Resolving biogeographic patterns in the deep sea using species distribution modeling

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Biogeography of *Lophelia pertusa*

1. What niche space does *L. pertusa* occupy in the Gulf of Mexico?
2. What is the likely distribution?
3. Can we predict occurrences accurately enough to inform field operations?

Erik Cordes
William Shedd
Maxent Modeling

- Broad scale model: 25 m
- Fine scale models (7 sites): 5-8 m
- Variables:
  - Rugosity
  - Slope
  - Eastness/Westness
  - Curvature (plan/profile/tangential)
  - Seismic (hard bottoms)
  - Topographic Position Index (fine/broad scales)
  - Omega aragonite
  - POC flux
Broad scale (25 m) model
Viosca Knoll 826 model

Habitat Suitability
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0

1300 m

Habitat Suitability vs. Depth (m)
- Depth range: 450 - 700 m
- Habitat Suitability range: 0.0 - 1.0

Habitat Suitability vs. TPI (broad)
- TPI range: -60 to 40
- Habitat Suitability range: 0.0 - 1.0
Importance of hard substrate

- Broad scale model
- Location of hard bottom polygons from BOEM seismic and geologic data analysis
- Model contribution: 43%

- Fine scale model
- Binning of high-resolution seismic reflectivity survey at each site
- Average model contribution: 25%
Model validation

- Regularization parameter tuned
- Controls model complexity
- Model performance assessed via:
  - Training data (75%)
  - Testing data (25%)
  - Ground-truthing data
  - Independent AUV survey
    - 7 random transects over site
    - 3,000+ images analyzed
## Transferability of the model

<table>
<thead>
<tr>
<th>Site</th>
<th>AUC 'Sentry'</th>
<th>AUC Ground truth</th>
<th>Spearman's $\rho$</th>
<th>Overlap ($I$)</th>
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</thead>
<tbody>
<tr>
<td>Viosca Knoll</td>
<td>0.972</td>
<td>0.928</td>
<td>0.813</td>
<td>0.891</td>
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<tr>
<td>VK826</td>
<td>0.961</td>
<td>0.881</td>
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<tr>
<td>VK862/VK906</td>
<td>0.926</td>
<td>0.769</td>
<td>0.256</td>
<td>0.456</td>
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<tr>
<td>Mississippi Canyon</td>
<td>0.952</td>
<td>0.847</td>
<td>0.564</td>
<td>0.714</td>
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<tr>
<td>MC751</td>
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<td>0.643</td>
<td>0.895</td>
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<td>MC885</td>
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<td>0.820</td>
<td>0.550</td>
<td>0.782</td>
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<tr>
<td>Garden Banks</td>
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<td>0.742</td>
<td>0.643</td>
<td>0.721</td>
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<td>GB535</td>
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<tr>
<td>Green Canyon</td>
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</tr>
</tbody>
</table>
Groundtruthing Viosca Knoll
Groundtruthing Viosca Knoll
Conclusions

- *L. pertusa’s* distribution delineated with a few variables: substrate, terrain, depth
- Clear preference for elevated, irregular topography with hard substrate
- Not hard to get models that perform well, need independent validation and ground-truthing
- Default settings test well but do not transfer to new sites
- Likely many undiscovered *L. pertusa* sites in the Gulf of Mexico
Ecological speciation in the deep sea

- How is diversity in the deep-sea generated?
- Testing the depth-divergence hypothesis (Rex & Etter 2010)

Key Questions:
1. Do closely related species of cold-water corals occupy distinct ecological niches?
2. Is niche divergence important in the evolution of these species?
Maxent Modeling

- Resolution: 5, 25 m
- Variables:
  - Rugosity
  - Slope
  - Eastness/Westness
  - Curvature (plan/profile/tangential)
  - Seismic (hard bottoms)
  - Topographic Position Index (fine/broad scales)
  - Omega calcite
  - POC flux
  - Dissolved oxygen
  - Salinity
  - Temperature
  - Presence of seep
Genetically and morphologically distinct

Quattrini et al. 2013 *Molecular Ecology*
Ecologically distinct?

C. a. delta

C. gracilis

Habitat suitability index

1.0 0.8 0.6 0.4 0.2 0.0
Callogorgia niche space

Seep presence – 58.3%
Calcite – 19.8%
Salinity – 9.4%
AUC=0.995±0.002

Depth – 70.6%
Salinity – 10.7%
Dissolved oxygen – 9.3%
AUC=0.977±0.004
Ecological speciation in the deep sea

Two-tailed T-test, p<0.001

Average suitability index

Seep
Non-seep

C. a. delta
C. gracilis

* Indicates significant difference
Identity test (ENM Tools)

Measured overlap ($I = 0.014$, $p<0.001$)

Pseudoreplicate overlap (±95% CI)
Background test (ENM Tools)

C. a. delta
environment

C. gracilis
environment

Measured overlap
(I = 0.014, p<0.001)
Ecological speciation in the deep sea

- *C. a. delta* – a non-seep organism with a clear seep preference
- *C. gracilis* and *C. a. delta* occupy distinct niches
- Our results support the depth-divergence hypothesis
- Depth or depth-related variables?
- Did ecology drive speciation, or did niches diverge after speciation?

Quattrini et al. 2013 *Molecular Ecology*
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