Modeling distributions of deep-sea corals offshore of the southeastern United States to guide efficient discovery and protection of sensitive habitats

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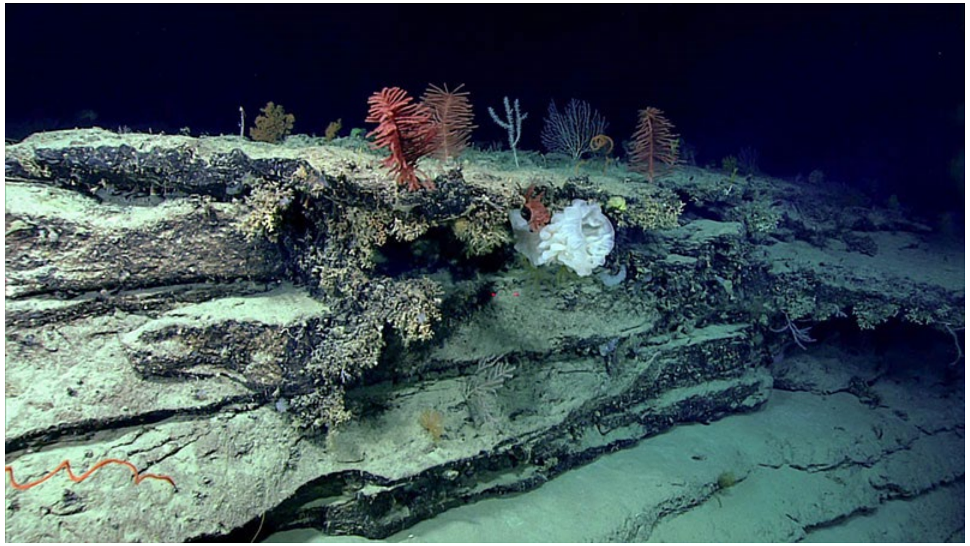
Background

- BOEM identified need for information on spatial distributions of sensitive benthic habitats offshore southeastern US
- Deep-sea corals can form complex 3-D structures that increase local biodiversity by providing microhabitats for other organisms
- Exposed hard substrate provides surface for attachment of sessile invertebrates and may be associated with increased diversity and abundance of large fish

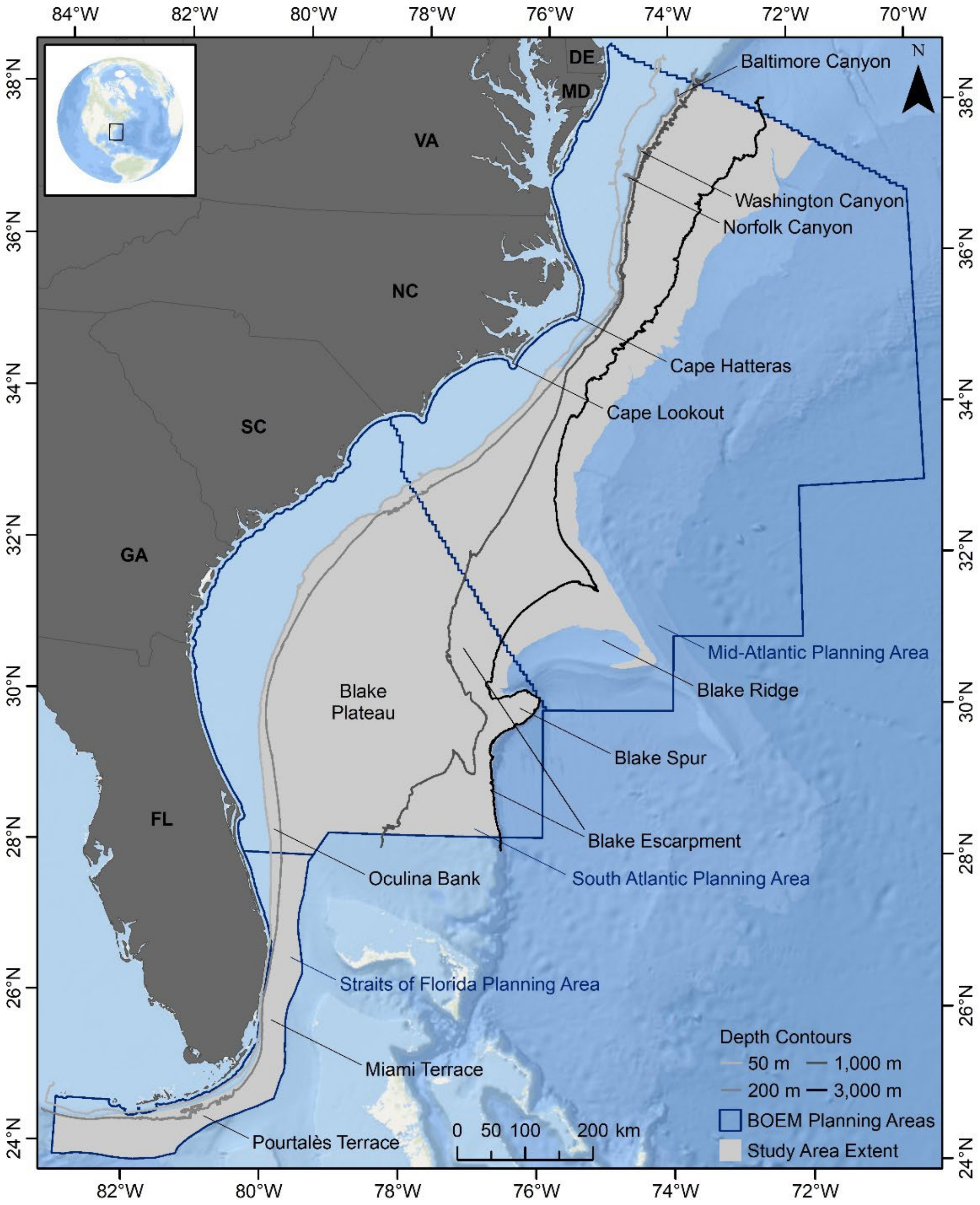
Credit: NOAA OER



Credit: NOAA OER

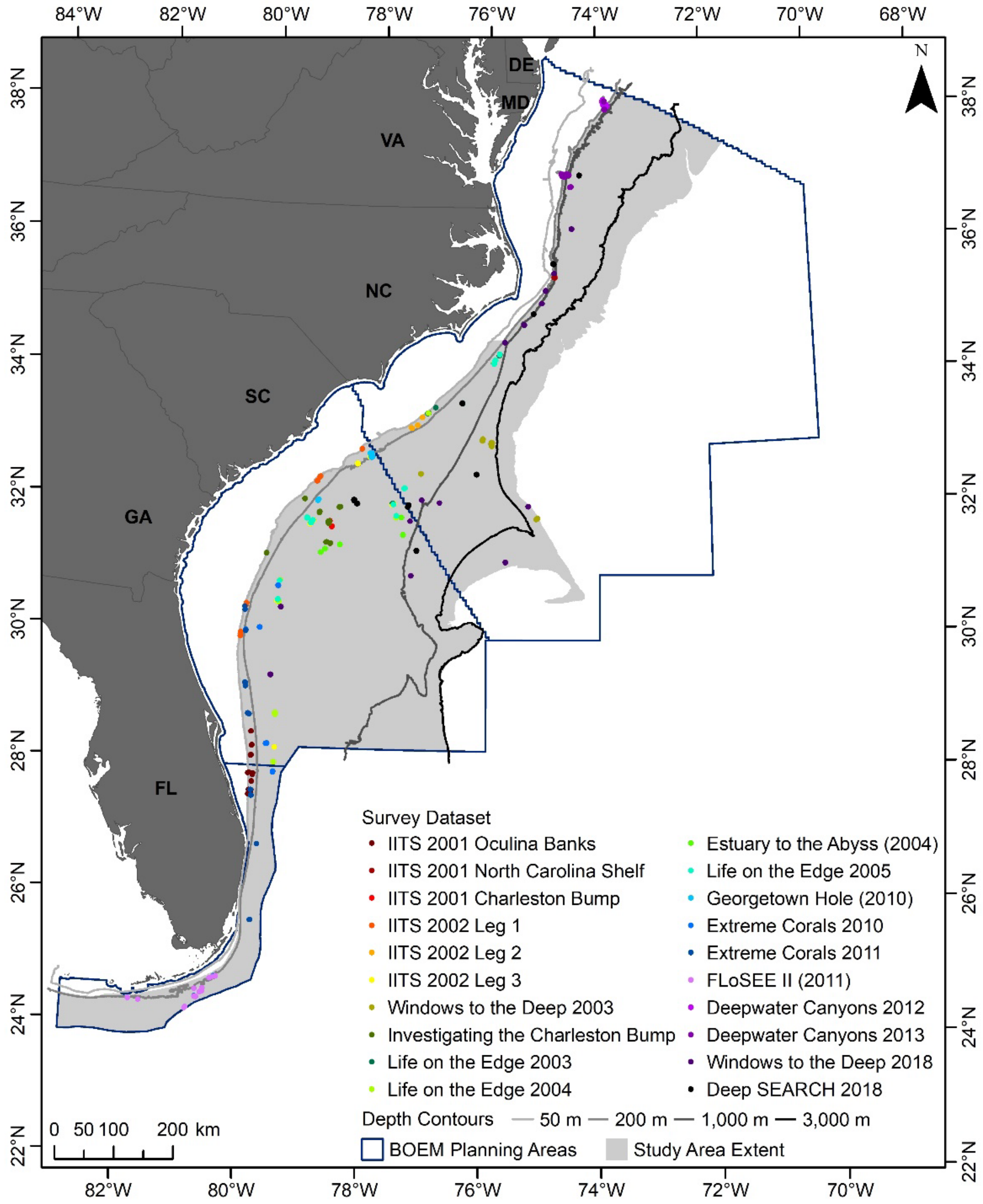
Background

- Hourigan et al. (2017) described four major concentrations of hardbottom habitats that support DSC communities
  1. Miami and Pourtalès Terraces
  2. *Oculina* coral mounds off FL
  3. continental shelf, shelf break
  4. continental slope, Blake Plateau
- Farther north, submarine canyons



Why Predictive Models?

- Although considerable research and exploration has been done, much of the region is still unmapped and unexplored
- Field surveys in the deep sea are logistically difficult and expensive
- Models can predict and map estimated occurrence to inform:
  - siting, environmental assessment
  - conservation, management decisions
  - selection of targets for mapping and exploration



Existing Predictive Models

- Unpublished regional scale models for group of structure-forming stony corals by Davies
- NCCOS regional scale models for 3 species and 1 genus of structure-forming stony corals, several other groups of DSCs
- Mienis et al. (2014) – two regional scale models for *Lophelia pertusa*
- Gasbarro et al. (2022) – models at multiple scales for *L. pertusa*

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Cold-water coral growth under extreme environmental conditions, the Cape Lookout area, NW Atlantic

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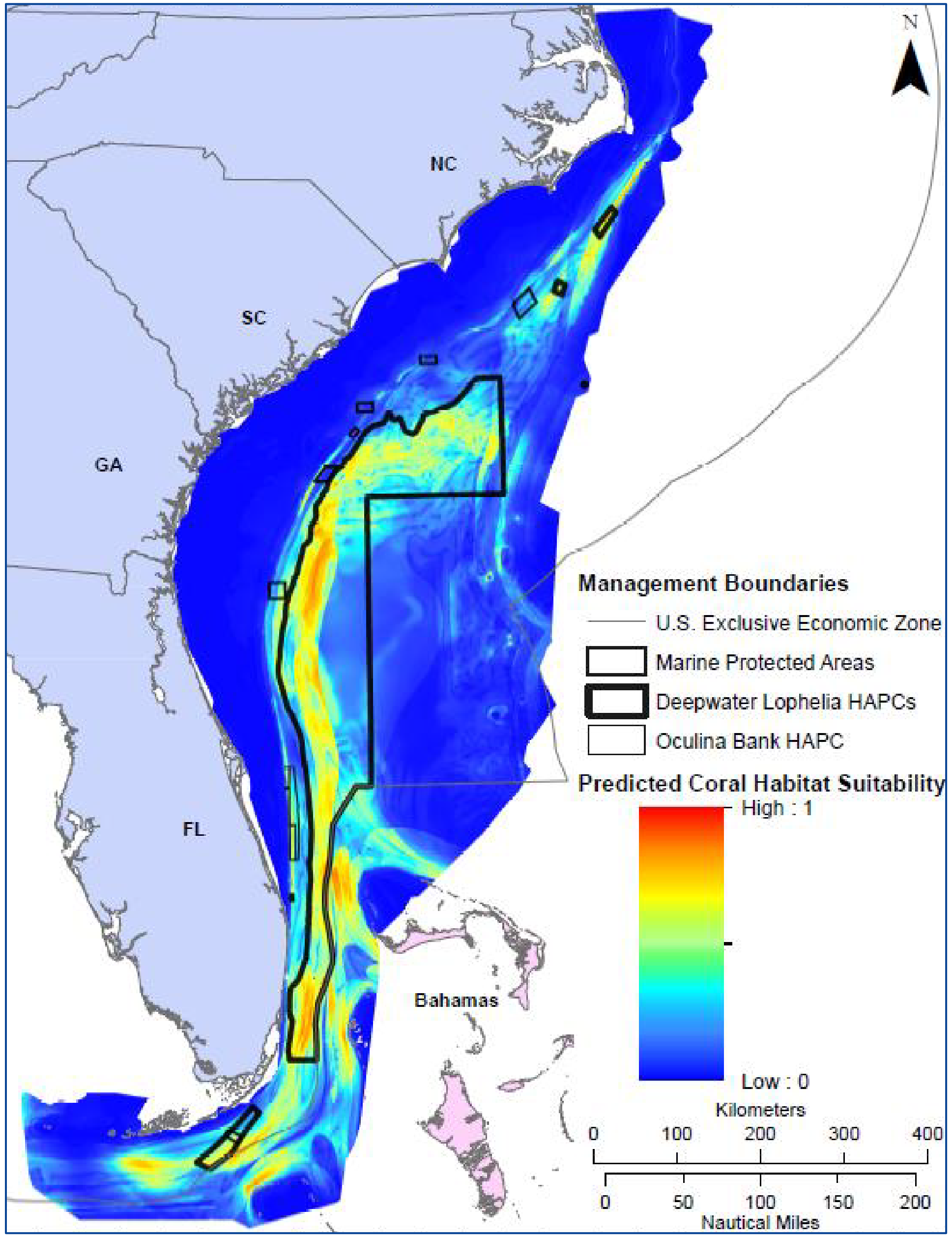
Why *New* Predictive Models?

- Earlier models used environmental predictors derived from regional bathymetry model
- Many of earlier models created for broad taxonomic groups that combined taxa with different habitat requirements
- Existing models were all presence-background models, fit using DSC presence data and randomly selected background locations rather than absence data



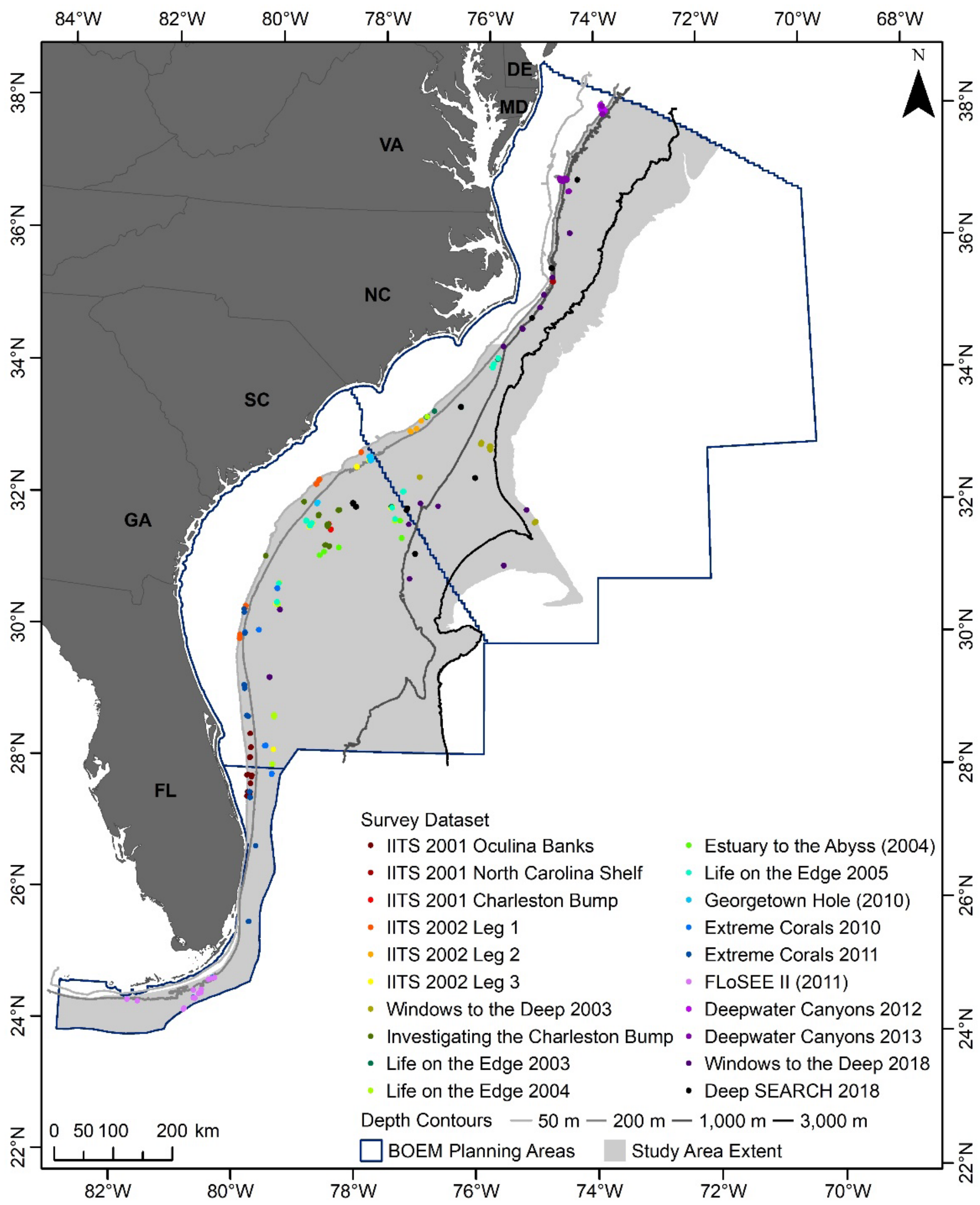
Objectives

- Data Synthesis: compile database of presence-absence records of DSC occurrence with associated measures of sampling effort and bottom type

- Predictive Modeling: develop predictive models that relate the occurrence of DSCs and hardbottom habitats to spatial environmental predictors in order to predict and map their potential spatial distributions across the study area

Methods (Data Synthesis)

- Inventory of available data from field surveys conducted by submersibles and ROVs used to compile a database of presence-absence records
- Each database record assigned a spatial position, estimate of survey area, DSCs observed, description of bottom type



Methods (Data Synthesis)

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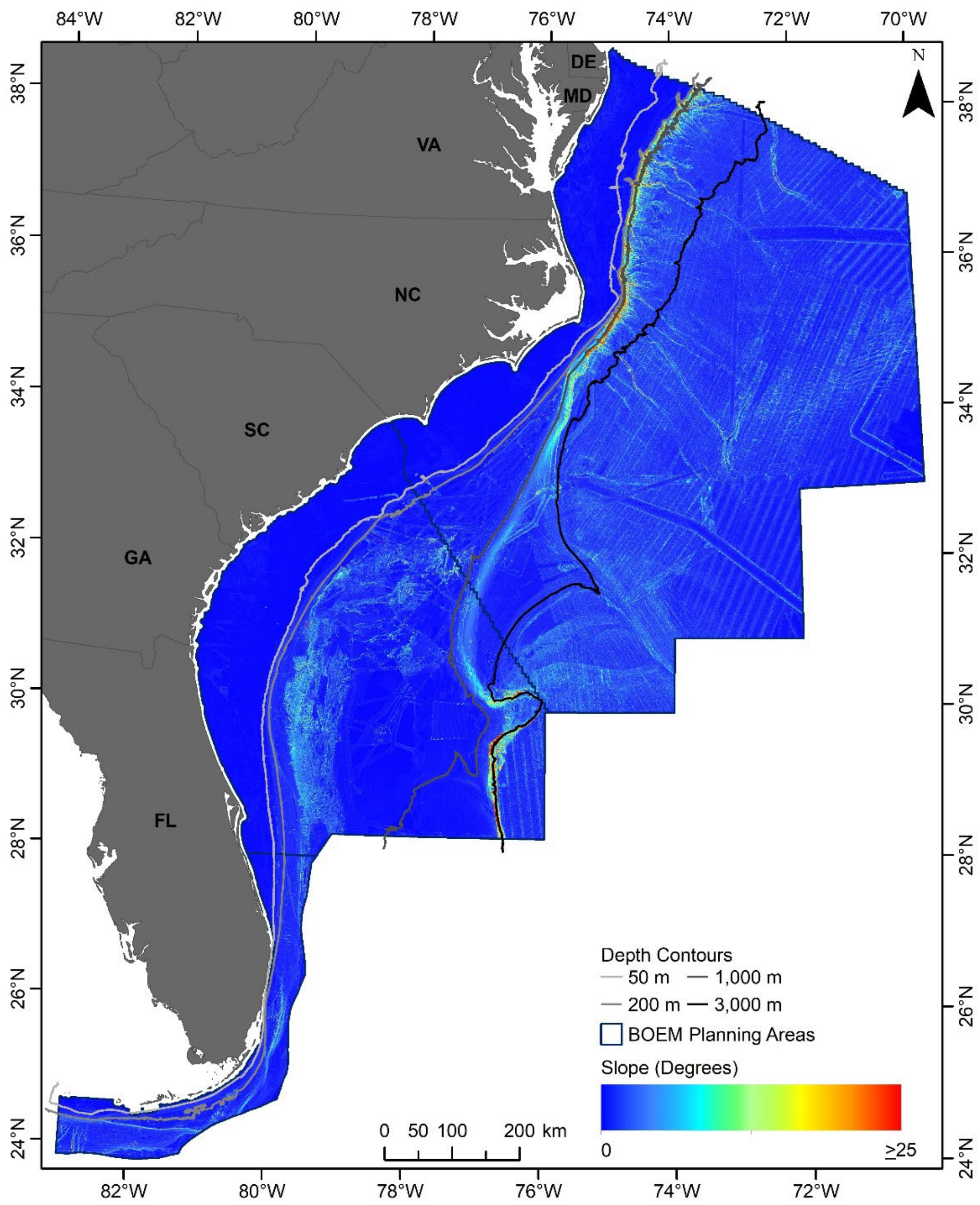
Table 1. Field survey datasets used to create the presence-absence database of deep-sea corals and hardbottom habitats

Survey Dataset	Principal Investigator	Dives	Samples	Sites	Total Area (m^2)
Islands in the Stream 2001 Oculina Banks	Shepard, Koeing	16	41	33	8,110
Islands in the Stream 2001 NC Shelf	Ross, Sulak	10	28	16	3,987
Islands in the Stream 2001 Charleston Bump	Sedberry	3	62	36	9,987
Islands in the Stream 2002 Leg 1	Sedberry	10	166	70	19,728
Islands in the Stream 2002 Leg 2	Ross, Sulak	11	61	39	11,054
Islands in the Stream 2002 Leg 3	Pomponi, Reed	23	209	106	37,728
Windows to the Deep 2003	Ruppel, Van Dover	7	144	113	33,023
Investigating the Charleston Bump (2003)	Sedberry, Stancyk	13	193	80	25,114
Life on the Edge 2003	Ross, Baird, Sulak, Nizinski	17	202	64	25,276
Life on the Edge 2004	Ross, Baird, Sulak, Nizinski	25	202	100	27,675
Estuary to the Abyss (2004)	Sedberry, Mitchell	6	20	18	5,080
Life on the Edge 2005	Ross, Baird, Sulak, Nizinski	18	302	122	36,960
Georgetown Hole (2010)	Sedberry	5	136	66	12,533
Extreme Corals 2010	Ross, Brooke	8	356	89	13,800
Extreme Corals 2011	David, Reed	9	72	65	20,705
Florida Shelf-Edge Exploration II (2011)	Reed	13	66	13	2,409
Deepwater Canyons 2012	Ross, Brooke	20	3,673	438	64,470
Deepwater Canyons 2013	Ross, Brooke	13	3,585	264	57,920
Windows to the Deep 2018	Morrison, Sautter	17	86	84	16,300
Deep SEARCH 2018	Cordes	10	219	132	29,056

Dives = number of submersible or remotely operated vehicle dives from the dataset that were used in this study.
Samples = number of still images or video segments from the dataset that were analyzed to obtain deep-sea coral observations.
Sites = number of model grid cells containing samples from the dataset.
Total Area = sum of the survey area for all samples from the dataset.

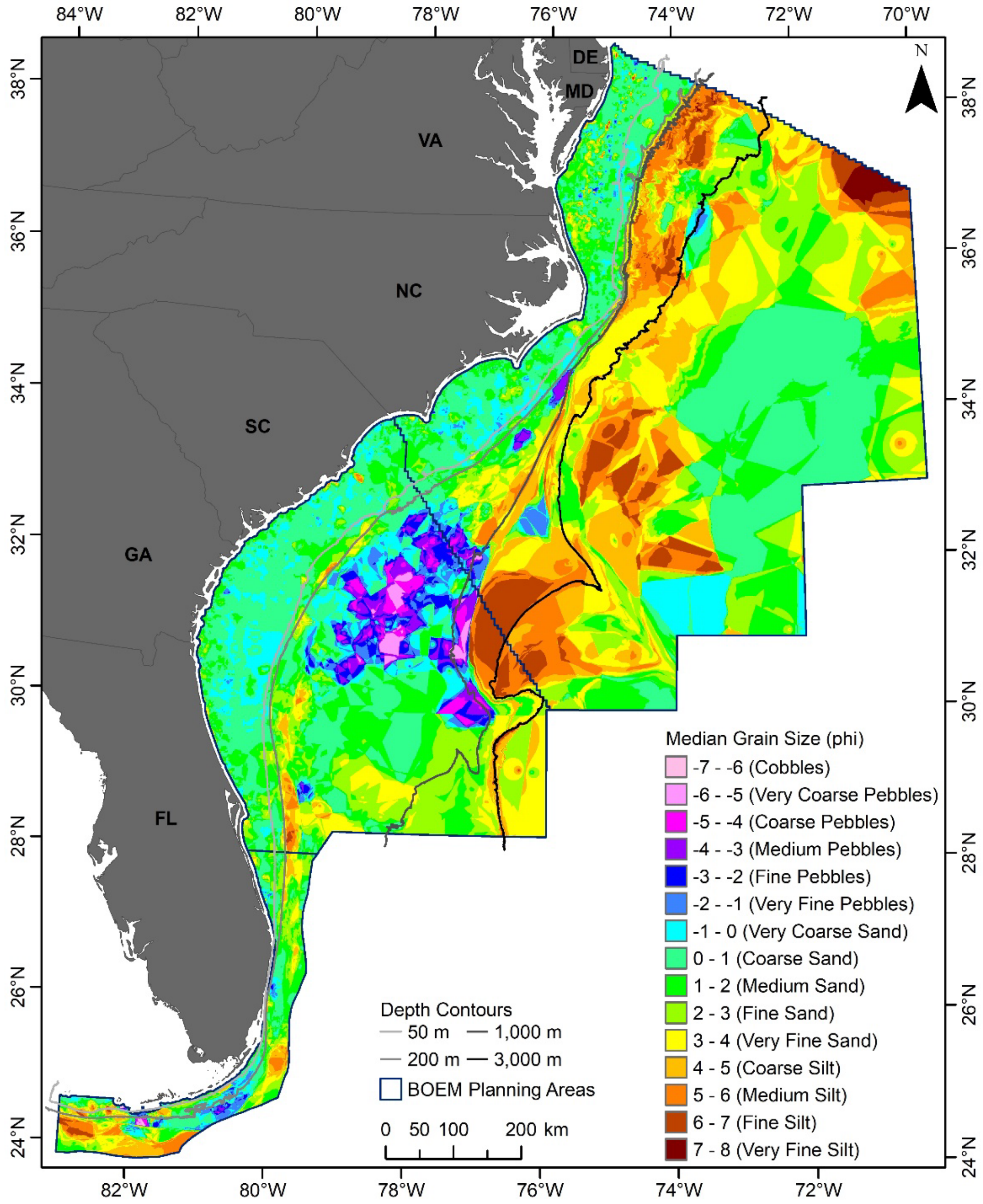
Methods (Predictive Models)

- Environmental predictors depicting:
  - depth and seafloor topography



Methods (Predictive Models)

- Environmental predictors depicting:
  - depth and seafloor topography
  - substrate



Methods (Predictive Models)

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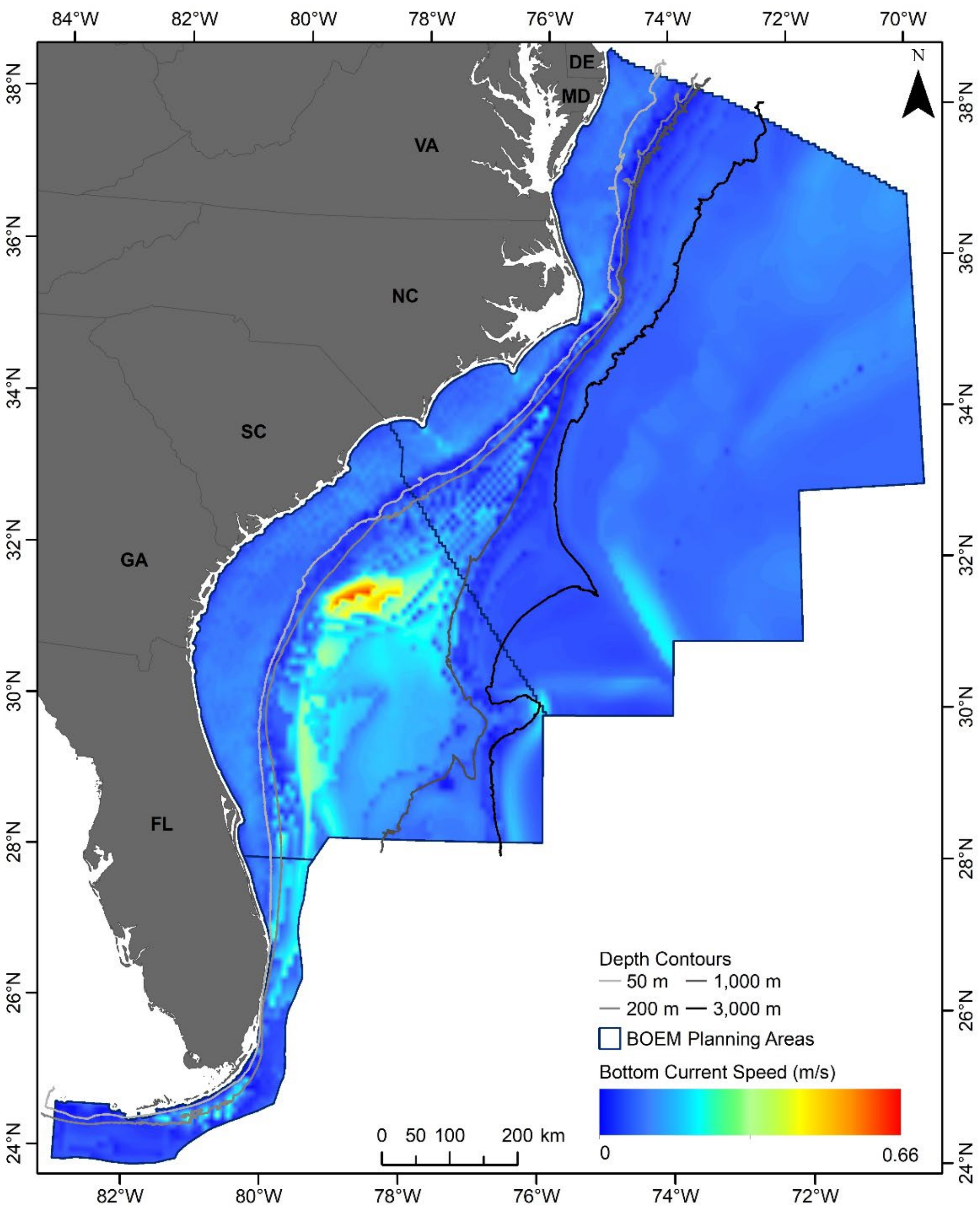
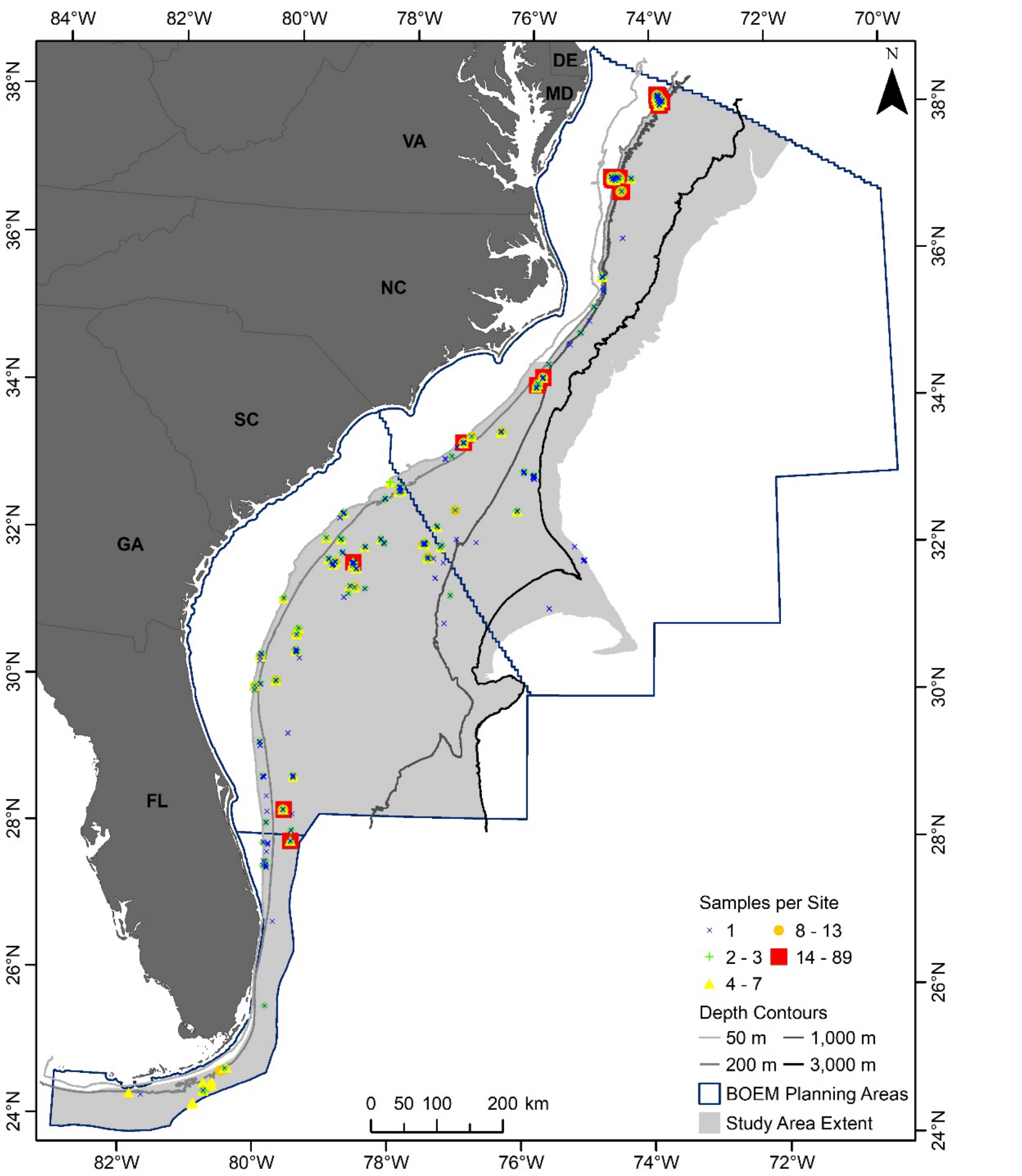
- Environmental predictors depicting:
  - depth and seafloor topography
  - substrate
  - oceanography
  - latitude/longitude

- Model grid at 100x100 m resolution

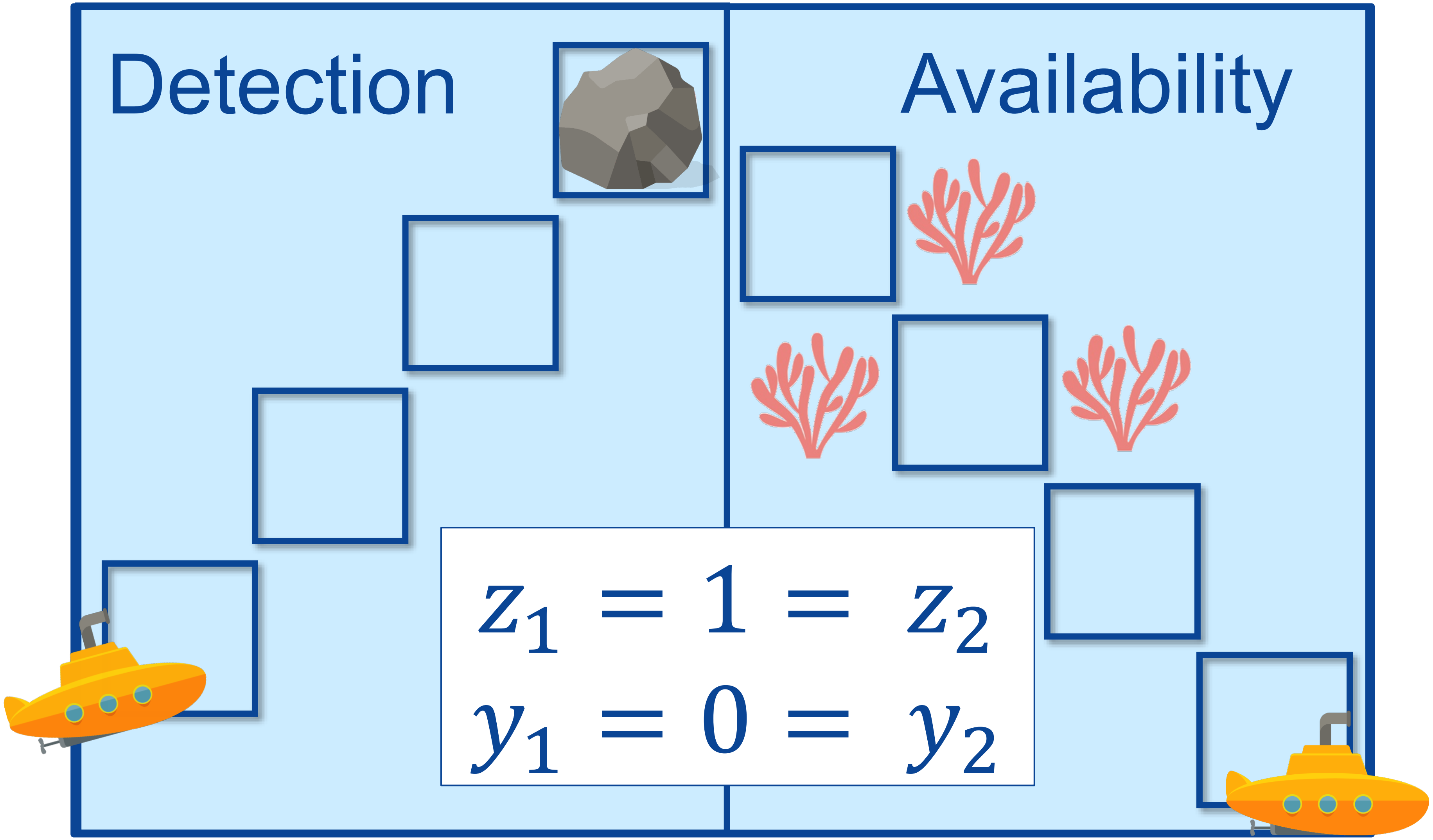


Methods (Predictive Models)

- Occupancy models – estimate both the probability of occurrence (occupancy probability) at a site (grid cell) and the probability of detecting an organism present at a site (detection probability)
- Space-for-time substitution using spatial replicates



Methods (Predictive Models)



Methods (Predictive Models)

- Occupancy analysis assumptions:

1. Imperfect detection – sampled absences not treated as true absences
2. No false positives – DSC observations only to finest taxonomic level for which observation could be identified with confidence
3. Closure – sampling time frame short relative to system dynamics
4. Independence of occupancy and detection probabilities
5. Homogeneity of detection probability – assumption that detectability was consistent throughout study area unlikely to be met b/c of differences in survey data included; effort offset used to account for heterogeneity in detection probability; taxon- and site-level effects on detection probability also included

Methods (Predictive Models)

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- Overall structure

$$\boxed{y_{ijk}} \sim Bernoulli\left(\boxed{z_{ik}}\boxed{p_{ijk}}\right)$$

presence-absence data | estimated occupancy state | detection probability

- State process (occupancy)

$$z_{ik} \sim Bernoulli\left(\boxed{\Psi_{ik}}\right)$$

occupancy probability

$$cloglog(\Psi_{ik}) = \boxed{beta_{0k}} + \sum_{v=1}^{n} \boxed{f_{vk}}\left(x_{vi}, \boxed{beta_{vk}}\right)$$

genus-specific occupancy intercept | natural cubic polynomial spline | predictor-specific occupancy coefficients

$$beta_{0k} \sim Normal(u_{beta_0}, \tau_{beta_0})$$

$$beta_{vk} \sim Normal(u_{beta}, \tau_{beta})$$

i = site
j = occasion
k = genus
v = predictor
n = # predictors

Methods (Predictive Models)

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- Observation process (detection)

$$cloglog(\boxed{p_{ijk}}) = \boxed{alpha_0} + \boxed{alpha_{1,i}} + \boxed{alpha_{2,k}} + log(effort_{ij})$$

detection probability	detection intercept	site effect on detection	genus effect on detection	effort (area)

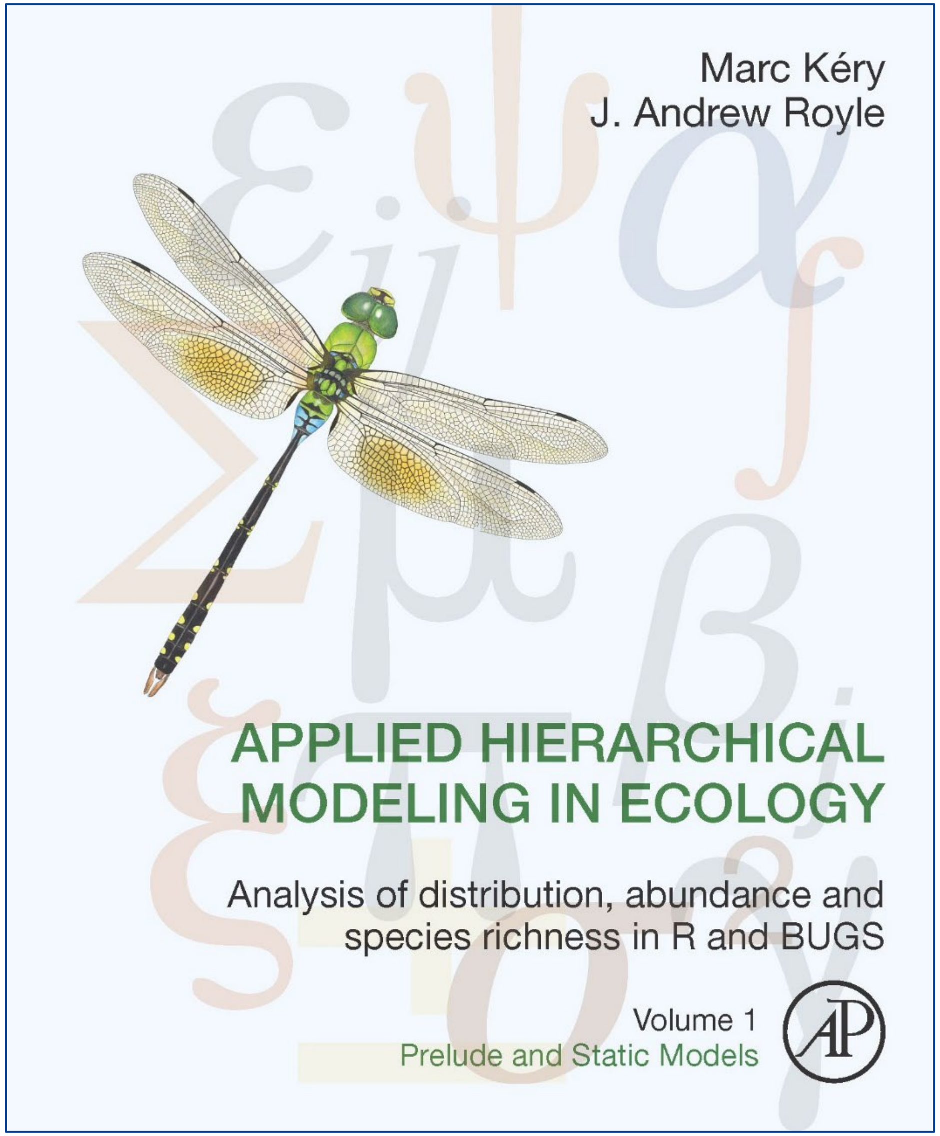
$$alpha_{1,i} \sim Normal(0, \tau_{clp1})$$

$$alpha_{2,k} \sim Normal(0, \tau_{clp2})$$

i = site
j = occasion
k = genus

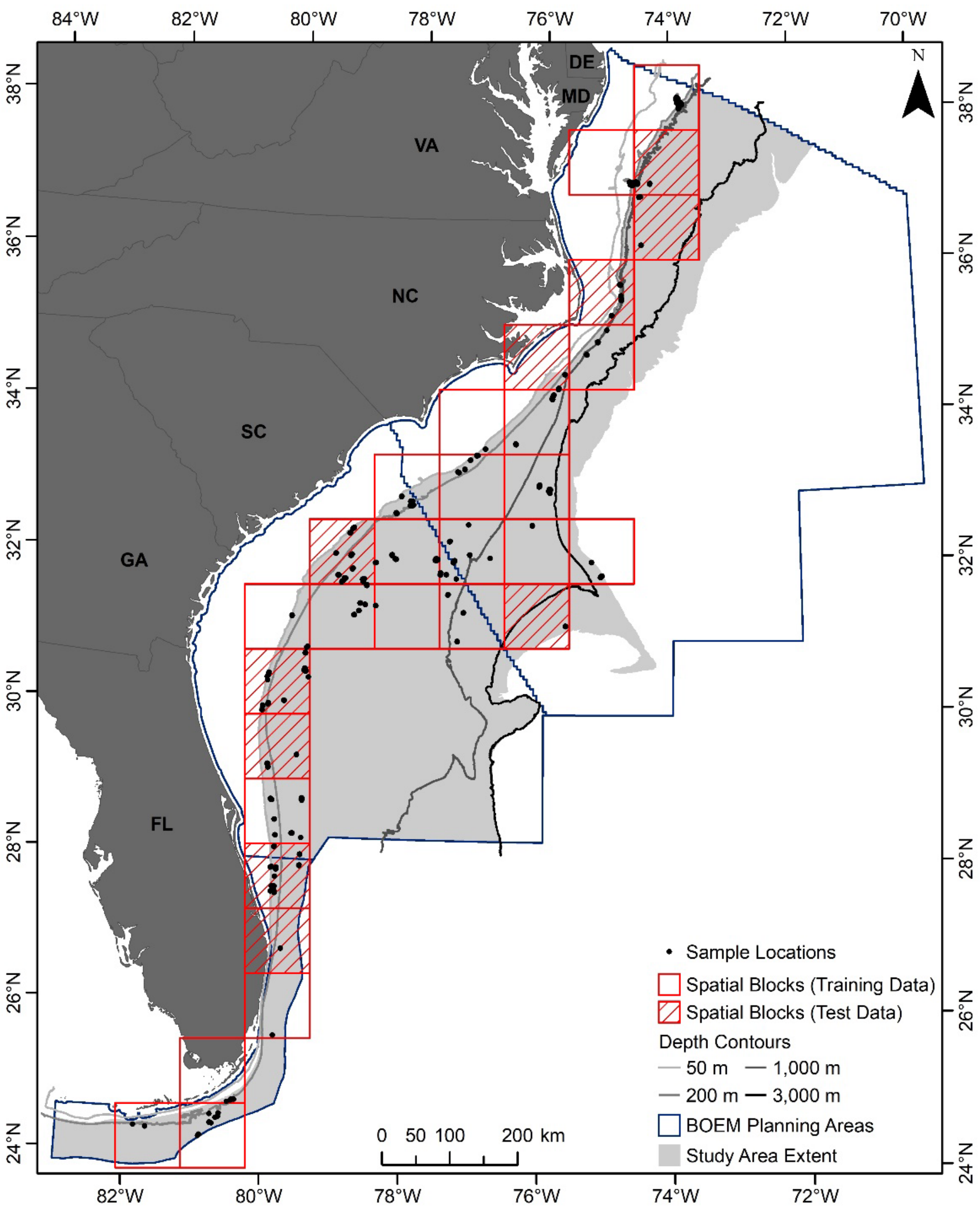
Methods (Predictive Models)

- Bayesian hierarchical approach
- Multi-taxon model – allowed estimate of richness
- 23 genera of DSCs:
  - 6 genera of stony corals
  - 5 genera of black corals
  - 12 genera of gorgonian corals
- 1 family – Stylasteridae
- Hardbottom habitats



Methods (Predictive Models)

- Model fit assessed using AUC, point-biserial correlation coefficient
- Model predictive performance from validation – spatial blocks used to define training and test subsets of the sample data



Results

- Model predictive performance
  median correlation coefficient was 0.3
  several genera >0.6 (including *Lophelia*, *Oculina*)
  most test AUC values >0.9
  a few genera had test AUC values <0.6

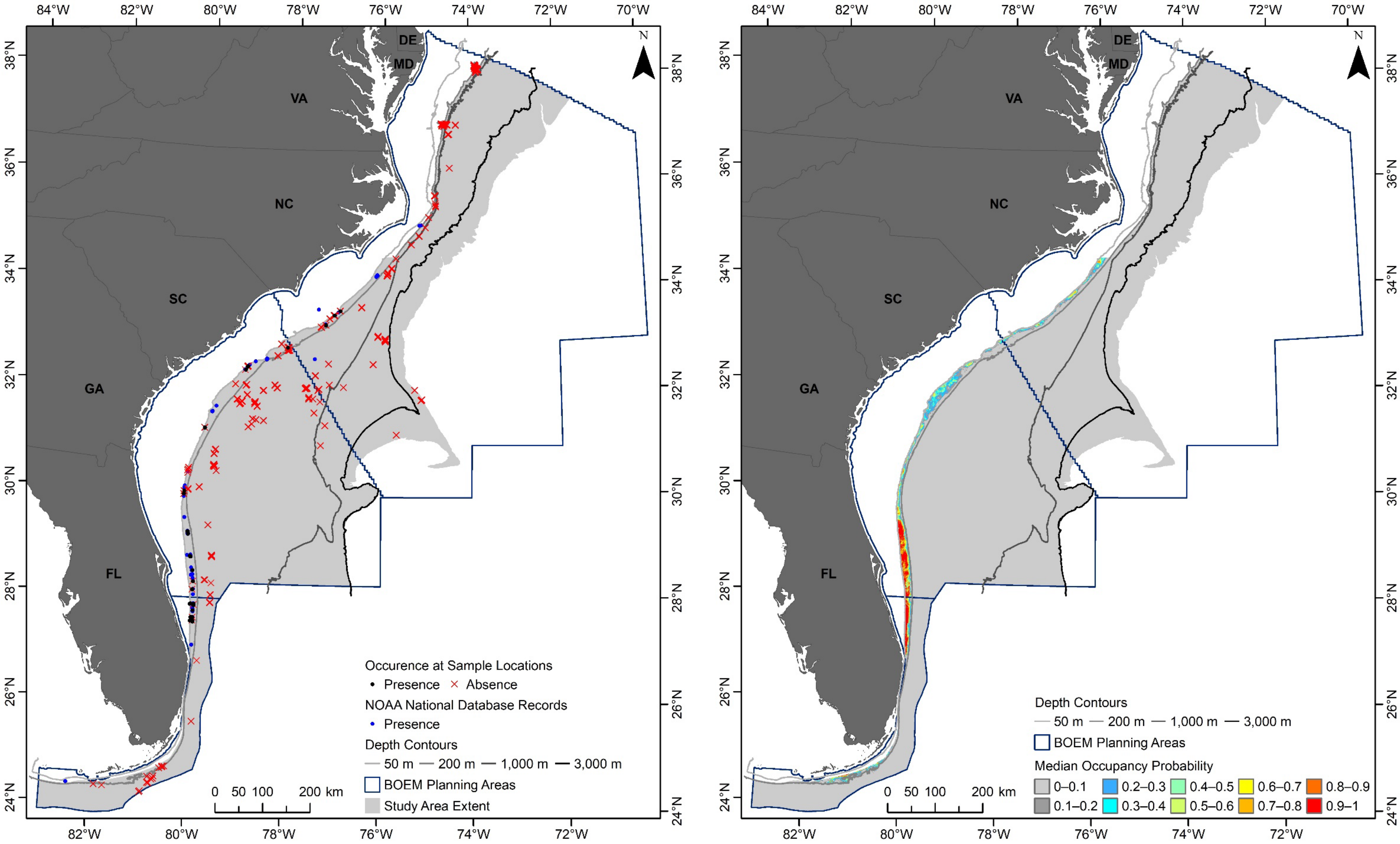
Results

Table 8. Assessment of model performance from validation

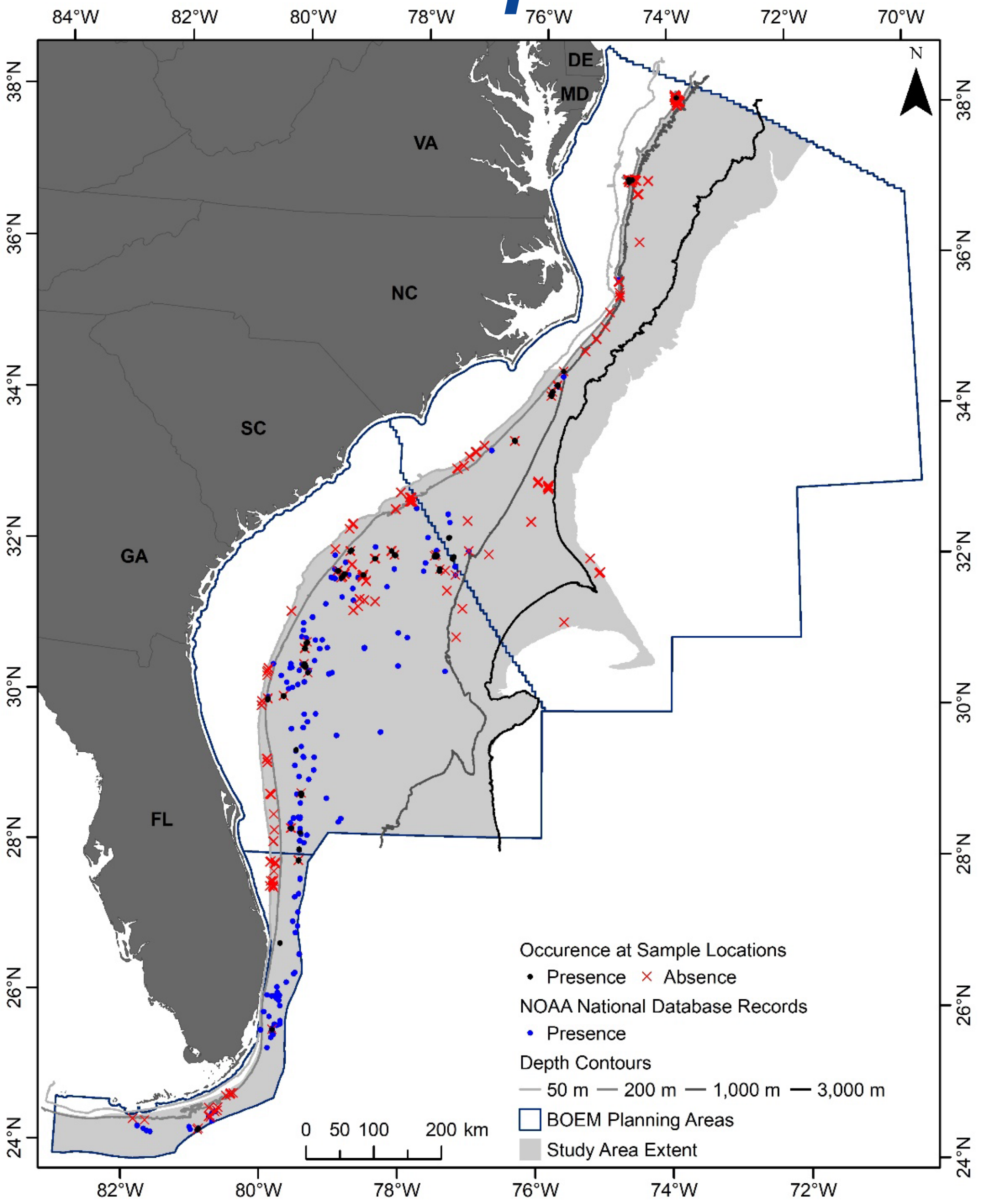
Taxon	Samples (Training)		Samples (Test)		r_{pb} (Training)		r_{pb} (Test)	AUC (Training)		AUC (Test)
	Presence	Absence	Presence	Absence	P1	P2	P2	P1	P2	P2
Lophelia	642	6,464	502	2,215	0.86	0.73	0.81	0.99	0.95	0.97
Solenosmilia	179	6,927	139	2,578	0.65	0.36	0.34	0.97	0.87	0.98
Oculina	70	7,036	90	2,627	0.84	0.69	0.80	1.00	0.99	1.00
Madrepora	66	7,040	66	2,651	0.45	0.26	0.30	0.97	0.93	0.97
Cladocora	8	7,098	17	2,700	0.85	0.57	0.61	1.00	1.00	1.00
Enallopsammia	15	7,091	7	2,710	0.87	0.36	0.24	1.00	0.99	0.99
Stichopathes	55	7,051	137	2,580	0.84	0.62	0.77	1.00	0.98	1.00
Leiopathes	97	7,009	49	2,668	0.61	0.29	0.17	0.98	0.91	0.96
Antipathes	46	7,060	44	2,673	0.46	0.31	0.70	0.99	0.97	1.00
Tanacetipathes	37	7,069	8	2,709	0.63	0.33	0.22	0.99	0.97	1.00
Bathypathes	25	7,081	19	2,698	0.49	0.14	0.08	0.99	0.93	0.96
Paragorgia	915	6,191	6	2,711	0.62	0.51	0.29	0.96	0.91	0.76
Plumarella	437	6,669	240	2,477	0.81	0.57	0.66	0.98	0.94	0.99
Anthothela	336	6,770	10	2,707	0.50	0.31	-0.01	0.95	0.87	0.59
Acanthogorgia	173	6,933	122	2,595	0.66	0.35	-0.02	0.97	0.88	0.58
Paramuricea	156	6,950	52	2,665	0.82	0.35	0.09	1.00	0.90	0.53
Eunicella	85	7,021	77	2,640	0.80	0.41	0.10	0.99	0.96	0.98
Muricea	57	7,049	69	2,648	0.65	0.48	0.84	0.99	0.98	1.00
Thesea	48	7,058	30	2,687	0.66	0.39	0.37	0.99	0.98	0.99
Callogorgia	52	7,054	0	2,717	0.58	0.11	0.02	1.00	0.95	0.90
Nicella	18	7,088	30	2,687	0.53	0.23	0.33	0.99	0.97	0.99
Chrysogorgia	22	7,084	5	2,712	0.67	0.21	0.17	1.00	0.95	0.97
Acanella	9	7,097	16	2,701	0.81	0.28	0.00	1.00	0.98	0.80
Stylasteridae	462	7,594	198	1,569	0.88	0.73	0.54	1.00	0.98	0.93
Hardbottom	4,287	3,397	1,851	288	0.88	0.64	0.40	0.98	0.87	0.78

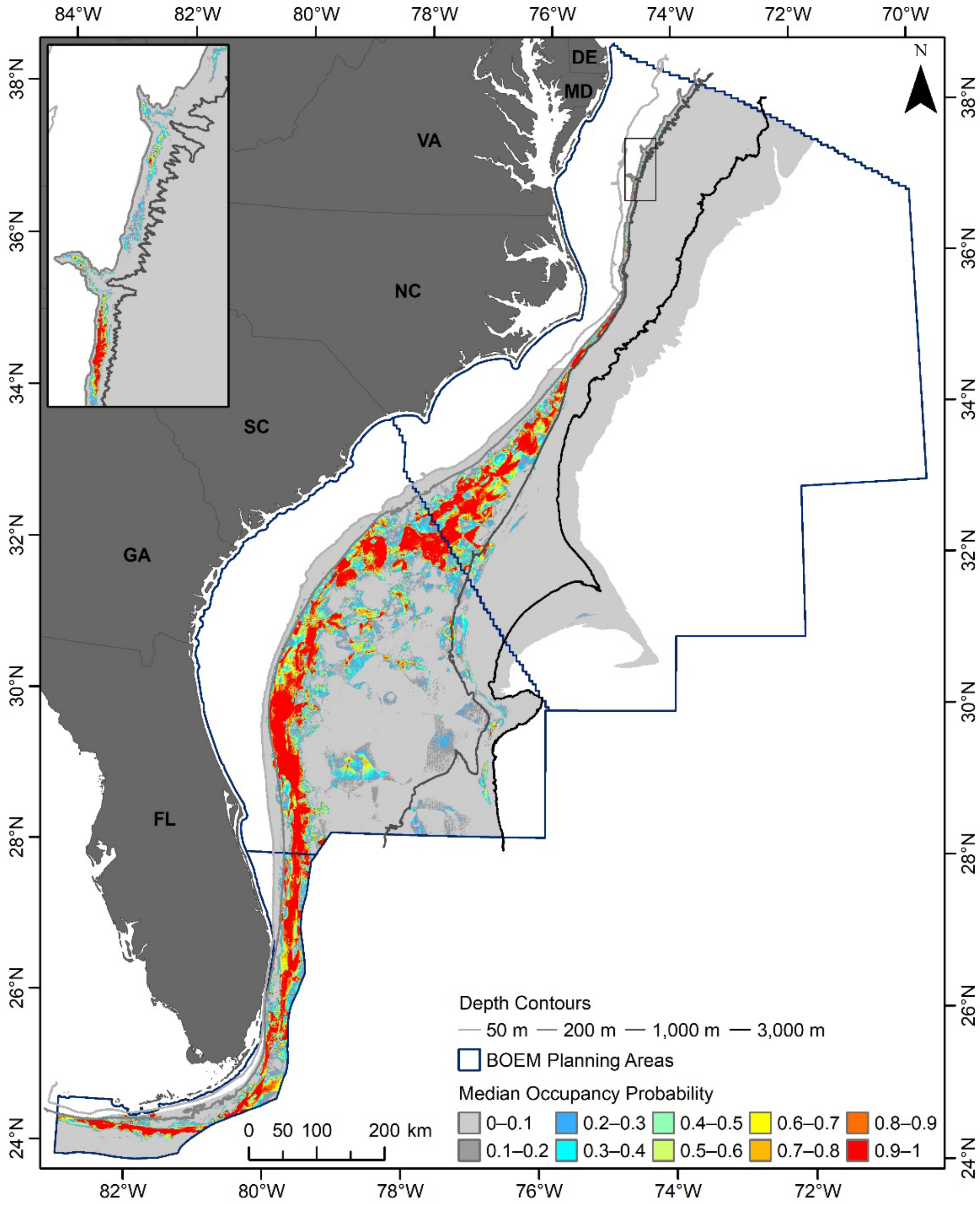
r_{pb} = point-biserial correlation coefficient.
AUC = area under the receiver operating characteristic curve.
P1: predicted probabilities were calculated as the product of the estimated occupancy states (z_{ik}) and estimated detection probabilities (p_{ijk}); i.e., $z_{ik}p_{ijk}$.
P2: predicted probabilities were calculated by substituting the estimated occupancy probability (Ψ_{ik}) for z_{ik} and adjusting the estimated detection probability by setting the estimated site-level effect ($\alpha_{1,i}$) to zero.

Results – *Oculina*

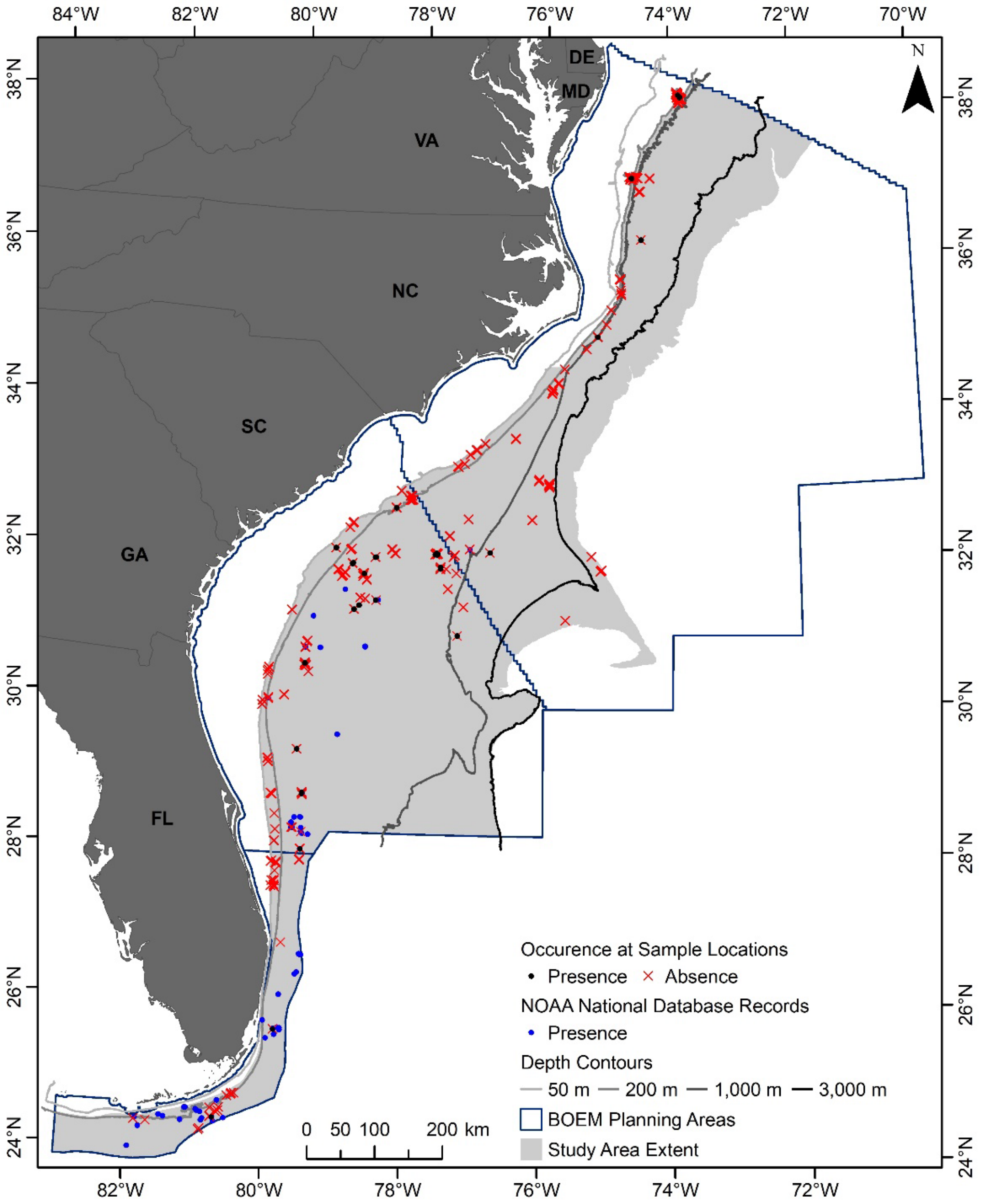


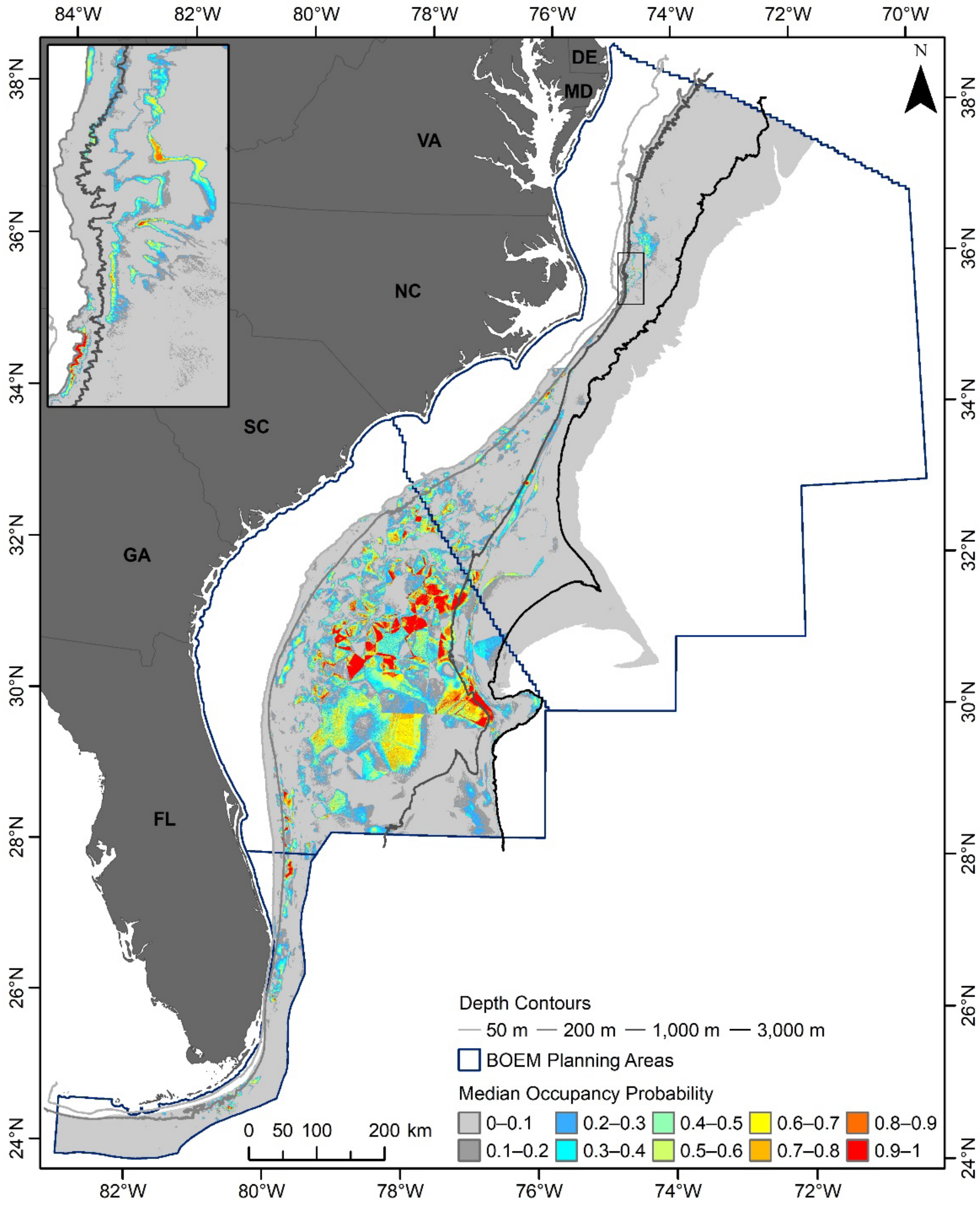
Results – *Lophelia*



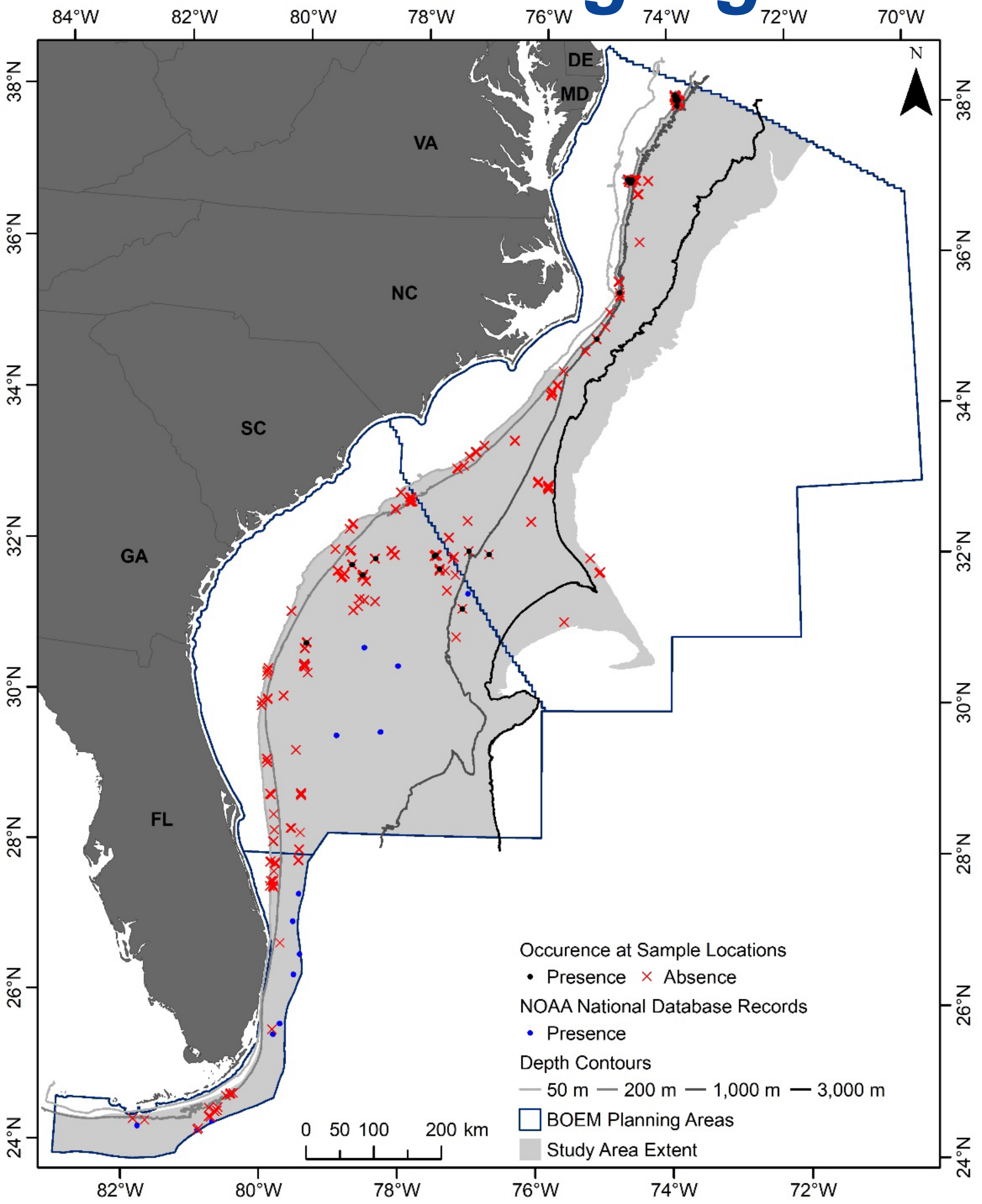


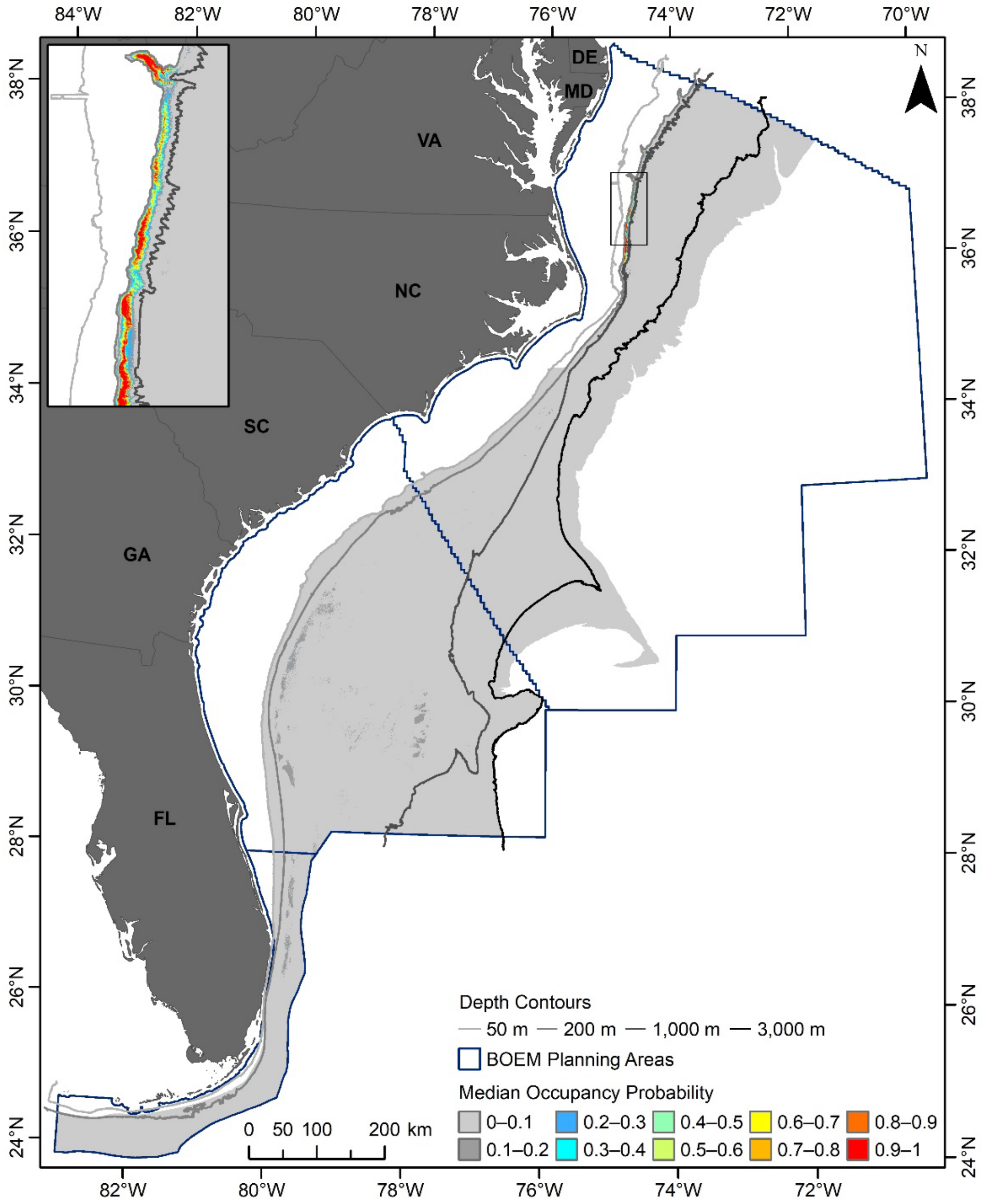
Results – *Paramuricea*



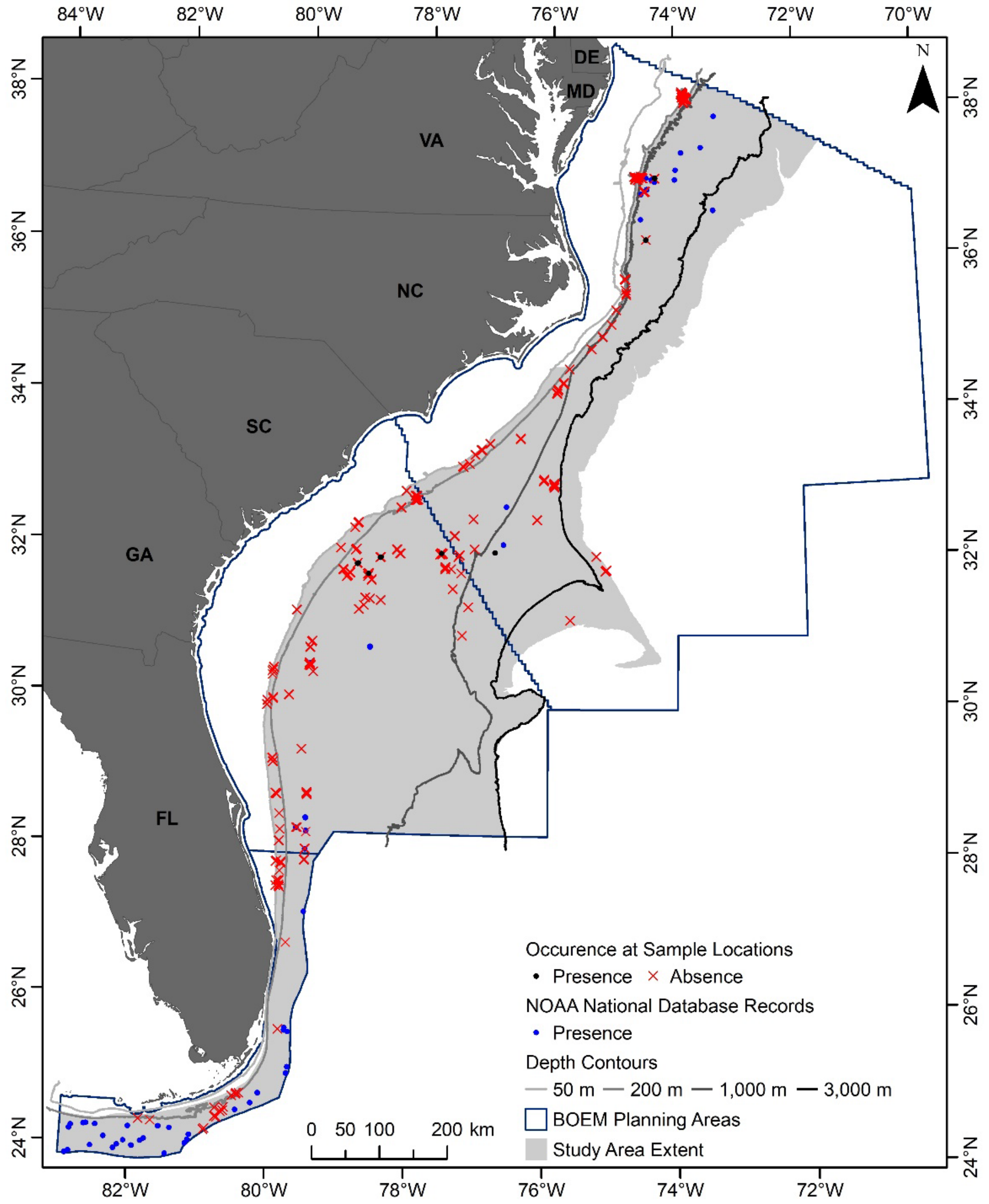


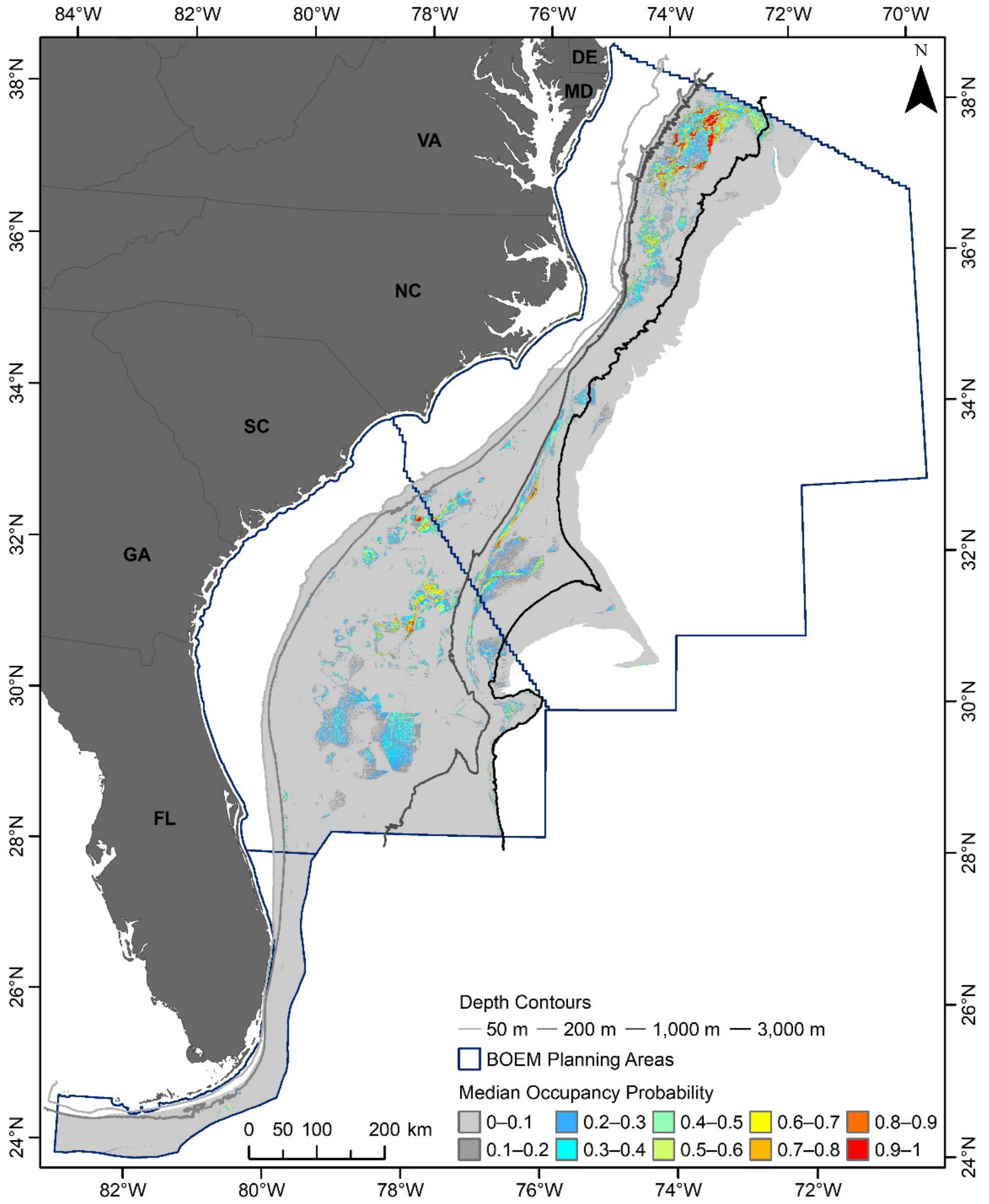
Results – *Paragorgia*



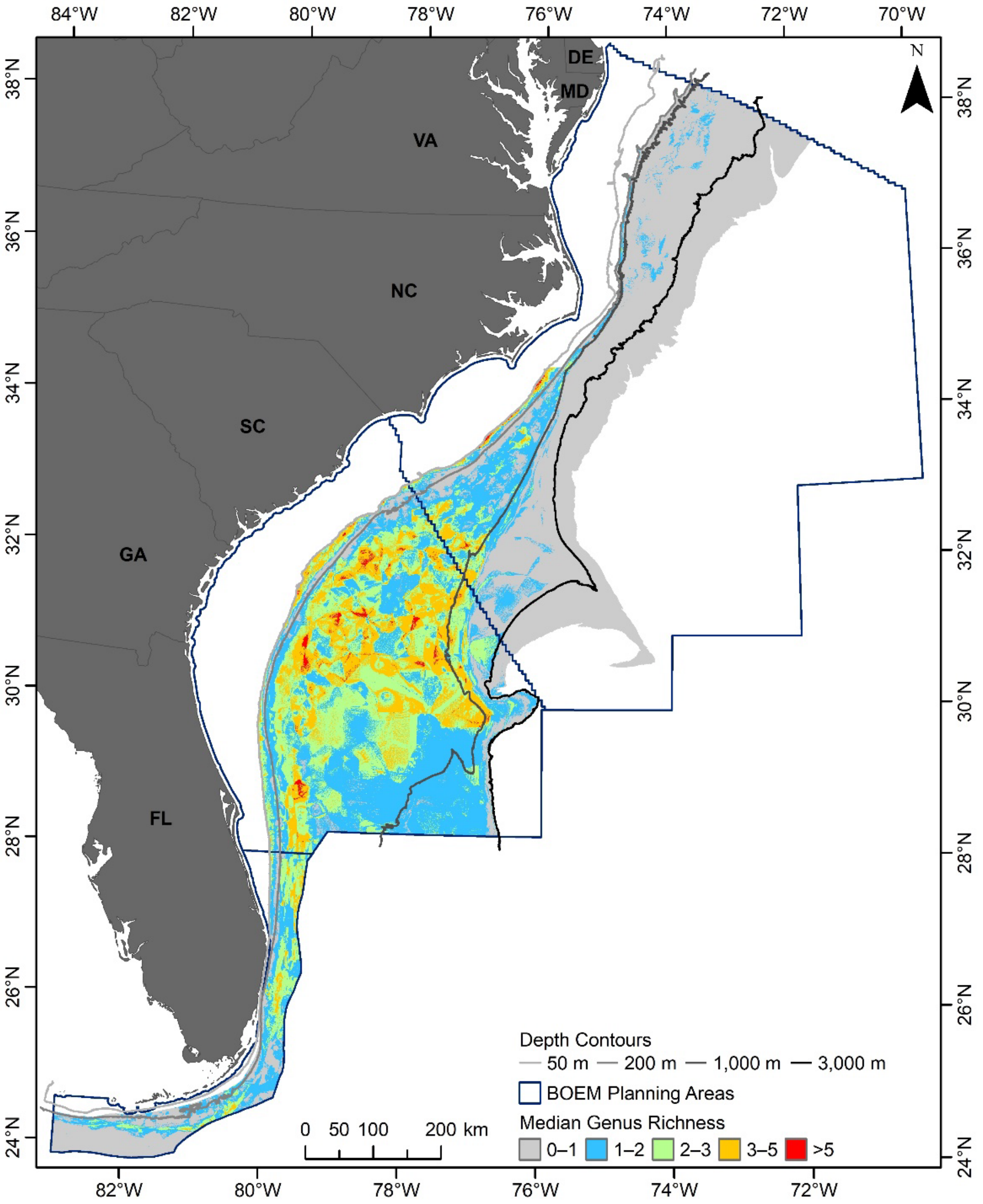


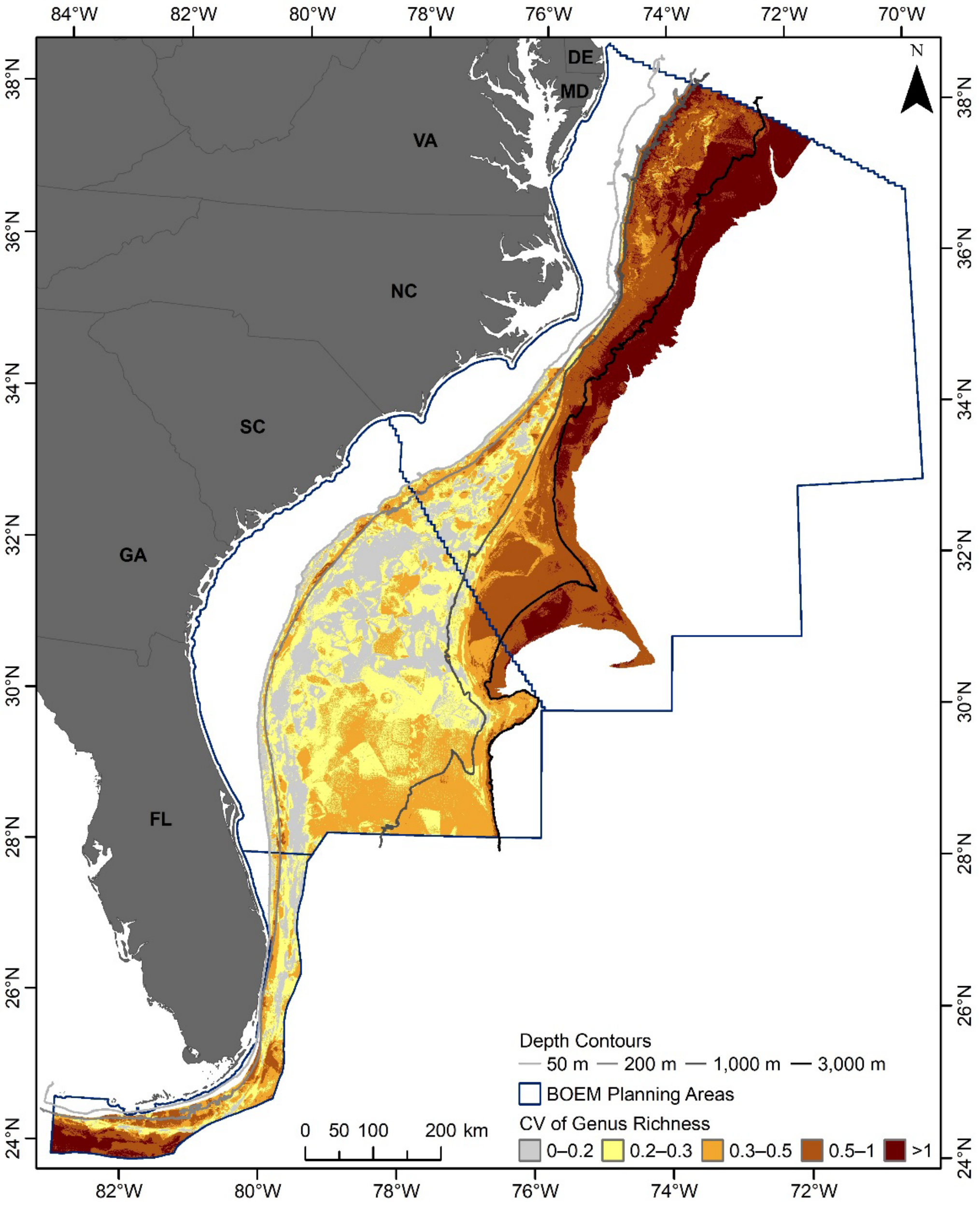
Results – *Acanella*





Results – Genus Richness





Data Products

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- Data products include:
  - MS Access database of presence-absence records
  - maps and GIS data of model predictions
- Data products can be used to support environmental risk assessments, environmental impact statements, etc. related to review of proposed offshore activities
- Data products can also inform future research and exploration

Conclusions

- Improvements over existing models for DSCs in region:
  - incorporation of absence data with associated sampling effort
  - models attempted to distinguish true from false absences
  - incorporation of bathymetry data from multibeam mapping
  - incorporation of ocean current predictors
  - genus level models instead of broad taxonomic groups
  - joint modeling of multiple genera

Conclusions

- Limitations:
  - challenges of ‘opportunistic’ compilation of sample data
    - sample dataset unbalanced, not standardized
  - variability in # of observations, replicate samples at each site
  - missing environmental predictor variables
  - spatial scale and resolution

- Recommendation:
  - promote systematic sampling design intended to inform models of abundance/density

Acknowledgments

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- Survey data provided by:
    - NOAA Central Library
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    - Harbor Branch Oceanographic Institute
    - Florida State University
    - NOAA OER
    - Temple University
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    - Scott Harris (College of Charleston)
- Surficial sediment data layers provided by:
    - Chris Jenkins (University of Colorado)
- Feedback on maps of model predictions:
    - Martha Nizinski (NOAA)
    - Sandra Brooke (FSU)

Questions?

For more information, see:

https://espis.boem.gov/final%20reports/BOEM_2022-038.pdf

https://coastalscience.noaa.gov/project/characterizing-spatial-distributions-of-deep-sea-corals-and-hardbottom-habitats-in-the-u-s-southeast-atlantic/

or contact: Matthew Poti, matthew.poti@noaa.gov