Forecasting future range of sea scallops using a trophically-linked species distribution model: Will climate change constrain scallop distribution in the Mid-Atlantic Bight?

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Landings in the Mid-Atlantic Bight (MAB) area have been unusually high in recent years.
Southern and inshore distribution is limited by summer maximum bottom temperatures.

Intolerant to temperatures above 18°C (Posgay 1953; Dickie 1958; Stewart and Arnold 1994).
Decrease in Biomass in the South MAB

Delmarva

Virginia Beach

Source: 2016 VIMS PDT Document
Offshore extent is probably limited by high pre-recruit predation by *Astropecten americanus* sea stars (Franz and Worley 1981; Shank et al. 2012).
Evidences in both HabCam camera and dredge surveys showing strong negative relationships between *Astropecten* and scallop recruitments.
Astropecten distribution is limited by winter minimum bottom temperatures (>5°C; Franz et al. 1981; Hart and Chute pers. obs).

Significant shifts in the Astropecten distribution in recent years.

Astropecten biomass from NEFSC dredge survey.
Hypothesis:

Increases in water temperature may result in a contraction of the sea scallop habitat in the MAB.
compare the extent of the theoretical and realized habitat

ROMS Hindcast and Forecast of Bottom Temperature

Theoretical Habitat (published thermal habitat)

Realized Habitat Model (survey data)
Theoretical and Realized Habitat Area in MAB (1980-2015)

**Theoretical habitat**: area with maximum temperatures < 18°C and minimum salinities > 25ppt (Posgay 1953; Dickie 1958; Petrie and Jordan 1993; Stewart and Arnold 1994; Frenette and Parsons 2001)

**Realized habitat**: scallop recruitment (2-year old) habitat area estimated using dredge survey data and ROMS bottom temperature predictions

- Modeling scallop recruitment:
  - Counts
  - Probability of presence
  - 2-stage counts

- Explanatory Variables:
  - Different lag years of *Astropecten* biomass or minimum temperature
  - Different lag years of maximum temperature
  - Depth
  - Latitude
  - Year

- Thresholds:
  - ROC curves were used to find thresholds for counts and probability of presences
  - Areas with model predictions above the threshold are considered as good habitat for scallop recruitment
Realized Habitat Model Relationships

Due to temperature

Lag 2-year Maximum Bottom Temperature

Due to Astropecten

Lag 1-year Minimum Bottom Temperature

Lag 2-year Astropecten Biomass

Depth
Annual Change in Theoretical and Realized Habitat Area for Scallops

Habitat Size (km²) vs. Year
Maps of estimated theoretical and realized habitat for scallop recruitment from 1987 to 2015

Realized habitat: areas where more than half of the models classified them as good habitat
Annual Change in Size of Realized Habitat by Area
Forecast Changes in Scallop Habitat Using ROMS Climate Change Scenarios for Northwest Atlantic

◆ **Three Climate Change Scenarios:** Ocean conditions from 2070 to 2099 were simulated based on RCP8.5 - assuming little to no stabilization of greenhouse gas emissions by 2100 using three global climate models.

◆ **Delta Method:** Difference between mean conditions from 2070-2099 and 1976-2005 (e.g., right figure) were added to the observed period 1976-2005 (e.g, left figure; Alexander et al. 2020).

◆ **A baseline scenario and three climate change scenarios:** We estimated the theoretical and realized habitat areas under these four scenarios.

Source: [www.esrl.noaa.gov/psd/ipcc/roms/](http://www.esrl.noaa.gov/psd/ipcc/roms/)
Annual Relative Change in Theoretical and Realized Habitat Area for Scallops Under Four Climate Scenarios

- CTRL: Baseline Control Scenario
- GFDL: NOAA Geophysical Fluid Dynamics Laboratory ESM2M
- HADGEM: Hadley Center HadGem2-CC
- IPSL: Institute Pierre Simon Laplace CM5A-MR

Relative Difference = \( \frac{x - \text{CTRL}}{\text{CTRL}} \times 100\% \)
Annual Relative Change in Size of Theoretical and Realized Habitat for Scallops Under Four Climate Scenarios
# Relative Difference in Mean Size of Theoretical and Realized Habitat Area for Scallops Under Four Climate Scenarios

<table>
<thead>
<tr>
<th>Climate Change Scenario</th>
<th>Relative Difference in Mean Habitat Size (%) with 95% CI (x-CTRL/CTRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Line Control Scenario (CTRL)</td>
<td>0</td>
</tr>
<tr>
<td>GFDL; NOAA Geophysical Fluid Dynamics Laboratory ESM2M</td>
<td>-23%</td>
</tr>
<tr>
<td>HADGEM; Hadley Center HadGem2-CC</td>
<td>-46%</td>
</tr>
<tr>
<td>IPSL; Institute Pierre Simon Laplace CM5A-MR</td>
<td>-31%</td>
</tr>
</tbody>
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Summary

❑ Hindcast:
  a. Theoretical habitat decreased slightly over time, whereas realized habitat decreased abruptly from 1987 to 2000 and then highly fluctuated after 2000.
  b. Both realized and theoretical habitat areas seem narrower in recent years.

❑ Forecast: if the current greenhouse gas emissions continue, 2-year old scallop habitat could potentially drop by 23%-55%, depend on the global climate models.

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