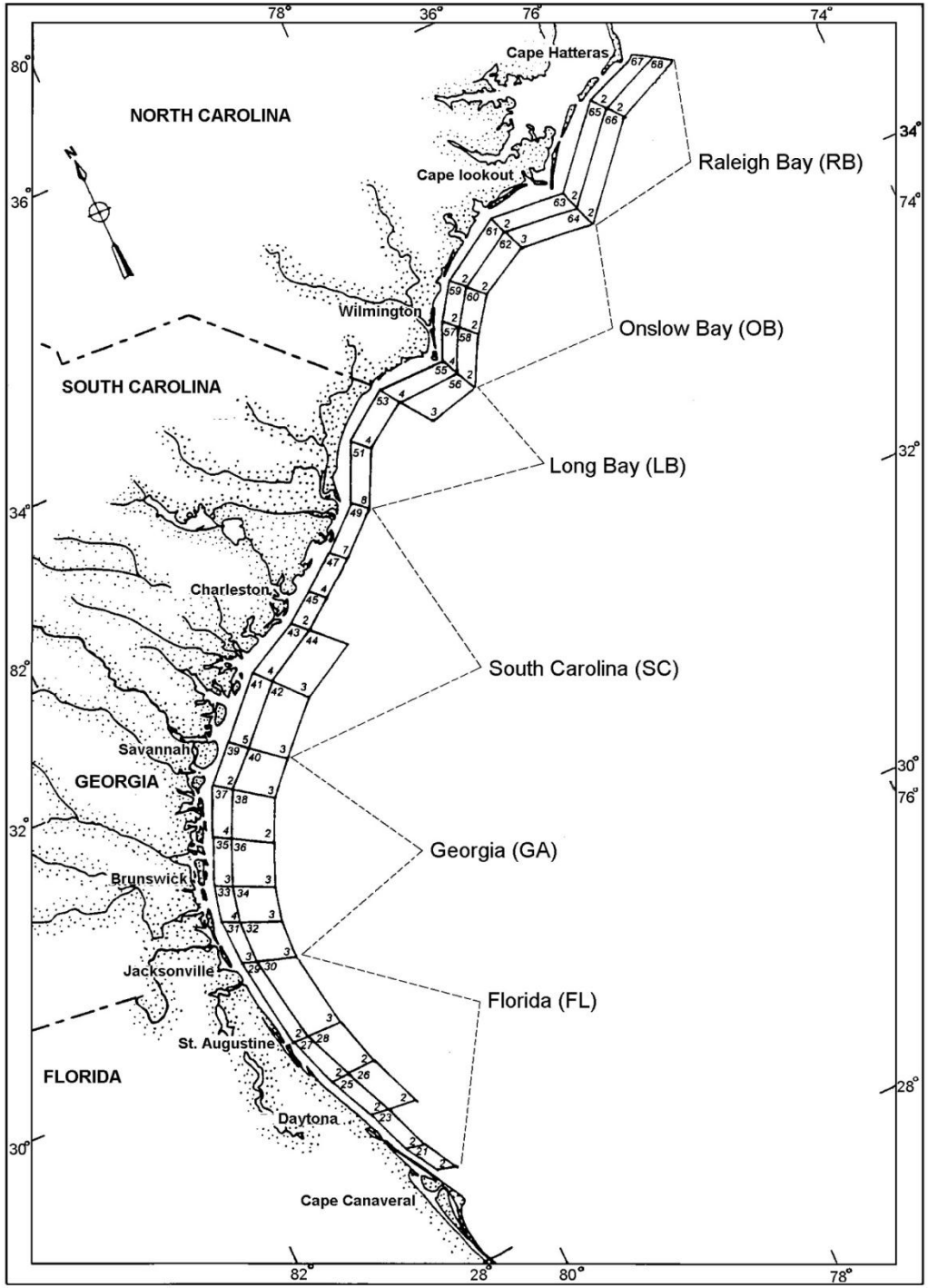
# Conclusions

- Fishery-independent data is crucial (unbiased)
  - Status of stock
  - Life history bottlenecks
- Dynamic salinity = dynamic movement
  - Influences catch efficiency
  - Influences population size
- Protection of spawning stock is crucial
  - Supplies recruits
  - Catch limits/Catch shares
  - No-take sanctuaries
  - Stock enhancement

# Acknowledgements


- Graduate students & staff
- NC DMF staff (S. McKenna, K. West)
- High School Students (& teachers/parents)
- NSF, NC Sea Grant, Z. Smith Reynolds, Blue Crab Advanced Research Consortium

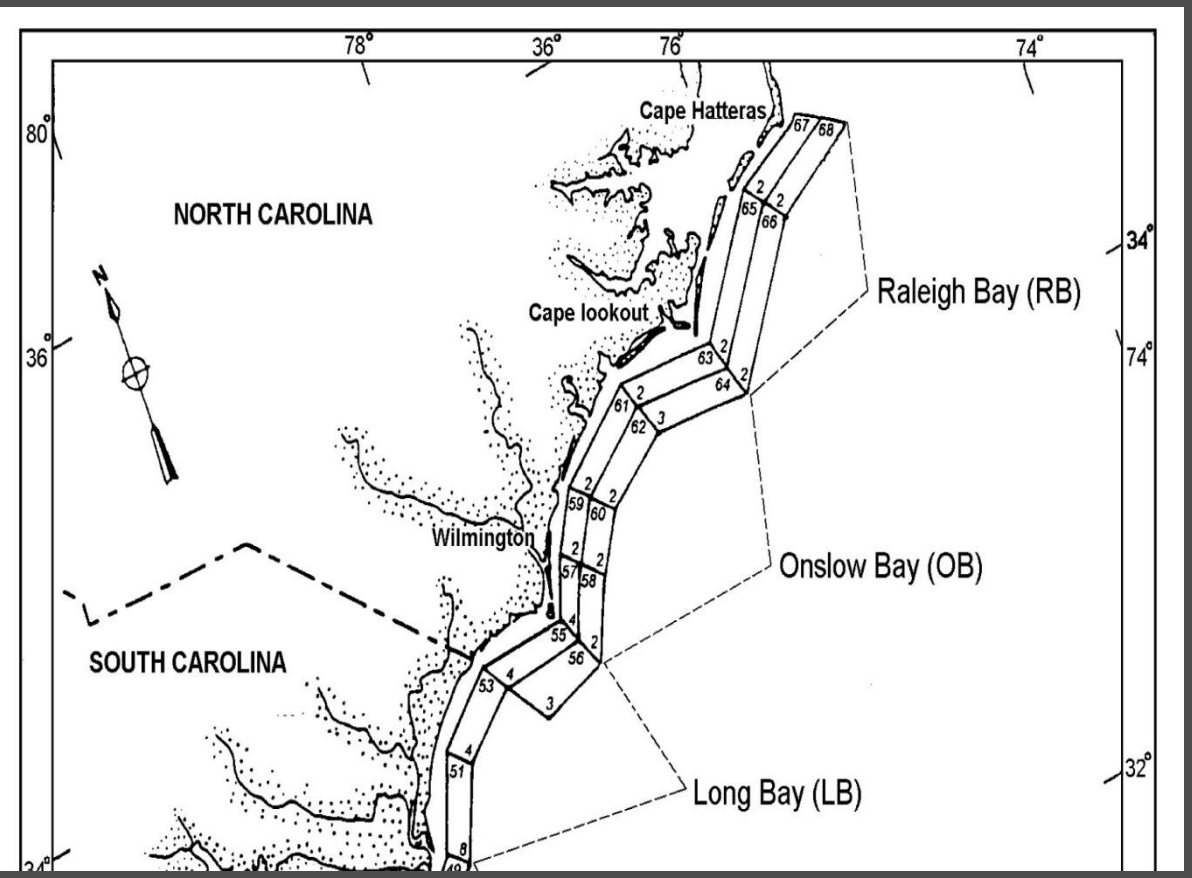
Questions?




# Shallow Water Trawl Survey

- Paired Mongoose Trawls in 4m-10m depths
- 78 stations w/in 24 inshore strata
  -Spring, Summer, fall Surveys

**http://www.seamap.org**



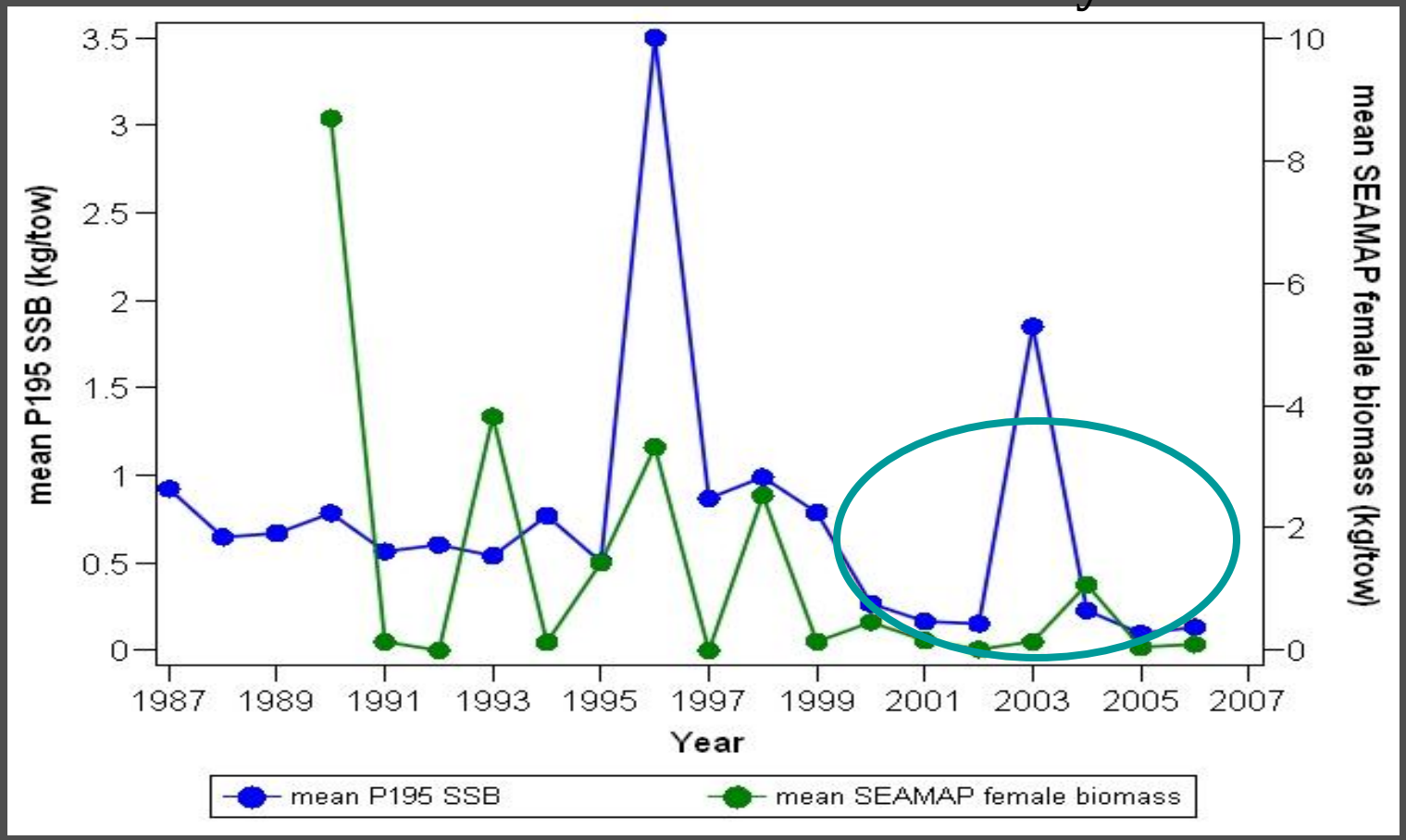

* Any correspondence between P195 & SEAMAP?

## Beginning in 2000:

- Only inshore strata sampled
- Increased number of trawls per strata from 2 to 4
- Focused on Raleigh Bay

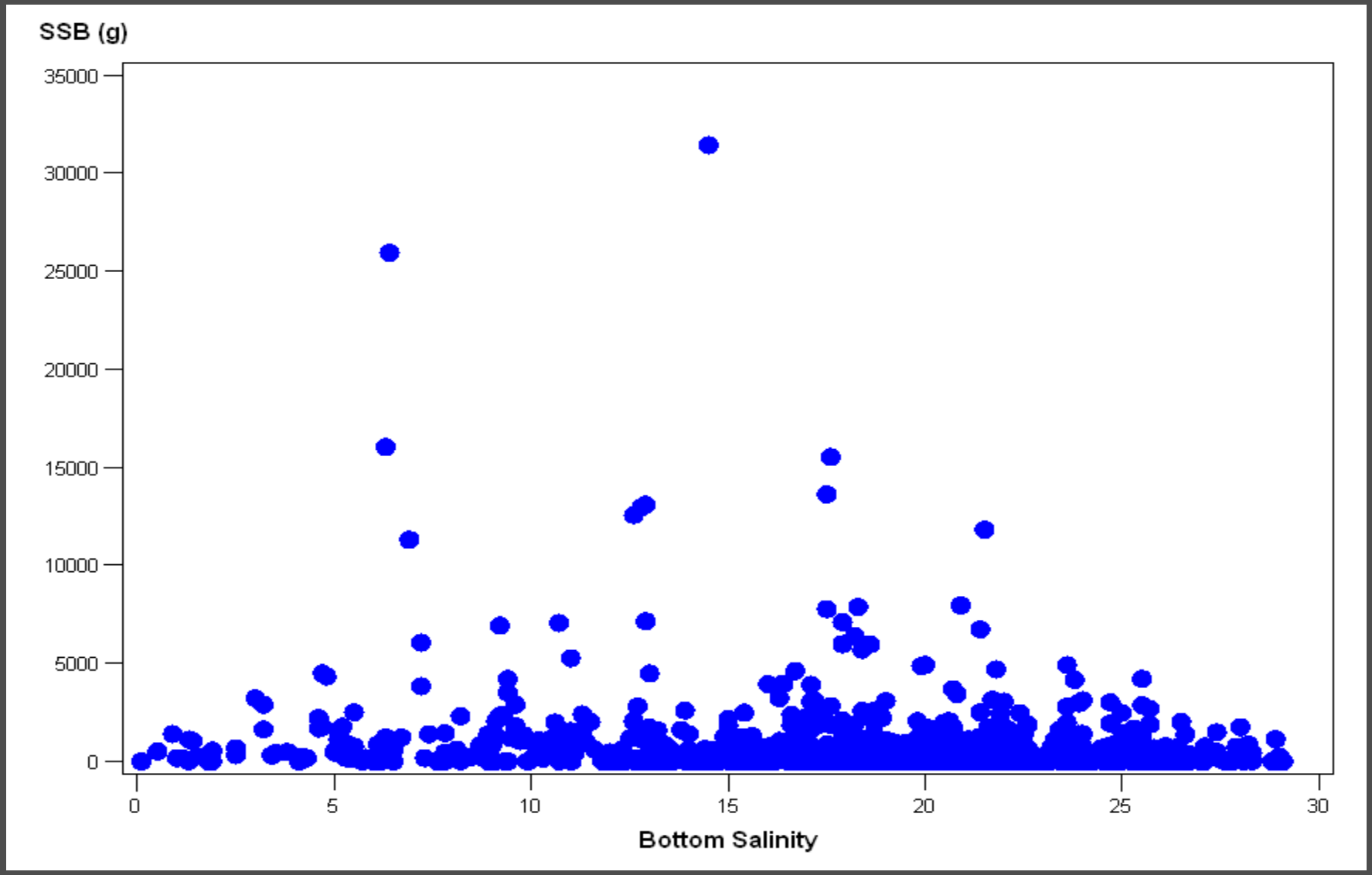
# Is there a relationship between P195 and SEAMAP Female Biomass

**Summer SEAMAP Survey**




- Not really; Correlation coefficient = -0.08
- Kg/tow twice as high offshore than in estuary

# SSB vs. Bottom Salinity at P195 Fall Sample Stations

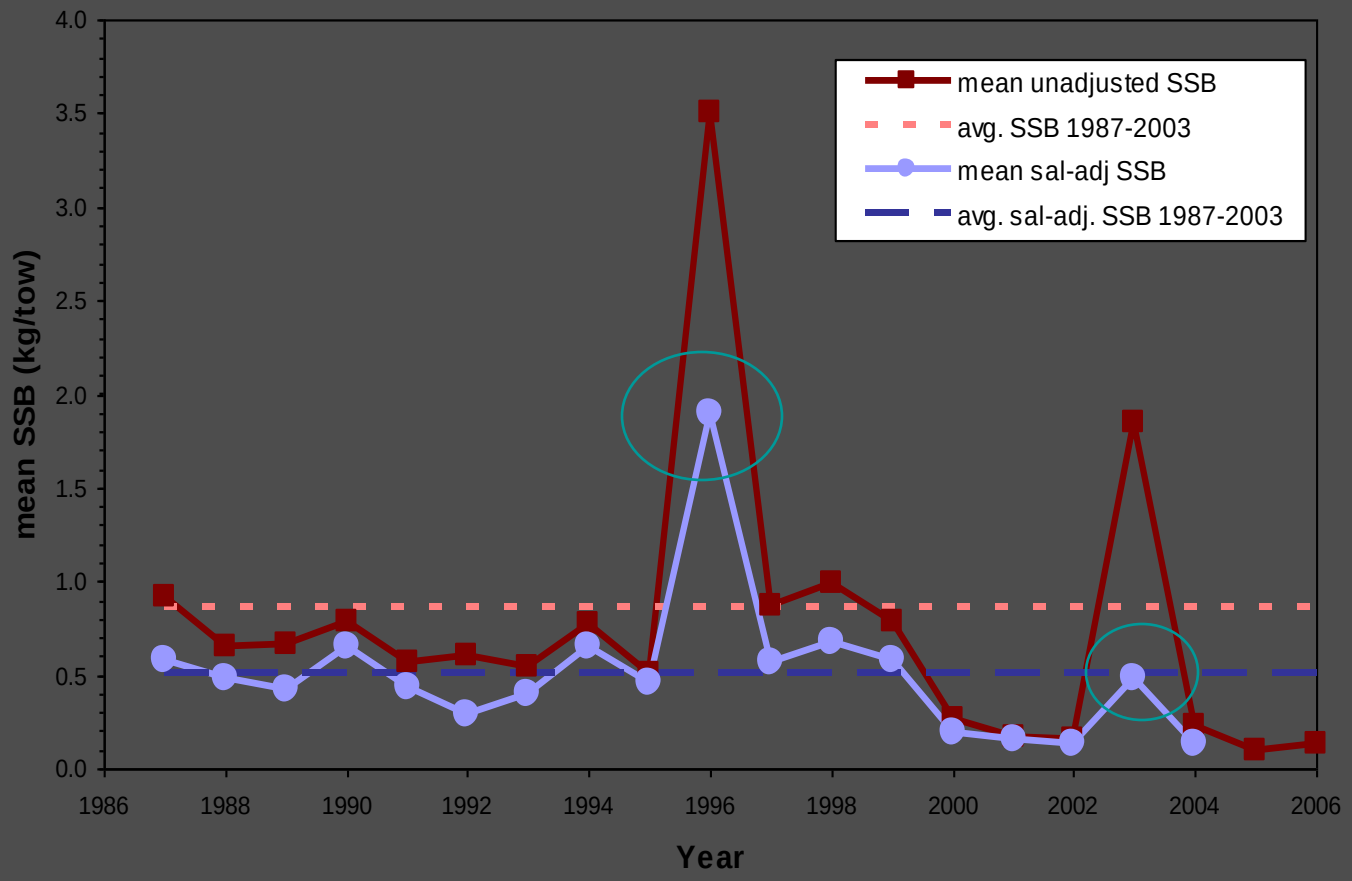



* Optimum at intermediate salinities??

# 1. Are there biases in index of SSB?

Yes!

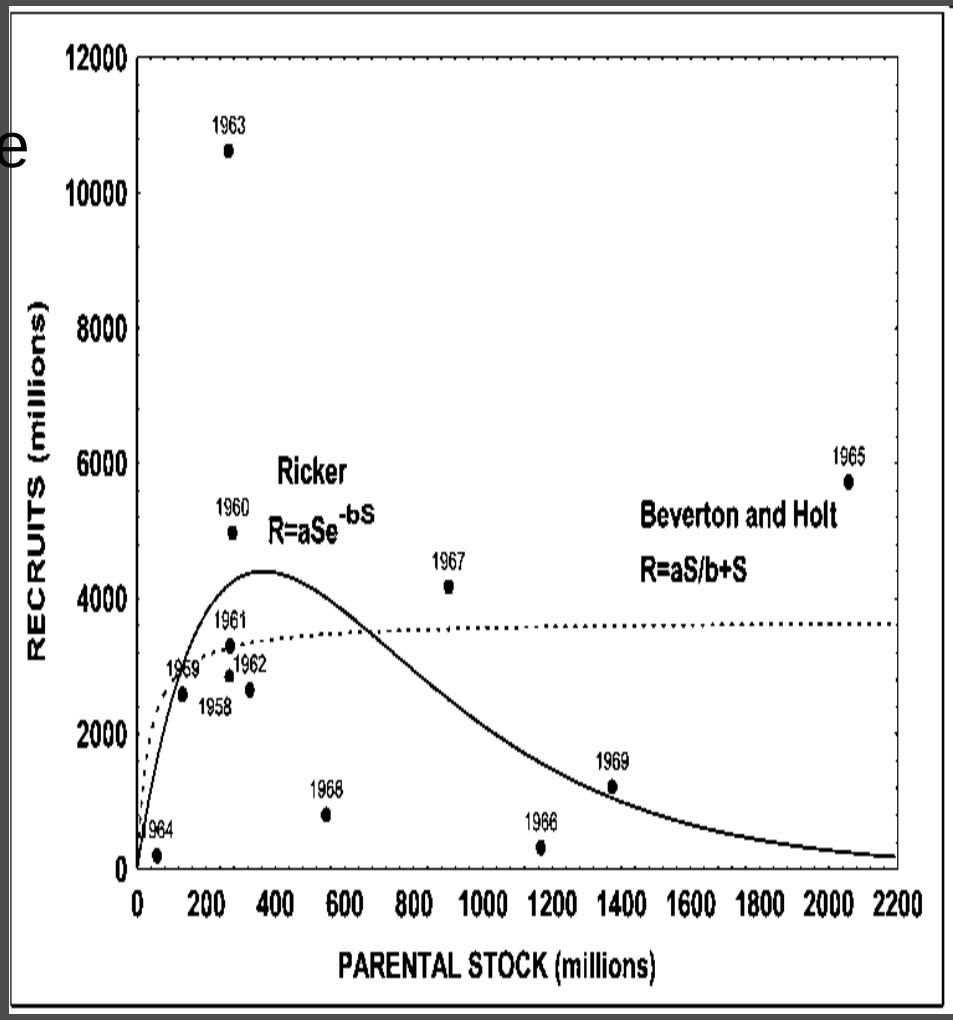
## Environmentally-adjusted vs. Unadjusted SSB




* So, what caused decline in SSB starting in 1999?

# Spawning stock-recruit relationship

- Problems
  - Often weak, w/ high variance
  - Variance driven by environment & climate
  - If we can account for uncertainty, then we can better manage S/R




S/R for Cockle, *Cerastoderma edule*

# Blue crab biology in Texas estuaries


Zack Darnell

University of Texas Marine Science Institute

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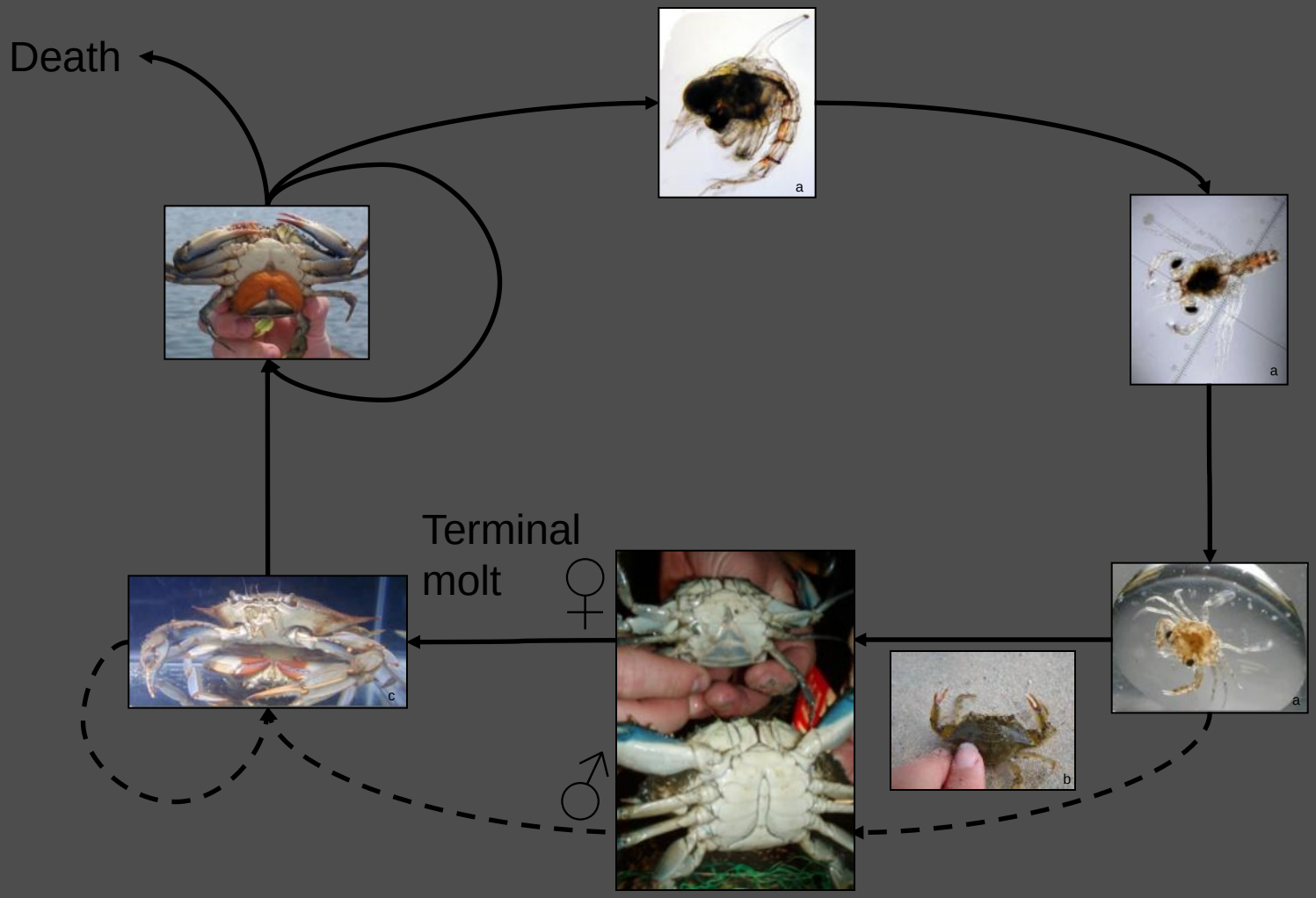
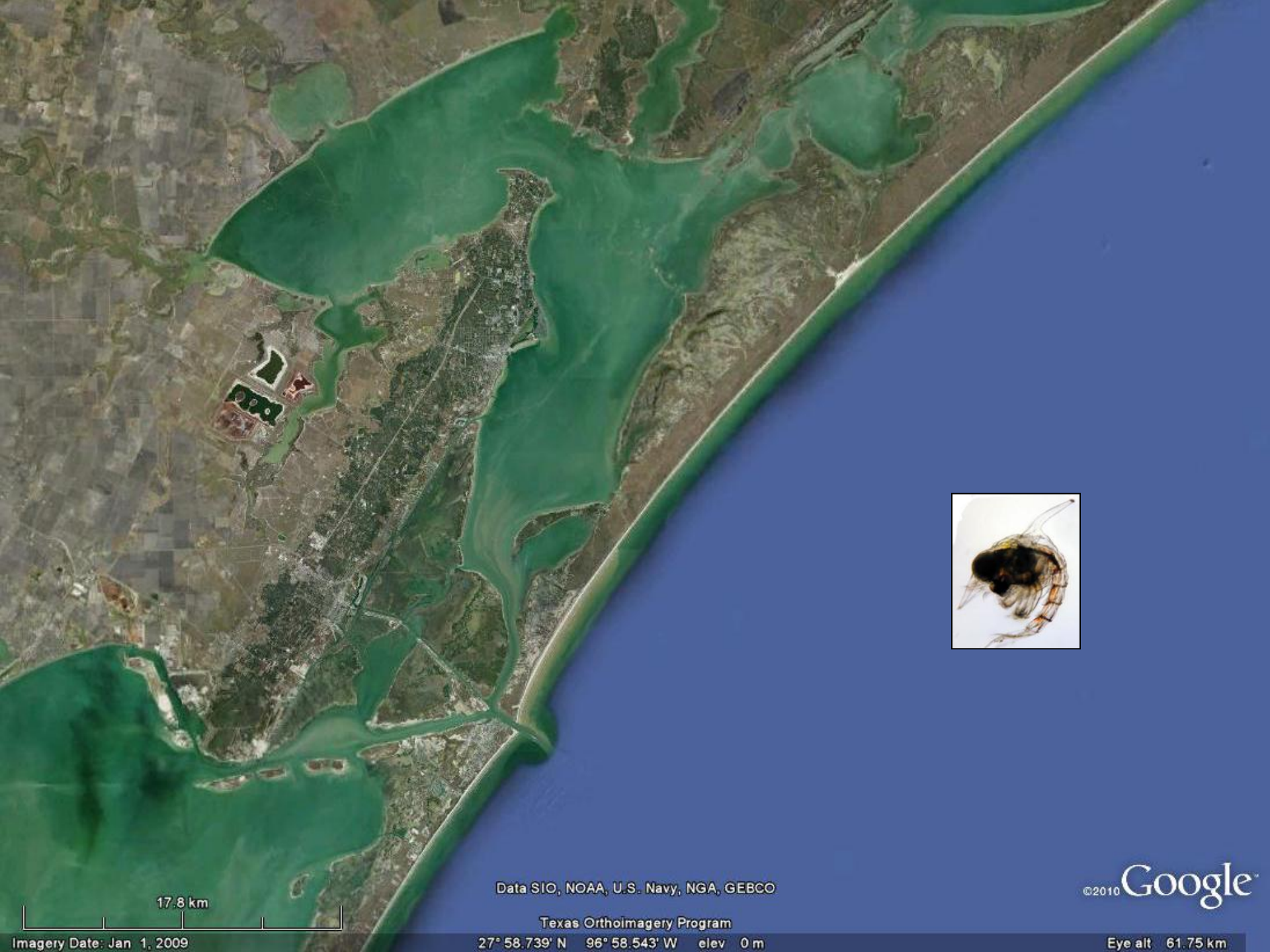
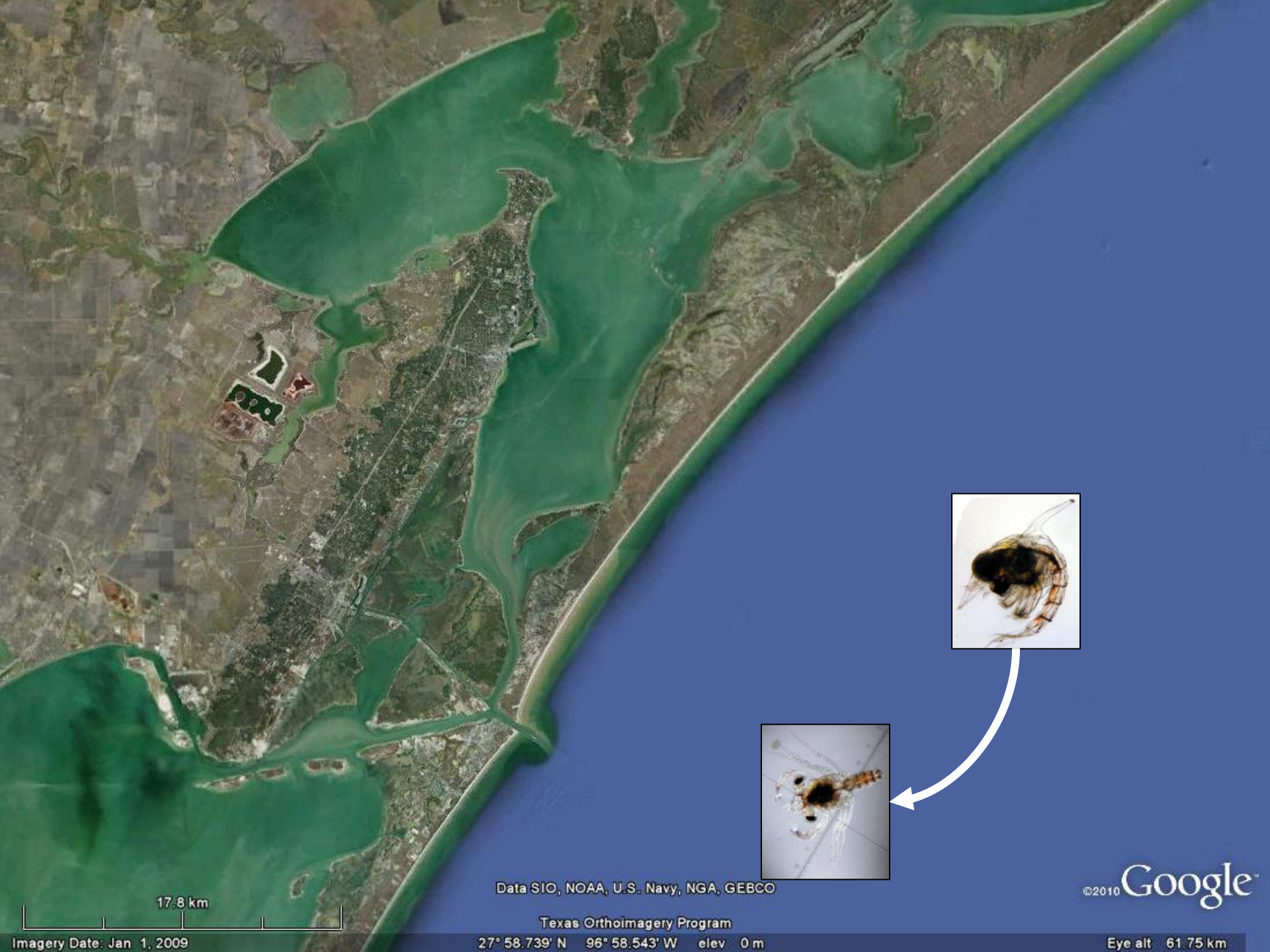
- Blue crab life history
- Ecological importance in estuaries
- Gulf of Mexico
- Texas
  - Seasonality
  - Spawning
  - Size at maturity

# Blue crab life cycle




a.http://www.serc.si.edu/education/resources/bluecrab/lifecycle.jsp
Photo by Alicia Young-Williams
b.http://research.myfwc.com/features/view_article.asp?id=25786
c. http://www.serc.si.edu/education/resources/bluecrab/mating.aspx


17.8 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2010 Google
Texas Orthoimagery Program
Imagery Date: Jan 1, 2009
27° 58.739' N 96° 58.543' W elev 0 m
Eye alt 61.75 km


17.8 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Texas Orthoimagery Program
©2010 Google
Imagery Date: Jan 1, 2009
27° 58.739' N 96° 58.543' W elev 0 m
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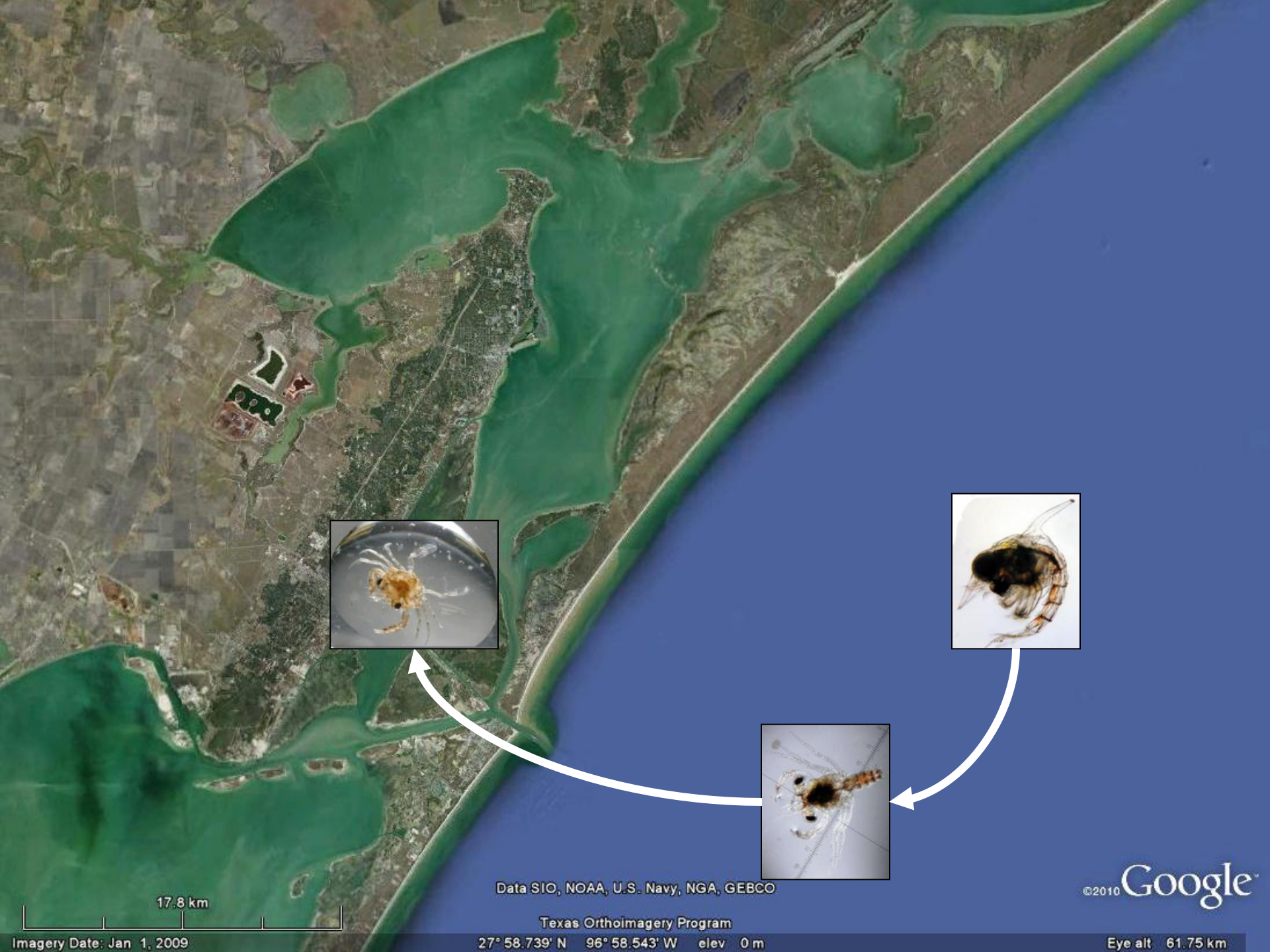
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Texas Orthoimagery Program
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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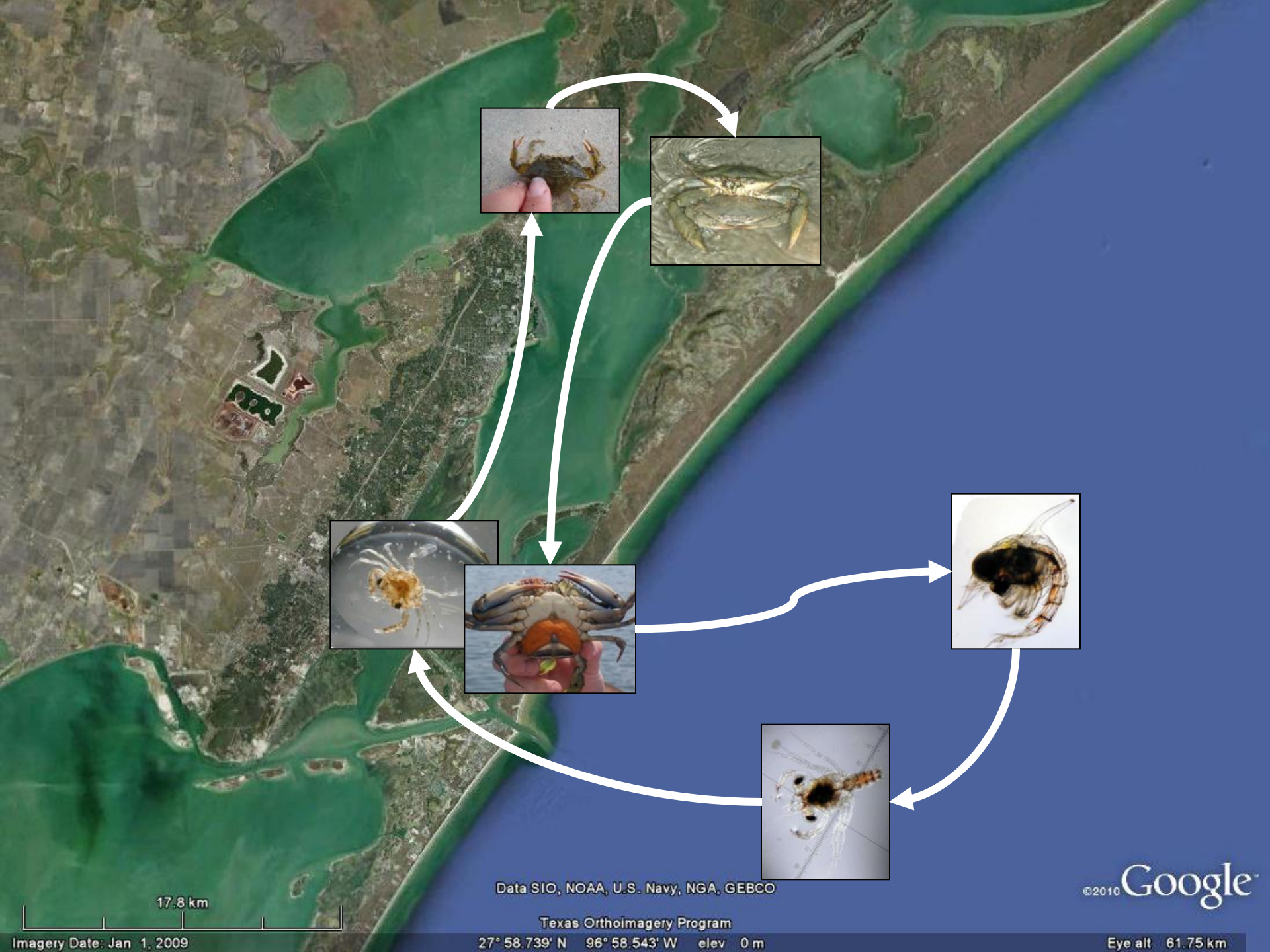
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17.8 km
Texas Orthoimagery Program
Imagery Date: Jan 1, 2009
27° 58.739' N 96° 58.543' W elev 0 m
Eye alt 61.75 km

# Blue crab predators, prey

Images from:
http://www.washingtonpost.com/wp-dyn/content/article/2010/03/29/AR2010032902964.html
http://www.tpwd.state.tx.us/huntwild/wild/species/reddrum/
http://www.tpwd.state.tx.us/spdest/visitorcenters/seacenter/education/coastal_habitats/bays/animals/croaker.phtml
http://www.serc.si.edu/education/resources/bluecrab/lifecycle.jsp
http://research.myfwc.com/features/view_article.asp?id=25786
http://en.wikipedia.org
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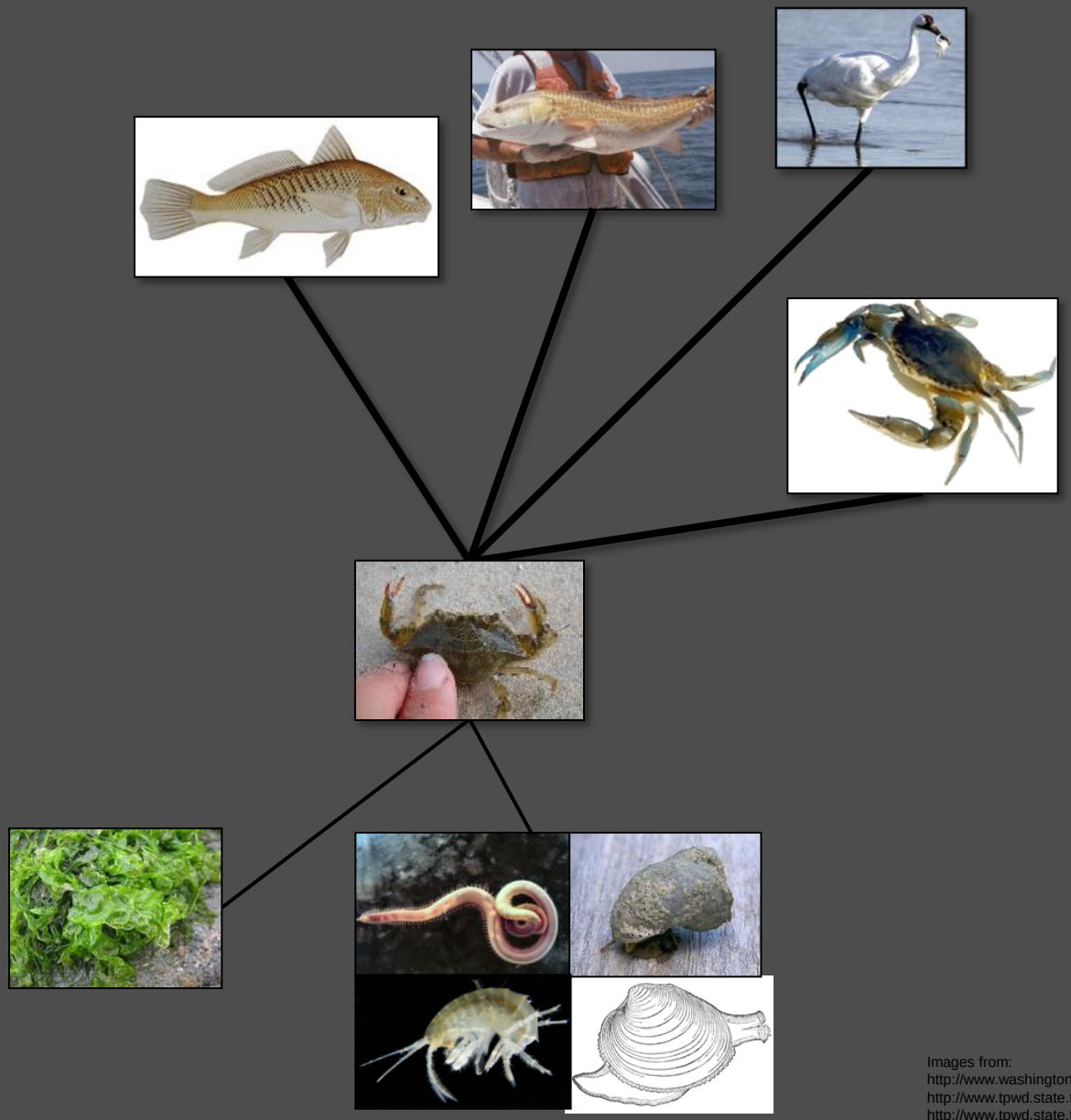

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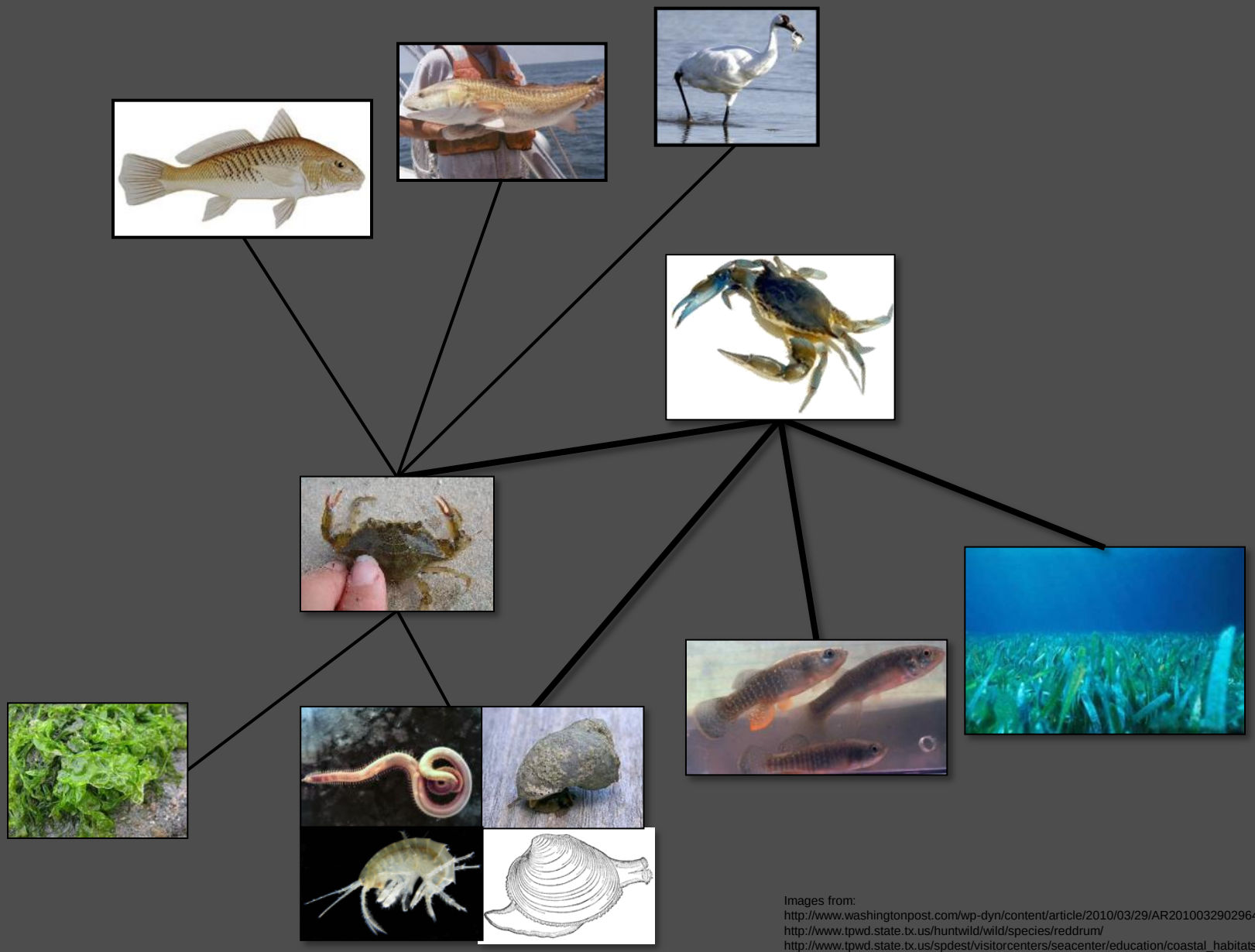

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http://www.serc.si.edu/education/resources/bluecrab/lifecycle.jsp
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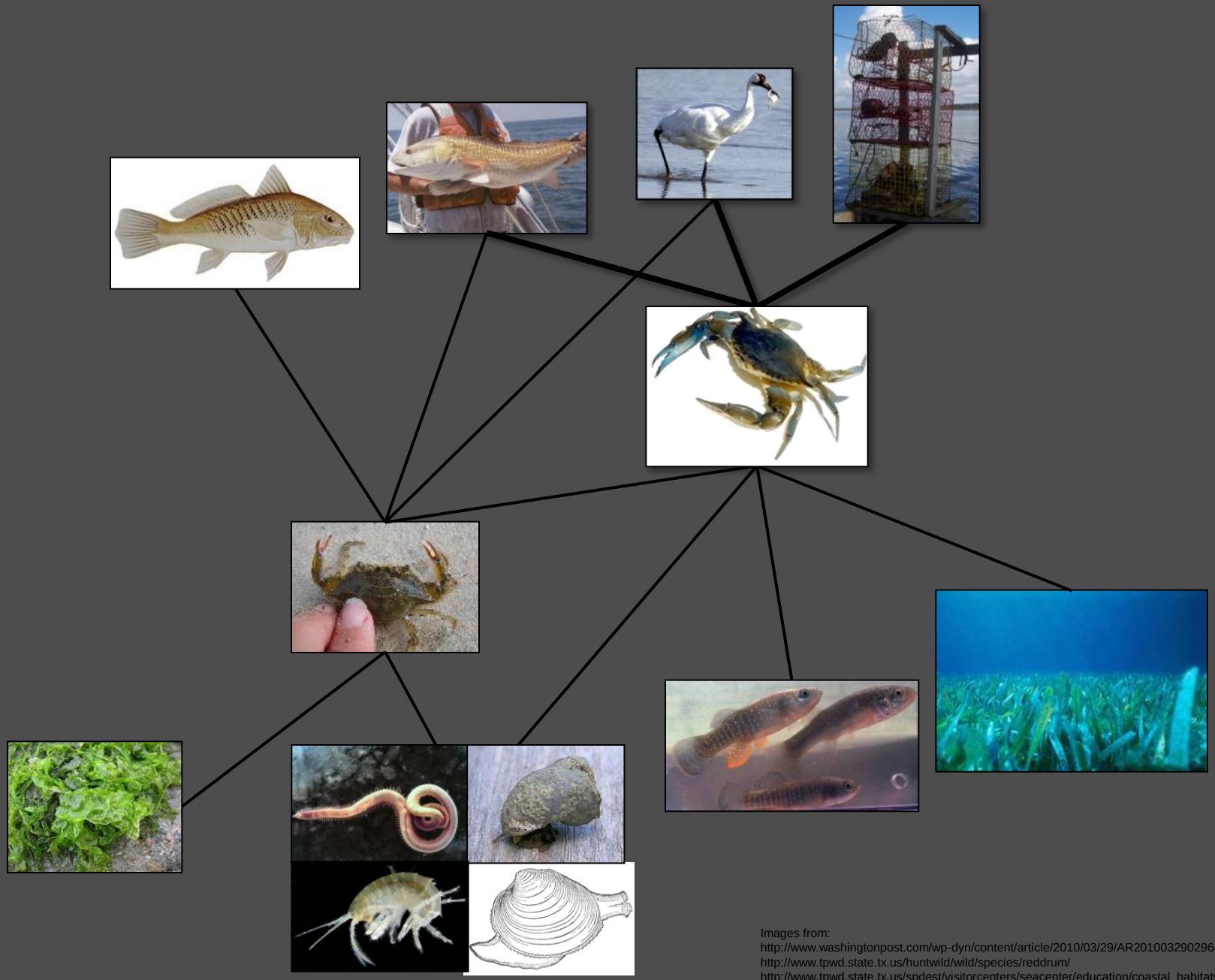

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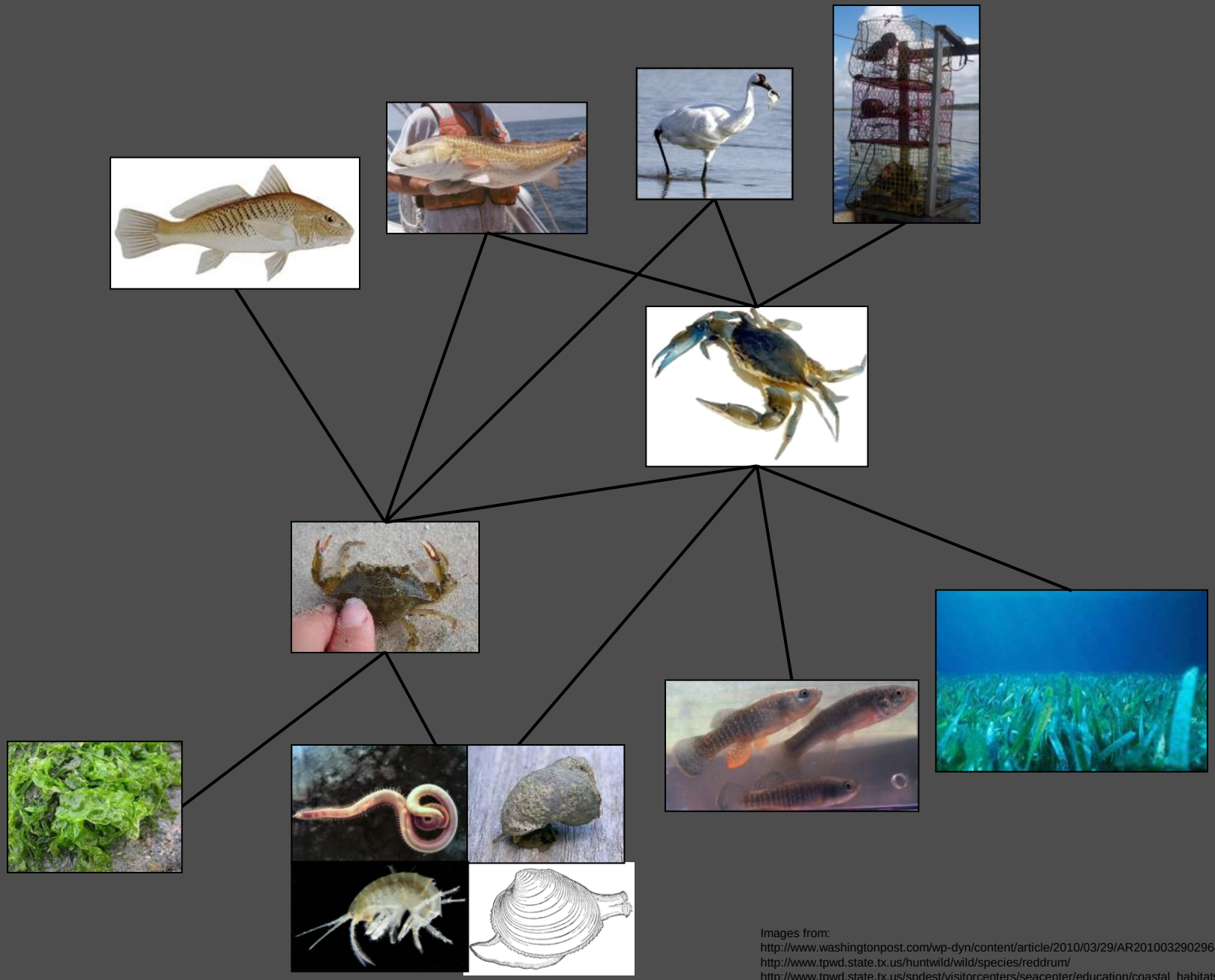

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http://en.wikipedia.org
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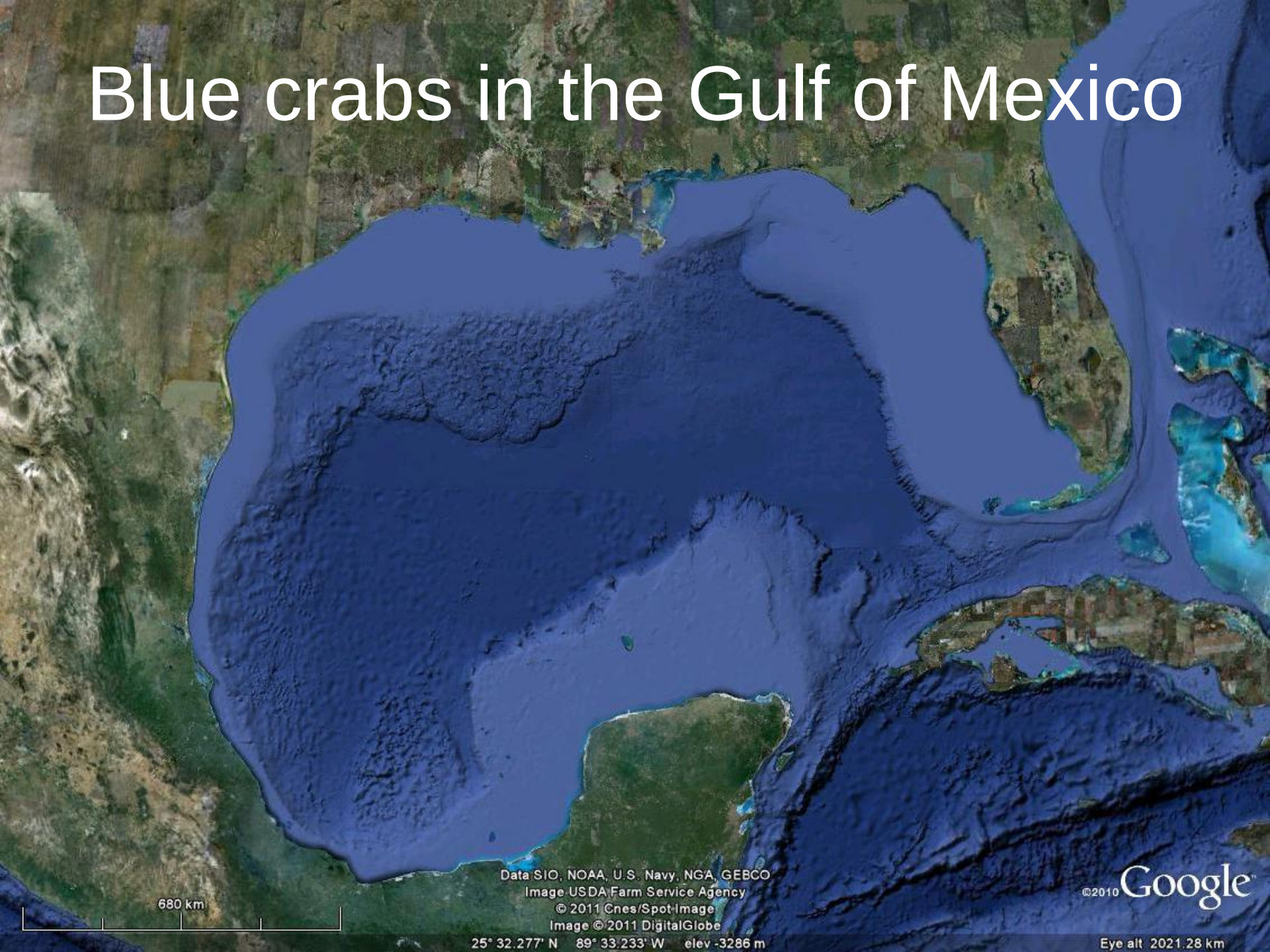
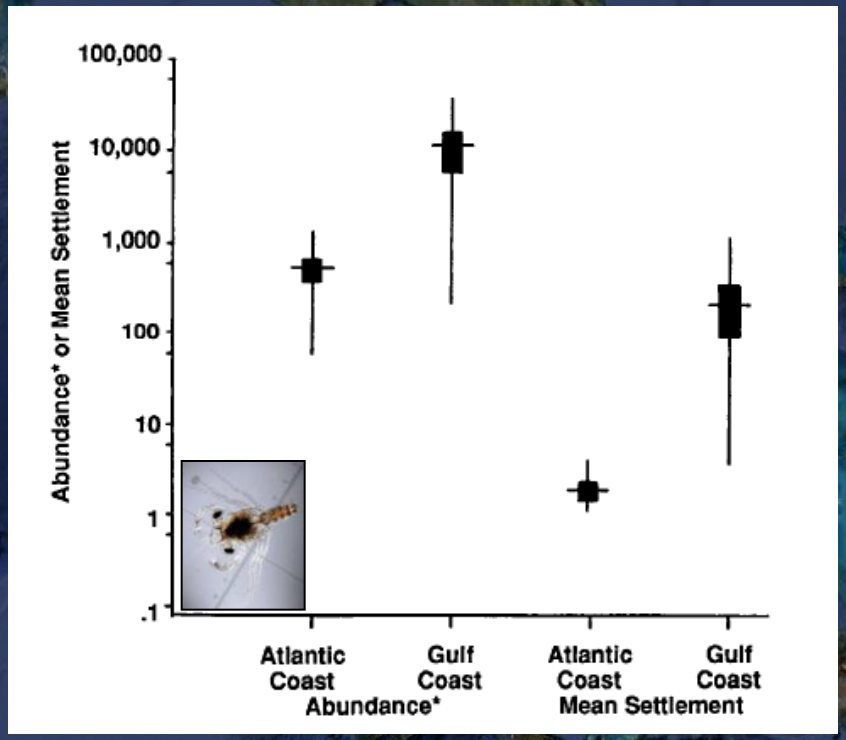
# Blue crabs in the Gulf of Mexico



# Blue crabs in the Gulf of Mexico

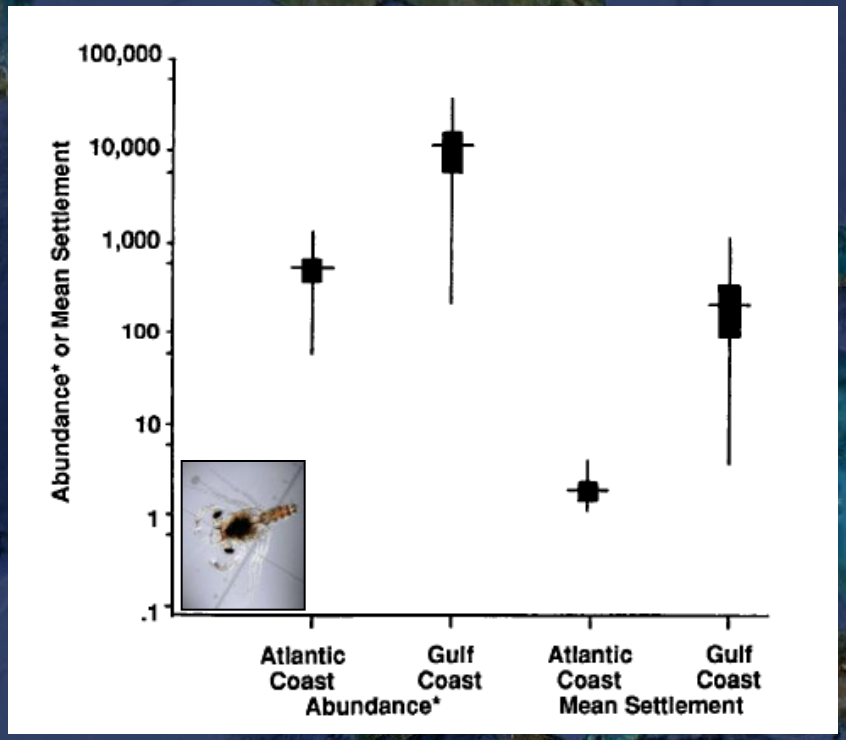
- High recruitment




Rabalais, N.N. et al. 1995. Settlement of *Callinectes sapidus* megalopae on artificial collectors in four Gulf of Mexico estuaries. Bulletin of Marine Science 57:855-876.

# Blue crabs in the Gulf of Mexico

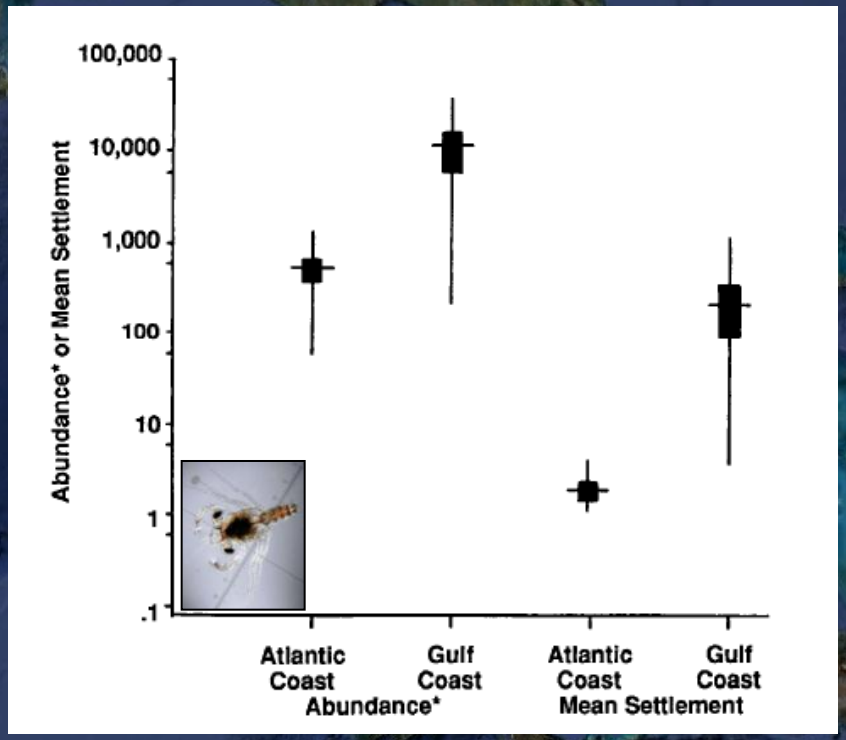
- High recruitment
- Not recruitment-limited
  - Local variation?




Rabalais, N.N. et al. 1995. Settlement of *Callinectes sapidus* megalopae on artificial collectors in four Gulf of Mexico estuaries. Bulletin of Marine Science 57:855-876.

# Blue crabs in the Gulf of Mexico

- High recruitment
- Not recruitment-limited
  - Local variation?
- Protracted spawning, activity season

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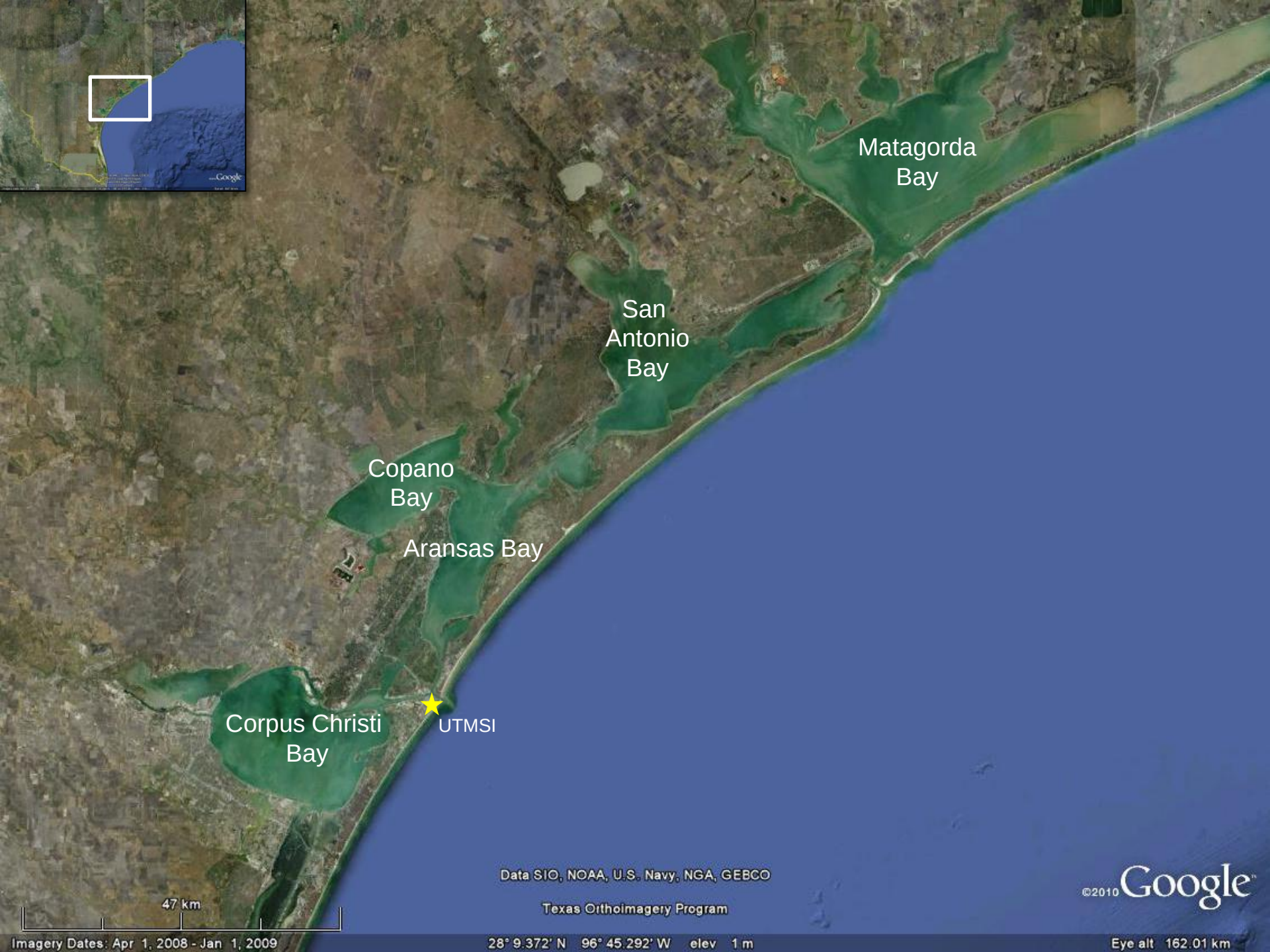
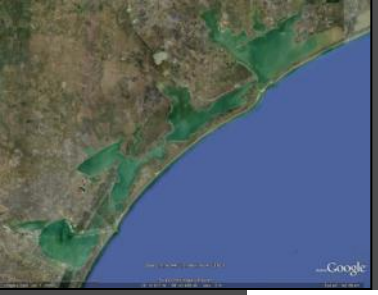
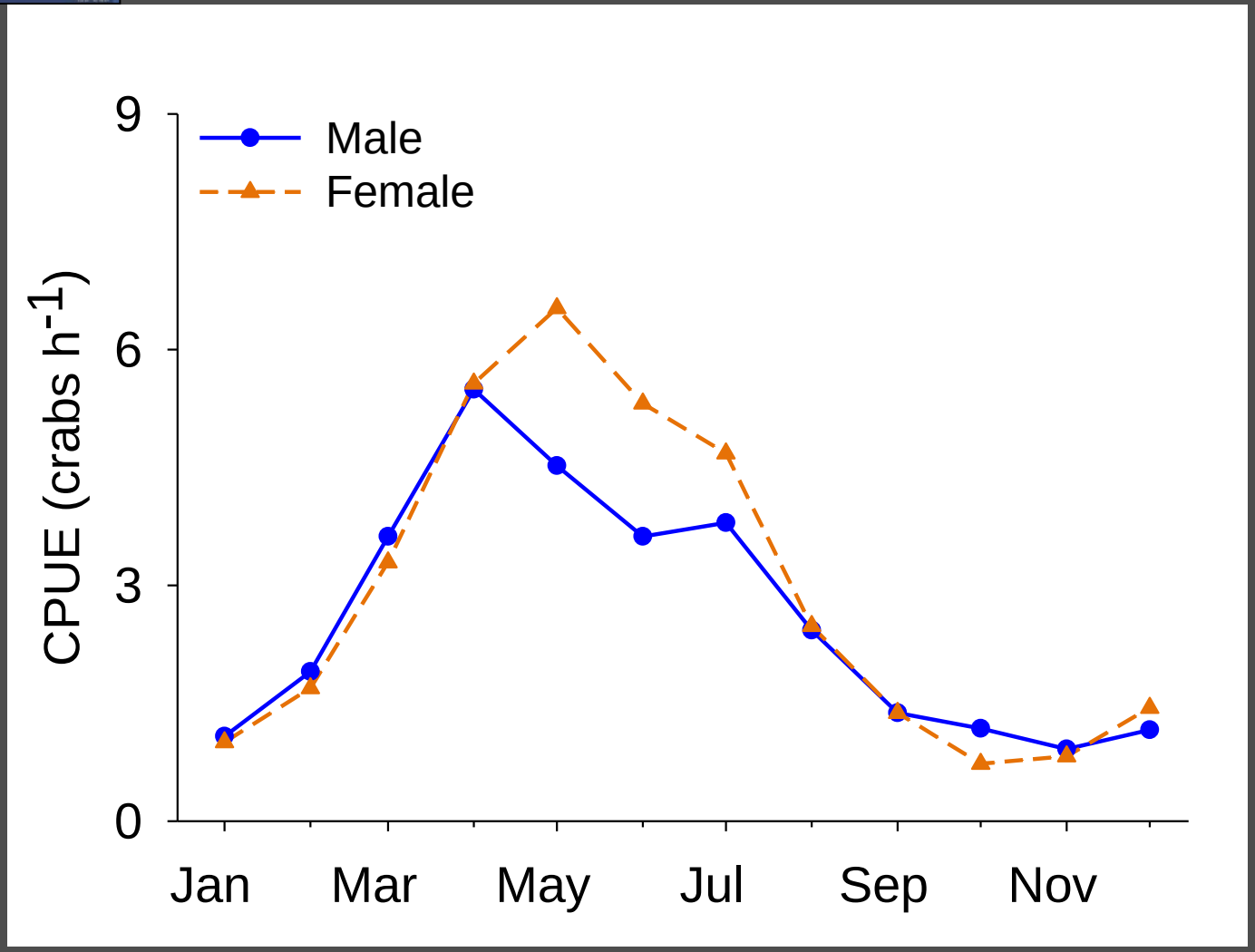
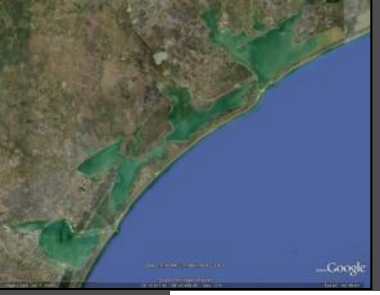

Matagorda Bay
San Antonio Bay
Copano Bay
Aransas Bay
Corpus Christi Bay
UTMSI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Texas Orthoimagery Program
©2010 Google
47 km
Imagery Dates: Apr 1, 2008 - Jan 1, 2009
28° 9.372' N 96° 45.292' W elev 1 m
Eye alt 162.01 km



# Seasonality

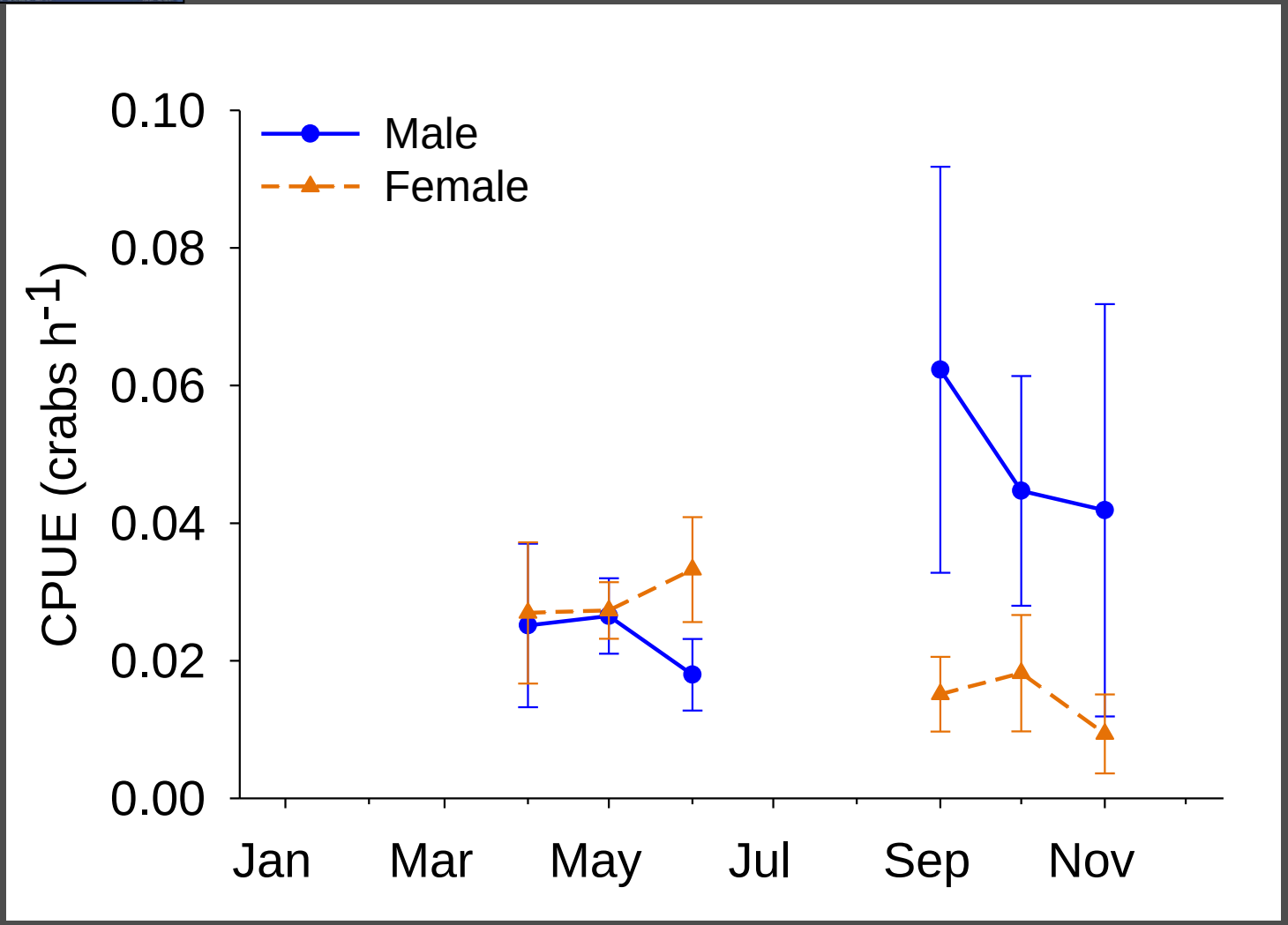
Trawl, by sex

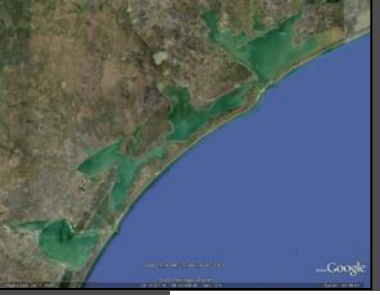




# Seasonality

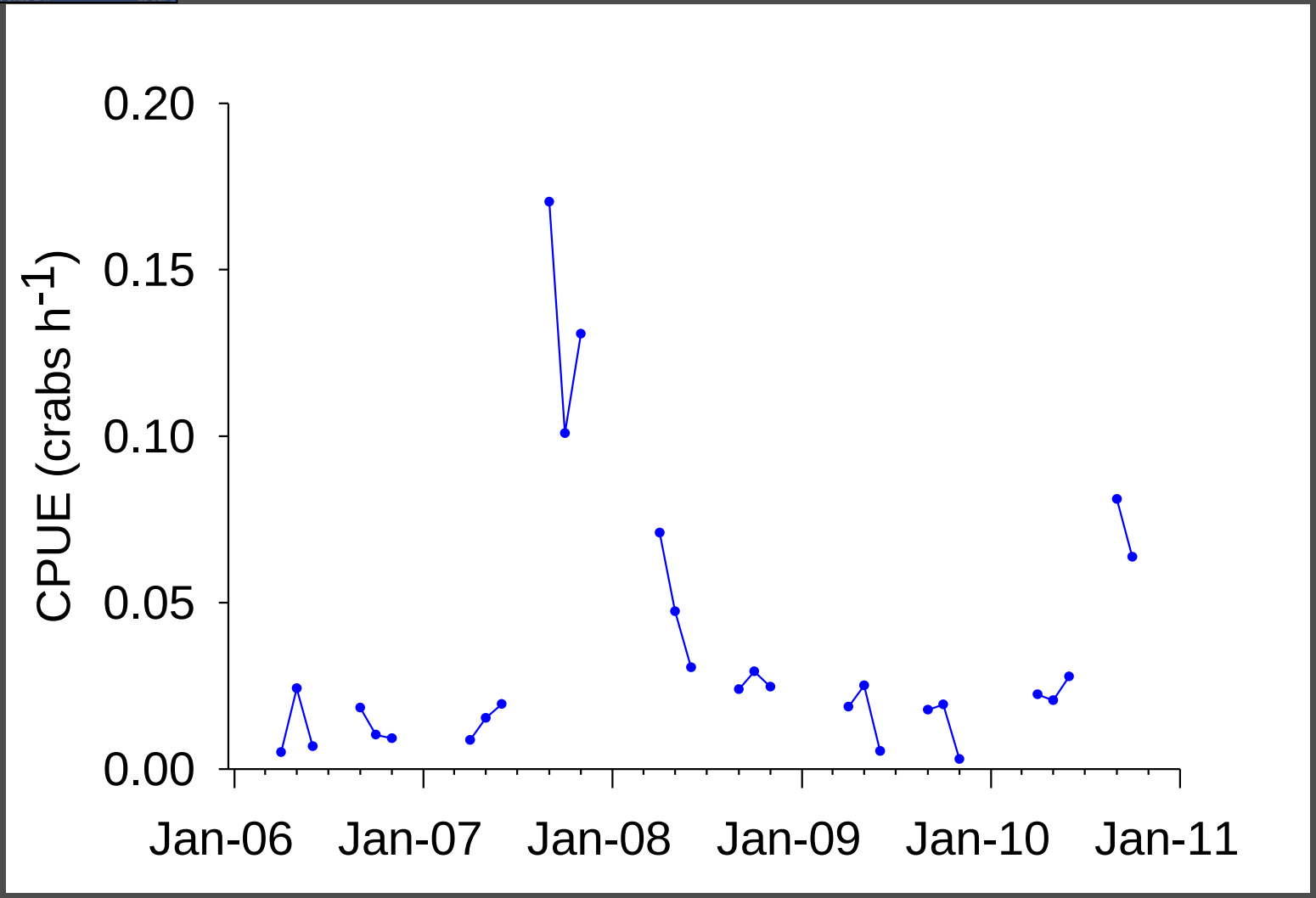
Gill net, by sex

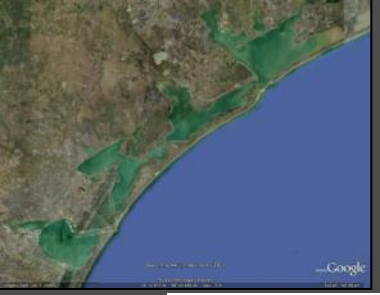




# Seasonality

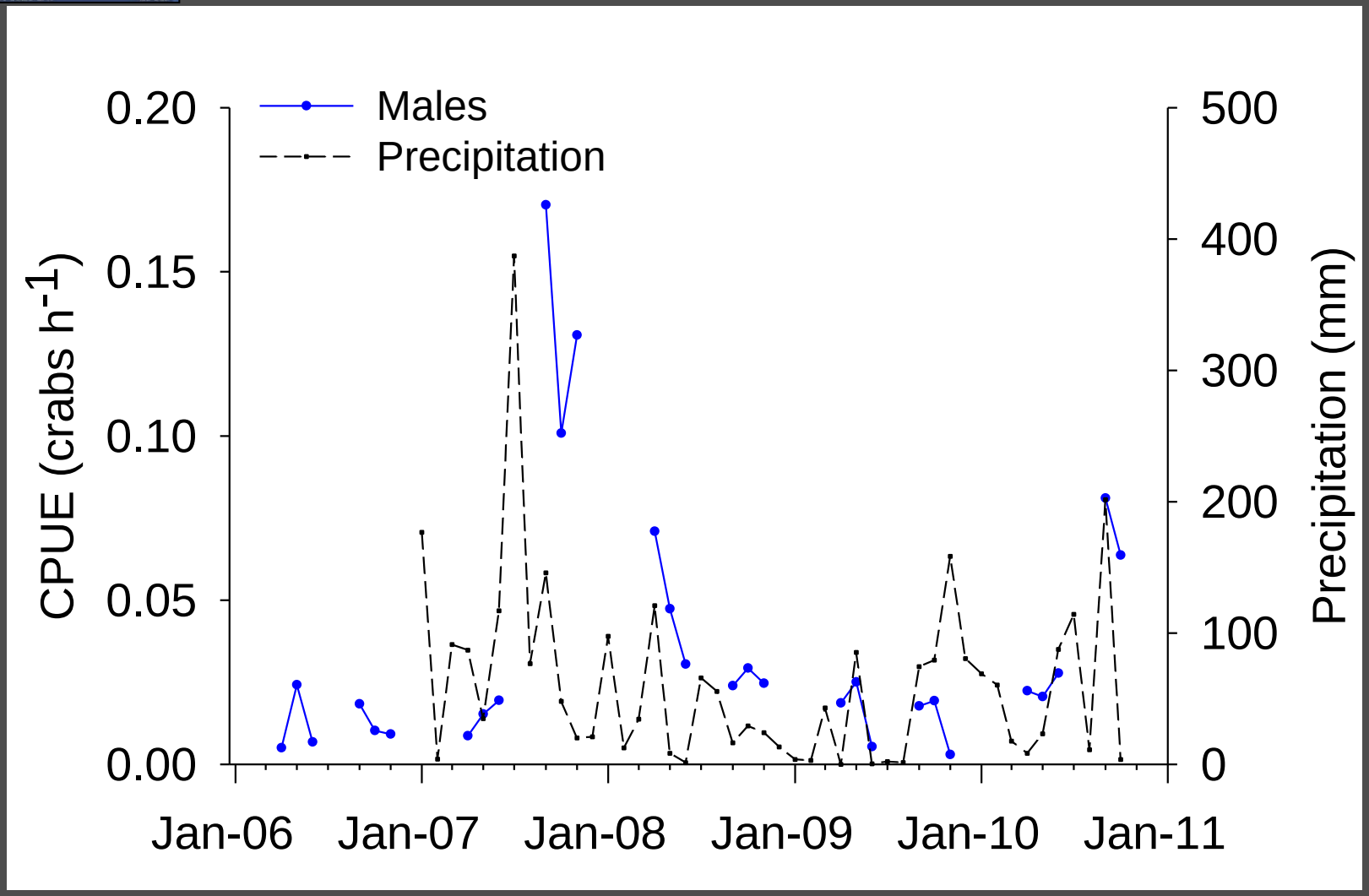
Gill net, males only

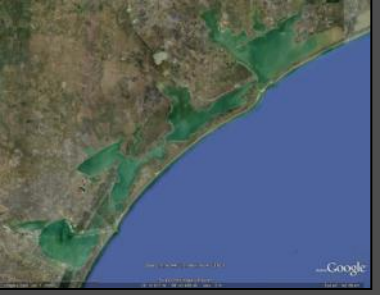




# Seasonality

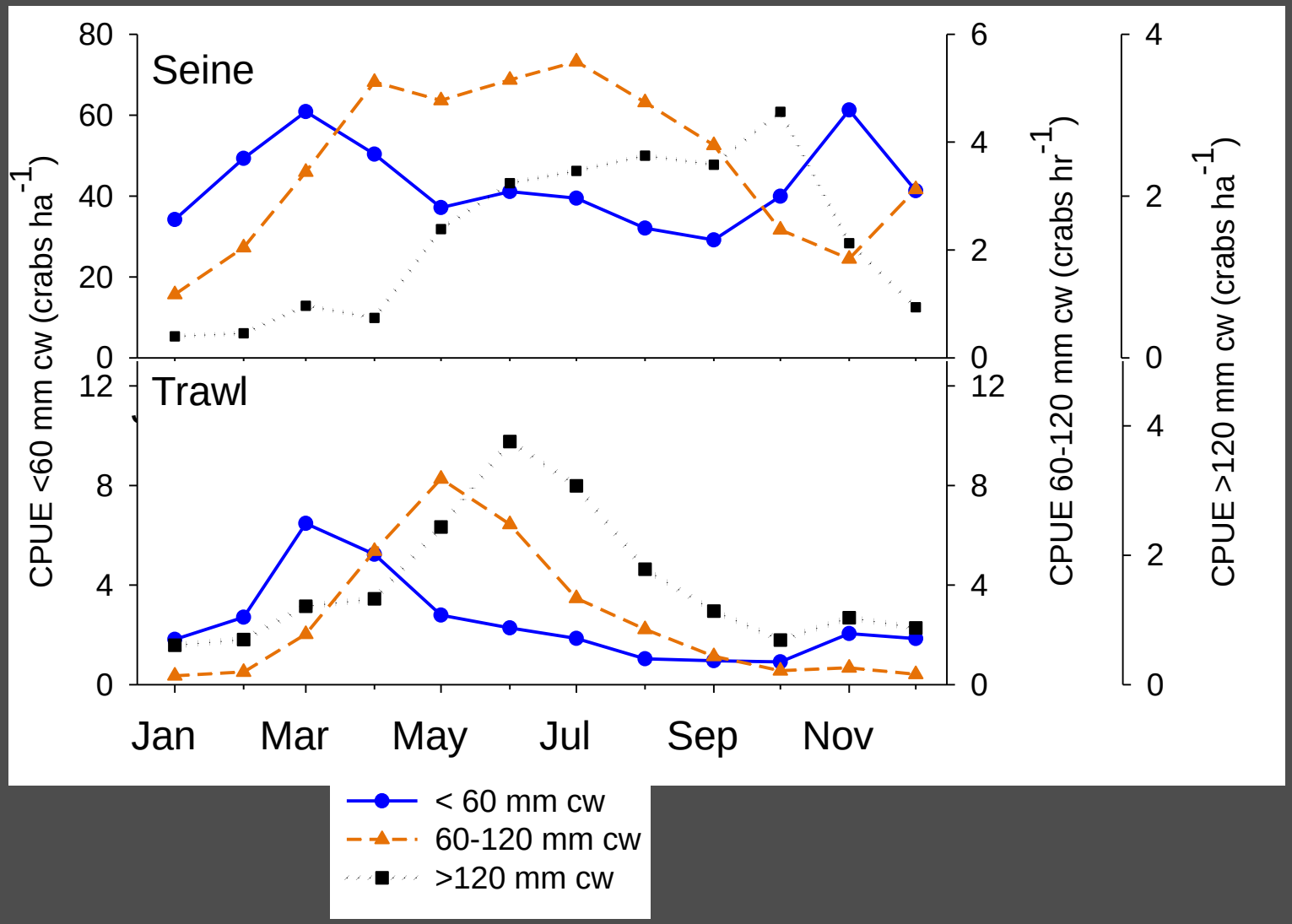
Gill net, males only

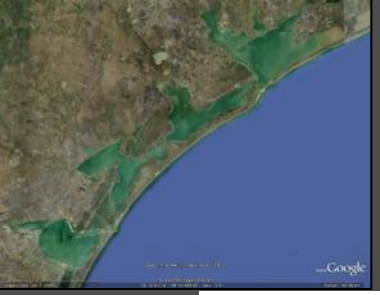




# Seasonality

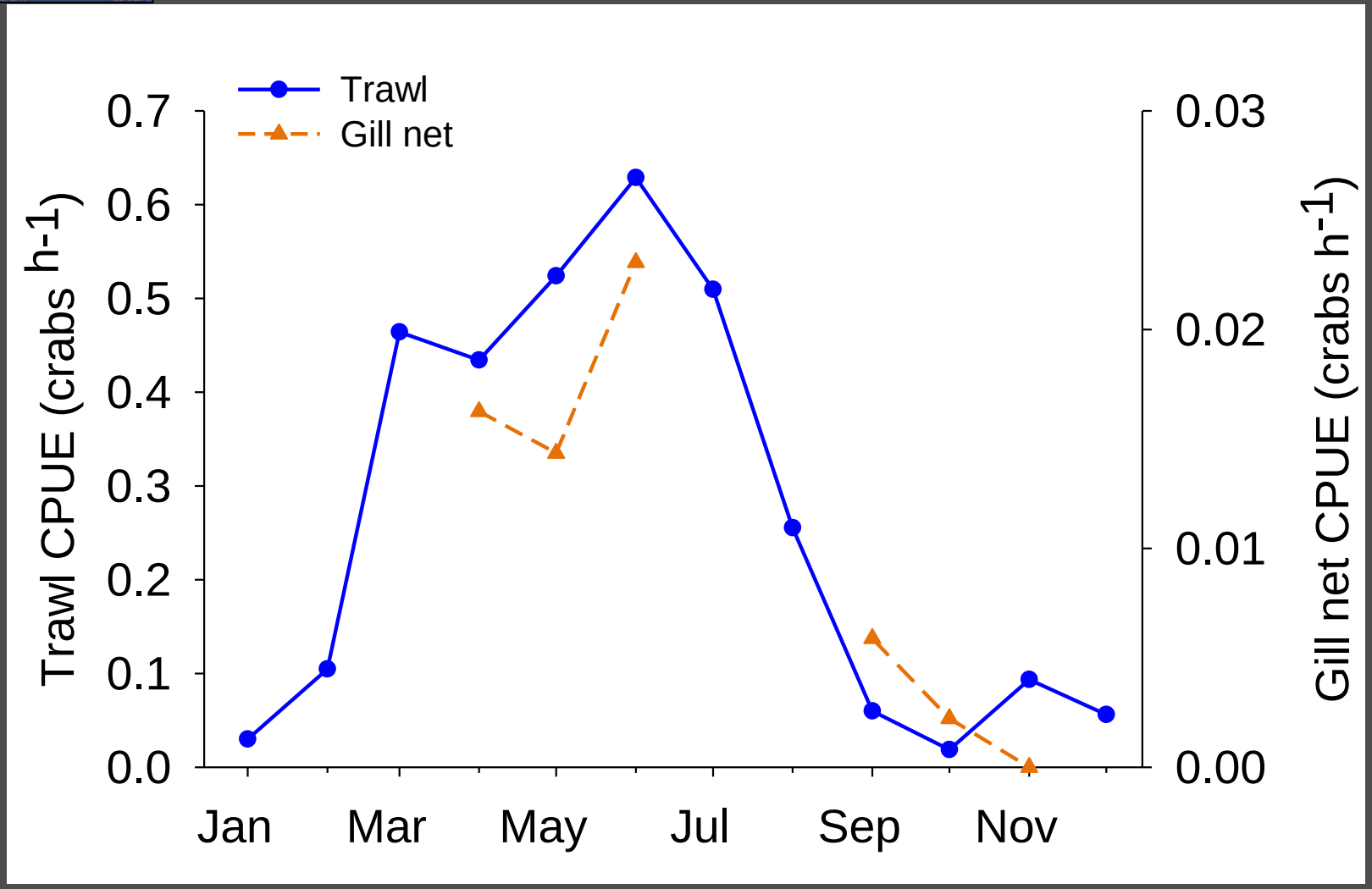
by size class

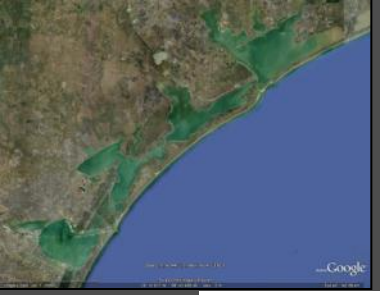




# Spawning

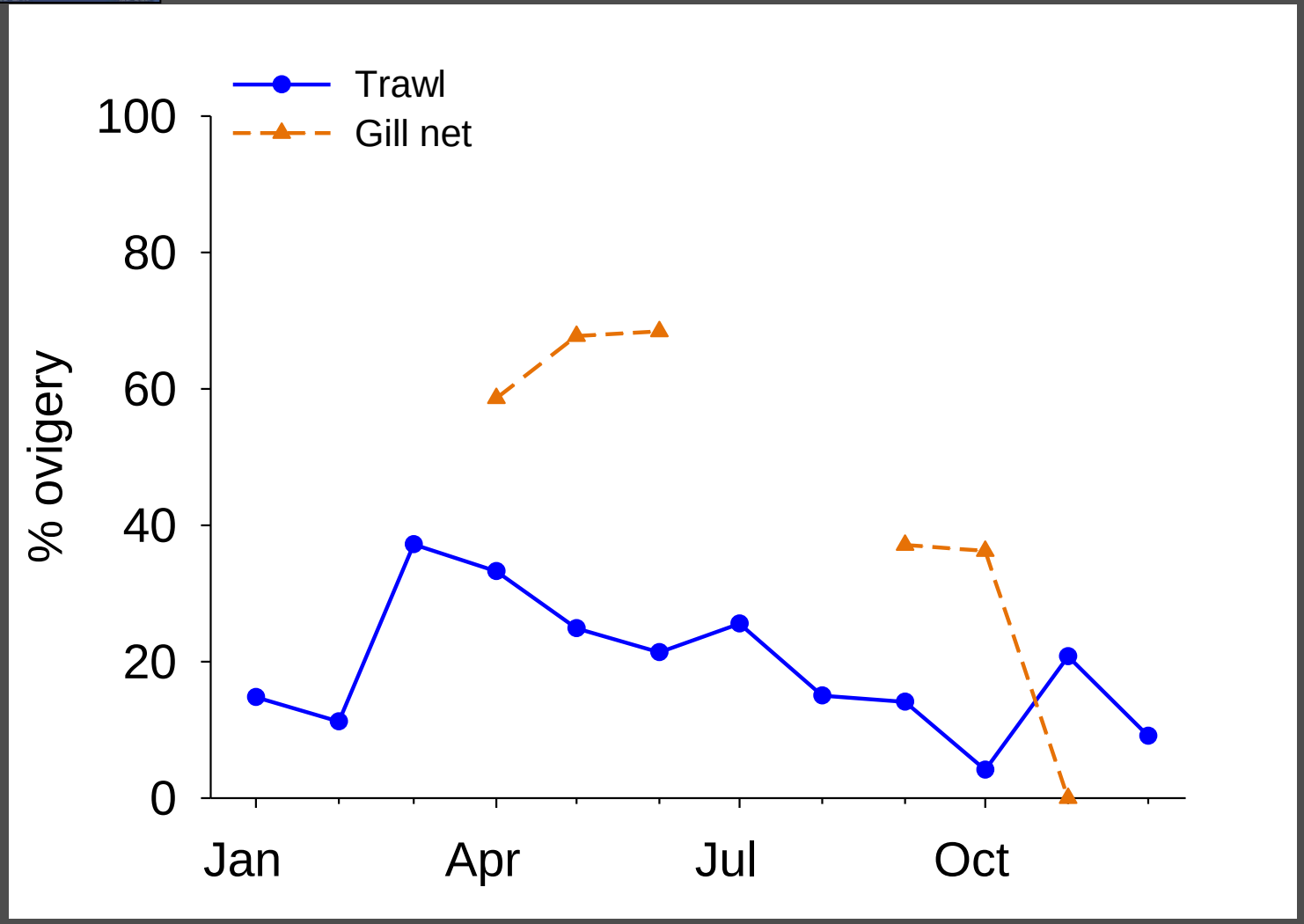
Ovigerous females, gill net and trawl

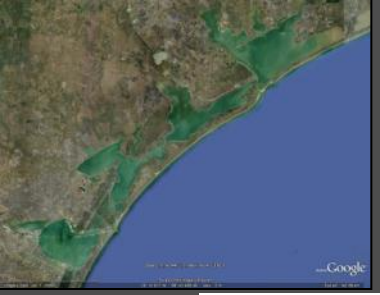




# Spawning

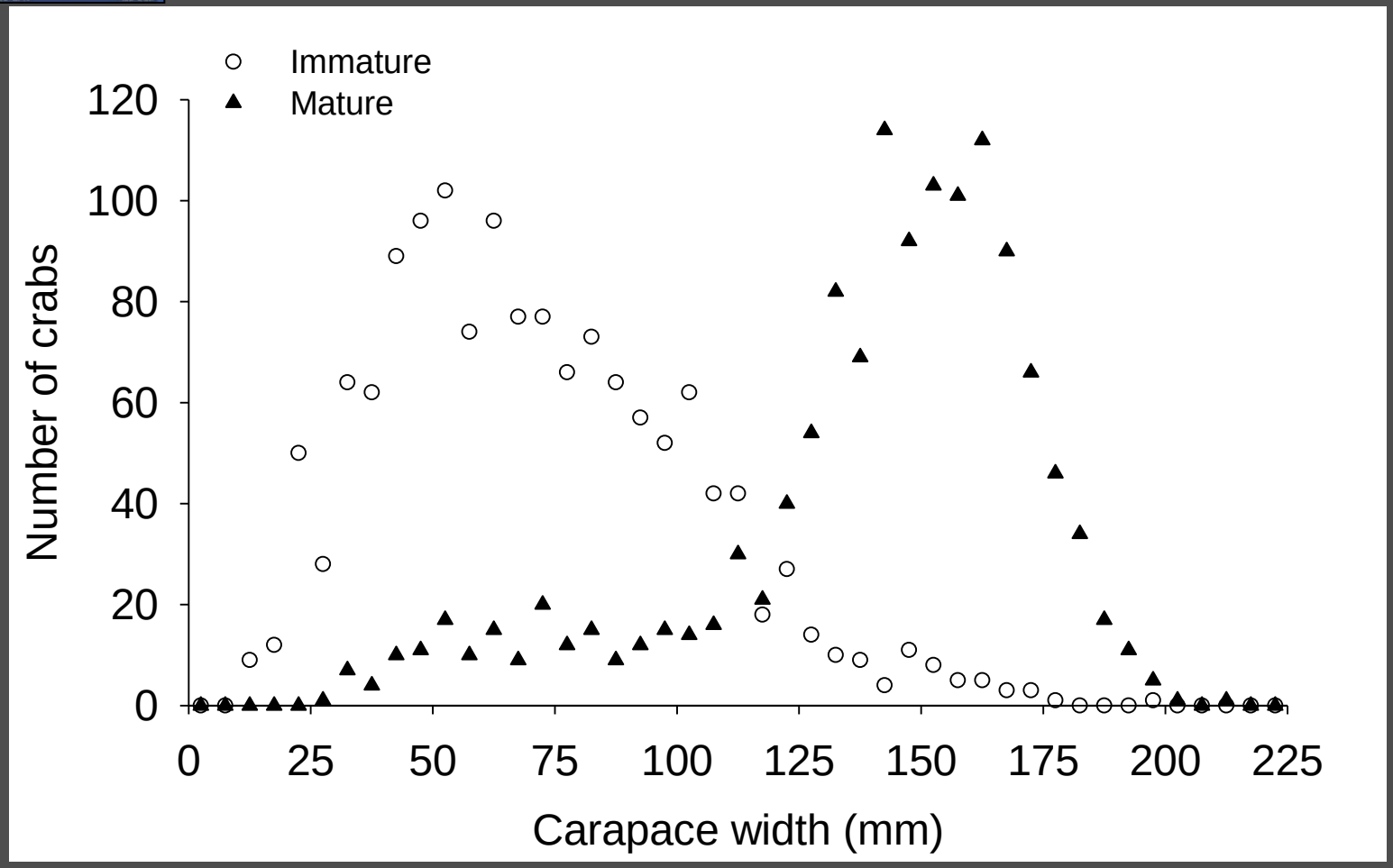
Ovigerous females, gill net and trawl

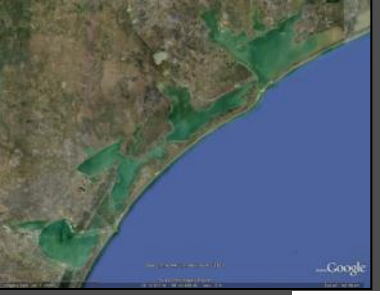




# Size at maturity

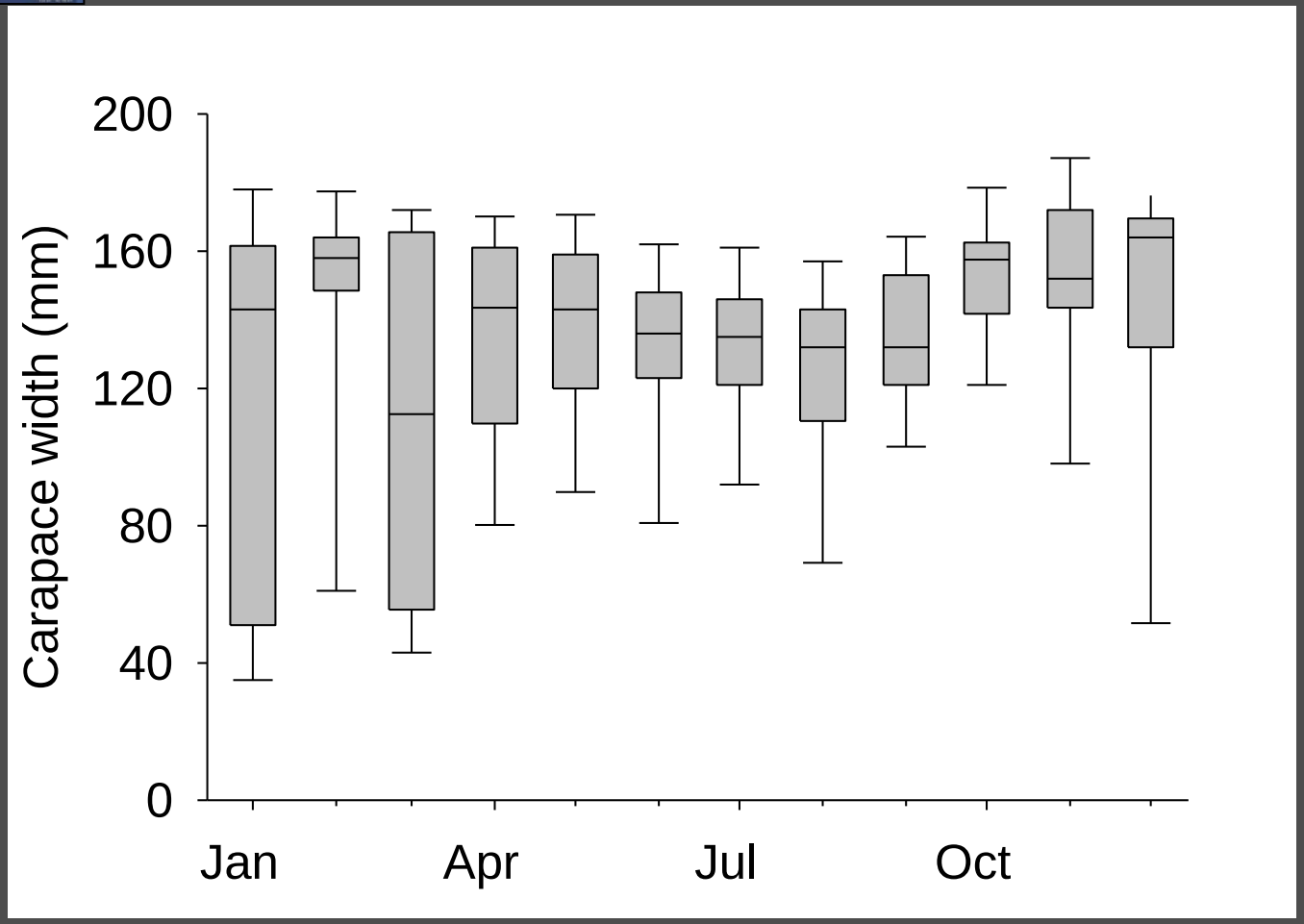
gill net + trawl

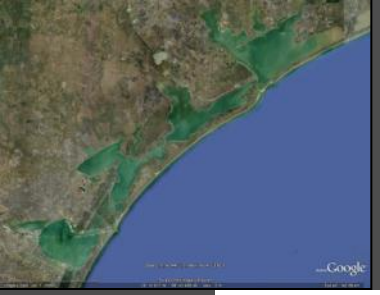




# Size at maturity

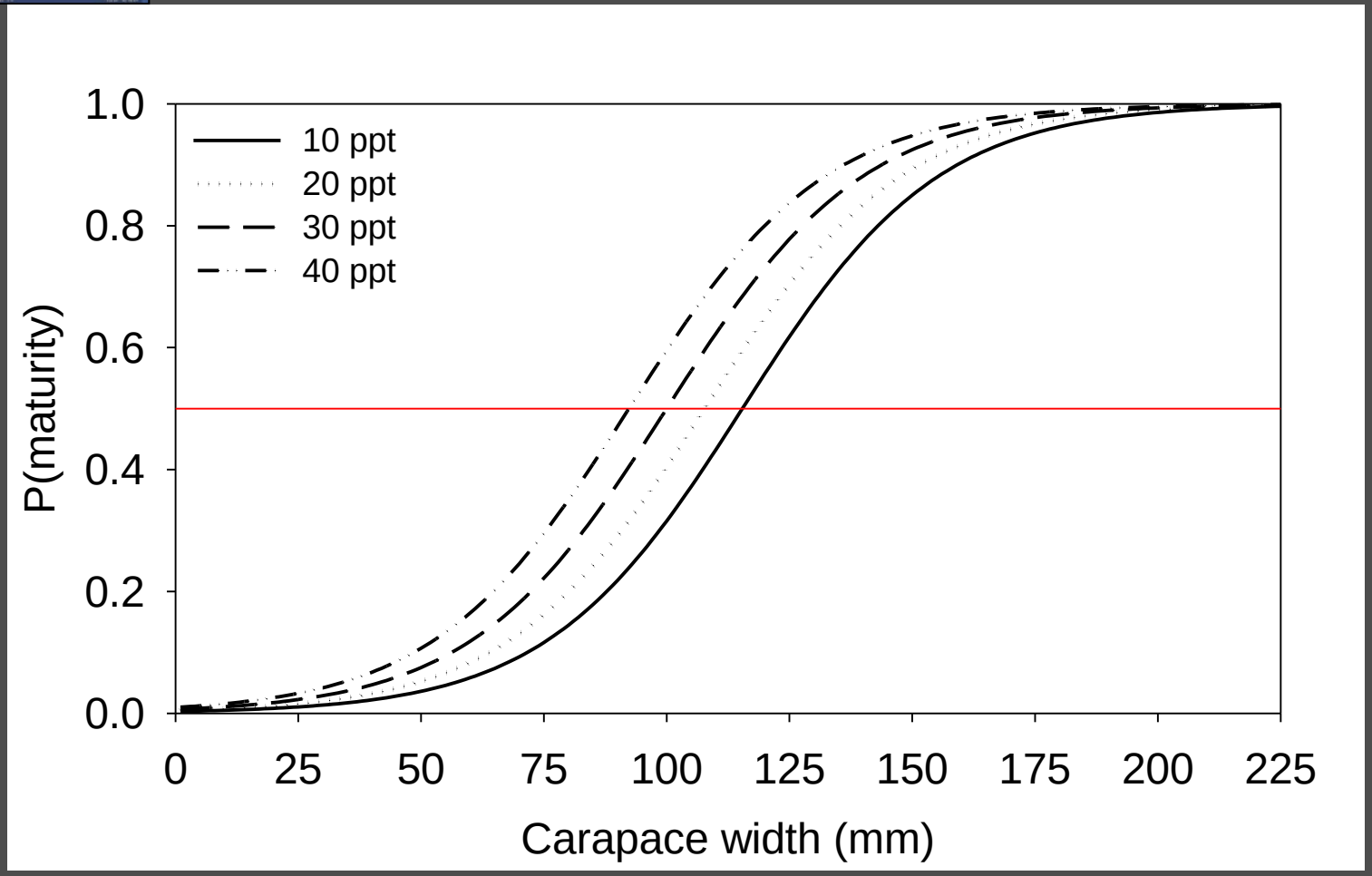
gill net + trawl

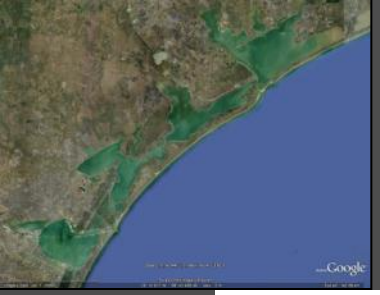




# Size at maturity

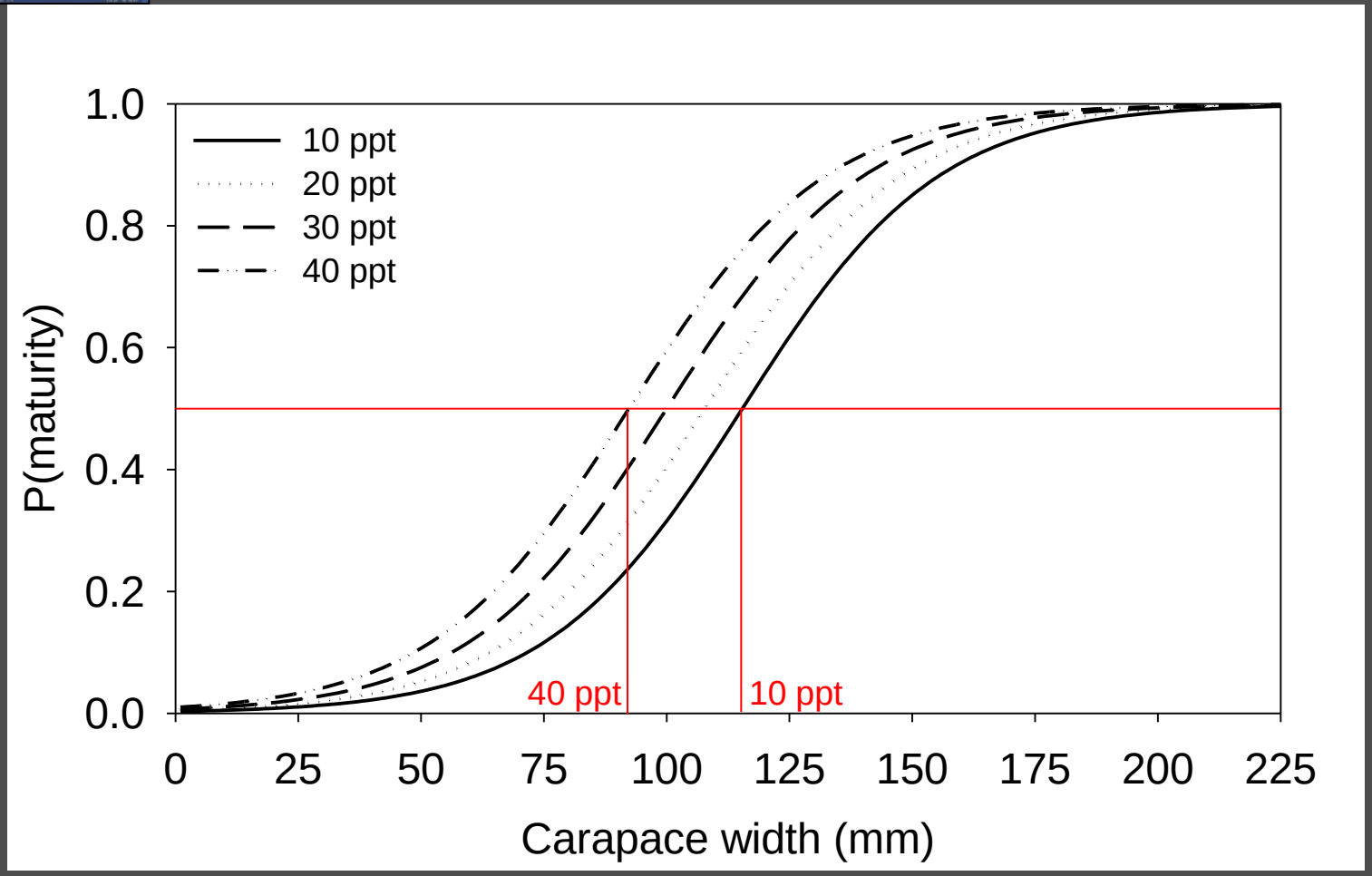
gill net + trawl





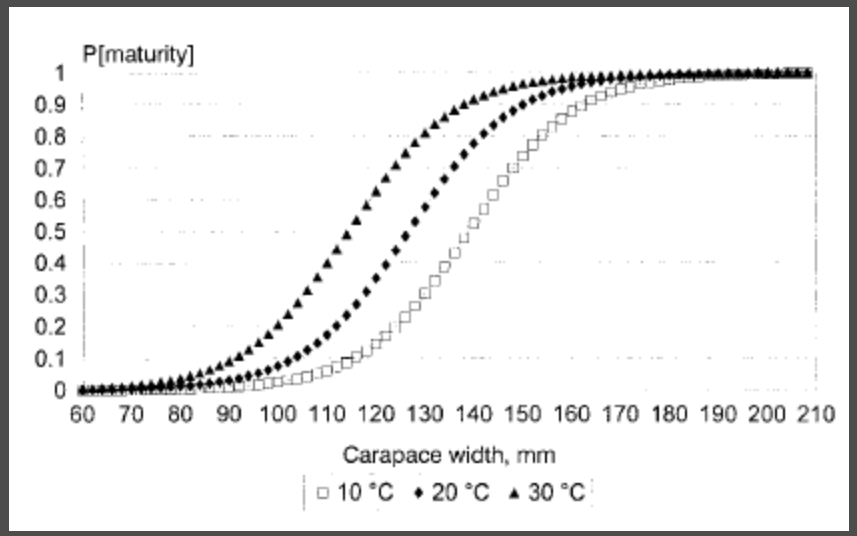
# Size at maturity

gill net + trawl

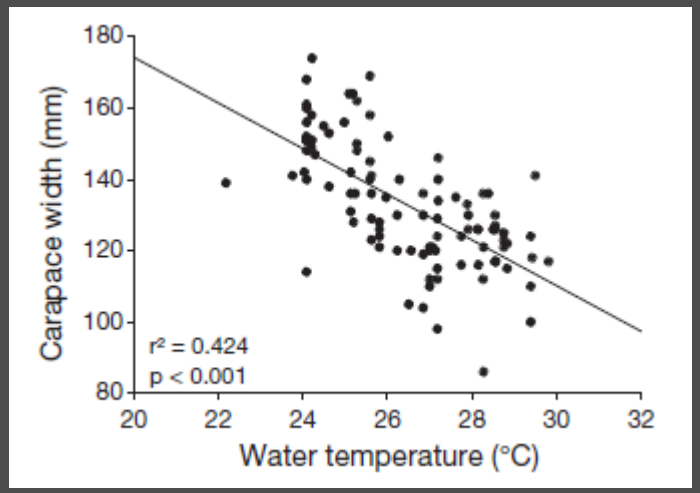


# Size at maturity

- Also generally a temperature effect
  - Cooler water = bigger crabs
  - Warmer water = smaller crabs




Fisher, M.R. 1999. Effect of temperature and salinity on size at maturity of female blue crabs. Transactions of the American Fisheries Society 128:499-506.

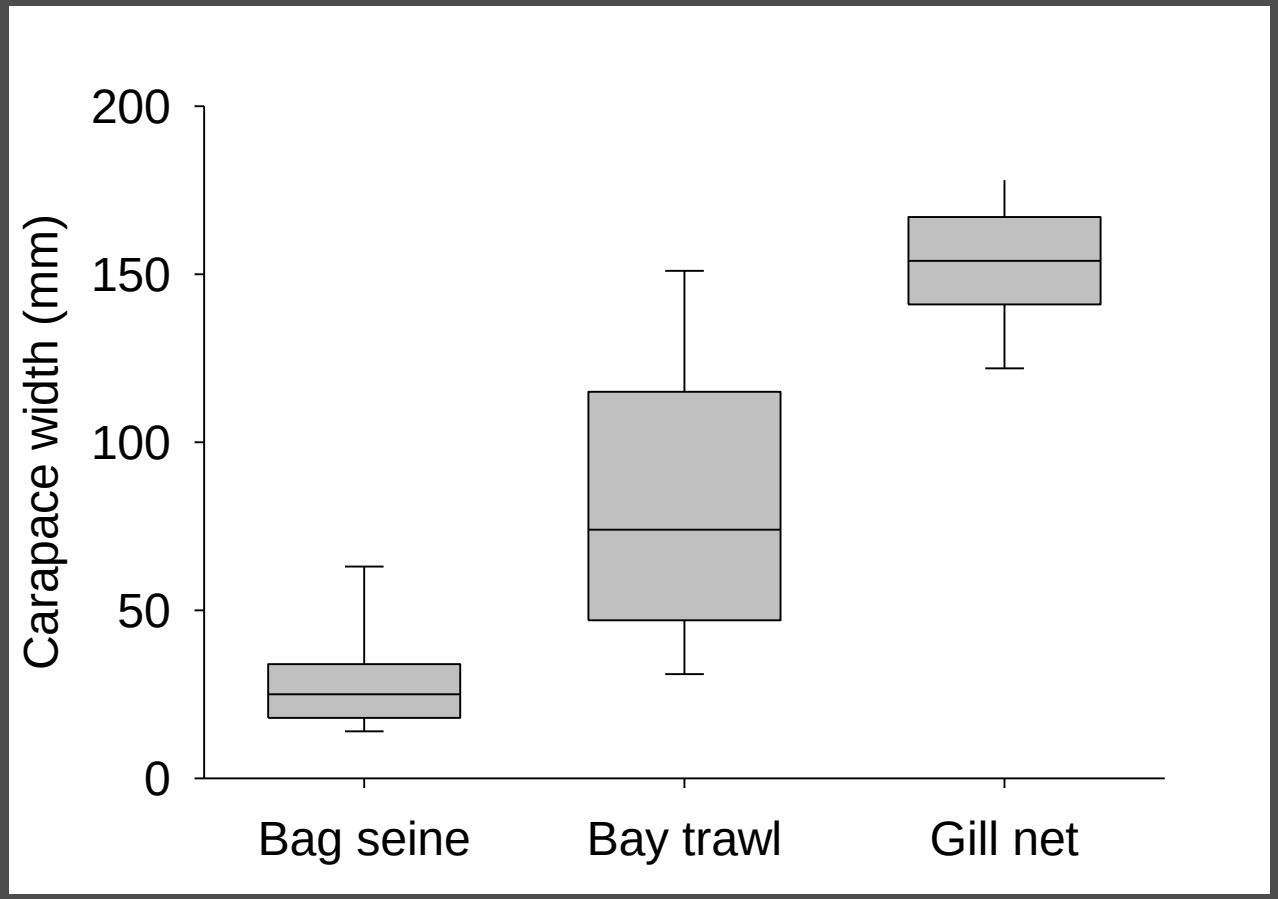


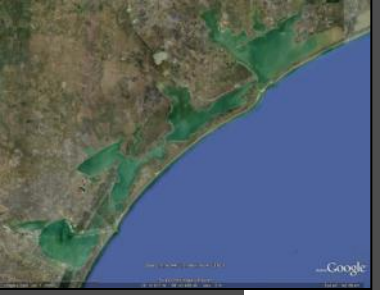

Darnell, M.Z. et al. 2009. Lifetime reproductive potential of female blue crabs *Callinectes sapidus* in North Carolina, USA. Marine Ecology Progress Series 394:153-163.

# Summary

- Migratory life cycle
- Ecologically important predator and prey species
- In GOM, high recruitment
  - Post-settlement processes limit populations
  - BUT, not well studied in all areas. Likely local variation
- In central Texas:
  - Peak CPUE in the spring and summer
  - Spawning occurs throughout the year, peaks in the spring and summer
  - Size at maturity related to salinity, temperature(?)

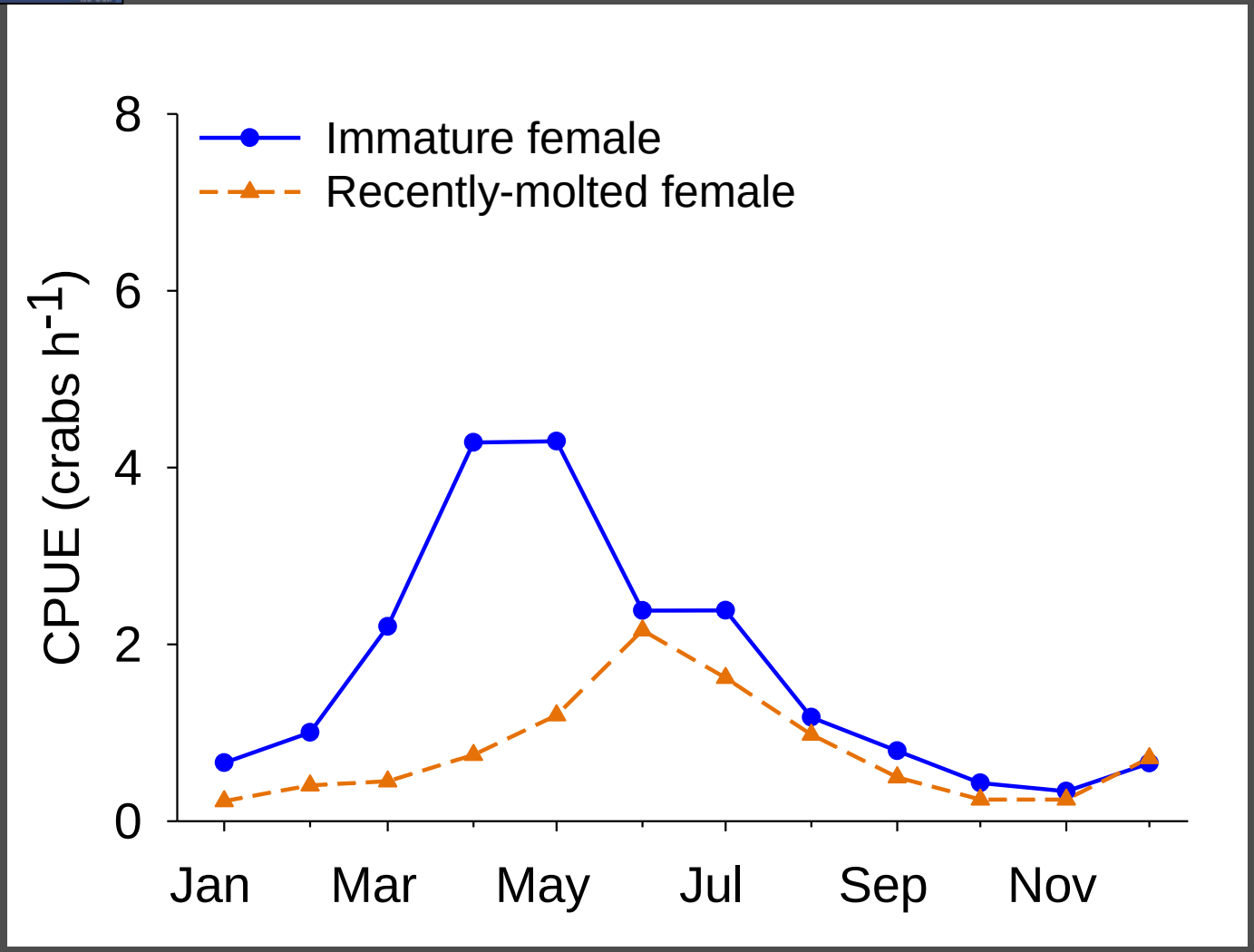
# TPWD Fishery-independent Survey

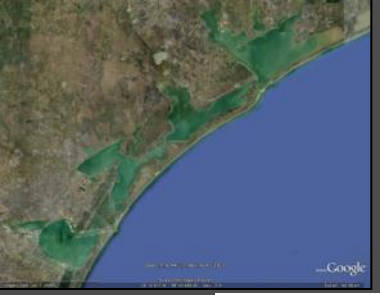




# Seasonality

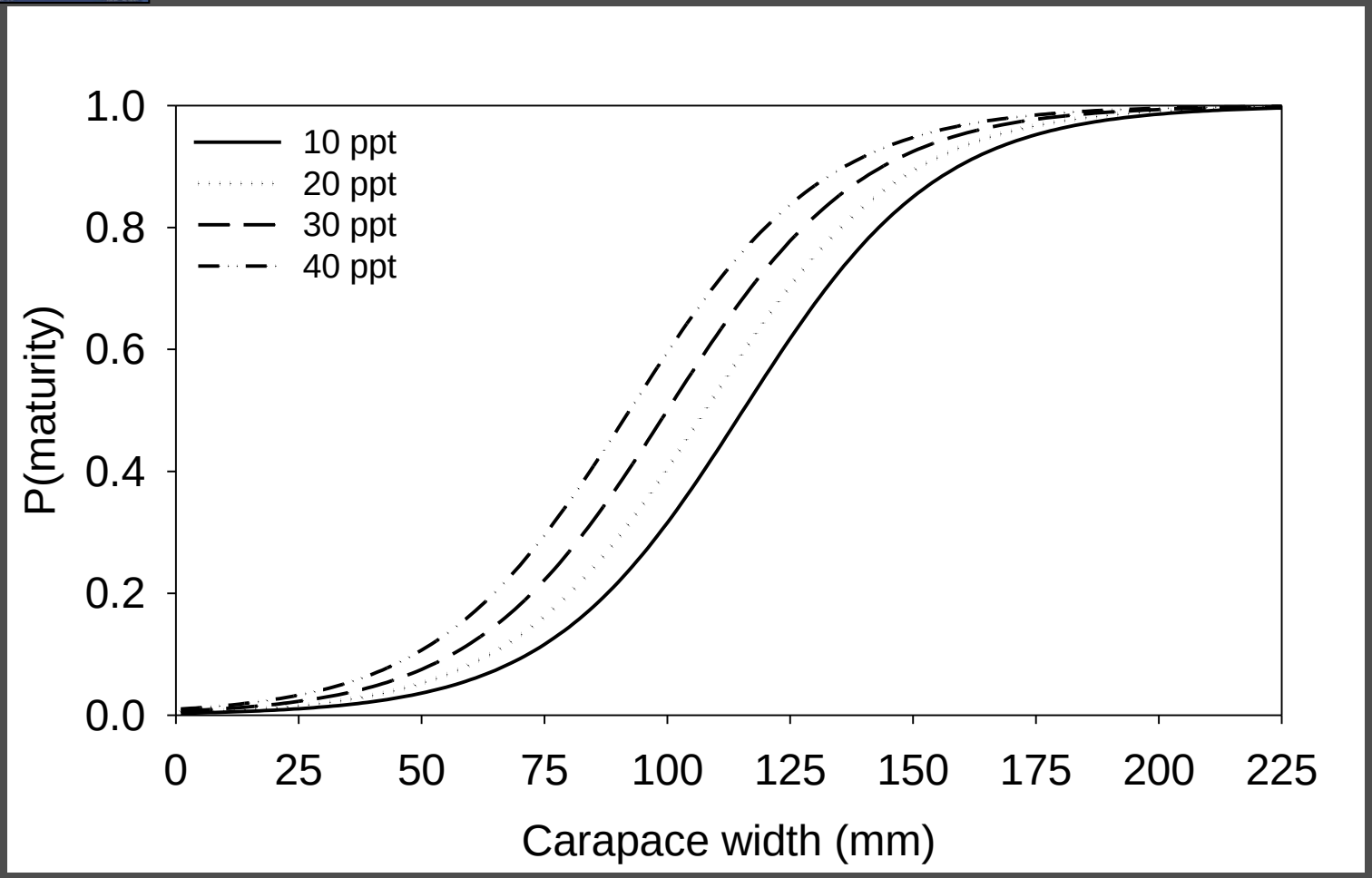
Trawl, immature and recently-matured females

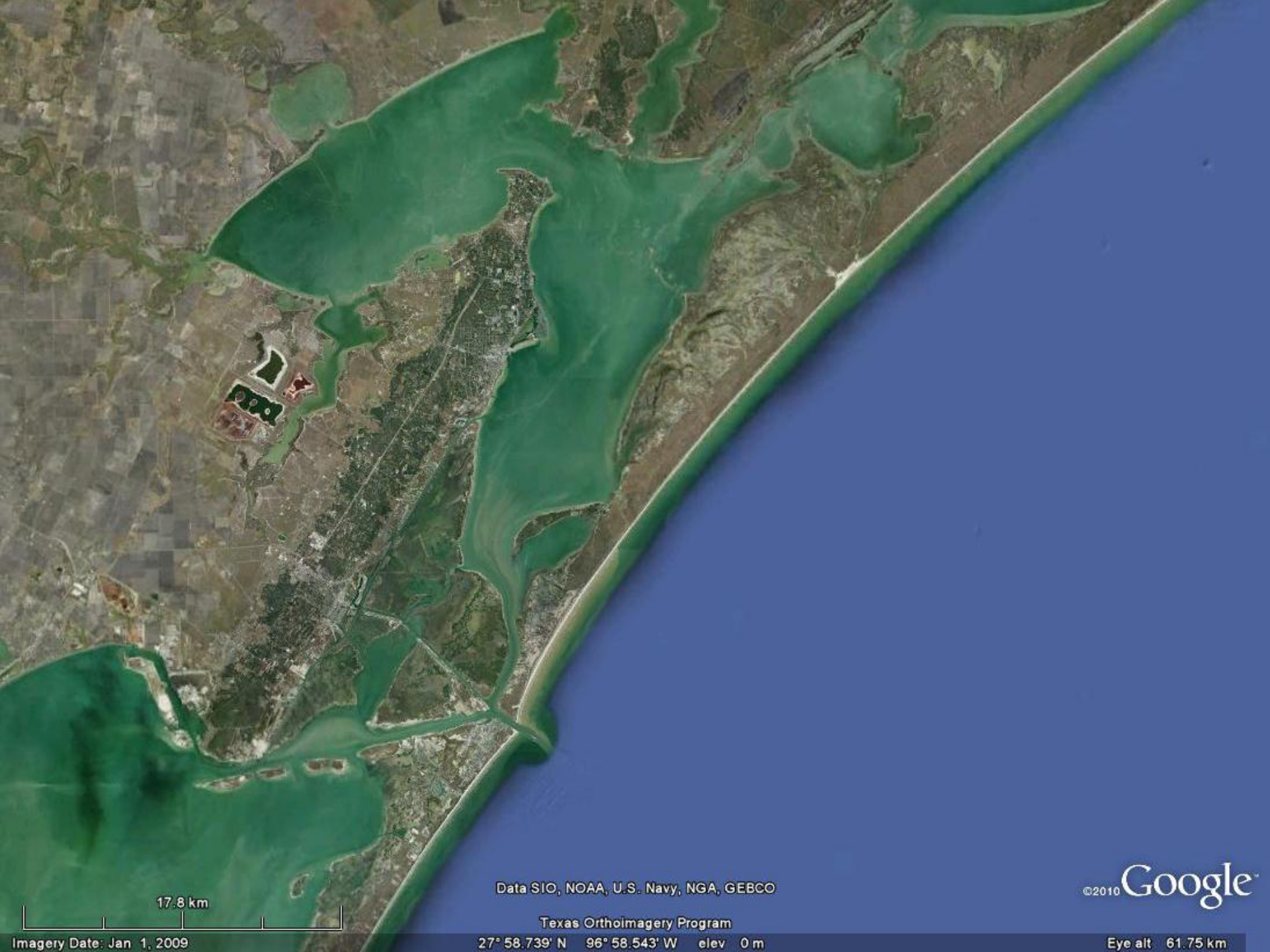




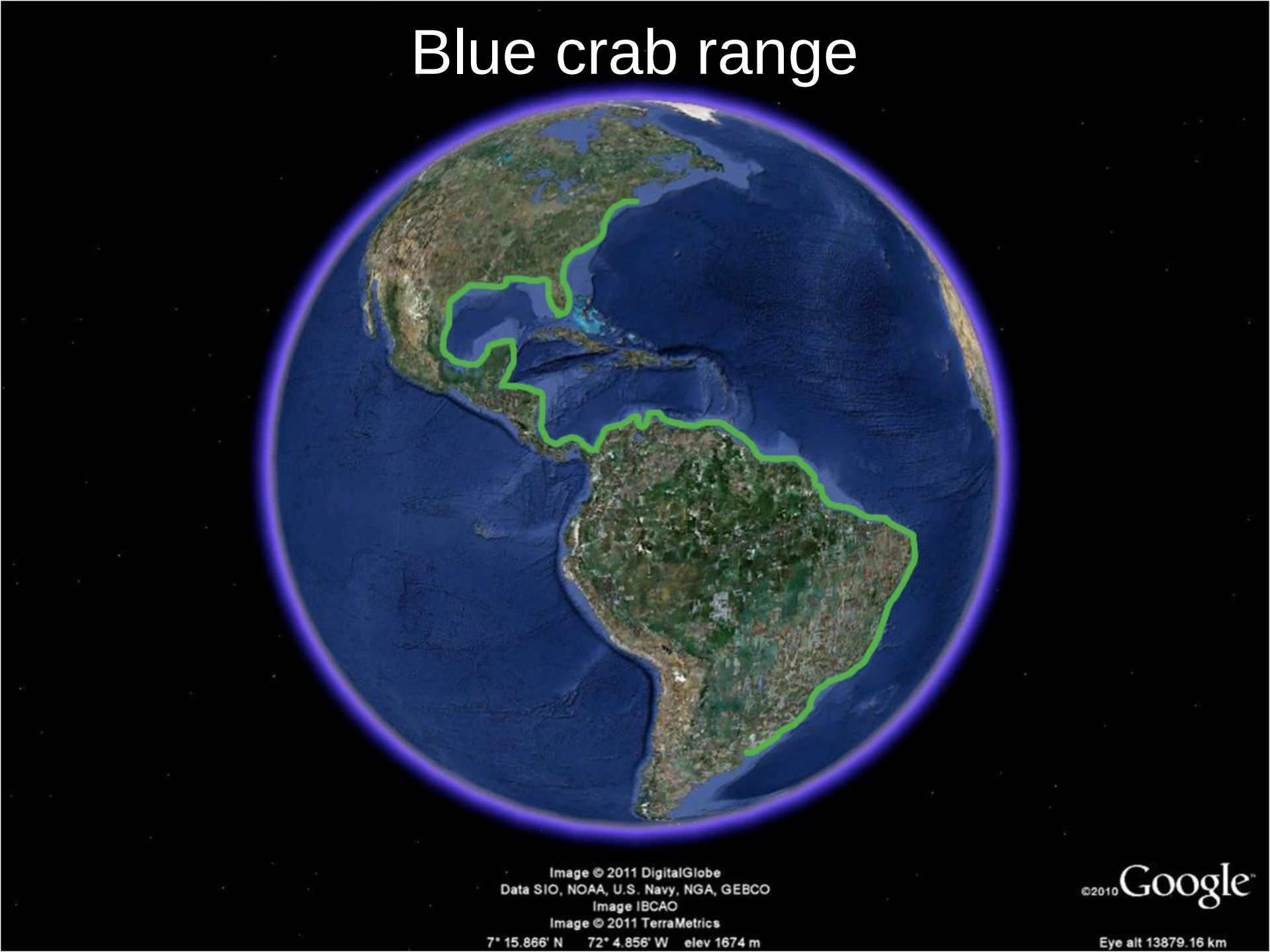
# Size at maturity

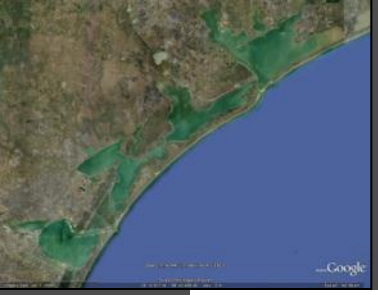
gill net + trawl




17.8 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2010 Google
Texas Orthoimagery Program
Imagery Date: Jan 1, 2009
27° 58.739' N 96° 58.543' W elev 0 m
Eye alt 61.75 km

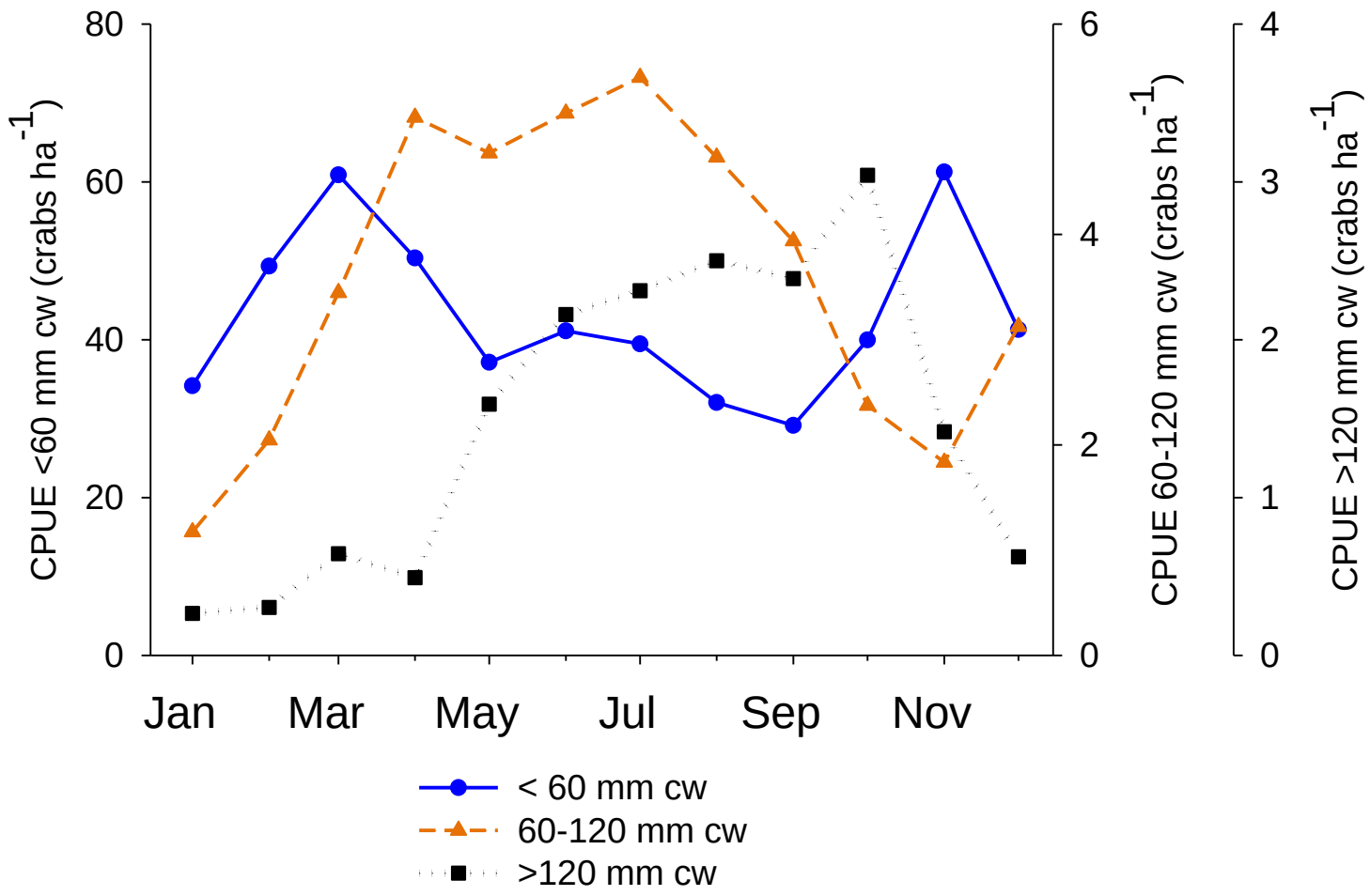
# Blue crab range





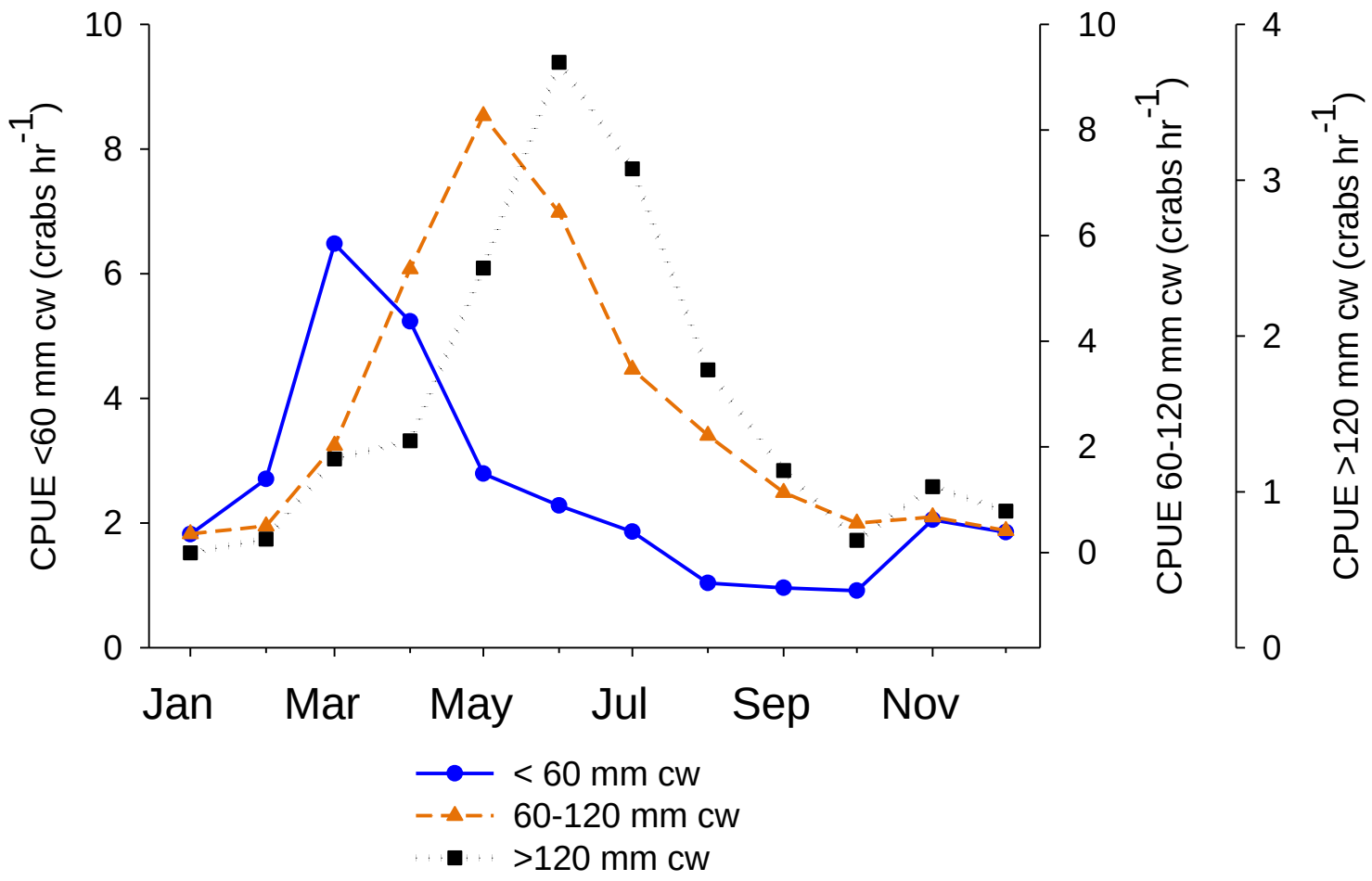
# Seasonality

Seine, by size class



# Seasonality

Trawl, by size class



# Blue Crab Biology

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# Acknowledgements


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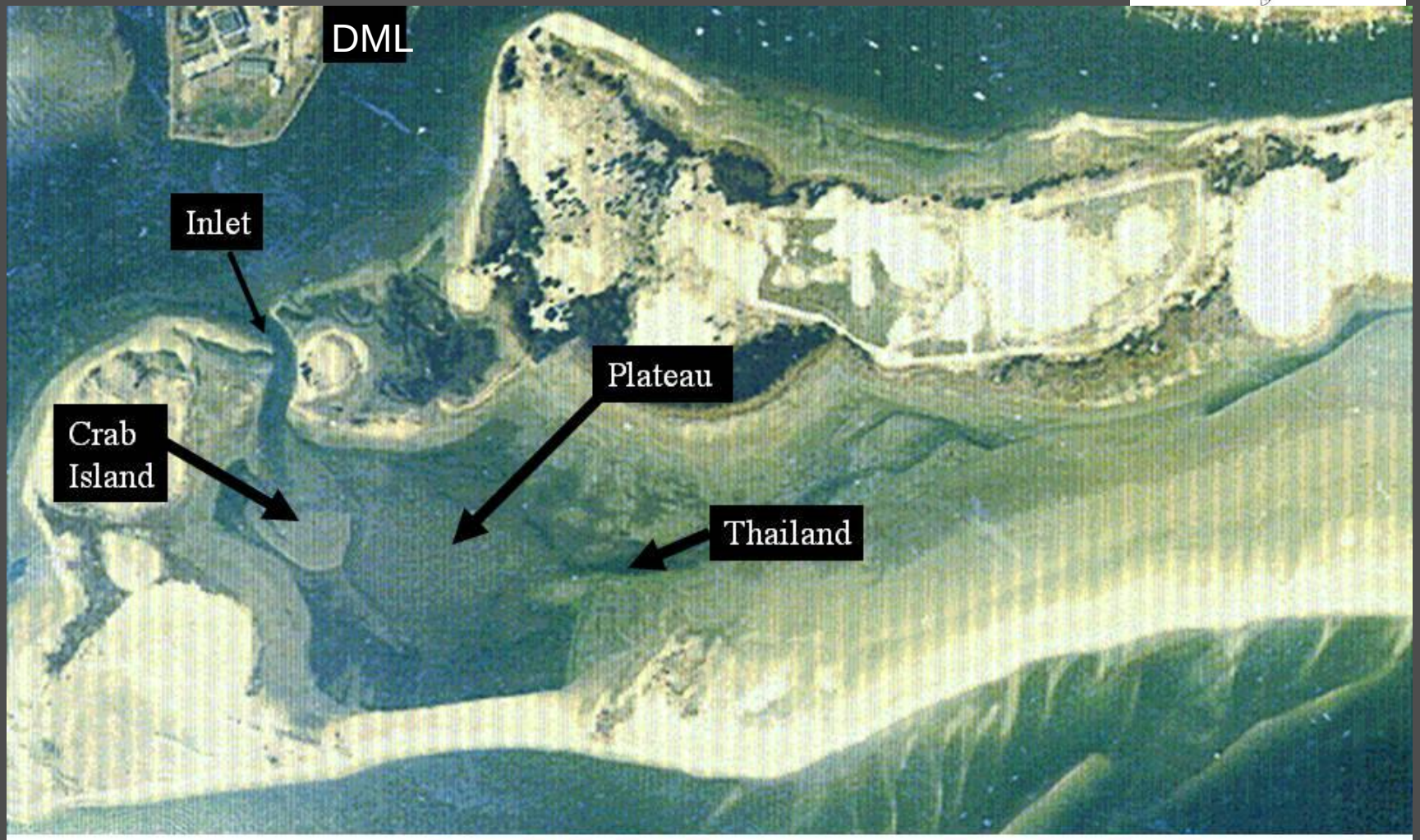
- Jeanne Rittschof, Sean Ramach, Matt Ogburn, Maggie Goldman,Tuck Hines,
- Jim Welch, Jim Hench, T&D Wolcott,

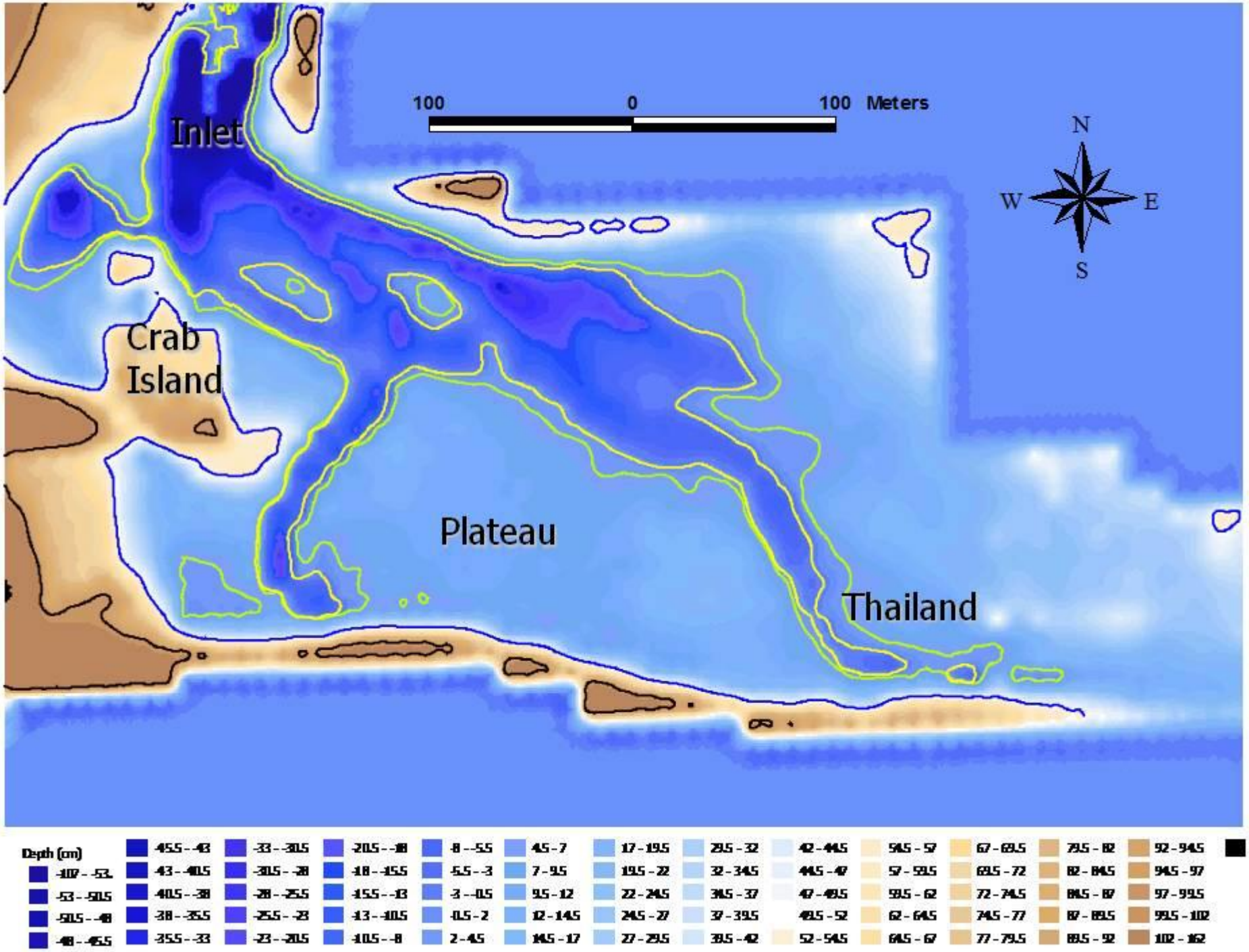
# Blue Crab Biology

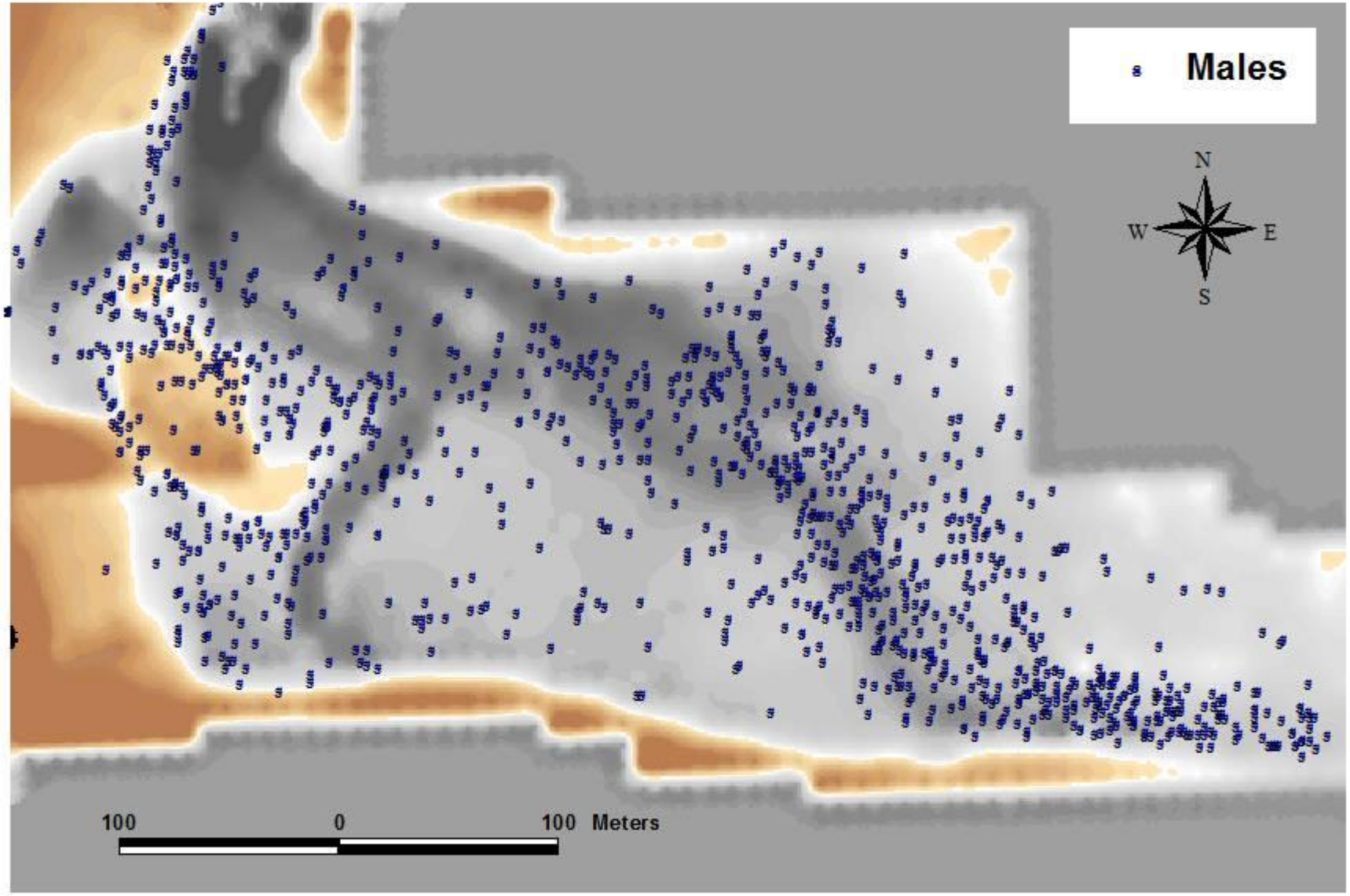
## Juveniles and Adults
## Sex and Fecundity
## Spawning Migrations
## Settlement Migrations


Beaufort Inlet Drainage Study Area

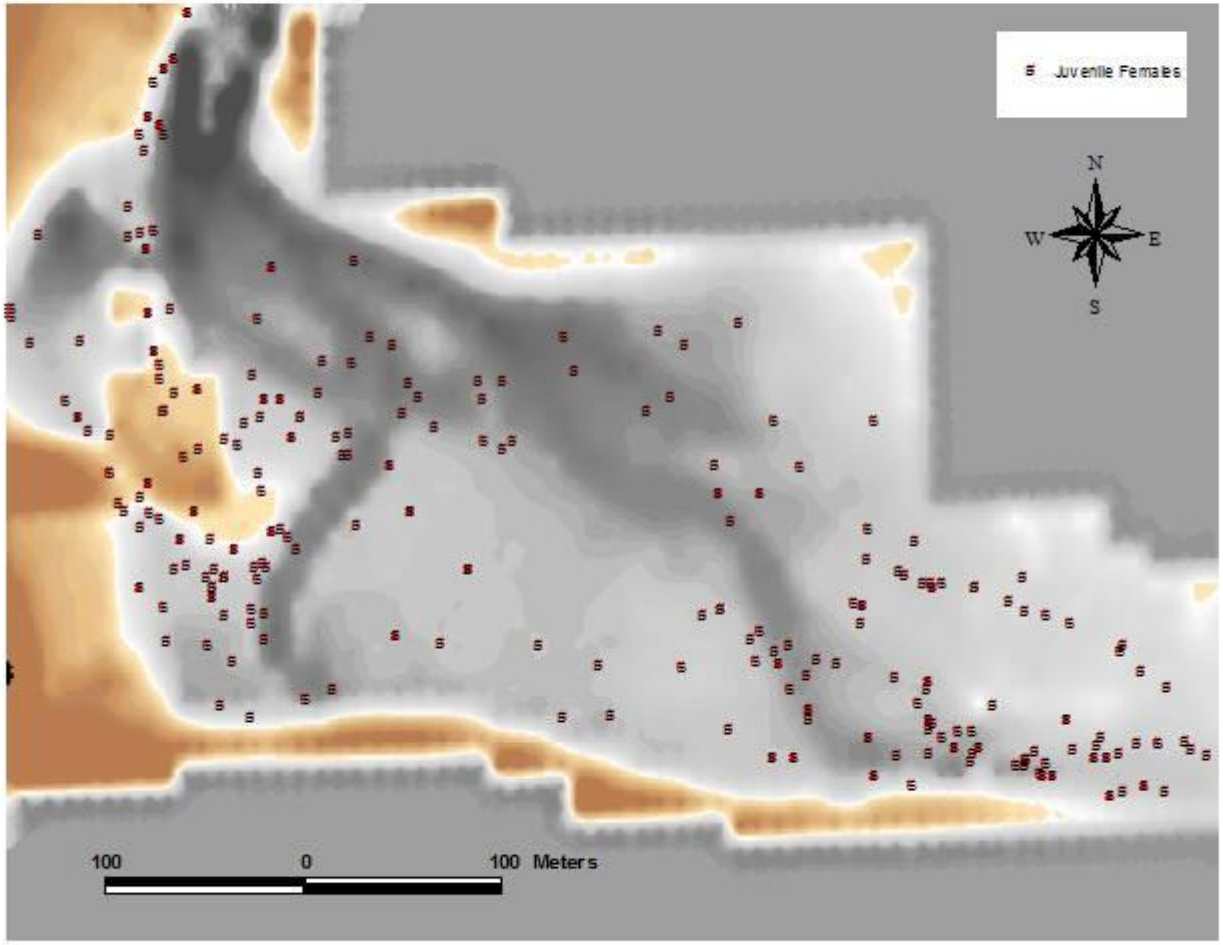
QuickTime™ and a
Cinepak decompressor
are needed to see this picture.


DML
Inlet
Plateau
Crab
Island
Thailand

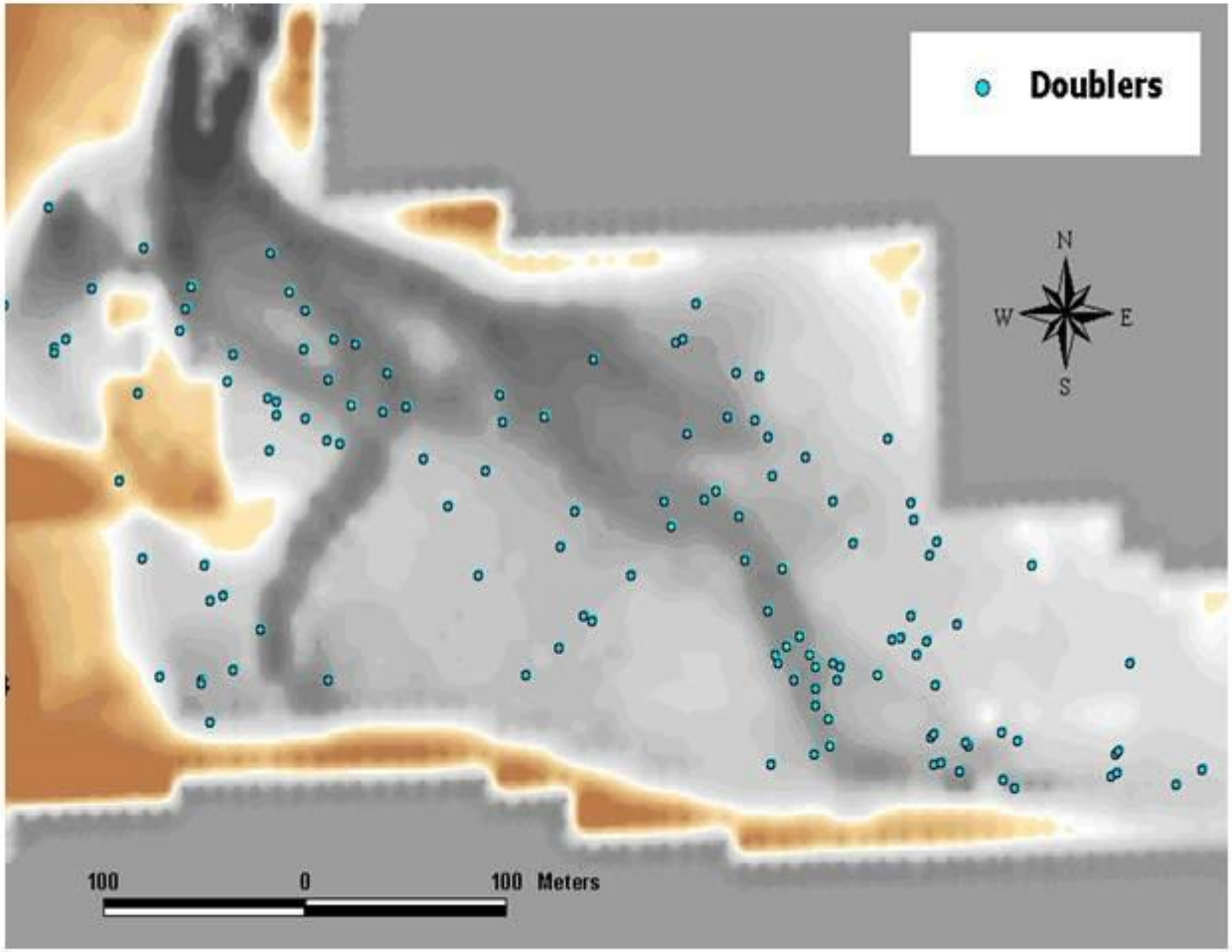

100
0
100 Meters
N
W
E
S
Inlet
Crab Island
Plateau
Thailand
Depth (cm)
-107 - -53
-53 - -50.5
-50.5 - -48
-48 - -45.5
-45.5 - -43
-43 - -40.5
-40.5 - -38
-38 - -35.5
-35.5 - -33
-33 - -30.5
-30.5 - -28
-28 - -25.5
-25.5 - -23
-23 - -20.5
-20.5 - -18
-18 - -15.5
-15.5 - -13
-13 - -10.5
-10.5 - -8
-8 - -5.5
-5.5 - -3
-3 - -0.5
-0.5 - 2
2 - 4.5
4.5 - 7
7 - 9.5
9.5 - 12
12 - 14.5
14.5 - 17
17 - 19.5
19.5 - 22
22 - 24.5
24.5 - 27
27 - 29.5
29.5 - 32
32 - 34.5
34.5 - 37
37 - 39.5
39.5 - 42
42 - 44.5
44.5 - 47
47 - 49.5
49.5 - 52
52 - 54.5
54.5 - 57
57 - 59.5
59.5 - 62
62 - 64.5
64.5 - 67
67 - 69.5
69.5 - 72
72 - 74.5
74.5 - 77
77 - 79.5
79.5 - 82
82 - 84.5
84.5 - 87
87 - 89.5
89.5 - 92
92 - 94.5
94.5 - 97
97 - 99.5
99.5 - 102
102 - 162

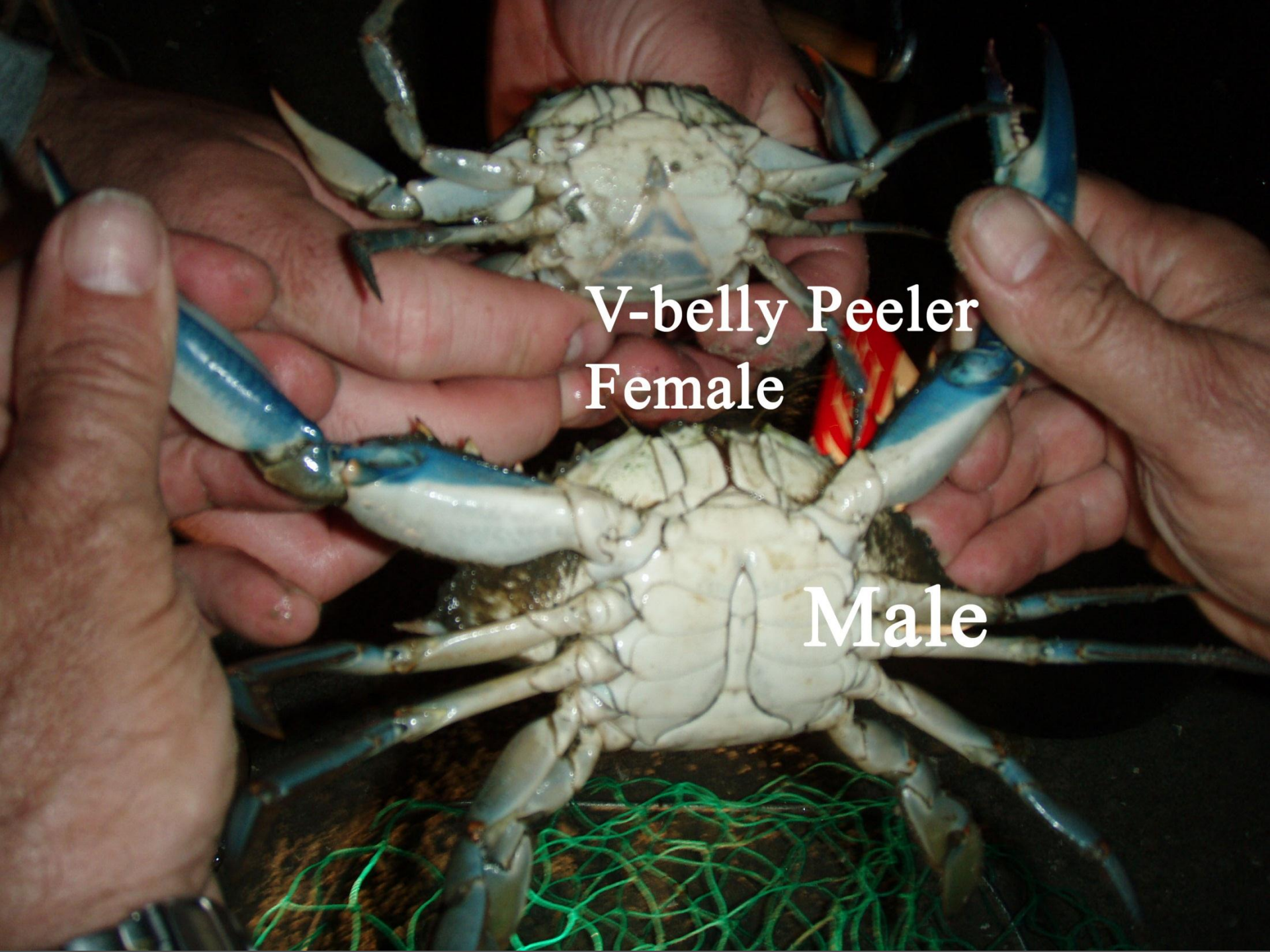

Males
N
W
E
S
100
0
100 Meters

# Juvenile Females



# Doubler Crabs




V-belly Peeler
Female
Male

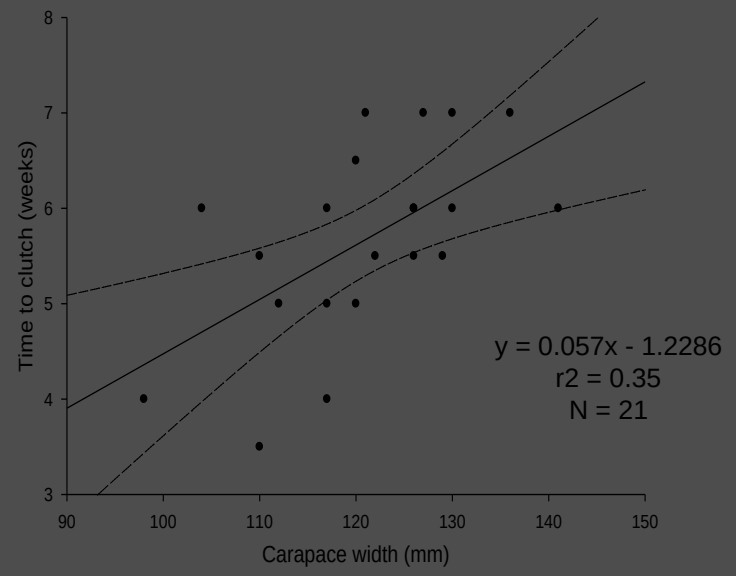

DUD


$TUD!

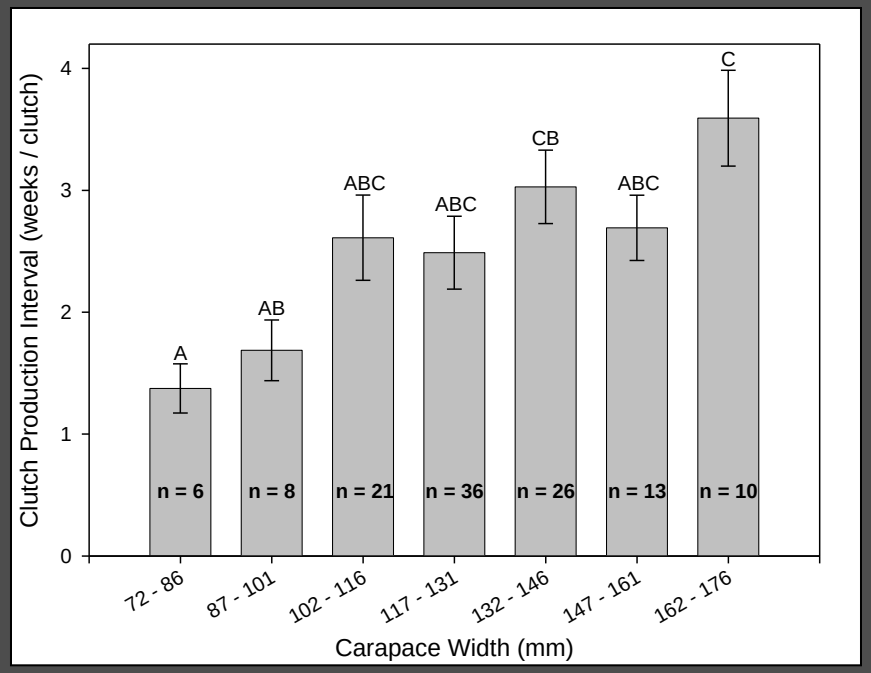
# Pair Ready to be Removed

Timing of Clutch Production Post Mating
Clutch Production Interval and Size
Clutch Size and Clutch Number
Fecundity and Size

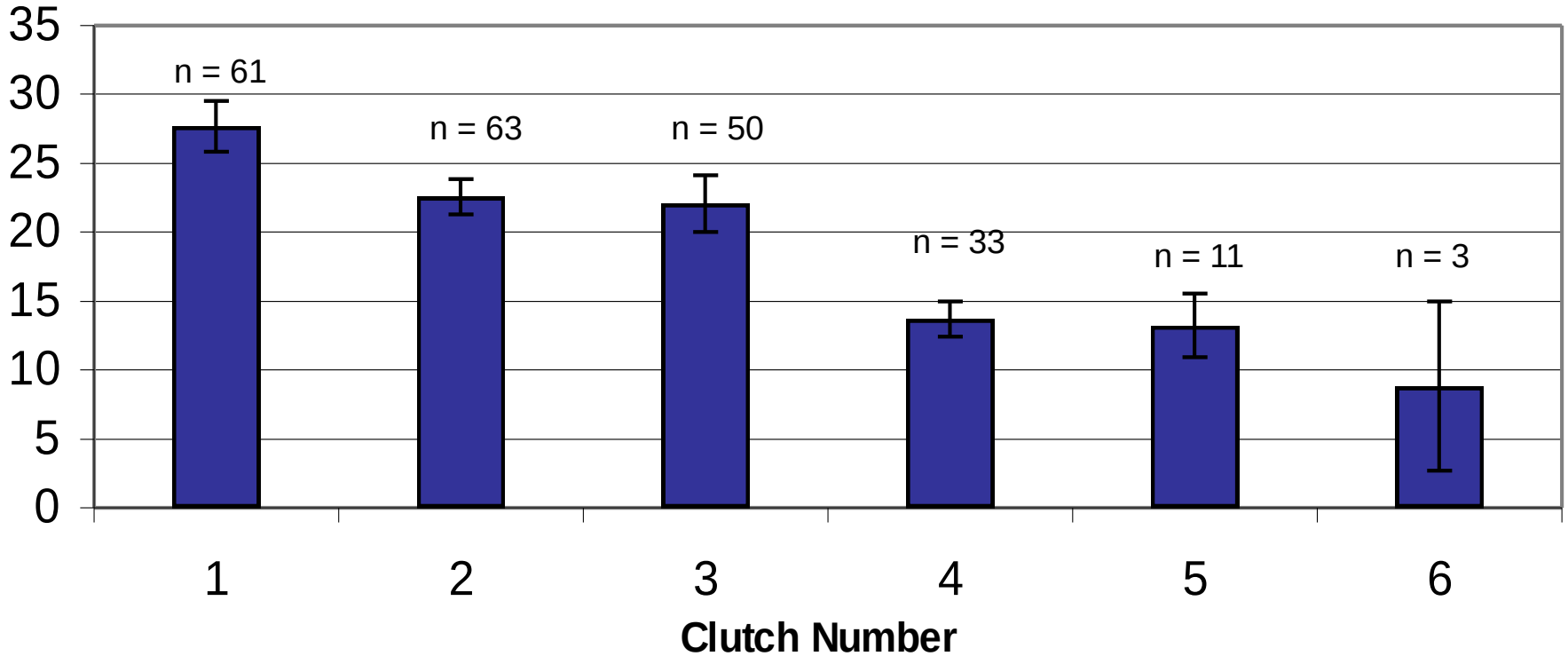
## Time to First Clutch After Mating vs SIZE



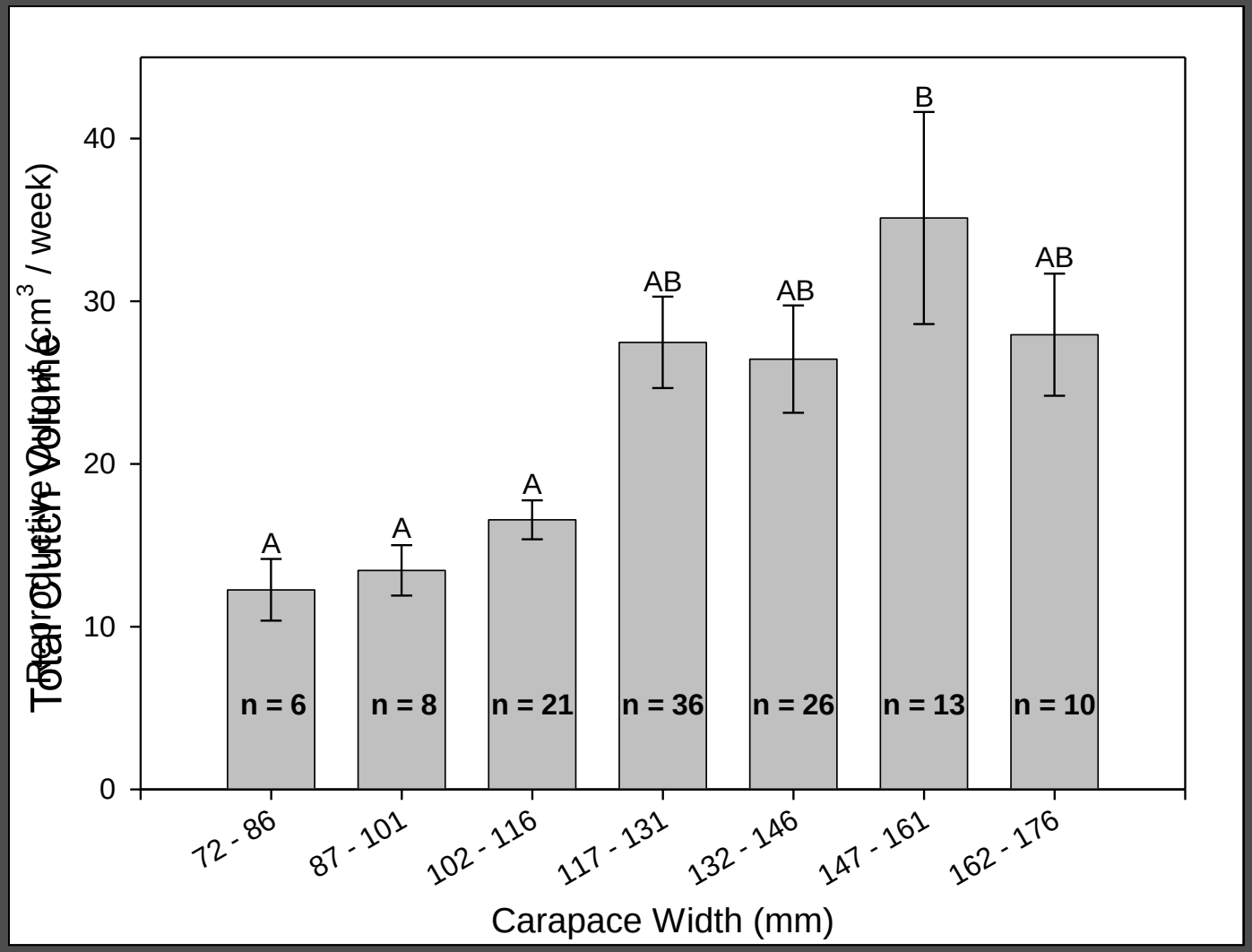

## Clutch Production Interval vs SIZE



# Clutch Size by Clutch Number

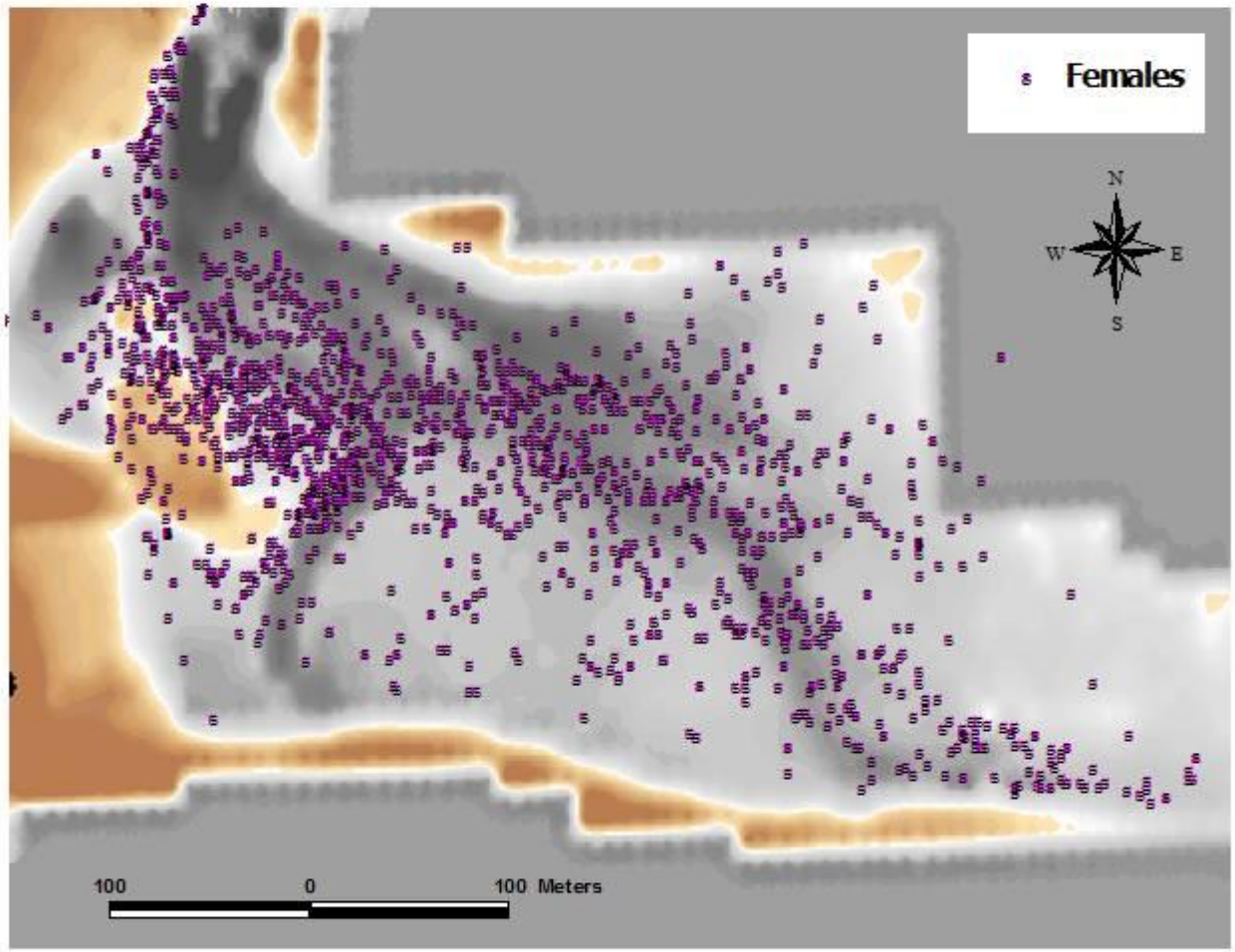


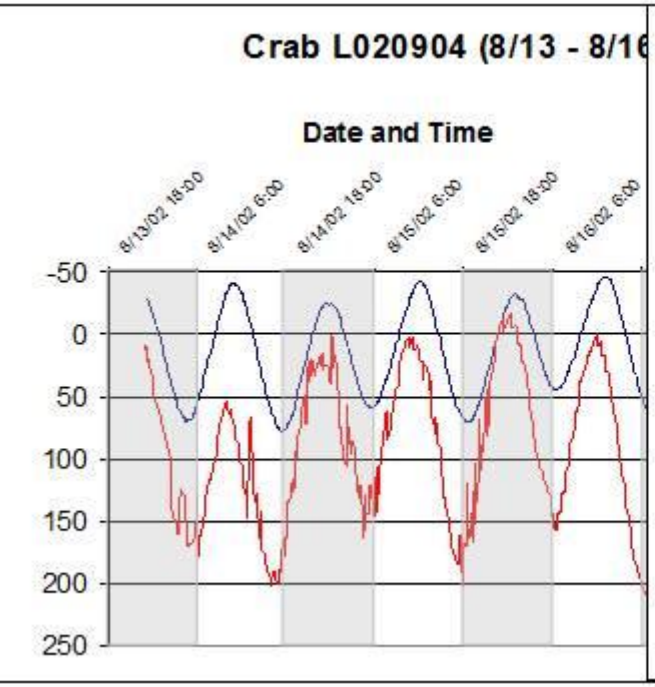
# Fecundity and Size

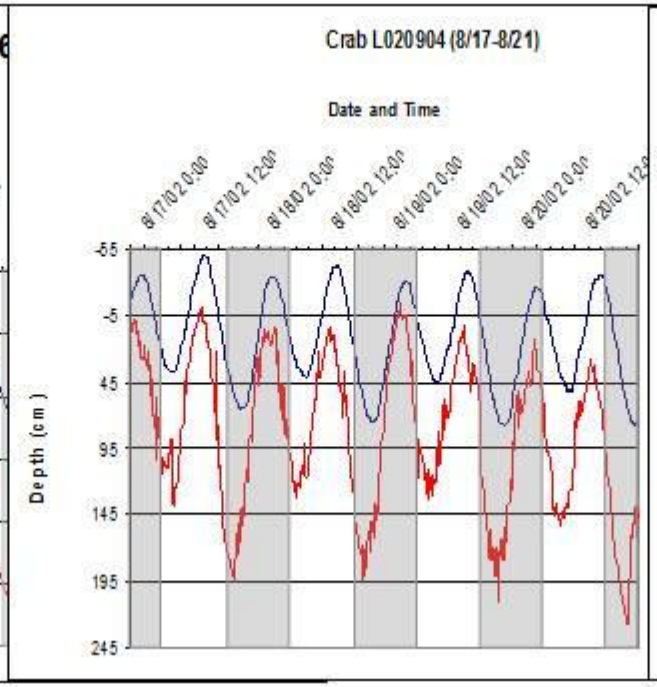


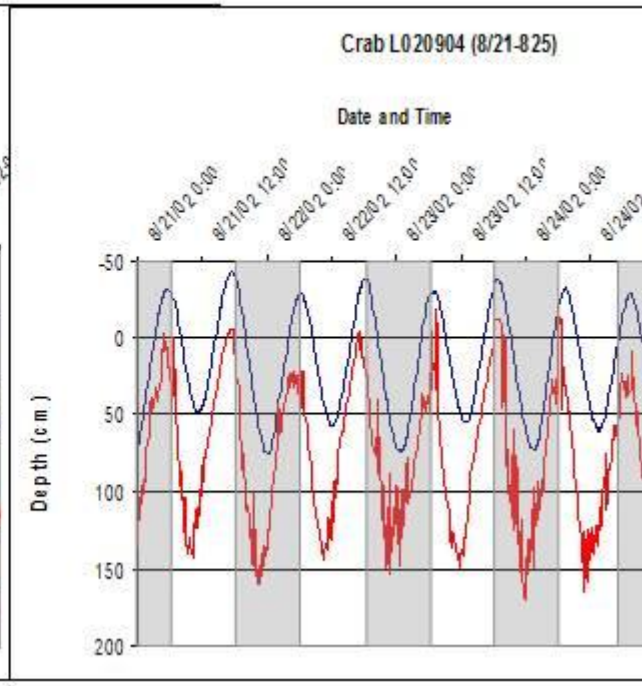

**All but Smallest Crabs have Same Fecundity**

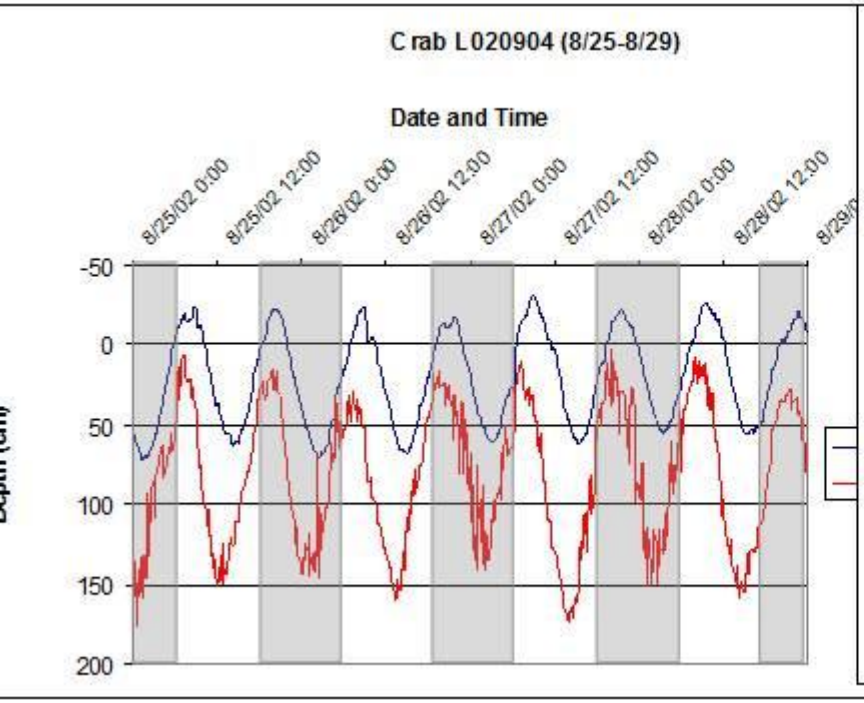
# Female Crabs

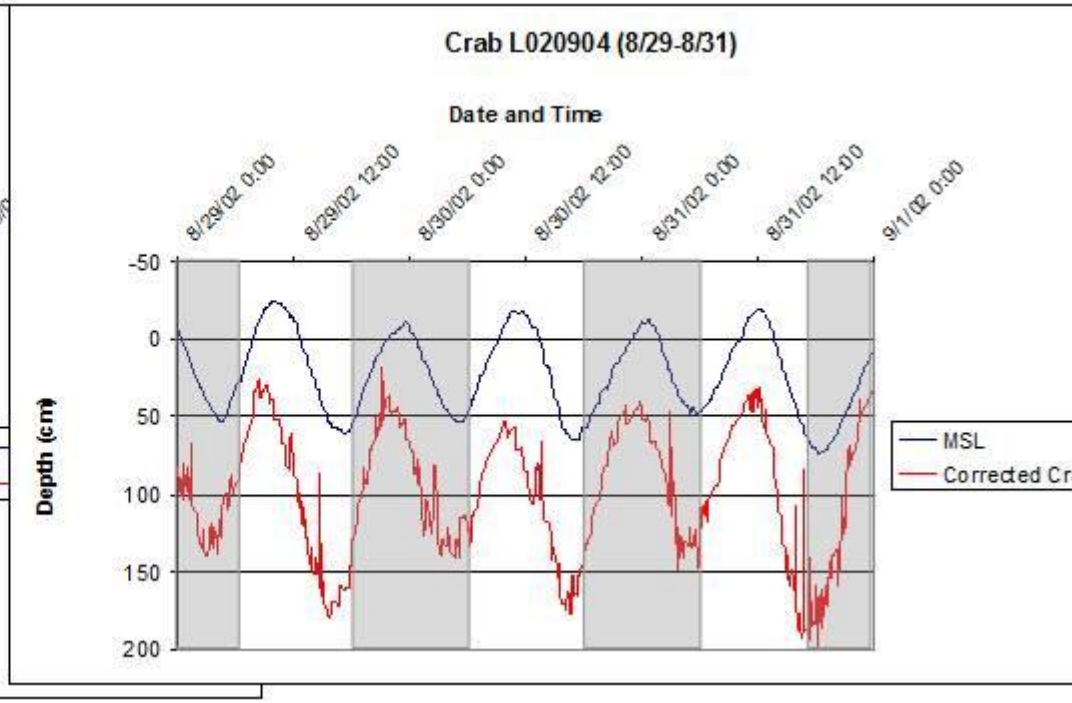



Crab L020904 (8/13 - 8/16
Date and Time
8/13/02 18:00
8/14/02 6:00
8/14/02 18:00
8/15/02 6:00
8/15/02 18:00
8/16/02 6:00
-50
0
50
100
150
200
250

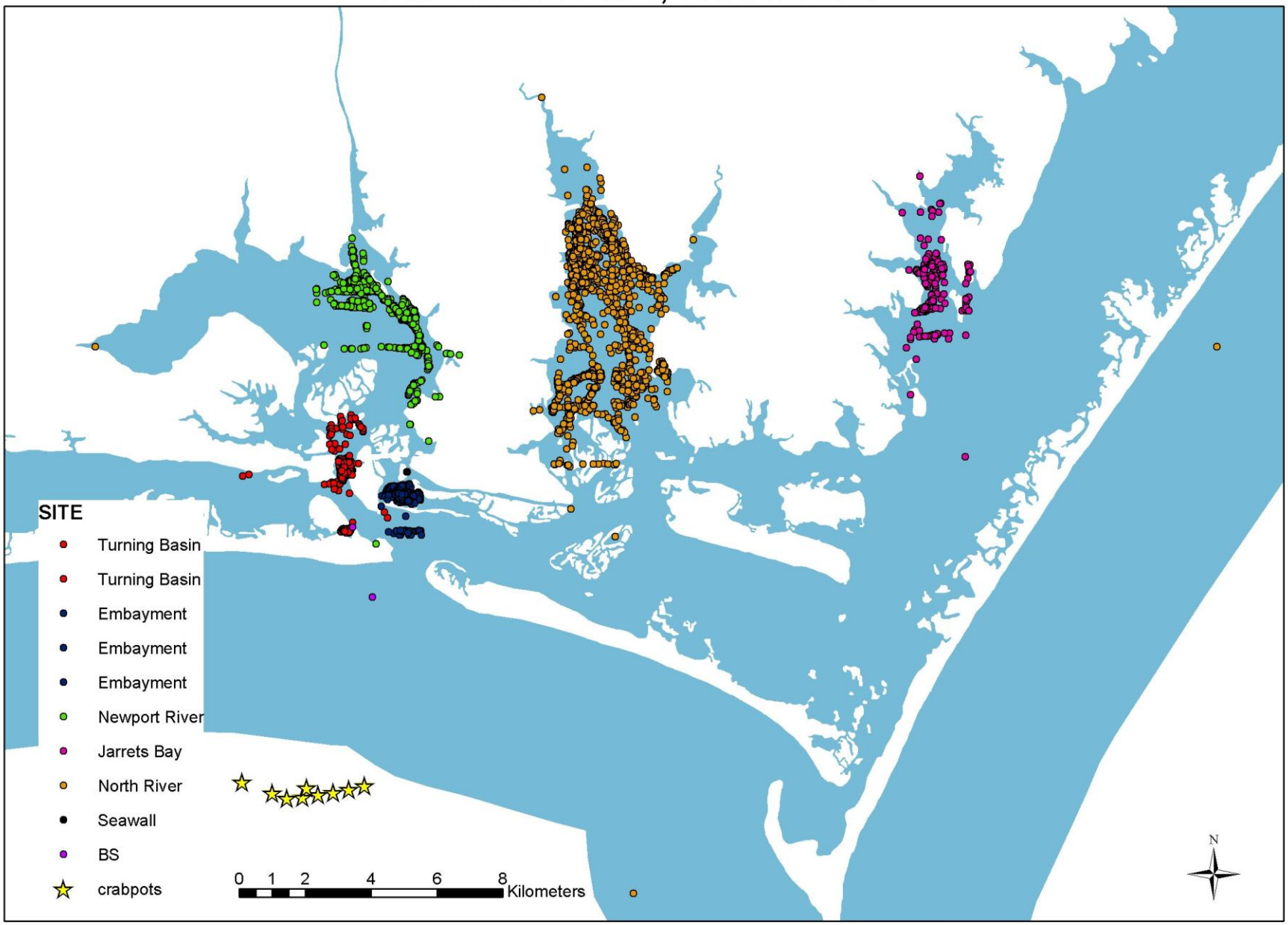

Crab L020904 (8/17-8/21)
Date and Time
8/17/02 0:00
8/17/02 12:00
8/18/02 0:00
8/18/02 12:00
8/19/02 0:00
8/19/02 12:00
8/20/02 0:00
8/20/02 12:0
Depth (cm)
-55
-5
45
95
145
195
245

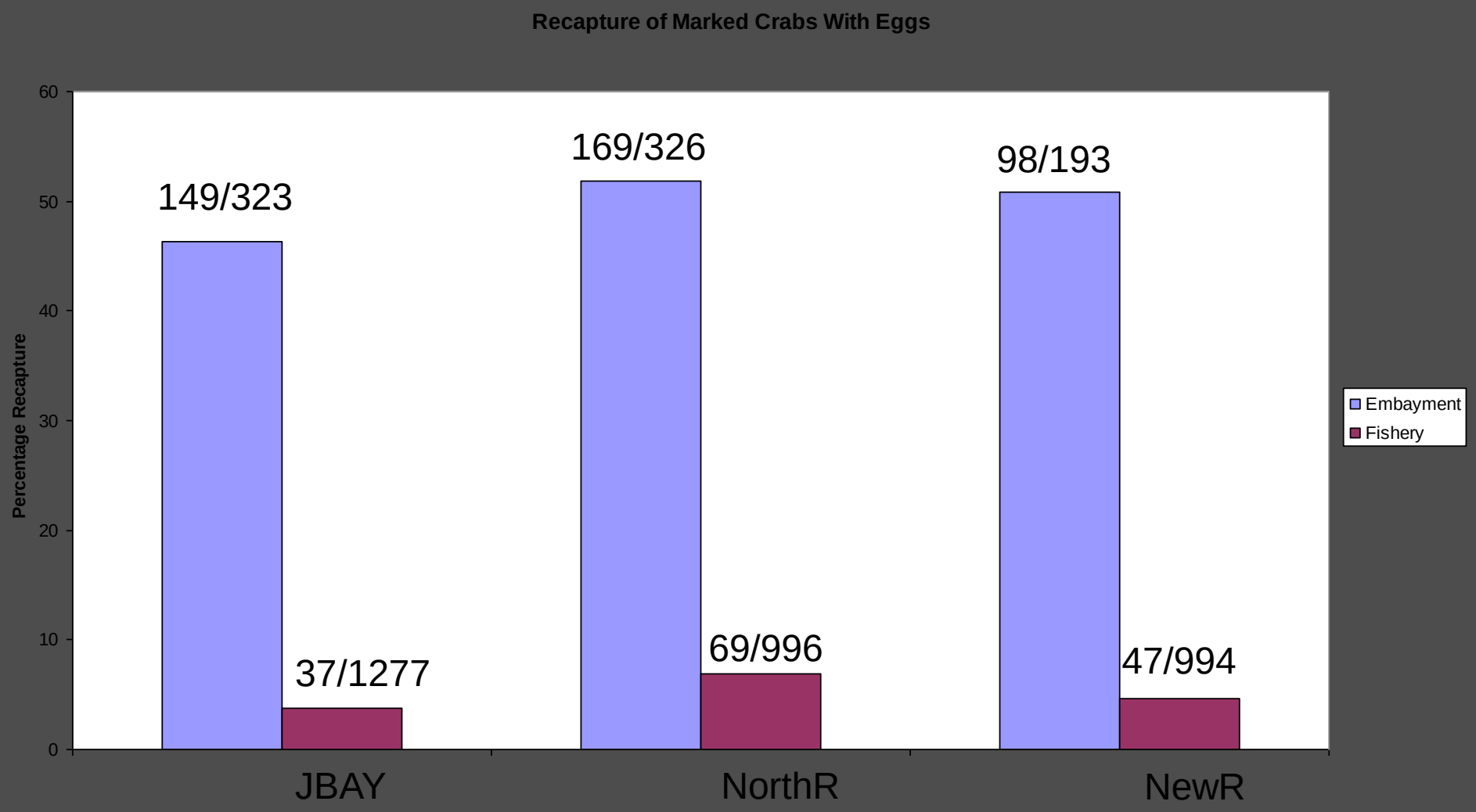

Crab L020904 (8/21-825)
Date and Time
8/21/02 0:00
8/21/02 12:00
8/22/02 0:00
8/22/02 12:00
8/23/02 0:00
8/23/02 12:00
8/24/02 0:00
8/24/02
Depth (cm)
-50
0
50
100
150
200


Crab L020904 (8/25-8/29)
Date and Time
8/25/02 0:00
8/25/02 12:00
8/26/02 0:00
8/26/02 12:00
8/27/02 0:00
8/27/02 12:00
8/28/02 0:00
8/28/02 12:00
8/29/0
-50
0
50
100
150
200

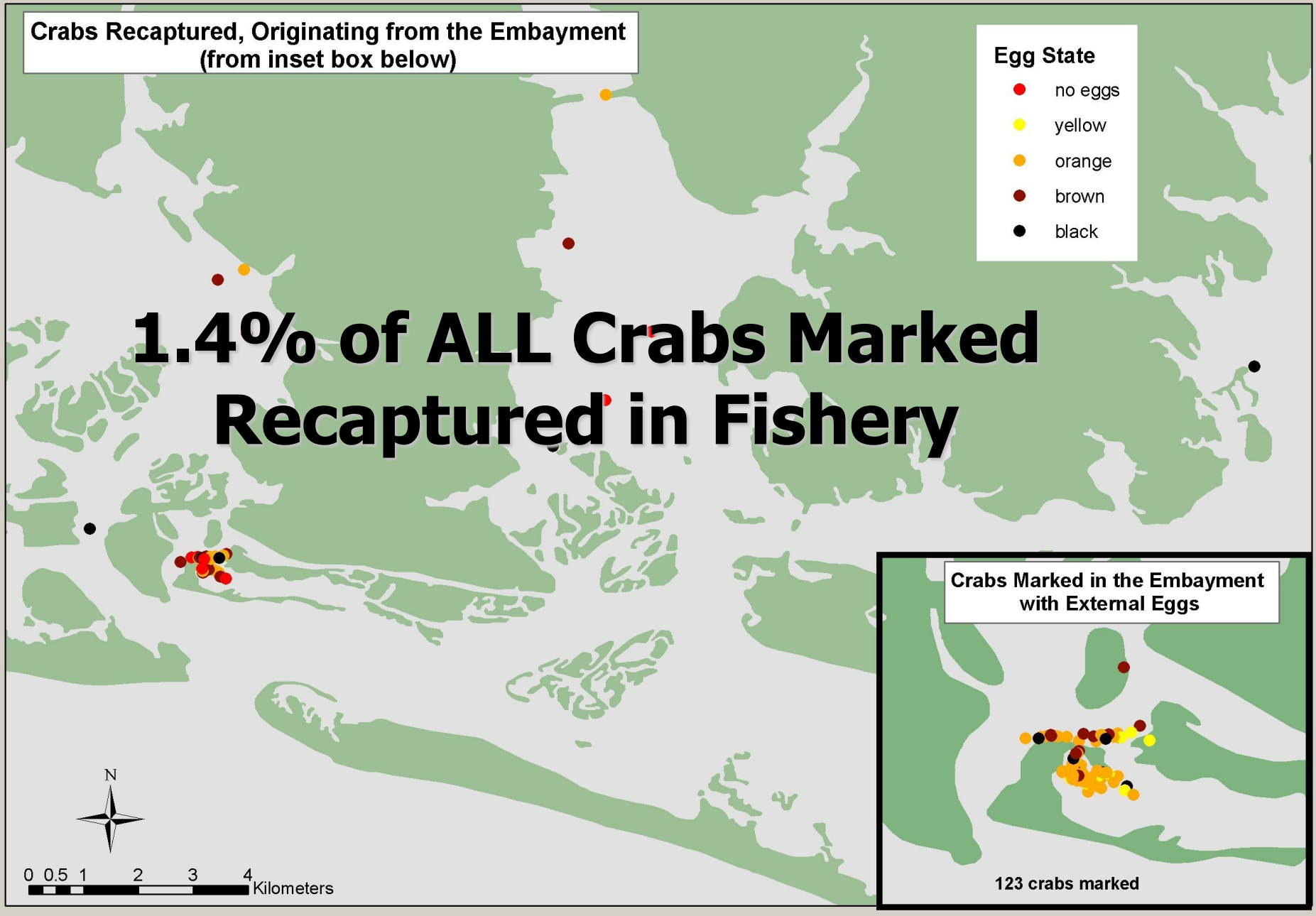

Crab L020904 (8/29-8/31)
Date and Time
8/29/02 0:00
8/29/02 12:00
8/30/02 0:00
8/30/02 12:00
8/31/02 0:00
8/31/02 12:00
9/1/02 0:00
Depth (cm)
-50
0
50
100
150
200
MSL
Corrected Cr

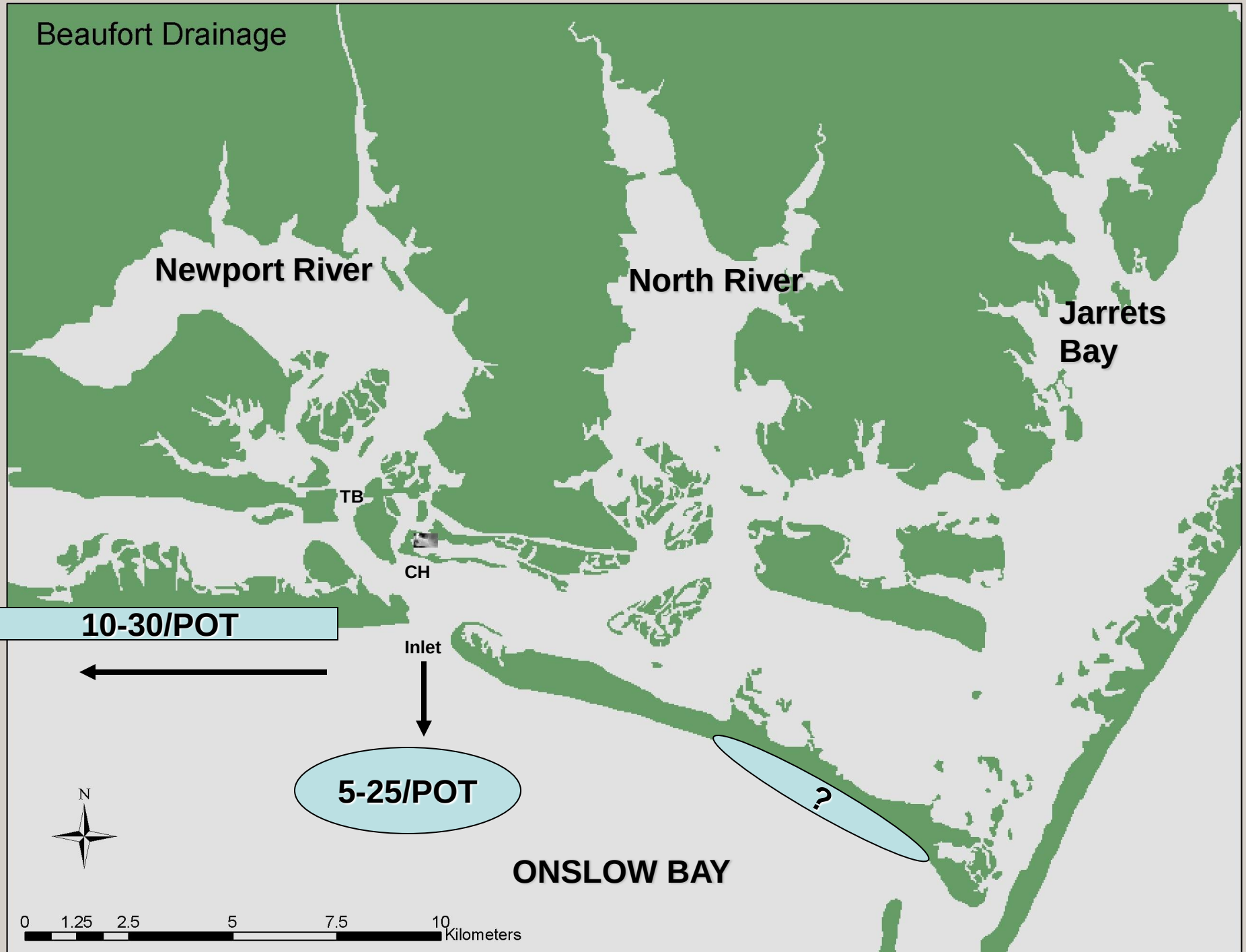
# All Crab Data, 2000-2002

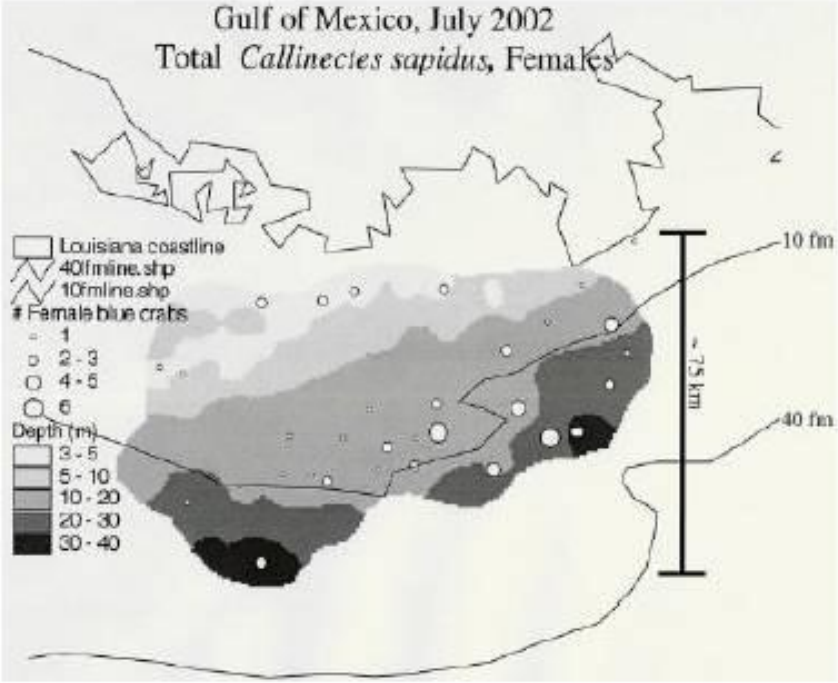


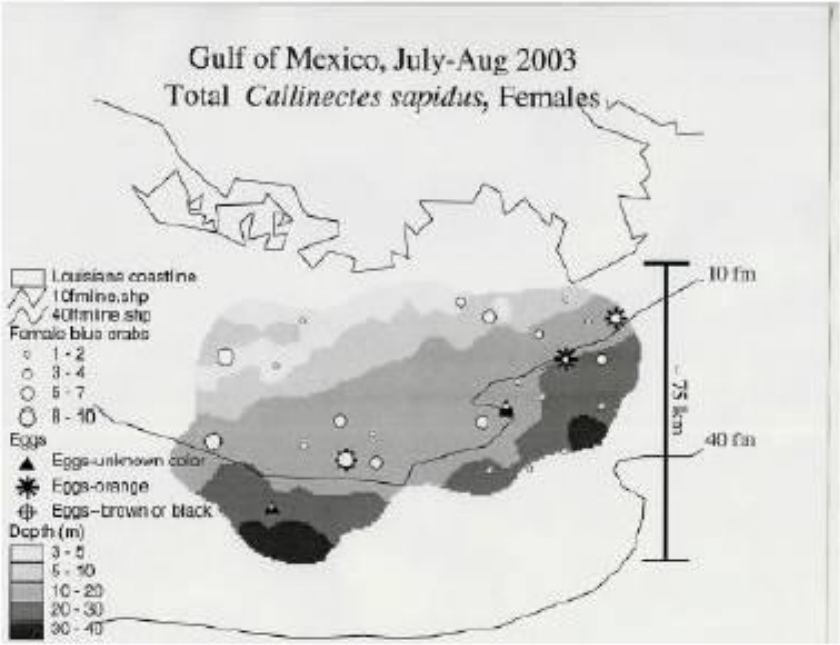

Recapture of Marked Crabs With Eggs
Percentage Recapture
60
50
40
30
20
10
0
149/323
37/1277
169/326
69/996
98/193
47/994
JBAY
NorthR
NewR
Embayment
Fishery

# 2002 Crab Recaptures: Where the Crabs in the Embayment are Going




Beaufort Drainage
Newport River
North River
Jarrets Bay
TB
CH
10-30/POT
Inlet
5-25/POT
?
ONSLOW BAY
N
0 1.25 2.5 5 7.5 10 Kilometers


Gulf of Mexico, July 2002
Total *Callinectes sapidus*, Females
Louisiana coastline
40fmline.shp
10fmline.shp
# Female blue crabs
1
2 - 3
4 - 5
6
Depth (m)
3 - 5
5 - 10
10 - 20
20 - 30
30 - 40
10 fm
~ 75 km
40 fm

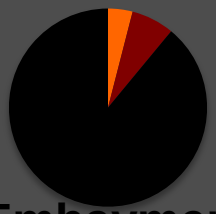

Gulf of Mexico, July-Aug 2003
Total *Callinectes sapidus*, Females
Louisiana coastline
10fmline.shp
40fmline.shp
Female blue crabs
1 - 2
3 - 4
5 - 7
8 - 10
Eggs
Eggs-unknown color
Eggs-orange
Eggs-brown or black
Depth (m)
3 - 5
5 - 10
10 - 20
20 - 30
30 - 40
10 fm
~ 75 km
40 fm

North River

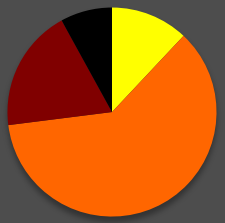
Newport River

Jarrets Bay

Turning Basin

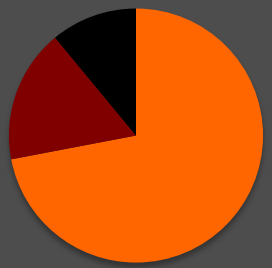


Embayment

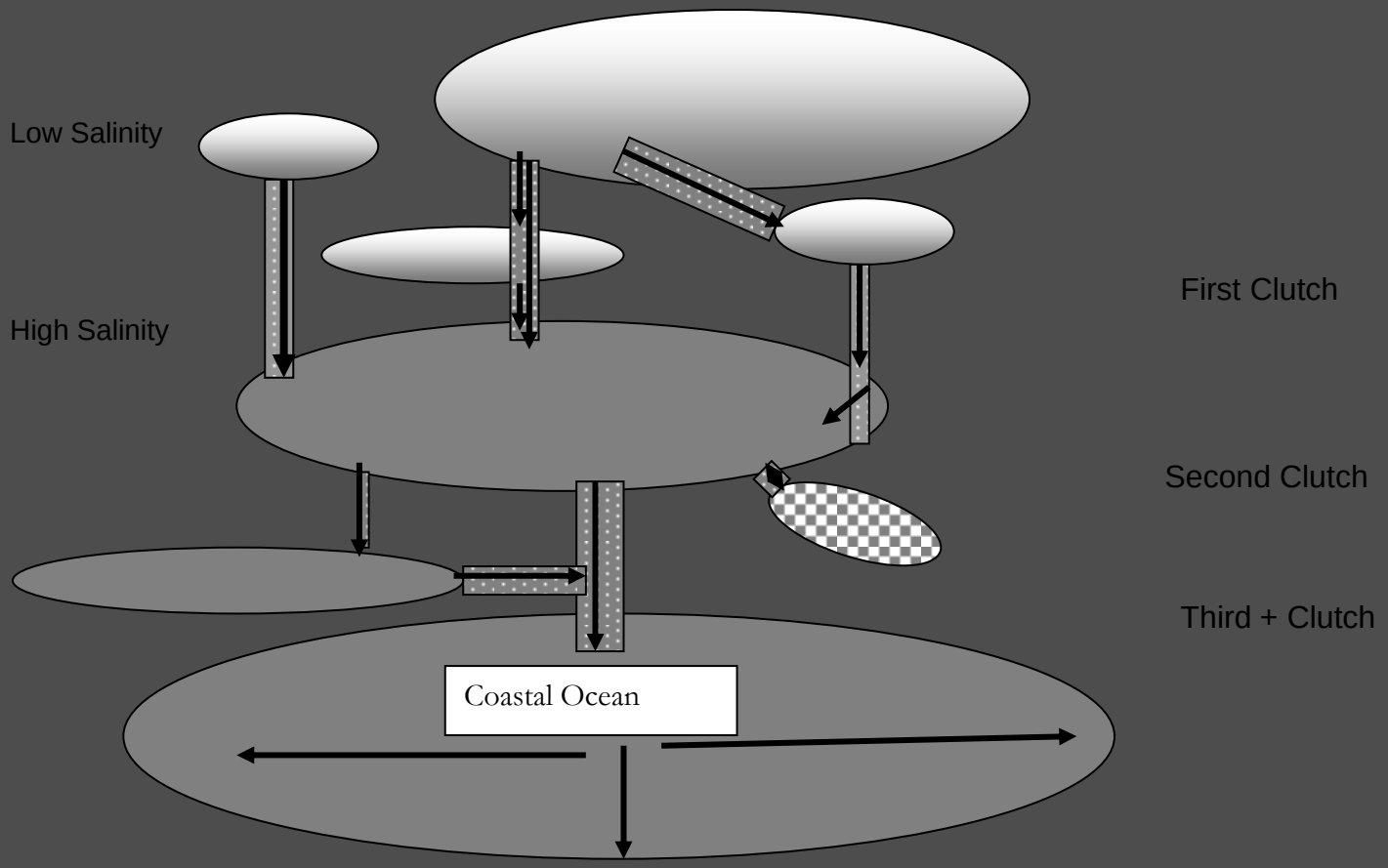


Radio Island Channel

Fishing Piers



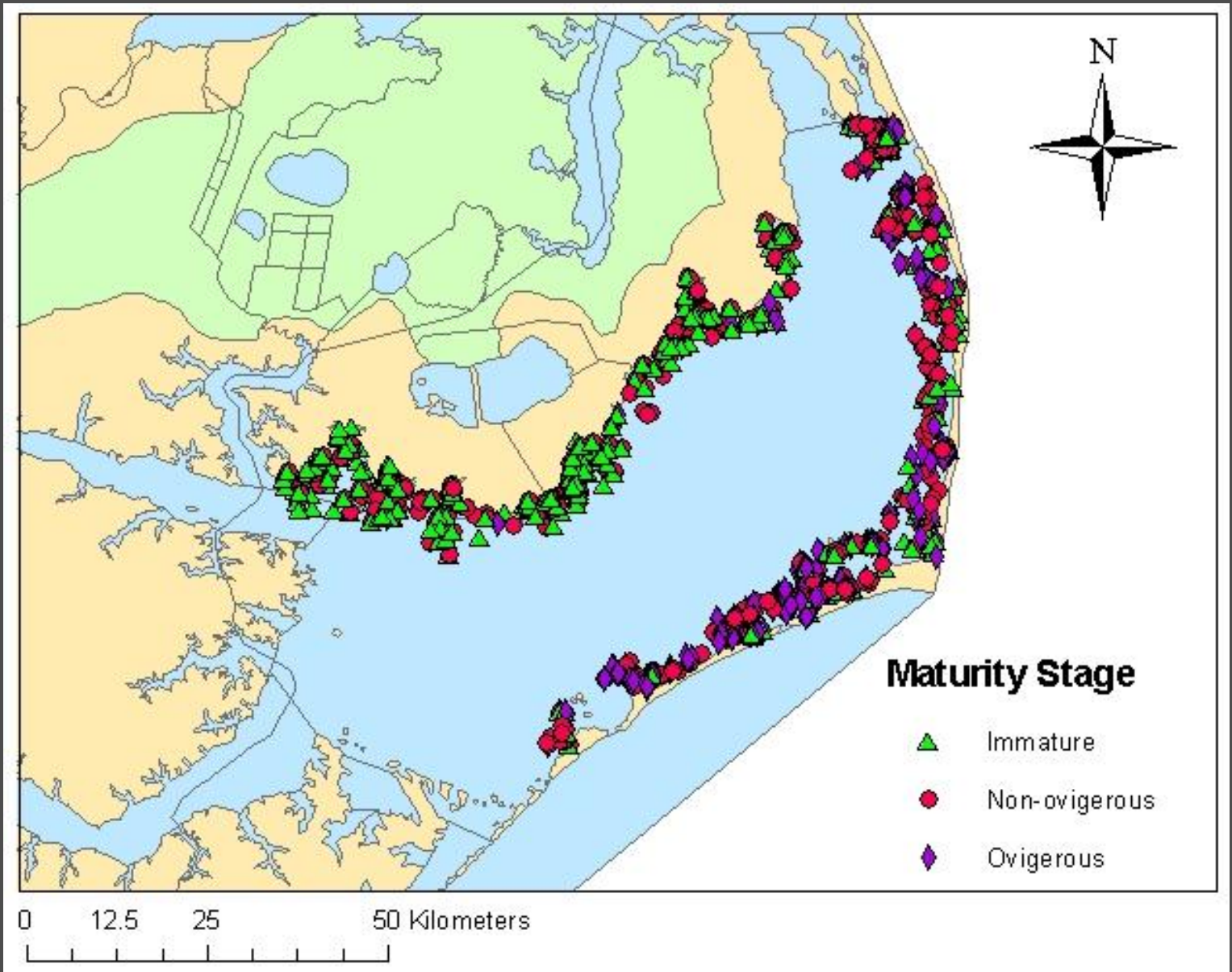
Onslow Bay


Low Salinity
High Salinity
First Clutch
Second Clutch
Third + Clutch
Coastal Ocean

# Small Tidal Estuary

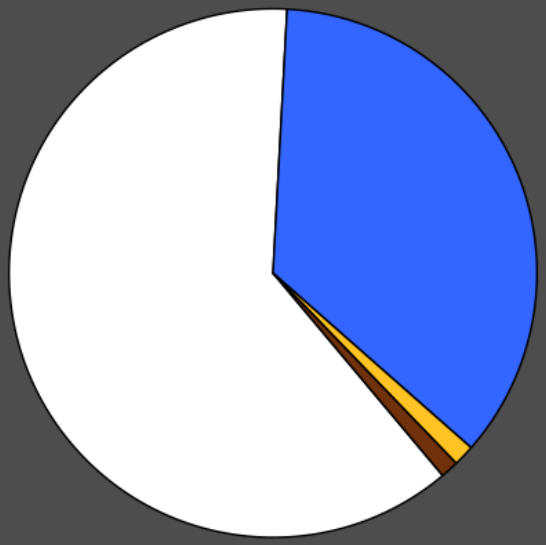
- Extrude Eggs March to October
- Migrate >22 Salinity with First Clutch
- Migrate Out with each Clutch
- Build up in Ocean in September

# Female Crabs-Big Estuary



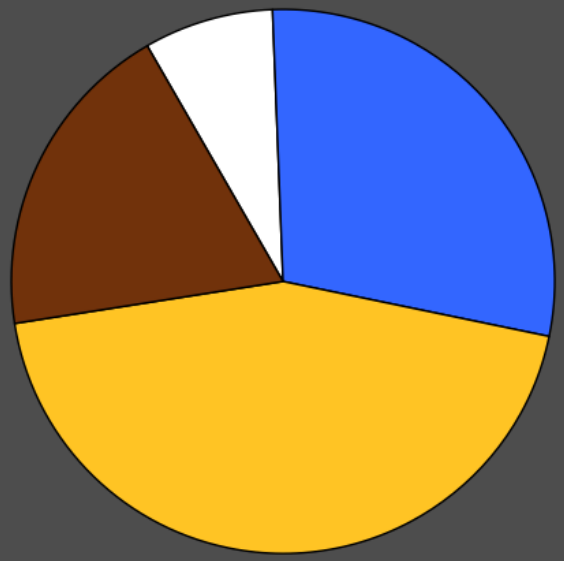
# Females

Immature: ***61.9%***
**Non-ovigerous**: 35.6%
Sponge: **2.4%**



WEST

Immature: ***7.7%***
**Non-ovigerous:** 28.7%
Sponge: **63.3%**



EAST

# How do megalopae find Inlets?

Estuarine plume contains terrestrial and estuarine humic acids
Humics alter crab behavior and induce metamorphosis

# Where do megalopae Settle?

Sea grasses and salt marsh grasses

# Megalopa Collectors

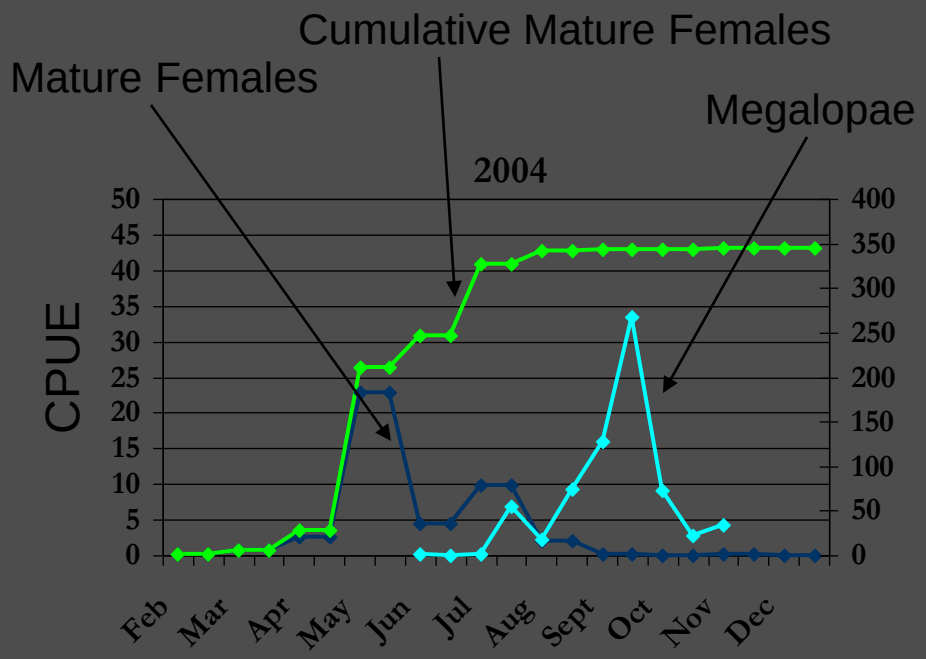
# Odors megalopae Avoid

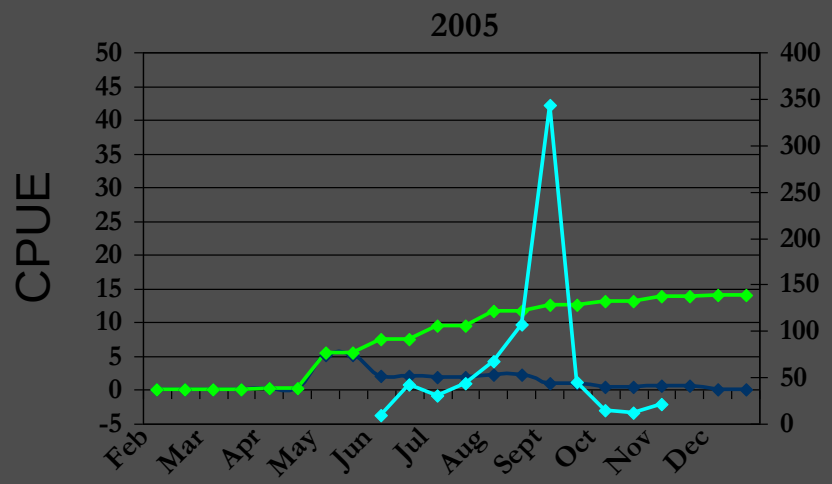
Fiddler crab, mud crab, grass shrimp

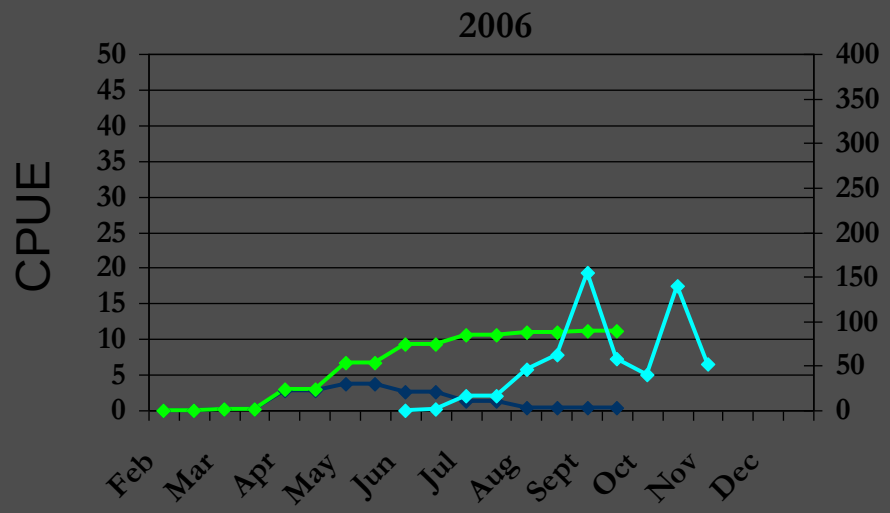
# Odors megalopae Ignore

Blue crab, commercial shrimp

# Mature Females and Megalopae



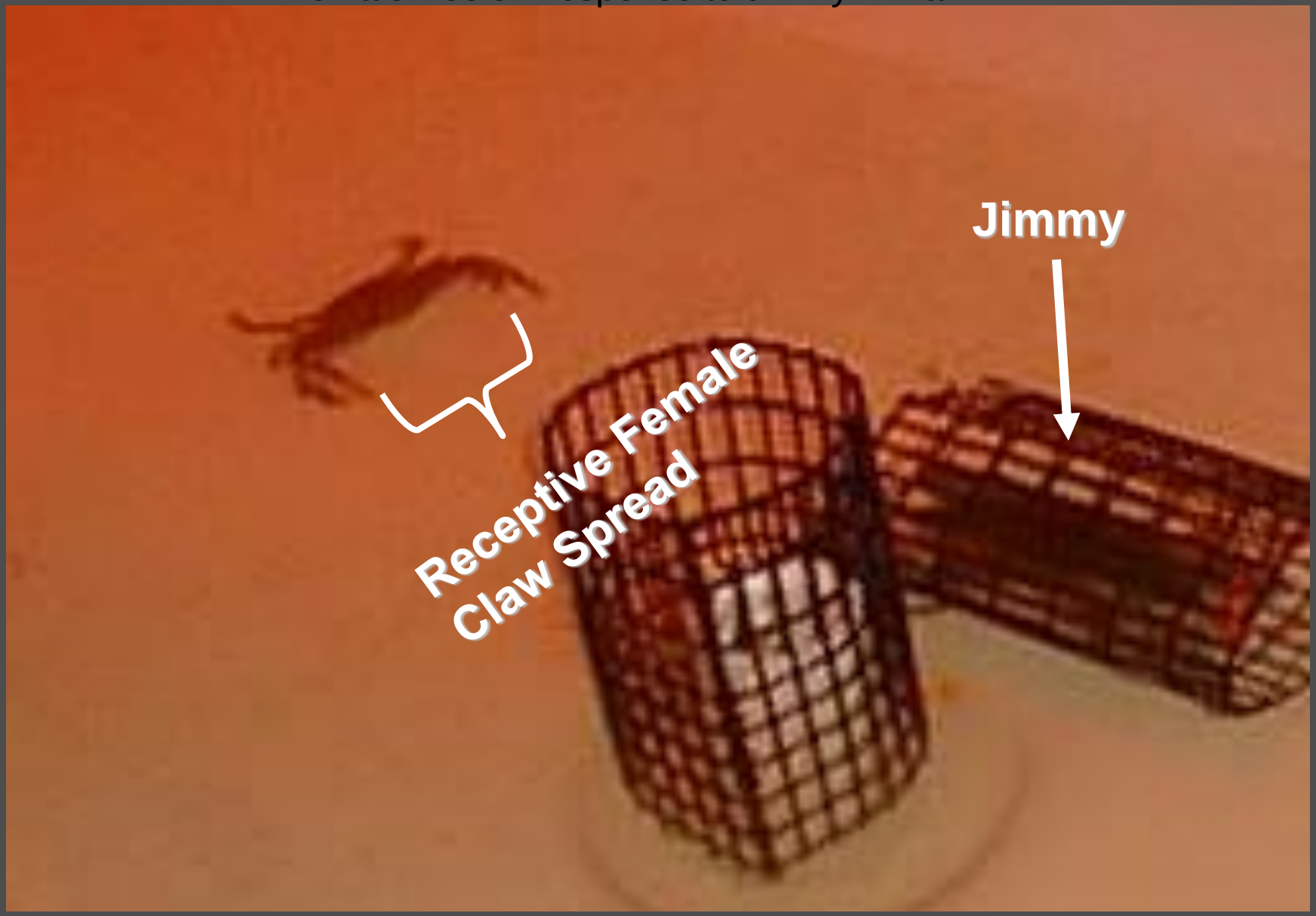



# Conclusions
# North Carolina Crabs

- **Females Have Multiple Clutches of Eggs**
  - **March to October NC**
- **Migrate out with each clutch**
- **Accumulate in High Salinity Water**
- **Spawning peaks August-September**
- **Megalopae return by changing behavior in response to estuarine chemical cues and riding tides**

Duke University Marine Laboratory

# Female Peeler Response to Jimmy in Dark

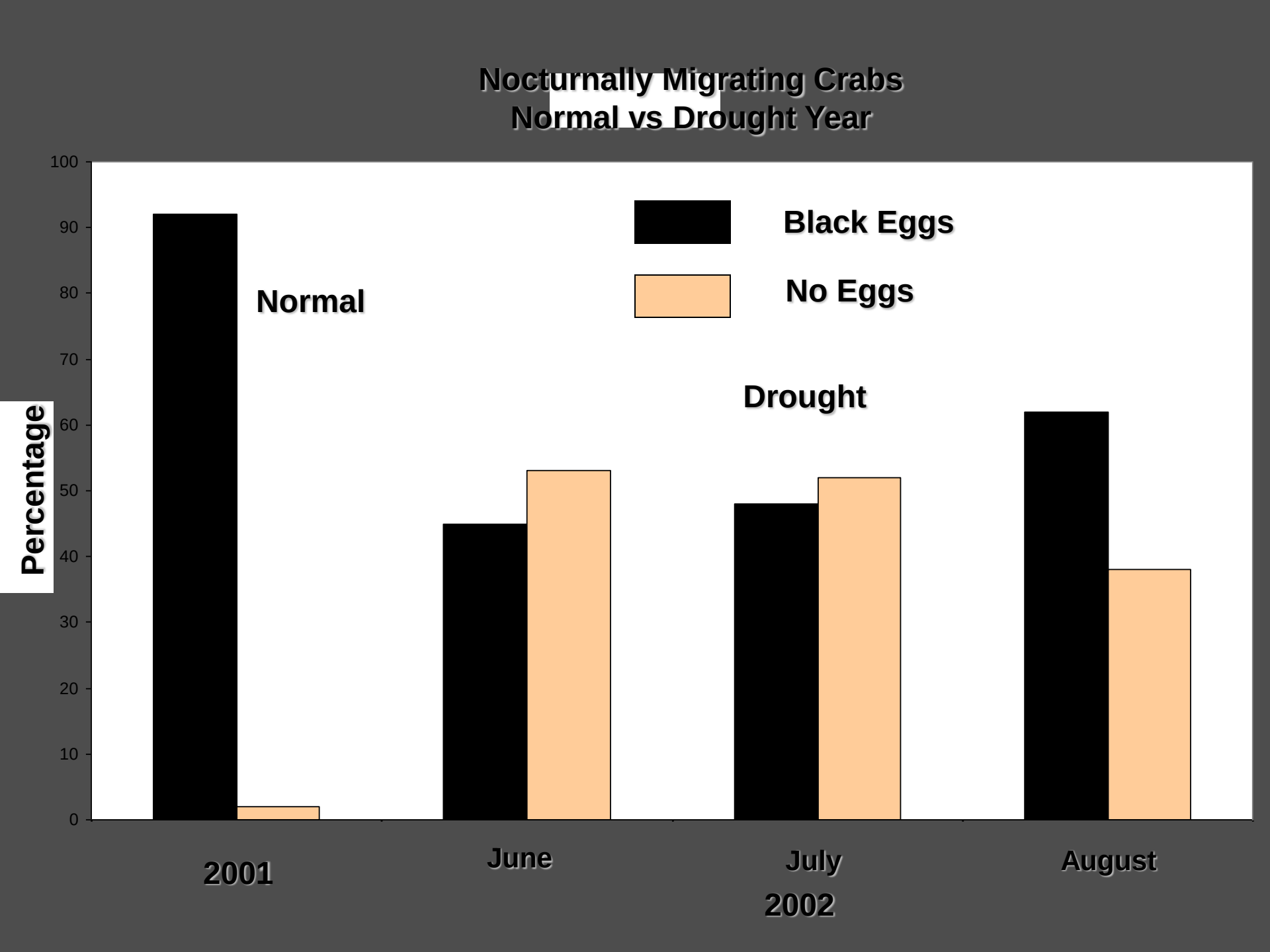


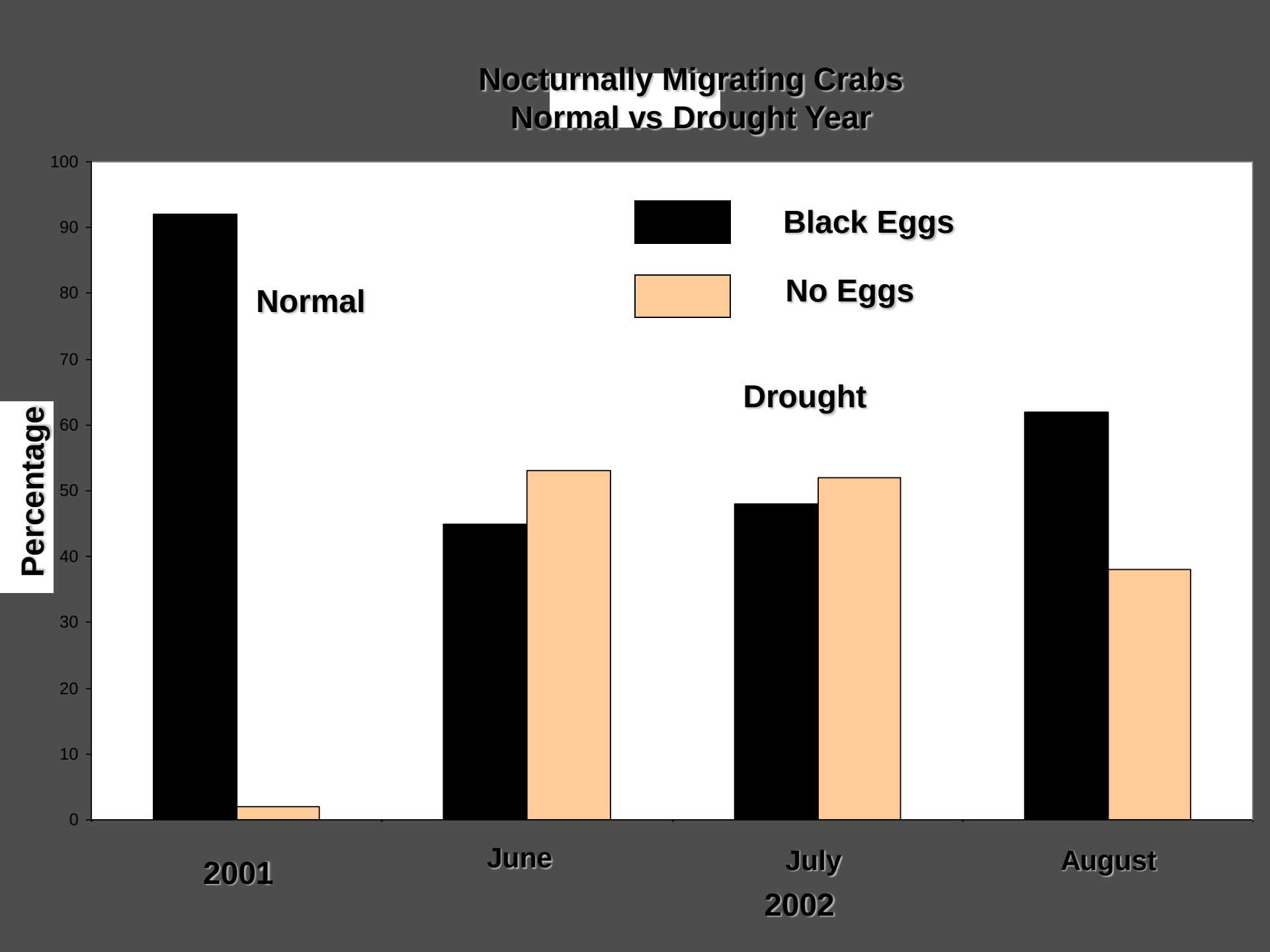
# No Response

# Response

Mating

Female


Nocturnally Migrating Crabs
Normal vs Drought Year
Black Eggs
No Eggs
Normal
Drought
Percentage
100
90
80
70
60
50
40
30
20
10
0
2001
June
July
August
2002


Nocturnally Migrating Crabs
Normal vs Drought Year
Black Eggs
No Eggs
Normal
Drought
Percentage
100
90
80
70
60
50
40
30
20
10
0
2001
June
July
August
2002

# Conclusions

Data support Hines et al., (2003, Fl- Lab) and Dickinson *et al*. (2006, NC-Field) findings of multiple clutch production.

Crabs mating in the early summer rapidly produce first clutch (mean = 5.7 weeks) and produce clutches of eggs throughout the summer and into the fall.

Crabs mating in the fall overwinter before producing their first clutch of eggs the following spring.

Some crabs  produce several (at least 4-5) clutches of eggs before overwintering and then resume spawning in the spring.

**Size controls clutch size but not fecundity.**

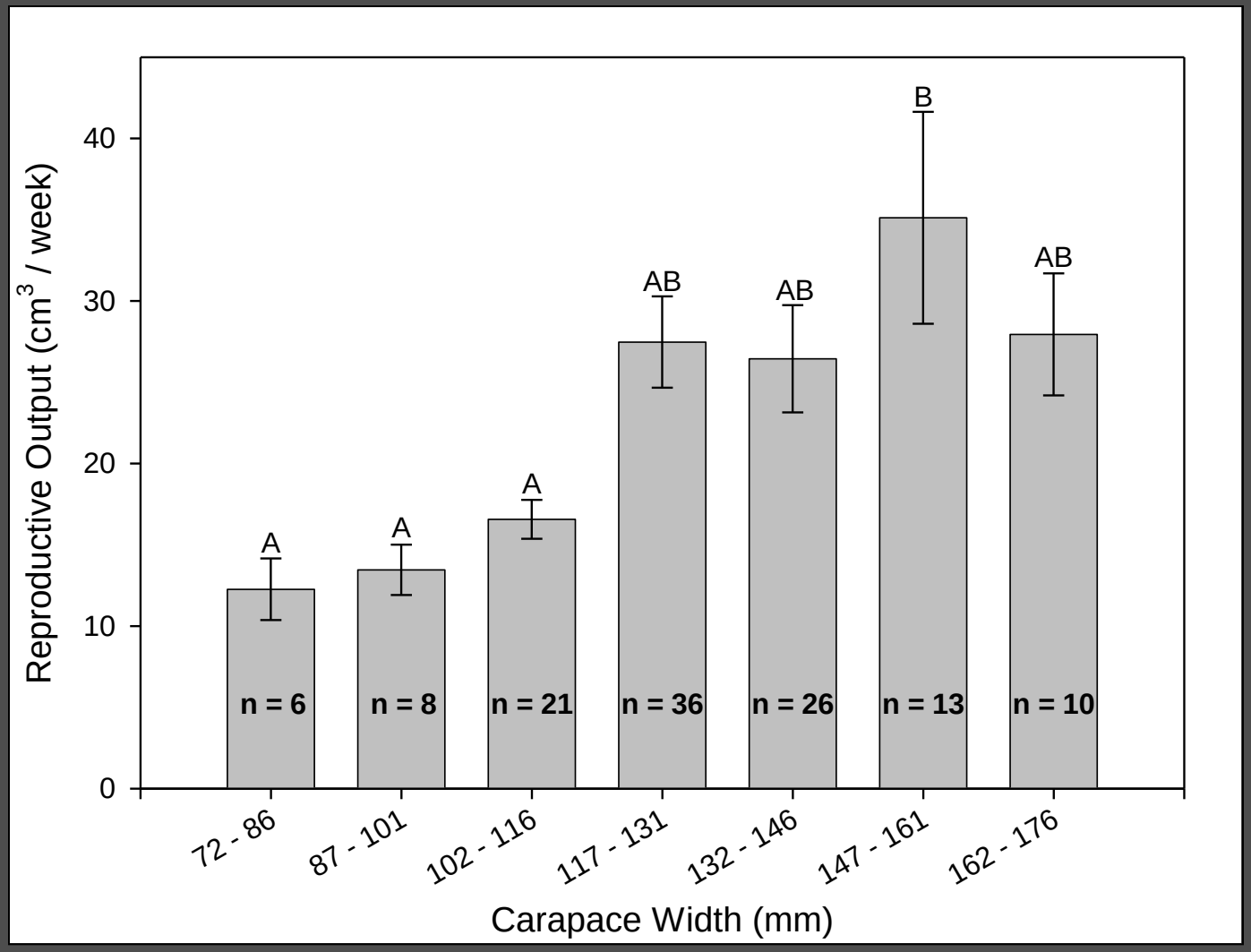
**Size appears largely enviornmentally determined.**

# Clutch Production and Fecundity in the Blue Crab, *Callinectes sapidus*

**Dan Rittschof M. Zachary Darnell, Gary H. Dickinson, and Catherine Latanich**

NCSU Subaward 2004-1772-15 and NC Sea Grant 06-BIOL-04

# Reproductive Output vs SIZE

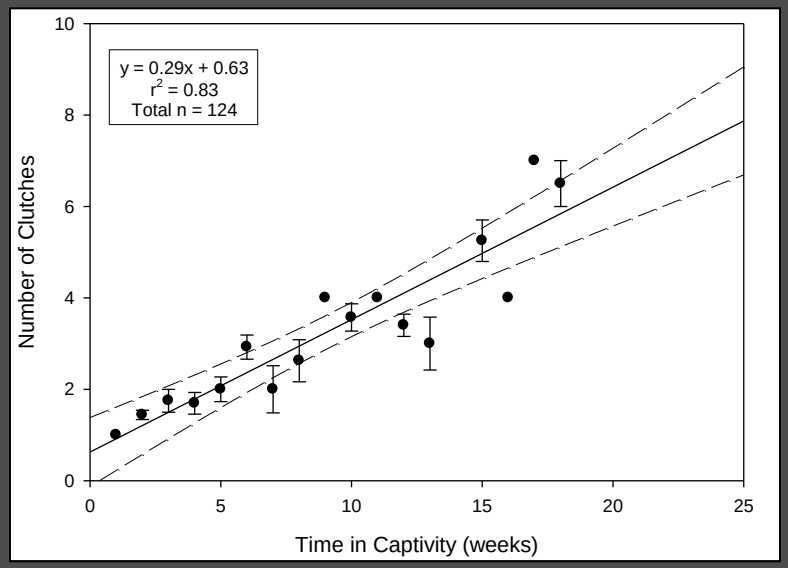


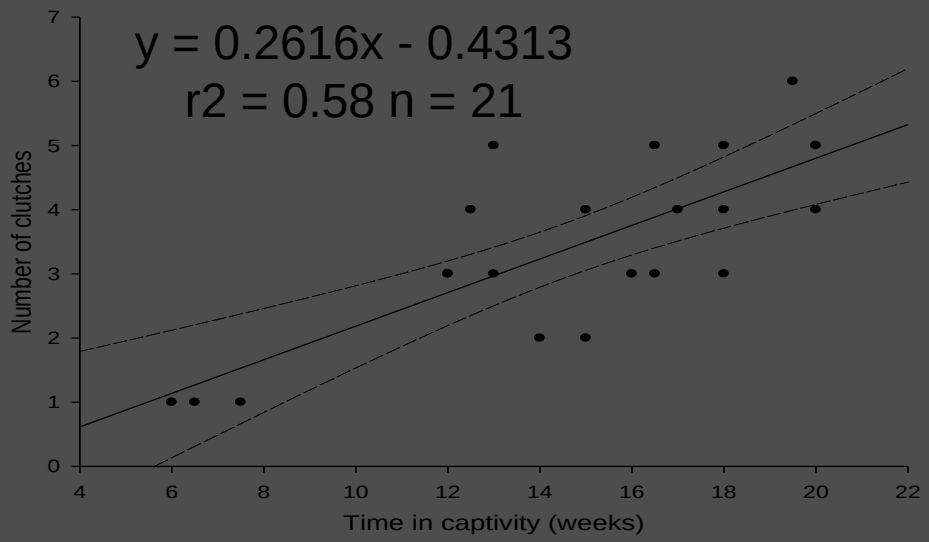
## Crabs CAN Overwinter and Spawn again in Spring

Crab 1, Clutch 6, March 18,2007, Mated June 21, 2006

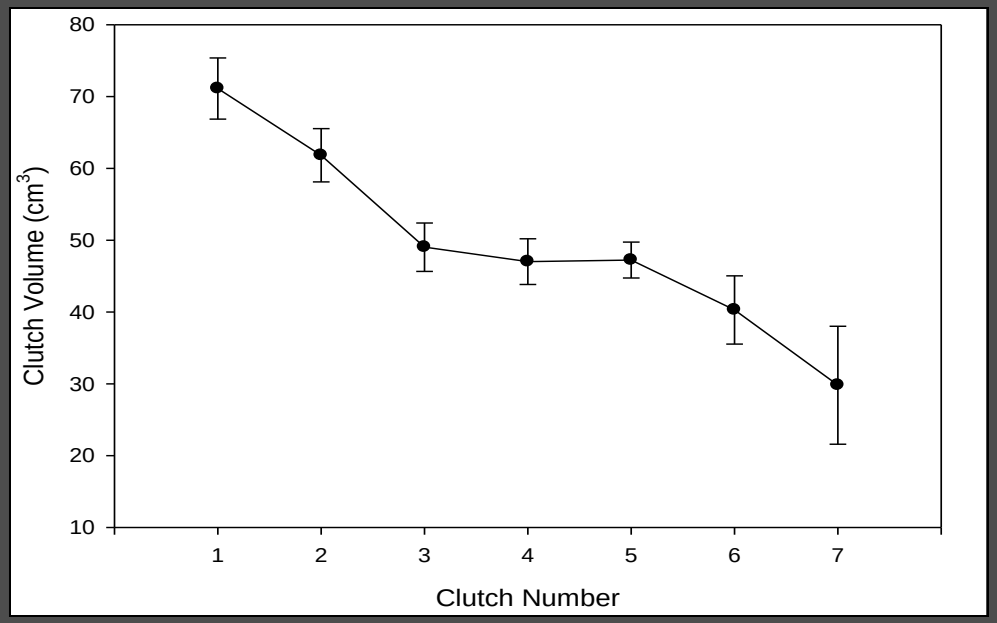
Crab 2, Clutch 5, March 18, 2007, Mated June 21, 2006
Brown Eggs March 18.  Not shown.

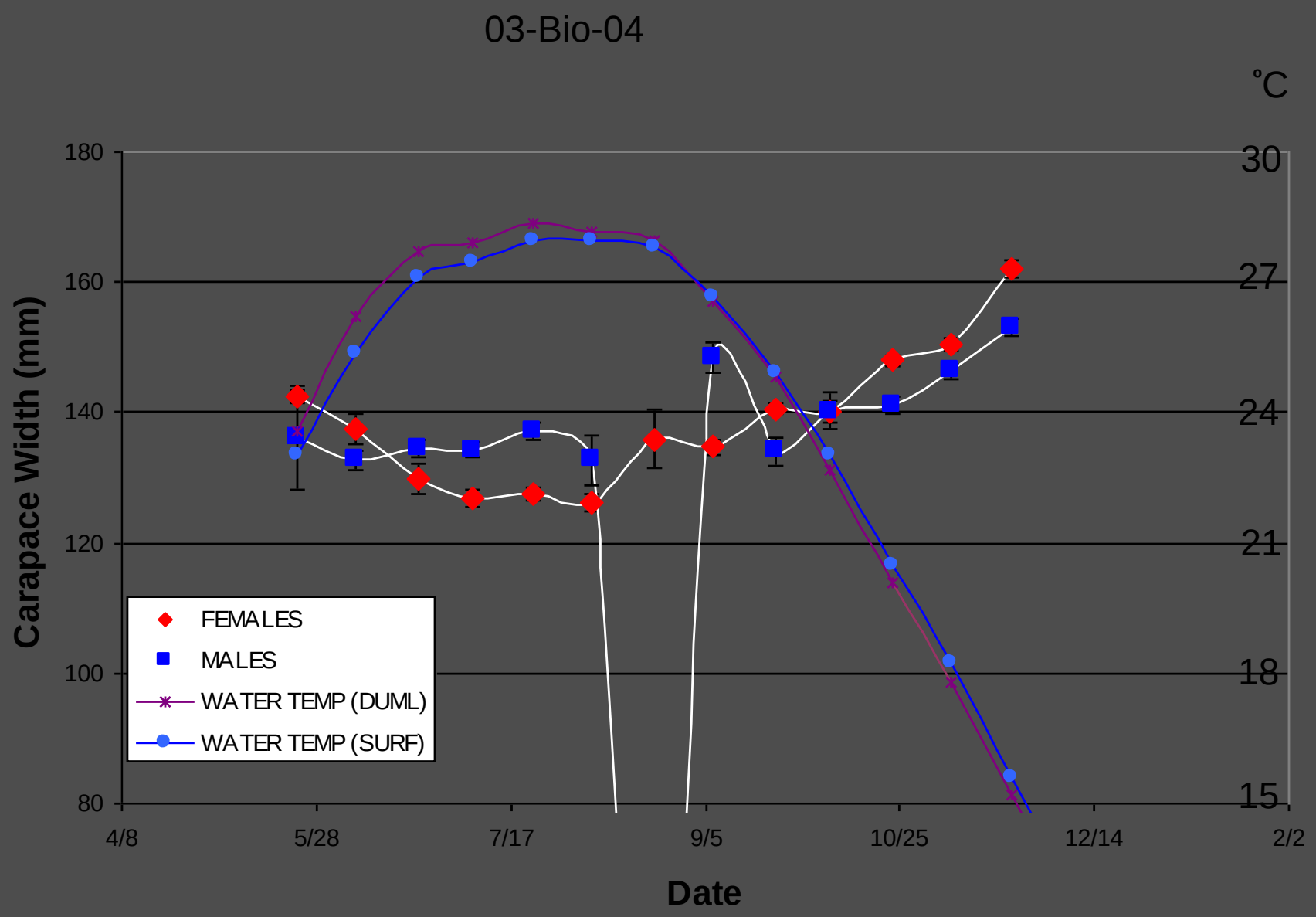
# Clutches vs Time




# Clutch Size vs Number





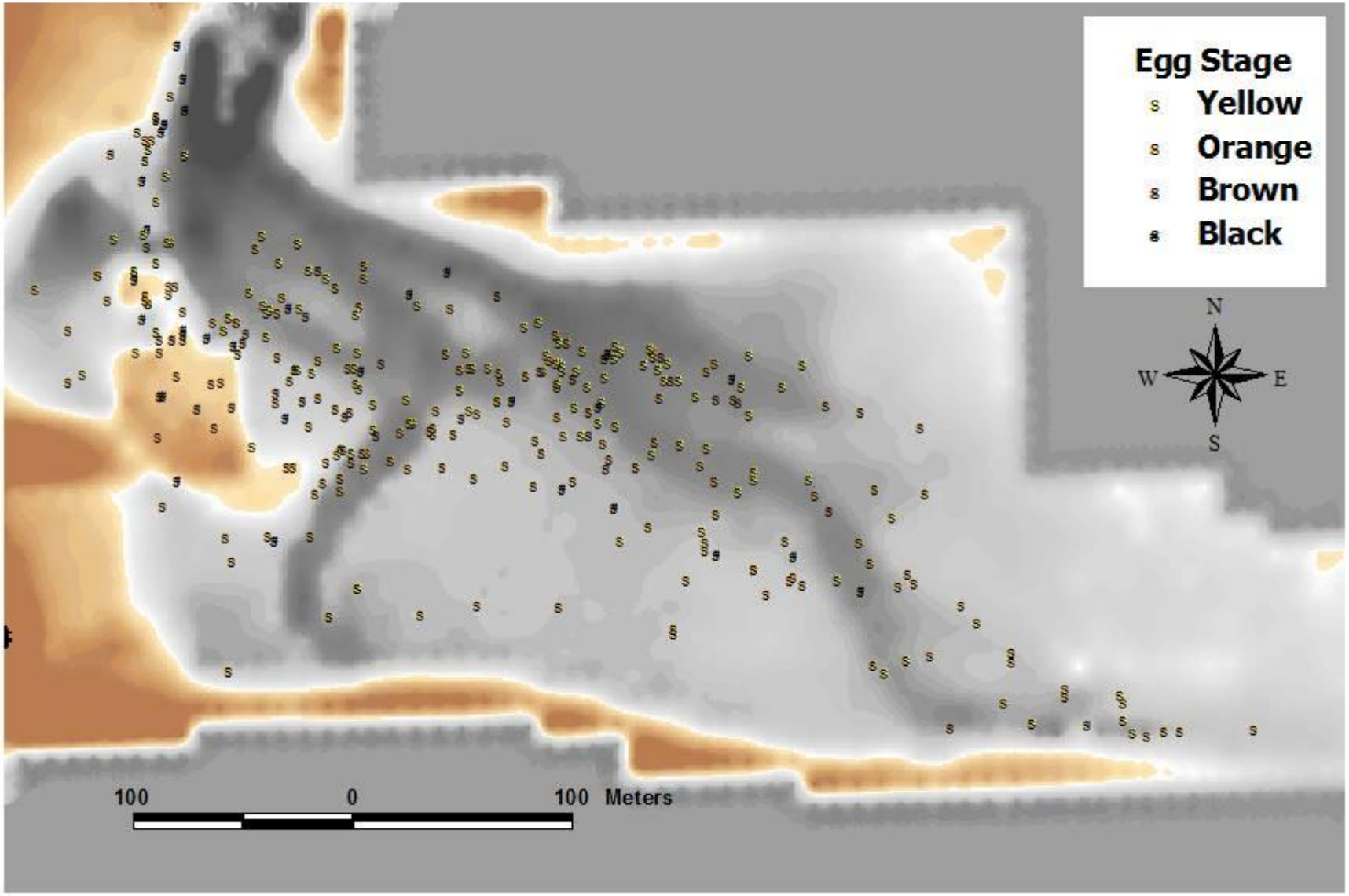

**Size Appears to be Largley Environmentally Determined**

# Tidal Driven System

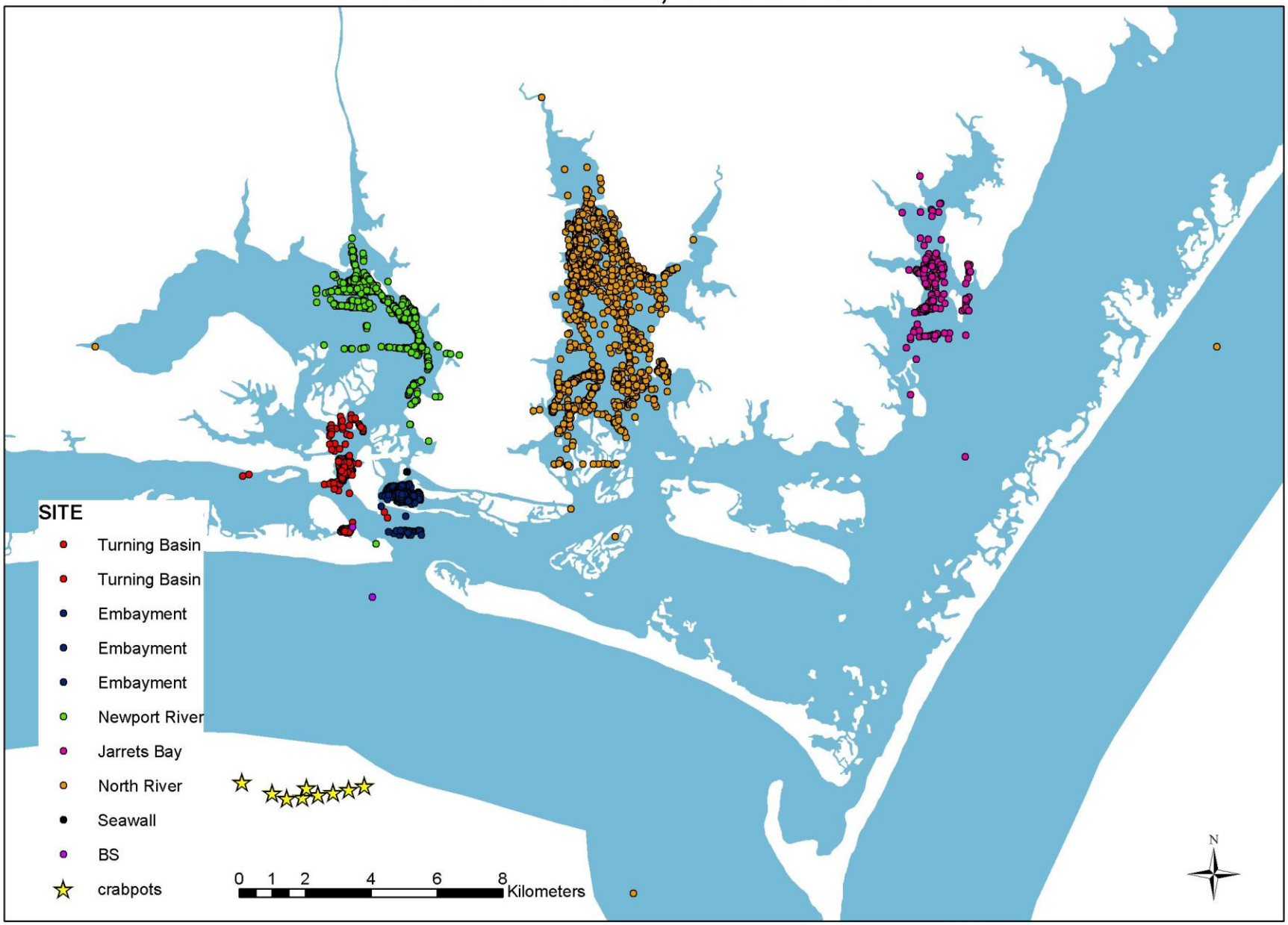
- Migration Out of the Fishery is Rapid
- Females have Multiple Clutches
  - Sojourns in High Salinity till Black Eggs
  - Always move on outgoing tides with Black eggs
- Migration is  OUT with Each Clutch
- Maturation is Continuous.
- Most Reproductive Females are in the Ocean by September
- Females Continue to Spawn in the Ocean

# Issues

- Females should be protected?
- How, when and where to protect females?
- Idea-
  - stop low salinity female fishery except peelers
  - cap high salinity female fishery or have specific closings


Egg Stage
Yellow
Orange
Brown
Black
N
W
E
S
100
0
100 Meters

# All Crab Data, 2000-2002



# Status of the Blue Crab Population in Texas

Mark Fisher, Ph.D.

Science Director, Coastal Fisheries

Texas Parks and Wildlife Department

# Status of the Blue Crab Population in Texas

- Abundance is declining, locally and statewide.
- Mortality (Z) of juveniles increased 1982-2000, steady since 2001.
- Mortality (Z) of subadults and adults is *decreasing.*
- Recruitment of juveniles is the bottleneck.

# TPWD Fishery-Independent Monitoring Program


- Monitor abundance, size and distribution of saltwater finfish and shellfish
- Stratified random sample design
- Standardized methods

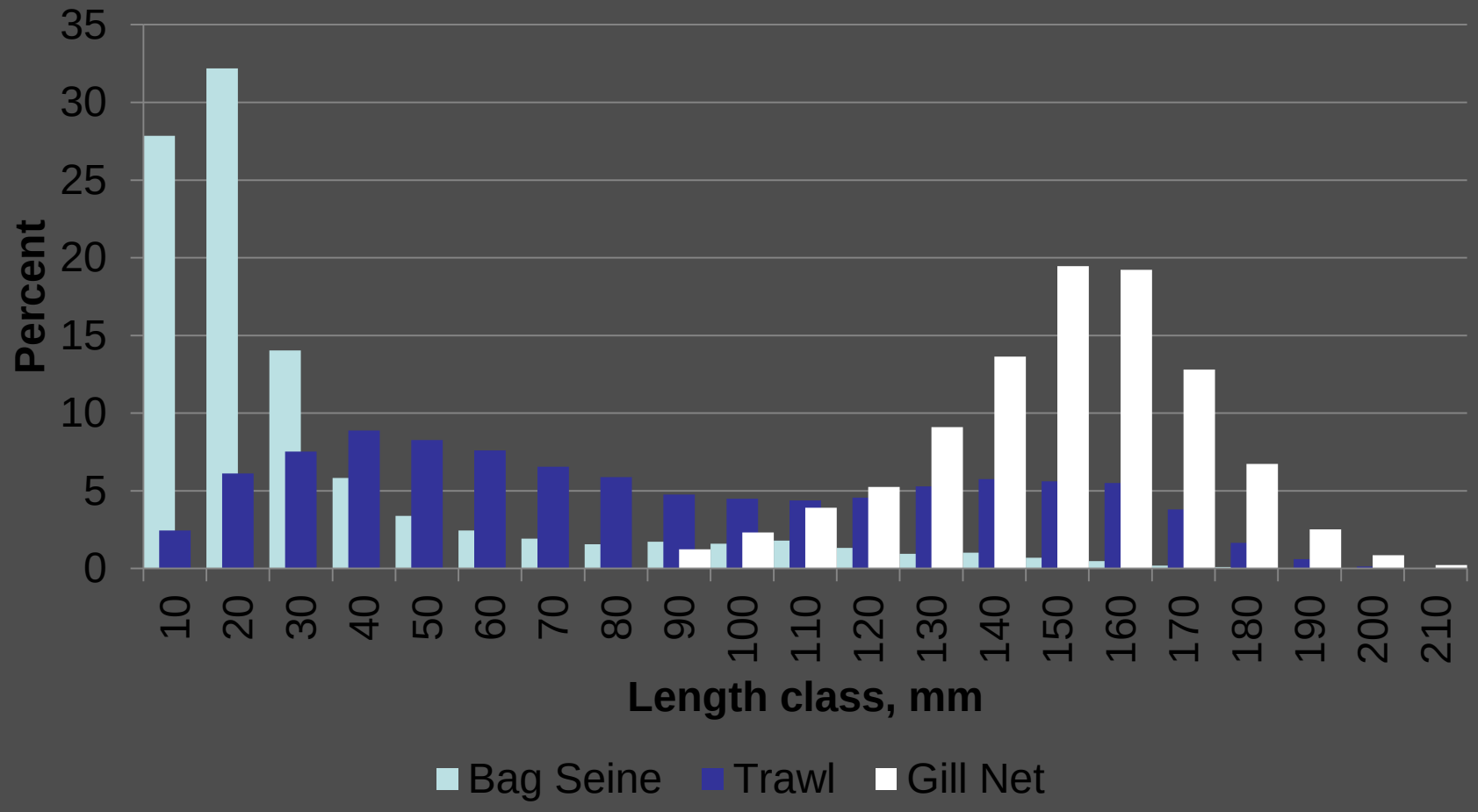
TEXAS PARKS & WILDLIFE

# Fishery-Independent Sampling Gear Used

- Bag Seines
  - Shorelines, 60-feet wide, ½” mesh, 50-foot pulls
  - 20/month/bay; 2,160/year statewide
- Bay Trawls
  - Open water, 20-feet wide, 1 ½” mesh, 10-minute tows
  - 20/month/bay, 1,680/year statewide
- Gill Nets
  - Shorelines, 600-feet long, 3”, 4”, 5” and 6” mesh panels, overnight (~12-hour) sets
  - 45/season/bay (spring and fall only), 780/year statewide

Each gear captures different size classes of crabs

# Lengths of Blue Crabs Captured by Sample Gear



# Length-Based Mortality Estimator

## Hoenig, 1987

$$Z = log_e \frac{\left[\left(e^{-K}\left(\overline{CW} - CW_\infty\right)\right) + CW_\infty - CW_r\right]}{\left(\overline{CW} - CW_r\right)}$$

K = Brody Growth Coefficient = 0.663

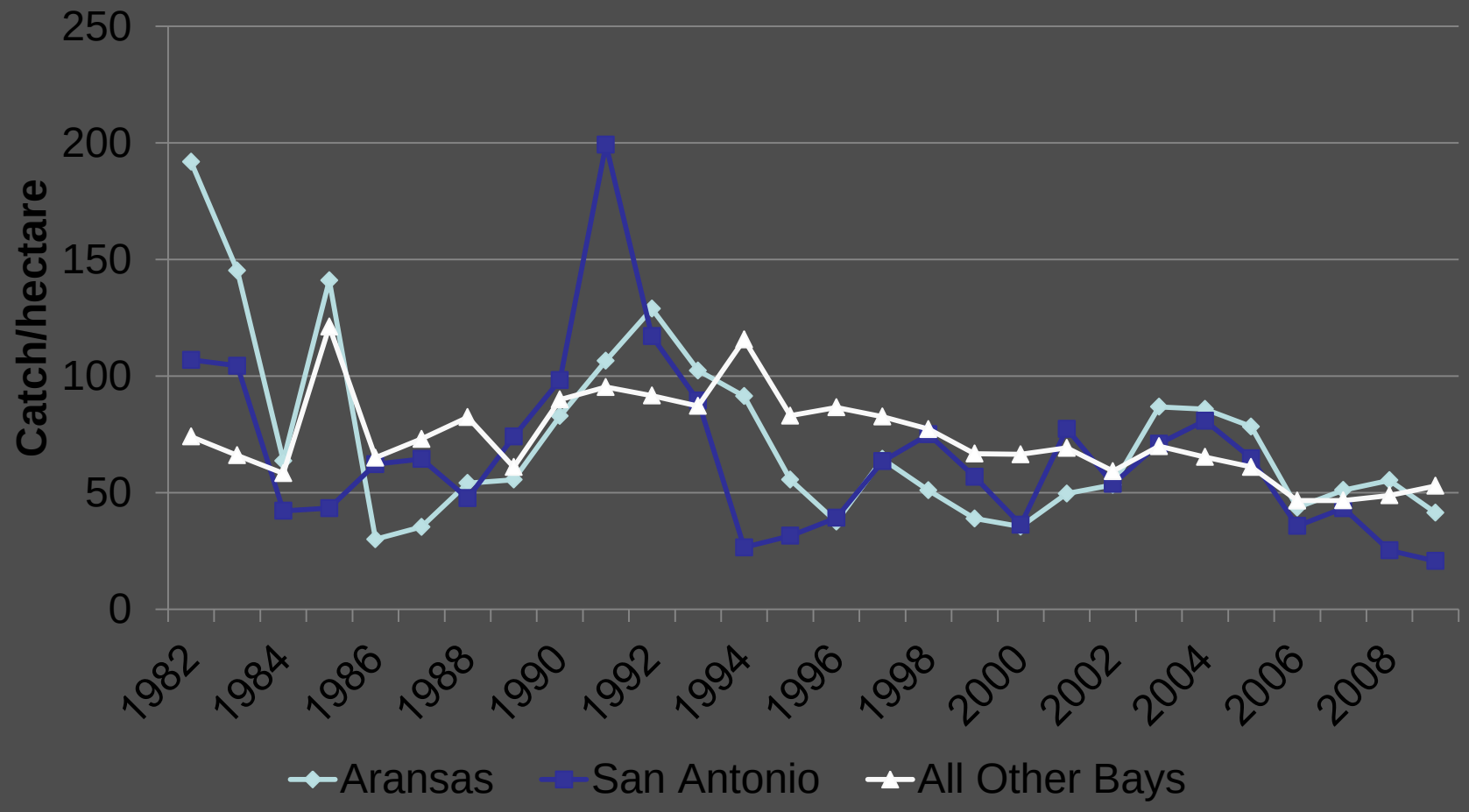
$CW_\infty$ = Asymptotic Maximum Length = 268 mm

$CW_r$ = Size at full recruitment = 15mm for bag seines

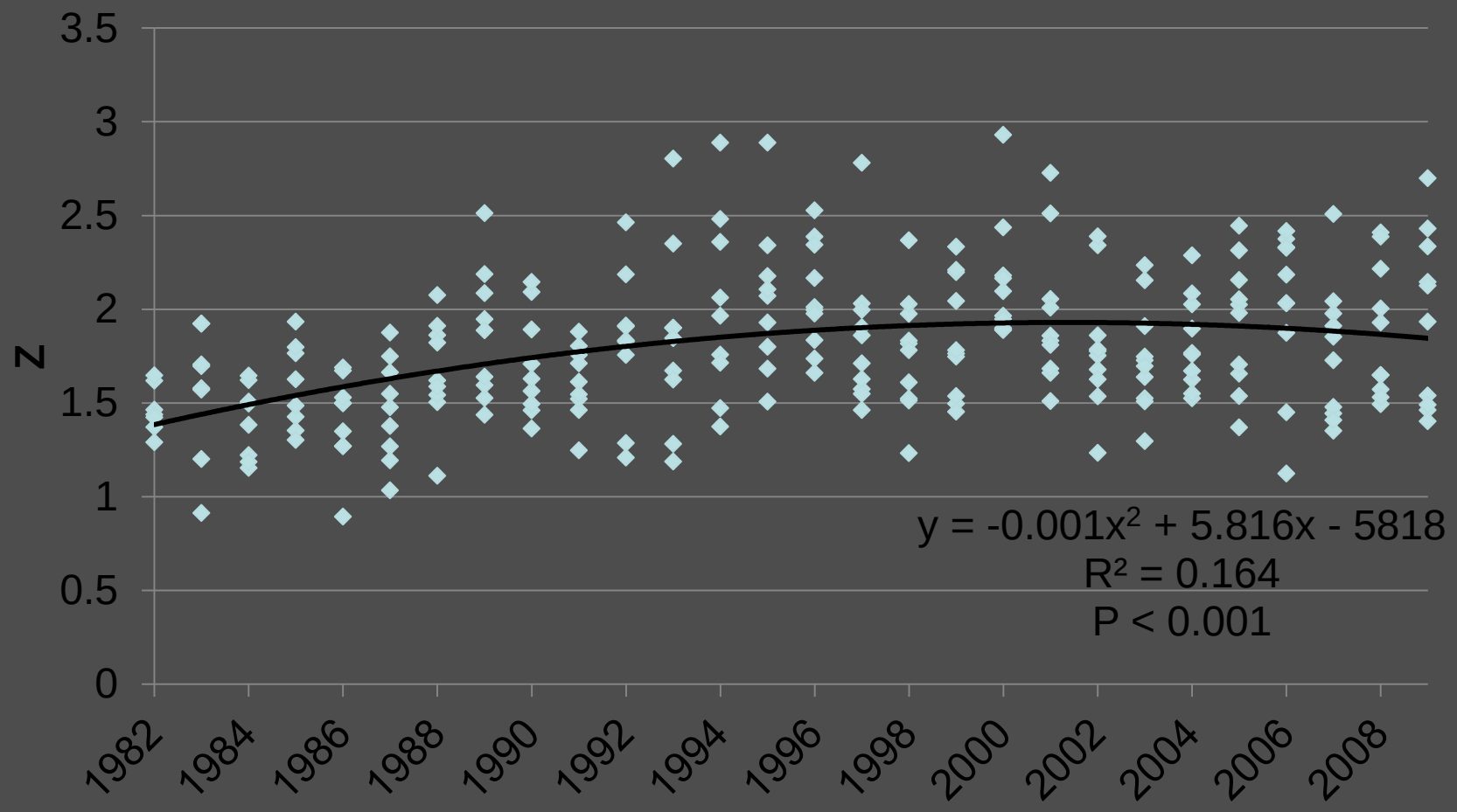
$CW_r$ = 40 mm for trawls

$CW_r$ = 120 mm for gill nets

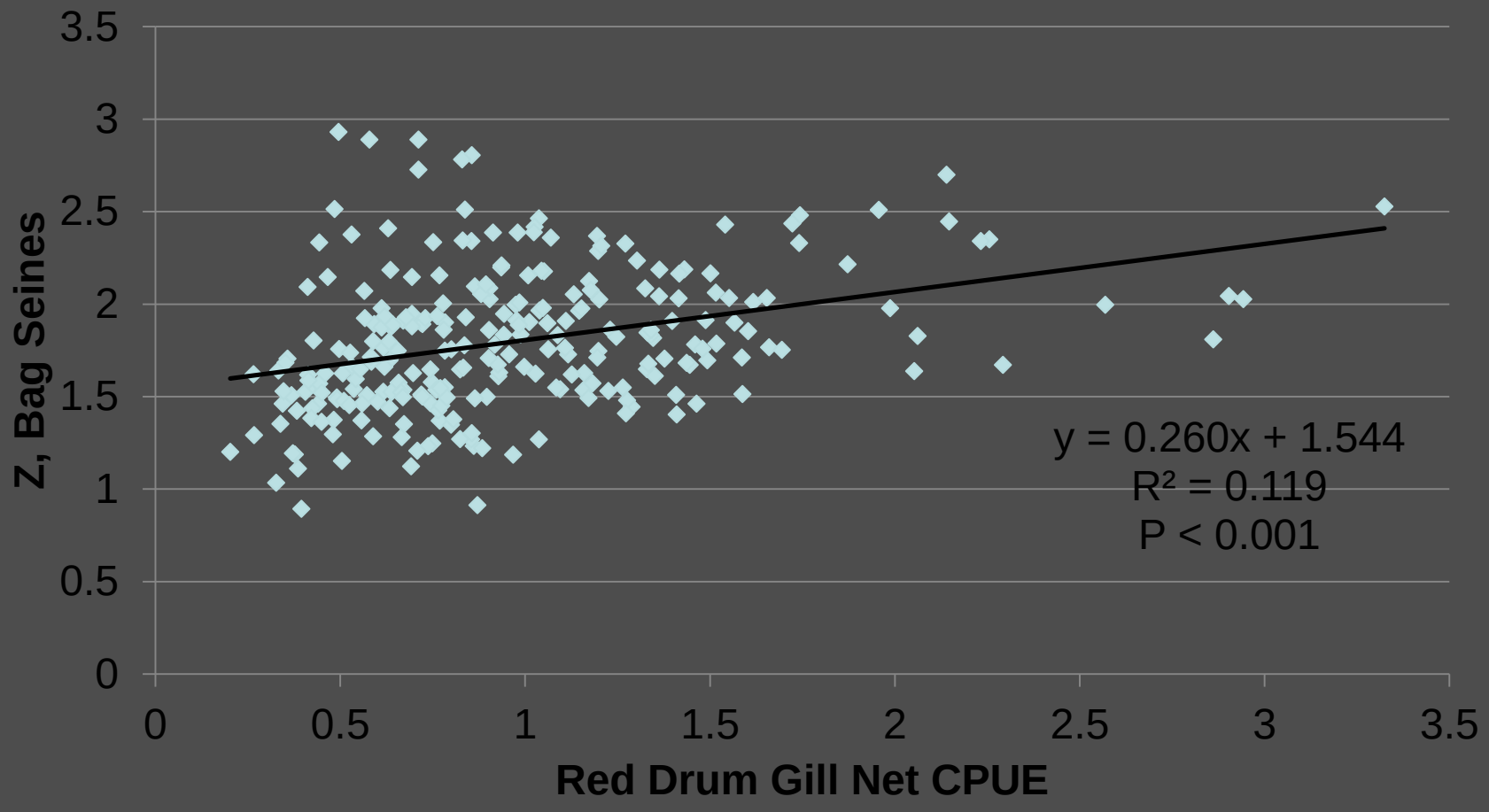
# Annual Bag Seine CPUE
# Blue Crabs



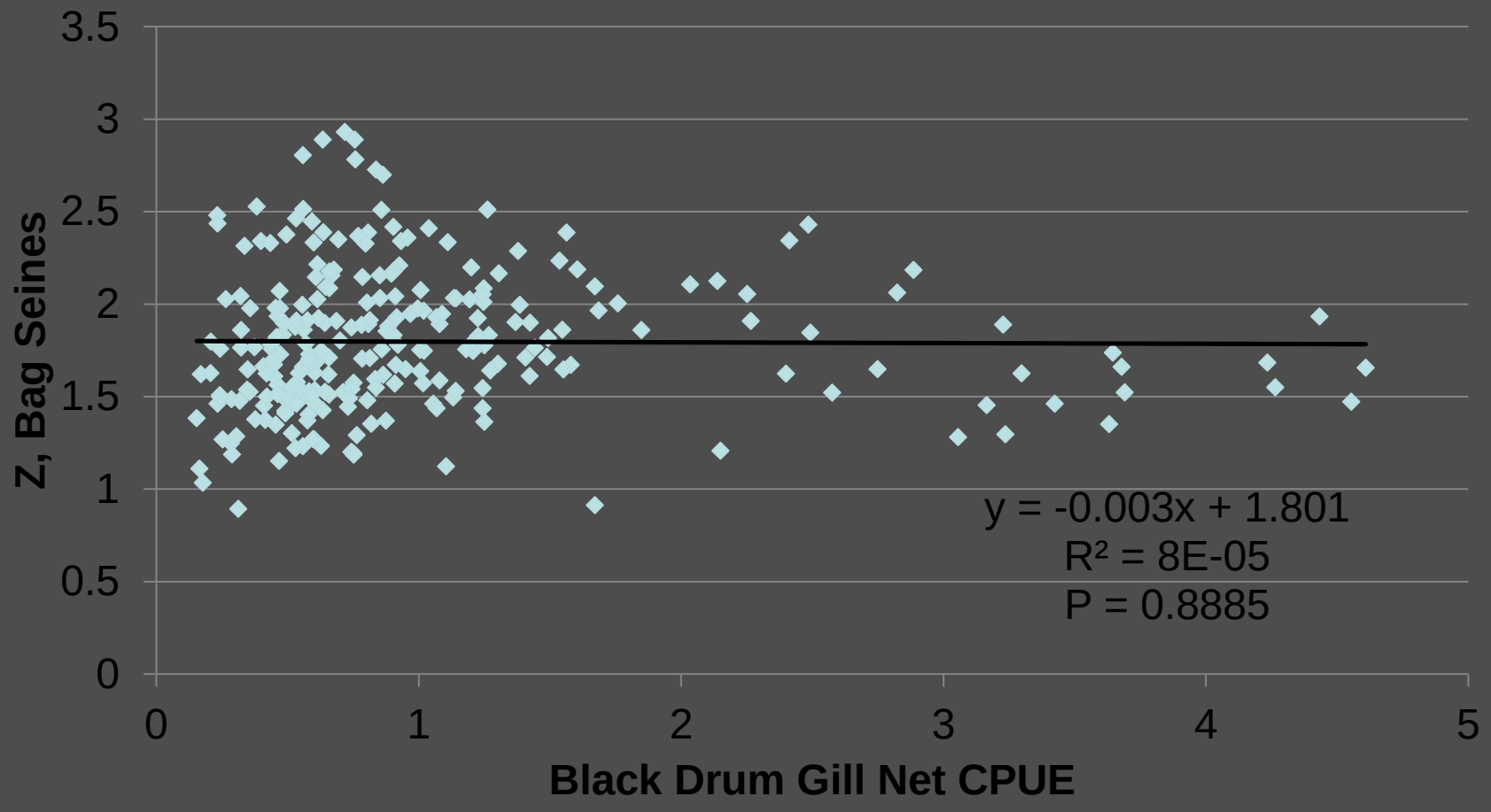
# Blue Crab Mortality Estimates, Bag Seines, All Bays Included



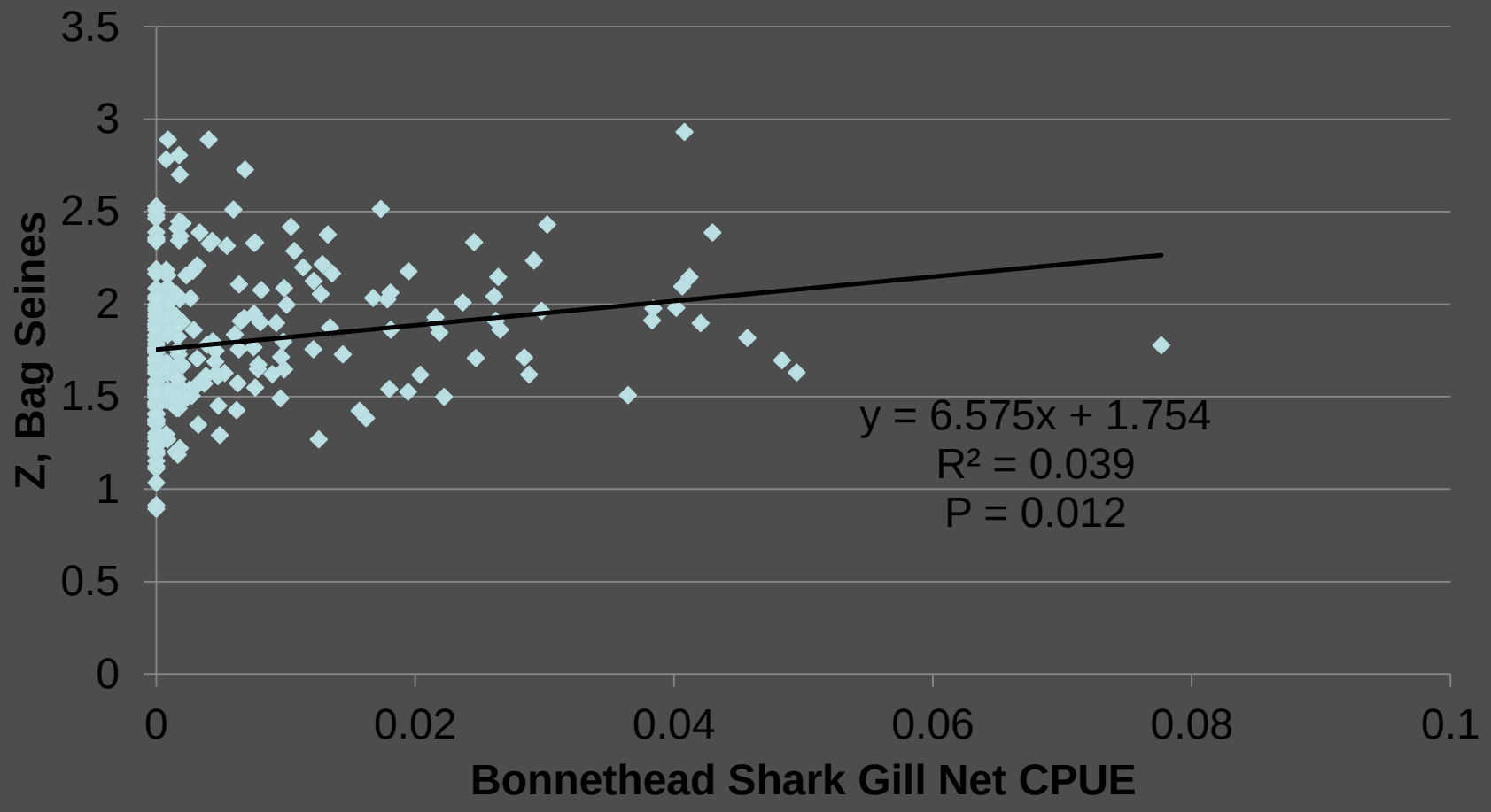
# Blue Crab Mortality Estimates vs Abundance of Red Drum



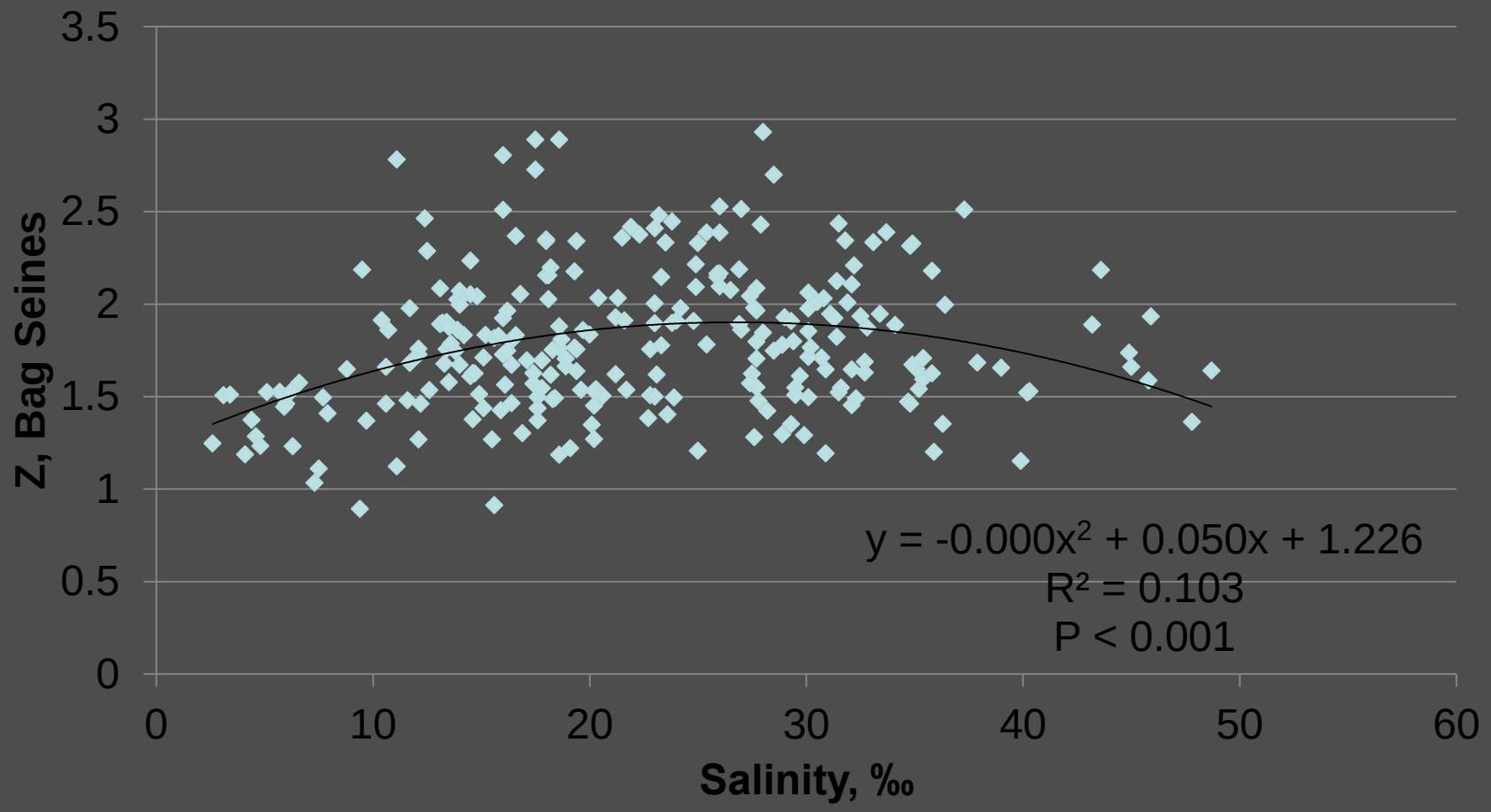
# Blue Crab Mortality Estimates vs Abundance of Black Drum



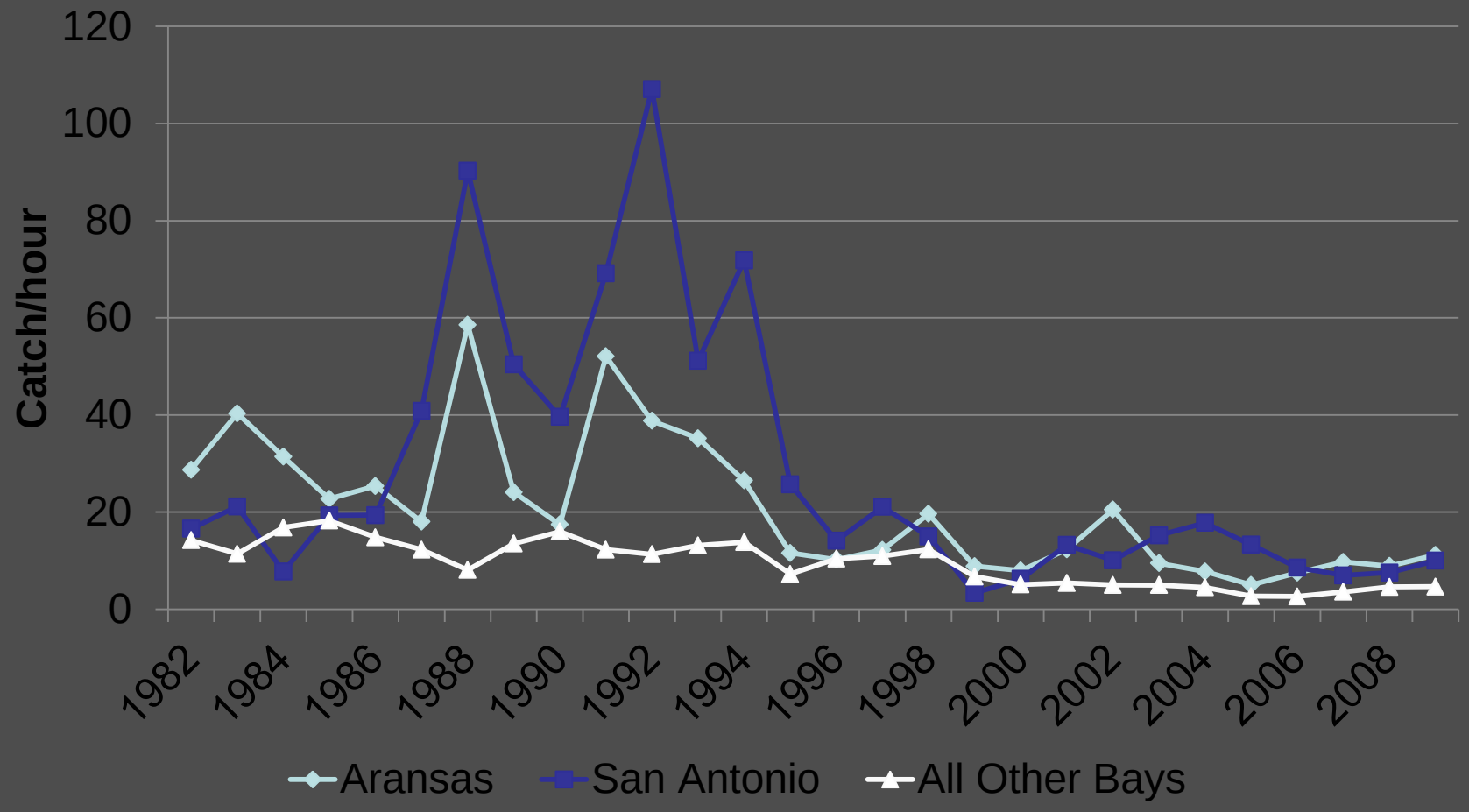
# Blue Crab Mortality Estimates vs Abundance of Bonnethead Sharks



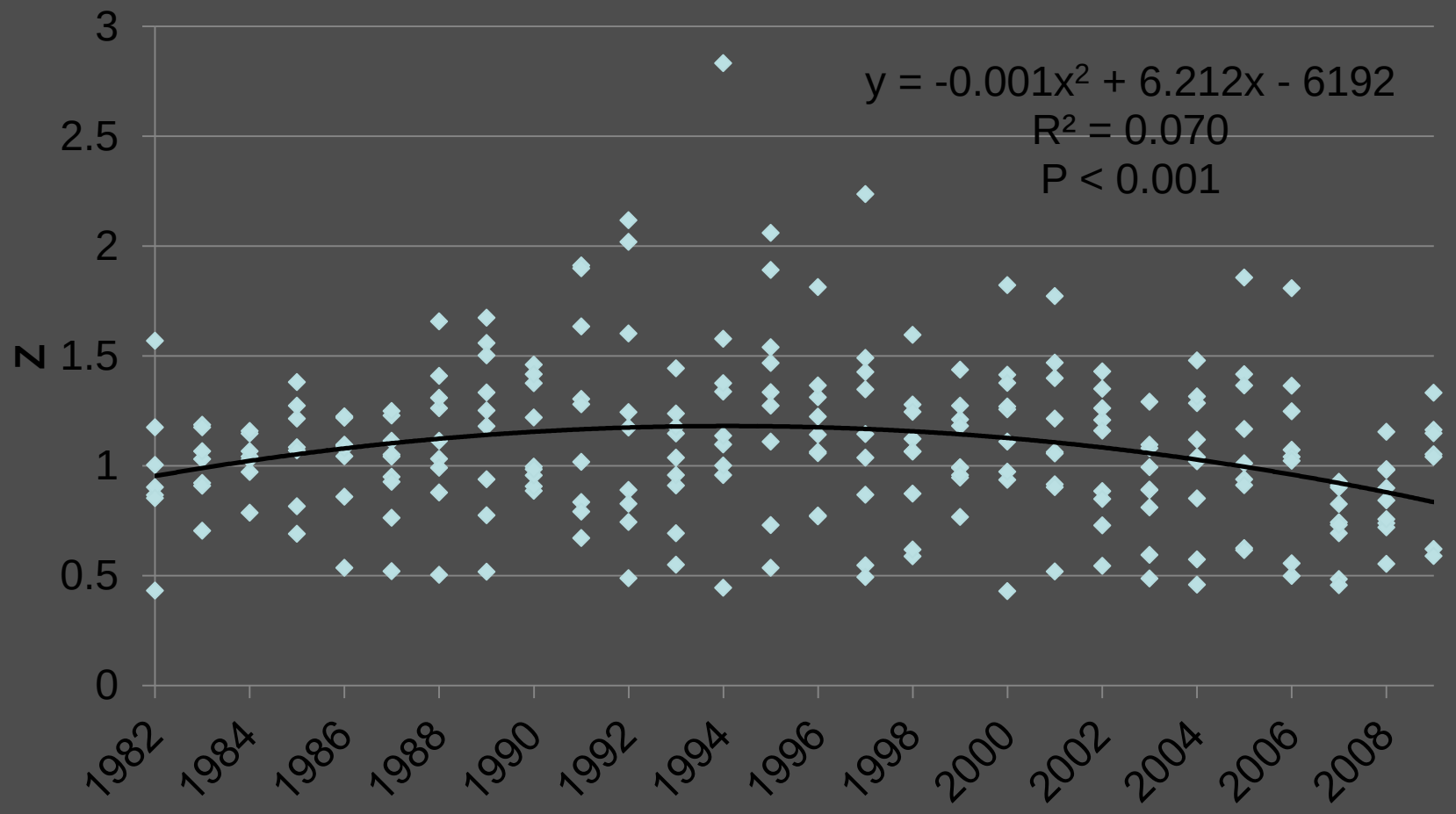
# Blue Crab Mortality Estimates vs Salinity, All Bays Included



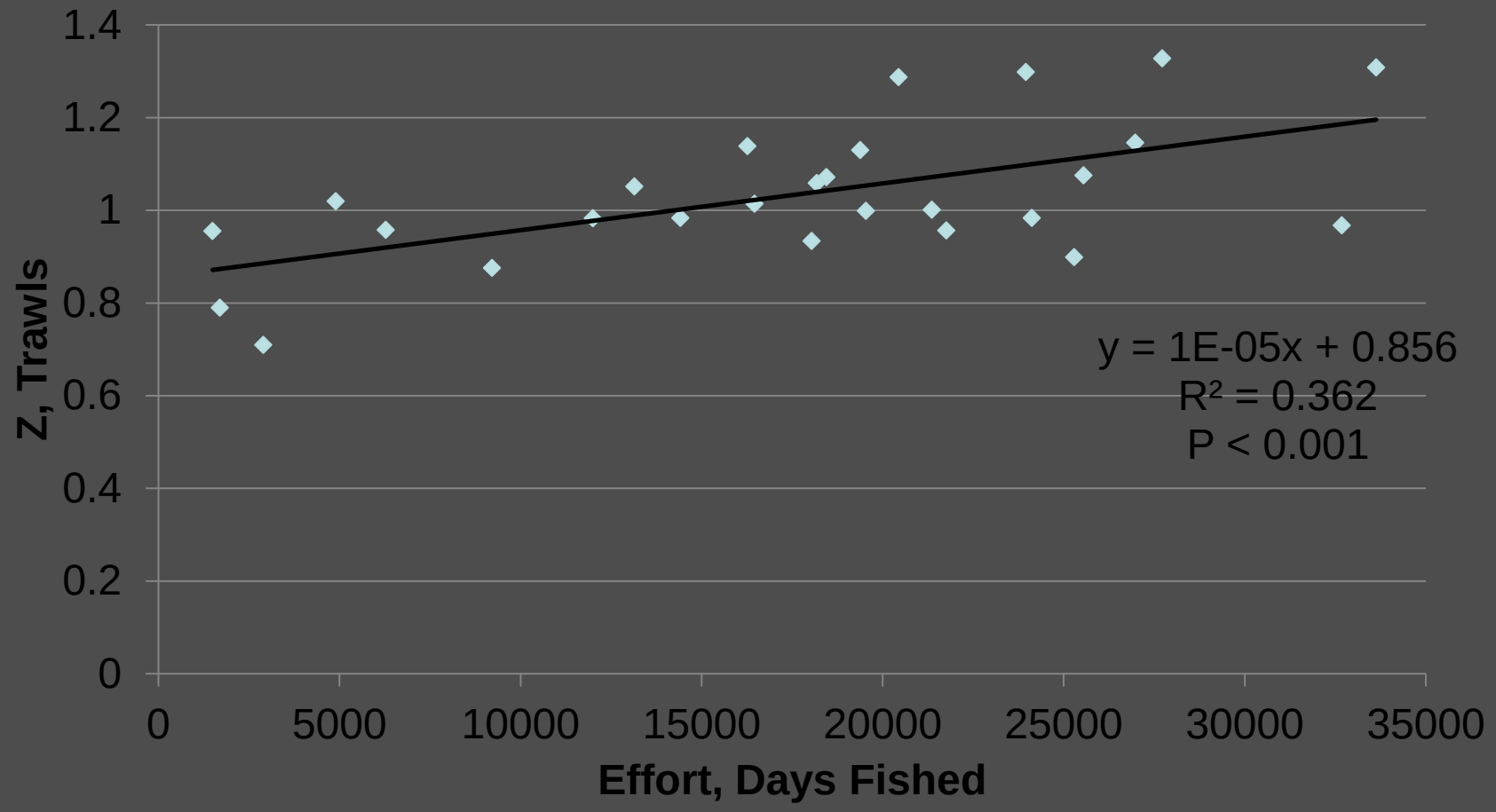
# Annual Bay Trawl CPUE
# Blue Crabs



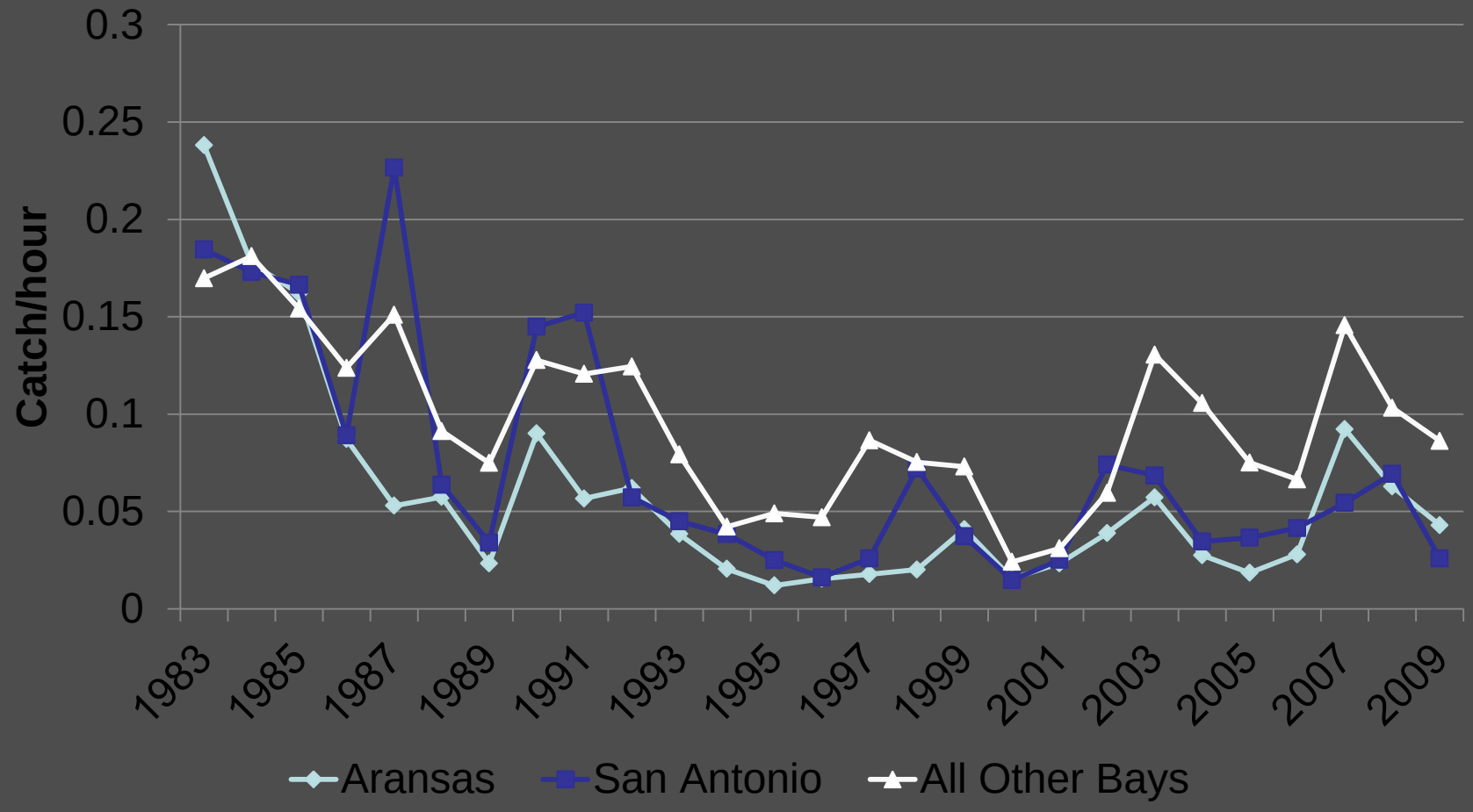
# Blue Crab Mortality Estimates, Bay Trawls, All Bays Included



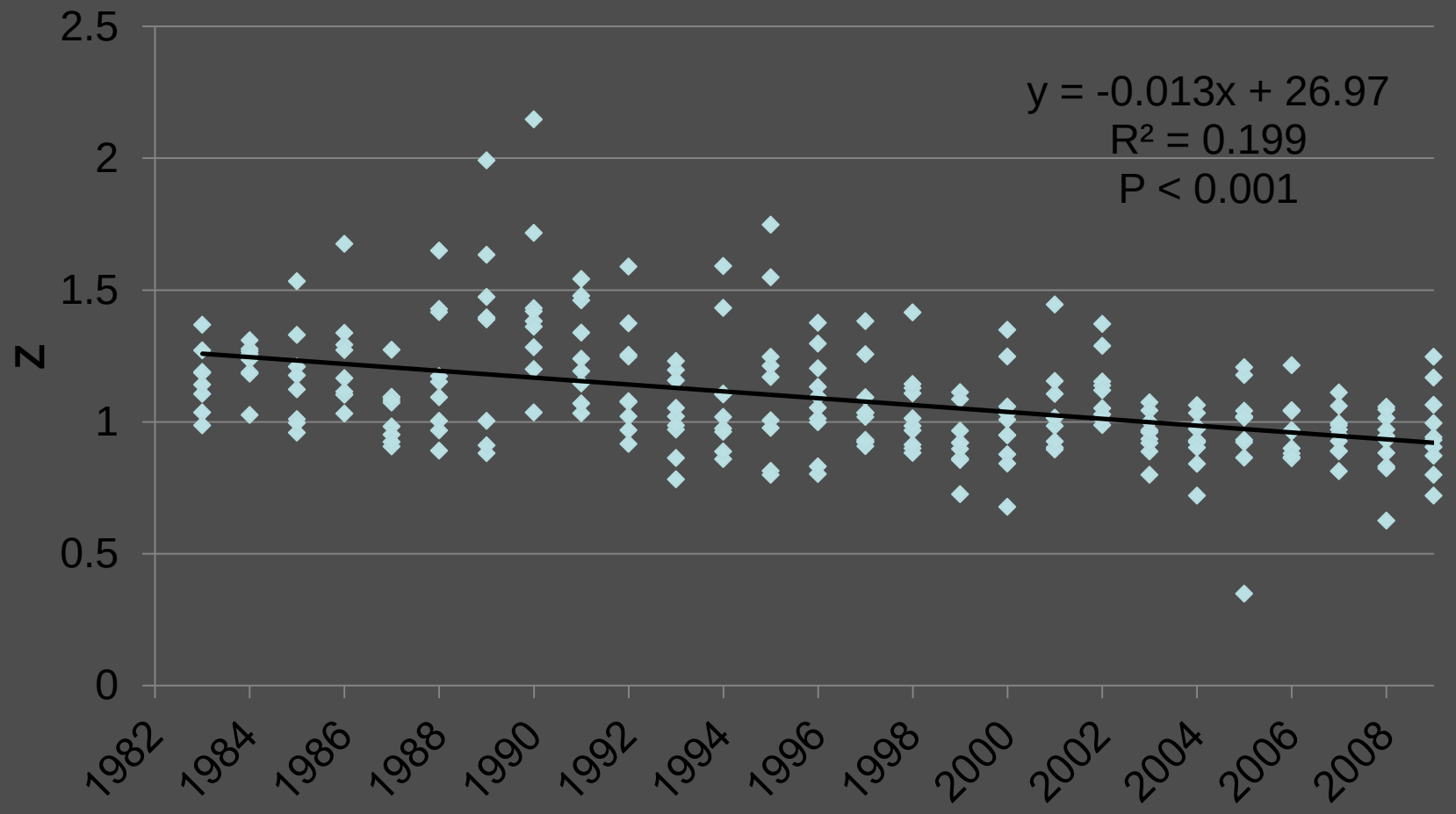
# Blue Crab Mortality vs Coastwide Commercial Shrimping Effort



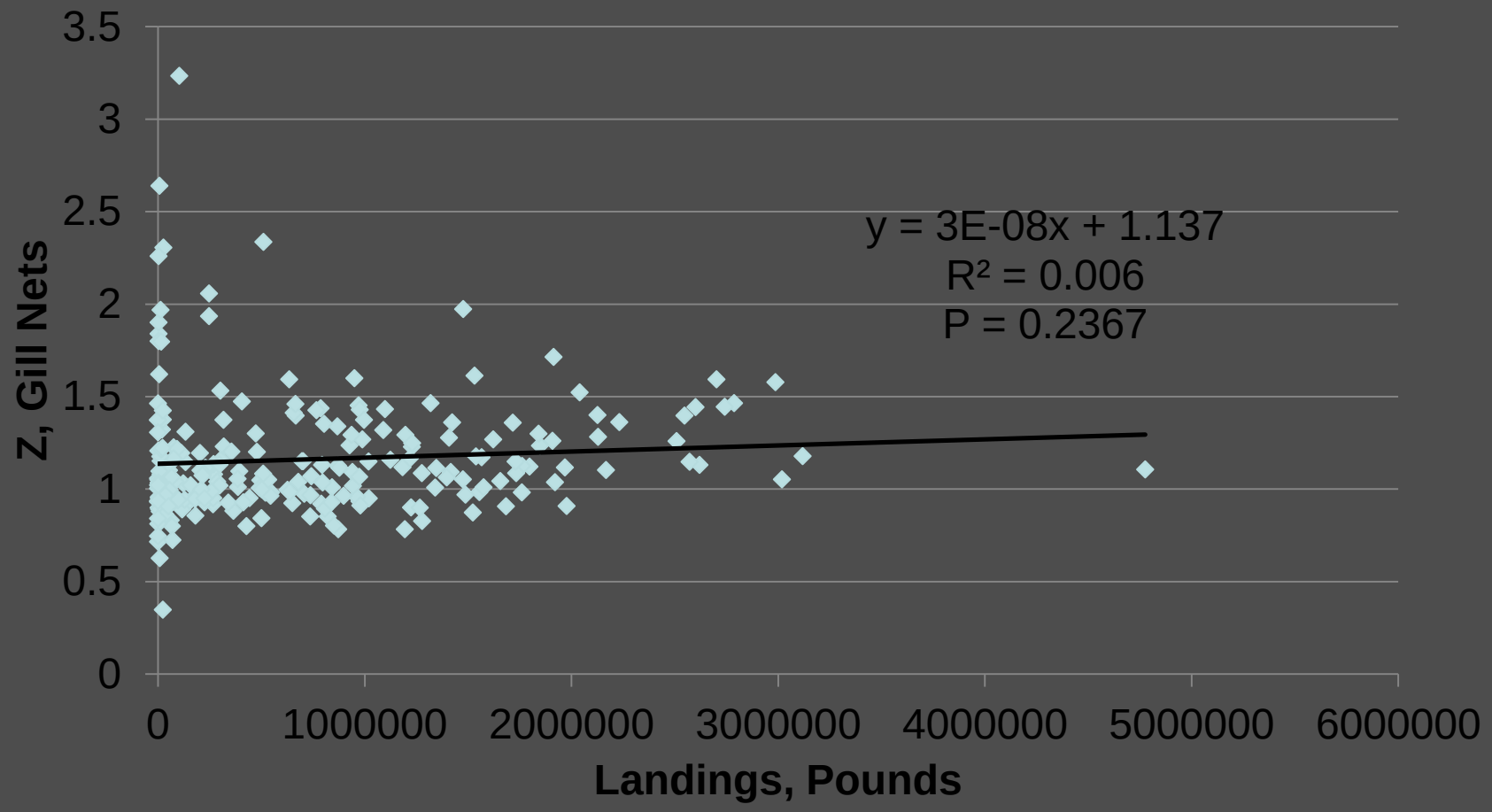
# Annual Gill Net CPUE
# Blue Crabs



# Blue Crab Mortality Estimates, Gill Nets, All Bays Included



# Blue Crab Mortality Estimates vs Commercial Crab Landings



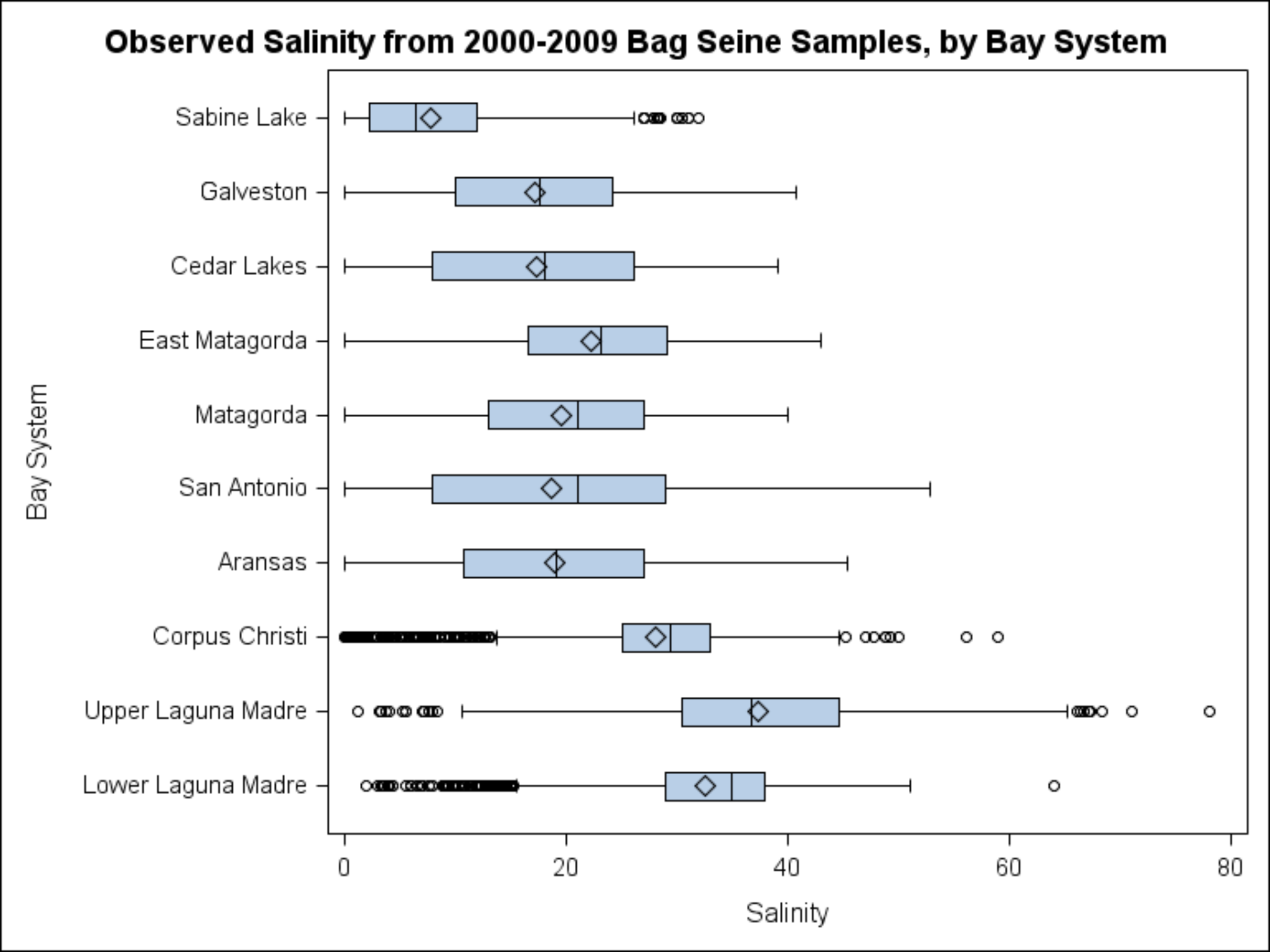
# Summary

- Abundance is declining, locally and statewide.
- Mortality (Z) of juveniles increased 1982-2000, steady since 2001.
- Mortality (Z) of subadults and adults is *decreasing.*
- Recruitment of juveniles is the bottleneck.

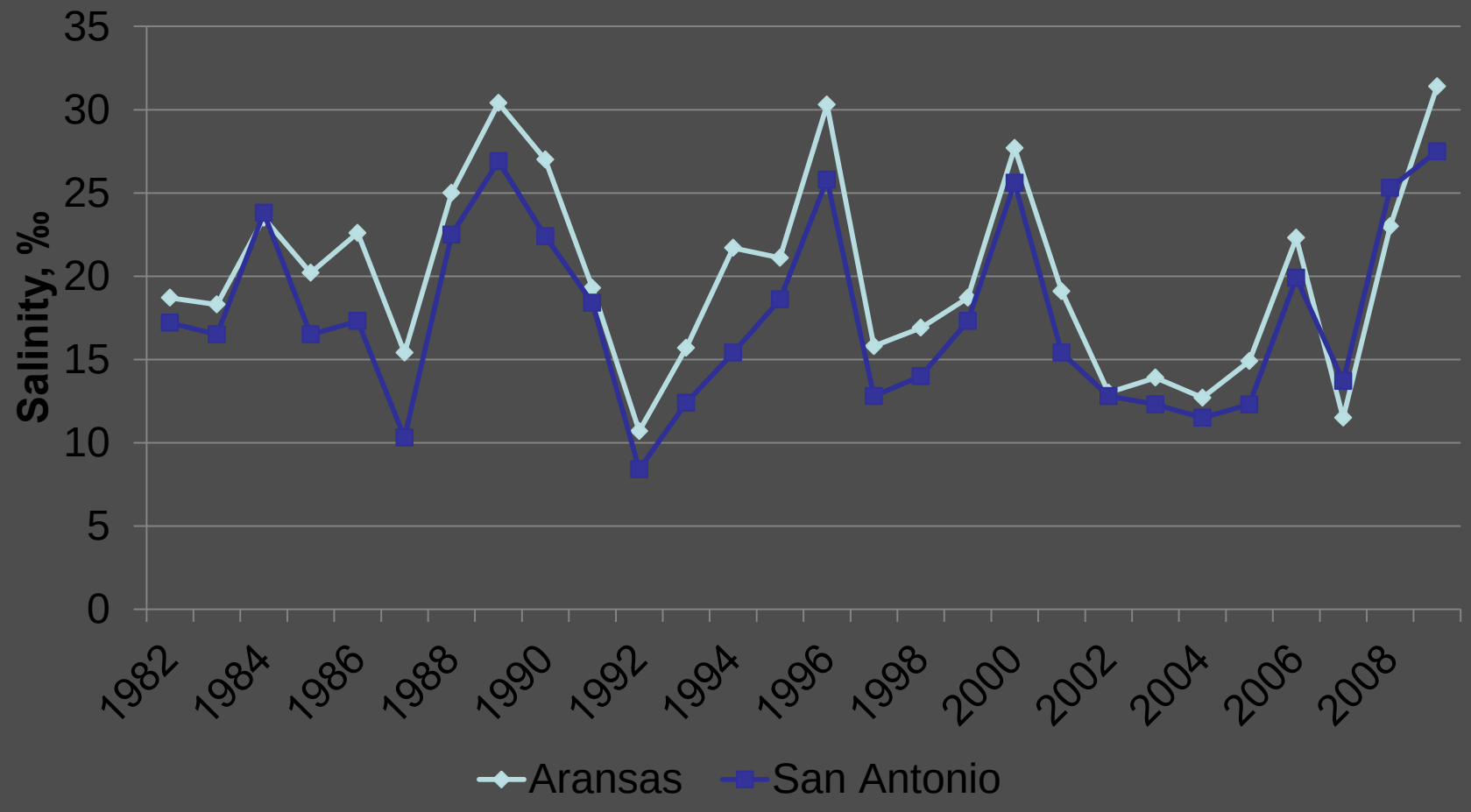
TEXAS

PARKS &

WILDLIFE

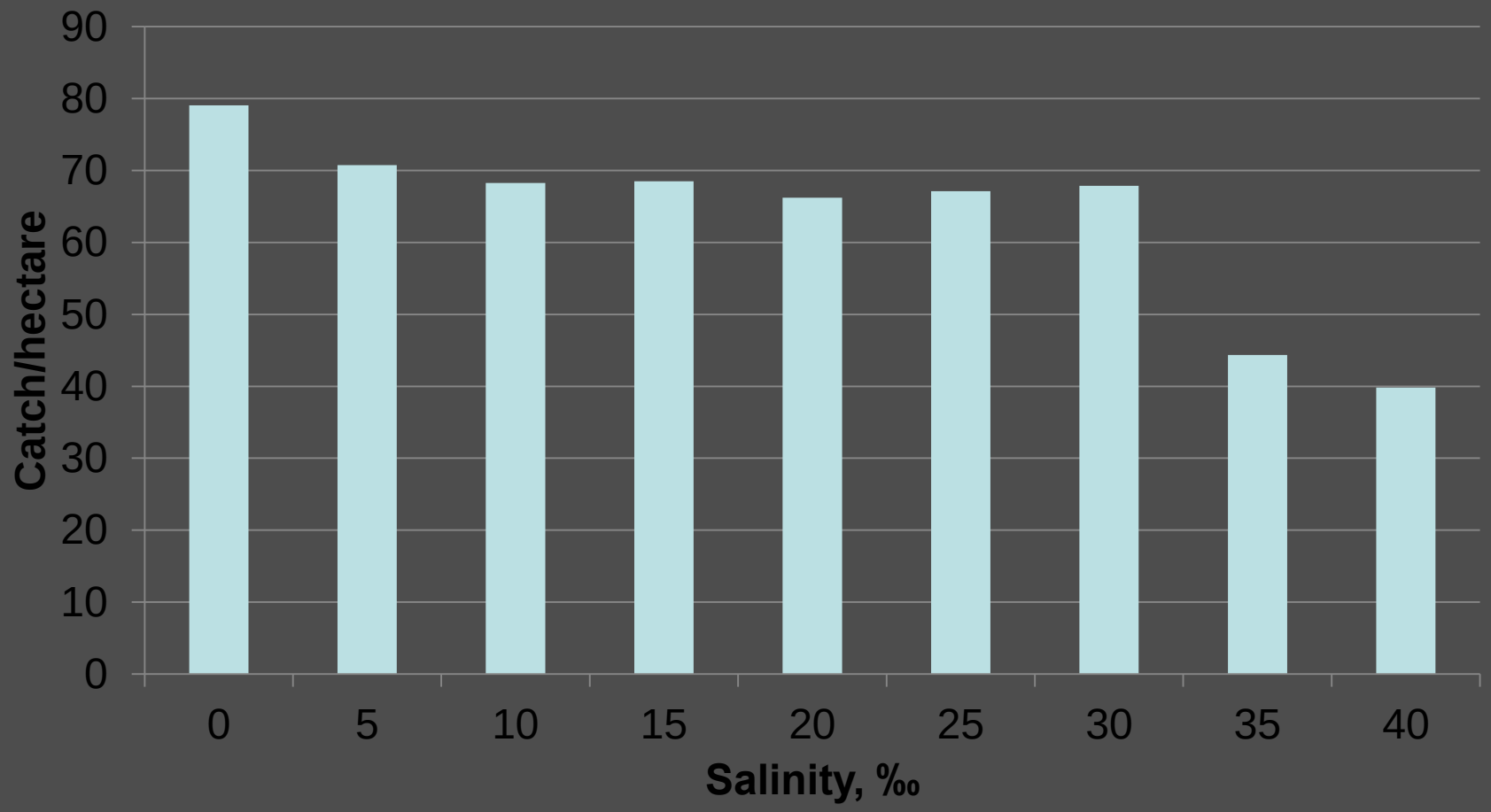

Observed Salinity from 2000-2009 Bag Seine Samples, by Bay System
Sabine Lake
Galveston
Cedar Lakes
East Matagorda
Matagorda
San Antonio
Aransas
Corpus Christi
Upper Laguna Madre
Lower Laguna Madre
Bay System
0
20
40
60
80
Salinity

# Annual Mean Salinity



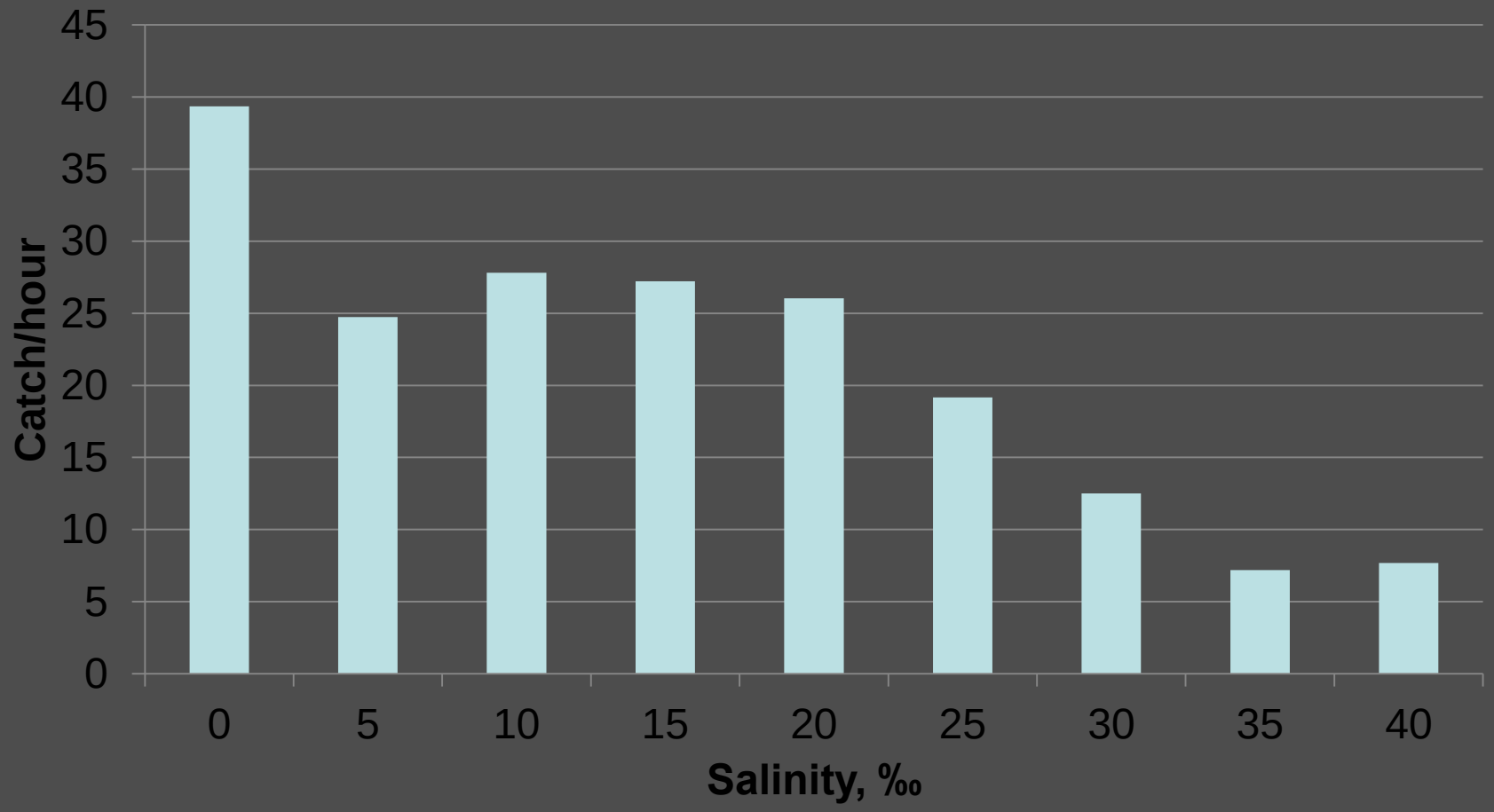

From bag seine and bay trawl samples

# Blue Crab Bag Seine CPUE by Salinity



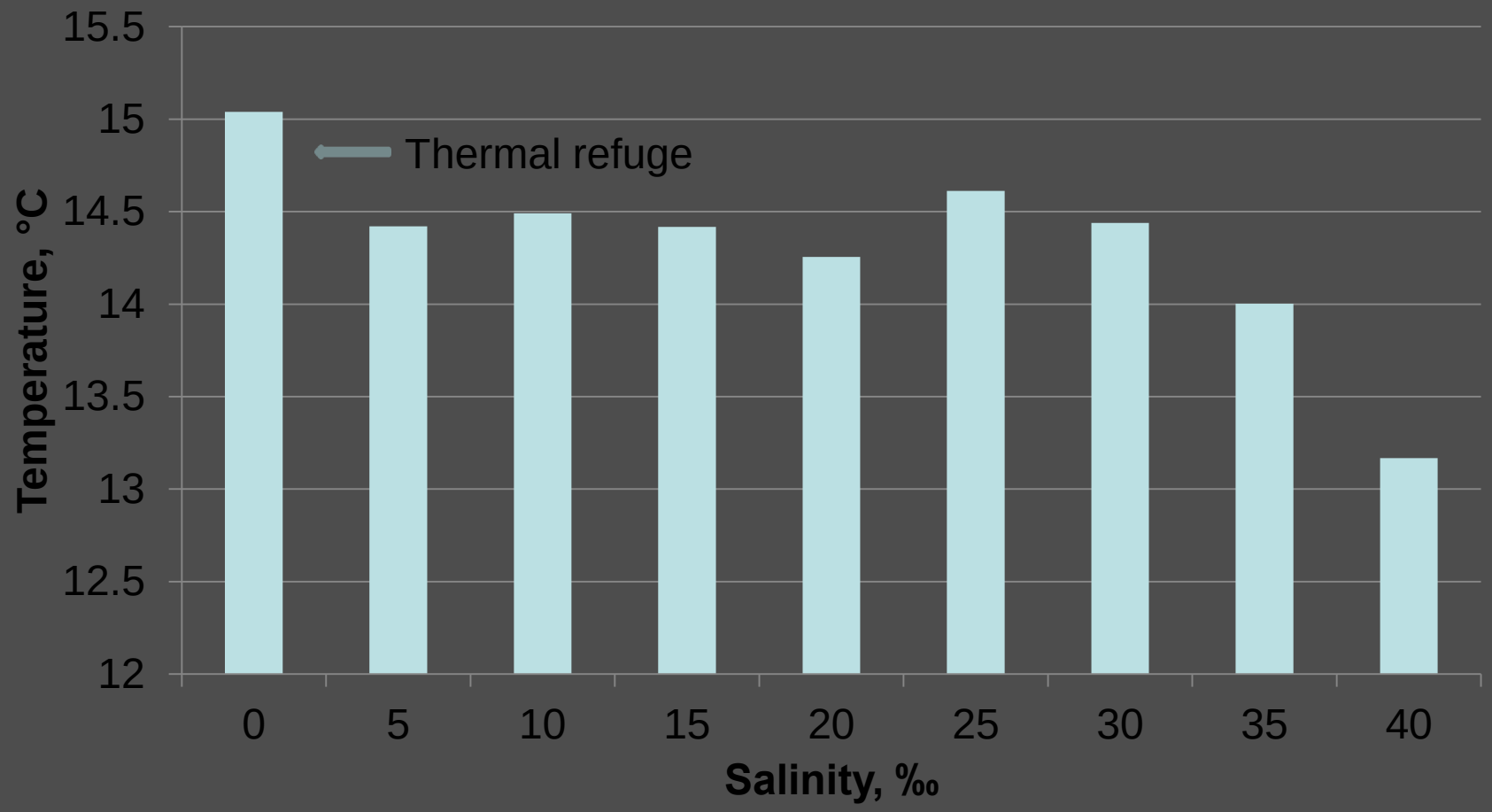

Aransas and San Antonio Bays combined

# Blue Crab Bay Trawl CPUE by Salinity



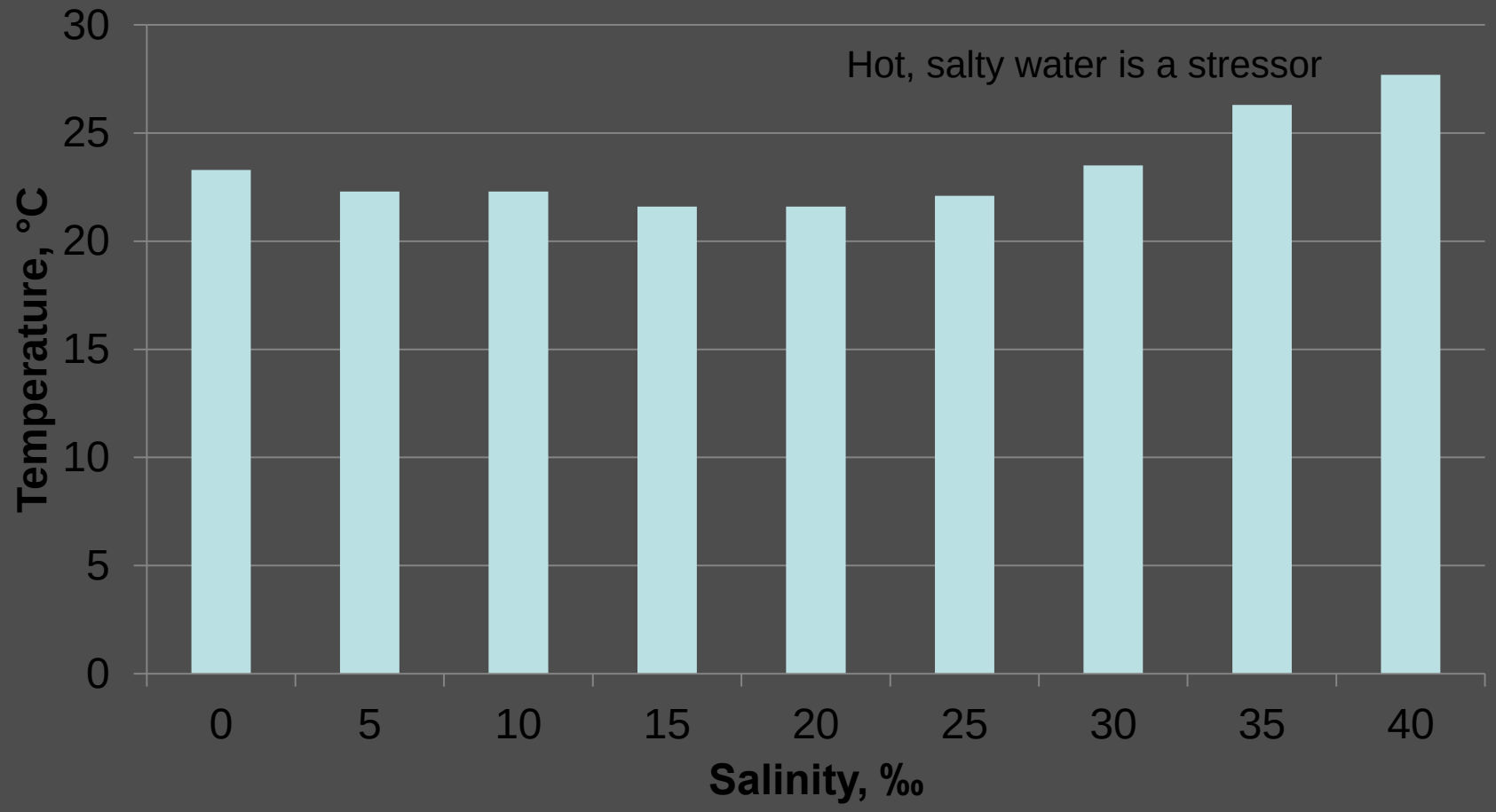

Aransas and San Antonio Bays combined

# Dec-Feb Mean Water Temperature by Salinity

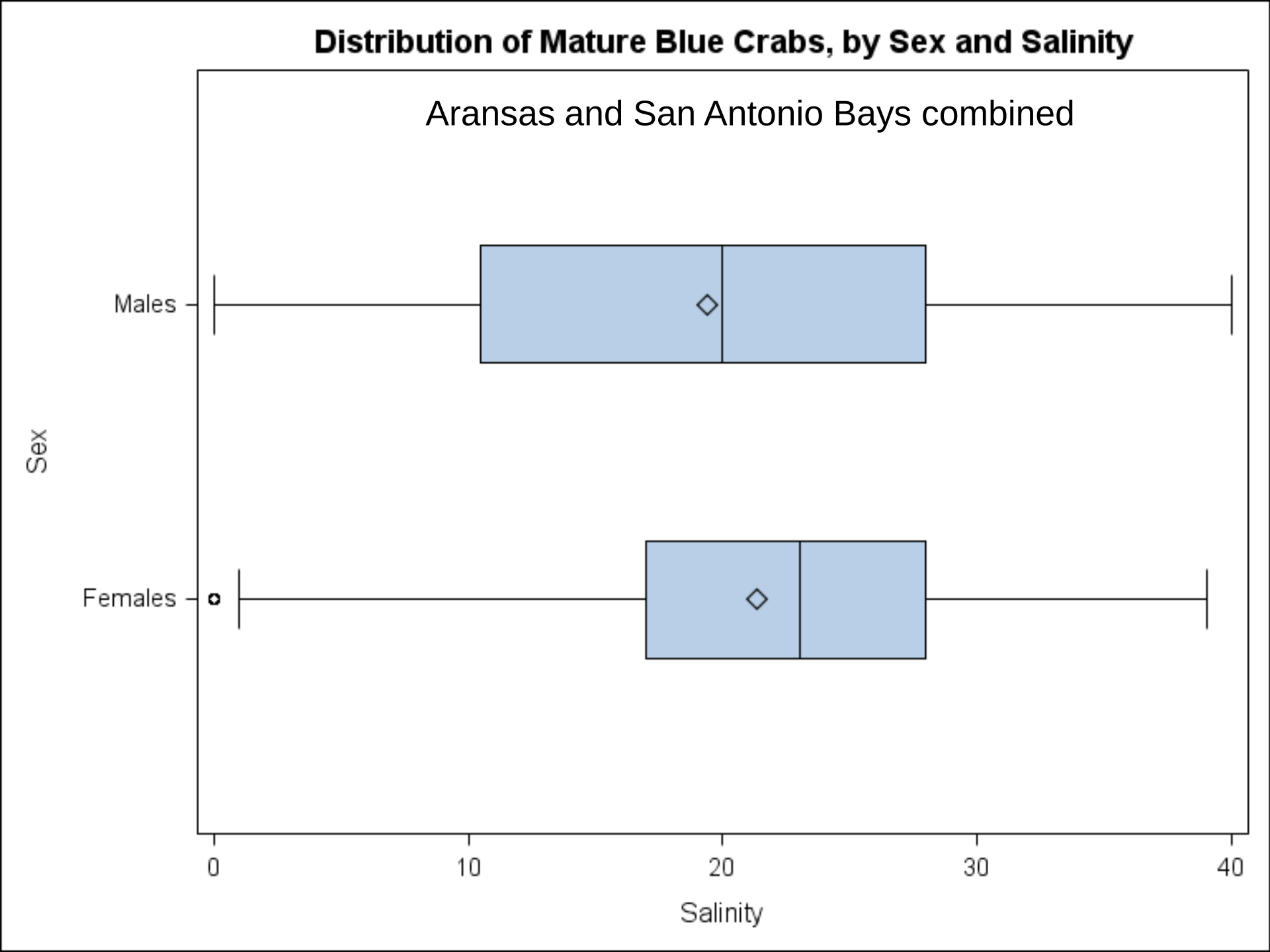



Aransas and San Antonio Bays combined

# Annual Mean Water Temperature by Salinity




Aransas and San Antonio Bays combined


Distribution of Mature Blue Crabs, by Sex and Salinity
Aransas and San Antonio Bays combined
Males
Females
Sex
0
10
20
30
40
Salinity

# Summary

- Blue crabs are declining in abundance along the Texas coast
- Blue crabs have a wide salinity tolerance
- Temperature can influence blue crab distributions
- Blue crabs are not a good indicator species for freshwater inflows

# Foraging Ecology of the Whooping Crane: Winter Range

Liz Smith, Ph.D.

International Crane Foundation

&

Center for Coastal Studies, TAMU-CC

# Whooping Crane

- **Height:** ~5 ft.
- **Weight:** ~1
- **Wingspan:**
- White with
  wingtips

http://www.savingcranes.org/whoopingcrane.html

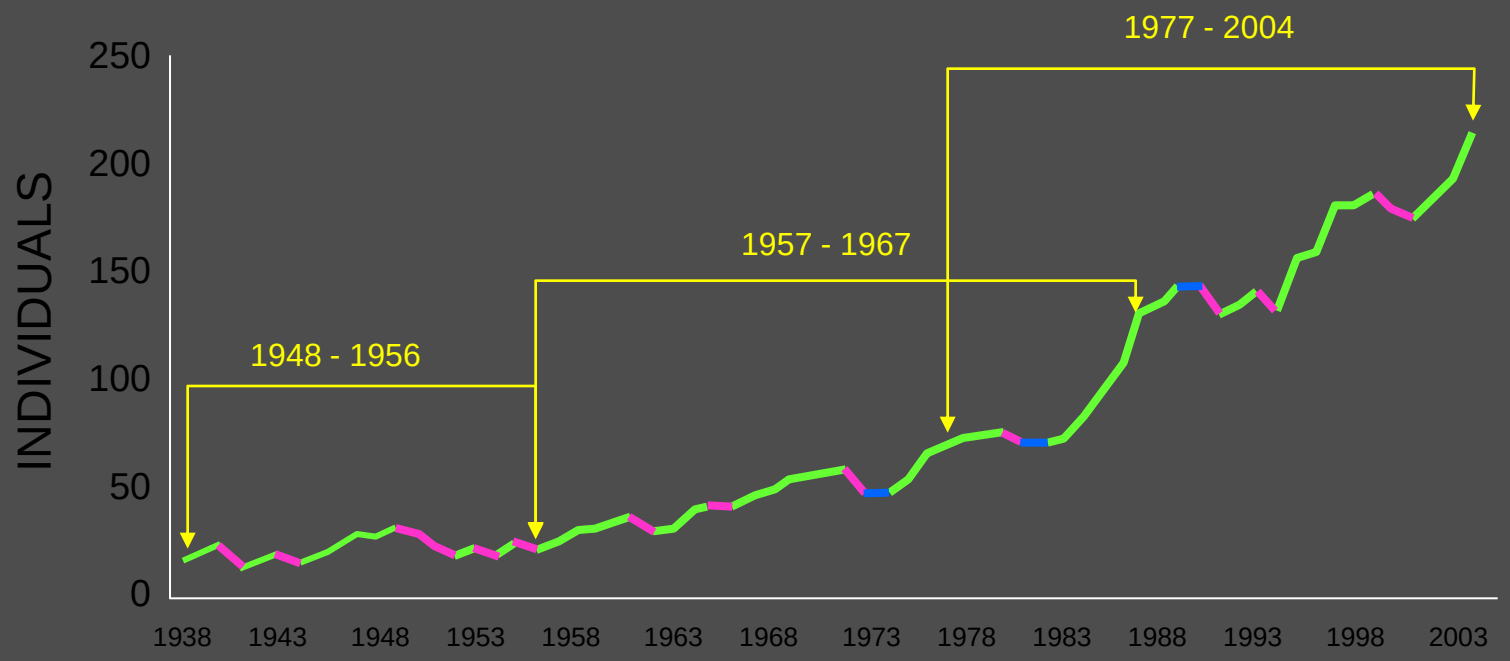
# Whooping Crane

# Whooping Crane

- **Height:** ~5 ft.
- **Weight:** ~14-17 lbs.
- **Wingspan:** ~7-8 ft
- **Population:** ~400
- Natural Pop: ~270
- **Trend:** Increasing
- Status: Endangered

http://www.savingcranes.org/whoopingcrane.html

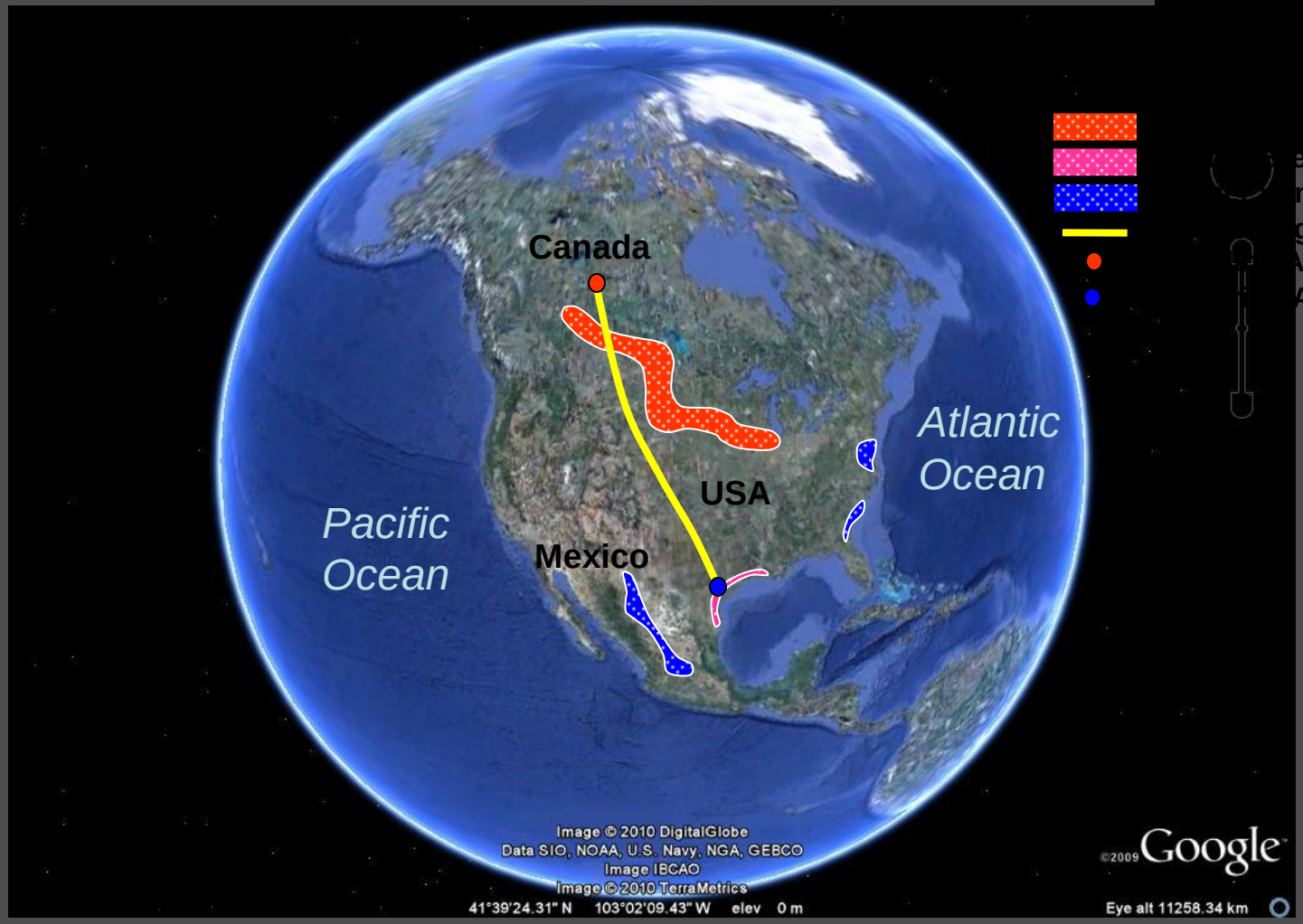
# Whooping Crane Population Dynamics: 1938 - 2004




Three General Growth Phases Green-growth, pink-decline, blue-stability

Gil de Weir (2006)

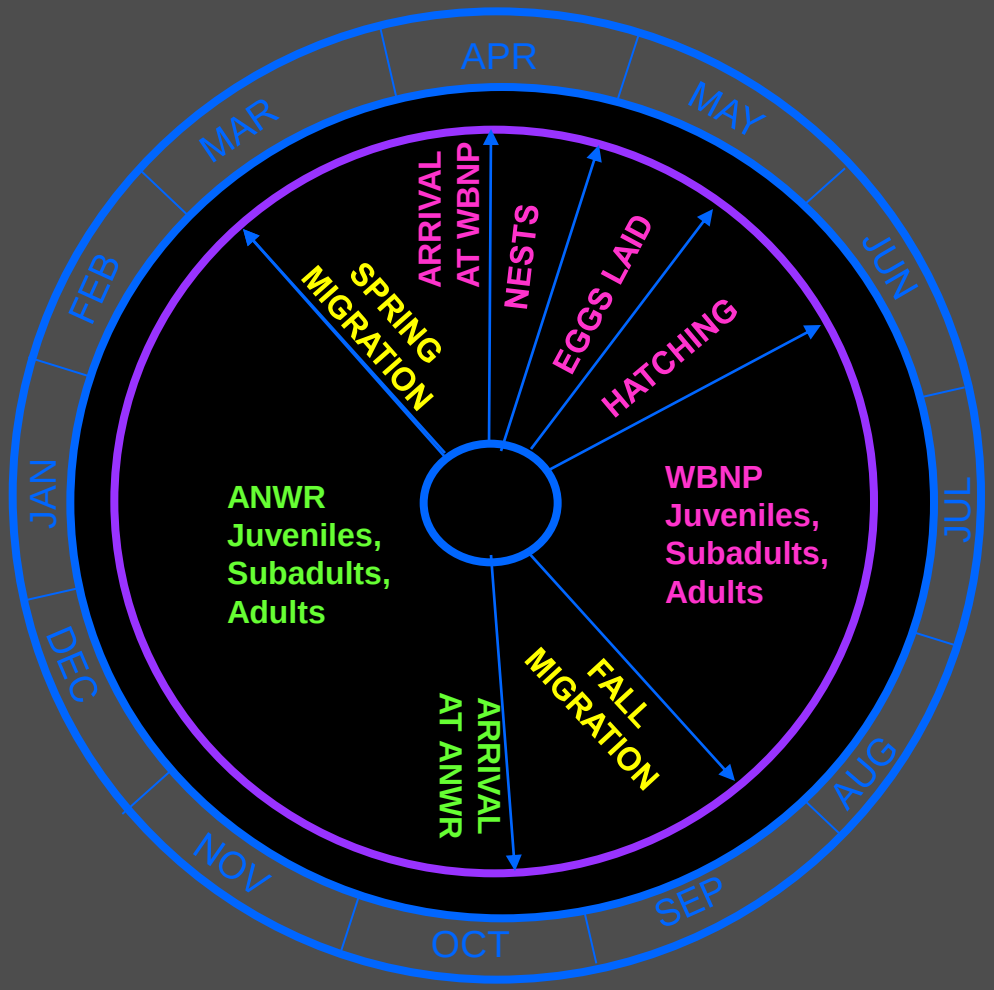
# Whooping Crane
# Historical & Current Range



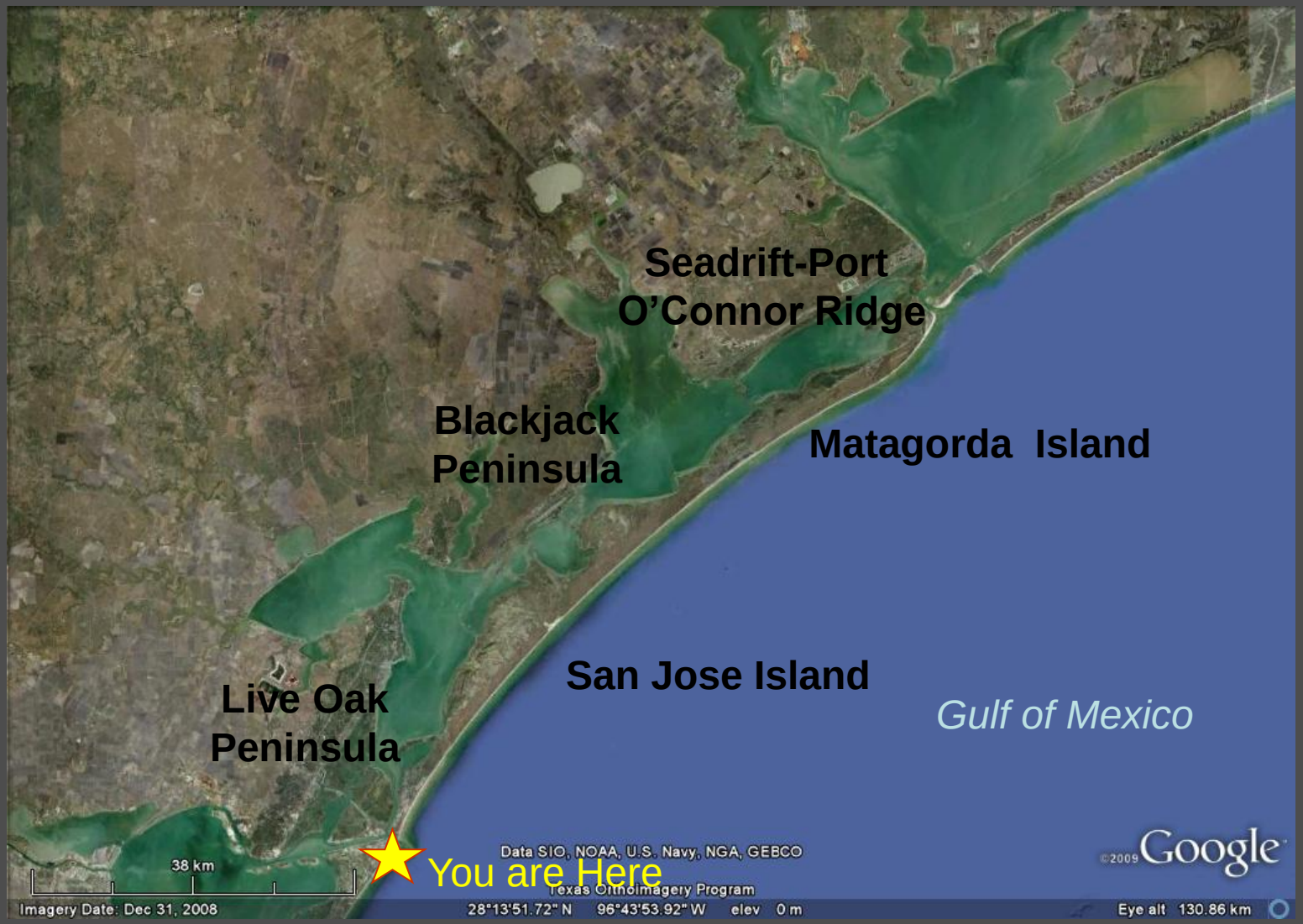

rea
eeding & Wintering Area
ntering Area
gration Route
rea in Wood Buffalo NP
Area in Aransas NWR

http://www.hww.ca/hww2.asp?id=79

# Whooping Crane Annual Cycle



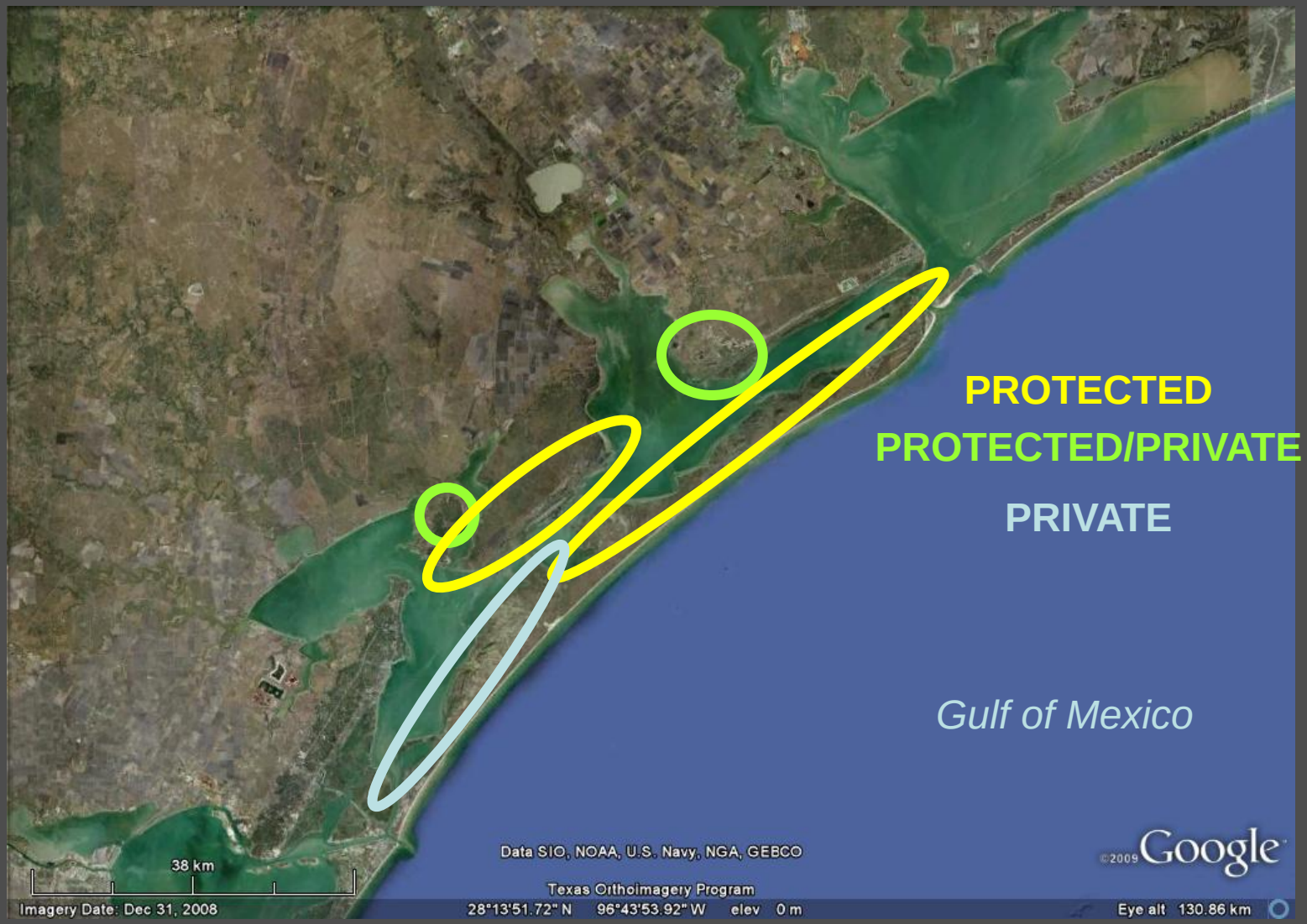

# Central Texas Coast: Landforms



# Central Texas Coast: Estuaries

# Central Texas Coast: Gulf Passes

# Whooping Crane Wintering Range

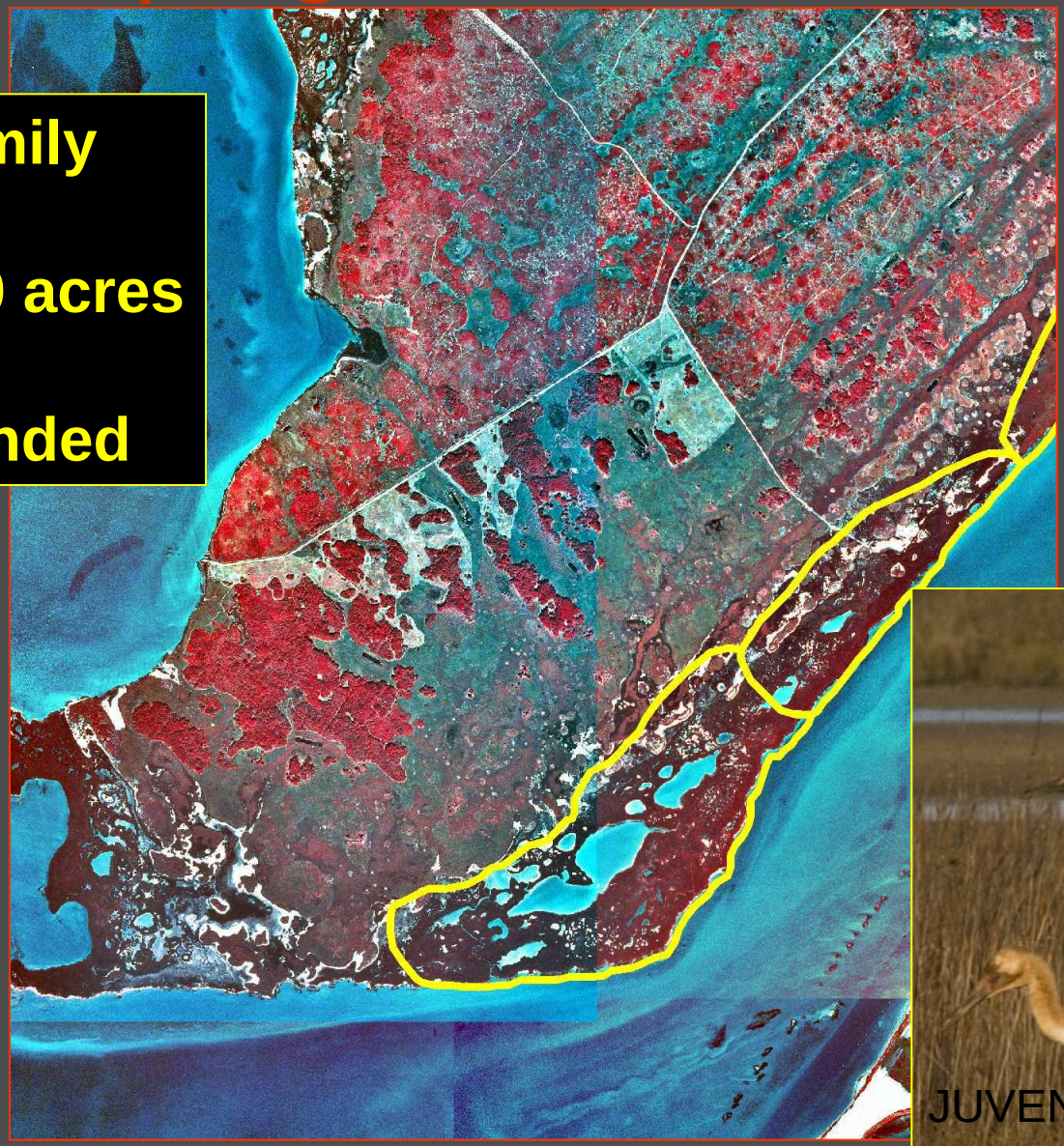


# Whooping Crane Territories

**1 Family**

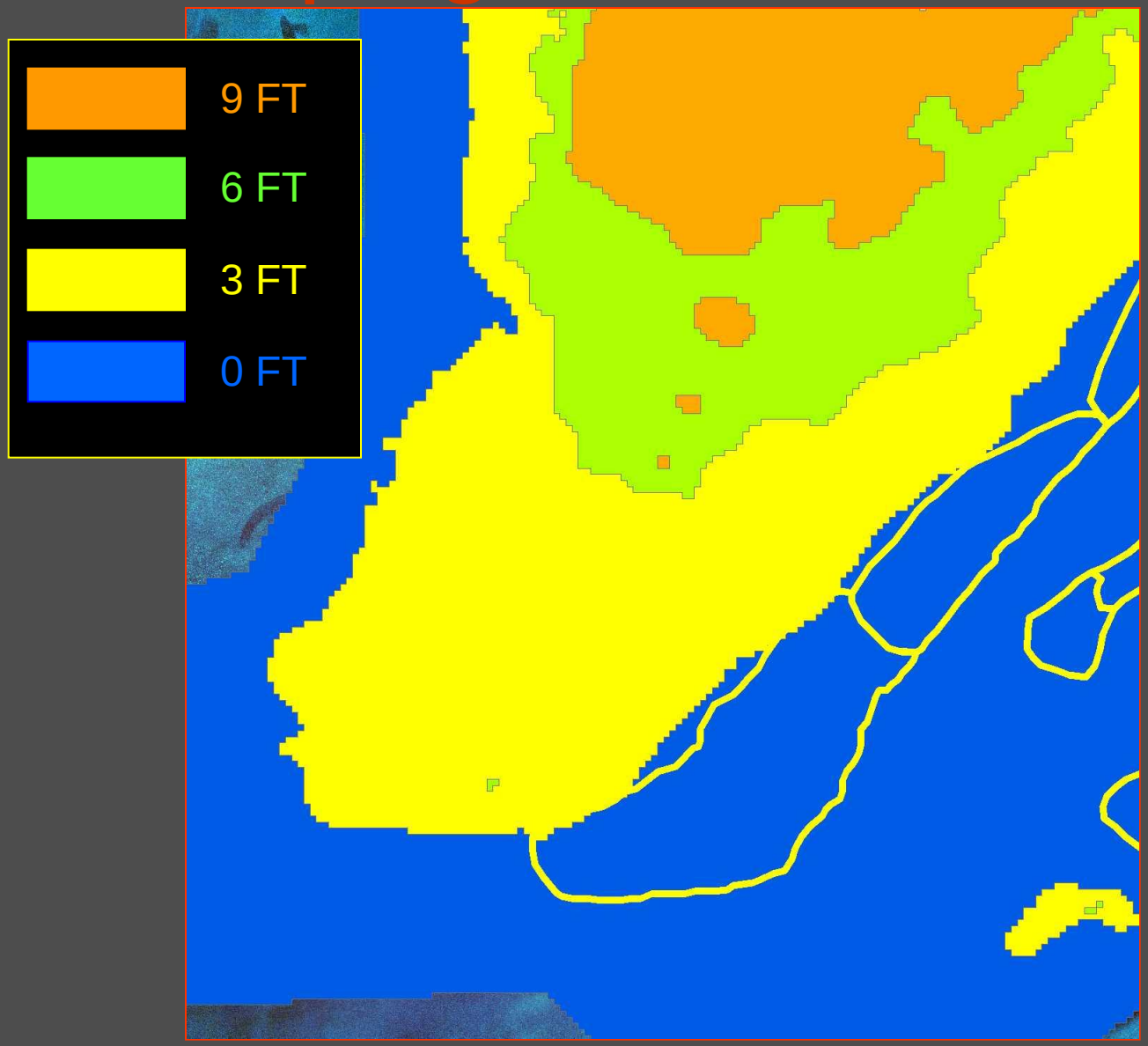
**~ 300 acres**

**Defended**



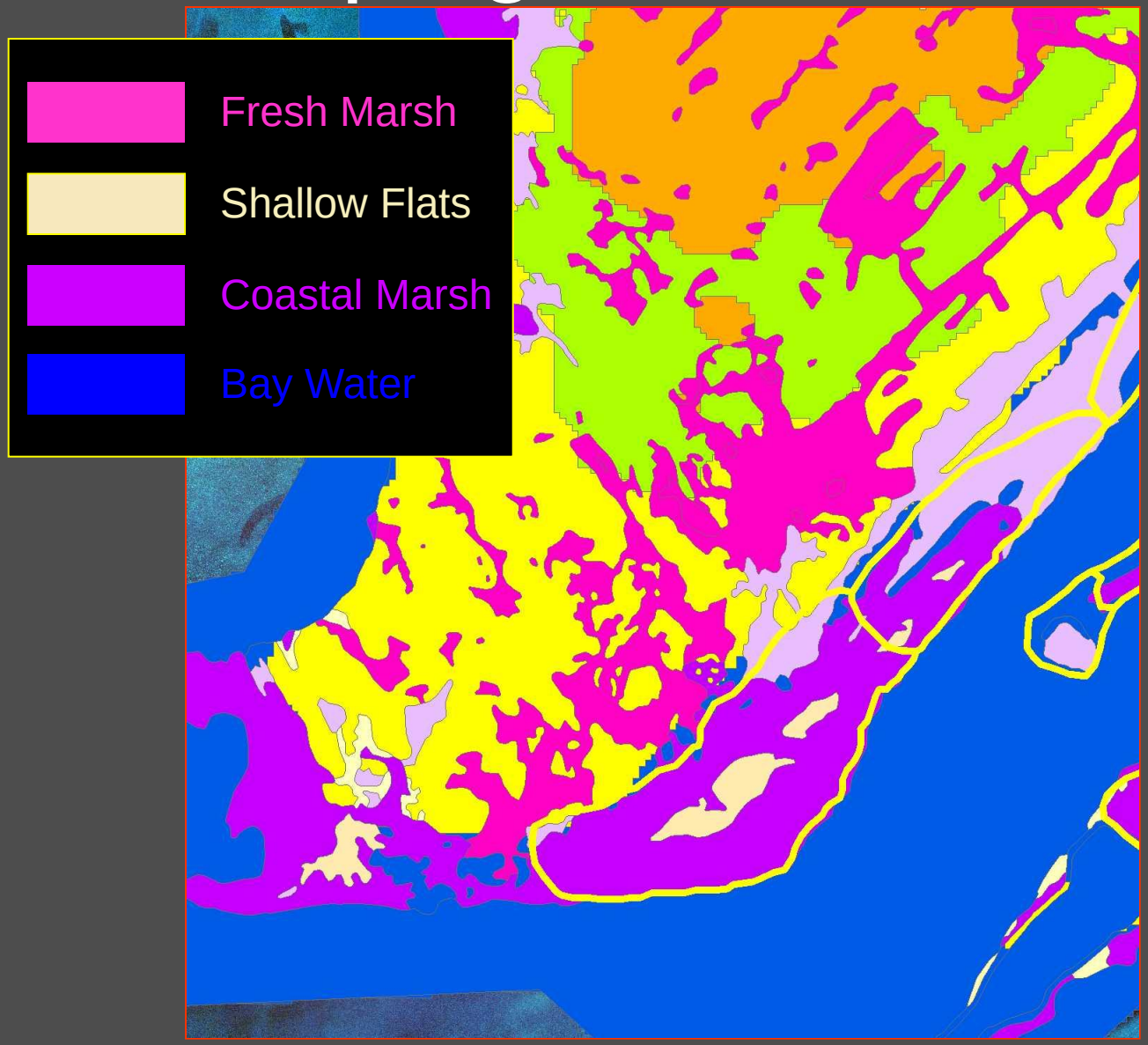

Aransas National Wildlife Refuge
Blackjack Peninsula

# Whooping Crane Territories




**Current Elevation**

# Whooping Crane Habitats



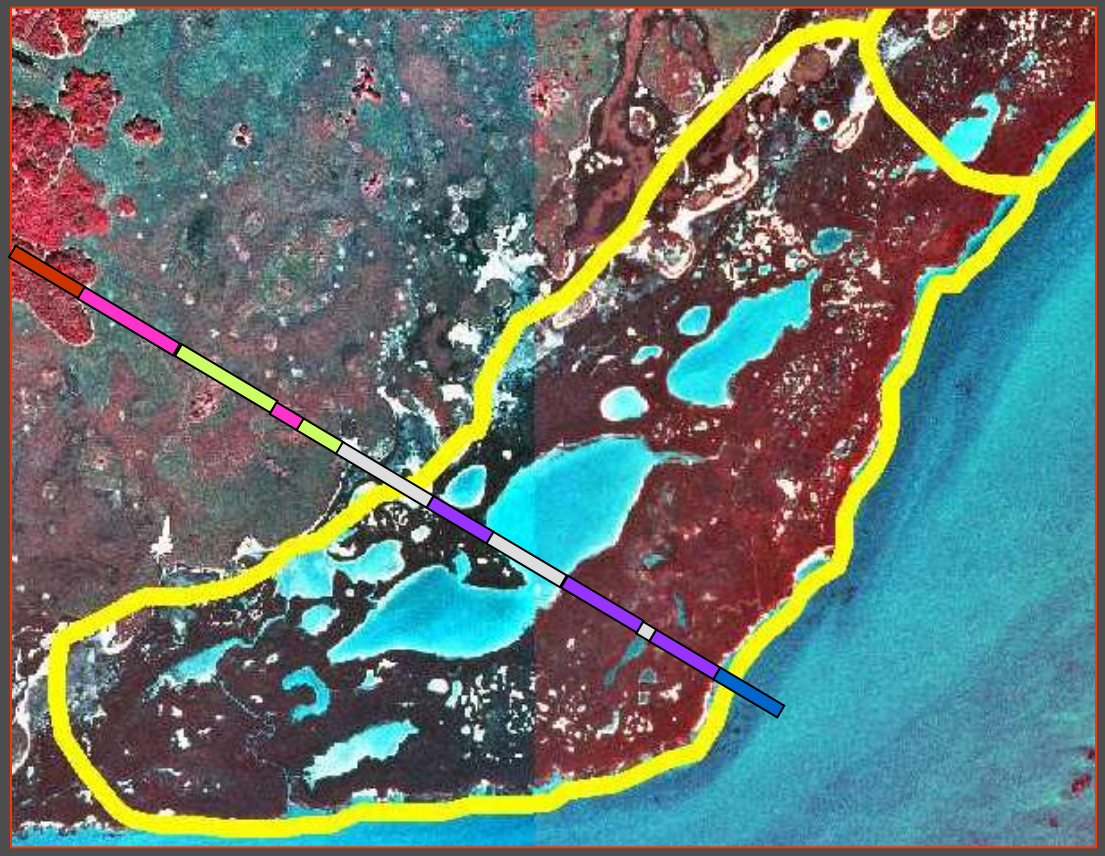
# Whooping Crane Territories


Habitat Diversity
Safe Shelter
Food

# Primary Food Items

- Blue Crab
- Wolfberry Fruits
- Clams, Snails, shrimp
- Acorns, snakes, lizards, insects, small rodents

# Coastal Habitat Availability



Oak Woodland

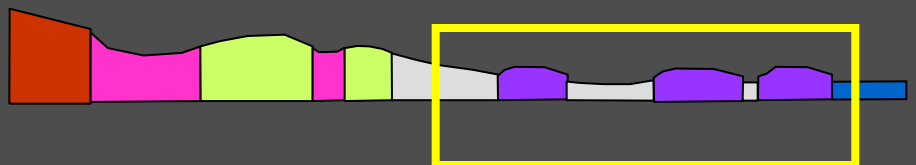
Fresh Marsh

Coastal Prairie

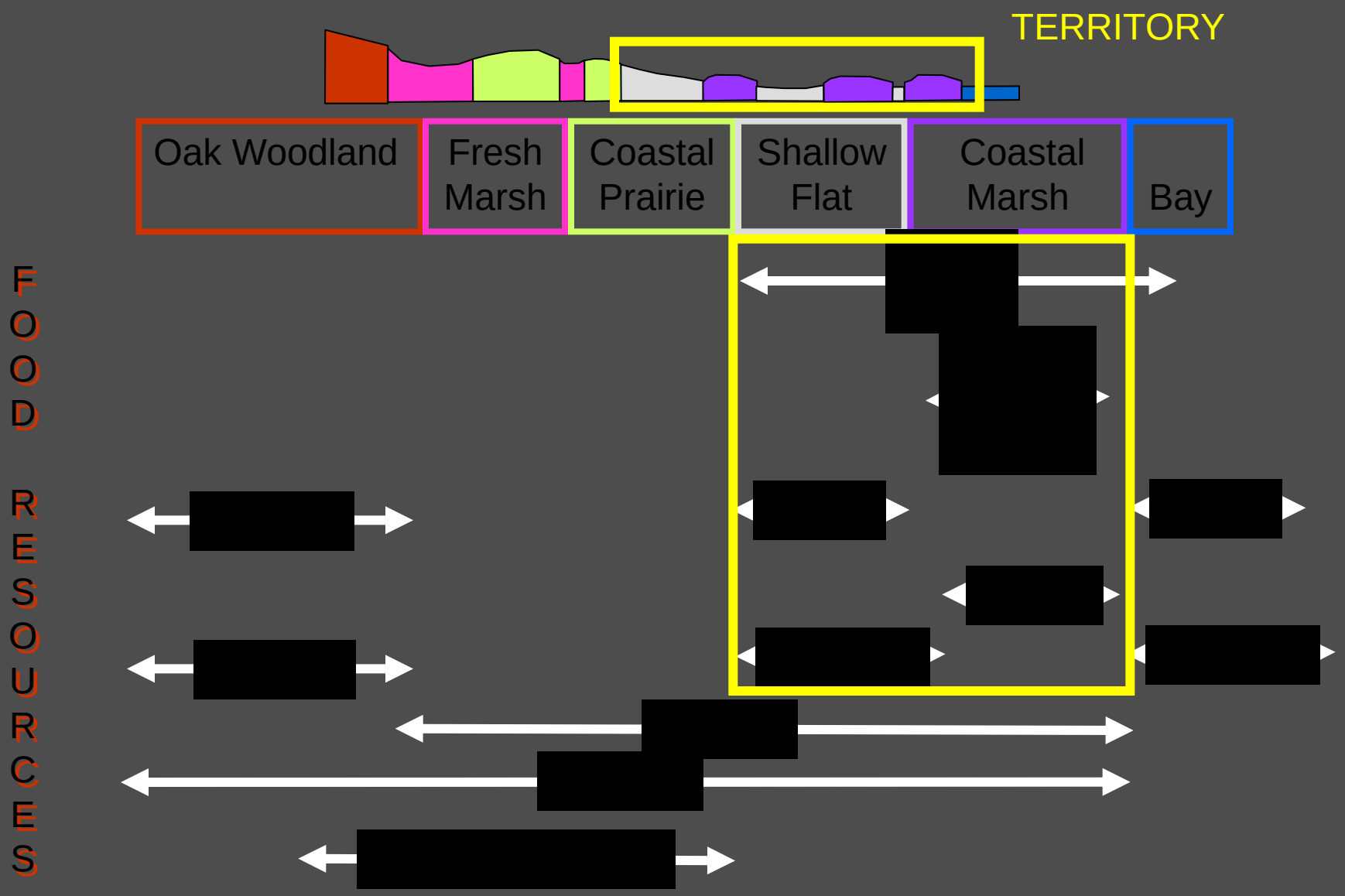
Shallow Flat

Coastal Marsh

Bay



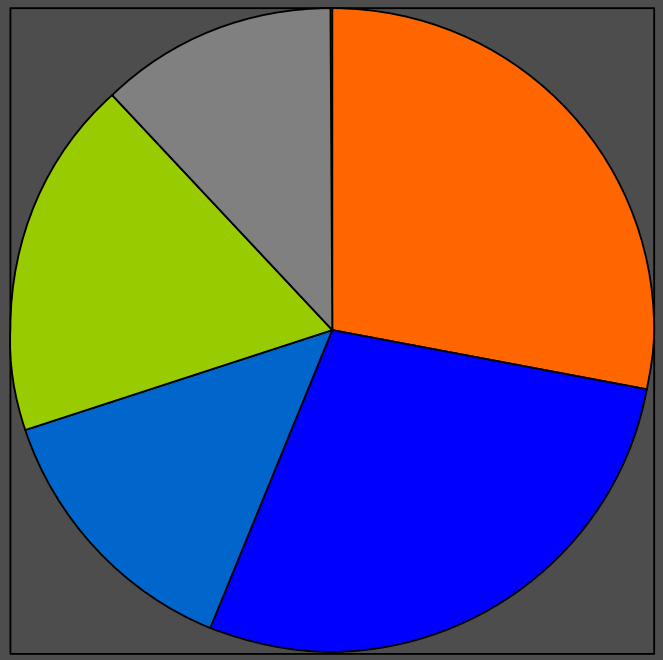
# HABITATS


TERRITORY
Oak Woodland
Fresh Marsh
Coastal Prairie
Shallow Flat
Coastal Marsh
Bay
FOOD RESOURCES

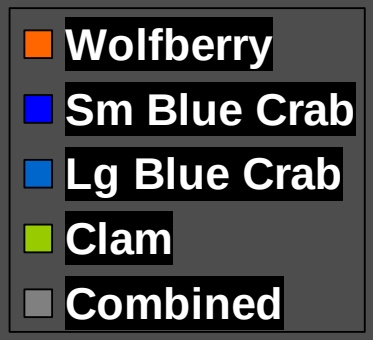
# Blue Crab – Prime Prey

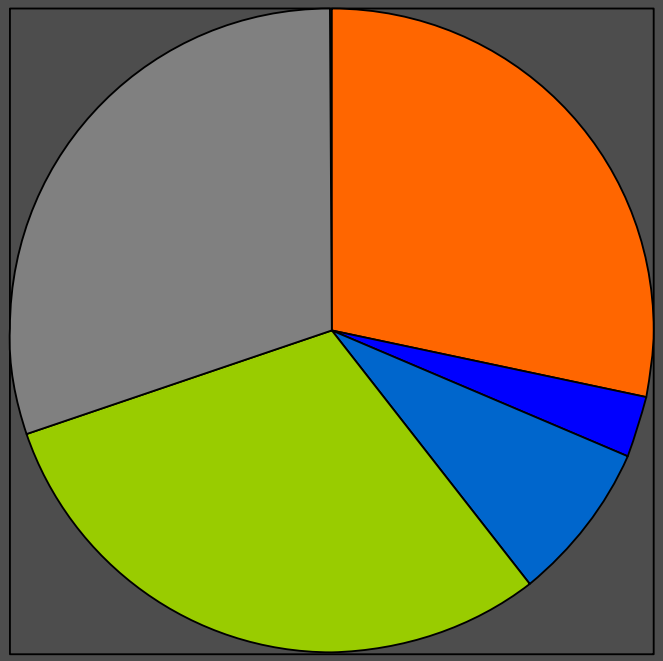
# Dry Mass of Food Items

## Calculated from Observation Data



**2004-2005**



**2005-2006**

Temporal Sequence: Wolfberry > Blue Crab, Clams, Snails, Insects

Spatial Sequence: Tides > Lunar, Wind, Isolation

Greer (2010)

# Blue Crab Availability: Implications to Whooping Cranes

- Essential protein source for overwintering, migration, and nesting success
- Relationship between wet/dry years and crab availability and crane mortality
- Understanding crab dynamics and factors impacting crab availability critical to maintain and increase whooping crane population

# Thank You!

PLEASE CONTACT:

Liz Smith, Whooping Crane Conservation Biologist
International Crane Foundation
Texas Office, 361-543-0303

TAMU-CC Office, 361-825-6069

# Environmental conditions and hydrodynamics of Texas bays and estuaries

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

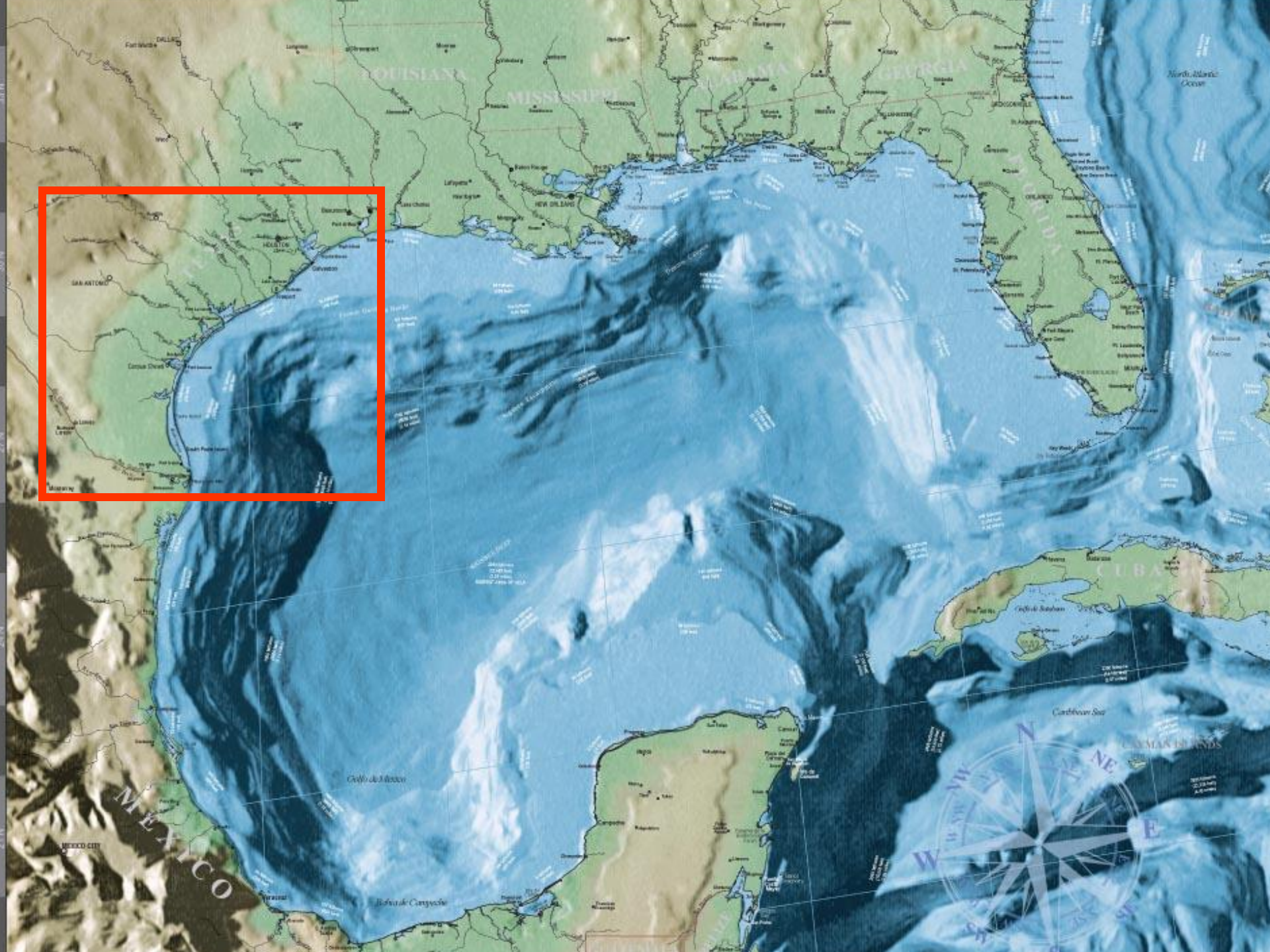
MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

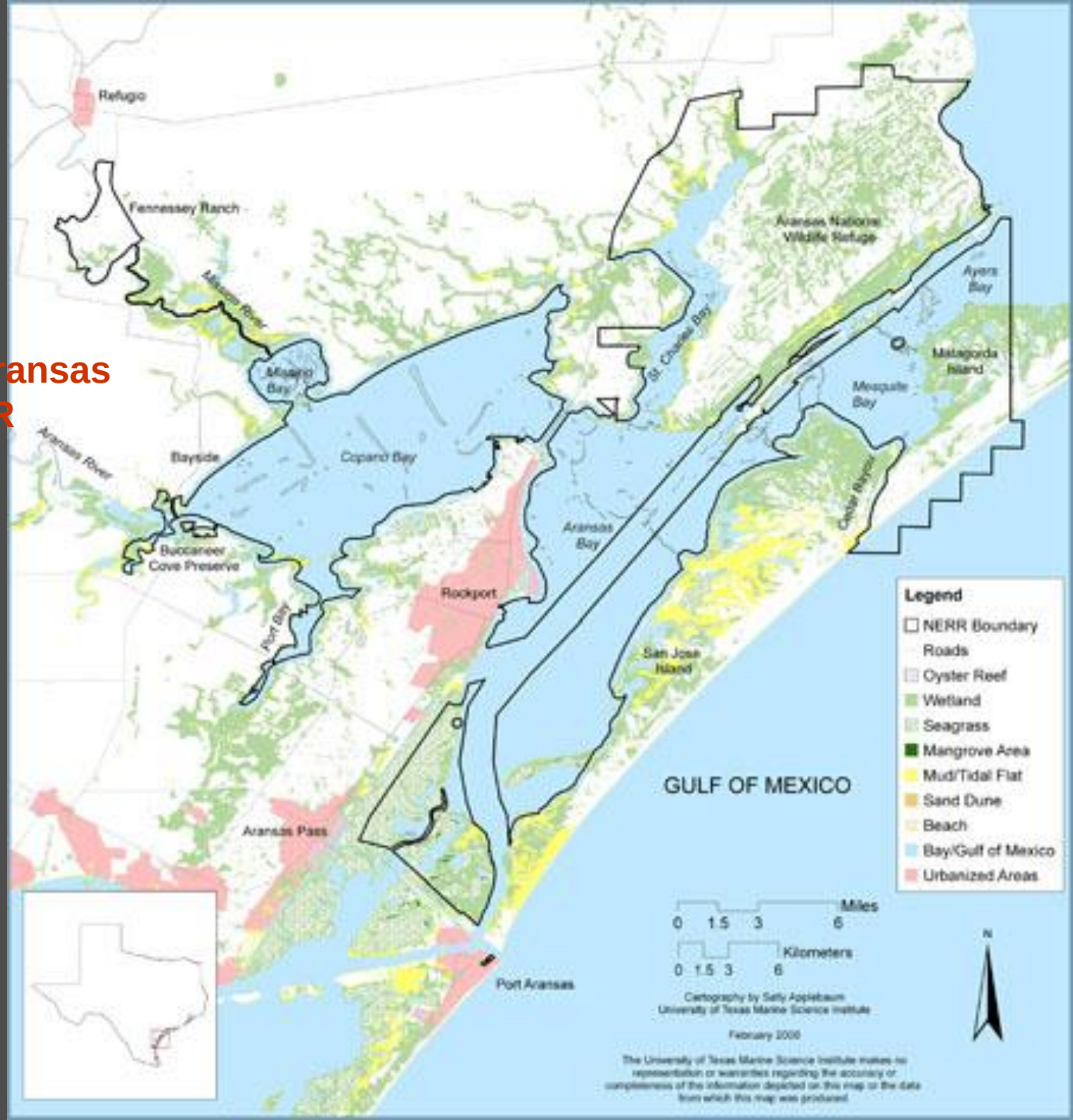
FRESHWATER INFLOW

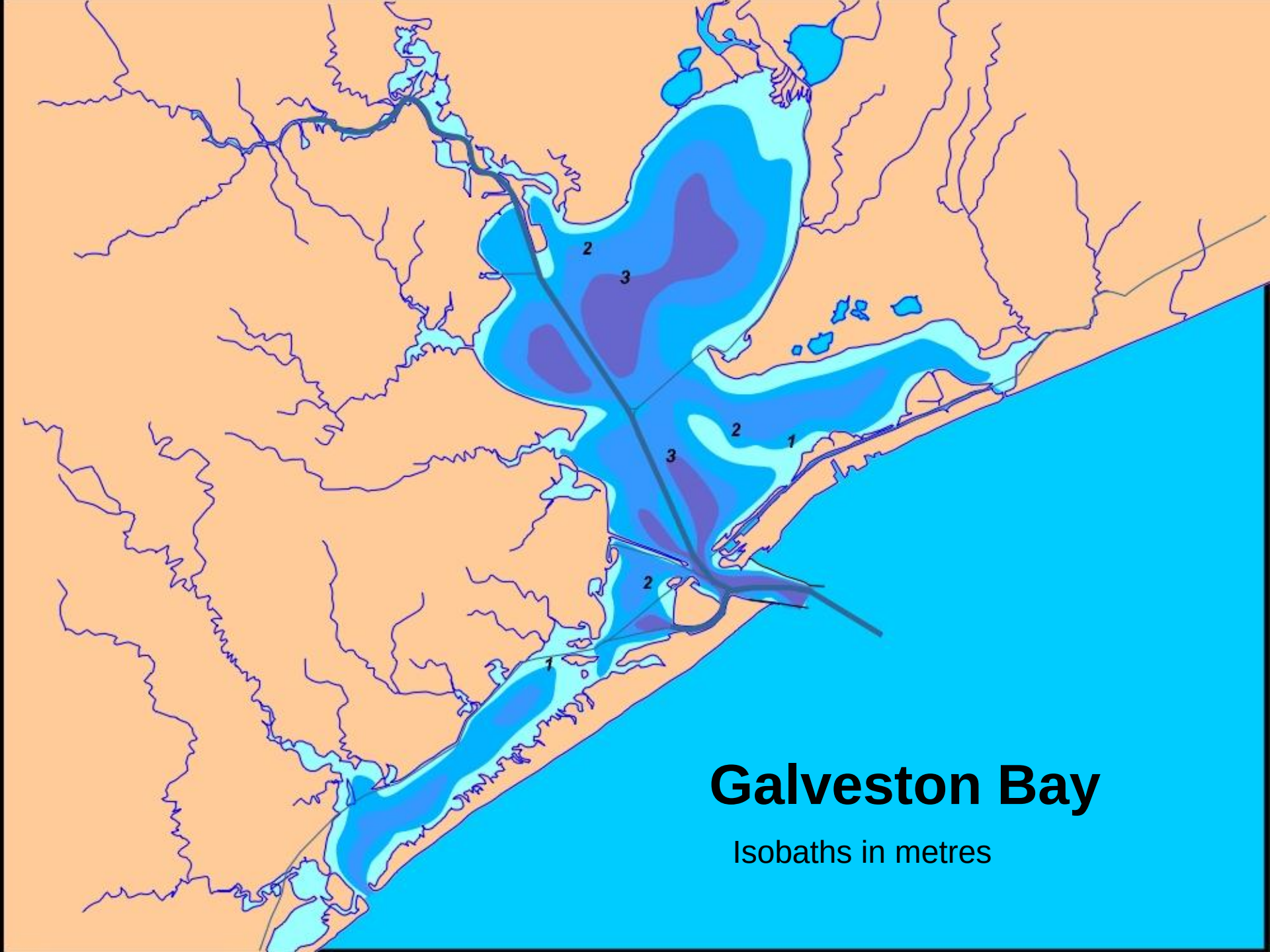
SALINITY & WATER QUALITY

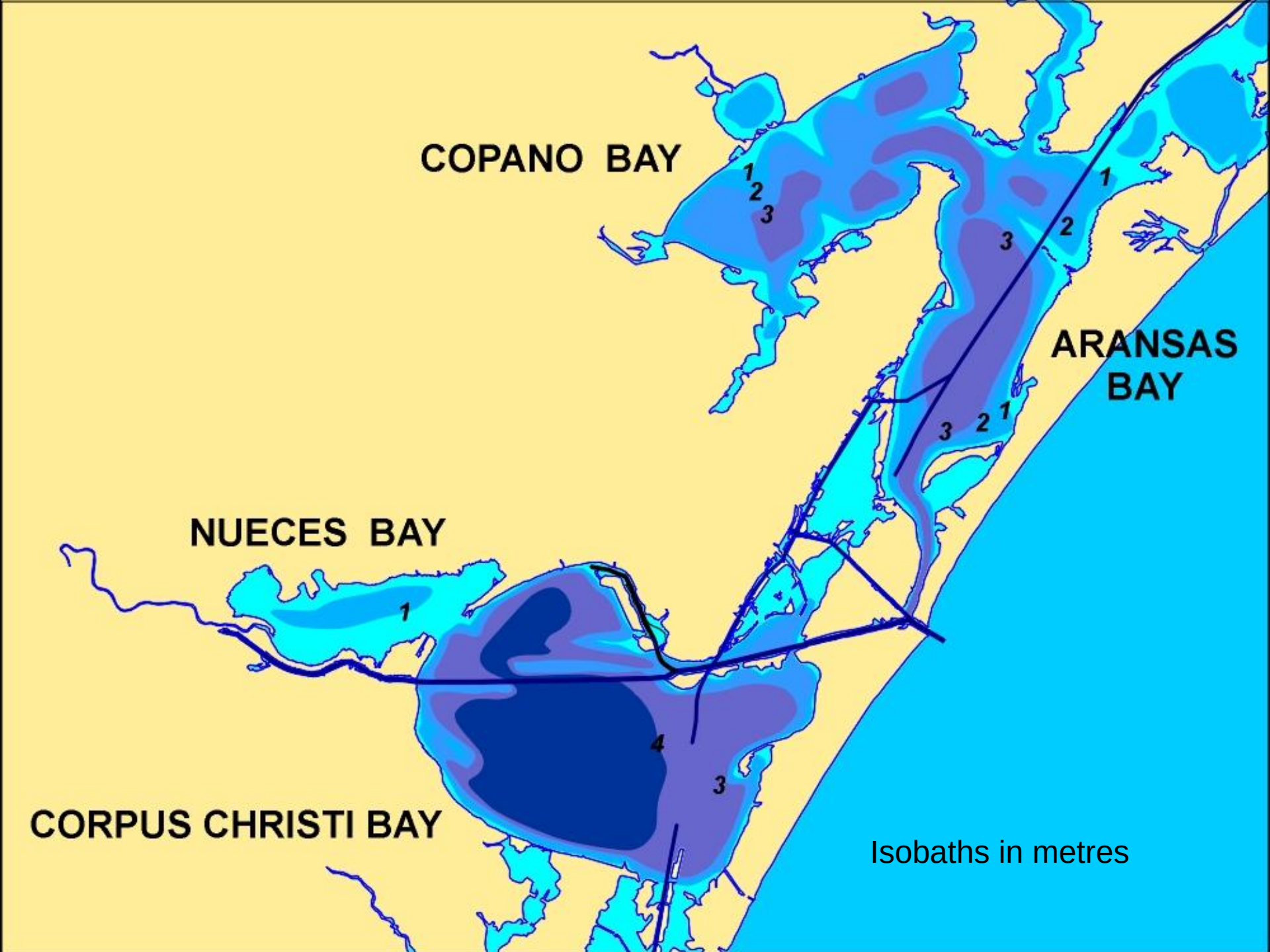

LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
NEW ORLEANS
HOUSTON
Galveston
SAN ANTONIO
North Atlantic Ocean
CUBA
Golfo de Batabano
Caribbean Sea
CAYMAN ISLANDS
Golfo de México
MEXICO
MEXICO CITY
Bahía de Campeche
N
NE
E
SE
S
SW
W
NW

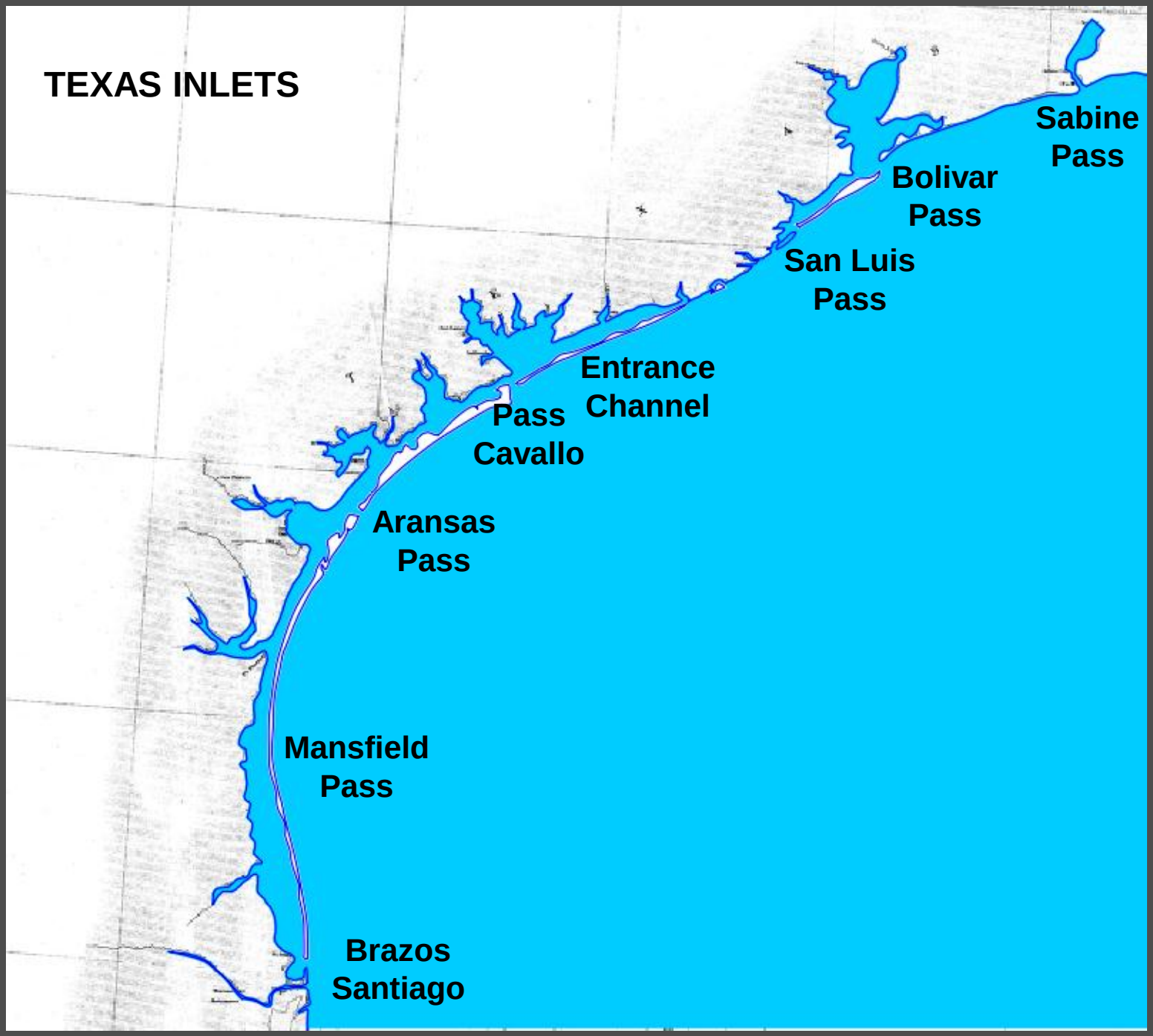

TEXAS BAYS
GALVESTON BAY
SABINE LAKE
MATAGORDA BAY
Mission-Aransas NERR
SAN ANTONIO BAY
ARANSAS-COPANO BAY
CORPUS CHRISTI BAY
UPPER LAGUNA MADRE
LOWER LAGUNA MADRE

# Mission-Aransas NERR

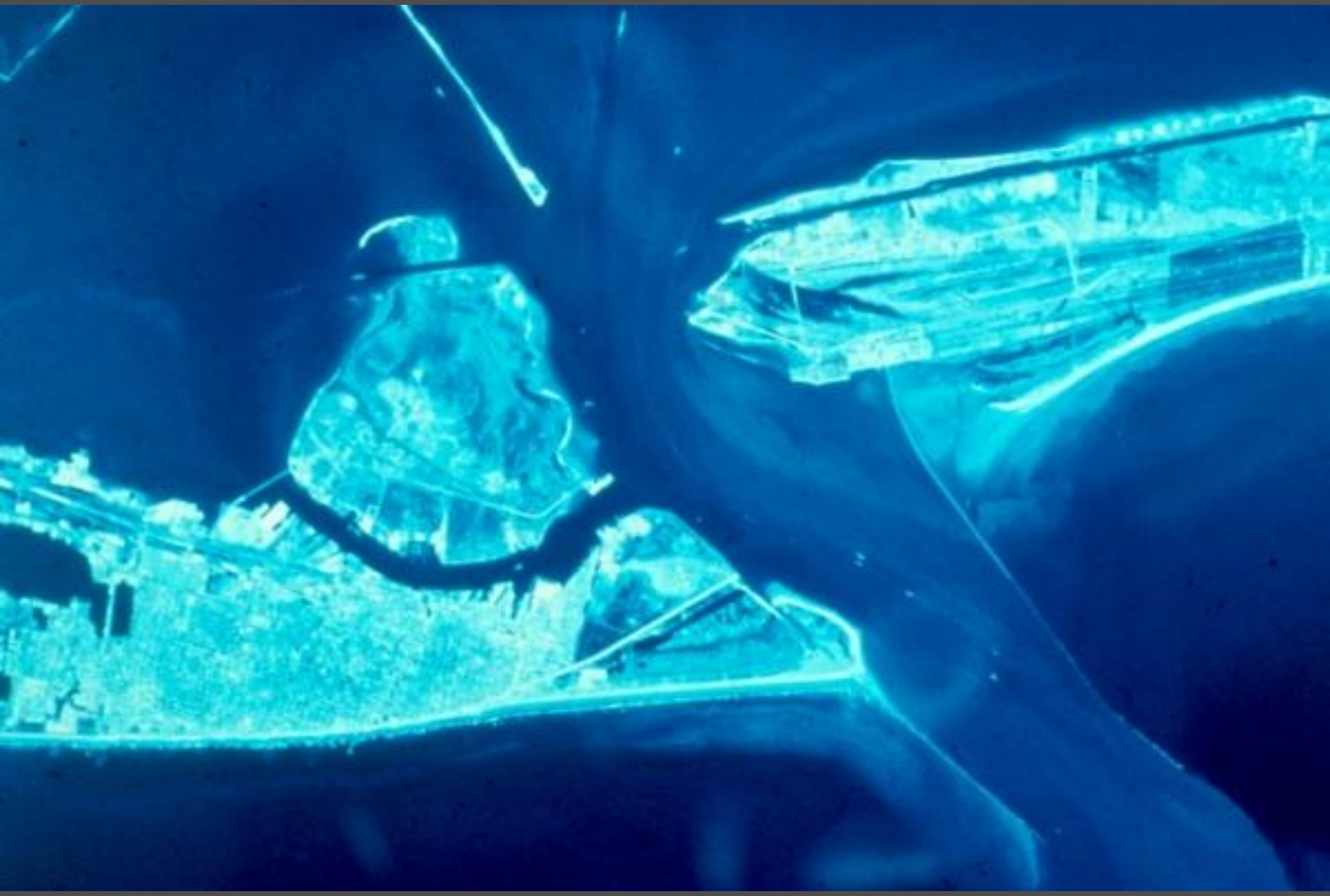



2
3
2
1
3
2
1
Galveston Bay
Isobaths in metres


COPANO BAY
ARANSAS BAY
NUECES BAY
CORPUS CHRISTI BAY
Isobaths in metres


TEXAS INLETS
Sabine Pass
Bolivar Pass
San Luis Pass
Entrance Channel
Pass Cavallo
Aransas Pass
Mansfield Pass
Brazos Santiago


Lavaca Bay
Matagorda Bay
MSC Entrance Channel
Pass Cavallo
San Antonio Bay
Copano Bay
Aransas Bay
Cedar Bayou
Nueces Bay
Corpus Christi Bay
Aransas Pass




SAN LUIS PASS


Matagorda Bay
MSC Entrance Channel
Pass Cavallo
San Antonio Bay
Copano Bay
Aransas Bay
Cedar Bayou
Nueces Bay
Corpus Christi Bay
Aransas Pass

Photograph by Dr Richard Watson


Cedar Bayou
August 2009

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

# THREE FACTOIDS
# ABOUT TIDES ON THE TEXAS COAST

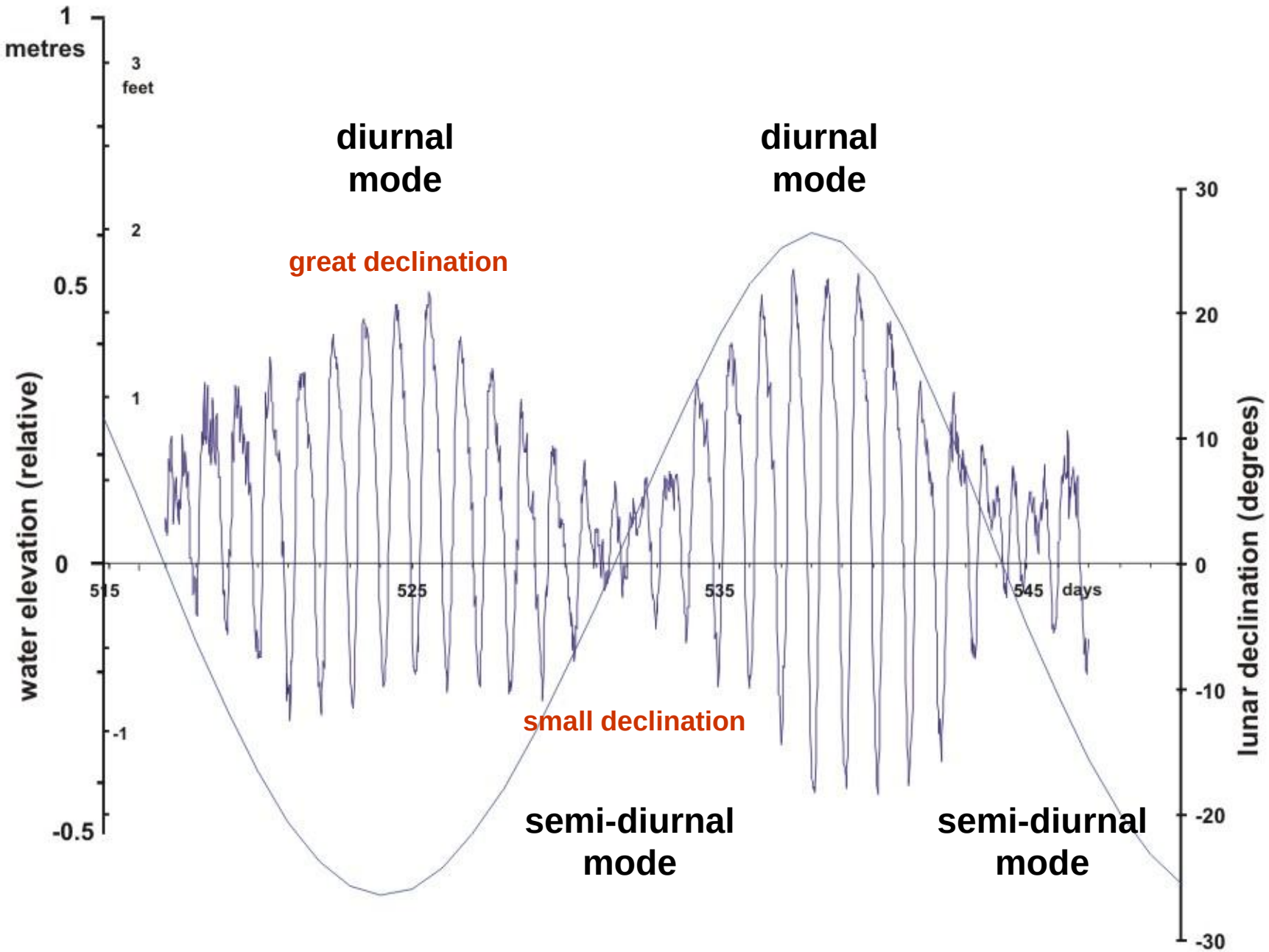
**“Microtidal” - Offshore tidal range around a meter**

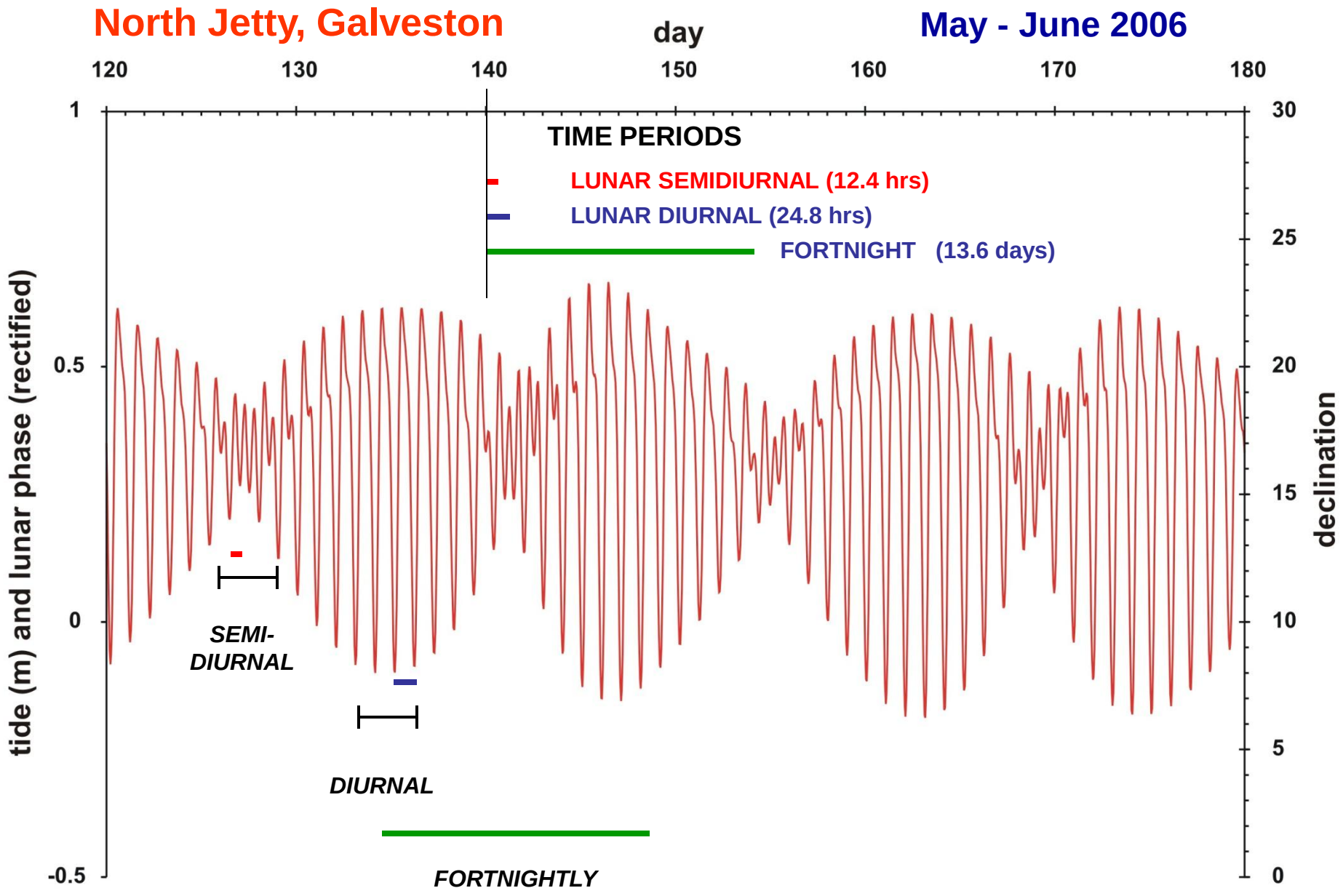
**Tide range larger on the Gulf shore, smaller inside the bays**

**Dominated by 4 – 5 principal frequencies**

# Bob Hall Pier

## June 2009




North Jetty, Galveston
May - June 2006
day
120
130
140
150
160
170
180
1
0.5
0
-0.5
30
25
20
15
10
5
0
tide (m) and lunar phase (rectified)
declination
TIME PERIODS
LUNAR SEMIDIURNAL (12.4 hrs)
LUNAR DIURNAL (24.8 hrs)
FORTNIGHT (13.6 days)
SEMI-
DIURNAL
DIURNAL
FORTNIGHTLY

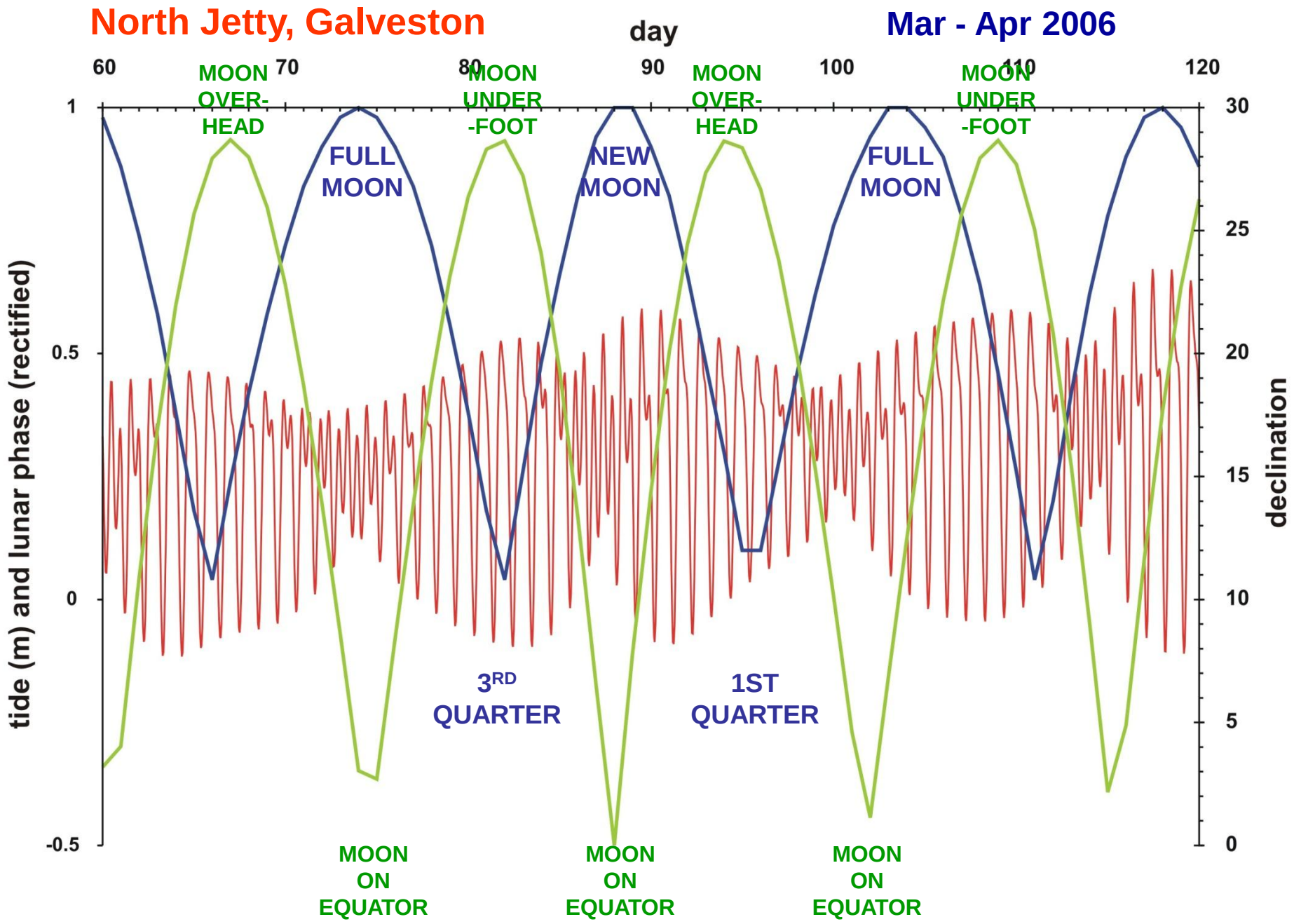
# Predominant tidal harmonics on Texas coast

| | | |
|---|---|---|
| SEMIDIURNAL | 12.4 hr | LUNAR |
| DIURNAL | 24.8 hr | LUNAR |
| FORTNIGHTLY | 13.6 da | LUNAR DECLINATION |


YOU
LIE !!!

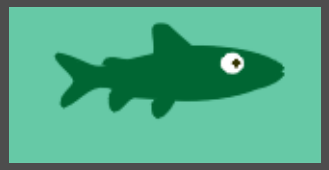
*What about Lunar phase?!*

*Spring tides and neap tides?!*

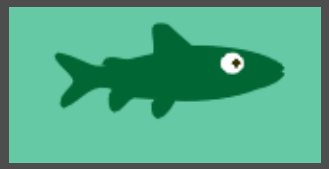

North Jetty, Galveston
Mar - Apr 2006
day
60
70
80
90
100
110
120
MOON OVER-HEAD
MOON UNDER-FOOT
MOON OVER-HEAD
MOON UNDER-FOOT
FULL MOON
NEW MOON
FULL MOON
3RD QUARTER
1ST QUARTER
MOON ON EQUATOR
MOON ON EQUATOR
MOON ON EQUATOR
tide (m) and lunar phase (rectified)
1
0.5
0
-0.5
declination
30
25
20
15
10
5
0

# ~~THREE~~ Four FACTOIDS ABOUT TIDES ON THE TEXAS COAST

“Microtidal” - Offshore tidal range around a meter

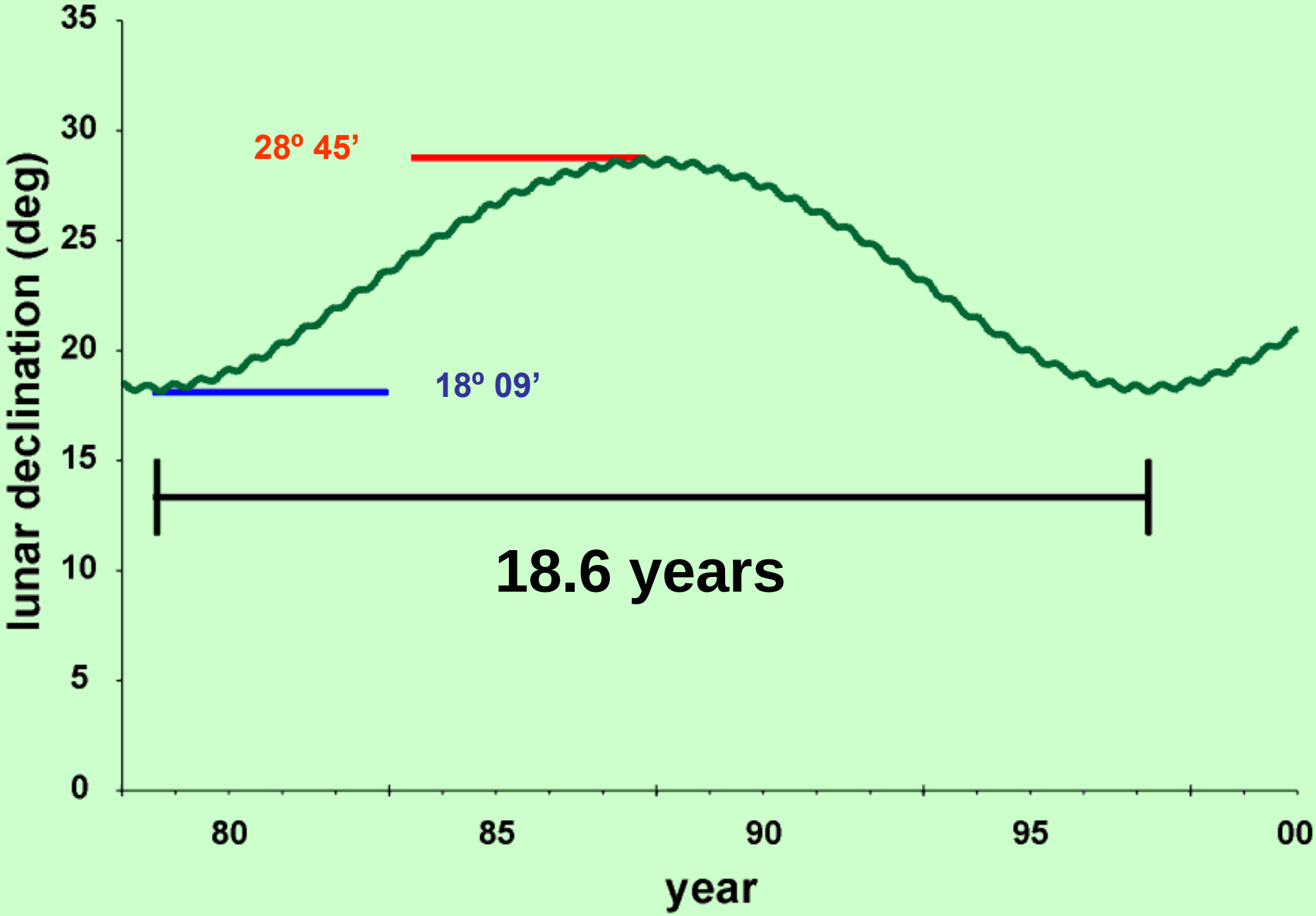


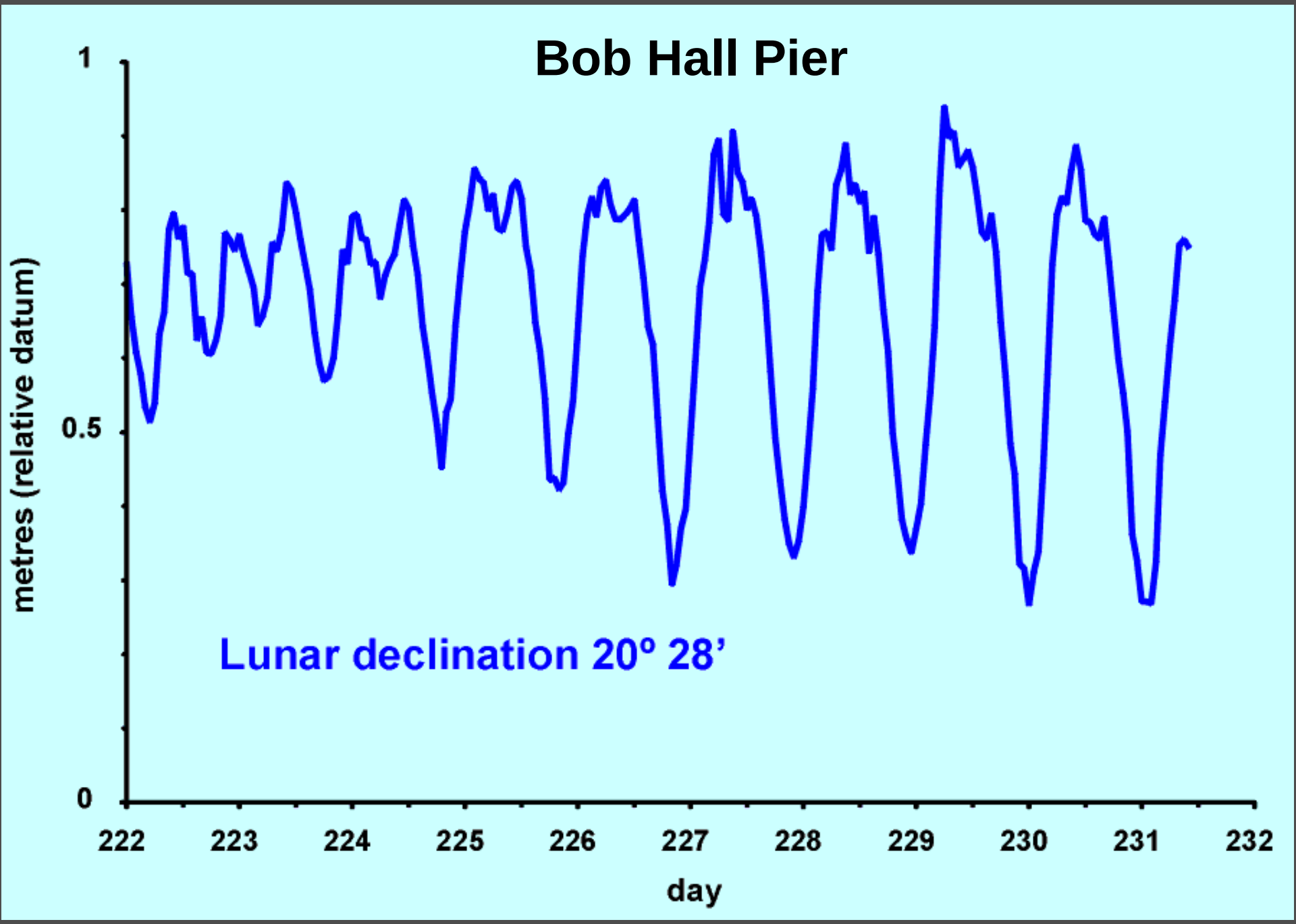
Tide range larger on the Gulf shore, smaller inside the bays

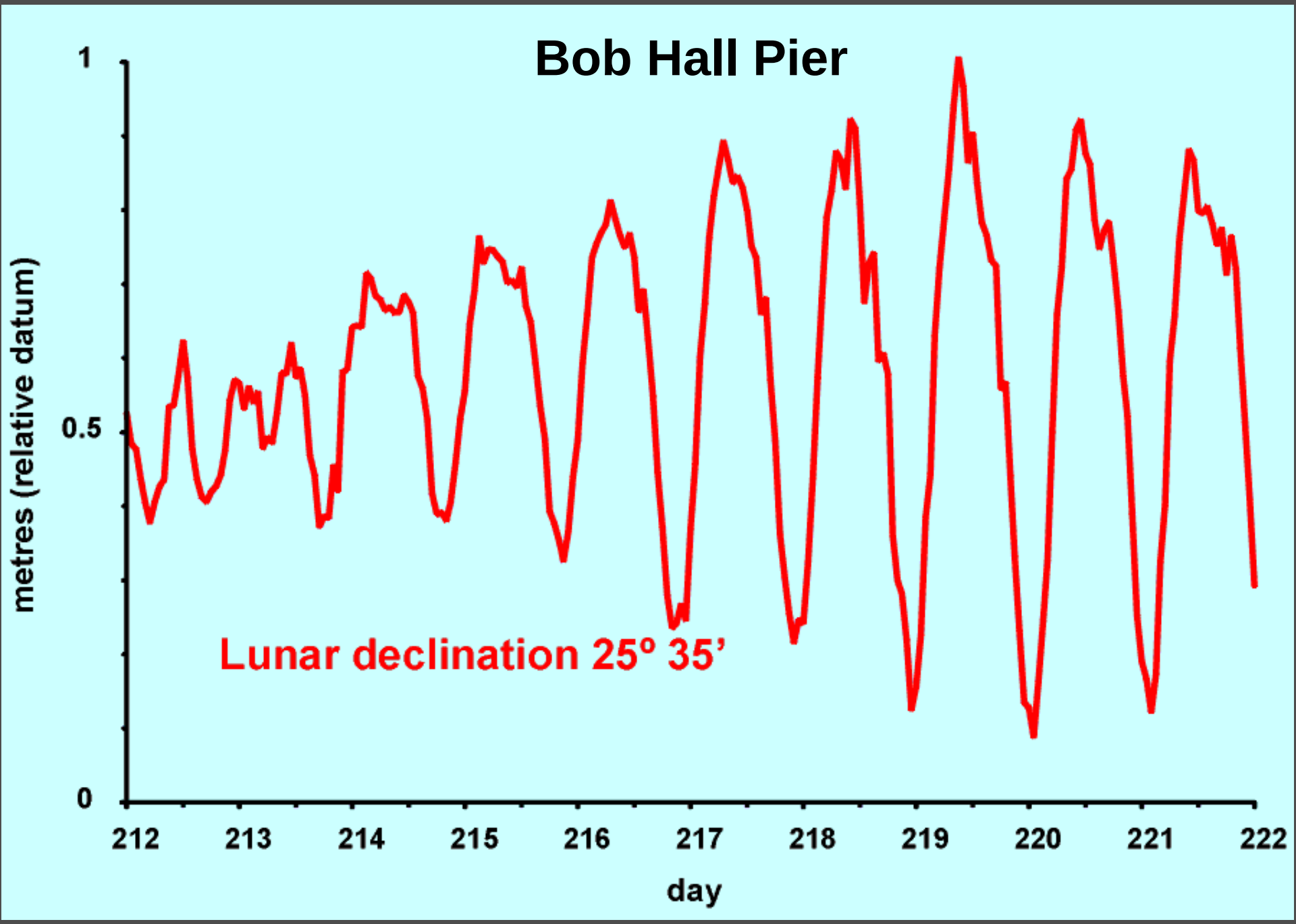


Dominated by 4 – 5 principal frequencies

Phase of the moon has nothing to do with it!

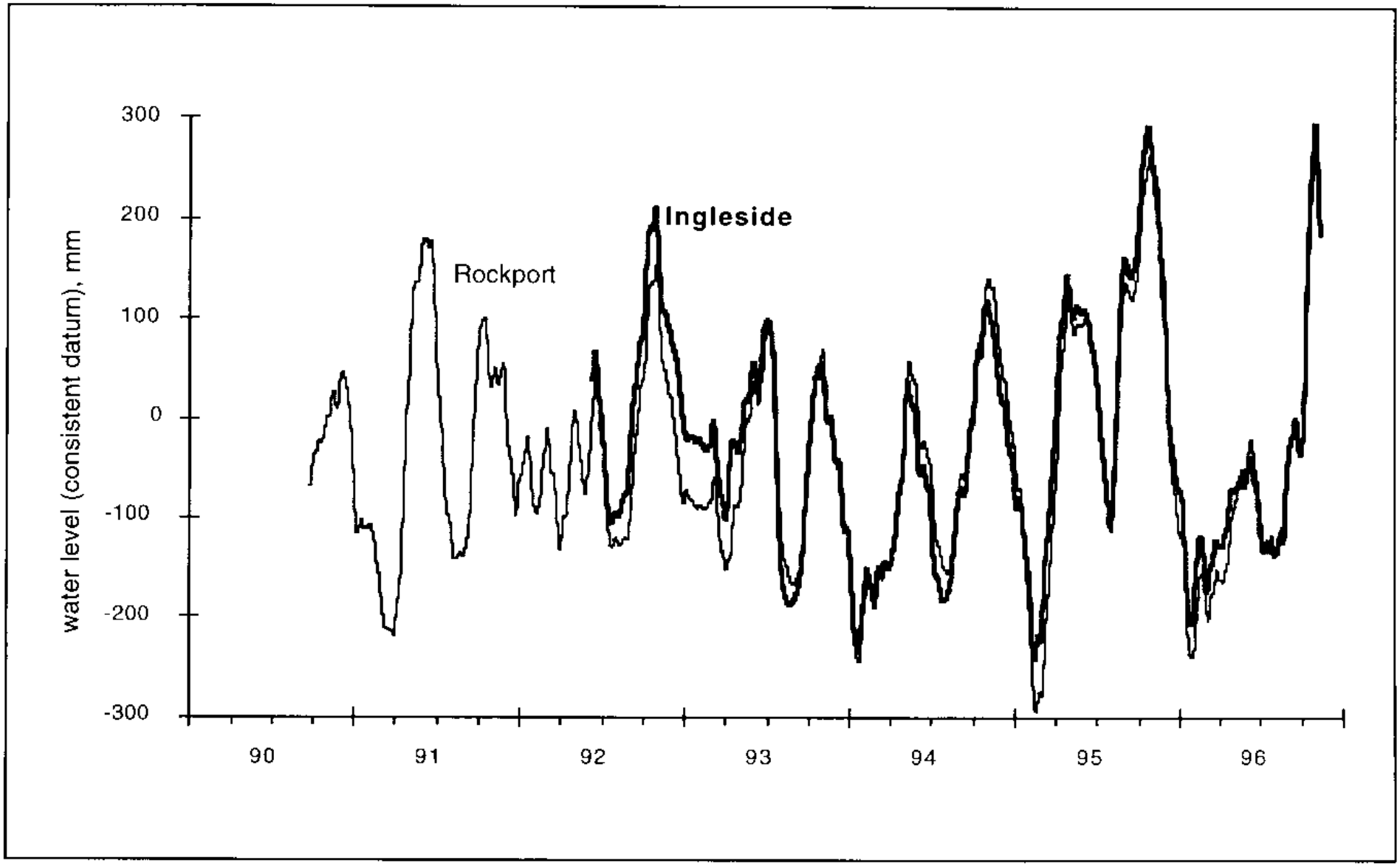

35
30
25
20
15
10
5
0
lunar declination (deg)
28º 45'
18º 09'
18.6 years
80
85
90
95
00
year


Bob Hall Pier
1
0.5
0
metres (relative datum)
Lunar declination 20º 28'
222
223
224
225
226
227
228
229
230
231
232
day

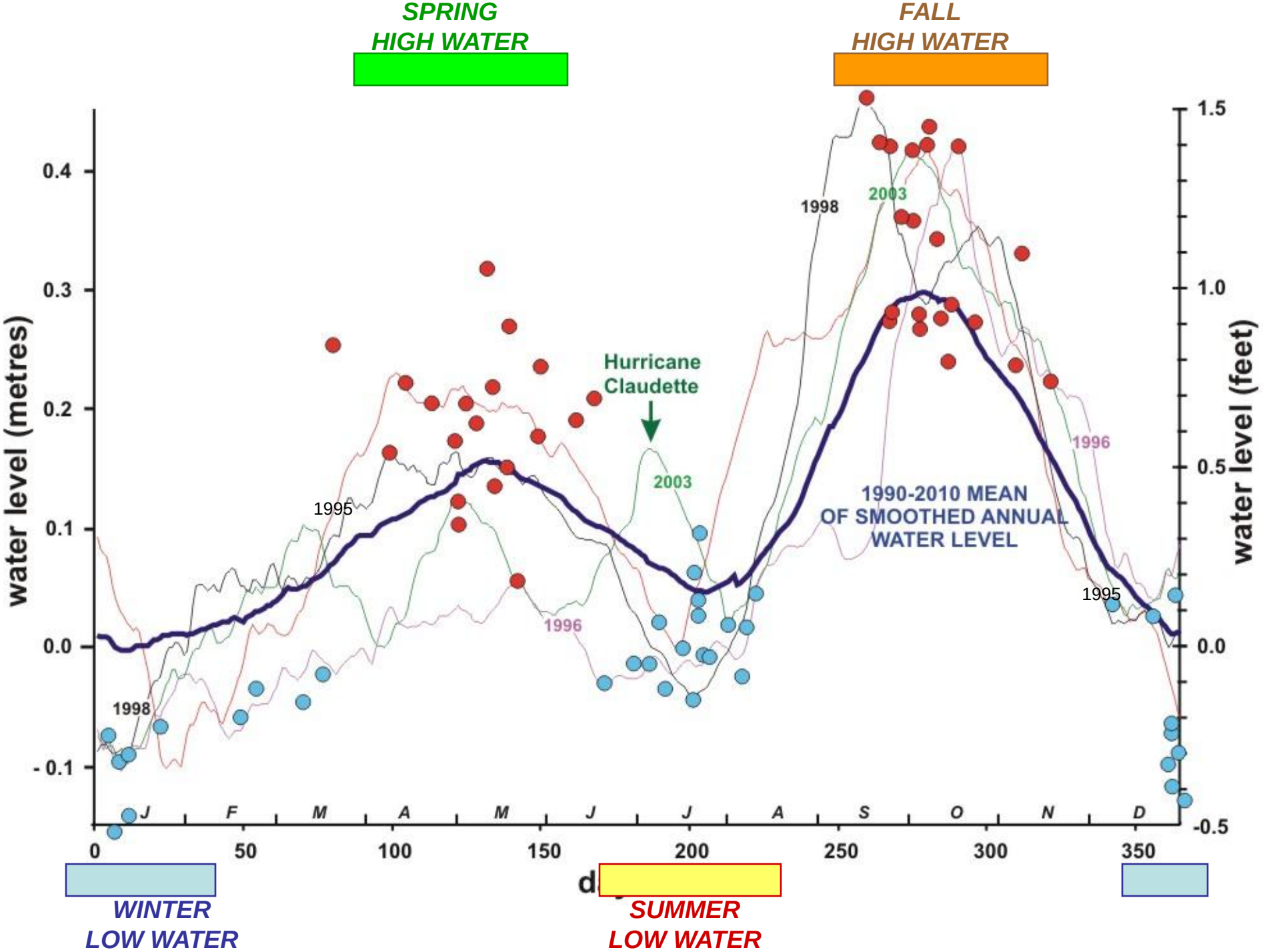

Bob Hall Pier
1
0.5
0
metres (relative datum)
Lunar declination 25º 35'
212
213
214
215
216
217
218
219
220
221
222
day

# Predominant tidal harmonics on Texas coast

| | | |
|---|---|---|
| SEMIDIURNAL | 12.4 hr | LUNAR |
| DIURNAL | 24.8 hr | LUNAR |
| FORTNIGHTLY | 13.6 da | LUNAR DECLINATION |
| DECLINATION | 18.6 yr | TIDAL EPOCH |

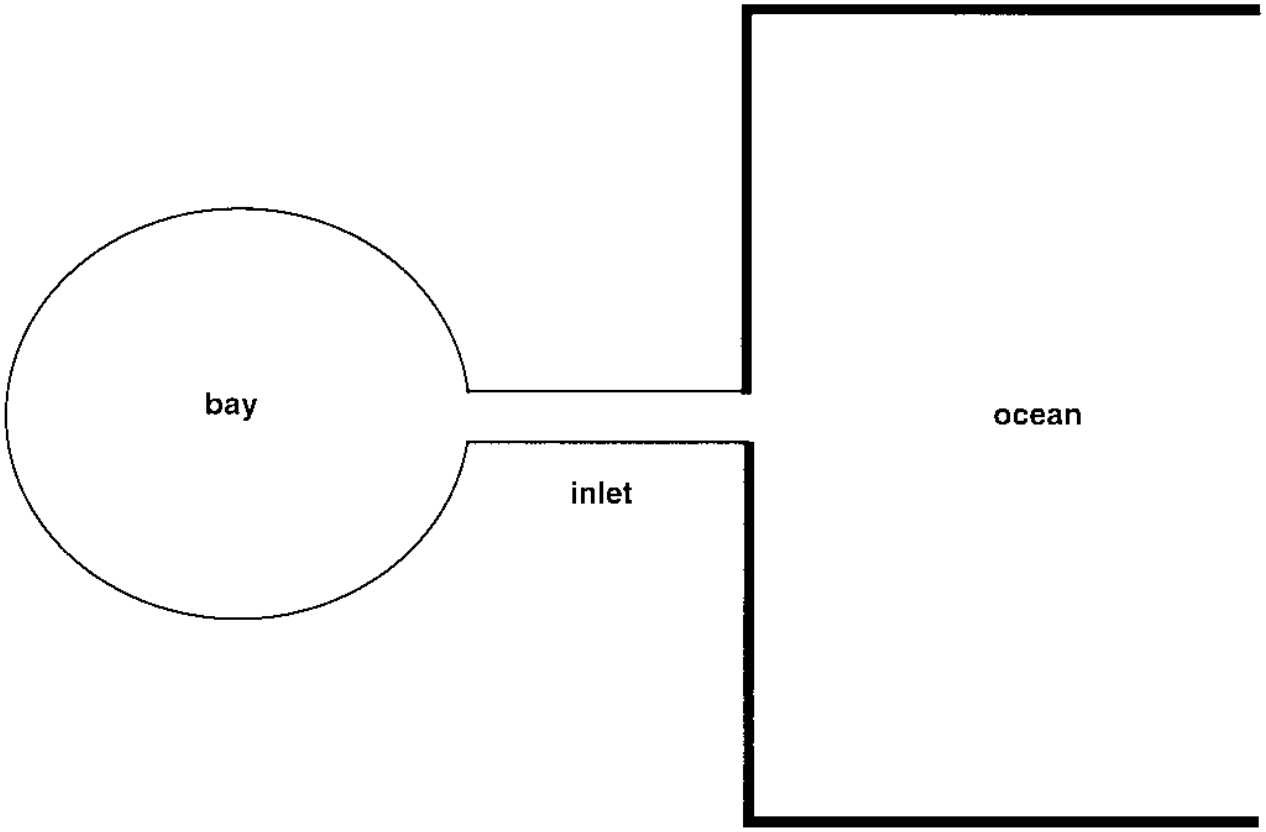



**27-day sliding mean of water level at two stations in Coastal Bend bays**

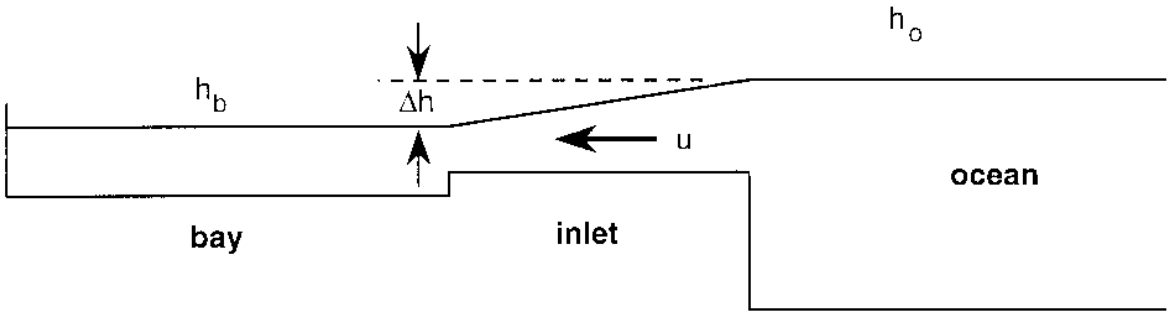

SPRING
HIGH WATER
FALL
HIGH WATER
water level (metres)
water level (feet)
0.4
0.3
0.2
0.1
0.0
- 0.1
1.5
1.0
0.5
0.0
-0.5
Hurricane
Claudette
1998
2003
1995
1996
1990-2010 MEAN
OF SMOOTHED ANNUAL
WATER LEVEL
J
F
M
A
M
J
J
A
S
O
N
D
0
50
100
150
200
250
300
350
WINTER
LOW WATER
SUMMER
LOW WATER

# Predominant “tidal” harmonics on Texas coast

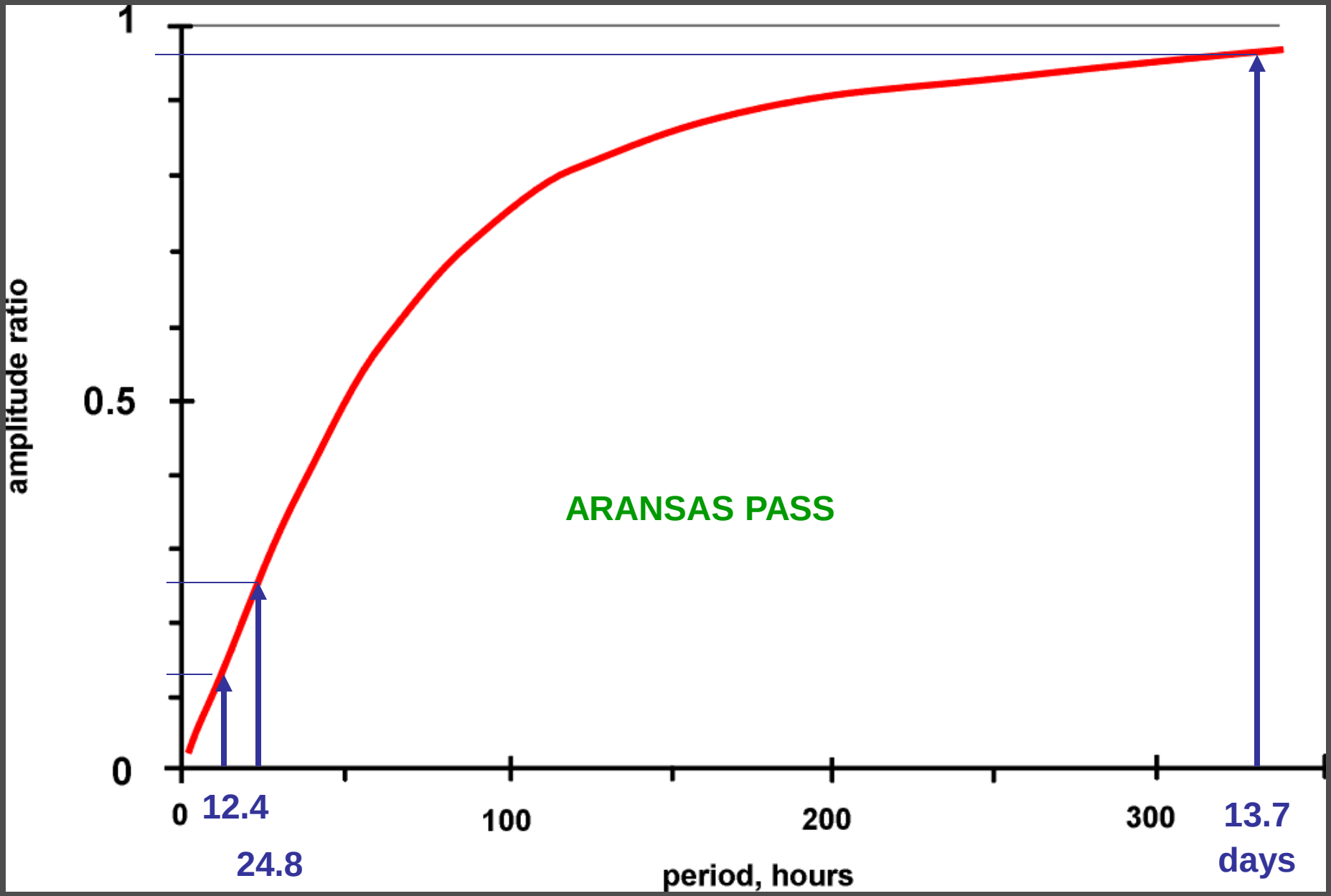
| | | |
|---|---|---|
| SEMIDIURNAL | 12.4 hr | LUNAR-SOLAR |
| DIURNAL | 24.8 hr | LUNAR-SOLAR |
| FORTNIGHTLY | 13.6 da | LUNAR DECLINATION |
| SEMIANNUAL | 6 mos | SECULAR |
| DECLINATION | 18.6 yr | TIDAL EPOCH |

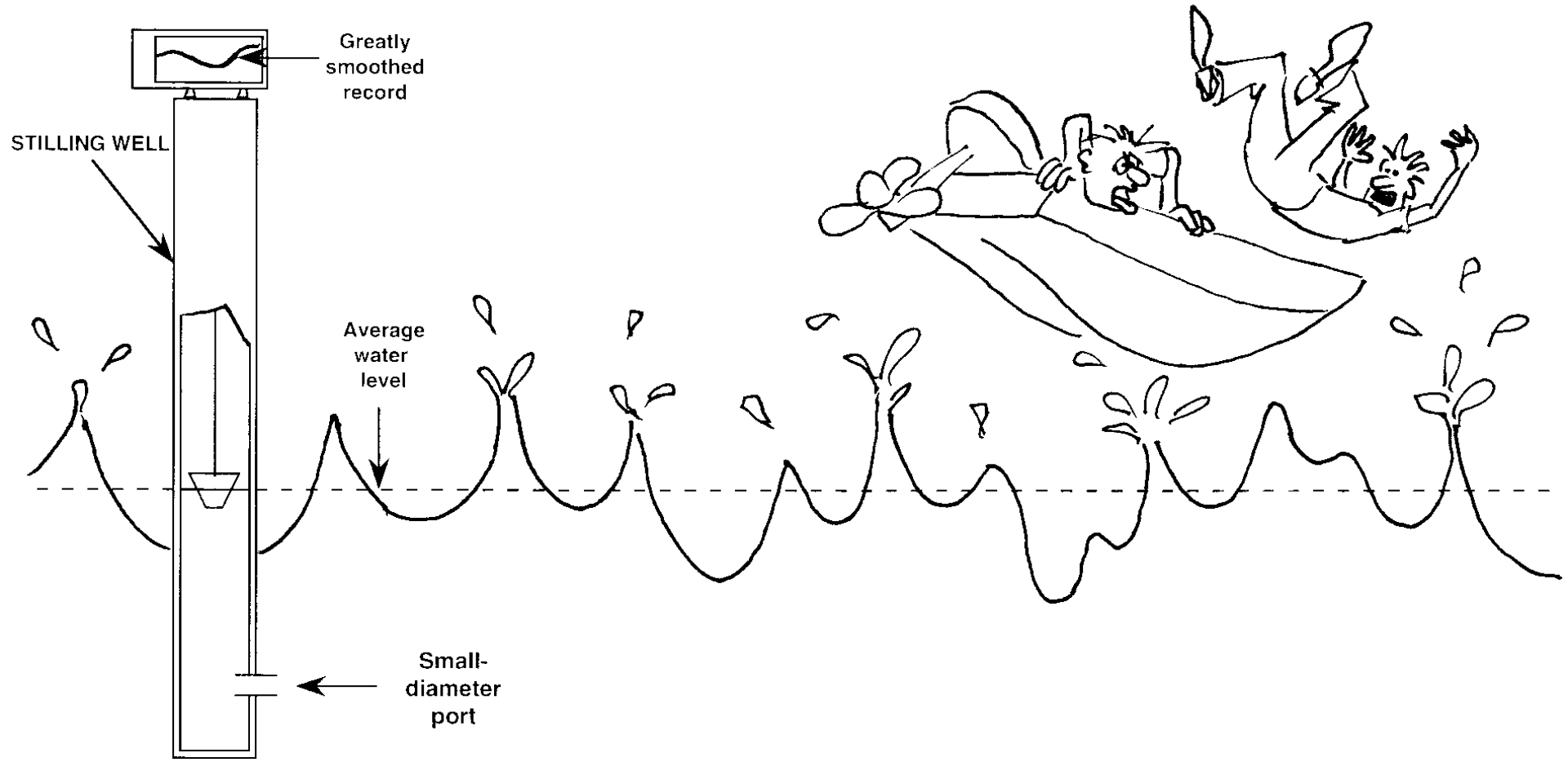



**PLAN VIEW**




**CROSS SECTION**

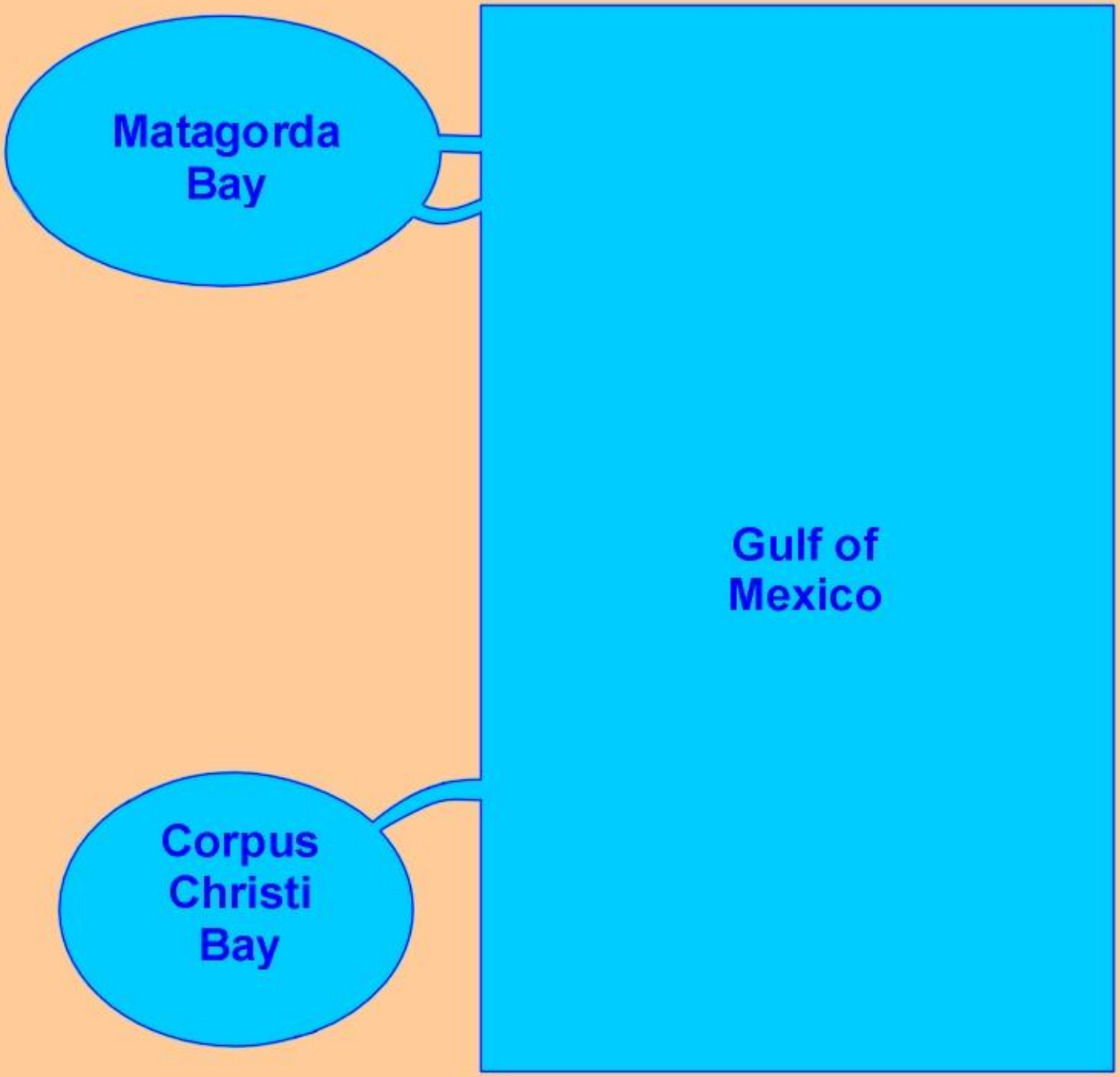

1
0.5
0
amplitude ratio
ARANSAS PASS
0
12.4
24.8
100
200
300
13.7
days
period, hours

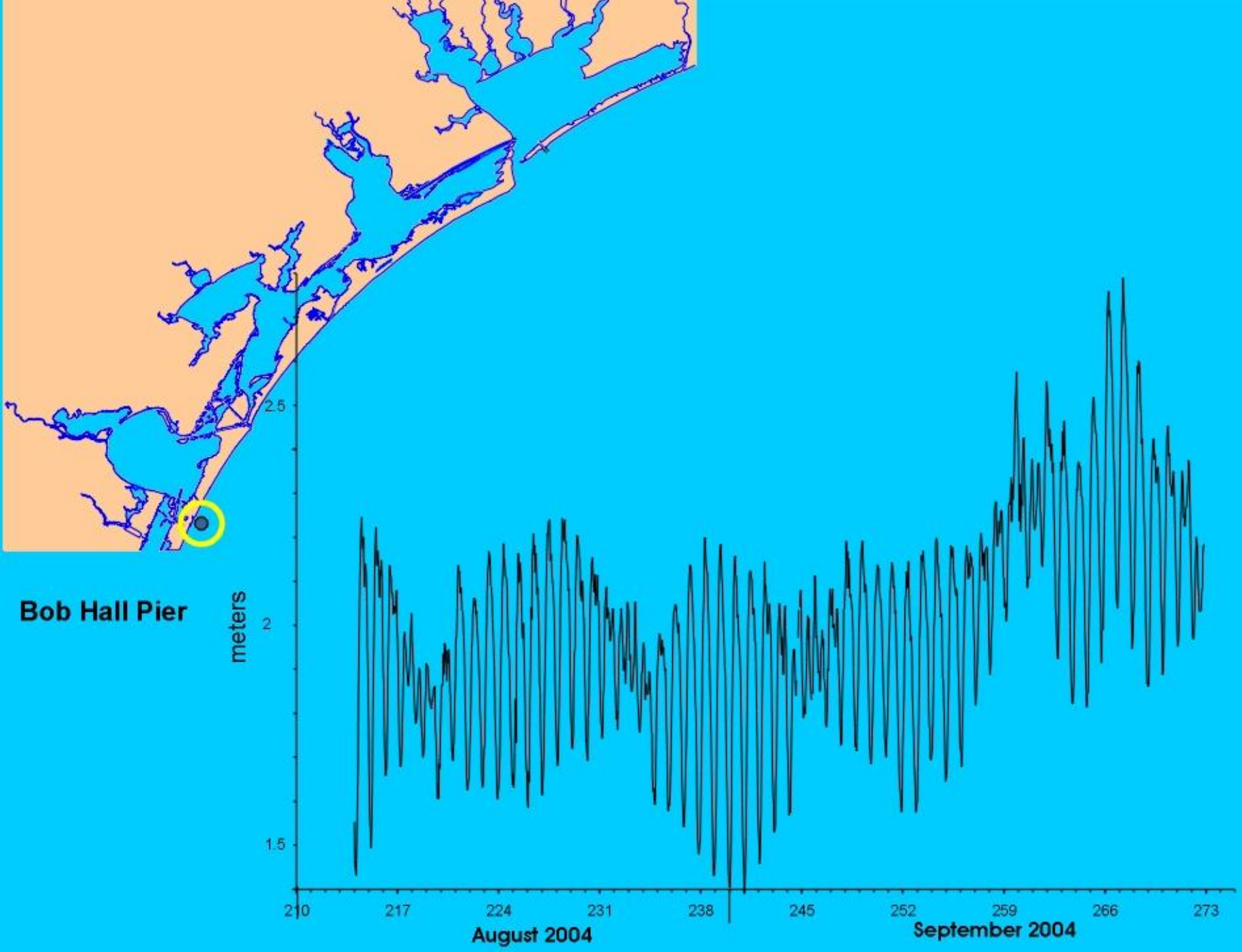


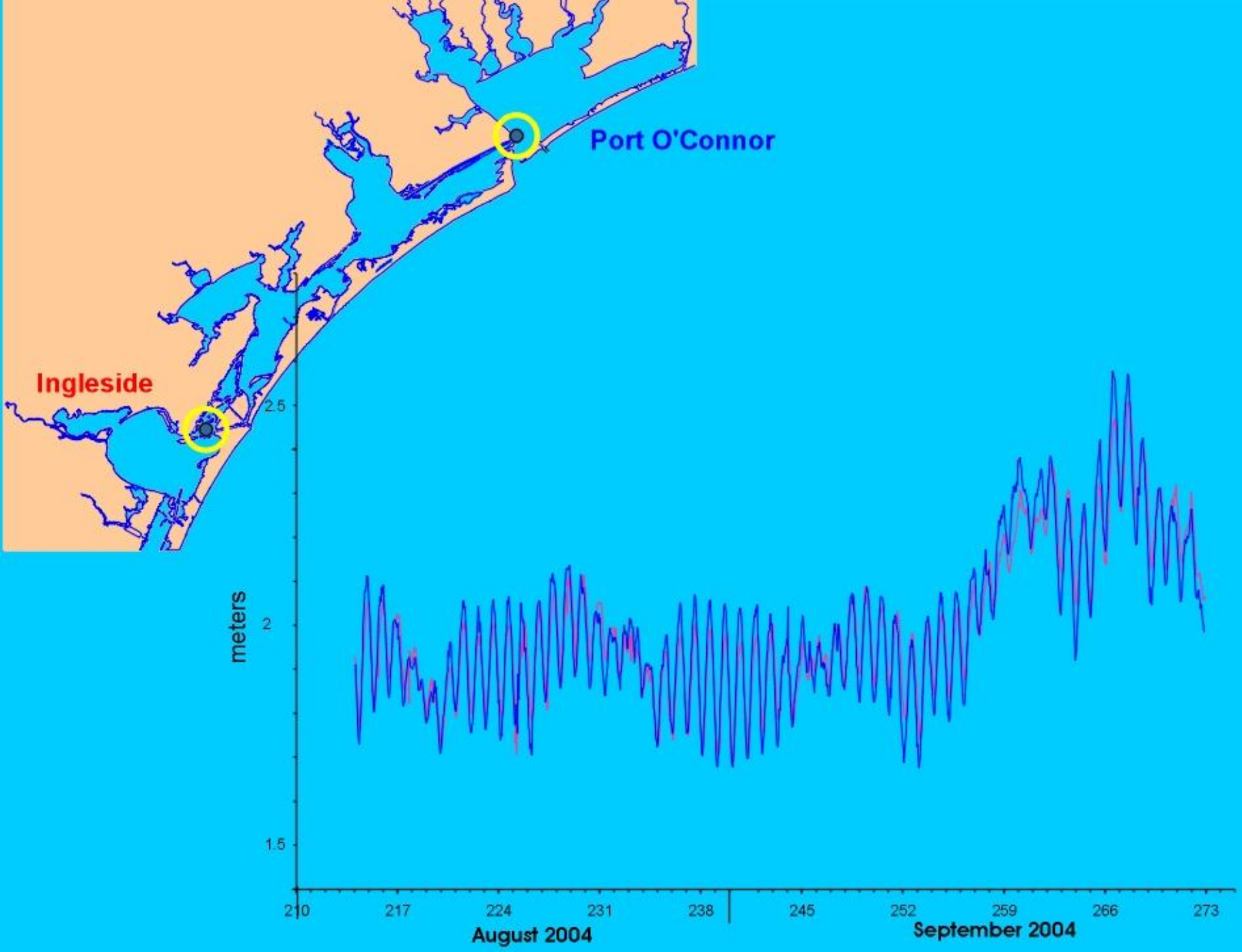

# STILLING WELL PRINCIPLE

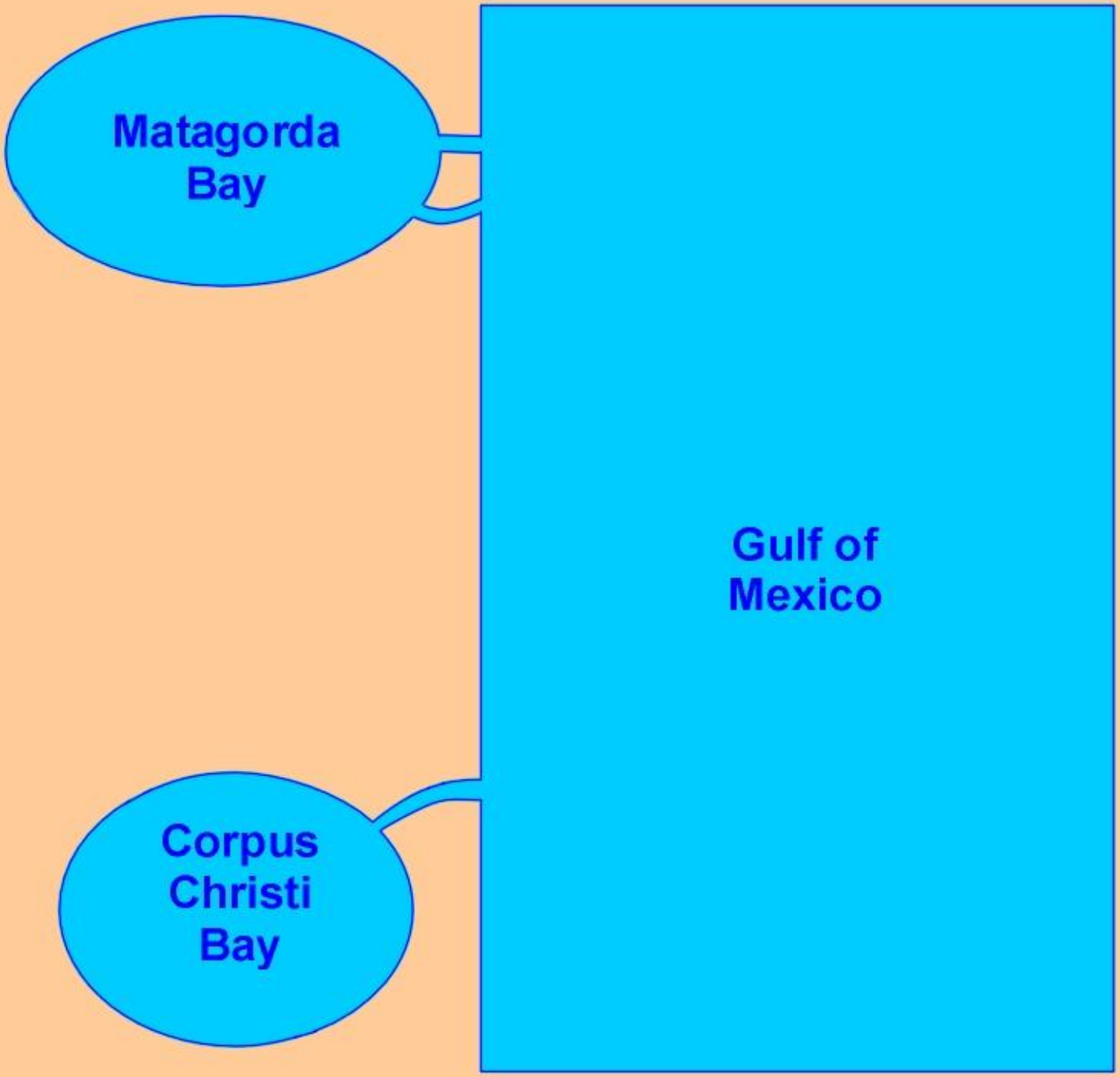

Lavaca Bay
Matagorda Bay
MSC Entrance Channel
Pass Cavallo
San Antonio Bay
Copano Bay
Aransas Bay
Nueces Bay
Corpus Christi Bay
Aransas Pass

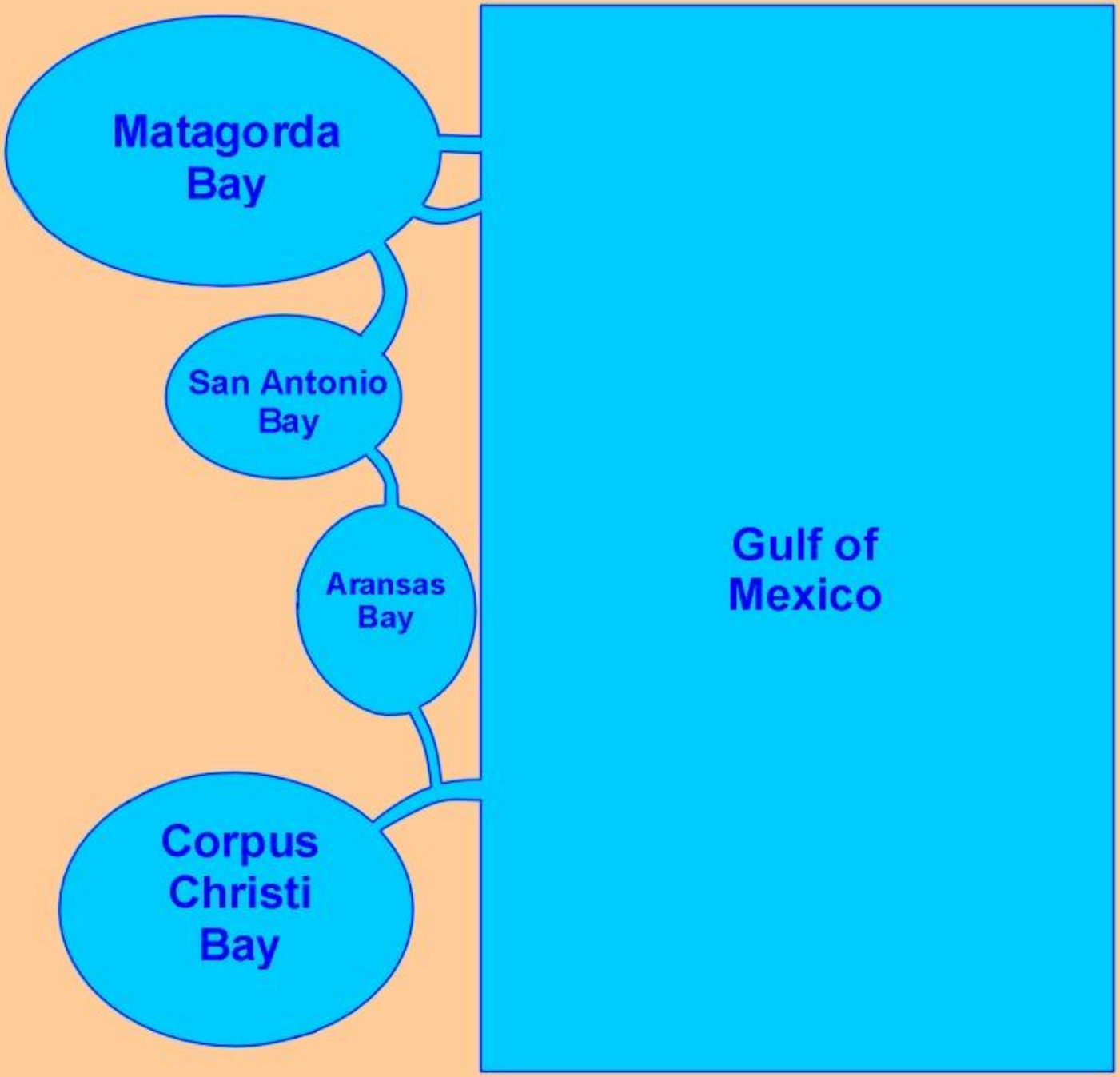
Gulf of
Mexico

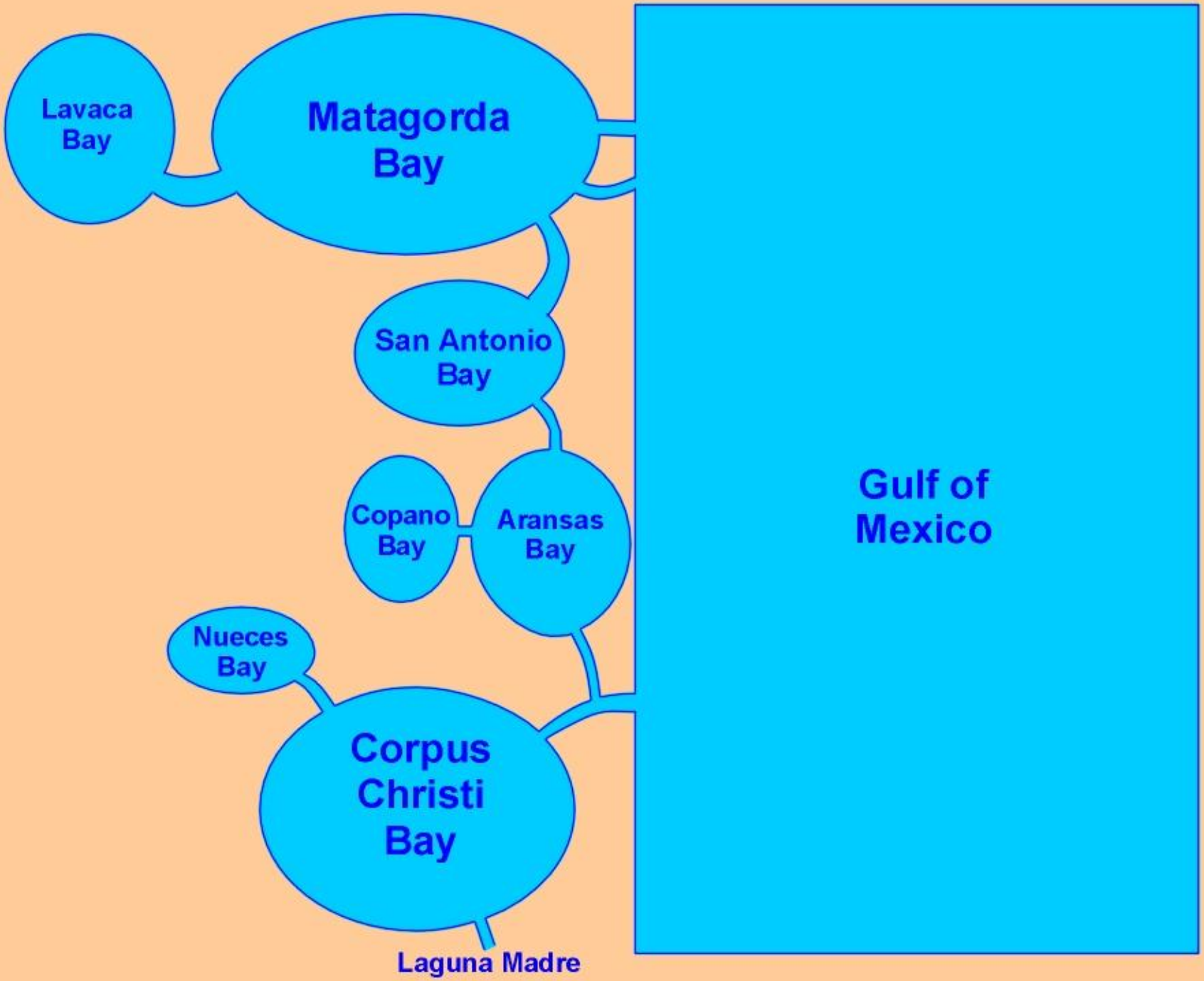

Matagorda Bay
Gulf of Mexico
Corpus Christi Bay

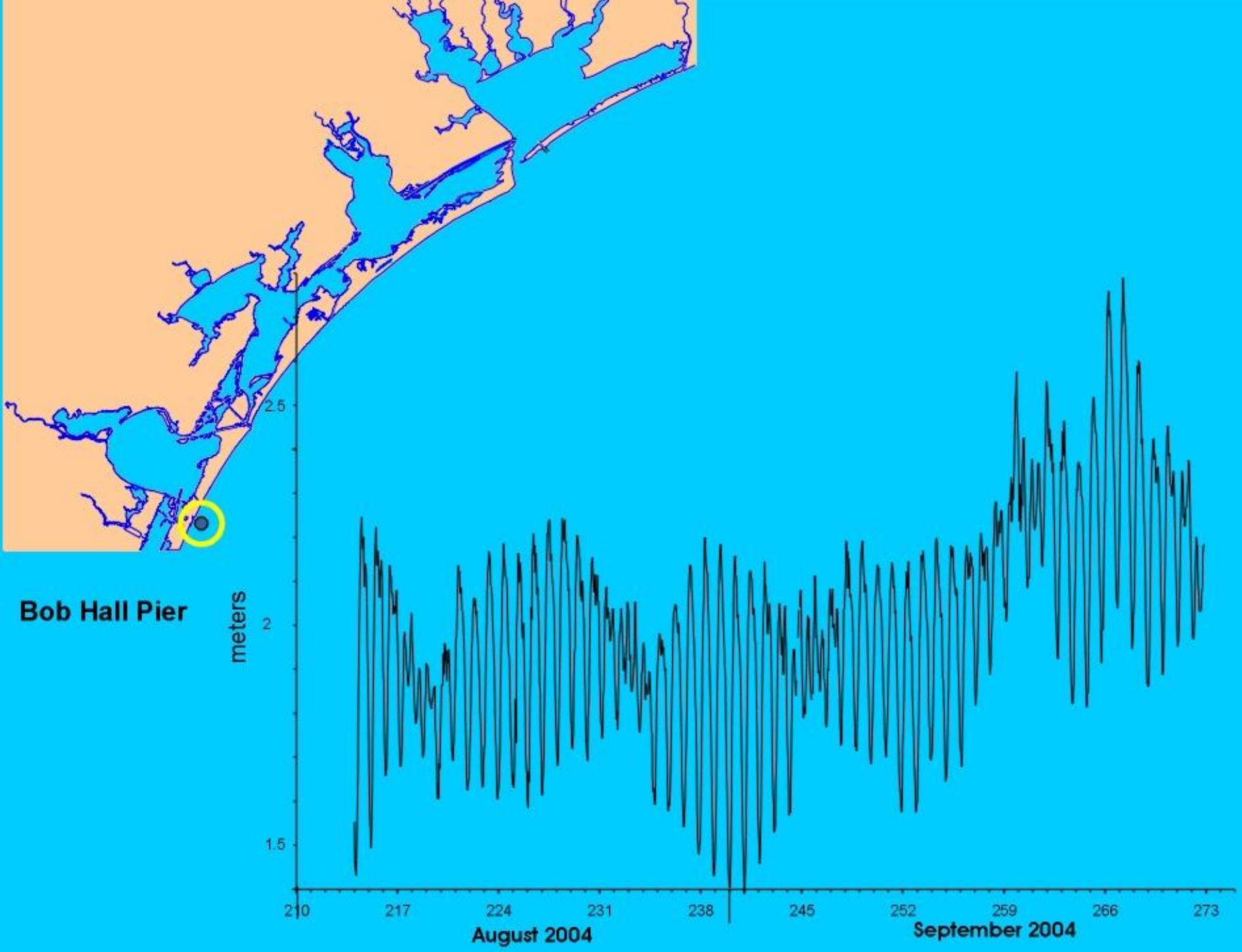

Bob Hall Pier
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004

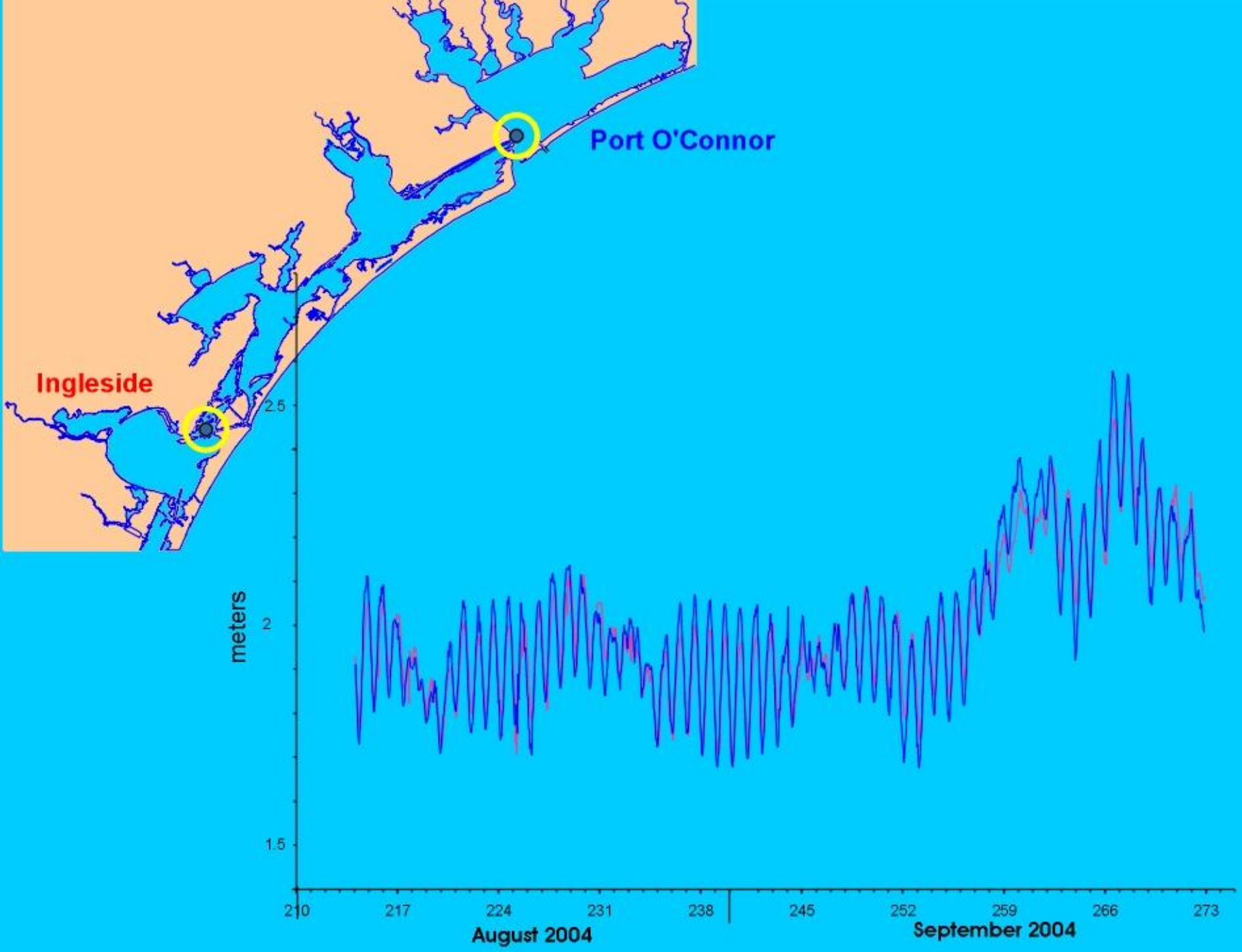

Port O'Connor
Ingleside
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004

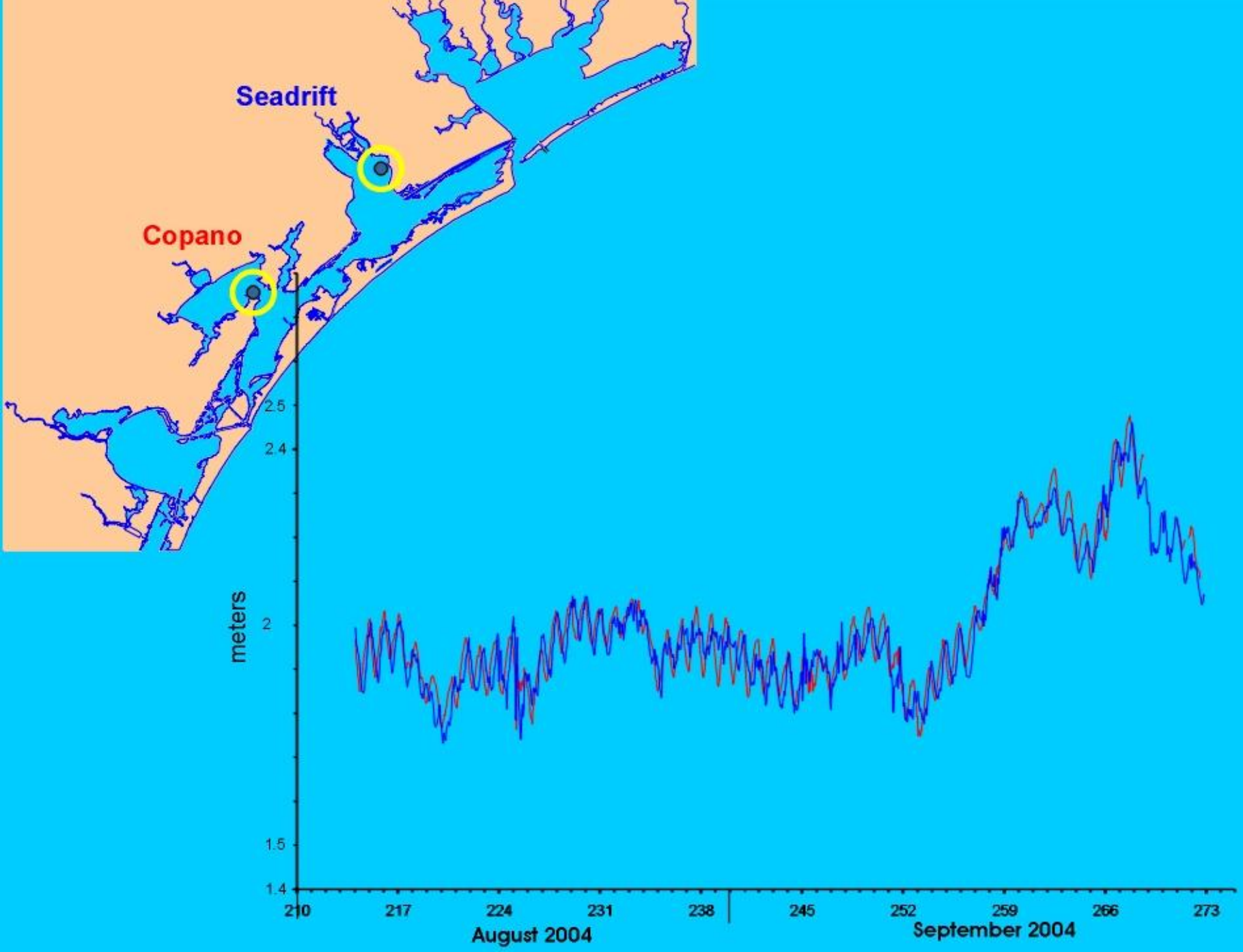

Matagorda Bay
Gulf of Mexico
Corpus Christi Bay


Matagorda Bay
San Antonio Bay
Aransas Bay
Corpus Christi Bay
Gulf of Mexico


Lavaca Bay
Matagorda Bay
San Antonio Bay
Copano Bay
Aransas Bay
Gulf of Mexico
Nueces Bay
Corpus Christi Bay
Laguna Madre


Bob Hall Pier
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004


Port O'Connor
Ingleside
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004


Seadrift
Copano
meters
2.5
2.4
2
1.5
1.4
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

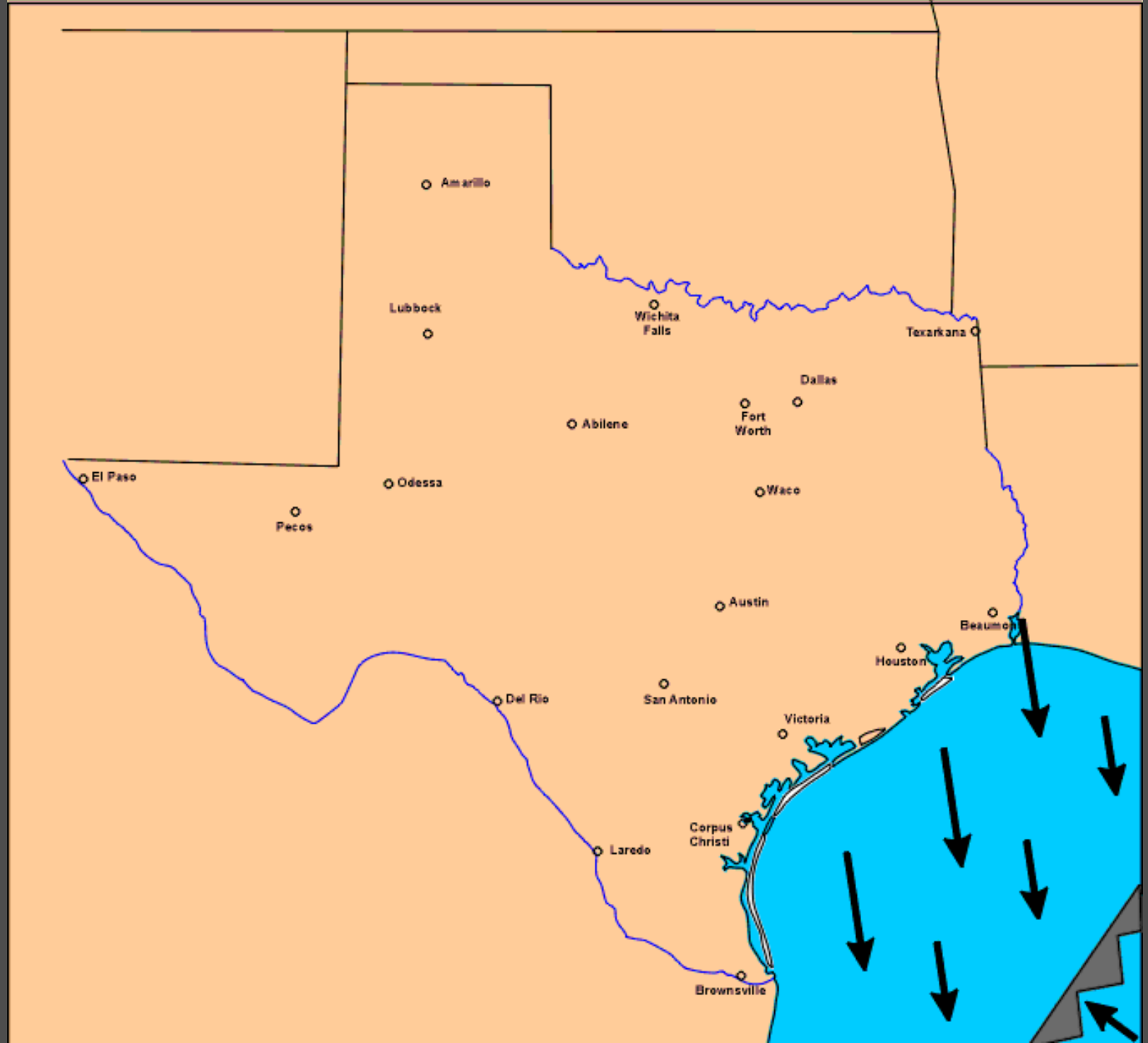
MORPHOLOGY

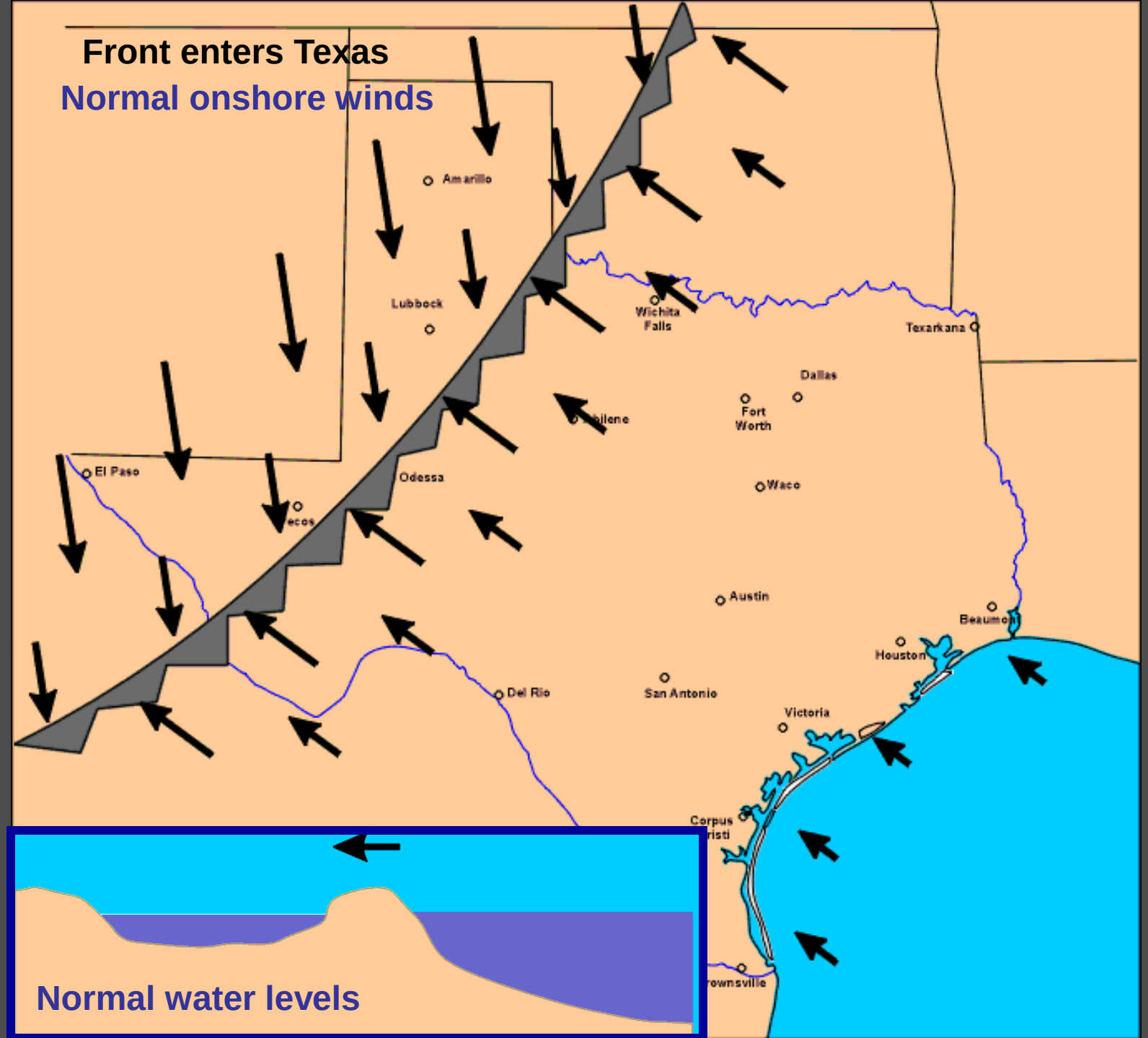
TIDES

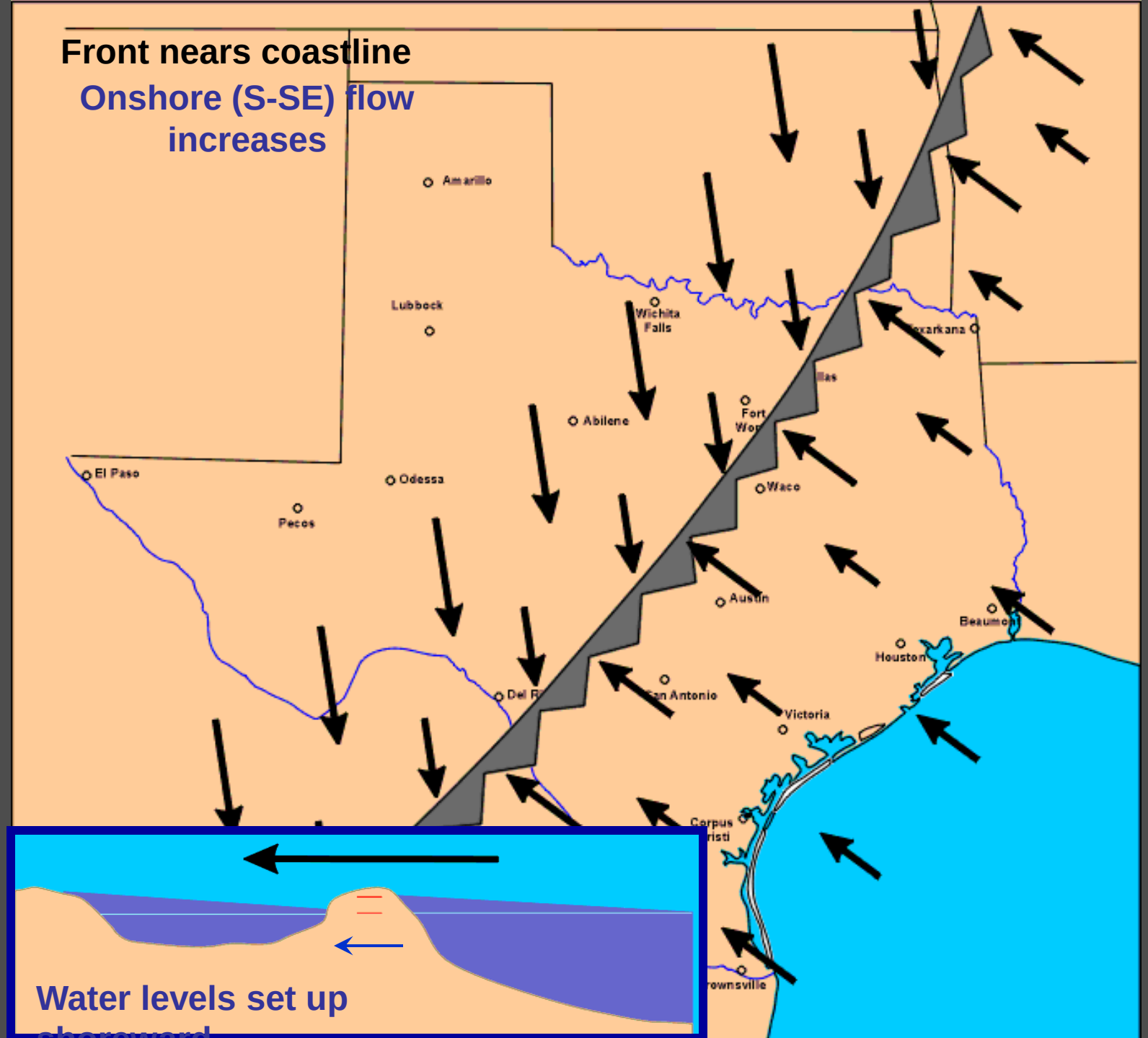
METEOROLOGICAL FORCING

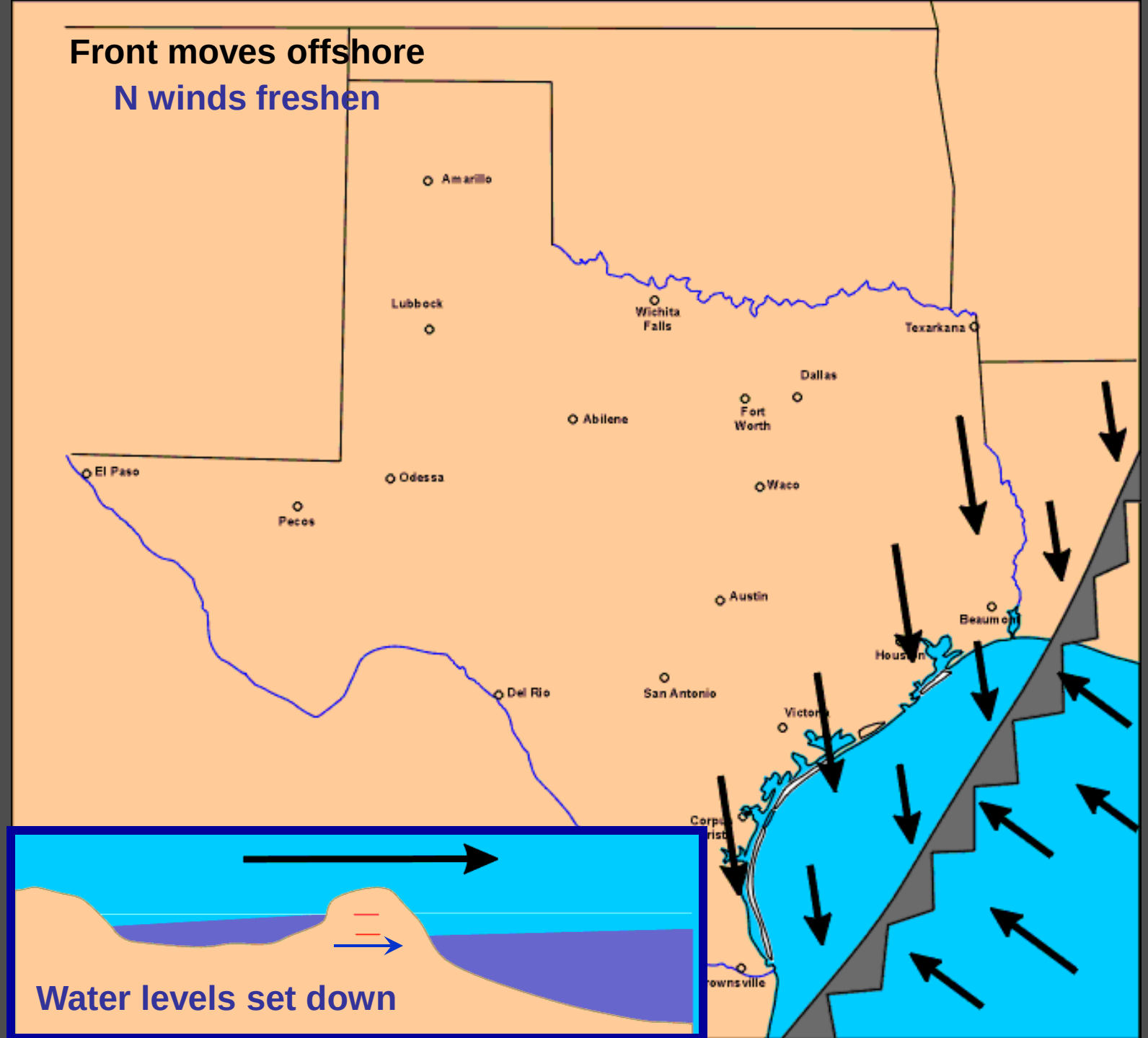
FRESHWATER INFLOW

SALINITY & WATER QUALITY


Amarillo
Lubbock
Wichita Falls
Texarkana
Dallas
Fort Worth
Abilene
El Paso
Odessa
Waco
Pecos
Austin
Beaumont
Houston
Del Rio
San Antonio
Victoria
Corpus Christi
Laredo
Brownsville


Front enters Texas
Normal onshore winds
Amarillo
Lubbock
Wichita Falls
Texarkana
Dallas
Fort Worth
Abilene
El Paso
Odessa
Pecos
Waco
Austin
Beaumont
Houston
Del Rio
San Antonio
Victoria
Corpus Christi
Brownsville
Normal water levels


Front nears coastline
Onshore (S-SE) flow increases
Amarillo
Lubbock
Wichita Falls
Abilene
Fort Worth
Waco
El Paso
Odessa
Pecos
Austin
Beaumont
Houston
San Antonio
Victoria
Corpus Christi
Brownsville
Water levels set up


Front moves offshore
N winds freshen
Amarillo
Lubbock
Wichita Falls
Texarkana
Dallas
Fort Worth
Abilene
El Paso
Odessa
Waco
Pecos
Austin
Beaumont
Houston
Del Rio
San Antonio
Victoria
Corpus Christi
Brownsville
Water levels set down

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

MORPHOLOGY

TIDES

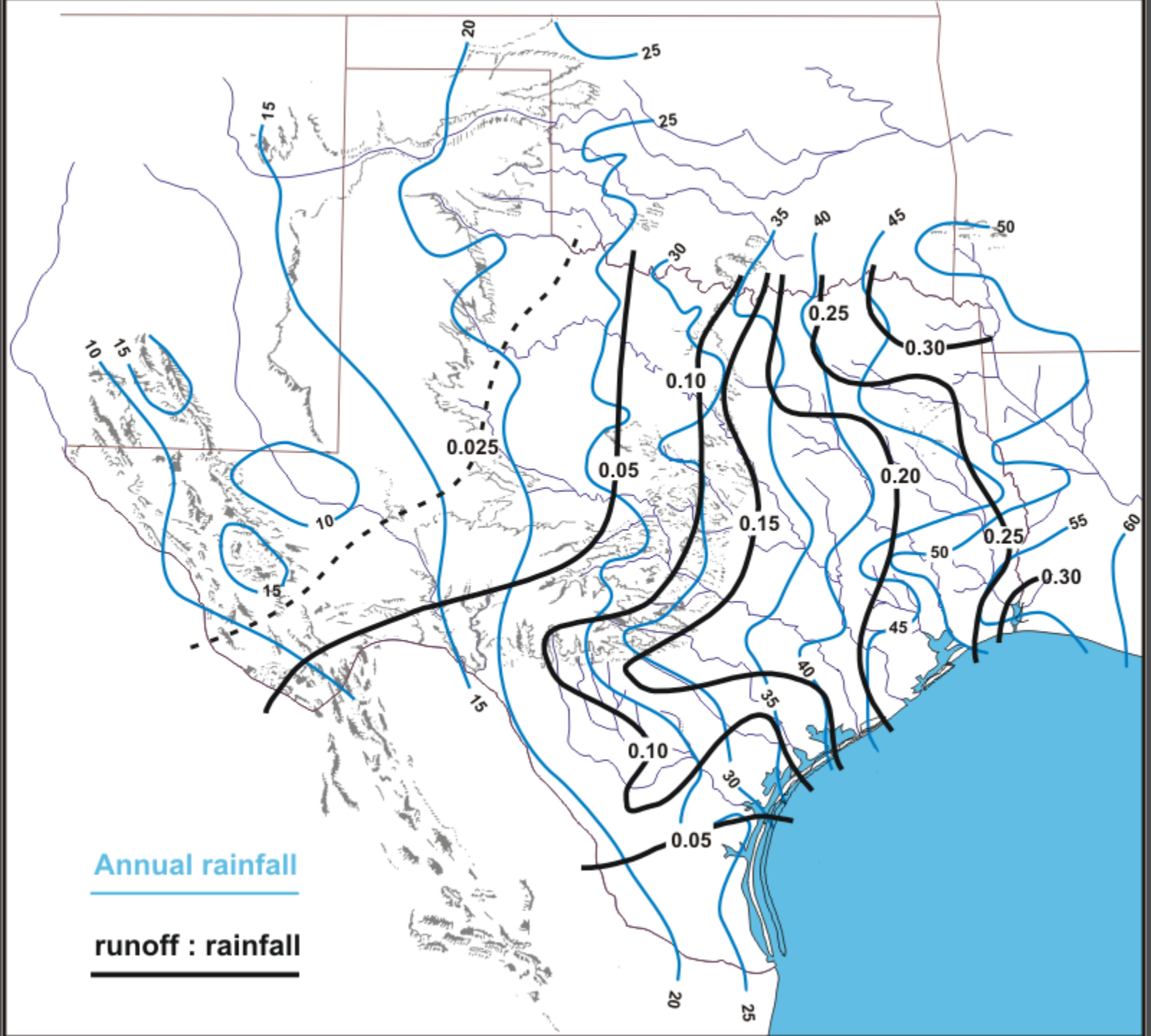
METEOROLOGICAL FORCING

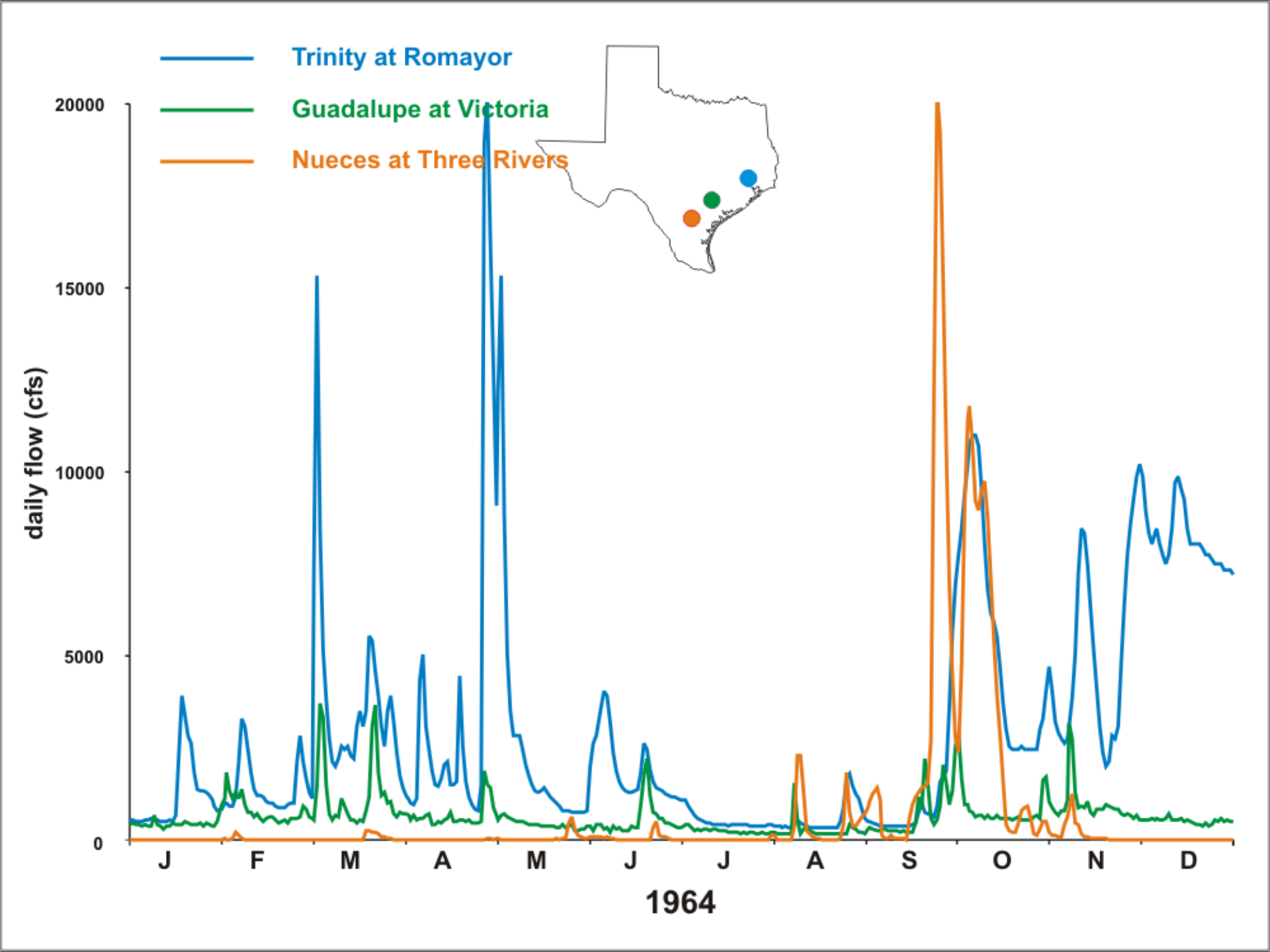
FRESHWATER INFLOW

SALINITY & WATER QUALITY

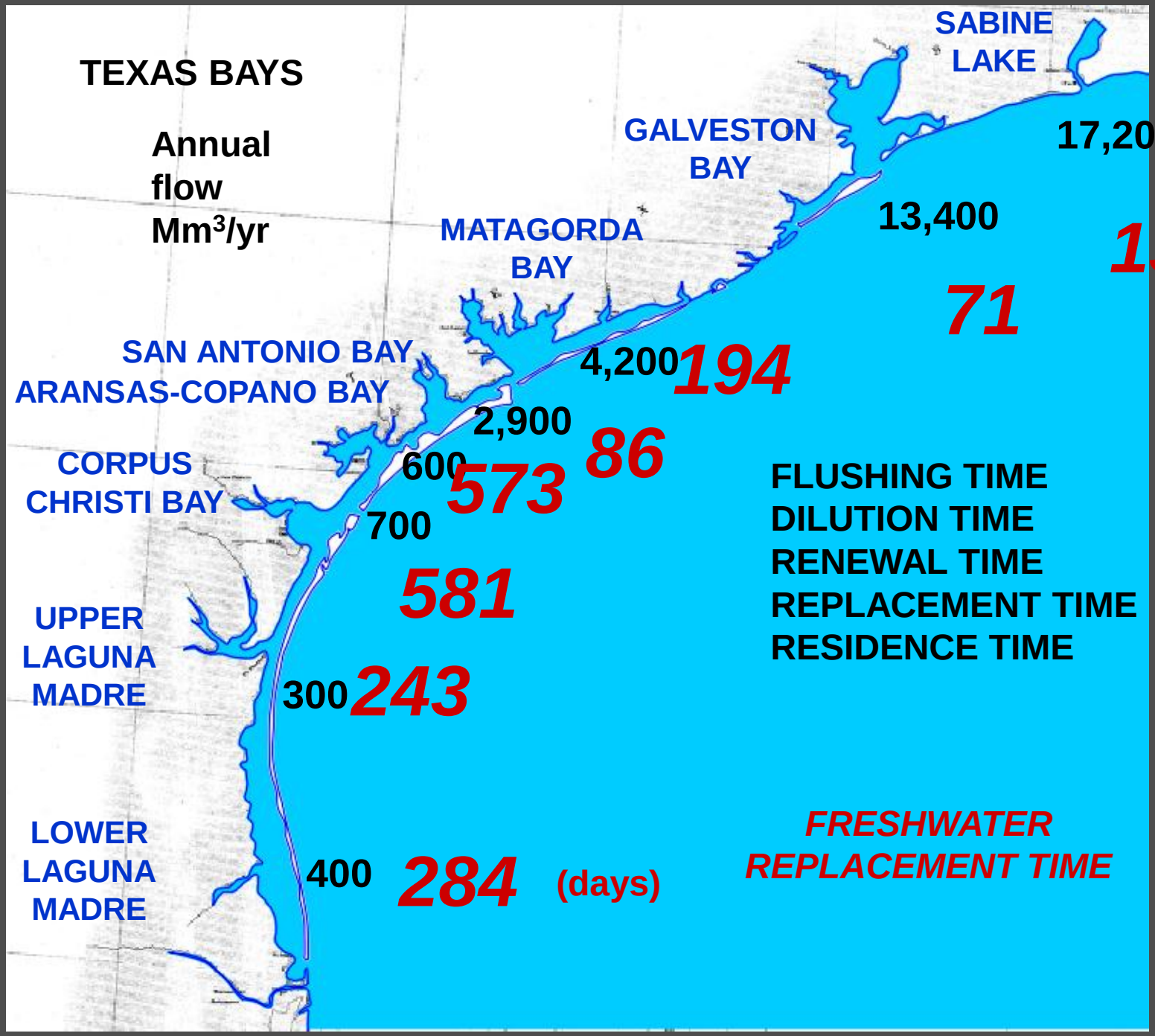
# FACTOIDS ABOUT TEXAS SURFACE WATER

- RAINFALL IS PRODUCED ALMOST ENTIRELY FROM DEEP CONVECTION
- RAINFALL DECLINES PRECIPITOUSLY FROM EAST TO WEST
- RUNOFF IS SMALL AS A PROPORTION OF RAINFALL
- RUNOFF DECLINES EVEN MORE PRECIPITOUSLY FROM EAST TO WEST
- STREAMFLOW IS FLASHY
- STREAMFLOW EXHIBITS LARGE VACILLATIONS ON TIME SCALES OF MONTHS TO YEARS


Annual rainfall
runoff : rainfall
10
15
20
25
30
35
40
45
50
55
60
0.025
0.05
0.10
0.15
0.20
0.25
0.30


Trinity at Romayor
Guadalupe at Victoria
Nueces at Three Rivers
20000
15000
10000
5000
0
daily flow (cfs)
J
F
M
A
M
J
J
A
S
O
N
D
1964


Lavaca/Navidad
Colorado
Guadalupe
Aransas/Mission/Copano
Nueces


TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
17,200
13
GALVESTON BAY
13,400
71
MATAGORDA BAY
SAN ANTONIO BAY
ARANSAS-COPANO BAY
4,200
194
2,900
86
CORPUS CHRISTI BAY
600
573
700
581
UPPER LAGUNA MADRE
300
243
LOWER LAGUNA MADRE
400
284
(days)
FLUSHING TIME
DILUTION TIME
RENEWAL TIME
REPLACEMENT TIME
RESIDENCE TIME
FRESHWATER REPLACEMENT TIME

MORPHOLOGY

TIDES

METEOROLOGICAL FORCING

FRESHWATER INFLOW

SALINITY & WATER QUALITY

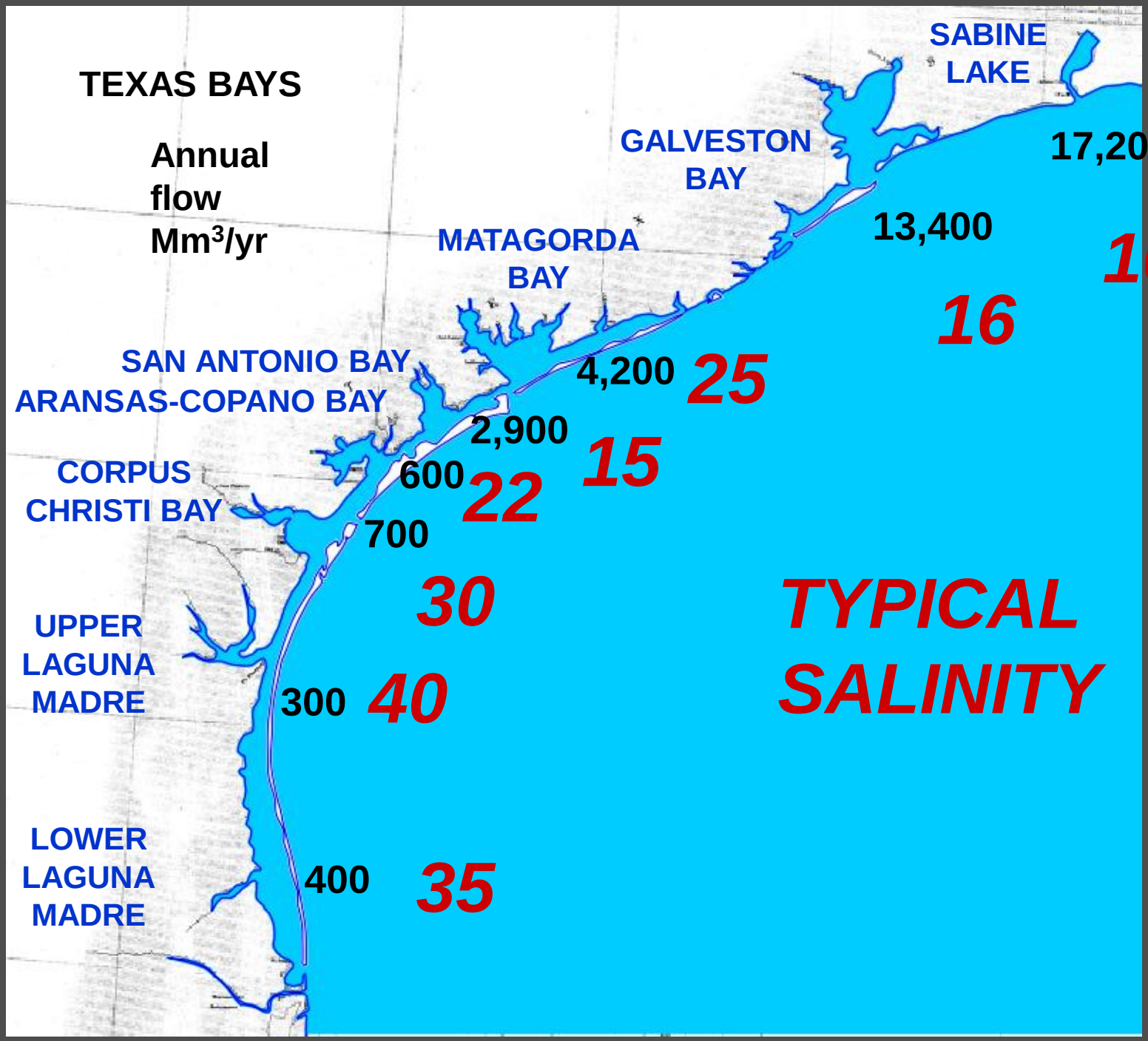
MORPHOLOGY

TIDES

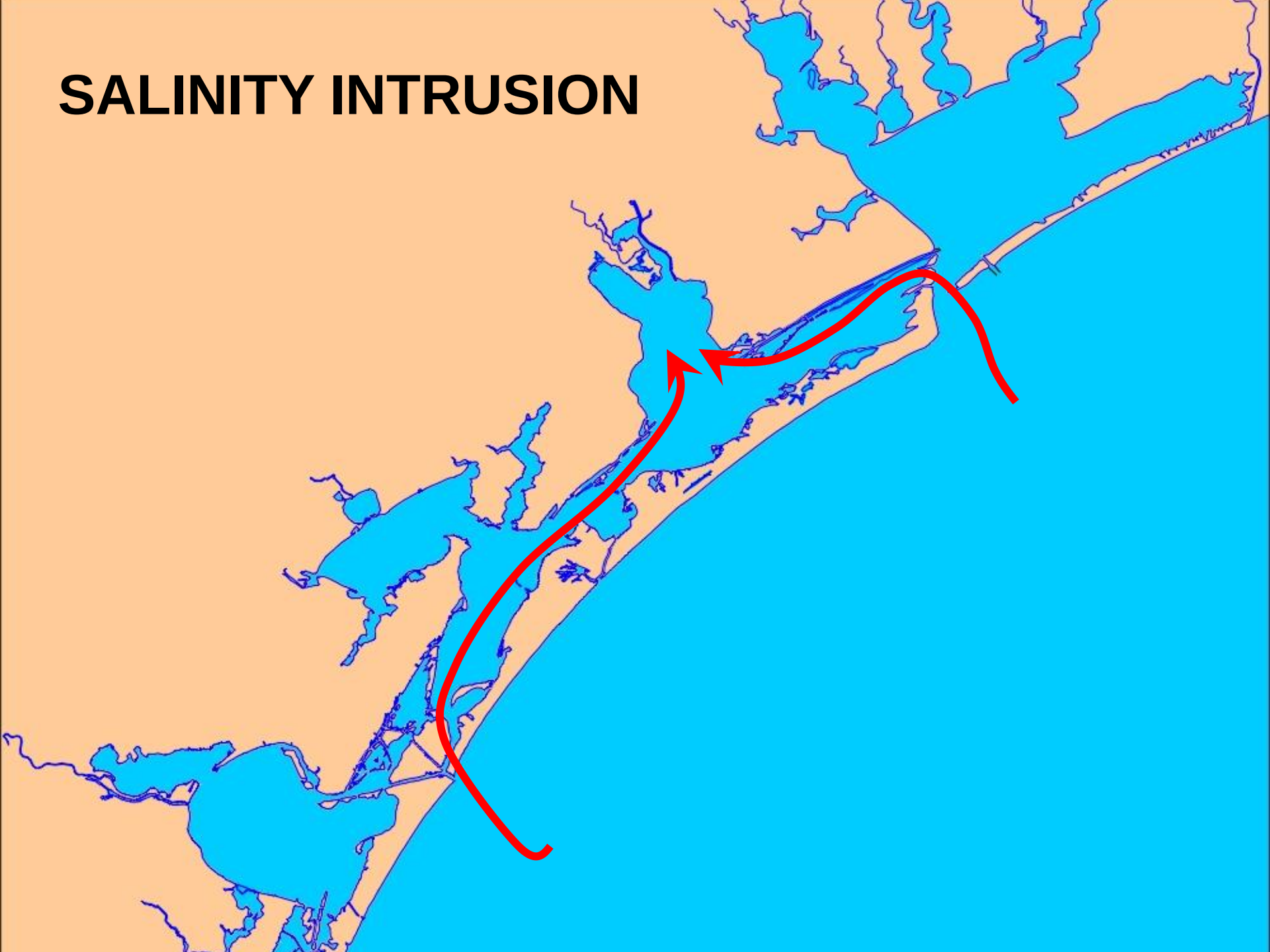
METEOROLOGICAL FORCING

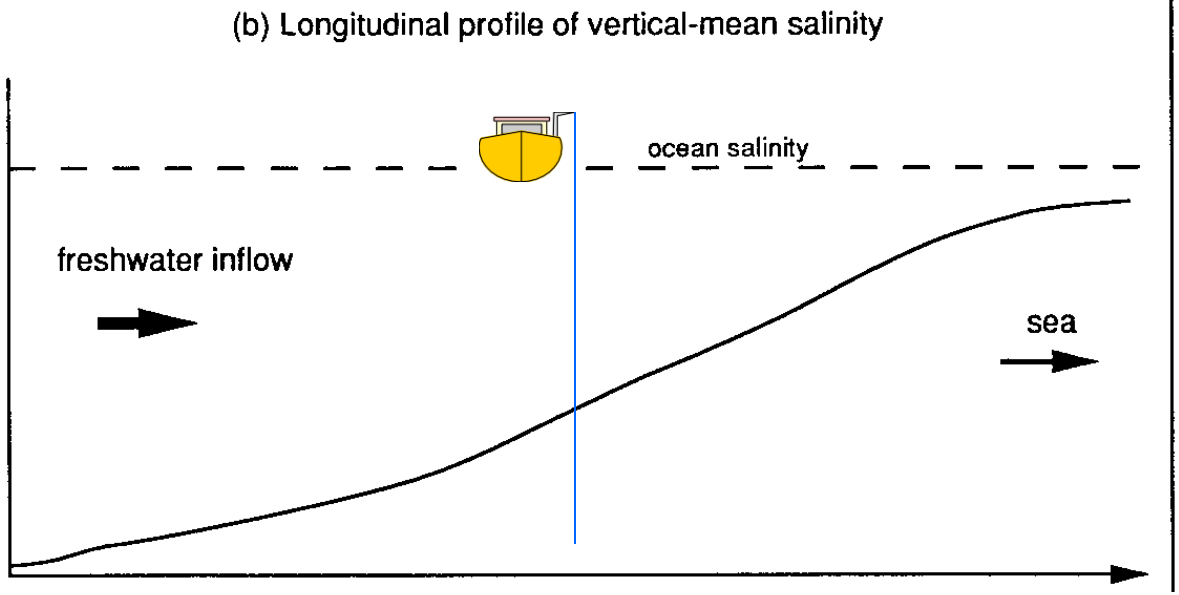
FRESHWATER INFLOW

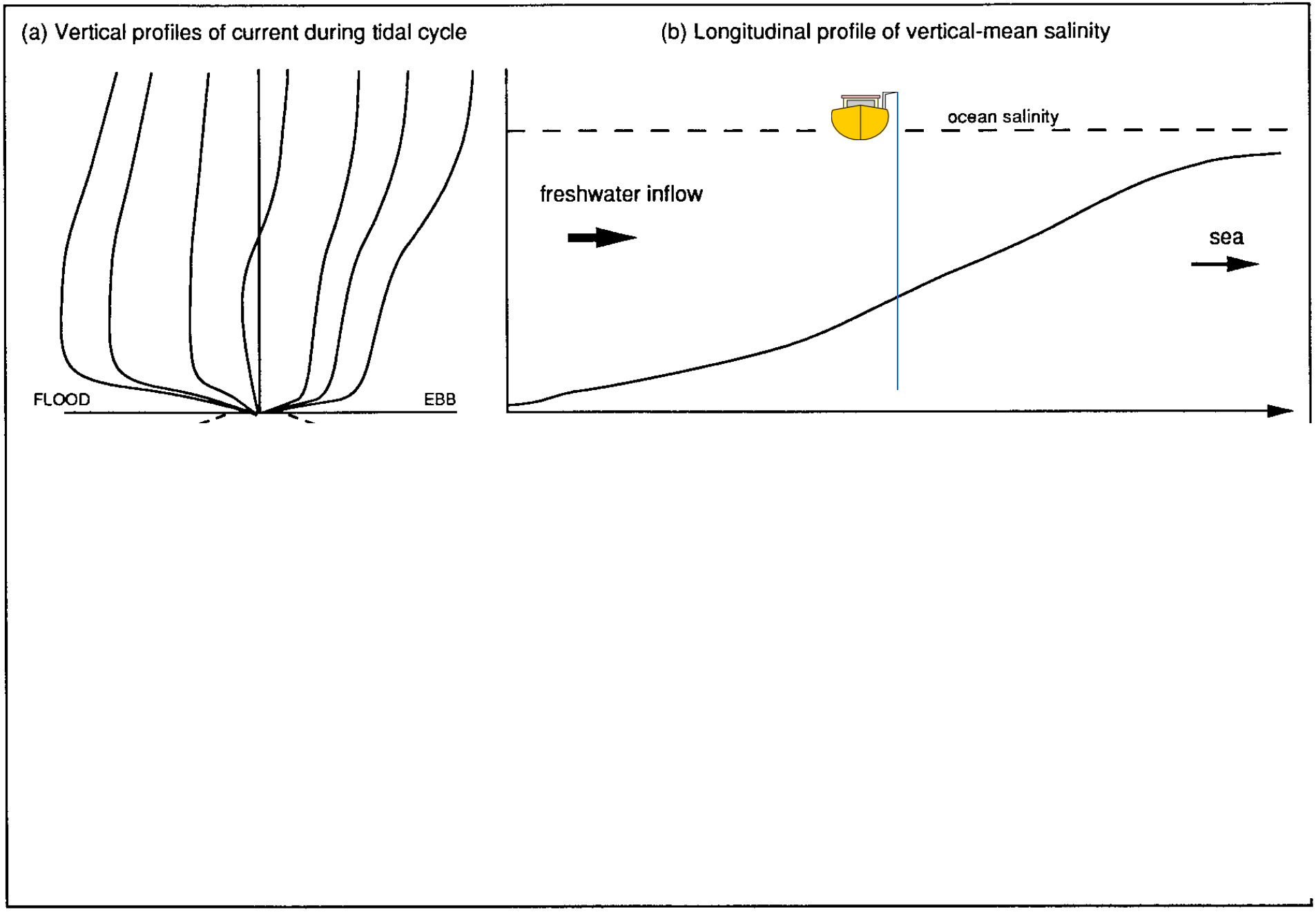
SALINITY & WATER QUALITY

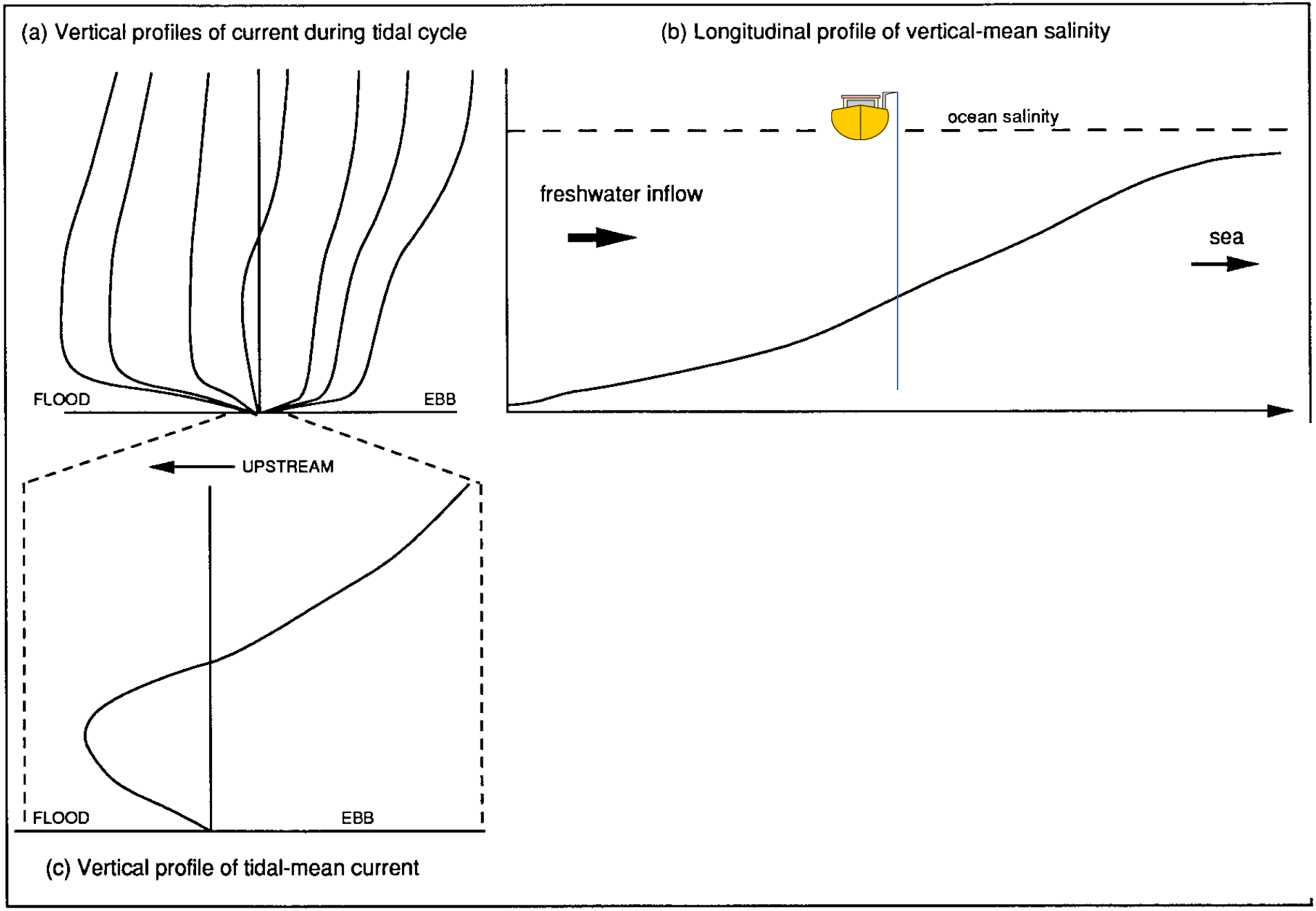

TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
17,200
10
GALVESTON BAY
13,400
16
MATAGORDA BAY
4,200
25
SAN ANTONIO BAY
ARANSAS-COPANO BAY
2,900
15
CORPUS CHRISTI BAY
600
22
700
30
UPPER LAGUNA MADRE
300
40
LOWER LAGUNA MADRE
400
35
TYPICAL SALINITY

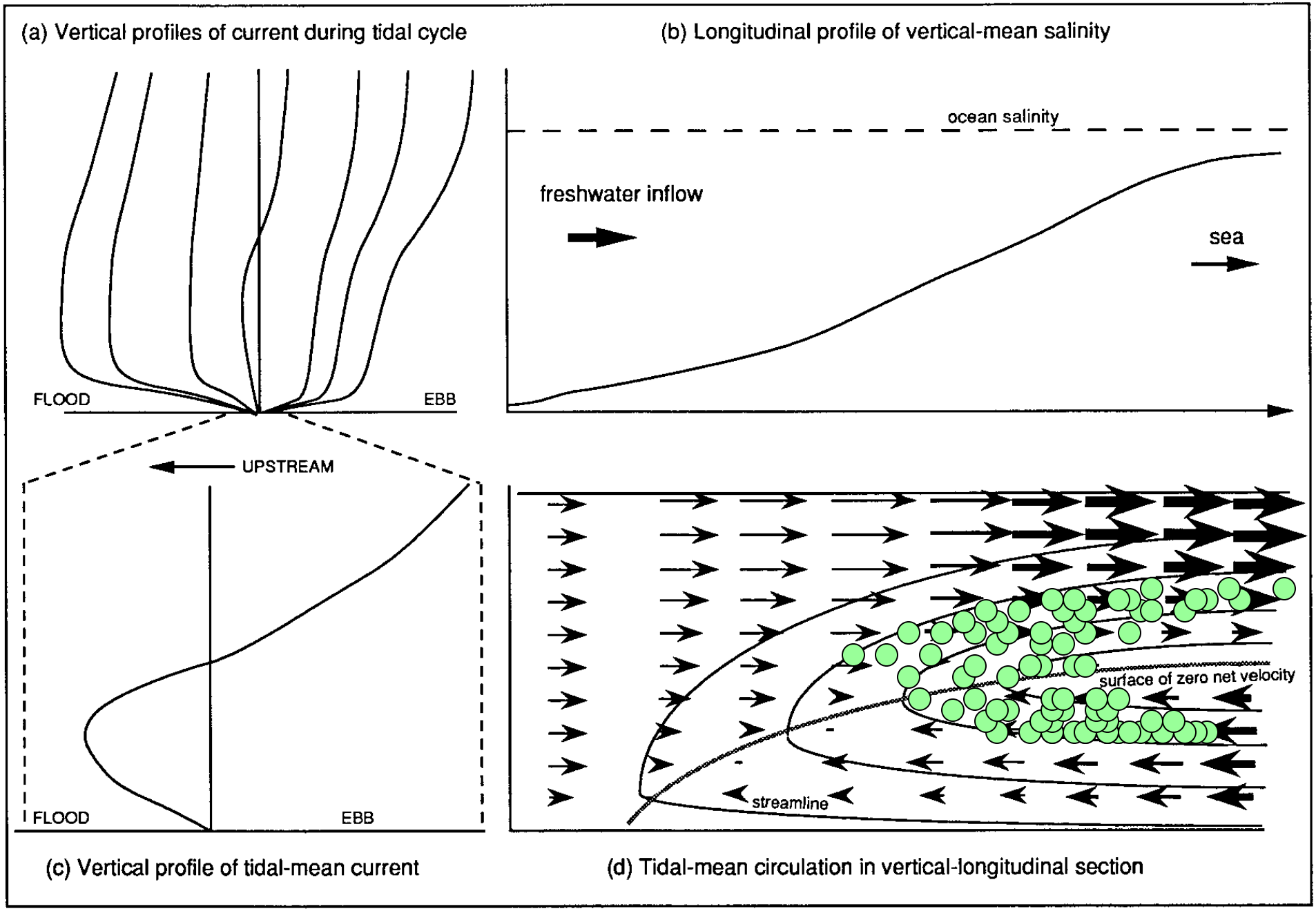
# SALINITY INTRUSION




(b) Longitudinal profile of vertical-mean salinity
ocean salinity
freshwater inflow
sea


(a) Vertical profiles of current during tidal cycle
FLOOD
EBB
(b) Longitudinal profile of vertical-mean salinity
ocean salinity
freshwater inflow
sea


(a) Vertical profiles of current during tidal cycle
FLOOD
EBB
UPSTREAM
FLOOD
EBB
(c) Vertical profile of tidal-mean current
(b) Longitudinal profile of vertical-mean salinity
ocean salinity
freshwater inflow
sea


(a) Vertical profiles of current during tidal cycle
FLOOD
EBB
(b) Longitudinal profile of vertical-mean salinity
ocean salinity
freshwater inflow
sea
UPSTREAM
FLOOD
EBB
surface of zero net velocity
streamline
(c) Vertical profile of tidal-mean current
(d) Tidal-mean circulation in vertical-longitudinal section

THREE (3) FACTOIDS ABOUT

# DENSITY CURRENTS

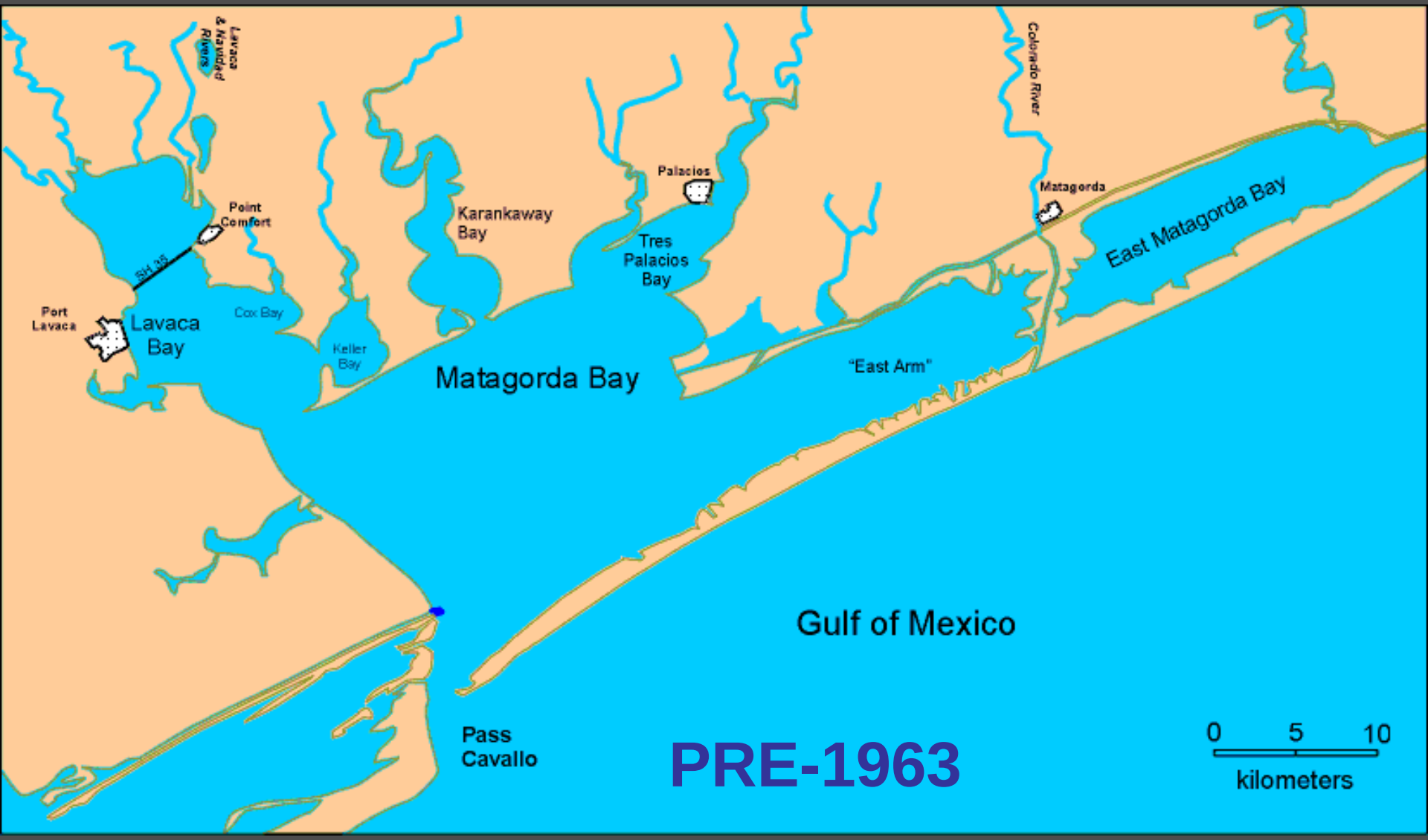
FORCED BY THE HORIZ HORIZONTAL SALINITY

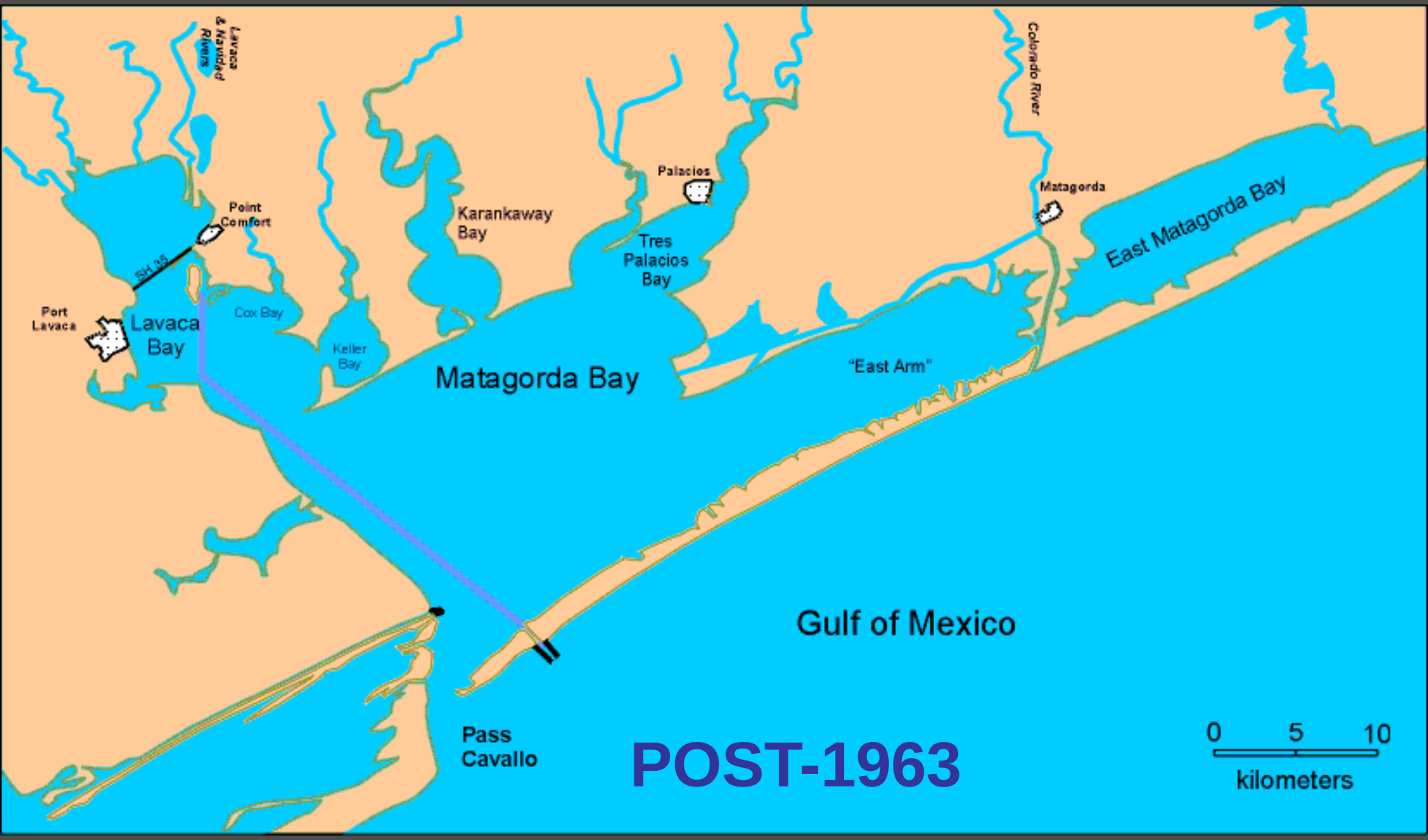
FLOW ABOUT AN ORDER OF MAGNITUDE GREATER THAN INFLOW

INCREASES AS THE CUBE OF DEPTH

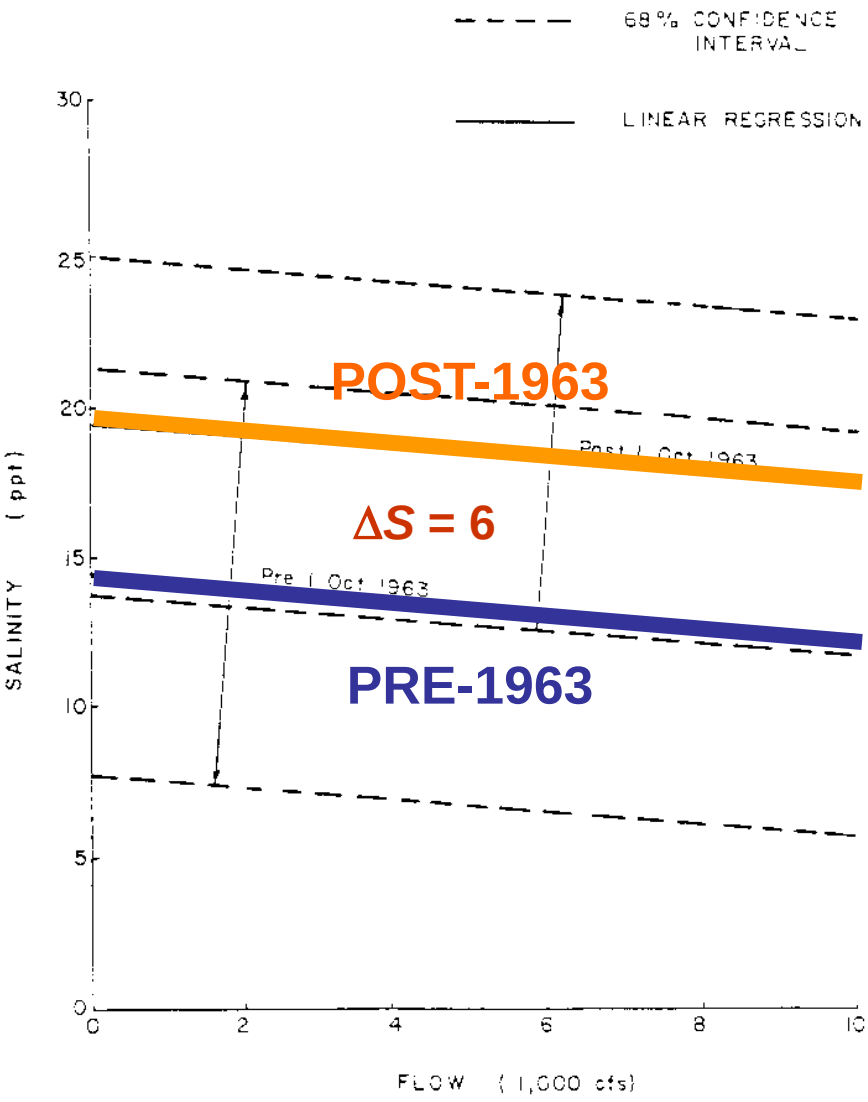
## DEVELOPMENT OF HOUSTON SHIP CHANNEL

| *date* | *depth (ft)* |
|---|---|
| **1880** | **12** |
| **1910** | **19** |
| **1914** | **25** |
| **1922** | **30** |
| **1937** | **32** |
| **1950** | **36** |
| **1965** | **40** |
| **1998** | **45** |


Lavaca & Navidad Rivers
Point Comfort
SH 35
Port Lavaca
Lavaca Bay
Cox Bay
Keller Bay
Karankaway Bay
Palacios
Tres Palacios Bay
Matagorda Bay
"East Arm"
Colorado River
Matagorda
East Matagorda Bay
Gulf of Mexico
Pass Cavallo
PRE-1963
0 5 10
kilometers

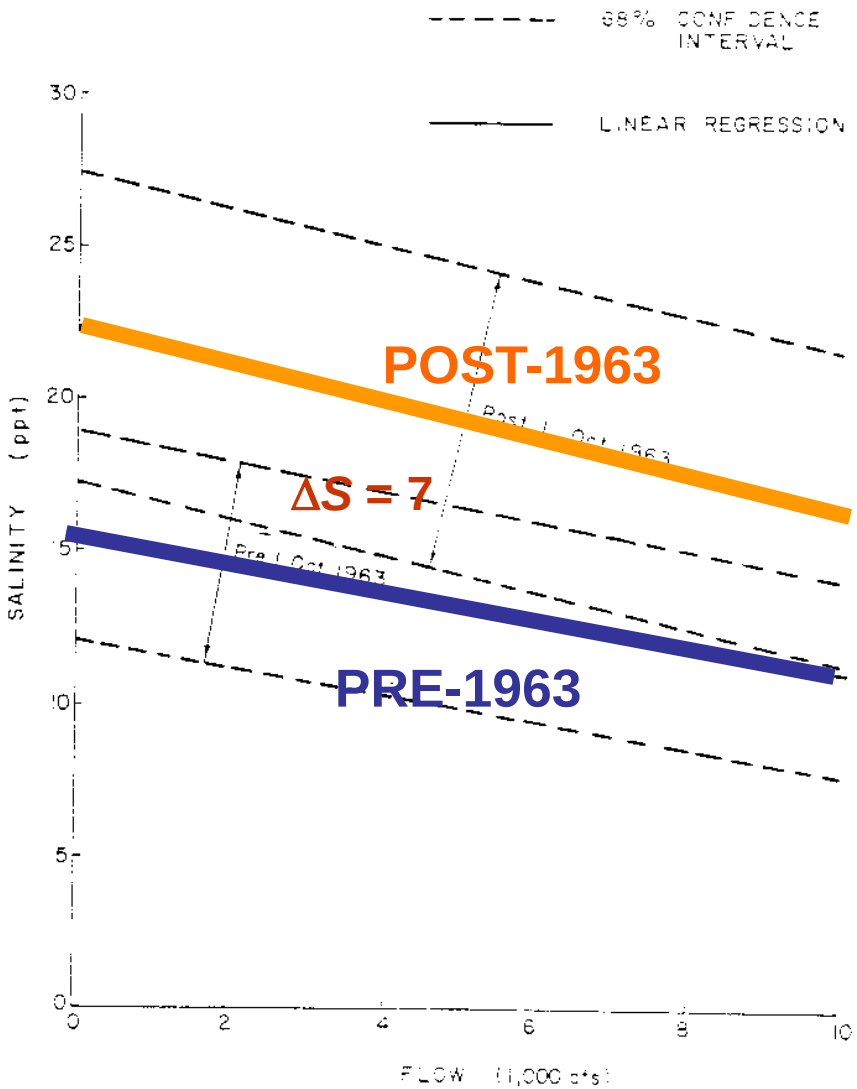

Lavaca & Navidad Rivers
Colorado River
Palacios
Matagorda
Point Comfort
Karankaway Bay
Tres Palacios Bay
East Matagorda Bay
SH 35
Port Lavaca
Lavaca Bay
Cox Bay
Keller Bay
Matagorda Bay
"East Arm"
Gulf of Mexico
Pass Cavallo
POST-1963
0 5 10
kilometers

## LAVACA BAY

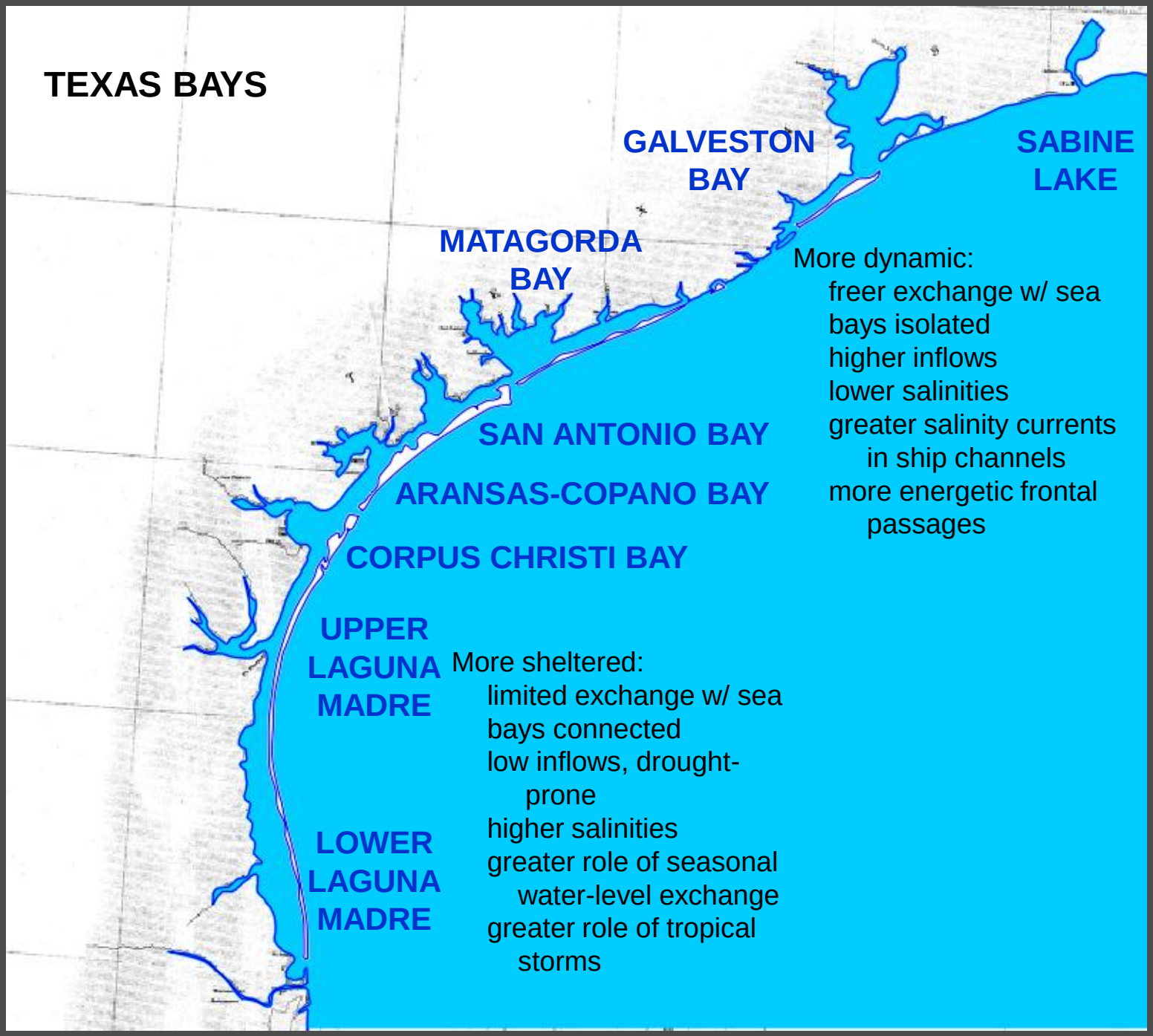



Salinity regressions, Lavaca Bay (West)

## UPPER MATAGORDA BAY

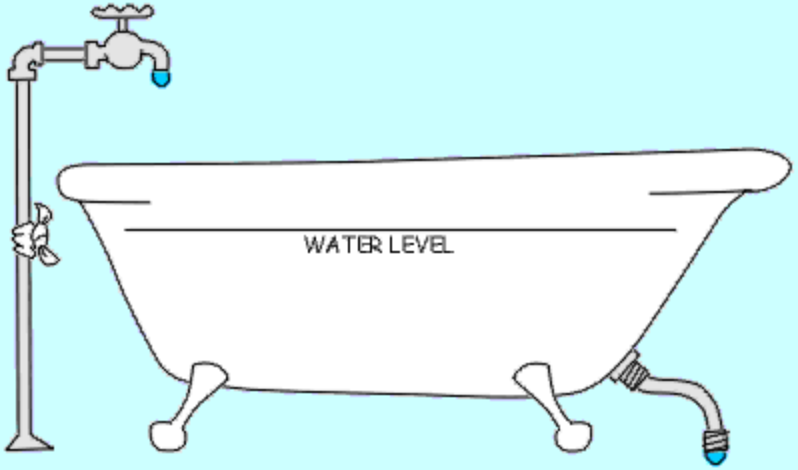



Salinity regressions, Upper Matagorda Bay (West)

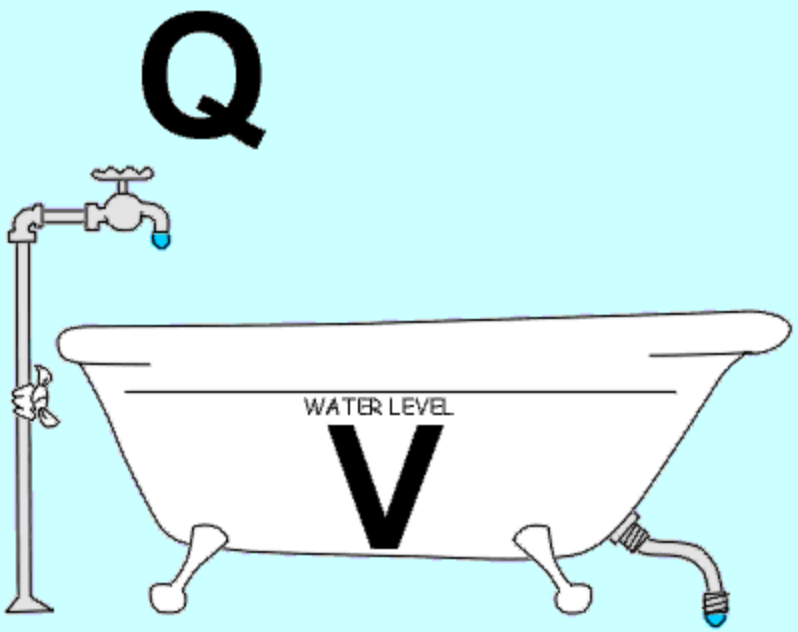

TEXAS BAYS
GALVESTON BAY
SABINE LAKE
MATAGORDA BAY
More dynamic:
freer exchange w/ sea
bays isolated
higher inflows
lower salinities
greater salinity currents in ship channels
more energetic frontal passages
SAN ANTONIO BAY
ARANSAS-COPANO BAY
CORPUS CHRISTI BAY
UPPER LAGUNA MADRE
More sheltered:
limited exchange w/ sea
bays connected
low inflows, drought-prone
higher salinities
greater role of seasonal water-level exchange
greater role of tropical storms
LOWER LAGUNA MADRE

# WHOLE-VOLUME WATER BUDGET OF BAY

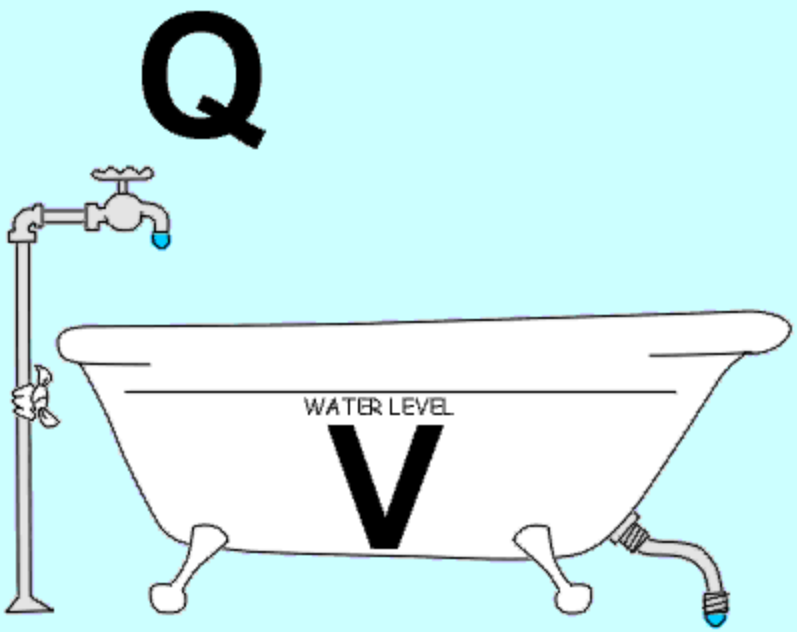
**FRESHWATER INFLOW**



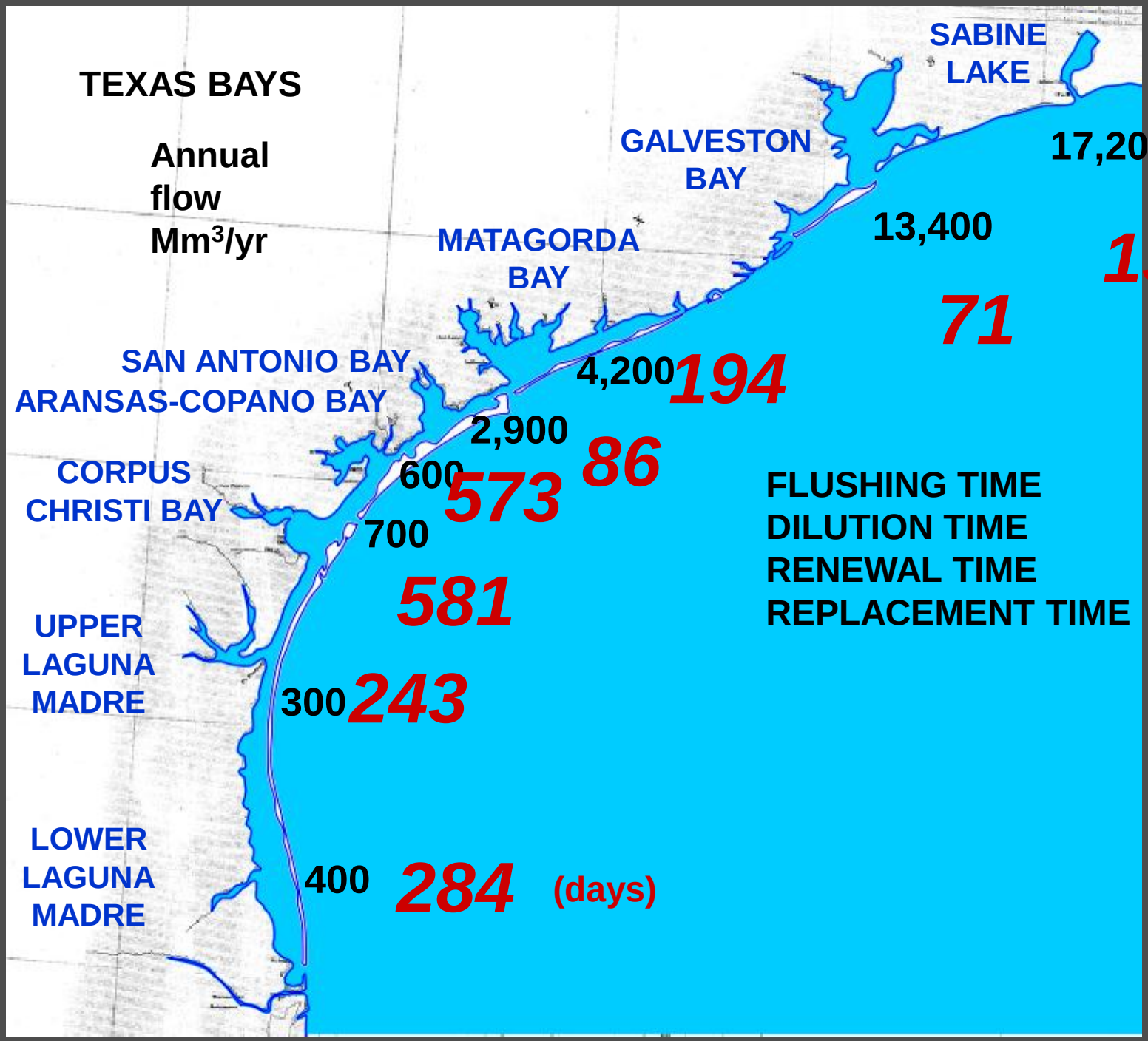
FRESHWATER
INFLOW



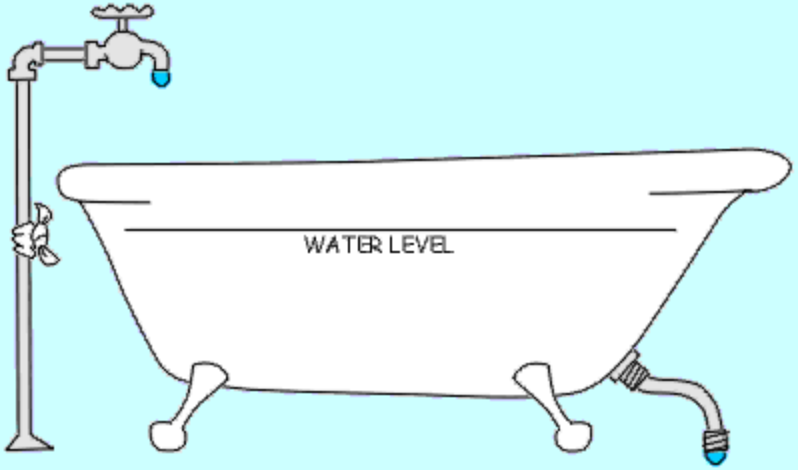
FRESHWATER
INFLOW




$$T = V/Q$$

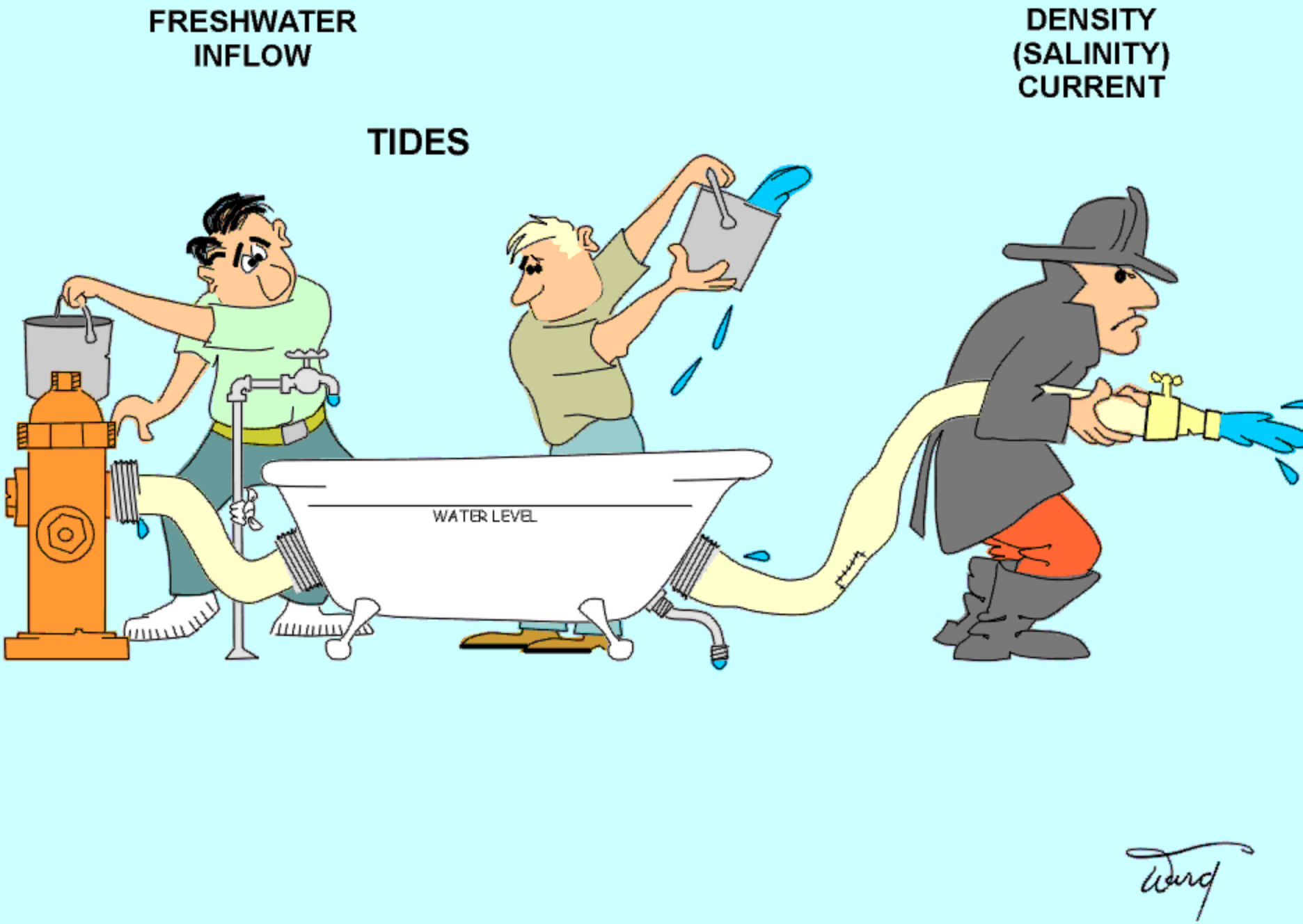

TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
17,200
13
GALVESTON BAY
13,400
71
MATAGORDA BAY
SAN ANTONIO BAY
ARANSAS-COPANO BAY
4,200
194
2,900
86
CORPUS CHRISTI BAY
600
573
700
581
UPPER LAGUNA MADRE
300
243
LOWER LAGUNA MADRE
400
284
(days)
FLUSHING TIME
DILUTION TIME
RENEWAL TIME
REPLACEMENT TIME

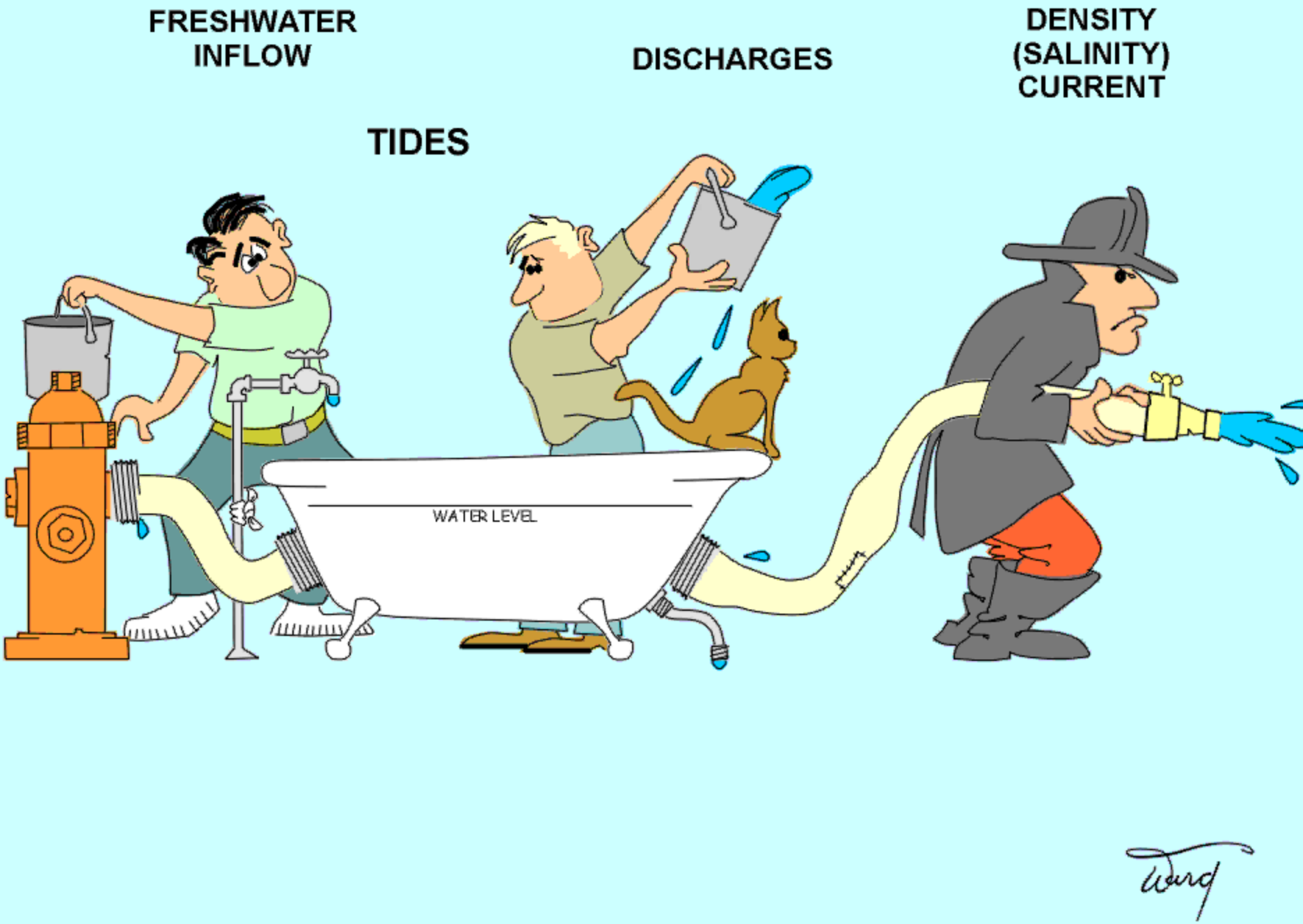
**FRESHWATER INFLOW**



FRESHWATER
INFLOW

TIDES


FRESHWATER INFLOW
TIDES
DENSITY (SALINITY) CURRENT
WATER LEVEL


FRESHWATER INFLOW
TIDES
DISCHARGES
DENSITY (SALINITY) CURRENT
WATER LEVEL

# COMPONENTS OF EXCHANGE

**UNI-DIRECTIONAL** **(a.k.a. throughflow)**

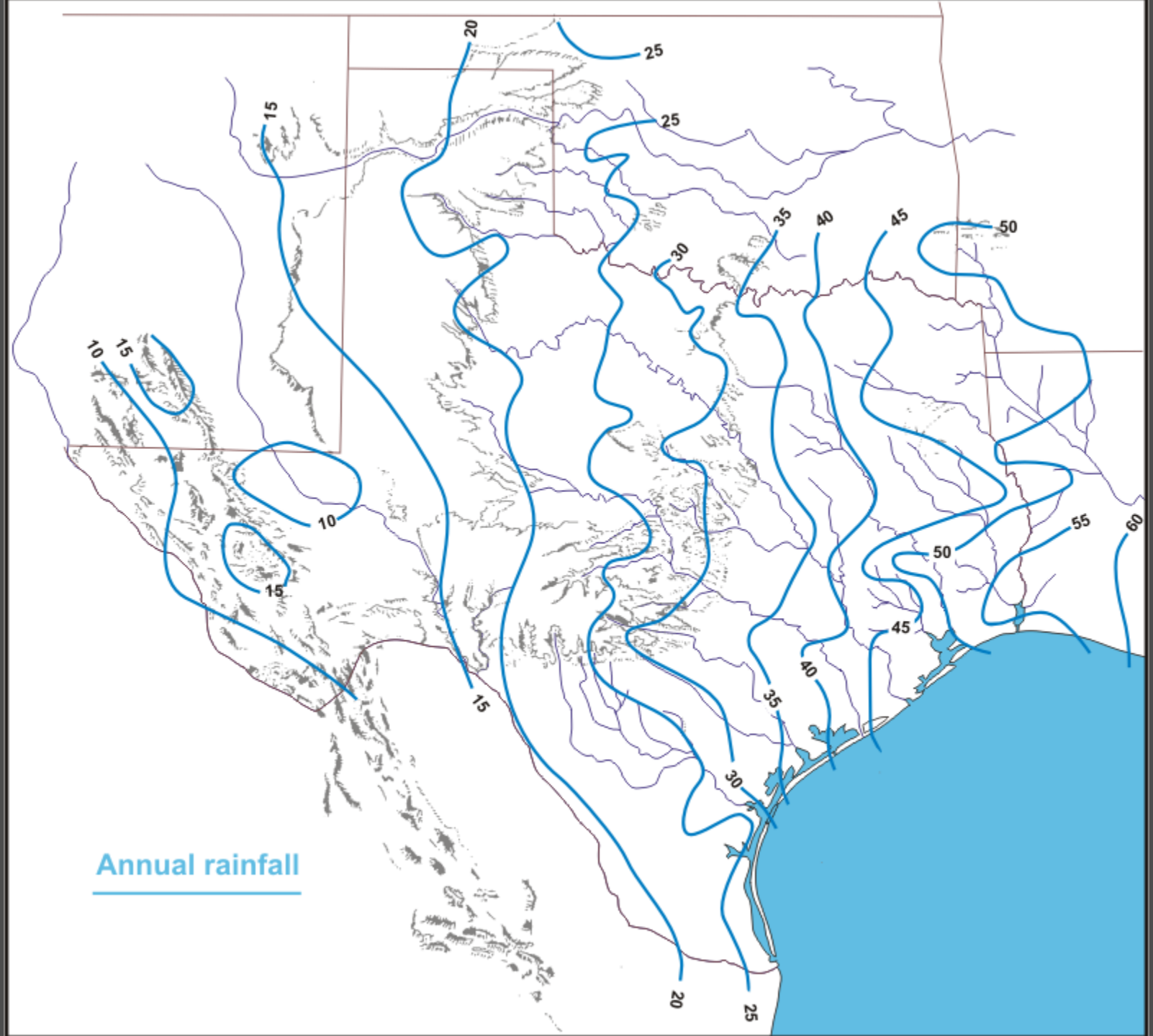
**Inflow, diversions, discharges, density current**

**BI-DIRECTIONAL** **(a.k.a. sloshing)**

**Tides, meteorological exchanges,**

**secular exchanges**


2400
2200
2000
1200
1000
600
400
200
Austin
Beaumont
Houston
Sabine Lake
Galveston Bay
Del Rio
San Antonio
Victoria
Matagorda Bay
San Antonio Bay
Aransas-Copano Bays
Corpus Christi
Corpus Christi Bay
Laredo
Upper Laguna Madre-
Baffin Bay
Lower Laguna Madre
Brownsville


Annual rainfall
10
15
20
25
30
35
40
45
50
55
60

# FACTOIDS ABOUT TEXAS SURFACE WATER

RAINFALL IS PRODUCED ALMOST ENTIRELY FROM DEEP CONVECTION

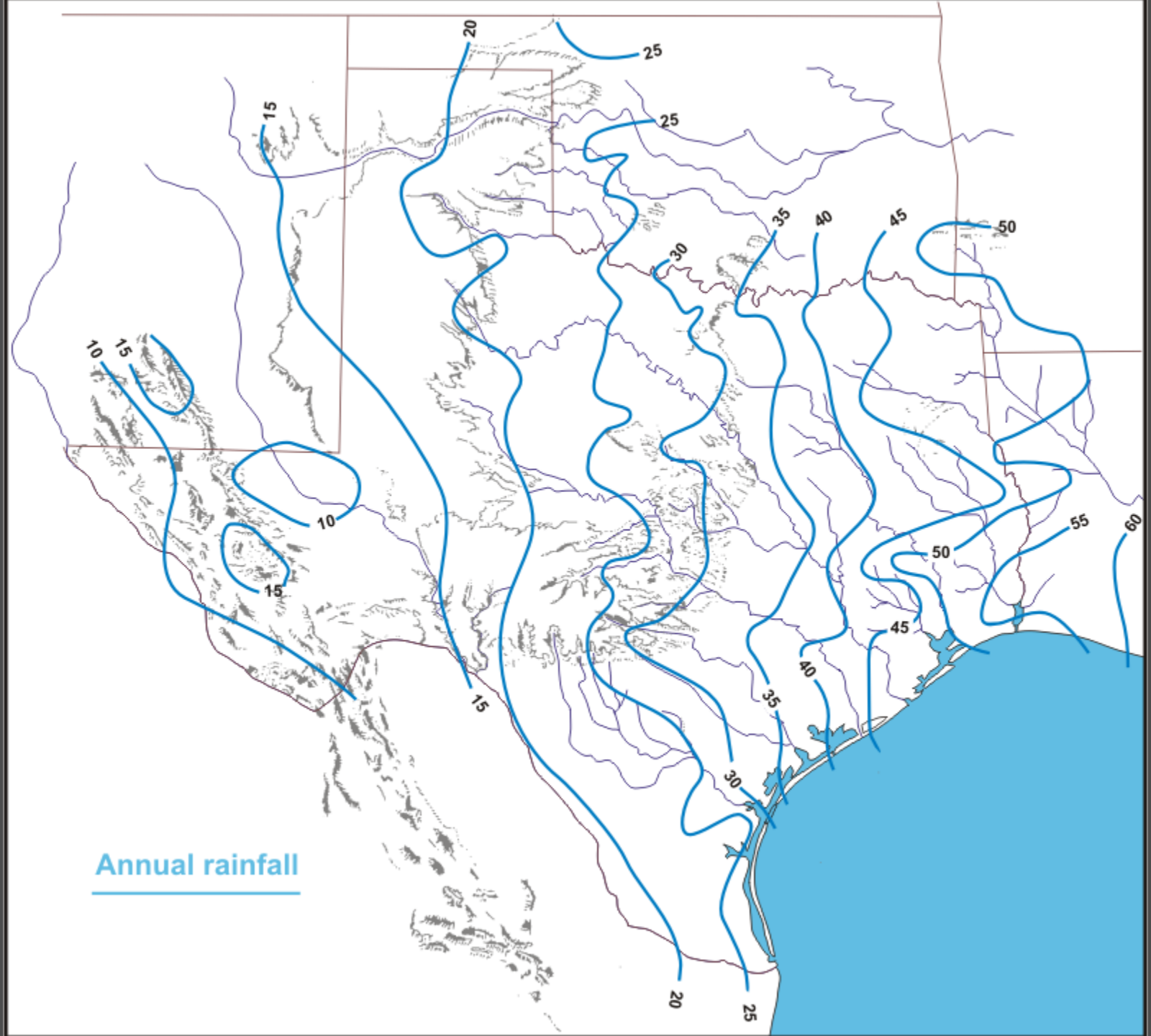
RAINFALL DECLINES PRECIPITOUSLY FROM EAST TO WEST

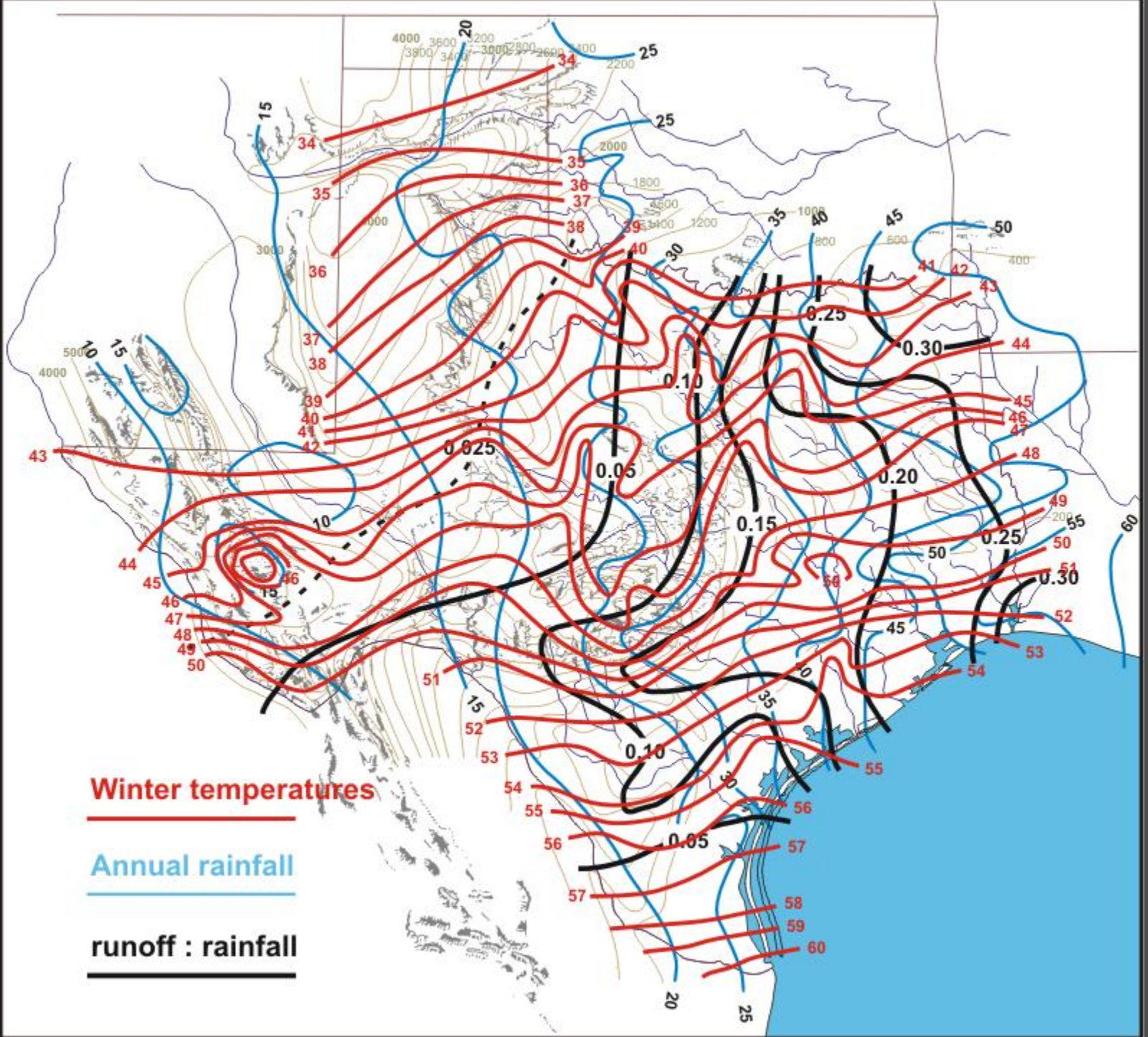
RUNOFF IS SMALL AS A PROPORTION OF RAINFALL

RUNOFF DECLINES EVEN MORE PRECIPITOUSLY FROM EAST TO WEST

STREAMFLOW IS FLASHY

STREAMFLOW EXHIBITS LARGE VACILLATIONS ON TIME SCALES OF MONTHS TO YEARS


Annual rainfall
10
15
20
25
30
35
40
45
50
55
60


Winter temperatures
Annual rainfall
runoff : rainfall

# FACTOIDS ABOUT TEXAS SURFACE WATER

RAINFALL IS PRODUCED ALMOST ENTIRELY FROM DEEP CONVECTION

RAINFALL DECLINES PRECIPITOUSLY FROM EAST TO WEST

RUNOFF IS SMALL AS A PROPORTION OF RAINFALL

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# FACTOIDS ABOUT TEXAS SURFACE WATER

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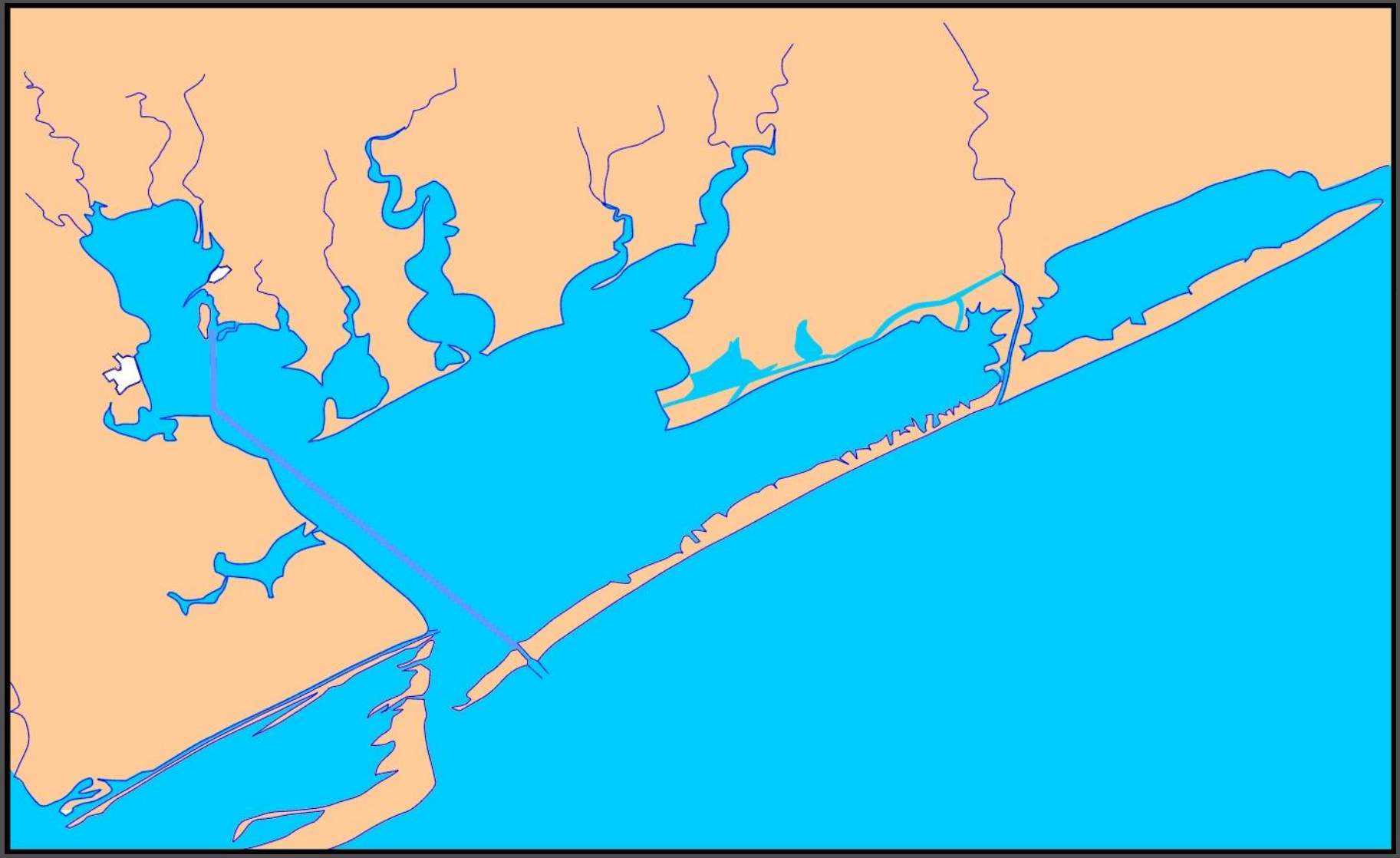
STREAMFLOW IS FLASHY

STREAMFLOW EXHIBITS LARGE VACILLATIONS ON TIME SCALES OF MONTHS TO YEARS

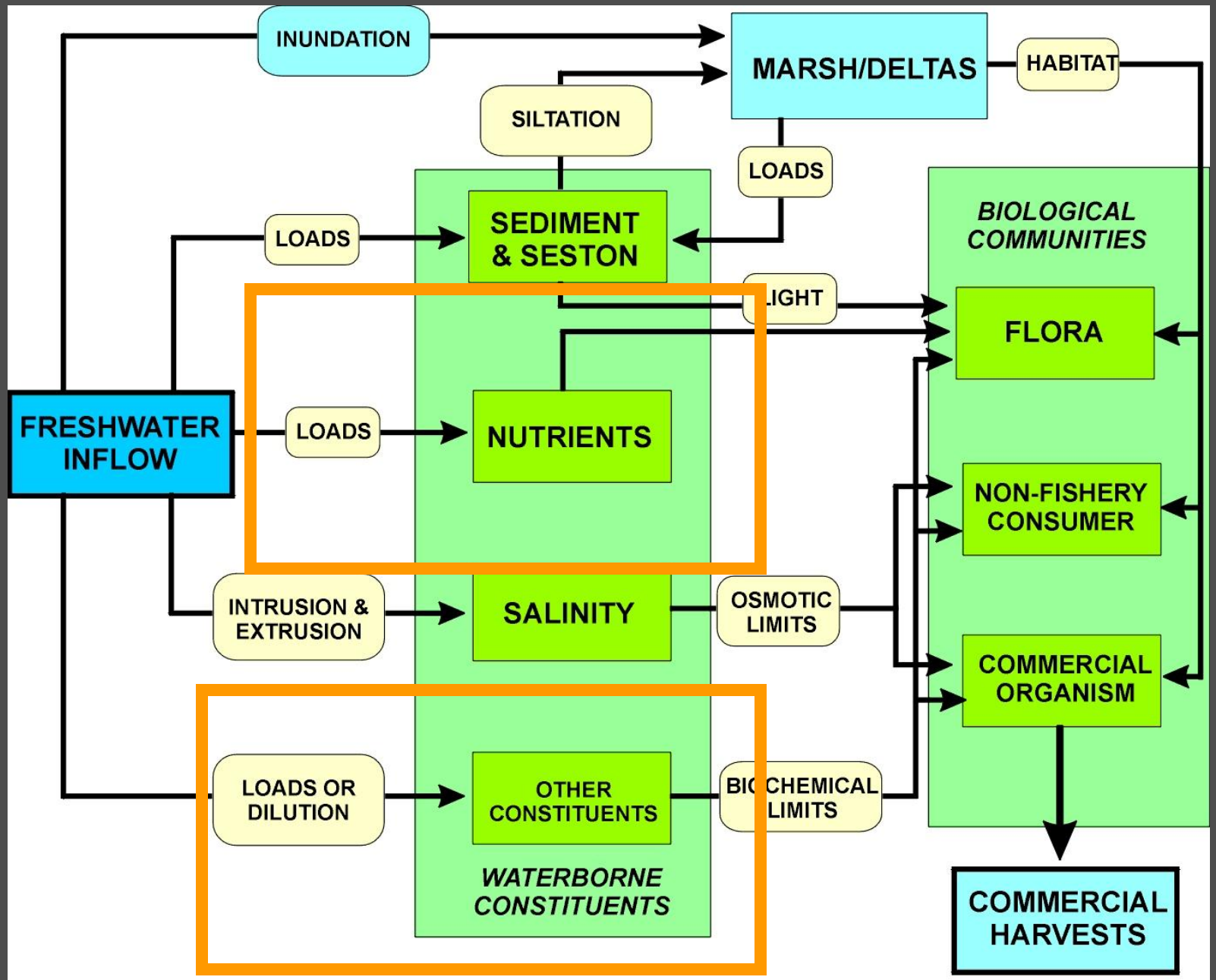
# MAJOR STATE-WIDE DROUGHTS IN TEXAS OBSERVATIONAL RECORD

| | |
|---|---|
| 1884-90 | Great Die-off |
| 1930-36 | Dust Bowl |
| 1951-59 | Drought of the 50's |

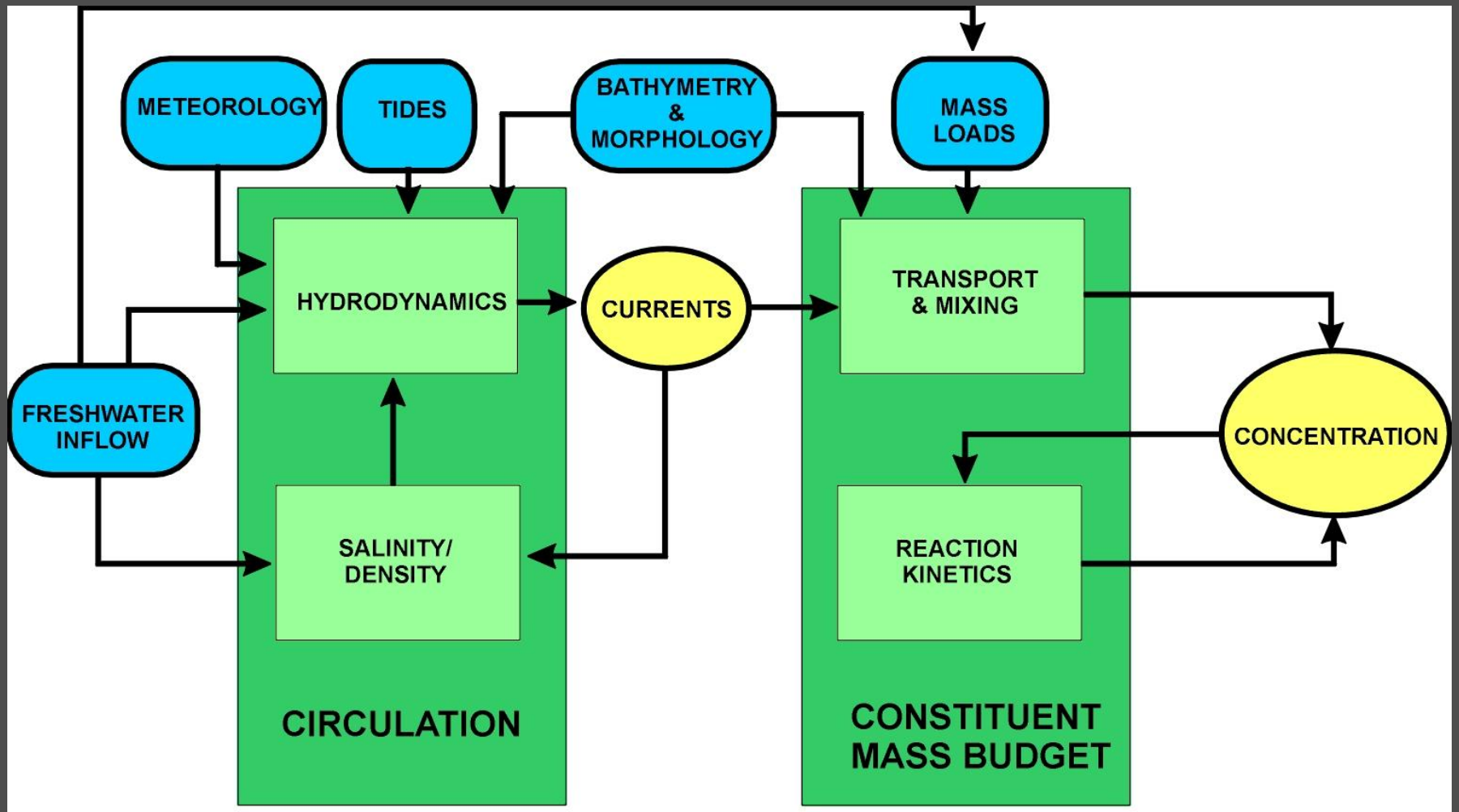


# ESTUARY CHARACTERISTICS

- TRANSITIONAL BETWEEN FRESHWATER & MARINE
- INFLUENCED BY MANY FACTORS
- DYNAMIC, HIGHLY VARIABLE
- PRODUCTIVE, BUT WITH SPECIALIZED ORGANISMS
- WIDE RANGE IN HABITATS SPANNING THE ESTUARINE ZONE
- MAJORITY OF THE LARGER ANIMALS IN ESTUARY ONLY TEMPORARILY FOR SPECIFIC BIOLOGICAL PURPOSES



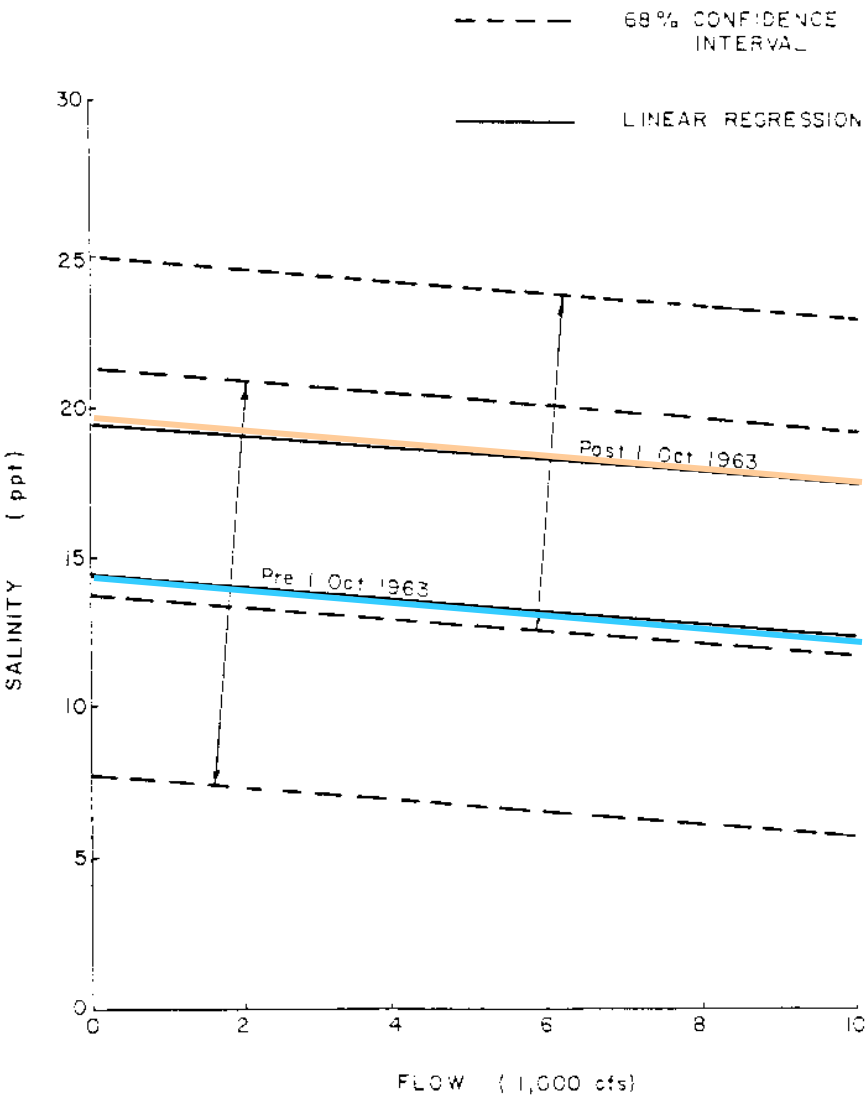

SCHEMATIC OF CAUSAL LINKS BETWEEN INFLOW AND ELEMENTS OF ESTUARY ECOSYSTEM



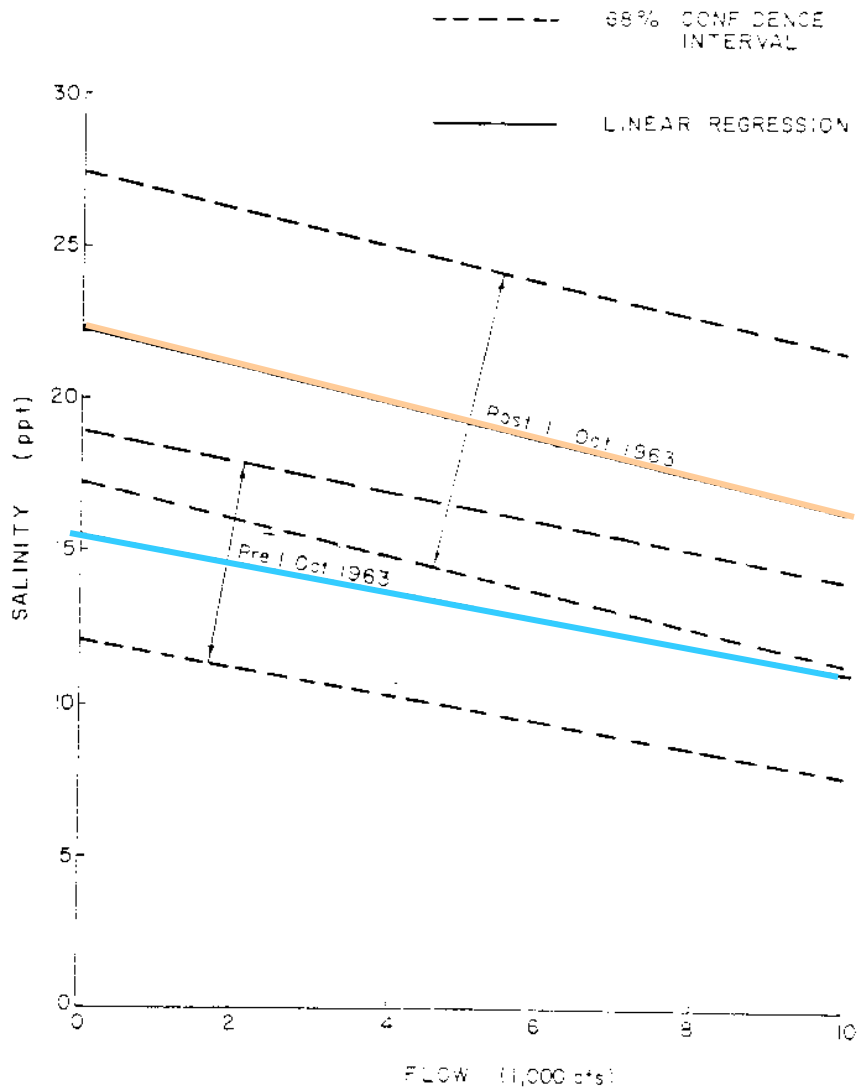

SCHEMATIC OF PROCESSES CONTROLLING CONSTITUENT CONCENTRATION IN ESTUARY


Lavaca & Navidad Rivers
Point Comfort
SH 35
Port Lavaca
Lavaca Bay
Cox Bay
Keller Bay
Karankaway Bay
Palacios
Tres Palacios Bay
Matagorda Bay
"East Arm"
Colorado River
Matagorda
East Matagorda Bay
Gulf of Mexico
Pass Cavallo
0 5 10
kilometers

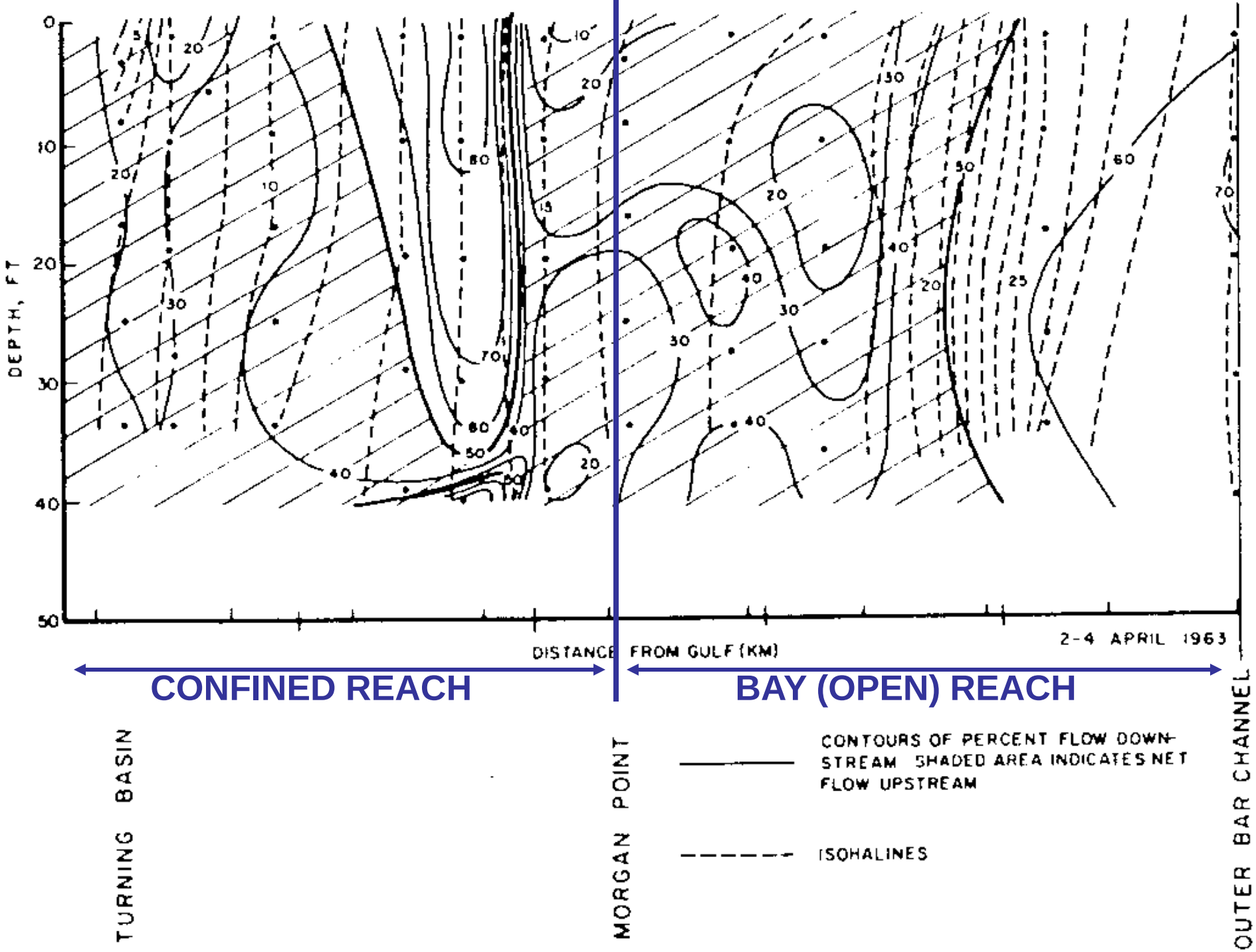

Lavaca & Navidad Rivers
Point Comfort
SH 35
Port Lavaca
Lavaca Bay
Cox Bay
Keller Bay
Karankaway Bay
Palacios
Tres Palacios Bay
Matagorda Bay
"East Arm"
Colorado River
Matagorda
East Matagorda Bay
Gulf of Mexico
Pass Cavallo
0 5 10
kilometers

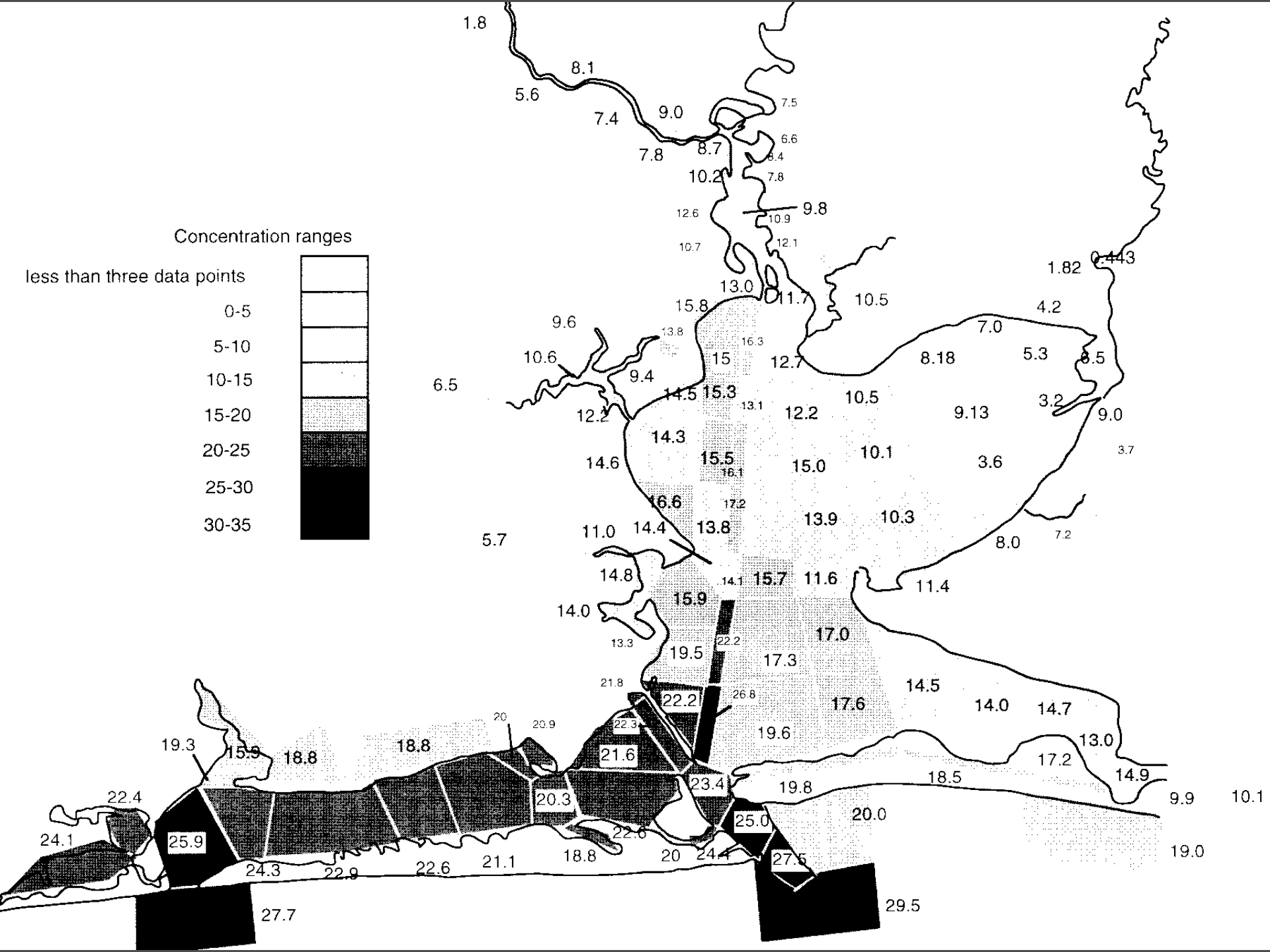


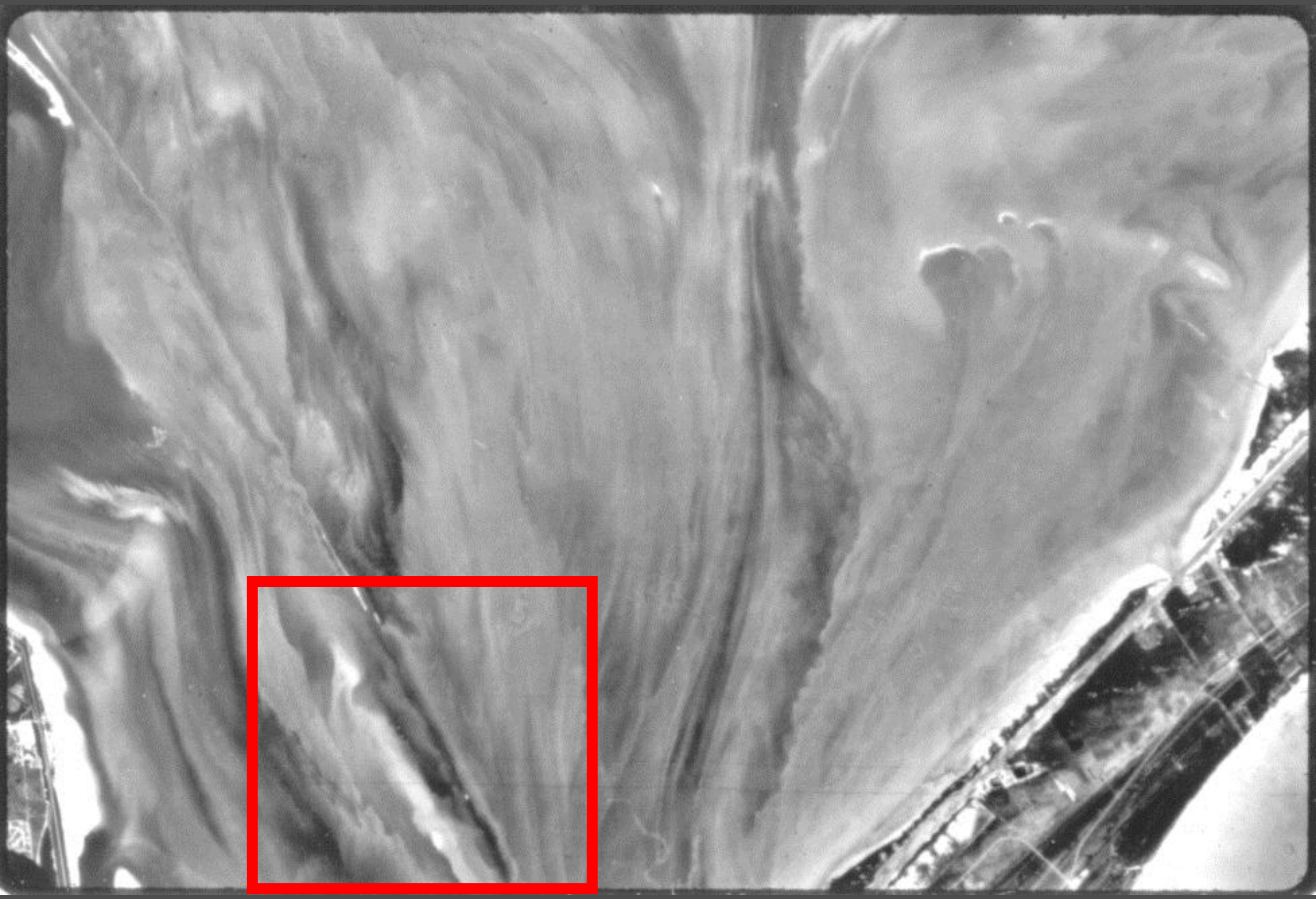

Salinity regressions, Lavaca Bay (West)

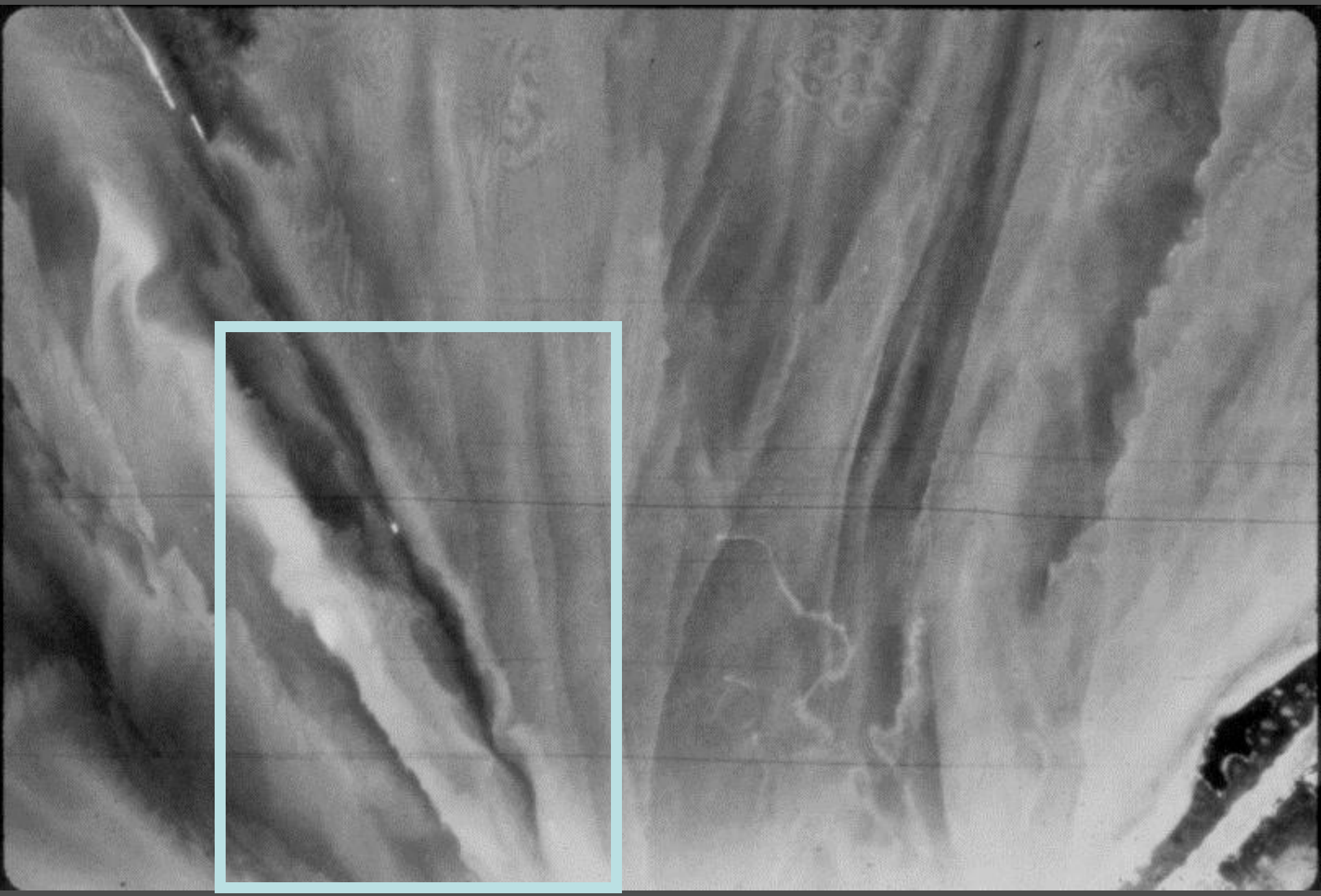



Salinity regressions, upper Matagorda Bay (West)


DEPTH, FT
DISTANCE FROM GULF (KM)
2-4 APRIL 1963
CONFINED REACH
BAY (OPEN) REACH
TURNING BASIN
MORGAN POINT
OUTER BAR CHANNEL
CONTOURS OF PERCENT FLOW DOWNSTREAM SHADED AREA INDICATES NET FLOW UPSTREAM
ISOHALINES

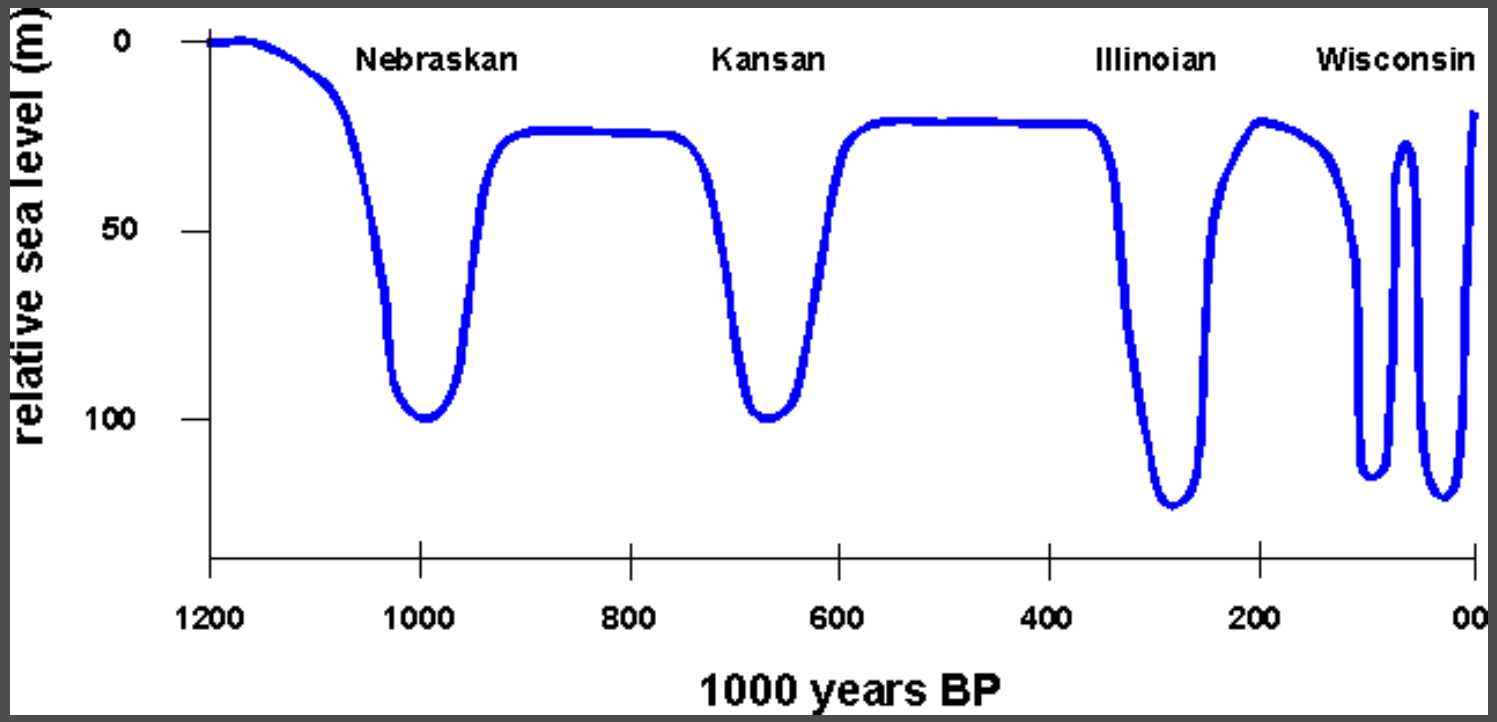

Concentration ranges
less than three data points
0-5
5-10
10-15
15-20
20-25
25-30
30-35

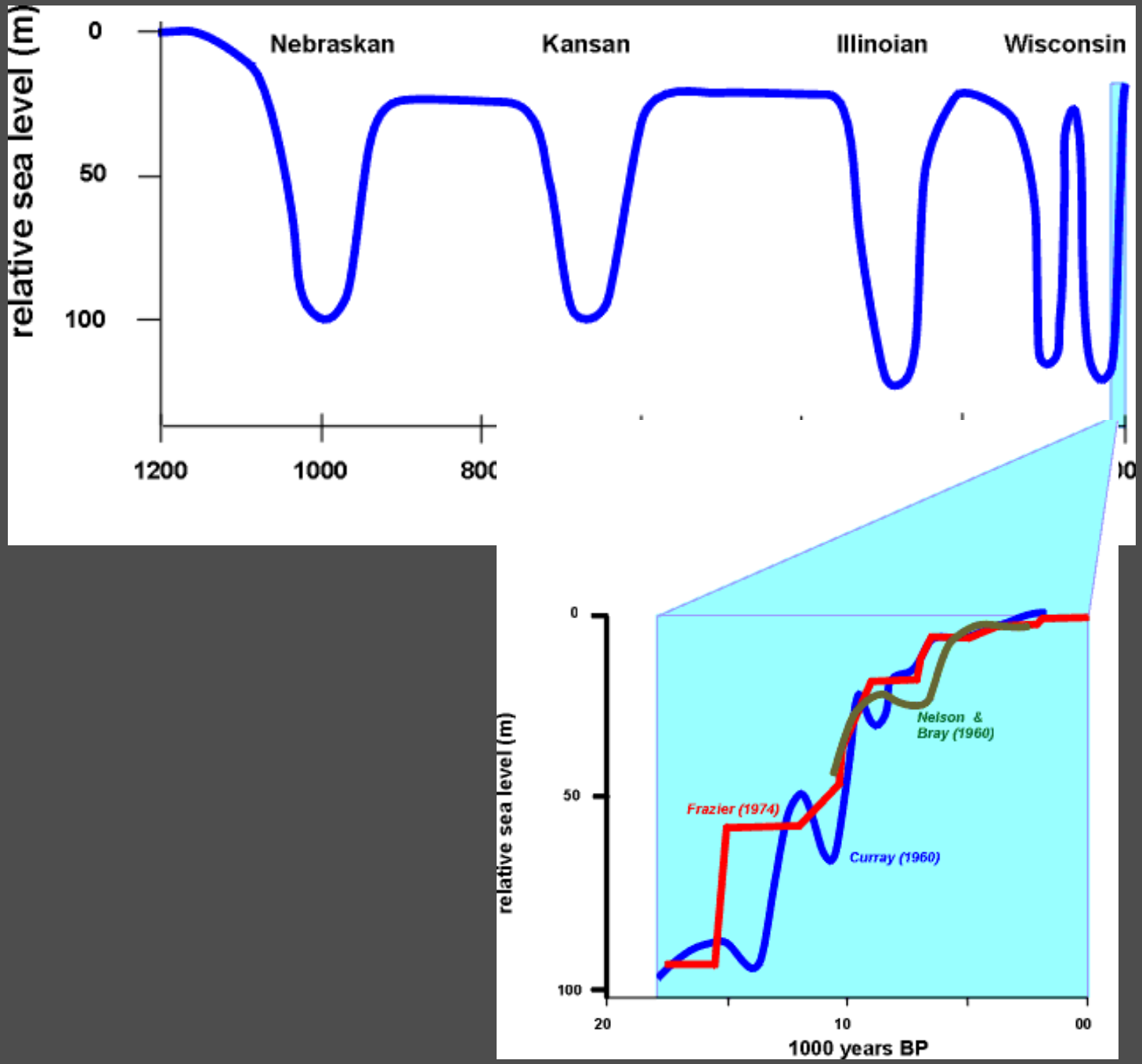


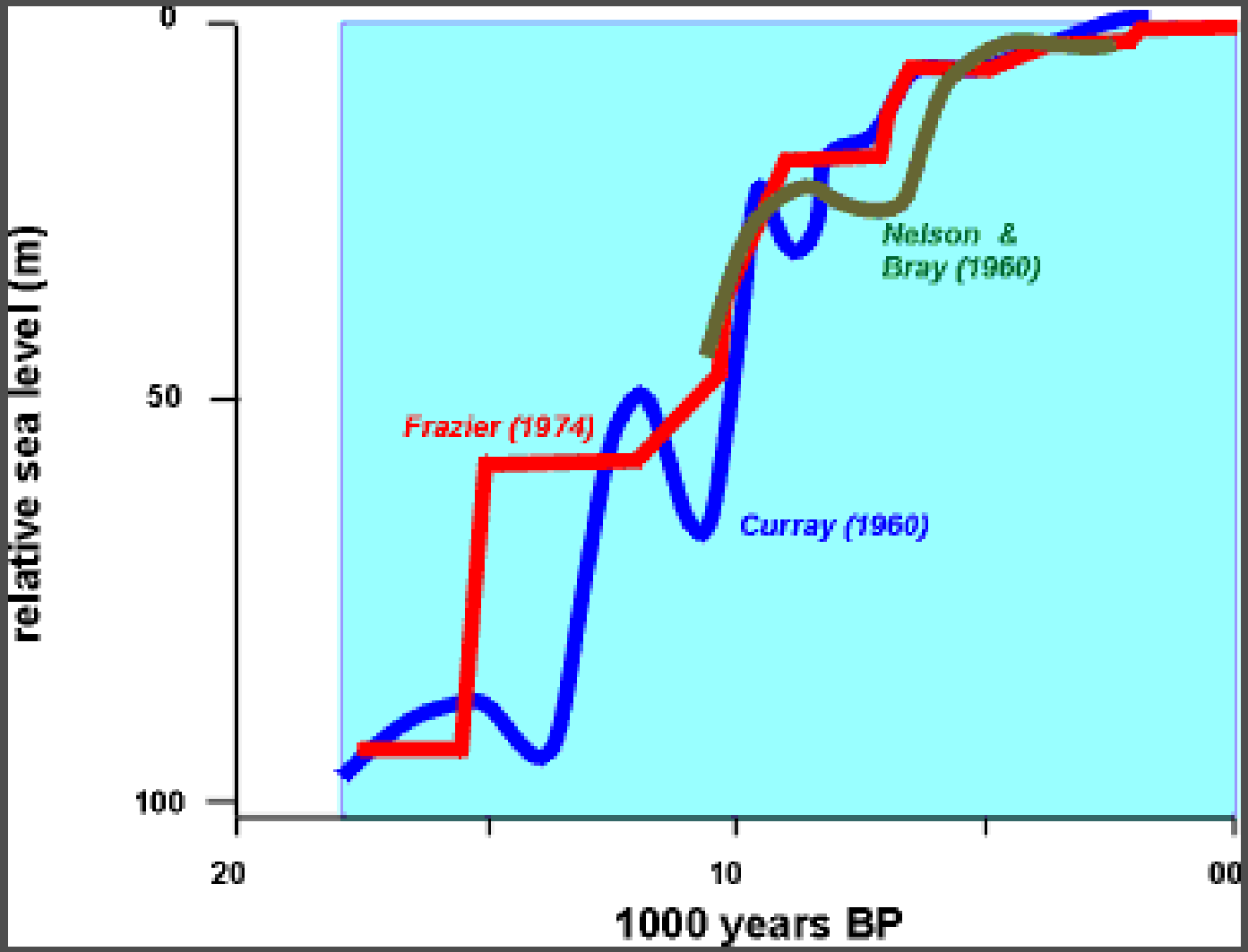


## Potential freshwater inflow effects on estuary

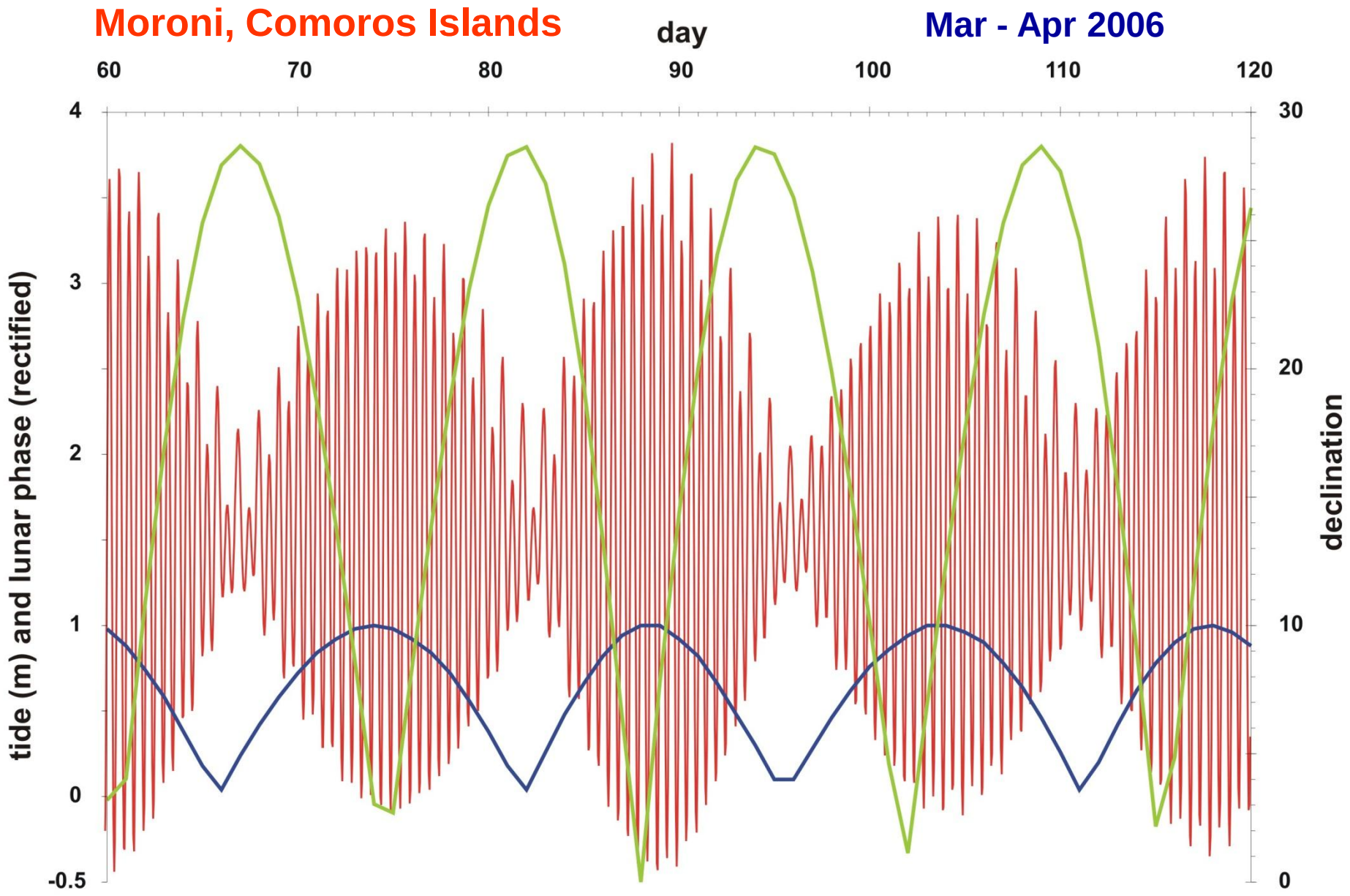
- dilutes seawater
- carries nutrients, trace constituents, and terrestrial sediments into estuary
- contributes to gradient of water properties across estuary
- produces inundation and flushing of important zones, due to short-term flooding
- variability over time creates fluctuation in estuarine properties, important to ecosystem function
- source of renewal water


relative sea level (m)
0
50
100
Nebraskan
Kansan
Illinoian
Wisconsin
1200
1000
800
600
400
200
00
1000 years BP


relative sea level (m)
0
50
100
Nebraskan
Kansan
Illinoian
Wisconsin
1200
1000
800
relative sea level (m)
0
50
100
Nelson & Bray (1960)
Frazier (1974)
Curray (1960)
20
10
00
1000 years BP


0
50
100
relative sea level (m)
20
10
00
1000 years BP
Frazier (1974)
Curray (1960)
Nelson &
Bray (1960)


2400
2200
2000
1200
1000
600
400
200
Austin
Beaumont
Houston
Sabine Lake
Galveston Bay
Del Rio
San Antonio
Victoria
Matagorda Bay
San Antonio Bay
Aransas-Copano Bays
Corpus Christi
Corpus Christi Bay
Laredo
Upper Laguna Madre-
Baffin Bay
Lower Laguna Madre
Brownsville


Moroni, Comoros Islands
day
Mar - Apr 2006
60
70
80
90
100
110
120
4
3
2
1
0
-0.5
30
20
10
0
tide (m) and lunar phase (rectified)
declination

# EXCHANGES AS FRACTION OF BAY VOLUME

| Bay: | Copano | Aransas | Corpus | Nueces | Laguna | Baffin |
|---|---|---|---|---|---|---|
| ***Bi-directional exchanges (per cent)*** | | | | | | |
| diurnal tide | 4 | 4 | 4 | 31 | 7 | - |
| semifortnightly | 5 | 4 | 3 | 12 | 10 | - |
| seasonal | 13 | 12 | 8 | 37 | 104 | - |
| ***Uni-directional exchanges (per cent /month)*** | | | | | | |
| inflow | -12 | 12 | 4 | 119 | 13 | 2 |
| P-E | -2 | -2 | -2 | -6 | -21 | -4 |
| Net returns | 0 | 0 | 0 | -22 | 0 | 0 |
| SES return | 0 | 0 | 0 | 99 | -65 | 0 |
| density current | 0 | 0 | 0 | 0 | 0 | 0 |

*Aransas inflow includes Copano, Corpus inflow includes Nueces, Laguna inflow includes Baffin*

# COMPONENTS OF COASTAL SAND TRANSPORT

## *WATERBORNE (currents & waves)*

**Horizontal:**

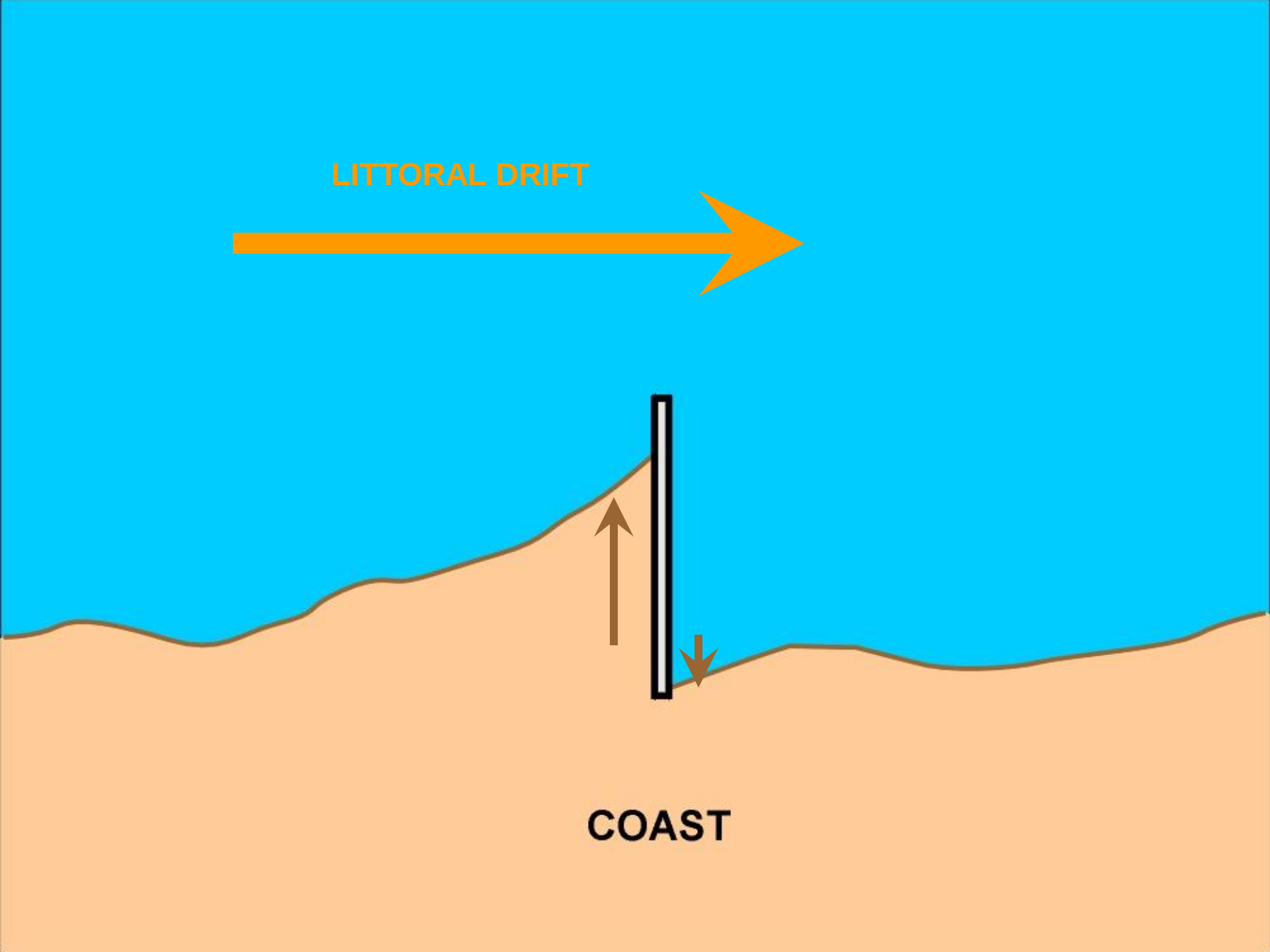
**Littoral / longshore drift / transport**

**Onshore/landward offshore/seaward**

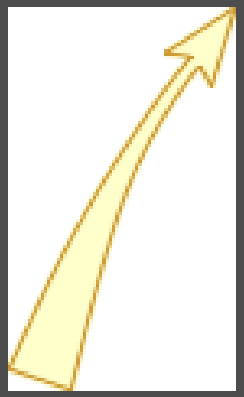
**Vertical:**

**Scour & deposition**

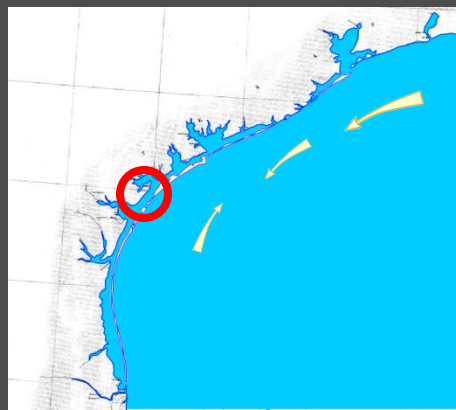
## *AIRBORNE (ÆOLIAN)*

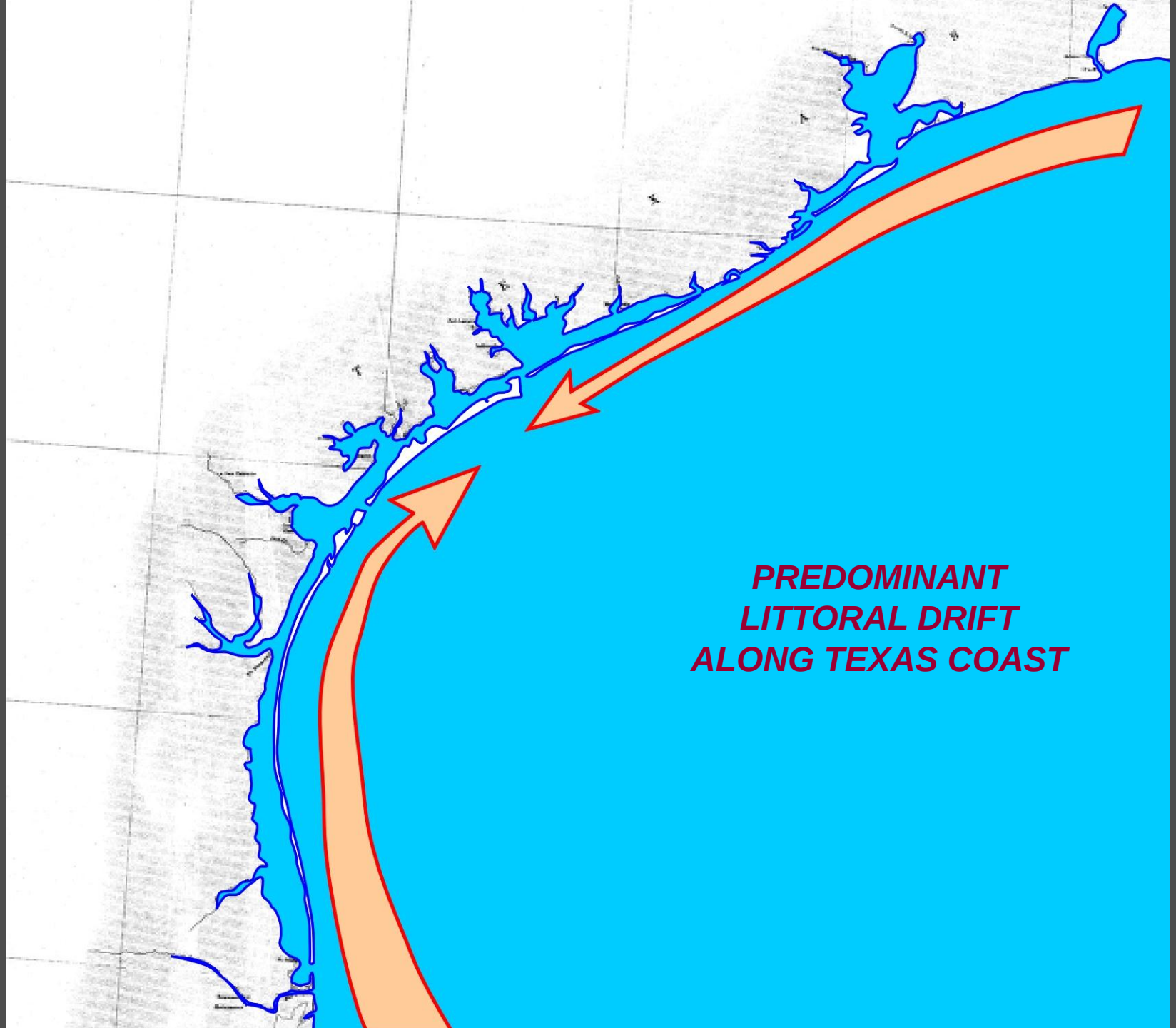

LITTORAL DRIFT
COAST

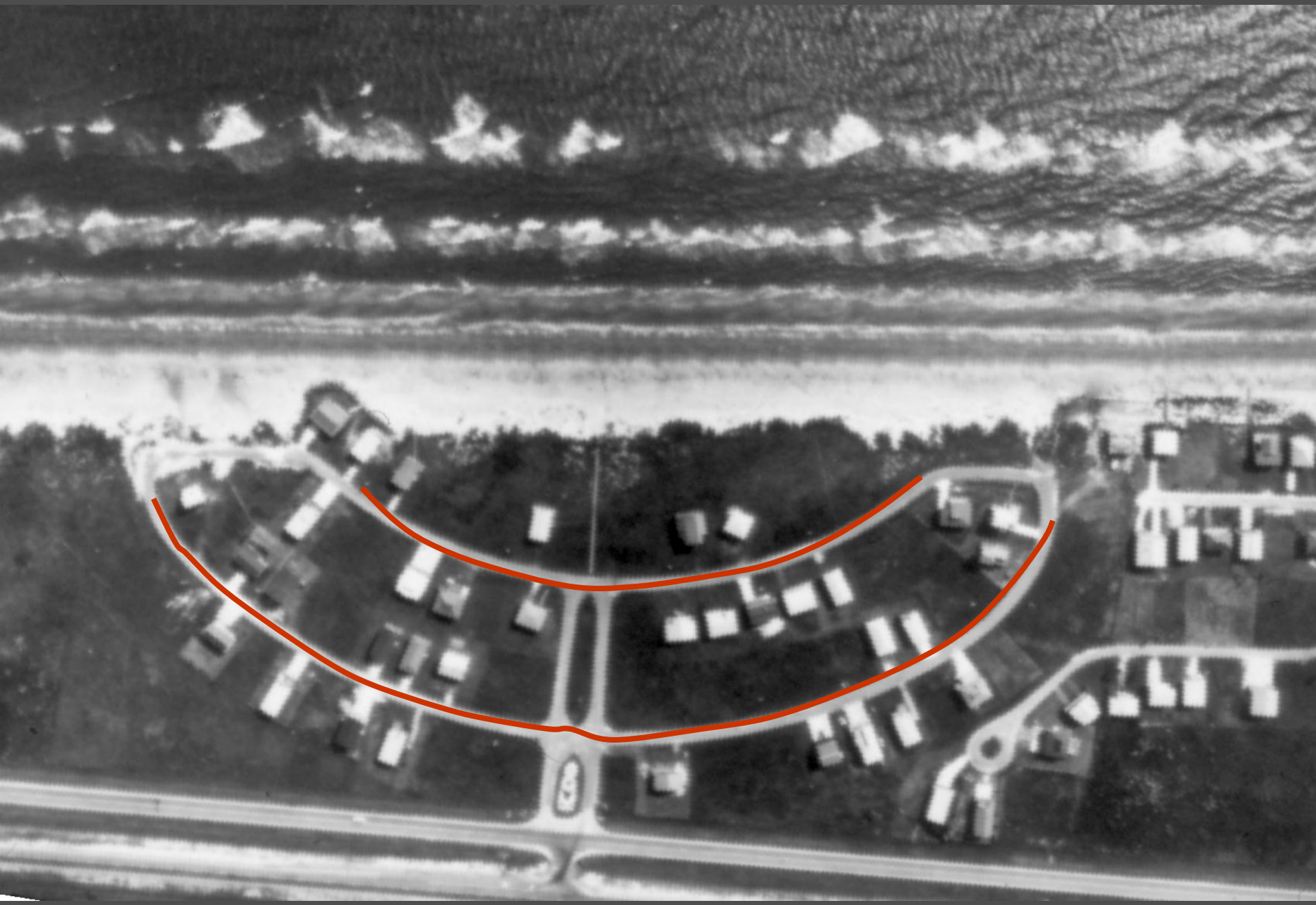

TRAPPED LITTORAL SEDIMENTS
PREDOMINANT LITTORAL DRIFT
MATAGORDA ENTRANCE CHANNEL

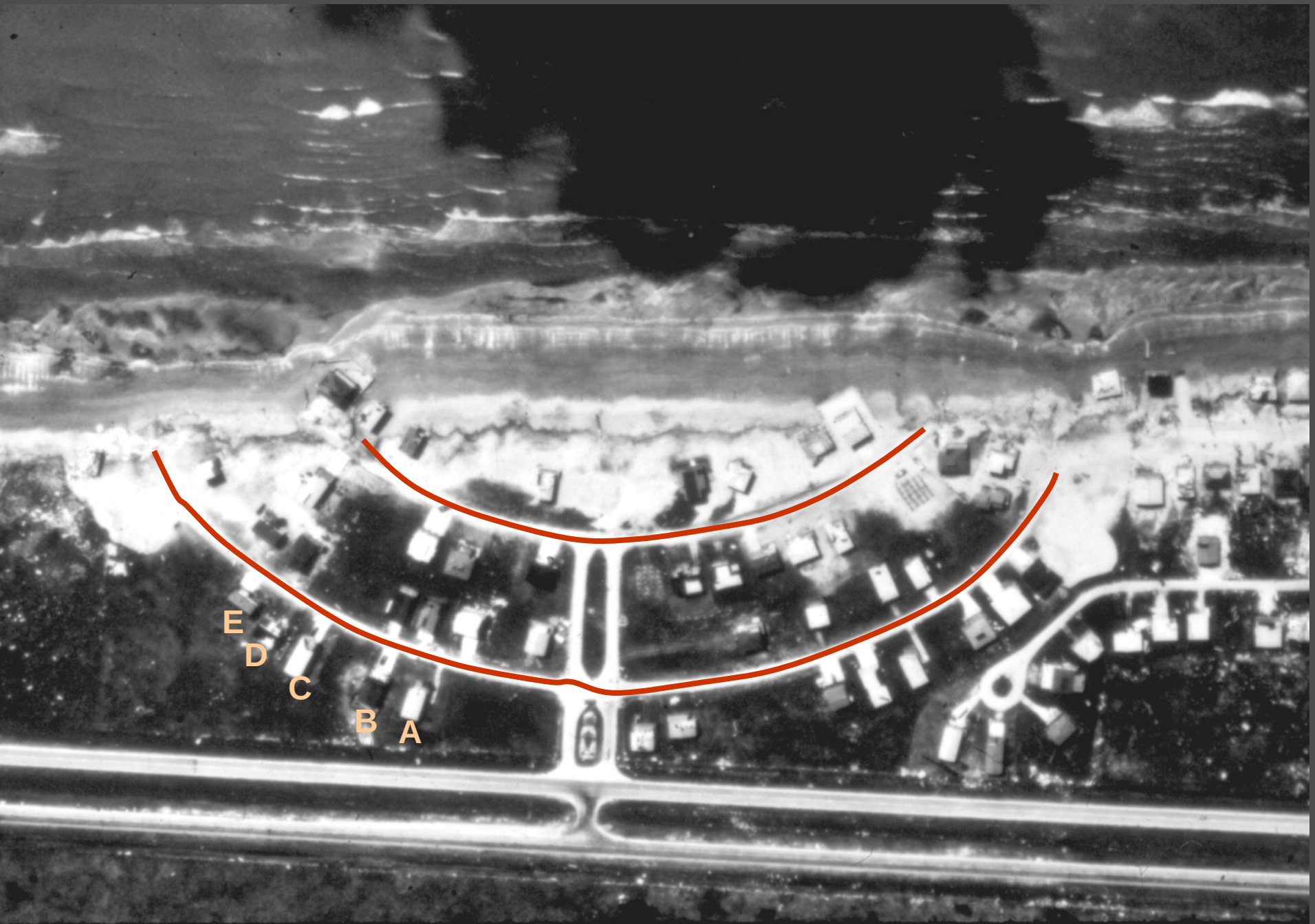



PREDOMINANT
LITTORAL
DRIFT




PREDOMINANT
LITTORAL DRIFT
ALONG TEXAS COAST




E
D
C
B
A


E
D
C
B
A


E
D
C
B
A

# ENVIRONMENTAL FLOWS


QUESTIONS ?