Environmental cues for herring spawning timing in northern Bristol Bay

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Historical monthly average sea ice edge (total concentration 5%, 1978-2004)

Bering sea ice: NOAA
Herring spawning

• Important component of ecology
• Spawning in end of April – beginning of May

>30cm
Spawning Area

- Main spawning area in EBS
Herring fishing

- Base of the cultures and economy
• High latitude $\rightarrow$ later spawning (Hay 1984)
• Interannual variability=30days
  - Prediction models with air temperature (Wespestad and Gundarson 1991) $\rightarrow$ errors
  - Better and more persisting model with explanation of mechanism
Spatiotemporally explicit analyses
The past models

Air temperature ≈ sea temperature change around spawning ground with wind effect

$\text{Herring spawning/arrival timing}$

$t_{April}$

$= b \times \text{air temperature at Cape Newenham} + a$

Model structures

Past models
Environmental variables

Herring
Environmental variables

Herring spawning/arrival timing

$\text{Model structures} \rightarrow \text{New models}$

$= b + c + a$

$t_1$, $t_2$, $\ldots$, $t_n$
Environmental variables

Herring spawning/arrival timing

Life-history approach

Correlation

Information
Sampling windows

January

February

March

April

May

June

See poster
Data

- Environmental variables (January-April)
  - Surface air temperature (SAT), Sea surface temperature (SST)
    - Comprehensive Ocean-Atmosphere Dataset (COADS)
    - Validated for the best estimation
  - Sea ice total concentration (Sea ice TC)
    - Sea ice archive (National Ice Center)
  - Cape Newenham air temperature (1953-2005)
Data

  - ADF&G aerial survey records
    - >1.6km (1 mile) spawns (spawning day) ...GIS calculation
    - Arrival at management area (arrival day)
Possible combination

Model structures ➔ New models

Environmental variables 1

Environmental variables 2

Herring spawning/arrival timing

\[ t_1 = b + c + a \]

\[ x_1 \]

\[ x_2 \]
Possible combination

\[ Herring\text{ }spawning/arrival\text{ }timing = x_1 b + c x + a \text{ }CN\text{ }air\text{ }temp \]

- Environmental variables
- Air temperature ≈ sea temperature change in spawning ground with wind effect

Model structures \(\rightarrow\) Improved models
Selection of the best combination

**Draft modeling**
- Stepwise regression
- Analyses for each variables vs. spawning
- Leave-one-off cross validation
  - (A) Significance
  - (B) RMS of error
  - (C) Error patterns in time series

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**Candidate models**

**Model selection**
- (1) AIC
- (2) Cross Validation

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**Best models (structures)**
Results (correlation)

Spawning day vs. April SST

Spawning day vs. April sea ice TC

Correlation ($r$)

...(Only the significant ($P < 0.05$) correlation is colored)
### Spawning day prediction

<table>
<thead>
<tr>
<th>Air-sea-ice variables</th>
<th>$r^2$</th>
<th>Month$_1$</th>
<th>$P_1$</th>
<th>Month$_2$</th>
<th>$P_2$</th>
<th>Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Newenham SAT</td>
<td>0.59</td>
<td>April</td>
<td>&lt;0.01</td>
<td>March</td>
<td>0.02</td>
<td>118</td>
</tr>
<tr>
<td>COADS SAT</td>
<td>0.48</td>
<td>April</td>
<td>&lt;0.01</td>
<td>January</td>
<td>0.03</td>
<td>133</td>
</tr>
<tr>
<td>COADS SST</td>
<td>0.23</td>
<td>April</td>
<td>0.02</td>
<td></td>
<td></td>
<td>135</td>
</tr>
<tr>
<td>sea ice TC</td>
<td>0.69</td>
<td>April</td>
<td>&lt;0.01</td>
<td>March</td>
<td>0.03</td>
<td>118</td>
</tr>
</tbody>
</table>

*all... n > 25, P < 0.01*
## Results (draft modeling)

### Arrival day prediction

<table>
<thead>
<tr>
<th>Air-sea-ice variables</th>
<th>$r^2$</th>
<th>Month&lt;sub&gt;1&lt;/sub&gt;</th>
<th>$P_1$</th>
<th>Month&lt;sub&gt;2&lt;/sub&gt;</th>
<th>$P_2$</th>
<th>Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Newenham SAT</td>
<td>0.45</td>
<td>April</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>COADS SAT</td>
<td>0.45</td>
<td>April</td>
<td>&lt;0.01</td>
<td>January</td>
<td>0.02</td>
<td>129</td>
</tr>
<tr>
<td>COADS SST</td>
<td>0.19</td>
<td>April</td>
<td>0.03</td>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>sea ice TC</td>
<td>0.60</td>
<td>April</td>
<td>&lt;0.01</td>
<td>March</td>
<td>0.05</td>
<td>114</td>
</tr>
</tbody>
</table>

All...$n > 25$, $P < 0.01$
Validation (draft models)

- April variable was always significant
- RMS errors are less with:
  - Sea ice total concentration
  - Cape Newenham air temperature
The selected model

a. Spawning date

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>Δi</th>
<th>$r^2$</th>
<th>$f(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP 1</td>
<td>126.5</td>
<td>0.0</td>
<td>0.79</td>
<td>$y = 24.79x \text{ sea ice TC in April} - 5.36x \text{ sea ice TC in March} - 1.17x \text{ Cape Newenham SAT in April} + 118.14$</td>
</tr>
<tr>
<td>SP 2</td>
<td>127.5</td>
<td>1.0</td>
<td>0.75</td>
<td>$y = 20.49x \text{ sea ice TC in April} - 1.37x \text{ Cape Newenham SAT in April} + 117.46$</td>
</tr>
</tbody>
</table>

b. Arrival date

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>Δi</th>
<th>$r^2$</th>
<th>$f(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR 1</td>
<td>128.0</td>
<td>0.0</td>
<td>0.75</td>
<td>$y = 22.54x \text{ sea ice TC in April} - 7.05x \text{ sea ice TC in March} - 1.12x \text{ Cape Newenham SAT in April} + 116.17$</td>
</tr>
</tbody>
</table>

$...n = 25, P < 0.01$
Validation (spawning)

April sea ice TC

April Cape Newenham SAT

The Best Model (SP1)

April and March sea ice TC

April and March sea ice TC

The Best Model (SP2)

…examples

Validation (arrival)

April sea ice TC

April and March sea ice TC

April Cape Newenham SAT

The Best Model (AR1)
• April thermal dynamics at pre-spawning migration passage and coastal pre-spawning habitat
Discussion

- Pre-spawning herring response to environment is spatio-temporally unique depending on years

\[
\text{Intercept} + k_1 x_1 + k_2 x_2 + \varepsilon
\]

Wanna’ move? Wanna’ work?

Then spawn
Discussion

- Atmospheric gradients effects to southeastern Bering Sea in April
- Future changes of climate
  - Herring brings the messages of the sea and air

Right: Sea surface level pressure comparisons
For future?

- For example, shifting the spawning location? Or...!??
- What can we share? Imaginations?
For future

( 1 ) Various spatially and temporally specific scenario simulation (with validations)

( 2 ) Spatially and temporally explicit designs in field

Extreme changes in finer temporal resolution in 2006 season was brought by strong Siberian high-pressure system in April
Thank you
Example: Residuals from NPI (April) model

Intensity = scientifically informative, but not really useful

$P=0.03$, $r^2 = 0.18$