The importance of environmental exposure history in forecasting Dungeness crab megalopae occurrence using J-SCOPE, a high-resolution model for the US Pacific Northwest

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Photo Credit: R. Norton
Dungeness Crab Fishery: Valuable but Variable

- One of the most valuable fisheries in the Pacific Northwest
- Interannual fluctuations
  - Driven by environmental variability
- Co-managed by State and Tribes
  → Managers are interested in forecasting tools

Historical Catch in Oregon

We’re on it!

https://www.dfw.state.or.us/MRP/shellfish/commercial/crab/landings.asp
Megalopae Abundance Correlated with Adult Crab Fishery 4 Years Later

Aim: Forecast megalopae occurrence and habitat.

Density-dependent effects

Limited by recruitment

Fig. 6 in Shanks, 2013: *Fish. Oceanogr.* 22:4, 263-272
Dungeness Crab Life Cycle: Benthic and Pelagic Stages

Eggs
released after
3-5 months

Zoea
5 stages, ~3 months

Megalopa
~30 days, strong swimmers

Juvenile
settle, 2 yrs to mature

Adult

Pelagic

Benthic
Exposure History is Important for Some Pelagic Organisms: Pteropod Survival

Particles initialized at sampling locations with vertical migration behavior

Dispersal simulations run forward and backward for 30 days to estimate undersaturation days
Hypothesis:

Including environmental exposure history will improve our ability to predict megalopae occurrence and habitat compared to using only co-occurring environmental conditions (‘\textit{in situ}’).

GLM = Generalized Linear Model

Dungeness Megalopae Occurrence Data

- 13 surveys from nine years
- 2009-2016: develop GLMs
- 2017: test GLM performance
- 37 sampling locations
- May + June surveys
- Oblique bongo tows 0-30m
- Dungeness megalopae identified and counted

Thanks to C. Morgan for providing data; sampling conducted by Bonneville Power Administration and Northwest Fisheries Science Center (NOAA)

J-SCOPE (JISAO’s Seasonal Coastal Ocean Prediction of the Ecosystem)
Forecasts Seasonal Coastal Marine Conditions for PNW

- NOAA’s Climate Forecast System (CFS) – global coupled air/sea/land model – used for boundary and atm forcing of ROMS-based regional model with biogeochemistry (Cascadia domain, ~1.5 km res)
- Empirically-derived relationships applied to modeled fields to predict additional quantities (e.g. pH and fish)

Currently forecasting:
• T, S, O, NO₃, Chl a, pH, Ω
• Sardine Habitat (Kaplan et al., 2016)
• in prep: OA specific indices for adult crab, shellfish, pteropods; and hake habitat (Malick et al., in prep)

Next talk: Skill and uncertainty of environmentally driven forecasts of Pacific hake distribution
Siedlecki et al., 2016.

Check out our website: http://www.nanoos.org/products/j-scope/home.php
“in situ” Variable Extractions

- From J-SCOPE at times and locations concurrent with megalopae sampling (37 stations, 2009-2016)
- Averaged over sampling depth (0-30m depth)

Estimating exposure history is more complicated...

Exposure History: Particle Dispersal Tracked Backward for 30 Days with LTRANSv2b¹

1. Advection and environmental conditions from J-SCOPE

¹North et al., 2008; 2011; Schlag and North, 2012
1. Advection and environmental conditions from J-SCOPE

2. Larval Behavior

Exposure History: Particle Dispersal Tracked Backward for 30 Days with LTRANSv2b

L = 100 particles/stn

North et al., 2008; 2011; Schlag and North, 2012

Develop EH models

EH-S1: Surface-following
EH-P1: Passive dispersal initialized at 1m
EH-P30: Passive initialized 30m
EH-DVM30: Diel vertical migration (DVM) 0-30m
EH-DVM60: DVM 0-60m

3. Random displacement in horizontal + vertical directions

1 North et al., 2008; 2011; Schlag and North, 2012
Environmental Conditions Extracted Along Particle Trajectories

Particle tracks over SST field

Day in simulation

Temperature at one particle

Indicative of DVM

Temperature histogram for all particles

Calculated Two Types of Exposure Histories

**Variables**

1. **Average conditions**
2. **Severity Index**: Time and degree by which a threshold was surpassed

**Develop EH models**

Exposure History Models Show Better Fit and Performance Than *in situ* Model

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Predictor Variables (bold p&lt;0.05)</th>
<th>ΔAIC</th>
<th>in-sample AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>in situ</em></td>
<td>-N</td>
<td>11.8</td>
<td>0.602</td>
</tr>
<tr>
<td>EH-P1</td>
<td>+S, +O</td>
<td>0.0</td>
<td>0.658</td>
</tr>
<tr>
<td>EH-P30</td>
<td>+P, -SI Ωar</td>
<td>1.9</td>
<td>0.625</td>
</tr>
<tr>
<td>EH-DVM30</td>
<td>+O</td>
<td>4.7</td>
<td>0.644</td>
</tr>
<tr>
<td>EH-DVM60</td>
<td>+S, +O</td>
<td>5.3</td>
<td>0.650</td>
</tr>
<tr>
<td>EH-S1</td>
<td>-T, -N, -SI Ωca</td>
<td>7.9</td>
<td>0.645</td>
</tr>
</tbody>
</table>

- **Relative Model Fit (0 is best)**
  - Model Performance (0→1, higher is better)
  - Worst model fit and performance
  - 4 EH models have good fit and performance
  - Assemble “biological ensemble”

Predictor(s) in GLM with direction (-/+ ) of correlation to megalopae occurrence


Compare models
Biological Ensemble Skillfully Forecasts Megalopae Occurrence

- Biological ensemble represents multiple behaviors
- 94% agreement with 2017 megalopae survey
- Predicts habitat on outershelf and northern areas

Conclusions

- Prediction of pelagic habitat for Dungeness megalopae is possible with a combination of tools: ocean conditions model, particle tracking, statistical modeling.
- Models that include exposure history outperform those that solely rely on *in situ* conditions.
- Simulated behavior affects depth habitat and ultimately drives environmental exposure.
- Best prediction was the result of a biological ensemble that includes multiple behaviors.

Acknowledgements

Funding for this project provided by NOAA Ocean Acidification Program. Funding for J-SCOPE provided by NOAA MAPP and NOAA OAP. Thanks to Bonneville Power Administration, NOAA NWFSC, and F/V Frosti crew for sample collection.

For more information, check out our website: http://www.nanoos.org/products/j-scope/home.php

Photo Credit: R. Norton
Ocean Condition Observations for J-SCOPE Skill Assessment

- Surface, seafloor, and water column measurements
- Moorings and cruises
- 2009-2017
Select Environmental Variables to Consider for Occurrence Model

Criterion 1: Reported as important for megalopae in the literature

1b: Critical thresholds exist to calculate severity indices

Criterion 2: Modeled by J-SCOPE (or could be derived from modeled variables)
Assess Skill of Modeled Variables

Motivation: Variable skill will influence performance of occurrence models → investigate patterns of J-SCOPE skill

• Paired modeled and observed variables within specific depth habitats and seasonal windows:
  1) Pearson’s Correlation Coefficient ($r > 0.5$)
  2) Normalized Root Mean Square Error ($-1 < \text{NRMSE} < 1$)

⇒ Significant skill for most variables; skill increases subsurface
Results: Particle tracking simulations

Passive Dispersal

DVM Behavior

Larval dispersal

Day -0.083
Behavior and Initialization Depth Affect Dispersal Trajectory

Develop EH models

Environmental Exposure Influenced by Depth Habitat

1. Averages: **Depth habitat**
drives exposure patterns –
shallow (EH-S1) and deep
(EH-P30) habitats are most
divergent

2. **Severity Indices**: Severe
conditions experienced in
deep habitats (EH-P30,
DVM60)

Recall Aim: Model megalopae occurrence using in situ vs. exposure history variables

- Binomial distribution (‘present’ or ‘absent’) requires logit link function

\[
\text{Probability of Presence} = \log \left( \frac{\mu}{1-\mu} \right)
\]

where

\[
\mu = \frac{e^{X_b}}{1+e^{X_b}}
\]

\(X_b\) is linear combinations of predictor variables

- Considered all variables as potential predictors
  - Selected best combination of variables based on lowest AIC score
### Biological ensemble – 2017 performance

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Equation ( \text{(bold } p&lt;0.05) )</th>
<th>2017 AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>EH-P1</td>
<td>(-11.0 + 0.248<em>S + 0.0111</em>O)</td>
<td>0.914</td>
</tr>
<tr>
<td>EH-DVM30</td>
<td>(-3.01 + 0.109*O)</td>
<td>0.814</td>
</tr>
<tr>
<td>EH-DVM60</td>
<td>(-6.42 + 0.132<em>S + 0.00988</em>O)</td>
<td>0.936</td>
</tr>
<tr>
<td>EH-S1</td>
<td>(1.77 - 0.157<em>T - 0.0994</em>N - 79.5*(S_{\Omega ca}))</td>
<td>0.757</td>
</tr>
</tbody>
</table>

**Biological Ensemble:** 0.936
11:50a – 12:10p: 15 min talk + 5 min Q