Integrating species environmental thresholds to explore species interactions and parameterize multi-species models

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What are the impacts of climate on structuring species distributions and interactions?
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Habitat volume and spatial extent influence species distribution and abundance. Climate change is expected to influence the distribution and volume of ocean habitats.
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Predicting responses to climate change requires understanding habitat associations and environmental tolerances - determinants that influence biogeography.
Shifts in spatial distribution
Shifts in species interactions
Shifts in recruitment and abundance
Shifts in species life history, phenology, and recruitment
Climate variability and directional climate change
How are individual species distributed and what are the important thresholds?
- Spatial mapping of individual species abundance and variation in abundance
- Identified critical thresholds
- Examined evidence for resource partitioning, competitive exclusion, and predation avoidance (MARSS) and response to environmental forcing (DFA)
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How to integrate that knowledge in models of species dynamics?
- Use environmental correlates to explain residuals in stock-recruitment
- Estimate shifts in habitat volume as means to project forward
Spatial extent and intensity of the Cold Pool

... a residual body of cold water (legacy of sea ice extent)
Importance of size, life-stage, predator prey ratios

walleye pollock (< 10cm)

walleye pollock (10-40cm)
Importance of size, life-stage, predator prey ratios
Determine method to delineate distinct ecological regions

Premise: Importance of Biogeography
- Ecosystems occur at a hierarchy of scales
  - synthesize physical and biological data
  - identify regional structure
  - delineate meaningful spatial boundaries
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Approach
- Identify threshold shifts in community composition
Random forests – *Species responses to physical variables*

Fits multiple regression trees, with bootstrap sample
Applies binary recursive partitioning as a statistical classifier

Quantifies…
- extent to which environmental variables predict distribution patterns ($R^2$)
- relative importance of a variable
Each tree... an accuracy and error related to observations not in bootstrap sample

Variable importance – increase in prediction error when values randomized
Extended forests – Community shifts along environmental variable

Synthesize goodness-of-fit ($R^2$) and predictor importance of RFs of multiple species
Determine thresholds or breakpoints in community composition

Density of split importance standardized by the density of number of splits at a value
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Density of split importance standardized by the density of number of splits at a value.
Use ordination to determine how stations distribute on environmental gradients.

Coordinate position represents inferred biological composition associated with environmental predictors.
Overlay weighted distribution of species at each station

Scallop spp.
Overlay weighted distribution of species at each station

Mussel spp.
Clam spp.

Overlay weighted distribution of species at each station
Dissimilarity index for separation of survey stations into ecoregions. Isolation indicates relative distinctness between regions (the Northern region is most distinct).

<table>
<thead>
<tr>
<th>Ecoregion</th>
<th>No. stations</th>
<th>Maximum dissimilarity</th>
<th>Mean dissimilarity</th>
<th>Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Inner shelf</td>
<td>101</td>
<td>0.023</td>
<td>0.010</td>
<td>0.900</td>
</tr>
<tr>
<td>(2) Middle/inner (south)</td>
<td>48</td>
<td>0.019</td>
<td>0.009</td>
<td>0.965</td>
</tr>
<tr>
<td>(3) Southern</td>
<td>59</td>
<td>0.022</td>
<td>0.010</td>
<td>1.155</td>
</tr>
<tr>
<td>(4) Northern</td>
<td>50</td>
<td>0.027</td>
<td>0.011</td>
<td>2.057</td>
</tr>
<tr>
<td>(5) Middle/outer (north)</td>
<td>64</td>
<td>0.020</td>
<td>0.012</td>
<td>1.035</td>
</tr>
<tr>
<td>(6) Shelf break</td>
<td>54</td>
<td>0.018</td>
<td>0.009</td>
<td>0.949</td>
</tr>
</tbody>
</table>
Delineation of Ecoregions (integrated over 30 years)
Delineation of ecoregions will shift with different climate regimes

Warm phase (2001-2005)

Cold Phase (2006-2010)
Cross-shelf transport (shelf/basin exchange)

Surface Currents
A Split Shelf: North/South changes in Currents

Summer time circulation patterns appear to be separate north and south of ~$60^\circ$N
Walleye Pollock

Eastern Bering Sea pollock fisheries have averaged 1.2 million tonnes annually and represent the largest US fishery.
Walleye Pollock spatial distribution by lifestage (1982-2015)
Walleye Pollock spatial distribution by lifestage (1982-2015)

<10cm
Walleye Pollock spatial distribution by lifestage (1982-2015)
Walleye Pollock spatial distribution by lifestage (1982-2015)
Walleye Pollock spatial distribution by lifestage (1982-2015)
Habitat for juvenile walleye pollock and capelin is controlled by different processes.

Capelin distributions are limited by oceanographic conditions. Pollock are controlled by prey availability and predation.
Forage Fish: Juvenile Pollock (age-0)

Parker-Stetter, Horne, Urmy, Farley, Eisner
Forage Fish: Capelin

Parker-Stetter, Horne, Urmy, Farley, Eisner
Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea

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Overlap of juvenile pollock and capelin higher in cold years
Walleye Pollock (all ages)
Capelin
Walleye Pollock (all ages)
Time series of relative biomass for range of species in the Bering Sea in past years
Time series of future Bering Sea surface temperature based on climate models
Evaluating management strategies for eastern Bering Sea walleye pollock (*Theragra chalcogramma*) in a changing environment

James N. Ianelli¹, Anne B. Hollowed¹, Alan C. Haynie¹, Franz J. Muetter², and Nicholas A. Bond³
Factors affecting recruitment:

(i) ice and temperature determine early growth;

(ii) stratification during the first summer affects growth and vulnerability to predation;

(iii) predation is influenced by the spatial overlap between juvenile pollock and their predators
Factors affecting recruitment:

(i) Recruitment and survival decrease with increasing temperature (Mueter et al. 2011)
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(i) Recruitment and survival decrease with increasing temperature (Mueter et al. 2011)
(ii) Predation is stronger in warm years (Coyle et al. 2011)
Time series of pollock recruitment (bars), based on stock assessment estimates and anomaly time series of environmental variables
Competition and Predation

Proportion of diet by weight

Length (cm)

Graphic: Kirstin Holsman
Residual Natural Mortality

Predation Natural Mortality

\[ Z_{ij,y} = M_{1ij} + M_{2ij,y} + F_{ij,y} \]
Residual Natural Mortality
Predation Natural Mortality

\[ Z_{ij,y} = M_{1ij} + M_{2ij,y} + F_{ij,y} \]
As a first cut...
recruitment deviations
As a first cut...

recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)
As a first cut…

recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)

\[ \log(R_t) = \log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1} \]

Graphic: Kirstin Holsman
As a first cut, recruitment deviations

More habitat will reduce density-dependent constraints (linear relationship)

\[
\log(R_t) = \log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1} + \sum \beta_k \cdot X_{k,t} + \epsilon,
\]

- recruitment
- productivity
- carrying capacity
- environmental effects on carrying capacity

Graphic: Kirstin Holsman
As a first cut...

recruitment deviations

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Graph: Kirstin Holsman

ROMS/ NPZ Indices
As a first cut… (retrospective)

(1) Applied random forest output to determine threshold tolerances

(2) Used ROMS to determine environmental parameters and copepod and euphasusiid abundance within a spatial extent that matched biological data

(3) Developed output for:
   (i) overlap of pollock and arrowtooth
   (ii) copepod abundance
   (iii) environmental thresholds

(4) Applied covariates to explore whether this explains recruitment deviates
Marginal importance is determined given a regression function (e.g. species presence) dependent on multiple variables.
Used a linear regression model with bootstrapping to determine breakpoints where the linear relation changes (distinct segments)
Covariate: Percent habitat with temperature in tolerance range (>2°C)
Covariate: Relative availability of copepods within juvenile pollock habitat
Next…
forward projection given ROMS estimates of ecoregion volume
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