Land Use Change & Freshwater Inflow
Exploring Effects on Blue Crabs

Kiersten Madden
Stewardship Coordinator
Mission-Aransas NERR
361.749.6779
kiersten.madden@mail.utexas.edu
January 26, 2011
Background
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 = Geographic Information System

Integrates hardware, software, and data . . .

- **Store Data**
- **Model Data**
- **Map Data**
Water Consumption

**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
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
Kerrville - 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
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
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

**Developed Areas**
- High Intensity = 15 DU/acre
- Medium Intensity = 10 DU/acre
- Low Intensity = 5 DU/acre
- Open Space = 1 DU/acre

**Assumptions**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Active Development Scenario</th>
</tr>
</thead>
</table>

- **TimeScope Time**
  - 2001
  - 2000
  - 2001 year

- **Assumption - Average Vehicle Trip Length**
  - 9.76 miles

- **Assumption - Annual Commercial Energy Use**
  - 51,000 square feet/sq ft

- **Assumption - Annual Household Energy Use**
  - 92 million Btu/household/day

- **Assumption - Daily Household Water Use**
  - 381 gallons/dwelling/day

- **Assumption - Household Vehicle Mileage per Day**
  - 21.3 miles/gallon

- **Assumption - Percent Employed**
  - 93.9 percent of population

- **Assumption - Percent School Children**
  - 18.9 percent of population

- **Assumption - Persons per Household**
  - 2.54 persons/household

- **Assumption - Auto Emissions - CO**
  - 475.76 grams/gallon

- **Assumption - Auto Emissions - CO2**
  - 15.70 lbs/gallon

- **Assumption - Auto Emissions - NOx**
  - 29.89 grams/gallon

**January 26, 2011**
Impacts - Baseline

**TimeScope Built Buildings**

**School Children**
Common Impacts Calculation

**Labor Force Population**
Common Impacts Calculation

**Residential Water Use**
Common Impacts Calculation

**Residential Energy Use**
Common Impacts Calculation

**Annual CO2 Auto Emissions**
Common Impacts Calculation
Revised impacts - Baseline
DEVELOPED AREAS
High Intensity = 15 DU/acre
Medium Intensity = 10 DU/acre
Low Intensity = 5 DU/acre
Open Space = 1 DU/acre
Impacts - 2050

TimeScope Built Buildings

School Children
Common Impacts Calculation

Labor Force Population
Common Impacts Calculation

Residential Water Use
Common Impacts Calculation

Residential Energy Use
Common Impacts Calculation

Annual CO2 Auto Emissions
Common Impacts Calculation
Runoff

Nonpoint-Source Pollution & Erosion Comparison Tool

- 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
Nonpoint-Source Pollution & Erosion Comparison Tool
Data

Land Use/Land Cover Coefficients

<table>
<thead>
<tr>
<th>Land Use/Land Cover</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed, High Intensity</td>
<td>0.89</td>
<td>0.92</td>
<td>0.94</td>
<td>0.95</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Woody Wetland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Pollutant Coefficients - Nitrogen

<table>
<thead>
<tr>
<th>Land Use/Land Cover</th>
<th>Nitrogen</th>
<th>TSS</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed, High Intensity</td>
<td>2.22</td>
<td>71</td>
<td>0.47</td>
</tr>
<tr>
<td>Woody Wetland</td>
<td>1.1</td>
<td>19</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Results - Current LULC

Runoff

Nitrogen

Legend
Accumulated Runoff (L) Value
High
Low

Legend
Accumulated Nitrogen (kg) Value
High
Low
Results - Future LULC

Runoff

Nitrogen

+20%

+40%

Legend
Accumulated Runoff (L) Value
High
Low

Legend
Accumulated Nitrogen (kg) Value
High
Low
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

Things that affect your elements: Scenarios

What will happen to the things you care about?

What should you do to help meet multiple objectives?
Condition Model

Blue Crab Distribution + Landscape Condition = Modified Distribution

Landscape Condition
- Salinity
- Pollutants
- Habitat type
- Fishing pressure

Low
High

Low
High
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 decisions.
Questions??

Kiersten Madden

Stewardship Coordinator

Mission-Aransas NERR

361.749.6779

kiersten.madden@mail.utexas.edu
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

\[
CPUE = \frac{17 \text{ crab}}{4 \text{ effort units}} = 4.25
\]
What is catchability?

- A function of the population proportion in the surveyed area

\[
CPUE = \frac{11 \text{ crab}}{4 \text{ effort units}} = 2.75
\]
Index of SSB biased by environmental change

- Environmental change
- Spatial re-distribution
- Altered catchability
- Biased estimate of relative stock size
- Ineffective index of stock status
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
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

- Stratified, random trawl survey
- 54 stations each June & Sept
- 1987-Pres
Data Sources--Megalopal settlement
Eggleston et al. 2010

Sampling stations

- Eastern
- Northern
- Western
- Southern

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? Addressed w/ 3 statistical models

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)

\[
y = 1.9027x + 6.9068 \\
r^2 = 0.2807 \\
P = 0.006
\]
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
• 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)

- 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 km² 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

Broodstock → Spawning → Juvenile

Mature ♀ Release → Tagging
Under-used nurseries linked by migration corridors to spawning sanctuary

Chesapeake Stock Enhancement concept
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

Spawning Stock

SERC

VIMS
• 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
Beginning in 2000:

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

* Any correspondence between P195 & SEAMAP?
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, with 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

mzd@mail.utexas.edu
- Blue crab life history
- Ecological importance in estuaries
- Gulf of Mexico
- Texas
  - Seasonality
  - Spawning
  - Size at maturity
Blue crab life cycle

Death

Terminal molt

♂

♀

a. http://www.serc.si.edu/education/resources/bluecrab/lifecycle.jsp
Photo by Alicia Young-Williams
Blue crab predators, prey
Blue crabs in the Gulf of Mexico
Blue crabs in the Gulf of Mexico

- High recruitment

Blue crabs in the Gulf of Mexico

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

Blue crabs in the Gulf of Mexico

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

Seasonality
Trawl, by sex
Seasonality
Gill net, by sex

CPUE (crabs h$^{-1}$)
Seasonality
Gill net, males only
Seasonality
Gill net, males only

CPUE (crabs h\(^{-1}\))

Precipitation (mm)

Males

Precipitation

Jan-06  Jan-07  Jan-08  Jan-09  Jan-10  Jan-11

0.00
0.05
0.10
0.15
0.20

0
100
200
300
400
500

0
100
200
300
400
500

Jan-06  Jan-07  Jan-08  Jan-09  Jan-10  Jan-11
Seasonality by size class

**Seine**

- CPUE <60 mm cw (crabs ha$^{-1}$)
- CPUE >120 mm cw (crabs ha$^{-1}$)
- CPUE 60-120 mm cw (crabs ha$^{-1}$)

**Trawl**

- CPUE <60 mm cw (crabs ha$^{-1}$)
- CPUE 60-120 mm cw (crabs ha$^{-1}$)
- CPUE >120 mm cw (crabs ha$^{-1}$)

Legend:
- < 60 mm cw
- 60-120 mm cw
- >120 mm cw
Spawning
Ovigerous females, gill net and trawl
Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net

Spawning
Ovigerous females, gill net and trawl

% ovigery

Trawl
Gill net
Size at maturity
gill net + trawl

- Carapace width (mm)
  - 0 25 50 75 100 125 150 175 200 225
- Number of crabs
  - 0
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120

Immature
Mature

- Number of crabs
- Carapace width (mm)
Size at maturity

gill net + trawl

[Box plot showing carapace width (mm) for different months, with Jan, Apr, Jul, and Oct on the x-axis and carapace width on the y-axis.]
Size at maturity

gill net + trawl

![Graph showing the relationship between carapace width (mm) and probability of maturity (P) at different salinity levels (10 ppt, 20 ppt, 30 ppt, 40 ppt). The graph indicates that the probability of maturity increases with carapace width and varies with salinity.]
Size at maturity

gill net + trawl

Carapace width (mm)

P(maturity)

10 ppt
20 ppt
30 ppt
40 ppt

Carapace width (mm)

P(maturity)
Size at maturity

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


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

Carapace width (mm)

Bag seine  Bay trawl  Gill net
Seasonality
Trawl, immature and recently-matured females

CPUE (crabs h$^{-1}$)

- Immature female
- Recently-molted female
Size at maturity

gill net + trawl

Carapace width (mm)

P(maturity)

0.0

0.2

0.4

0.6

0.8

1.0

10 ppt

20 ppt

30 ppt

40 ppt

Carapace width (mm)
Blue crab range
Seasonality
Seine, by size class
Seasonality
Trawl, by size class

- CPUE <60 mm cw (crabs hr⁻¹)
- CPUE 60-120 mm cw (crabs hr⁻¹)
- CPUE >120 mm cw (crabs hr⁻¹)
Blue Crab Biology

Dan Rittschof
Duke University Marine Laboratory
Nicholas School, Duke University
Acknowledgements

- Zack & Kelly Darnell, Ruth McDowell,
- Ray Golden, Danny Rimmer, Ernie Small
- Robert, Debbie and Ron Cahoon
- Katie West, NC DMF, Dell Newman
- Tony Austin, Tracey Ziegler, GOMEX
- Brownwyn Llewelyn, Katie Greganti
- Jim Hench, Sara Carr, Dick Forward, Holly West, Melissa Sanderson, Rick Tankersley
- 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.
Juvenile Females
Doubler Crabs
$TUD!$
Pair Ready to be Removed

Pheromone Water
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

\[ y = 0.057x - 1.2286 \]
\[ r^2 = 0.35 \]
\[ N = 21 \]

Clutch Production Interval vs SIZE

\[ n = 6 \]
\[ n = 8 \]
\[ n = 21 \]
\[ n = 36 \]
\[ n = 10 \]
\[ n = 26 \]
\[ n = 13 \]
\[ n = 10 \]
Clutch Size by Clutch Number

- Clutch Number 1: n = 61
- Clutch Number 2: n = 63
- Clutch Number 3: n = 50
- Clutch Number 4: n = 33
- Clutch Number 5: n = 11
- Clutch Number 6: n = 3

Clutch Volume (Centimeters Cubed)
Fecundity and Size

All but Smallest Crabs have Same Fecundity
All Crab Data, 2000-2002
Recapture of Marked Crabs With Eggs

<table>
<thead>
<tr>
<th>Embayment</th>
<th>Fishery</th>
</tr>
</thead>
<tbody>
<tr>
<td>JBAY</td>
<td>37/1277</td>
</tr>
<tr>
<td>NorthR</td>
<td>69/996</td>
</tr>
<tr>
<td>NewR</td>
<td>47/994</td>
</tr>
</tbody>
</table>

Percentage Recapture

Bar chart showing the recapture rates for different embayments.
1.4% of ALL Crabs Marked Recaptured in Fishery
Gulf of Mexico, July 2002
Total Callinectes sapidus, Females

Gulf of Mexico, July-Aug 2003
Total Callinectes sapidus, Females
Newport River
North River
Turning Basin
Embayment
Radio Island
Channel
Fishing Piers
Onslow Bay
Jarrets Bay
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

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

East:
- Immature: 7.7%
- Non-ovigerous: 28.7%
- Sponge: 63.3%
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.
Megalopha Collectors
Odors megalopae Avoid

Fiddler crab, mud crab, grass shrimp

Odors megalopae Ignore

Blue crab, commercial shrimp
Mature Females and Megalopae

Cumulative Mature Females

CPUE

2004

2005

2006

Mature Females

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
Female Peeler Response to Jimmy in Dark

Receptive Female Claw Spread

Jimmy
Mating

Female
Migrating Crabs

Nocturnally Migrating Crabs
Normal vs Drought Year

<table>
<thead>
<tr>
<th>Year</th>
<th>June 2001</th>
<th>July 2002</th>
<th>August 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>90%</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Black Eggs</td>
<td>10%</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>No Eggs</td>
<td>90%</td>
<td>60%</td>
<td>40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>Normal</th>
<th>Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>90%</td>
<td>60%</td>
</tr>
<tr>
<td>July</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>August</td>
<td>40%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Nocturnally Migrating Crabs
Normal vs Drought Year

2001
June
July 2002
August

Normal
Drought

Black Eggs
No Eggs

Percentage
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 environmentally 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

<table>
<thead>
<tr>
<th>Carapace Width (mm)</th>
<th>Reproductive Output (cm³/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 - 86</td>
<td>A</td>
</tr>
<tr>
<td>87 - 101</td>
<td>A</td>
</tr>
<tr>
<td>102 - 116</td>
<td>A</td>
</tr>
<tr>
<td>117 - 131</td>
<td>AB</td>
</tr>
<tr>
<td>132 - 146</td>
<td>AB</td>
</tr>
<tr>
<td>147 - 161</td>
<td>B</td>
</tr>
<tr>
<td>162 - 176</td>
<td>AB</td>
</tr>
</tbody>
</table>

n = 6, n = 8, n = 21, n = 36, n = 10, n = 26, n = 13, n = 10
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.
Time in Captivity (weeks)

Number of Clutches

$y = 0.29x + 0.63$
$r^2 = 0.83$
Total n = 124

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
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 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
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

![Chart showing the distribution of blue crab lengths by sample gear: Bag Seine, Trawl, and Gill Net. The x-axis represents length classes in millimeters, and the y-axis represents percent.]
Length-Based Mortality Estimator
Hoenig, 1987

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

\[ \begin{align*}
K &= \text{Brody Growth Coefficient} = 0.663 \\
CW_\infty &= \text{Asymptotic Maximum Length} = 268 \text{ mm} \\
CW_r &= \text{Size at full recruitment} = 15\text{mm for bag seines} \\
CW_r &= 40 \text{ mm for trawls} \\
CW_r &= 120 \text{ mm for gill nets}
\end{align*} \]
Annual Bag Seine CPUE
Blue Crabs

Catch/hectare


Aransas  San Antonio  All Other Bays
Blue Crab Mortality Estimates, Bag Seines, All Bays Included

\[ y = -0.001x^2 + 5.816x - 5818 \]

\( R^2 = 0.164 \)

\( P < 0.001 \)
Blue Crab Mortality Estimates vs Abundance of Red Drum

\[ y = 0.260x + 1.544 \]

\[ R^2 = 0.119 \]

\[ P < 0.001 \]
Blue Crab Mortality Estimates vs Abundance of Black Drum

\[ y = -0.003x + 1.801 \]

\[ R^2 = 8E-05 \]

\[ P = 0.8885 \]
Blue Crab Mortality Estimates vs Abundance of Bonnethead Sharks

\[ y = 6.575x + 1.754 \]

\[ R^2 = 0.039 \]

\[ P = 0.012 \]
Blue Crab Mortality Estimates vs Salinity, All Bays Included

\[ y = -0.000x^2 + 0.050x + 1.226 \]

\[ R^2 = 0.103 \]

\[ P < 0.001 \]
Annual Bay Trawl CPUE
Blue Crabs

Catch/hour

Aransas
San Antonio
All Other Bays

Blue Crab Mortality Estimates, Bay Trawls, All Bays Included

\[ y = -0.001x^2 + 6.212x - 6192 \]

\[ R^2 = 0.070 \]

\[ P < 0.001 \]
Blue Crab Mortality vs Coastwide Commercial Shrimping Effort

\[ y = 1 \times 10^{-5}x + 0.856 \]
\[ R^2 = 0.362 \]
\[ P < 0.001 \]
Blue Crab Mortality Estimates, Gill Nets, All Bays Included

\[ y = -0.013x + 26.97 \]

\[ R^2 = 0.199 \]

\[ P < 0.001 \]
Blue Crab Mortality Estimates vs Commercial Crab Landings

$y = 3 \times 10^{-8} x + 1.137$

$R^2 = 0.006$

$P = 0.2367$
Summary

• Abundance is declining, locally and statewide.


• 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

Bay System:
- Sabine Lake
- Galveston
- Cedar Lakes
- East Matagorda
- Matagorda
- San Antonio
- Aransas
- Corpus Christi
- Upper Laguna Madre
- Lower Laguna Madre

Salinity range from 0 to 80.
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

Hot, salty water is a stressor

Aransas and San Antonio Bays combined
Distribution of Mature Blue Crabs, by Sex and Salinity

Aransas and San Antonio Bays combined

Sex

Males

Females

Salinity

0  10  20  30  40
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: ~14-17 lbs.
- Wingspan: ~7-8 ft
- White with black 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

Former Breeding Area
- Pacific Ocean
- Atlantic Ocean
- Canada
- USA
- Mexico

Current Migration Route

Former Breeding & Wintering Area
- Breeding Area in Wood Buffalo NP
- Wintering Area in Aransas NWR

Whooping Crane Historical & Current Range
Whooping Crane Annual Cycle

- **SPRING MIGRATION**: ANWR Juveniles, Subadults, Adults
- **ARRIVAL AT ANWR**: EGGs LAID
- **HATCHING**: WBNP Juveniles, Subadults, Adults
- **FALL MIGRATION**: ARRIVAL AT WBNP
Central Texas Coast: Landforms

Blackjack Peninsula

Live Oak Peninsula

San Jose Island

Matagorda Island

Seadrift-Port
O’Connor Ridge

Gulf of Mexico

You are Here
Central Texas Coast:
Estuaries

- Espiritu Santo Bay
- Ayres/Mesquite/Carlos Bays
- Aransas/Redfish Bays
- Lavaca/Matagorda Bays
- San Antonio/Hynes Bays
- Navidad/Lavaca Rivers
- Guadalupe/San Antonio Rivers
- Mission/Aransas Rivers
- Mission/Copano Bays

Drowned River Valley Estuaries
Bar-Built Estuaries

Gulf of Mexico
Central Texas Coast: Gulf Passes

- Lavaca/Matagorda Bays
- Pass Cavallo Matagorda Channel
- San Antonio/Hynes Bays
- Mission/Copano Bays
- Cedar Bayou
- Gulf of Mexico
- Aransas Channel
Whooping Crane
Wintering Range

Gulf of Mexico
Whooping Crane Territories

1 Family

~ 300 acres

Defended

Aransas National Wildlife Refuge
Blackjack Peninsula
Whooping Crane Habitats

- Fresh Marsh
- Shallow Flats
- Coastal Marsh
- Bay Water
Whooping Crane Territories

Habitat Diversity

Safe Shelter

Roosting Pond

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

Oak Woodland  Fresh Marsh  Coastal Prairie  Shallow Flat  Coastal Marsh  Bay

ACORN  BLUE CRAB  CLAM  WOLF  -  BERRY FRUIT  SNAIL  SHRIMP  COCONUT  SNAIL  SHRIMP  SNAKE  INSECT  LIZARD  SMALL RODENT
Dry Mass of Food Items
Calculated from Observation Data

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
Mission-Aransas NERR
Galveston Bay
Isobaths in metres
Isobaths in metres
SAN LUIS PASS
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
North Jetty, Galveston

May - June 2006

TIME PERIODS

LUNAR SEMIDIURNAL (12.4 hrs)

LUNAR DIURNAL (24.8 hrs)

FORTNIGHTLY (13.6 days)
Predominant tidal harmonics on Texas coast

<table>
<thead>
<tr>
<th>Harmonics</th>
<th>Period</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMIDIURNAL</td>
<td>12.4 hr</td>
<td>LUNAR</td>
</tr>
<tr>
<td>DIURNAL</td>
<td>24.8 hr</td>
<td>LUNAR</td>
</tr>
<tr>
<td>FORTNIGHTLY</td>
<td>13.6 da</td>
<td>LUNAR DECLINATION</td>
</tr>
</tbody>
</table>
YOU LIE !!!
What about Lunar phase?!

Spring tides and neap tides?!
North Jetty, Galveston

Mar - Apr 2006

FULL MOON
NEW MOON
FULL MOON
FULL MOON
MOON OVER-HEAD
MOON UNDER-FOOT
MOON OVER-HEAD
MOON UNDER-FOOT
MOON OVER-HEAD
MOON UNDER-FOOT
MOON ON EQUATOR
MOON ON EQUATOR
MOON ON EQUATOR

Tide (m) and lunar phase (rectified)

Declination

1st Quarter
3rd Quarter
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

Phase of the moon has nothing to do with it! 
Bob Hall Pier

Lunar declination $25^\circ \ 35\'$
Predominant tidal harmonics on Texas coast

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEMIDIURNAL</strong></td>
<td>12.4 hr</td>
<td>LUNAR</td>
</tr>
<tr>
<td><strong>DIURNAL</strong></td>
<td>24.8 hr</td>
<td>LUNAR</td>
</tr>
<tr>
<td><strong>FORTNIGHTLY</strong></td>
<td>13.6 da</td>
<td>LUNAR DECLINATION</td>
</tr>
<tr>
<td><strong>DECLINATION</strong></td>
<td>18.6 yr</td>
<td>TIDAL EPOCH</td>
</tr>
</tbody>
</table>
27-day sliding mean of water level at two stations in Coastal Bend bays
<table>
<thead>
<tr>
<th>Harmonic Type</th>
<th>Period</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominant “tidal”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on Texas coast</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SEMIDIURNAL</strong></td>
<td>12.4 hr</td>
<td>LUNAR-SOLAR</td>
</tr>
<tr>
<td><strong>DIURNAL</strong></td>
<td>24.8 hr</td>
<td>LUNAR-SOLAR</td>
</tr>
<tr>
<td><strong>FORTNIGHTLY</strong></td>
<td>13.6 da</td>
<td>LUNAR DECLINATION</td>
</tr>
<tr>
<td><strong>SEMIANNUAL</strong></td>
<td>6 mos</td>
<td>SECULAR</td>
</tr>
<tr>
<td><strong>DECLINATION</strong></td>
<td>18.6 yr</td>
<td>TIDAL EPOCH</td>
</tr>
</tbody>
</table>
ARANSAS PASS

amplitude ratio vs. period, hours

0 12.4 24.8

0 1 100 200 300

13.7 days
Gulf of Mexico
Matagorda Bay

Gulf of Mexico

Corpus Christi Bay
MORPHOLOGY
TIDES
METEOROLOGICAL FORCING
FRESHWATER INFLOW
SALINITY & WATER QUALITY
Front enters Texas

Normal onshore winds

Normal water levels
Front nears coastline

Onshore (S-SE) flow increases

Water levels set up shoreward
Front moves offshore
N winds freshen

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
TEXAS BAYS

Annual flow
Mm³/yr

SAN ANTONIO BAY
ARANSAS-COPANO BAY
CORPUS CHRISTI BAY
UPPER LAGUNA MADRE
LOWER LAGUNA MADRE

SABINE LAKE
GALVESTON BAY
MATAGORDA BAY

17,200
13,400
4,200
2,900
600
700
573
86
581
243
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
(b) Longitudinal profile of vertical-mean salinity

- Freshwater inflow
- Ocean salinity
- Sea
THREE (3) FACTOIDS ABOUT

DENSITY CURRENTS FORCED BY THE HORIZONTAL GRADIENT IN SALINITY

- Flow about an order of magnitude greater than inflow increases as the cube of depth.
## DEVELOPMENT OF HOUSTON SHIP CHANNEL

<table>
<thead>
<tr>
<th>Date</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880</td>
<td>12</td>
</tr>
<tr>
<td>1910</td>
<td>19</td>
</tr>
<tr>
<td>1914</td>
<td>25</td>
</tr>
<tr>
<td>1922</td>
<td>30</td>
</tr>
<tr>
<td>1937</td>
<td>32</td>
</tr>
<tr>
<td>1950</td>
<td>36</td>
</tr>
<tr>
<td>1965</td>
<td>40</td>
</tr>
<tr>
<td>1998</td>
<td>45</td>
</tr>
</tbody>
</table>
Salinity regressions, Lavaca Bay (West)

Salinity regressions, Upper Matagorda Bay (West)

$\Delta S = 6$

$\Delta S = 7$
TEXAS BAYS

More dynamic:
- freer exchange w/ sea
- bays isolated
- higher inflows
- lower salinities
- greater salinity currents in ship channels
- more energetic frontal passages

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
WHOLE-VOLUME WATER BUDGET OF BAY
FRESHWATER INFLOW
FRESHWATER INFLOW

Q

WATER LEVEL

V
FRESHWATER INFLOW

\[ T = \frac{V}{Q} \]
FRESHWATER INFLOW

TIDES
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
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
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

RUNOFF DECLINES EVEN MORE PRECIPITOUSLY FROM EAST TO WEST
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
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
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
Salinity regressions, Lavaca Bay (West)
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
Moroni, Comoros Islands
Mar - Apr 2006

The graph shows the tide (m) and lunar phase (rectified) for Moroni, Comoros Islands, from March to April 2006. The x-axis represents the number of days, and the y-axis represents the tide level in meters. The graph includes multiple sine waves representing the tide and lunar phase variations over the specified period.
## EXCHANGES AS FRACTION OF BAY VOLUME

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

*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
MATAGORDA ENTRANCE CHANNEL

TRAPPED LITTORAL SEDIMENTS

PREDOMINANT LITTORAL DRIFT

MATAGORDA ENTRANCE CHANNEL
ARANSAS PASS

TRAPPED LITTORAL SEDIMENTS

PREDOMINANT LITTORAL DRIFT
PREDOMINANT LITTORAL DRIFT ALONG TEXAS COAST
ENVIRONMENTAL FLOWS