Assessing the effects of freshwater inflows and other key drivers on the population dynamics of blue crab and white shrimp using a multivariate time-series modeling framework: Phase 2

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Dr. Edward J. Buskey

Mission-Aransas National Estuarine Research Reserve
Phase 1 summary

- Data from the Texas Parks and Wildlife Department (TPWD) Coastal Fisheries monitoring program, U.S. Geological Survey (USGS) flow gage stations, and several other sources were acquired for 1982–2013.

- Drivers of blue crab and white shrimp population dynamics were assessed using multivariate autoregressive (MAR) models.

- Detected significant lagged effects of predators, water temperature, salinity, and river discharge on the abundances of both focal species.

- Effects of freshwater inflows on focal species abundances must be assessed in conjunction with other drivers at time lags of up to two years.
Phase 2 Tasks

- Update datasets and rerun original models
- Reformat datasets to reflect TCEQ inflow standard seasonal increments
- Run new sets of MAR models using reformatted data
- Assess whether particular seasons are more influential on focal species abundances
- Model adaptation for inflow scenario assessment

Prepare & submit final report
  - Submit data and annotated R code
Updated Data

Seasonal divisions:
- Winter (Jan-Mar)
- Spring (Apr-Jun)
- Summer (Jul-Sep)
- Fall (Oct-Dec)

Blue crab (trawl)

White shrimp (trawl)
Updated Data

Seasonal divisions:

Winter (Jan-Mar)  Spring (Apr-Jun)  Summer (Jul-Sep)  Fall (Oct-Dec)

Water temperature

River discharge
Updated Data

Deviations from mean value (anomalies)
Updated Data

Deviations from mean value (anomalies)
Updated Data
Deviations from mean value (anomalies)
Updated Data

Deviations from mean value (anomalies)
MAR models

Example: no auto-regression

\[
\text{Sp1 estimate} = \text{Intercept} 90.6 + \text{Env1} \times 2.9 + \text{Env2} \times -8.2
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MAR models

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**MAR models**

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**MAR models**

**Example: auto-regression**

\[
\text{Sp1 estimate} = \text{Sp1}_{t-1} \times 0.56 + \text{Intercept} \times 13.5 + \text{Env1} \times 2.4 + \text{Env2} \times -3.5
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MAR models

Example: no auto-regression

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Estimates species abundance

Example: auto-regression

\[
\text{Sp1}_{t-1} \times 0.56 + \text{Intercept} 13.5 + \text{Env1} \times 2.4 + \text{Env2} \times -3.5
\]

Estimates change in species abundance from last time point
$$\text{Sp}_{1, t+1} \text{ estimate} = \text{Intercept} 0 + \text{Sp}_{1, t} \times b_1 + \text{Sp}_{2, t} \times b_2 + \text{Sp}_{3, t} \times b_3 + \text{Env}_{1, t} \times c_1 + \text{Env}_{2, t} \times c_2$$
**MAR-1 models**

\[
\text{Sp1}_{t+1} \text{ estimate} = \text{Intercept} \times b_1 + \text{Sp1}_t \times b_2 + \text{Sp2}_t \times b_3 + \text{Env1}_t \times c_1 + \text{Env2}_t \times c_2
\]
MAR-1 models

\[ \text{Sp}^{1}_{t+1} \text{ estimate} = \text{Intercept 0} + \frac{\text{Sp}_1}{b_1} + \frac{\text{Sp}_2}{b_2} + \frac{\text{Sp}_3}{b_3} + \frac{\text{Env}_1}{c_1} + \frac{\text{Env}_2}{c_2} \]
**MAR-1 models**

\[
\text{Sp1}_{t+1} \quad \text{estimate} = \text{Intercept } 0 + \text{Sp1}_t \times b_1 + \text{Sp2}_t \times b_2 + \text{Sp3}_t \times b_3 + \text{Env1}_t \times c_1 + \text{Env2}_t \times c_2
\]

<table>
<thead>
<tr>
<th></th>
<th>Sp1</th>
<th>Sp2</th>
<th>Sp3</th>
<th>Env1</th>
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<tbody>
<tr>
<td>Sp1</td>
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</table>
\[ \text{Sp1}_{t+1} \text{ estimate} = \text{Intercept} 0 + \frac{\text{Sp1}_t}{b_{1,1}} + \frac{\text{Sp2}_t}{b_{2,1}} + \frac{\text{Sp3}_t}{b_{3,1}} + \frac{\text{Env1}_t}{c_{1,1}} + \frac{\text{Env2}_t}{c_{2,1}} \]
MAR-1 models

\[
\text{Sp}^{1}_{t+1} \text{ estimate} = \text{Intercept} + \text{Sp}_1^t \times b_1 + \text{Sp}_2^t \times b_2 + \text{Sp}_3^t \times b_3 + \text{Env}_1^t \times c_1 + \text{Env}_2^t \times c_2
\]

\[
\text{Sp}^{2}_{t+1} \text{ estimate} = \text{Intercept} + \text{Sp}_1^t \times b_1 + \text{Sp}_2^t \times b_2 + \text{Sp}_3^t \times b_3 + \text{Env}_1^t \times c_1 + \text{Env}_2^t \times c_2
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**MAR-1 models**

\[
\begin{align*}
\text{Sp1}_{t+1} \text{ estimate} &= \text{Intercept} 0 + \text{Sp1}_t \times b_{1,1} + \text{Sp2}_t \times b_{2,1} + \text{Sp3}_t \times b_{3,1} + \text{Env1}_t \times c_{1,1} + \text{Env2}_t \times c_{2,1} \\
\text{Sp2}_{t+1} \text{ estimate} &= \text{Intercept} 0 + \text{Sp1}_t \times b_{1,2} + \text{Sp2}_t \times b_{2,2} + \text{Sp3}_t \times b_{3,2} + \text{Env1}_t \times c_{1,2} + \text{Env2}_t \times c_{2,2} \\
\text{Sp3}_{t+1} \text{ estimate} &= \text{Intercept} 0 + \text{Sp1}_t \times b_{1,3} + \text{Sp2}_t \times b_{2,3} + \text{Sp3}_t \times b_{3,3} + \text{Env1}_t \times c_{1,3} + \text{Env2}_t \times c_{2,3}
\end{align*}
\]

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Updated vs. Original Data Models

Blue crab 2-year lag
Coefficient values
Updated vs. Original Data Models

White shrimp 6-month lag
Coefficient values
# Seasonal models

**Blue crab: original model**

<table>
<thead>
<tr>
<th>Blue crab gill</th>
<th>Blue crab trawl</th>
<th>Blue crab seine</th>
<th>Red drum</th>
<th>Black drum</th>
<th>Spotted seatrout</th>
<th>sal</th>
<th>wtemp</th>
<th>discharge</th>
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</table>

6 response variables

9 predictor variables
Seasonal models

Blue crab: original model

- 54 coefficients
- $2^{54} = 18,014,398,509,481,984$ possible model configurations

- 6 response variables
- 9 predictor variables
**Seasonal models**

**Blue crab:** Model with 4 seasons included

<table>
<thead>
<tr>
<th>6 × 4 = 24 response variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 × 4 = 36 predictor variables</td>
</tr>
</tbody>
</table>
Seasonal models

Blue crab: Model with 4 seasons included

- $6 \times 4 = 24$ response variables
- $9 \times 4 = 36$ predictor variables

864 coefficients

$2^{864} = $ quite a few possible model configurations
Seasonal models

Blue crab: Model with 4 seasons & 2 year lags included

24 response variables

36 x 3 = 108 predictor variables
Seasonal models

Blue crab: Model with 4 seasons & 2 year lags included

24 response variables

36 × 3 = 108 predictor variables

2,592 coefficients

$2^{2,592}$ = a bit too many possible model configurations
Seasonal models

Models with 4 seasons & up to 2 year lags included
Seasonal models

Models with 4 seasons & up to 2 year lags included

- Focus on trawl datasets for focal species responses
  - Trawl samples taken throughout bays rather than only along perimeters (gill net and seine samples)
  - Trawl samples taken year-round rather than only in spring and fall (gill net samples)
  - Most consistent and ecologically plausible results in original models
Seasonal models

Models with 4 seasons & up to 2 year lags included

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  • Same reasons as above
Seasonal models

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• Remove predators as predictors
  • Gill net samples only taken in spring and fall
  • Influenced by FW inflows so would also have to be estimated
  • Removal has very little effect on model results
Seasonal models

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# Seasonal models

## Blue crab (winter, spring, summer, fall)

<table>
<thead>
<tr>
<th>Season</th>
<th>In Blue Crab t-1</th>
<th>In Discharge</th>
<th>Water Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>winter 0</td>
<td>spring 0</td>
<td>summer 0</td>
</tr>
<tr>
<td>Blue crab winter</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Blue crab spring</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Blue crab summer</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Blue crab fall</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
## Seasonal models

### Blue crab (winter, spring, summer, fall)

- Use BIC to select best model

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<tr>
<td>Blue crab fall</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Seasonal models

Blue crab (winter, spring, summer, fall)

- Use BIC to select best model
- Largest coefficients seen in winter model
  - High density dependence on preceding fall abundance
  - Positive effect of last winter’s river discharge
  - Strong negative effect of summer temperature at 2 year lag

<table>
<thead>
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<th>In Discharge</th>
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<td>Blue crab winter</td>
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<tr>
<td>Blue crab fall</td>
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</tbody>
</table>
Seasonal models

Blue crab: original vs. predicted abundance trends

<table>
<thead>
<tr>
<th></th>
<th>Aransas Bay</th>
<th>Copano Bay</th>
<th>San Antonio Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>log</strong></td>
<td>(blue crab CPUE + 1)</td>
<td>(blue crab CPUE + 1)</td>
<td>(blue crab CPUE + 1)</td>
</tr>
<tr>
<td><strong>1990</strong></td>
<td>![Graph of Aransas Bay data]</td>
<td>![Graph of Copano Bay data]</td>
<td>![Graph of San Antonio Bay data]</td>
</tr>
<tr>
<td><strong>2000</strong></td>
<td>![Graph of Aransas Bay data]</td>
<td>![Graph of Copano Bay data]</td>
<td>![Graph of San Antonio Bay data]</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>![Graph of Aransas Bay data]</td>
<td>![Graph of Copano Bay data]</td>
<td>![Graph of San Antonio Bay data]</td>
</tr>
</tbody>
</table>
Seasonal models

Blue crab: original vs. predicted abundance trends

Effects of temperature on long-term trends (discharge set to seasonal means)
Seasonal models

Blue crab: original vs. predicted abundance trends

Effects of discharge on long-term trends (temperature set to seasonal means)
Seasonal models

Blue crab: seasonal and overall abundance changes
- Decrease temperature 1°C each season
Seasonal models

Blue crab: seasonal and overall abundance changes
- Increase discharge 300% each season
### Seasonal models

**White shrimp (winter, spring, summer, fall)**

<table>
<thead>
<tr>
<th></th>
<th>In White shrimp t-1</th>
<th>In Discharge</th>
<th>Water Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>winter 0</td>
<td>spring 0</td>
<td>summer 0</td>
</tr>
<tr>
<td><strong>White shrimp</strong></td>
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<td></td>
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</tr>
<tr>
<td>winter</td>
<td>✓</td>
<td>✓</td>
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<td>spring</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>summer</td>
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</tr>
<tr>
<td>fall</td>
<td>✓</td>
<td>✓</td>
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</tr>
</tbody>
</table>

- ✓ indicates the presence of white shrimp in the respective season.
Seasonal models

White shrimp (winter, spring, summer, fall)

- Use BIC to select best model

<table>
<thead>
<tr>
<th></th>
<th>In White shrimp t-1</th>
<th>In Discharge</th>
<th>Water Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>winter 0</td>
<td>spring 0</td>
<td>summer 0</td>
</tr>
<tr>
<td>White shrimp winter</td>
<td>✓</td>
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<tr>
<td>White shrimp spring</td>
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<td>White shrimp summer</td>
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<tr>
<td>White shrimp fall</td>
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</tr>
</tbody>
</table>
Seasonal models

White shrimp (winter, spring, summer, fall)

- Use BIC to select best model
- Largest coefficients
  - High winter density dependence on preceding fall abundance
  - Negative effect of preceding year’s winter discharge on summer abundance
  - Positive lag-0 effect of river discharge on summer abundance
  - Negative effect of preceding summer’s temperature on fall abundance

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</table>
Seasonal models

White shrimp: original vs. predicted abundance trends
Seasonal models

White shrimp: original vs. predicted abundance trends

Effects of temperature on long-term trends (discharge set to seasonal means)
Seasonal models

White shrimp: original vs. predicted abundance trends

Effects of discharge on long-term trends (temperature set to seasonal means)
Seasonal models

White shrimp: seasonal and overall abundance changes
- Decrease temperature 1°C each season
Seasonal models

White shrimp: seasonal and overall abundance changes
- Increase discharge 100% each season
Summary

• Original model structure from phase 1 needed to be altered to accommodate multiple seasons of each variable in the analysis

• Predictor variables affected by FW inflows were omitted to avoid using estimated values to predict focal species abundances

• Model results:
  • Temperature
    - High summer temperatures negatively affect both blue crab and white shrimp abundances
  • Freshwater inflows
    - Large increases in winter river discharge are needed to see positive impacts on blue crab abundance
    - Summer river discharge positively affects white shrimp abundances