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MID-ATLANTIC MARINE-LIFE DATA ANALYSIS TEAM (MDAT) Final REPORT

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EXECUTIVE SUMMARY

The Marine-life Data Analysis Team produced "base layer" predictive model products with associated uncertainty products for 29 marine mammal species or species guilds and 40 avian species, and three geospatial products for 82 fish species. Marine mammal and avian products are habitat-based density estimates, incorporating several physical or biological habitat parameters, and were created for the whole US east coast. Fish species products, based on recommendations from advisory groups, were kept closer to the direct bottom trawl data, which exist from Cape Hatteras, NC to the Gulf of Maine. Base layer products are particularly relevant and useful in answering direct questions about specific species at certain times of year. Base products may be thought of as a *reference library*, with species-specific products available to be viewed and queried when detailed research is required for agency decision-making actions.

Mammal abundance distributions are either annual, seasonal, or monthly predictions and show predicted abundances of animals for the given time period. Avian relative abundance products are seasonal and annual, and can address the question of how abundant a given species is in an area, as compared to other areas. Fish biomass are in natural log kilograms per tow, and show expected biomass per tow, if a tow were to occur in the given area. Three map products show raw observations (bubble plot), mean for an area (hexagon plot), and interpolated biomass (Inverse-distance weighted plot). Targeted queries of species-specific products in this reference library are often the most reliable method for matching the data to specific management questions.

Careful consideration must be given to interpretation of all base layer products. Section 2 of the MDAT Final Report describes the methods and review processes for these base layer products, with caveats and considerations detailed for each taxa and product.

Because base layers total in the thousands, efforts to develop a general understanding of the overall richness or diversity in a particular area are not well served by the base products. To address this gap, MDAT has created several types of "synthetic", or summary aggregate map products from these base layers. Summary aggregate products are comprised of more than one species, and were created to allow quick access to map summaries about potential biological, management, or sensitivity *groups* of interest. Species were grouped according to these three categories, resulting in approximately 27 avian groups, 12 fish groups, and 9 mammal groups. Synthesis products provide a means to distill hundreds of data layer and time period combinations into more simplified maps that supplement the base-layer reference library. These summary products include total abundance or biomass, species richness, and diversity for all groups of species and are useful tools for seeing broad patterns in the underlying data or model results.

An additional map product was created to highlight the core areas of highest abundance or biomass by species. Core areas for individual species were created using a 50% population threshold. Each core area represents the smallest area containing 50% of the species' predicted abundance (mammals), 50% of the species' relative abundance per strip transect (avian) or 50% of the species' biomass. These core area layers were then aggregated across the above-mentioned groups to obtain a group core area abundance or biomass species richness product. Group core area richness maps aid users in identifying the "hotspots" of where certain groups of species have the highest abundance or biomass. Core area richness maps were created at two spatial scales: 1) the full US east coast; 2) the mid-Atlantic area of interest. Because these products are dependent on the extent of the data, they will differ at each scale.

As with the base layer products, careful consideration must be given when viewing and interpreting summary products. Section 3 of the MDAT Final Report describes the methods and review processes for these aggregate products, with caveats and considerations detailed for each taxa and each type of product.

Beyond individual species layers and summary products for species within each taxa group (birds, mammals, fish), multi-taxa products attempt to address broader ecosystem questions, with products that combine data layers from different taxa. Combining all three taxa is limited by the differing spatial extents of the available data and base layer products to the minimal common area of the datasets. Overlays of mammal, avian, fish products highlight the extent difference, with fish products ending at the 150m depth contour (the shelf break) and mammal and avian products extending to the US EEZ or beyond. Careful consideration should be given to interpreting the preliminary multi-taxa products, as described in Section 4 of the MDAT Final Report

Multi-taxa products were combined with data from outside the MDAT modeling work, such as data on benthic habitats, canyons, and deep-sea corals to facilitate exploration of potential Ecologically Rich Areas (ERAs). MDAT has done some preliminary work in this area, and continues to work with MARCO and Mid-Atlantic RPB members on furthering the criteria involved, methodological approaches, and additional data layers that might contribute to ERAs. Section 4 of the MDAT Final Report describes the exploratory methods and products that might be helpful in identifying ERAs, with caveats and considerations.

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1 INTRODUCTION

In 2015, the Mid-Atlantic Regional Council on the Ocean (MARCO) contracted with the Marine Geospatial Ecology Lab (MGEL) of Duke University to build upon and expand marine-life characterization work that MGEL began in 2014 in the Northeast region, as part of the Marine-life Data Analysis Team (MDAT). MARCO contracted work was done in support of the Mid-Atlantic Regional Planning Body. Models for avian and marine mammal species for the entire US east coast from Florida to the Gulf of Maine were already in progress as projects with BOEM, NASA and the US Navy, and fulfilled much of the interest to characterize marine life in the region. The information, statements, findings are those of the authors and do not necessarily reflect the views of the Mid-Atlantic Regional Planning Body or MARCO.

1.1 MDAT MEMBERS

MDAT is comprised of four organizations working together to deliver the best available marine life data for marine mammals, sea turtles, avian species, and fish species. Duke University's Marine Geospatial Ecology Lab (Duke MGEL) handled overall project coordination, as well as model products for marine mammals and sea turtles for the US East Coast. Beginning in 2011, MGEL worked with the National Aeronautics and Space Administration (NASA), NOAA's Southwest Fisheries Science Center (SWFSC), NOAA's Cetacean & Sound Mapping Working Group, and the Navy to create the best available marine mammal habitat-based density (HD) models for the US East Coast. As part of MDAT, MGEL also led the development of higher level synthetic products that look at species core areas, at intra- and inter-taxa species abundance, richness, and diversity as well as overlaying certain habitat layers (canyons, seabed form) and cold-water coral habitat-suitability models.

Brian Kinlan and Arliss Winship with the Center for Coastal Monitoring and Assessment Biogeography Branch at NOAA's National Centers for Coastal Ocean Science (NCCOS) created model products for avian species, as funded by and delivered to the Bureau of Ocean Energy Management (BOEM). NCCOS worked with Earvin Balderama of Loyola University to create models of extreme aggregations.

Michael Fogarty and Charles Perretti of NOAA's North East Fisheries Science Center (NEFSC) used independent trawl survey data from four sources to produce three spatial data products for fish species.

1.2 EXPERT WORK GROUP INVOLVEMENT

Under separate contract with the Northeast Regional Ocean Council (NROC), MDAT, NROC and the NE Regional Planning Body (NE-RPB) assembled three groups of experts (one for marine mammals and sea turtles, one for avian species, and one for fish species) from various sectors including federal government agencies, state government agencies, research institutions, and Non-Governmental Organizations (NGOs). Each of these three working groups met online three separate times over the course of seven months between August 2014 and March 2015 to review potential data sources, share expertise on specific species including life history and spatial and temporal distribution knowledge, and discuss potential products and product spatial extent. The mid-Atlantic region was represented in these Work Groups.

1.3 DATA SYNTHESIS WORK GROUP AND STAKEHOLDER INVOLVEMENT

The Mid-Atlantic RPB Data Synthesis Working Group (DSWG) provided regional guidance and oversight on the MDAT work in the mid-Atlantic region. Species selection, individual model review, uncertainty estimations, aggregate product parameters, and determinations to inform the development of ecologically rich area (ERA) were all informed and guided by both previously created expert work groups in the northeast region, as well as the mid-Atlantic RPB Data Synthesis Working Group (DSWG), with additional stakeholder engagement across both regions during the entire process. MDAT presented to the DSWG several times during the course of the project. Several in-person and web-based RPB meetings, stakeholder workshops, and briefings were held with MDAT presenting spatial data products and methodologies, and incorporating feedback when possible.

1.4 SUITE OF PRODUCTS

MDAT produced "base layer" predictive model products with associated uncertainty products for 29 marine mammal species or species guilds and 40 avian species, and three geospatial products for 82 fish species. Base layer data products total in the thousands when taking into account companion uncertainty layers and fine temporal scale products for some species (monthly/seasonal). These products are particularly relevant and useful in answering direct questions about specific species, in specific locations, at certain times of year. Many of these questions are management-relevant under existing authorities such as the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), and other state and federal authorities.

Efforts to build a general understanding of the ecological richness or diversity in a particular area are not well served by the base products. To address this gap, Duke MGEL has created several types of "synthetic", or derived, aggregate map products from these base layers. The northeast described the possible levels of data products visually, via a pyramid (Figure 1), with the species specific products at the base of the pyramid and species groups, and intra- and inter-taxa derived aggregate products as higher layers with fewer products. Species were grouped by ecological, regulatory, and stressor-sensitive characteristics. Core areas of abundance or biomass for individual species and for species groups (Figure 1, level three) represent the smallest area that encompasses 50% of the abundance or biomass of that species or group of species. Level four products (Figure 1) are aggregate synthetic products for all species in a taxon (avian, mammal, fish) or in a taxon group (i.e. ESA listed species). Aggregate products include total abundance or biomass, richness, and Shannon's diversity index.

FIGURE 1 Marine-life data product pyramid from the Northeast Regional Ocean Council ocean planning efforts.

Base products may be thought of as a *reference library*, with species-specific products available to be viewed and queried when detailed research is required for agency decision making actions. Marine mammal and avian products are habitat-based density estimates, incorporating several physical or biological habitat parameters, and were created at the full east coast spatial extent. Fish species products, based on recommendations from the expert working group, were kept closer to the direct trawl data, which exist from the North Carolina/Virginia border to the Gulf of Maine. While most of the mammal and avian models predict out to the US EEZ, the fish data collected via trawl surveys extend only to the shelf break. Details and methods for the base layer products can be found in Section 2.

For all three taxa, aggregated products comprised of more than one species were created to allow quick access to potential biological, management, or sensitivity groups of interest (Figure 2, number 2). Species groups were proposed by MDAT and refined with input from experts, the DSWG, and RPB members. For each defined group, MDAT aggregated the abundance, species richness, and diversity (Figure 2, number 3). Aggregate products are described in more detail in Section 3.

The top levels of the pyramid address broader ecosystem questions, with products that combine data layers from different taxa (Figure 2, number 4) and non-marine life data layers such as benthic habitat, canyons, and deep-sea corals to explore potential Ecologically Rich Areas (ERAs; Figure 2, number 5). Section 4 includes exploratory methods and results for identifying ERAs.

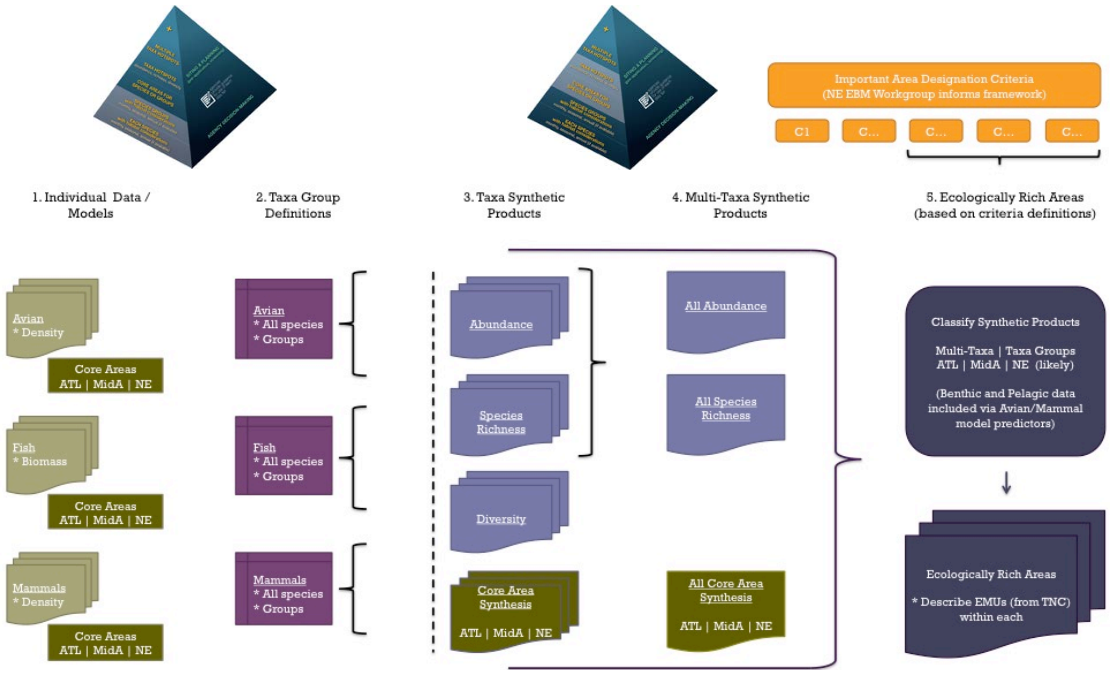


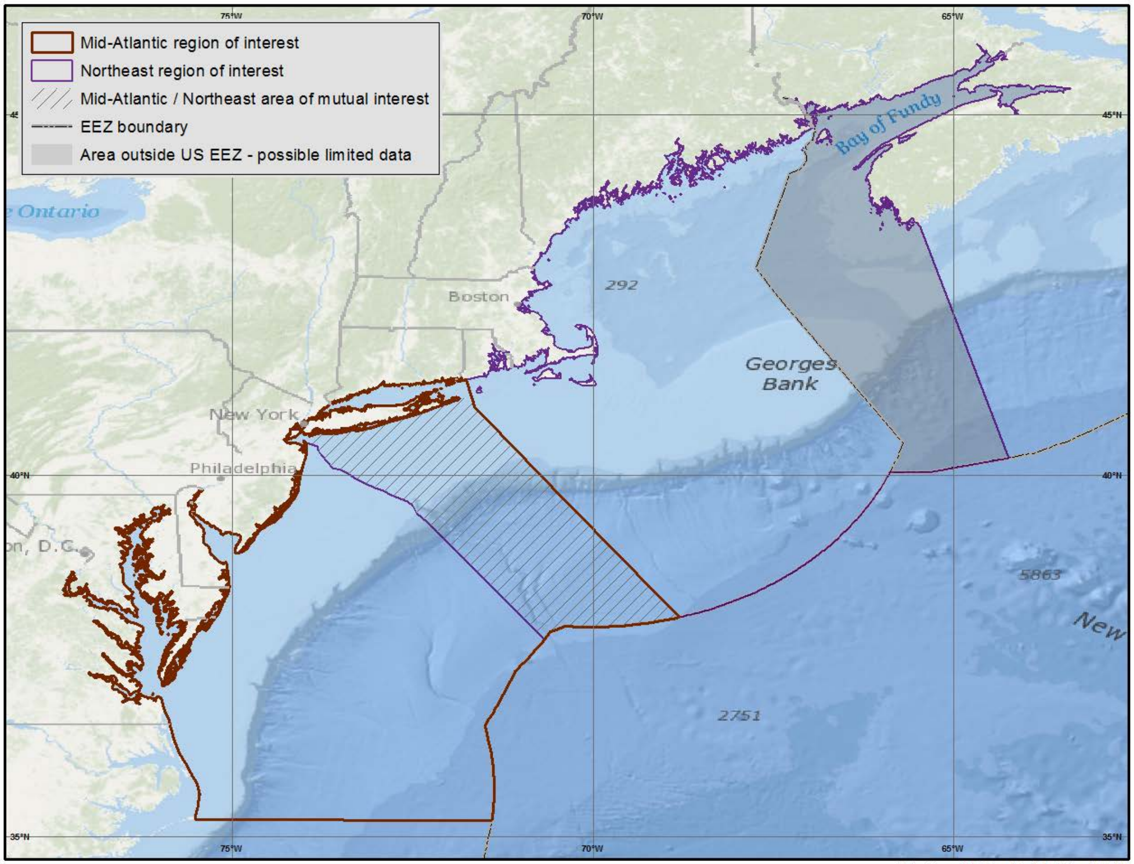
FIGURE 2 Break-down of the marine-life data product pyramid, from base layers to products for groups of species to multi-taxa products incorporating species across mammal, avian, and fish species.

2 BASE MODELS AND DATA PRODUCTS

MDAT collectively produced over 3,000 map products for models of individual avian and marine mammal species, uncertainty maps associated with those models, and map products of biomass and distribution for many fish species.

2.1 REGIONS OF INTEREST

Product assessment boundaries were decided with input from members of both the northeast and mid-Atlantic regional planning bodies, to reflect the commonality of species and habitat between the regions. As a result, the northeast and mid-Atlantic regions have an area of overlap, the "area of mutual interest", off the coast of New York (Figure 3). Base layer products are not dependent on the extent or an area boundary. All avian and marine mammal base products exist at the full east coast scale, to the extent possible given the underlying data, while the fish data products vary in extent from spanning both regions, to local state waters in New England. Derived products were created specific to each regional spatial extent, and for some products the results differ between the regions. Model details, spatial and temporal coverage details, and data limitations specific to each marine-life component, are described below. Working group call summaries and final work plans are available online at http://neoceanplanning.org/projects/marine-life/.



Marine Geospatial Ecology Lab, Duke University (2015)

FIGURE 3 Geographic boundaries for marine life mapping in the mid-Atlantic and Northeast regions of interest. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

2.2 AVIAN SPECIES

MDAT member NOAA National Centers for Coastal Ocean Science (NCCOS) supported the marine life assessment in partnership with Duke University. NCCOS coordinated a comprehensive synthesis of models and data on marine and coastal birds to develop spatial analyses and map products. This work leverages NCCOS's project currently funded by the Bureau of Ocean Energy Management (BOEM) to produce long-term average predictive maps of marine bird relative occurrence and relative abundance from large databases of at-sea transect survey and environmental data in the US Atlantic. NCCOS has been leading marine bird modeling work for marine spatial planning in the Northeast US since 2010, in collaboration with partners at BOEM, USGS, USFWS, DOE, NOAA/NMFS, New York State, NC-State, CUNY, Biodiversity Research Institute, and other regional institutions (Menza et al. 2012, Kinlan et al. 2012a, Kinlan et al. 2012b, Zipkin et al. 2014).

Abundance model results are the long-term average relative abundance of individuals per strip transect segment. It is not possible to infer absolute abundance because of how the survey data were collected and compiled, and how the models were generated.

Occurrence probability model results are the long-term average relative occurrence probability per strip transect segment. As with abundance, it is not possible to infer the absolute probability of occurrence. For species of high conservation concern, occurrence probability maps may be more useful than abundance maps. For example, if the take of one bird will trigger major mitigation measures it may be more useful to know how likely it is that the species will occur in a specific area relative to another area, rather than relative differences in abundance. In cases where the abundance model has high uncertainty, the occurrence model component may still be a useful resource.

2.2.1 AVIAN MODEL CAVEATS AND CONSIDERATIONS

1. It is important to recognize that the model predictions *do not represent absolute occurrence or abundance*, rather they are indices of occurrence or abundance. This is because during visual surveys individual birds may be missed and animal movement can bias estimates of abundance, and probabilities of detection are unknown. Avian relative abundance predictive maps may inform users in answering the question "relative to other areas, how many more of species X are there likely to be in this area?" Likewise, avian relative occurrence maps may inform users in answering questions like "relative to other areas, how much more likely is it that species X occurs in this area."
2. When calculating synthetic products, base products (i.e., long-term average annual and seasonal relative abundance model results) were first normalized by their mean values. Thus, avian synthetic products derived from base abundance products essentially 'weighted' each species' contribution equally.
3. Survey effort density contour layers are provided to aid the user in determining the number of survey data that contributed to model predictions in a particular area. Model predictions in areas with little survey effort should be interpreted cautiously.
4. Individual model performance statistics are included in Appendix A, and should be referenced when individual layers are used in agency decisions.
5. Some model predictions exhibit a distortion that is evident as a dominant east-west trend in predicted relative occurrence and abundance (i.e., vertical banding in the maps). This is due to an error in the computer code where one of the spatial coordinate predictors was scaled incorrectly when making spatial predictions, which sometimes distorted spatial patterns. It is difficult to quantify the amount of distortion in the predictions for any given model, but maps that exhibit a vertical banding pattern should be interpreted with caution. The error has been corrected, and incorporated into the next generation of models which are expected to be released and made available to MARCO users in the future.

2.2.2 SPATIAL COVERAGE, GRID SIZE, MODEL GAPS

NCCOS's marine bird models span the entire U.S. EEZ from Florida to Maine (Figure 4). (Synthetic and derived products for this MARCO effort were constrained to the mid-Atlantic spatial extent in Figure 3.) Model output and derived products are a grid consisting of 2km x 2km cells, which is the best resolution achievable with the available co-variates, beginning 1-2km offshore and extending to the US EEZ boundary. Model predictions may be absent within 0-2km of the coast due to the 2km model resolution and problems with obtaining reliable remote sensing and ocean model predictor data in the shore zone. Additional spatial gaps for model products include the Bay of Fundy, Long Island Sound, and inshore, nearshore, and estuarine areas. Model results are masked (grayed out) beyond 100 km from a minimum-distance path connecting the sighting location data for a given species and season. Uncertainty maps are also provided to inform confidence levels for delivered model predictions. Although model predictions span the entire EEZ, there were more survey data nearer to the coast and over the shelf than further offshore (Figure 4) so predictions offshore are supported by fewer data.

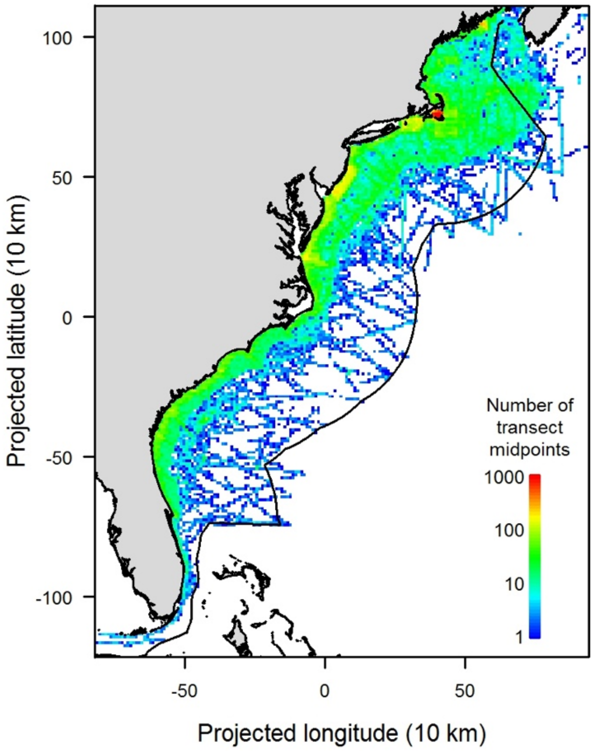


FIGURE 4 Survey effort coverage for the avian modeling effort along the US east coast. Data source is the 1 August 2014 version of the United States Geological Survey (USGS) and United States Fish and Wildlife Service (USFWS) 'Compendium of Avian Occurrence Information for the Continental Shelf waters along the Atlantic Coast of the U.S.' spanning the years 1978-2014. Effort is mapped as the number of transect segment mid-points of the standardized effort.

2.2.3 TEMPORAL COVERAGE, ASSESSMENT WINDOWS

Models were developed using a combination of science-quality at-sea marine bird survey data extracted from the 1 August 2014 version of the United States Geological Survey (USGS) and United States Fish and Wildlife Service (USFWS) 'Compendium of Avian Occurrence Information for the Continental Shelf waters along the Atlantic Coast of the U.S.'[1] and marine environmental data records including fronts, primary productivity, and ocean currents. For seasonal models, seasons are defined as:

- Winter: December 1 to February 28/29
- Spring: March 1 to May 31
- Summer: June 1 to August 31
- Fall: September 1 to November 30

Data were standardized into 15-minute, 10 knot equivalent transect segments. These models incorporate virtually all known science-quality at-sea seabird surveys from 1978-2014 (Table 1), including all AMAPPS and USFWS aerial and boat surveys, BRI's Mid-Atlantic Baseline surveys (aerial Hi-Def and boat), and recent surveys conducted by states, BOEM, and wind energy companies to inform energy siting off Rhode Island,

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[1] www.data.boem.gov/PI/PDFImages/ESPIS/5/5193.pdf

Massachusetts, Maine, and elsewhere in the north east and mid-Atlantic. Fewer data exist for the 1990s than for other decades.

TABLE 1 Analyzed datasets from the Compendium, for the MDAT avian modeling effort. The number of standardized transect segments within the study area is indicated by *n*. Datasets with an asterisk are not publicly available, but have been or are expected to be made available for use in modeling under a restricted usage agreement with the data owner or manager.

Code	Platform	Dates	Geographic range	*n*
AMAPPS_FWS_Aerial_Preliminary_Summer2010	aerial	Aug 2010	NC to FL	1863
AMAPPS_FWS_Aerial_Winter2010-2011	aerial	Dec 2010 – Jan 2011	NJ to NC	914
AMAPPS_FWS_Aerial_Summer2011	aerial	Jul-Aug 2011	entire coast	5177
AMAPPS_FWS_Aerial_Spring2012	aerial	Mar 2012	entire coast	5270
AMAPPS_FWS_Aerial_Fall2012	aerial	Sep-Oct 2012	entire coast	5157
AMAPPS_NOAA/NMFS_NEFSCBoat2011	boat	Jun-Jul 2011	offshore MA to NC	1274
AMAPPS_NOAA/NMFS_NEFSCBoat2013	boat	Jul-Aug 2013	offshore MA to NC	1318
AMAPPS_NOAA/NMFS_NEFSCBoat2014	boat	Mar-Apr 2014	offshore MA to NC	859
AMAPPS_NOAA/NMFS_SEFSCBoat2011	boat	Jun-Jul 2011	offshore MD to FL	822
AMAPPS_NOAA/NMFS_SEFSCBoat2013	boat	Jul-Sep 2013	offshore MD to GA	813
BarHarborWW05	boat	Jun – Oct 2005	ME	911
BarHarborWW06	boat	Jun – Oct 2006	ME	1022
CapeHatteras0405	boat	Aug 2004 – Feb 2005	NC	276
CapeWindAerial*	aerial	Mar 2002 – Feb 2004	MA	4035
CapeWindBoat*	boat	Apr 2002 – Sep 2003	MA	252
CDASMidAtlantic	aerial	Dec 2001 – Mar 2003	NJ to VA	1402
CSAP	boat	Apr 1980 – Oct 1988	entire coast	26271
DOEBRIBoatApril2012*	boat	Apr 2012	DE to VA	142
DOEBRIBoatJune2012*	boat	Jun 2012	DE to VA	143
DOEBRIBoatAug2012*	boat	Aug 2012	DE to VA	142
DOEBRIBoatSep2012*	boat	Sep 2012	DE to VA	144
DOEBRIBoatNov2012*	boat	Nov 2012	DE to VA	142
DOEBRIBoatDec2012*	boat	Dec 2012 – Jan 2013	DE to VA	139
DOEBRIBoatJan2013*	boat	Jan–Feb 2013	DE to VA	143
DOEBRIBoatMar2013*	boat	Mar 2013	DE to VA	145
DOEBRIBoatMay2013*	boat	May 2013	DE to VA	147
DOEBRIBoatJun2013*	boat	Jun 2013	DE to VA	146
DOEBRIBoatAug2013*	boat	Jul–Aug 2013	DE to VA	145
DOEBRIBoatSep2013*	boat	Sep 2013	DE to VA	148
DOEBRIBoatOct2013*	boat	Oct 2013	DE to VA	147
DOEBRIBoatDec2013*	boat	Dec 2013	DE to VA	147
DOEBRIBoatJan2014*	boat	Jan–Feb 2014	DE to VA	143
DOEBRIBoatApr2014*	boat	Apr 2014	DE to VA	140
EcoMonMay07	boat	May–Jun 2007	ME to NC	435
EcoMonAug08	boat	Aug 2008	ME to NC	411
EcoMonJan09	boat	Jan–Feb 2009	ME to NC	341
EcoMonMay09	boat	May–Jun 2009	ME to NC	543
EcoMonAug09	boat	Aug 2009	ME to NC	395
EcoMonNov09	boat	Nov 2009	ME to NC	379
EcoMonFeb10	boat	Feb 2010	ME to VA (not northern Gulf of ME)	292
EcoMonMay10	boat	May–Jun 2010	ME to NC	550
EcoMonAug10	boat	Aug–Sep 2010	Gulf of ME and offshore	427
EcoMonNov10	boat	Nov 2010	ME to NC	356
EcoMonNov2011	boat	Oct–Nov 2011	ME to NC	391
EcoMonFeb2012	boat	Feb 2012	ME to NC	472
EcoMonJun2012	boat	May–Jun 2012	MA to VA	389
EcoMonAug2012	boat	Aug 2012	ME to NC	560
EcoMonOct2012	boat	Oct–Nov 2012	ME to MD	428
FWSAtlanticWinterSeaduck2008	aerial	Feb 2008 – Feb 2011	entire coast	14377
FWS_MidAtlanticDetection_Spring2012	aerial	Mar 2012	VA	456
FWS_SouthernBLSC_Winter2012	aerial	Feb 2012	SC to GA	1582
GeorgiaPelagic	boat	Nov 1982 – Jun 1985	SC to FL (also Gulf of ME and offshore)	2187
HatterasEddyCruise2004	boat	Aug 2004	NC	93

HerringAcoustic06	boat	Sep 2006	Gulf of ME	243
HerringAcoustic07	boat	Oct 2007	Gulf of ME	283
HerringAcoustic08	boat	Sep–Oct 2008	Gulf of ME	710
HerringAcoustic09Leg1	boat	Sep 2009	Gulf of ME	109
HerringAcoustic09Leg2	boat	Sep–Oct 2009	Gulf of ME	245
HerringAcoustic09Leg3	boat	Oct 2009	Gulf of ME	227
HerringAcoustic2010	boat	Sep–Oct 2010	Gulf of ME	482
HerringAcoustic2011	boat	Sep–Oct 2011	Gulf of ME	690
MassAudNanAerial	aerial	Aug 2002 – Mar 2006	MA	4131
NewEnglandSeamount06	boat	Oct 2006 – Jun 2007	east of Gulf of ME	66
NJDEP2009	aerial & boat	Jan 2008 – Dec 2009	NJ	4446
NOAA/NMFS_NEFSCBoat2004	boat	Jun–Aug 2004	offshore MA to MD	1017
NOAA/NMFS_NEFSCBoat2007	boat	Aug 2007	Gulf of ME	516
NOAAMBO7880	boat	Jan 1978 – Nov 1979	mostly ME to NC, but also GA and FL	6979
PlattsBankAerial	aerial	Jul 2005	Gulf of ME	732
RISAMPAerial	aerial	Dec 2009 – Aug 2010	RI	2158
RISAMPBoat	boat	Jul 2009 – Aug 2010	RI	653
SEFSC1992	boat	Jan–Feb 1992	NC to FL	674
SEFSC1998	boat	Jul–Aug 1998	MD to FL	1146
SEFSC1999	boat	Aug–Sep 1999	NJ to FL	1058
WHOIJuly2010*	boat	Jul 2010	offshore NY Bight	71
WHOISept2010*	boat	Sep 2010	Gulf of ME	74

NCCOS developed models for species-season combinations for which there were at least 50 transect segments with a sighting of that species (Table 2). A subset of the models failed to converge, or were still in process at the time of delivery to MARCO, and may potentially be completed and delivered in the future. Non-modeled seasons are not included in annual averages (annual averages assume zero abundance in non-modeled seasons).

TABLE 2 Avian species sample sizes and priority. Sample sizes are the number of transect segments with a sighting. Priority ranking determined by working groups and informed NCCOS on the model run order. Cells with green shading indicate species-season combinations with complete models and uncertainty products; cells shaded in blue indicate species-season combinations with models only, no uncertainty products. Cells shaded in yellow indicate species-season combinations with failed or incomplete model runs, that may be modeled by NCCOS in the future. Cells shaded in red indicate species-season combinations with insufficient samples sizes for modeling.

Species	Number of standardized transect segments with sightings				Priority
	Spring	Summer	Fall	Winter	
Razorbill	720	78	170	1559	1
Black scoter	423	16	356	1163	1
White-winged scoter	415	5	550	1332	1
Common eider	893	159	537	2211	1
Red-throated loon	1699	11	387	1902	1
Great shearwater	586	6011	6176	134	1
Audubon's shearwater	129	876	286	169	1
Red-necked phalarope	132	167	156	14	1
Least tern	27	121	37	0	1
Roseate tern	56	195	74	3	1
Common tern	488	1538	683	4	1
Northern gannet	5667	1187	4002	6414	1
Red phalarope	461	214	286	44	1
Black guillemot	7	93	7	34	2
Atlantic puffin	209	246	91	249	2
Long-tailed duck	1152	1	485	3214	2
Surf scoter	745	8	761	1746	2
Common loon	2367	182	1185	3215	2
Leach's storm-petrel	223	2140	452	1	2
Brown pelican	66	127	87	76	2
Horned grebe	21	0	13	94	2
Cory's shearwater	106	2925	1547	1	2
Black-capped petrel	158	356	92	83	2
Arctic tern	44	154	44	0	2
Dovekie	260	49	404	962	3
Band-rumped storm-petrel	14	266	10	0	3
Bonaparte's gull	397	20	280	981	3
Laughing gull	711	1602	1560	114	3
Black-legged kittiwake	621	24	2083	3706	3
Sooty shearwater	790	1542	104	3	3
Manx shearwater	100	309	264	16	3
Royal tern	269	283	279	11	3
Common murre	90	22	5	160	4
Red-breasted merganser	73	0	26	121	4
Wilson's storm-petrel	1650	8392	1348	10	4
Herring gull	5721	2941	7439	4986	4
Ring-billed gull	181	46	312	704	4
Great black-backed gull	3423	3186	5390	3655	4
Double-crested cormorant	145	187	206	162	4
Northern fulmar	2244	737	1823	1809	4
South polar skua	22	74	121	0	4
Parasitic jaeger	47	76	177	12	4
Pomarine jaeger	110	144	709	21	4
Great skua	16	27	173	26	4
Bridled tern	33	101	63	3	4
Sooty tern	60	118	16	0	4

Specific features of the NCCOS modeling approach include:

- NCCOS employed a statistical modeling framework that relates occurrence and abundance to environmental predictor variables (Table 3)

- Seasonal climatologies of spatial environmental predictors were used (i.e., a climatological habitat modeling approach)
- A boosted generalized additive modeling framework that accounts for the large number of zero data (zero inflation) and the over-dispersed nature of marine bird count data was used

TABLE 3 Environmental predictor variables for avian NCCOS models.

Variable	Type	Seasonal
chlorophyll-a	spatial	yes
turbidity	spatial	yes
upwelling index	spatial	yes
sea surface temperature	spatial	yes
sea surface temperature SD	spatial	yes
sea surface temperature front probability	spatial	yes
sea surface height	spatial	yes
sea surface height SD	spatial	yes
probability of cyclonic eddy ring	spatial	yes
probability of anticyclonic eddy ring	spatial	yes
water current (u direction)	spatial	yes
water current (v direction)	spatial	yes
water current divergence	spatial	yes
water current vorticity	spatial	yes
wind stress (u direction)	spatial	yes
wind stress (v direction)	spatial	yes
wind divergence	spatial	yes
depth	spatial	no
slope (1.5 and 10 km resolution)	spatial	no
slope of slope (10 km resolution)	spatial	no
planform curvature (10 km resolution)	spatial	no
profile curvature (10 km resolution)	spatial	no
distance to shelf break (200 m isobath)	spatial	no
distance to land	spatial	no
longitude (projected)	spatial	no
latitude (projected)	spatial	no
year	temporal	n/a
day of year	temporal	n/a
Monthly North Atlantic Oscillation (NAO) index (current and 1-year lag)	temporal	n/a
Monthly Multivariate El Nino-Southern Oscillation index (MEI) (current and 1-year lag)	temporal	n/a
Monthly Trans-Nino Index (TNI) (current and 1-year lag)	temporal	n/a
Monthly Atlantic Multidecadal Oscillation (AMO) index (current and 1-year lag)	temporal	n/a

2.2.4 CHARACTERIZATION(S) OF MODEL UNCERTAINTY

Two measures of model uncertainty are provided for the habitat-based relative occurrence and relative abundance models. These measures of uncertainty were derived using a data re-sampling approach (non-parametric bootstrapping), and they reflect statistical uncertainty in the model predictions arising from a number of factors including the amount survey effort, the range of environmental predictor values covered by survey effort, and un-modeled variability in numbers of birds. In addition to the two measures of model uncertainty, an indication of the amount of survey data supporting model predictions is provided.

1. 90% confidence interval range – From model fit bootstrap procedure. Reflects the magnitude of variability in the model predictions of relative occurrence and abundance in individual cells across bootstrap iterations. A wider confidence interval range indicates a less certain prediction. Tends to be positively correlated with the mean prediction itself.
2. Coefficient of Variation (CV) – From model fit bootstrap procedure. This measure of uncertainty is equal to the bootstrap standard deviation divided by the bootstrap mean at each pixel. While also

reflecting the magnitude of variability in model predictions, the CV is less affected by the mean prediction than is the 90% confidence interval range, so it better reflects relative uncertainty across the study area and between models. Focal measure of model uncertainty.

3. Survey effort density contour layers – The number of standardized survey transect segments in each 2 x 2 km cell were calculated and a kernel density algorithm was applied to the resulting grid to determine the minimum area(s) that covered 95% of the survey effort. Model predictions in areas outside of these 95% contours should be interpreted cautiously as there were few survey data to support them.

2.3 FISH SPECIES

NOAA's Northeast Fisheries Science Center (NEFSC) lead the MDAT effort in summarizing fish biomass and distribution, as part of their ongoing Ecosystem Considerations work on the Northeast Continental Shelf, which spans Cape Hatteras, NC to the Gulf of Maine. Ecosystem Considerations provides a broad overview of the ecology of the region through several topics including climate change, ecosystem status, current conditions, spatial analyses, and modeling approaches. Part of the National Ocean Policy (established July 2010) identifies marine Ecosystem-based Management (EBM) as a guiding principle, and highlights the importance and need for Coastal and Marine Spatial Planning as an EBM tool.

While the marine mammal/sea turtle and avian MDAT partners developed models to show abundance and distribution, the Working Group guiding the process for fish products decided on products closer to the direct data sources, and on a subset of available data for species of priority which are "iconic" ecologically, culturally, or economically important (Table 4). There are four sources for fisheries trawl data: the NEFSC, North East Areas Monitoring and Assessment Program (NEAMAP), Massachusetts Division of Marine Fisheries (MDMF), and Maine & New Hampshire state trawls (ME/NH). There is some spatial overlap among the surveys, and the NEFSC survey area is much larger than any of the others (Figure 5). Each set of data sources have used standardized survey designs and data collection methodologies but some have used different vessels and gears over time. Results have been normalized to account for these vessel and gear differences within each data source, however no method has yet been applied to normalize data across the different sources. For that reason, they are presented separately.

2.3.1 FISH PRODUCT CAVEATS AND CONSIDERATIONS

1. Products are based on fisheries-independent bottom trawl surveys and do not take into account alternative sources of information such as long-line surveys, plankton surveys, or fisheries-dependent data.
2. Biomass shown is dependent on vessel and gear type which has been standardized across federal survey vessels, but has not been standardized between state surveys or between state and federal surveys. Therefore, all abundance and biomass estimates are relative estimates (not absolute estimates) with unknown selectivity across species and locations. Due to differences in selectivity and availability, all abundance and biomass estimates should be viewed within the context of each survey, and not compared across surveys.

2.3.2 FISH SPECIES DISTRIBUTION PRODUCTS

Three outputs were created for each species and each data source:

1. Bubble plot: Each raw observation is plotted as a circle, where circle size is proportional to the total fish biomass in the tow. Units are natural log kilograms per tow.

2. Hexagon plot: The survey area is divided into a grid of hexagons and the mean is calculated. Units are mean natural log kilograms expected per tow in the hexagon.
3. Inverse-distance weighted (IDW) interpolation plot: An inverse-distance weighting algorithm is applied to all observations to smooth over multiple observations and to interpolate in regions with few observations. Units are natural log kilograms expected per tow in the cell.

TABLE 4 Fish species (n=82) and number of positive tows for each species, where a positive tow captured at least one individual of that species. Four sources of trawl data are represented: NEFSC (Northeast Fisheries Science Center), NEAMAP (North East Areas Monitoring and Assessment Program), MDMF (Massachusetts Division of Marine Fisheries), and Maine and New Hampshire (ME/NH). All trawls occurred during the fall (September – December).

Common Name	NEFSC	NEAMAP	MDMF	ME/NH
ACADIAN REDFISH	3398	0	63	560
ALEWIFE	1656	44	305	1132
AMERICAN EEL	7	12	4	6
AMERICAN LOBSTER	5593	151	1540	1154
AMERICAN PLAICE	3984	0	666	801
AMERICAN SAND LANCE	3	6	0	9
AMERICAN SHAD	706	31	94	337
ATLANTIC COD	3888	0	426	437
ATLANTIC CROAKER	1793	577	0	0
ATLANTIC HALIBUT	387	0	13	216
ATLANTIC HERRING	2880	84	409	1069
ATLANTIC MACKEREL	1203	10	51	438
ATLANTIC MENHADEN	210	176	25	129
ATLANTIC SHARPNOSE SHARK	398	42	0	0
ATLANTIC STURGEON	24	0	0	0
ATLANTIC TORPEDO	88	21	46	11
ATLANTIC WOLFFISH	501	0	15	3
BANDED DRUM	330	146	0	0
BARNDOOR SKATE	1057	5	8	13
BAY ANCHOVY	1252	411	190	0
BLACK SEA BASS	1824	433	817	8
BLACKBELLY ROSEFISH	944	2	0	1
BLUEBACK HERRING	488	34	120	435
BLUEFISH	2963	853	348	10
BLUNTNOSE STINGRAY	676	157	0	0
BULLNOSE RAY	718	0	0	0
BUTTERFISH	7943	1098	2300	913
CAPELIN	0	0	0	7
CLEARNOSE SKATE	1567	955	14	2
CUNNER	565	7	261	119
CUSK	837	0	1	0
FOURSPOT FLOUNDER	5123	0	1065	0
GOOSEFISH	4293	14	376	648
GULF STREAM FLOUNDER	1791	39	40	15
HADDOCK	4477	6	232	485
HICKORY SHAD	18	13	1	0
HORSESHOE CRAB	962	478	274	0
JONAH CRAB	1996	14	761	819
LITTLE SKATE	6013	702	2340	276
LONGFIN SQUID	10035	1109	2755	848
LONGHORN SCULPIN	3787	2	924	846
NORTHERN KINGFISH	693	0	208	0
NORTHERN PIPEFISH	47	2	122	4
NORTHERN PUFFER	765	387	100	0
NORTHERN SAND LANCE	517	0	108	0
NORTHERN SEAROBIN	3001	295	842	12
NORTHERN SHORTFIN SQUID	6931	0	386	596
NORTHERN SHRIMP	977	0	8	593
OCEAN POUT	1955	0	683	0
PIGFISH	425	179	0	0

PINFISH	233	202	0	0
POLLOCK	1987	1	93	171
RED HAKE	6477	75	1205	935
ROSETTE SKATE	508	1	0	0
ROUGHTAIL STINGRAY	433	127	17	0
ROUND HERRING	1266	153	12	0
SAND TIGER	55	31	4	0
SCUP	3661	801	1636	87
SEA RAVEN	2828	19	497	306
SEA SCALLOP	3312	25	467	459
SILVER HAKE	9912	259	1352	1145
SMOOTH DOGFISH	2542	674	884	0
SMOOTH SKATE	1438	0	11	107
SOUTHERN STINGRAY	143	33	0	0
SPINY BUTTERFLY RAY	445	197	0	0
SPINY DOGFISH	6465	76	1096	491
SPOT	1863	546	16	0
SPOTTED HAKE	4270	665	190	42
STRIPED ANCHOVY	1230	560	77	4
STRIPED BASS	132	66	32	3
STRIPED SEAROBIN	1531	429	357	0
SUMMER FLOUNDER	3902	1038	1261	0
TAUTOG	122	40	277	0
THORNY SKATE	3010	0	208	178
TILEFISH	39	0	0	0
WEAKFISH	1958	726	85	0
WHITE HAKE	4916	1	736	1134
WINDOWPANE	4375	771	1503	642
WINTER FLOUNDER	3840	205	2034	1002
WINTER SKATE	3433	424	1557	77
WITCH FLOUNDER	2812	0	261	579
YELLOWTAIL FLOUNDER	3418	5	1118	228

2.3.3 SPATIAL COVERAGE, GRID SIZE, MODEL GAPS

For the hexagon plots, the minimum bounding box of each survey area was calculated and divided into a grid of 60 by 60 hexagons. IDW cells for all data sources are 10km x 10km. Output for NEFSC data products cover the northeast and mid-Atlantic continental shelf, while NEAMAP and state level products cover smaller and more coastal areas.

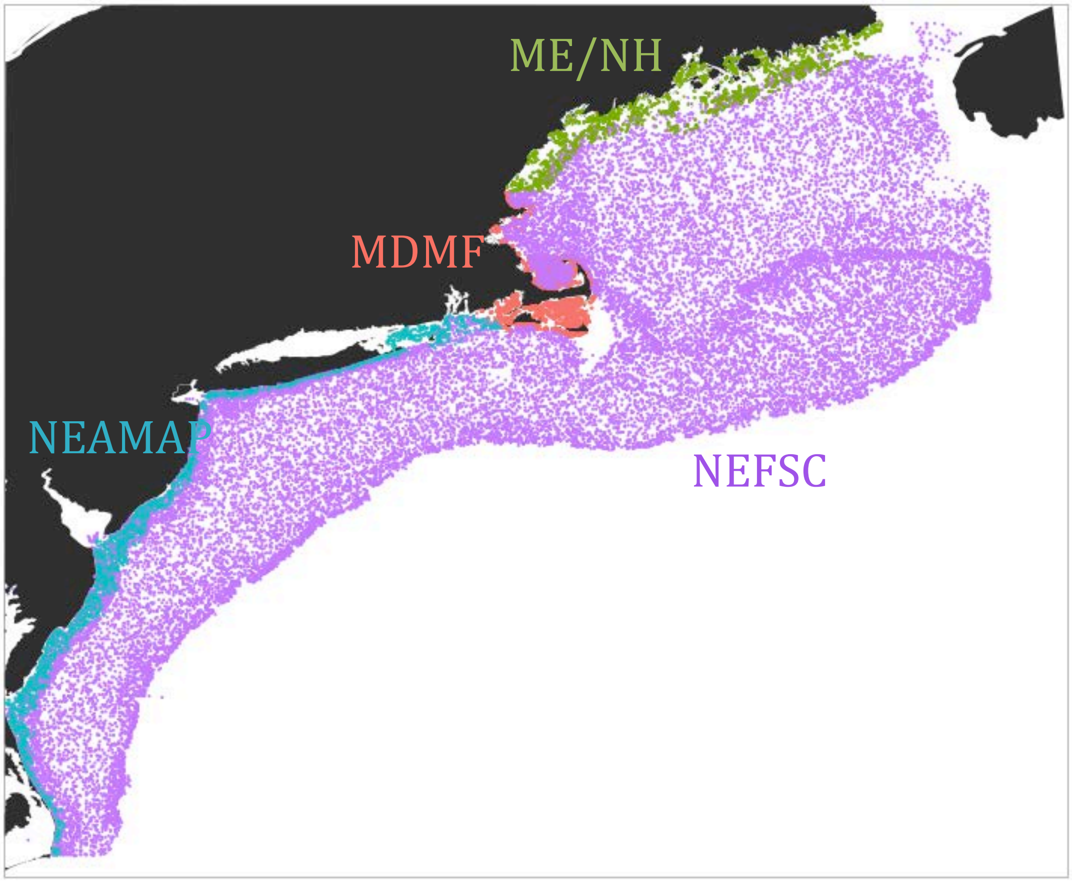

FIGURE 5 Federal and state bottom fish trawl survey locations.

2.3.4 TEMPORAL COVERAGE, ASSESSMENT WINDOWS

Survey samples for all data sources were collected primarily in September and October, with some in November and a small number in December ("Fall"). Products were produced for two time periods for all the data sets except NEAMAP, which has the shortest time span. Creating products for both the complete time span and for only the last decade allows comparisons, possibly highlighting spatial changes that have occurred in the recent past.

- NEAMAP 2007 – 2014
- NEFSC 1970- 2014
- NEFSC 2005 – 2014
- MDMF 1978 – 2014
- MDMF 2005 – 2014
- ME/NH 2000 – 2014
- ME/NH 2005 – 2014

2.3.5 CHARACTERIZATION(S) OF UNCERTAINTY

Uncertainty is estimated as the variance of the total fish biomass per tow within each hexagon (units are log-kilograms).

2.4 MARINE MAMMALS

Duke MGEL worked with the National Aeronautics and Space Administration (NASA), NOAA's Southwest Fisheries Science Center (SWFSC), NOAA's Cetacean & Sound Mapping Working Group, and the Navy to create the best available marine mammal habitat-based density (HD) models for the US East Coast. Models were created for species known to occur along the US east coast, either as an individual species or as a species guild.

2.4.1 MARINE MAMMAL MODEL CAVEATS AND CONSIDERATIONS

Many trade-offs and decisions were made by MDAT in the creation of the marine mammal density models. Density models are complex, involving variables that can be difficult to determine unambiguously, and must account for many factors, including the probability of detecting an animal according to how far it is from the observer, the speed and viewing characteristics of the observation platform, the size of the animal group, the sea state, the presence of sun glare, the availability of the animal at the ocean surface for detection, cryptic behaviors of the species being observed, and, ideally, the biases of individual observers, etc. During many expert review processes prior to engagement with either regional planning body, Duke MGEL considered and decided upon these options. A few specific caveats and considerations are highlighted below, as being most relevant to the ocean planning processes and efforts that they are likely to be used in.

Full documentation for every individual model can be accessed online at http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/, and full methods are documented in Roberts et al. (2016).

1. Stratified Density Models. Species with too few sightings available to model density from environmental predictors were instead fitted with a so-called stratified density model. Based on scientific literature reviews, some of these models were split into two or more areas, and stratified models were fit to each of those areas, or the species was considered absent from one or more of the areas. An example of this is the Clymene dolphin, which is assumed absent north of the Gulf Stream; south of the Gulf Stream it is further divided into on- and off-shelf abundance estimates.
2. Several species had too few sightings to fit individual detection functions to them (i.e. Clymene dolphin). In these cases, sightings were pooled with sightings from other species believed to exhibit similar detectability ("proxy species").
3. Seals are inherently difficult to generate marine mammal HD models for, with the same methodology applied to the cetacean species. Cetaceans spend all of their time at sea, while pinnipeds haul out on land (or ice) to rest, give birth, and nurse pups. MDAT did produce two seasonal models (June–August; September–May) for seals in the regions, however some caution should be used when interpreting the results of the models. Some characteristics of seals that present challenges to models:
    - The group sizes are highly variable, with large extremes (e.g. 4000 animals in one group)
    - They spend long periods of time on shore, and this behavior varies seasonally
    - Nearly all of the species identifications are ambiguous (i.e. the observer reported "unidentified seal")
    - They are hard to detect and we don't have good estimates of perception or availability biases
    - The numbers of animals in the study area has changed over the study period

2.4.2 MARINE MAMMAL MODEL OVERVIEW

HD models were created by applying distance sampling methods (Buckland et al. 2001, Buckland et al. 2004) to visual line transect surveys (Table 5) with sighting data for 29 marine mammal species or species guilds (Table 6), and linking physiographic and oceanographic covariates (Table 7) via Generalized Additive Models (GAMs). The database of line-transect data sources consists of data from multiple organizations, platforms (aerial and ship-based), and time periods (1992 – 2014) spanning the entire US East Coast and into Canadian waters (Table 5, Figure 6). Oceanographic covariates may be climatological (e.g. mean sea surface temperature at the location of the sighting for an 8-day period averaged over 30 years) or contemporaneous (daily sea surface temperature on the date of the sighting). Models were created using both types of covariates, and the better performing model was selected. Model performance was assessed with diagnostic tools and plots such as the Q-Q plot and explained deviance. A density surface was then predicted from the model at a monthly, seasonal, or yearly temporal resolution. When possible, fitted seasonal models used species-specific season definitions, based on known ecology. See Roberts et al. (2016) for model specifics.

TABLE 5 Northwest Atlantic line-transect surveys used in marine mammal density models.

Surveys	Start	End	On Effort Length (1000s km)	Effort Hours
NEFSC Aerial Surveys	1995	2008	70	412
NEFSC North Atlantic Right Whale Sighting Survey	1999	2013	432	2330
NEFSC Shipboard Surveys	1995	2004	16	1143
NJDEP Aerial Surveys	2008	2009	11	60
NJDEP Shipboard Surveys	2008	2009	14	836
SEFSC Atlantic Shipboard Surveys	1992	2005	28	1731
SEFSC Mid Atlantic Tursiops Aerial Surveys	1995	2005	35	196
SEFSC Southeast Cetacean Aerial Surveys	1992	1995	8	42
UNCW Cape Hatteras Aerial Surveys (Navy)	2011	2013	19	125
UNCW Early Marine Mammal Aerial Surveys	2002	2002	18	98
UNCW Jacksonville Aerial Surveys (Navy)	2009	2013	66	402
UNCW Onslow Bay Aerial Surveys (Navy)	2007	2011	49	282
UNCW Right Whale Aerial Surveys	2005	2008	114	586
Virginia Aquarium Aerial Surveys	2012	2014	9	53

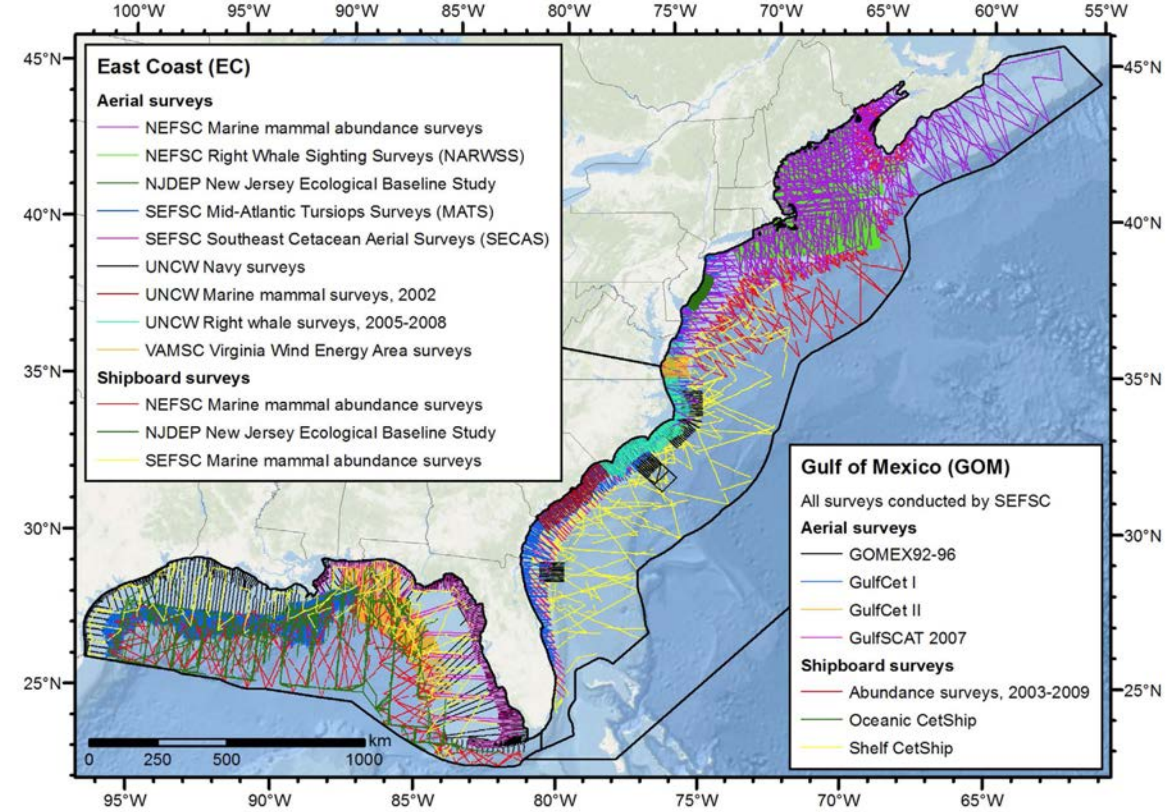

FIGURE 6 Marine mammal Survey effort and coverage for the US East Coast and Gulf of Mexico, Figure 1 from Roberts et al. (2016), based on the surveys listed in Table 5. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

TABLE 6 Cetacean and pinniped sightings from the available datasets that are suitable for density modeling. n = number of sightings along the full US east coast extent used in the model. Density surface prediction Temporal Resolution is monthly, seasonal, or year-round based on the availability of data. Species flagged with a Model Guild were not modeled individually but as part of the designated guild, due to insufficient sightings or ambiguous taxonomic identifications.

Family	Scientific Name	Common Name	n	Temporal Resolution	Model Guild
Cetaceans	Balaenoptera acutorostrata	Minke whale	1031	Monthly	
	Balaenoptera borealis	Sei whale	821	Monthly	
	Balaenoptera edeni	Bryde’s whale	4	Year-round	
	Balaenoptera musculus	Blue whale	8	Year-round	
	Balaenoptera physalus	Fin whale	2100	Monthly	
	Delphinus delphis	Common dolphin	1189	Monthly	
	Eubalaena glacialis	North Atlantic right whale	1634	Monthly	
	Globicephala	Unidentified pilot whale	823	Year-round	Pilot whales
	Globicephala macrorhynchus	Short-finned pilot whale	86	Year-round	Pilot whales
	Globicephala melas	Long-finned pilot whale	0	Year-round	Pilot whales
	Grampus griseus	Risso's dolphin	721	Monthly	
	Hyperoodon ampullatus	Northern bottlenose whale	4	Year-round	
	Kogia	Unidentified small sperm whale	24	Year-round	Kogia whales
	Kogia breviceps	Pygmy sperm whale	3	Year-round	Kogia whales
	Kogia sima	Dwarf sperm whale	4	Year-round	Kogia whales
	Lagenodelphis hosei	Fraser’s dolphin	2	Year-round	
	Lagenorhynchus acutus	Atlantic white-sided dolphin	2266	Monthly	
	Lagenorhynchus albirostris	White-beaked dolphin	12	Year-round	
	Megaptera novaeangliae	Humpback whale	2732	Monthly	
	Mesoplodon	Unidentified beaked whale	137	Year-round	Beaked whales
	Mesoplodon bidens	Sowerby's beaked whale	14	Year-round	Beaked whales
	Mesoplodon densirostris	Blainville's beaked whale	3	Year-round	Beaked whales
	Mesoplodon europaeus	Gervais’ beaked whale	3	Year-round	Beaked whales
	Mesoplodon mirus	True's beaked whale	3	Year-round	Beaked whales
	Orcinus orca	Killer whale	4	Year-round	
	Peponocephala electra	Melon-headed whale	4	Year-round	
	Phocoena phocoena	Harbor porpoise	2018	Monthly	
	Physeter macrocephalus	Sperm whale	501	Monthly	
	Pseudorca crassidens	False killer whale	2	Year-round	
	Stenella attenuata	Pantropical spotted dolphin	17	Year-round	
	Stenella clymene	Clymene dolphin	11	Year-round	
	Stenella coeruleoalba	Striped dolphin	195	Year-round	
	Stenella frontalis	Atlantic spotted dolphin	838	Year-round	
	Stenella longirostris	Spinner dolphin	2	Year-round	
	Steno bredanensis	Rough-toothed dolphin	11	Year-round	
	Tursiops truncatus	Bottlenose dolphin	4657	Monthly	
	Ziphiidae	Unidentified beaked whale	20	Year-round	Beaked whales
	Ziphius cavirostris	Cuvier's beaked whale	46	Year-round	Beaked whales
Pinnipeds	Caniformia	Unidentified seal	628	Seasonal	Seals
	Halichoerus grypus	Gray seal	19	Seasonal	Seals
	Phoca vitulina	Harbor seal	195	Seasonal	Seals

TABLE 7 Oceanographic covariates used in habitat density models. Not all variables are used in each model, the model selects the best predictor variables for each species based on the known ecology.

Type	Predictor	Description
Physiographic	Depth	Downscaled from SRTM30-PLUS to 10km resolution
	Slope	Computed from SRTM30-PLUS
	DistToShore	Distance to shore, not including Bermuda
	DistTo125m, DistTo300m, DistTo1500m	Distance to isobaths that delineate various ecologically relevant geomorphic features
	DistToCanyon	Distance to submarine canyon
	DistToCanyonOrSeamount	Distance to submarine canyon or seamount
SST & Winds	SST	Taken from GHRSST CMC 2.0 L4 SST, interpolated up to 10 km resolution
	DistToFront	Distance to closest SST front detected in CMC SST using Canny edge detection operator; tested several alternative formulations
	WindSpeed	30-day running mean of NCDC 1/4° Blended Sea Winds, interpolated up to 10 km resolution; only used for calving right whales in the southeast
Currents	TKE, EKE	Total kinetic energy and eddy kinetic energy derived from AVISO 1/4° DT-MADT and MSLA geostrophic currents, interpolated up to 10 km resolution
	DistToEddy, DistToAEddy, DistToCEddy	Distance to ring of closest geostrophic eddy having any/anticyclonic/cyclonic polarity, from AVISO 1/4° DT-MADT using a revision of the Chelton et al. (2011) algorithm; tested eddies at least 9, 4, an 0 weeks old.
Productivity	Chl	GSM merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll (chl) *a* concentration (Maritorena et al. 2010), smoothed with 3D Gaussian smoother to reduce data loss to < 10%
	VGPM, CumVGPM45, CumVGPM90	Behrenfeld et al. (1997) vertically generalized primary prod. model (VGPM) at 8-day, 9km resolution, trilinear-interpolated to daily resolution; also tested 45 and 90 day running cumulative sums
	PkPP, PkPB	Weekly zooplankton potential production and potential biomass from the SYPODYM ocean model (Lehodey et al. 2010)
	EpiMnkPP, EpiMnkPB	Weekly epiplelagic micronekton potential production and potential biomass from the SYPODYM ocean model (Lehodey et al. 2010)

2.4.3 SPATIAL COVERAGE, GRID SIZE, MODEL GAPS

Marine mammal models were created for the entire US East Coast and southeast Canada. Synthetic and derived products for this MARCO effort were constrained to the mid-Atlantic spatial extent in Figure 1. Model output and derived products are a grid consisting of 10km x 10km cells, which is a compromise between resolutions of oceanographic covariates, which range from 4km to 1/3°. Spatial gaps for base model products include various inshore areas: New York/New Jersey Harbor, Long Island Sound, all of the bays around Long Island, part of Block Island Sound, Narragansett Bay and nearby passages, part of Buzzard's Bay, part of Massachusetts Bay, and various bays along Maine and Canada.

2.4.4 TEMPORAL COVERAGE, ASSESSMENT WINDOWS

Data sources ranged from 1992 – 2014. Model results are on a seasonal or monthly basis when the data support that resolution, and when they don't the output is on an annual basis (Table 6). Species-specific seasons for pinnipeds are based on patterns in the sightings and reports in the literature.

2.4.5 CHARACTERIZATION(S) OF MODEL UNCERTAINTY

Several measures of model uncertainty are provided with each habitat-based density model. The percentile maps reflect the statistical uncertainty of the GAM that is predicting density from environmental predictors. The uncertainty at a given location relates mainly to how well the environmental conditions that occurred there were surveyed (via remote sensing), and how variable conditions are throughout the year.

1. 5th percentile – This measure indicates that the density of animals predicted by the model exceeds what is shown on the map 95% of the time.
2. 95th percentiles – On the 95th percentile map, the density of animals predicted by the model exceeds what is shown on the map only 5% of the time.
3. Standard error – Standard error estimates how close the estimated density is likely to be to the actual density, accounting for the number of sightings that were made and the modeled taxon and how effectively density was modeled statistically from the environmental variables. The units of standard error are the same as density. The standard error estimate does not account for the uncertainty in either the detection functions (which model the probability of detecting the taxon given its distance from the survey trackline) or the estimates of availability or perception bias (the tendencies to fail to detect the animal because it is submerged and unavailable for observation, or because it displays cryptic behaviors, is small and hard to see, etc.)
4. Coefficient of variation (CV) – The CV is the ratio of the standard error to the estimated density, and helps inform users about the magnitude of variation in model predictions from one place to another. Values greater than 1, i.e. where the standard error is greater than the density estimate, indicate substantial uncertainty. When high CVs occur where the density estimate is very low, as is often the case, there is little cause for concern. But when high CVs occur where the density estimate is high, it suggests the model cannot predict density well there.

3 SYNTHESIS PRODUCTS

Marine-life data synthesis products are secondary or tertiary distillations of the abundance models or observation data. Synthesis products provide a means to distill hundreds of data layer and time period combinations into more simplified maps that supplement the base-layer reference library, with those data and models continuing to be fundamental to ocean planning and decision making. Decisions made in the creation of the higher level map products were discussed with the DSWG, with other taxa, model and regional experts and the Mid-Atlantic RPB. Understanding the implication of applied thresholds and criteria is critical to appropriately interpret synthetic products. Higher-level, aggregate products are useful for revealing patterns in underlying data models and may not fully address the needs associated with answering species-level specific ecological or management questions. Targeted queries of species-specific products in the reference library are often the most reliable method for matching the data to specific questions.

Synthetic products include total abundance or biomass, "core area" abundance or biomass, species richness, and diversity. Each type of product was created for all species in a taxon, and for various groups of species in each taxon.

All synthetic products were created at the scale of the underlying data sets. For avian and mammal model products this is the US east coast out to the US EEZ, and for the NEFSC fish data the range is from Cape Hatteras NC to the Gulf of Maine out to the shelf break.

3.1 SPECIES SYNTHESIS PRODUCT CAVEATS AND CONSIDERATIONS

There are four main caveats when considering use of the higher-level aggregated products created for species groups, and for all species within each taxon.

1. The species within these groups represent only those modeled or mapped by MDAT. As an example, there may be additional "migrant" bird species in the Northeast region not captured in the "migrant" species group because there were insufficient observations available to model all migratory bird species.
2. The groups are not exhaustive and there are many potential additional groups. To develop species membership lists, we relied on working group input, expert judgment and published sources of information.
3. Group level products (abundance, richness, diversity, and 50% core area richness) were created from the annual prediction models, and so should be interpreted accordingly.
4. Groups may be dominated by one (or few) species of very high abundance, which are often not species of particular concern.

Caveats specific to the avian summary products:

- Avian summary products are based on normalized individual species annual relative abundance distributions. The overall mean value of the relative distribution was used to normalize the predicted relative abundance distribution values. This normalization helps reduce the impact of very large predicted populations in the subsequent synthetic product development.

Caveats specific to the fish summary products:

- Fish group species richness, group diversity, and core area biomass richness products represent the expected richness or diversity of a survey trawl done in that area, and are not representative of the true fish species richness or diversity in that location. This is the expected richness and diversity for the gear type used in NEFSC fall trawls, and not accounting for each species' catch-ability. These data are a fishery descriptor, not an ecosystem descriptor and are not meant to be used to determine absolute fish biomass hotspots.

Caveats specific to the marine mammal summary products:

- Summary products were created only for cetaceans. Seals were not included in any group summary product.

3.2 SPECIES GROUPS

Individual species products are vital to addressing specific questions and aiding in decisions that might impact a particular species in a particular area at a particular time of year (month or season.) The associated uncertainty products allow the user to understand the model accuracy, and weigh that along with the many other products and input sources that are considered in management decisions.

At other times, understanding the impact of a potential action upon multiple species could be better addressed by visualizing where and when that group of species occurs. For example, a user might want to know what animals will co-occur with proposed seismic activity, port expansion, increased ship traffic, etc. Looking at the distribution and abundance of all threatened and endangered species, or all species that are sensitive to high-frequency sounds could be more informative, than to try to review many individual species products. Species group products could be a starting point for certain investigative actions, with users then proceeding to the base layer products to obtain more detail on identified species of concern.

Species were grouped together according to three broad categories. Group definitions were suggested by MDAT with input from species and taxa experts, and reviewed and agreed upon by the expert work group members, DSWG members, and RPB members. Additionally, an "all species" group was created for each of the three taxa: all avian species, all fish species, all cetacean species. "All-species" groups might aid in early sighting or pre-screening activities in regional ocean planning.

3.2.1 REGULATED SPECIES

Maps of the *regulatory species groups* depict the distribution and densities or biomass of marine life species that have been formally protected, designated as a species of concern, or are managed through a specific state or federal program or partnership. To facilitate targeted data exploration and decision making, we developed aggregate maps for groups of species that have been specifically identified or listed through a regulatory authority. The marine life products in these groups provide the opportunity to determine whether a potential action or conservation measure could affect concentrations of species regulated or managed under existing authorities. Membership lists for regulatory species groups were developed from the published documentation associated with each regulatory authority.

Avian species are managed at both the state and federal level (Table 8). State listed species are listed by one or more states in the mid-Atlantic or northeast US. The BCR30 Priority group is the list of species in the New-England/Mid-Atlantic Coast Bird Conservation Region, the area of the North American Bird Conservation Initiative (http://www.nabci-us.org/) that spans the US east coast from Virginia to Maine. The grouping for MDAT contains species of highest, high and moderate priorities. The Atlantic Marine Bird Conservation Cooperative (AMBCC) and USFWS have also developed conservation prioritization categories (high, medium, and low).

TABLE 8 Regulatory groups for avian species including species that are listed by one or more states, one species that is listed as Endangered under the Endangered Species Act (ESA); species in the Bird Conservation Region 30 (BCR30) of the North American Bird Conservation Initiative (nabci); three tiers of species listed with the Atlantic Marine Bird Conservation Cooperative (AMBCC).

State listed	ESA listed	BCR30 Priority	AMBCC High	AMBCC Medium	AMBCC Low
Arctic tern	Roseate tern	Audubon's shearwater	Atlantic puffin	Arctic tern	Laughing-gull
Atlantic puffin		Common eider	Audubon's shearwater	Band-rumped storm petrel	
Leach's storm petrel		Common tern	Black-capped petrel	Black scoter	
Least tern		Cory's shearwater	Common eider	Black-legged kittiwake	
Razorbill		Great shearwater	Common loon	Brown pelican	
Roseate tern		Horned grebe	Common murre	Cory's shearwater	
		Least turn	Least turn	Great shearwater	
		Lesser scaup	Long-tailed duck	Leach's storm petrel	
		Long-tailed duck	Northern gannet	Manx shearwater	
		Manx shearwater	Razorbill	Red phalarope	
		Northern gannet	Red-necked phalarope	Royal tern	
		Razorbill	Red-throated loon		
		Red phalarope	Roseate tern		
		Red-throated loon	White-winged scoter		
		Roseate tern			
		Royal tern			
		Surf scoter			
		White-winged scoter			

Fish groups for regulated species (Table 9) are based on regulations from the New England Fishery Management Council (http://www.nefmc.org/), the Mid-Atlantic Fishery Management Council (http://www.mafmc.org/), the Atlantic States Marine Fisheries Commission (http://www.asmfc.org/), species with identified Essential Fish Habitat (EFH), and species managed under the Atlantic Highly Migratory Species Management Division (http://www.nmfs.noaa.gov/sfa/hms/). Other groups may be identified as important for the mid-Atlantic area, and could be derived from the base-layer products in the same methodology.

TABLE 9 Regulatory groups for fish species. Four groups are under the New England Fishery Management Council (NEFMC) authority; the Mid-Atlantic Fishery Management Council (MAFMC) species with Fish Management Plans (FMPs); the Atlantic States Marine Fisheries Commission (ASMFC) FMPs; species with Essential Fish Habitat (EFH) plans; and fish species managed by NMFS as highly migratory species.

NEFMC multispecies	MAFMC FMPs	ASMFC FMPs	EFH Species	Highly Migratory Species
Acadian redfish	Atlantic mackerel	Alewife	Acadian redfish	Atlantic Sharpnose shark
American plaice	Black sea bass	American eel	American plaice	Sand tiger
Atlantic cod	Bluefish	American lobster	Atlantic cod	
Atlantic halibut	Butterfish	American shad	Atlantic halibut	
Haddock	Longfin squid	Atlantic croaker	Atlantic herring	
Ocean pout	Scup	Atlantic herring	Atlantic mackerel	
Pollock	Shortfin squid	Atlantic menhaden	Barndoor skate	
White hake	Spiny dogfish	Atlantic sharpnose shark	Black sea bass	
Windowpane flounder	Summer flounder	Atlantic sturgeon	Bluefish	
Winter flounder	Tilefish	Black sea bass	Butterfish	
Witch flounder		Blueback herring	Clearnose skate	
Wolffish		Bluefish	Haddock	
Yellowtail flounder		Horseshoe crab	Little skate	
		Jonah crab	Longfin squid	
NEFMC small mesh multispecies		Northern shrimp	Monkfish	
Red hake		Sand tiger	Ocean pout	
Silver hake		Scup	Pollock	
		Smooth dogfish	Red hake	
NEFMC monkfish		Spiny dogfish	Rosette skate	
Goosefish		Spot	Scup	
		Striped bass	Sea scallop	
NEFMC skates		Summer flounder	Shortfin squid	
Barndoor skate		Tautog	Silver hake	
Clearnose skate		Weakfish	Smooth skate	
Little skate		Winter flounder	Spiny dogfish	
Rosette skate			Summer flounder	
Smooth skate			Thorny skate	
Thorny skate			Tilefish	
Winter skate			White hake	
			Windowpane flounder	
			Winter flounder	
			Winter skate	
			Witch flounder	
			Wolffish	
			Yellowtail flounder	

All marine mammals are managed by NOAA/NMFS under the Marine Mammal Protection Act (MMPA, 1972, http://www.nmfs.noaa.gov/pr/laws/mmpa/). Some marine mammal species are also listed as endangered under the Endangered Species Act (ESA), and have additional management actions also under authority of the NMFS. Six marine mammal species that occur in the mid-Atlantic that have been modeled by Duke MGEL are listed as Endangered under the ESA (Table 10).

TABLE 10 Regulatory groups for marine mammal species listed as Endangered under the Endangered Species Act (ESA).

ESA listed
Blue whale
Fin whale
Humpback whale
North Atlantic right whale
Sei whale
Sperm whale

3.2.2 ECOLOGICALLY BASED SPECIES GROUPS

Maps of *ecologically grouped species* portray the distribution and abundance or biomass of species with similar ecology or life history requirements, enabling a more ecosystem-based approach to managing and considering potential impacts to marine life. Mapping of ecologically based species groups enables a better understanding and encourages exploration of species connectedness, ecosystem function and redundancy, potential interactions with human activities, cumulative impacts, and susceptibility to changing conditions, including acidification and warming seas. Membership lists for ecologically based species groups were developed by taxa experts within MDAT with guidance and input from expert work group members, DSWG members, and RPB members.

Four categories of ecological or biological groupings were created for avian species: similar spatial patterns (Table 11), similar taxonomic identification (Table 12), common feeding strategies (Table 13), and common prey (Table 14). Additional groups were created classifying birds by how they use the region – breeding, feeding, migrating through, or resident (Table 15).

TABLE 11 Groups for avian species based on similar spatial distribution.

Nearshore	Offshore / Pelagic
Arctic tern	Atlantic puffin
Black scoter	Audubon's shearwater
Brown pelican	Black-capped petrel
Common eider	Common murre
Common loon	Cory's shearwater
Common tern	Dovekie
Double-crested cormorant	Great shearwater
Horned grebe	Leach's storm-petrel
Least tern	Manx shearwater
Long-tailed duck	Northern fulmar
Roseate tern	Pomarine jaeger
Royal tern	Razorbill
Red-throated loon	Red phalarope
Surf scoter	Red-necked phalarope
White-winged scoter	Sooty shearwater
	Wilson's storm petrel

TABLE 12 Groups for avian species based on similar taxonomic identification.

Coastal Waterfowl	Terns	Alcids	Gulls & Gannets
Black scoter	Arctic tern	Atlantic puffin	Black-legged kittiwake
Common eider	Common tern	Black guillemot	Bonaparte's gull
Common loon	Least tern	Common murre	Great black-backed gull
Long-tailed duck	Roseate tern	Dovekie	Herring gull
Red-breasted merganser	Royal tern	Razorbill	Laughing gull
Red-throated loon			Northern gannet
Surf scoter			Ring-billed gull
White-winged scoter			

TABLE 13 Groups for avian species based on common feeding strategies.

Divers & Pursuit Plungers	Benthic Feeders	Surface Feeders	Surface Plungers
Atlantic puffin	Black scoter	Band-rumped storm-petrel	Arctic tern
Audubon's shearwater	Common eider	Black-legged kittiwake	Brown pelican
Black guillemot	Long-tailed duck	Bonapartes' gull	Common tern
Common loon	Surf scoter	Great black-backed gull	Least tern
Common murre	White-winged scoter	Herring gull	Northern gannet
Cory's shearwater		Laughing gull	Roseate tern
Double-crested cormorant		Leach's storm-petrel	
Dovekie		Northern fulmar	
Great shearwater		Red phalarope	
Horned grebe		Red-necked phalarope	
Manx shearwater		Ring-billed gull	
Razorbill		Wilson's storm-petrel	
Red-breasted merganser			
Red-throated loon			
Sooty shearwater			

TABLE 14 Groups for avian species based on prey type.

Fish Eaters		Squid Eaters	Crustacean Eaters	Bivalve Eaters
Arctic tern	Herring gull	Band-rumped storm-petrel	Atlantic puffin	Black scoter
Atlantic puffin	Horned grebe	Black-capped petrel	Band-rumpped storm-petrel	Common eider
Audubon's shearwater	Laughing gull	Leach's storm-petrel	Black guillemot	Long-tailed duck
Band-rumped storm-petrel	Leach's storm-petrel		Black scoter	Surf scoter
Black guillemot	Least tern		Black-capped petrel	White-winged scoter
Black-capped petrel	Manx shearwater		Bonaparte's gull	
Black-legged kittiwake	Northern fulmar		Common murre	
Bonaparte's gull	Northern gannet		Dovekie	
Brown pelican	Razorbill		Horned grebe	
Common loon	Red-breasted merganser		Leach's storm-petrel	
Common murre	Red-throated loon		Long-tailed duck	
Common tern	Ring-billed gull		Razorbill	
Cory's shearwater	Roseate tern		Red Phalarope	
Double-crested cormorant	Royal tern		Red-necked phalarope	
Great black-backed gull	Sooty shearwater		Surf scoter	
Great shearwater	Wilson's storm-petrel		White-winged scoter	
			Wilson's storm-petrel	

TABLE 15 Groups for avian species based on space use for the Mid-Atlantic and Northeast regions.

Breeding	Feeding	Migrant
Atlantic puffin	Audubon's shearwater	Atlantic puffin
Black guillemot	Band-rumped storm-petrel	Audubon's shearwater
Common eider	Black scoter	Band-rumped storm-petrel
Common loon	Black-capped petrel	Black scoter
Common tern	Black-legged kittiwake	Black-capped petrel
Double-crested cormorant	Bonaparte's gull	Black-legged kittiwake
Great black-backed gull	Brown pelican	Bonaparte's gull
Herring gull	Common murre	Common loon
Laughing gull	Cory's shearwater	Common murre
Leach's storm-petrel	Dovekie	Common tern
Razorbill	Horned grebe	Cory's shearwater
Roseate tern	Long-tailed duck	Double-crested cormorant
	Manx shearwater	Dovekie
Resident	Northern fulmar	Horned grebe
Atlantic puffin	Northern gannet	Laughing gull
Black guillemot	Pomarine jaeger	Long-tailed duck
Brown pelican	Red phalarope	Manx shearwater
Double crested-cormorant	Red-breasted merganser	Northern fulmar
Great black-backed gull	Red-necked phalarope	Northern gannet
Herring gull	Red-throated loon	Pomarine jaeger
Laughing gull	Ring-billed gull	Red phalarope
Razorbill	Sooty shearwater	Red-breasted merganser
	Surf scoter	Red-necked phalarope
	White-winger scoter	Red-throated loon

	Wilson’s storm-petrel	Ring-billed gull
		Roseate tern
		Sooty shearwater
		Surf scoter
		White-winged scoter

Fish were grouped into three categories based on ecological or biological similarities (Table 16). Diadromous fish spend part of their life-cycle in fresh water (rivers, estuaries) and part in salt water. Forage fish are fish that are common prey items for other fish, marine mammals, or birds. Demersal fish primarily live on the seafloor.

TABLE 16 Groups for ecologically or biologically similar fish species.

Diadromous	Forage	Demersal	
Alewife	Alewife	Acadian redfish	Red hake
American eel	American sand lance	American plaice	Rosette skate
American shad	American shad	Atlantic cod	Scup
Atlantic sturgeon	Atlantic herring	Atlantic halibut	Sea raven
Blueback herring	Atlantic mackerel	Barndoor skate	Silver hake
Hickory shad	Atlantic menhaden	Black sea bass	Smooth skate
Shortnose sturgeon	Bay anchovy	Clearnose skate	Summer flounder
	Blueback herring	Cunner	Tautog
	Butterfish	Fourspot flounder	Thorny skate
	Capelin	Goosefish	White hake
	Hickory shad	Haddock	Windowpane flounder
	Northern sand lance	Little skate	Winter flounder
	Round herring	Longhorn sculpin	Witch flounder
	Striped anchovy	Ocean pout	Wolffish
		Pollock	Yellowtail flounder

Cetaceans were grouped based on phylogeny and ecology (Table 17). First, baleen whales were separated from the toothed whales. Next the toothed whales were split into sperm and beaked whales (all deep-diving teuthivores) and the delphinoids. Finally, the delphinoids were split into large delphinoids (the Globicephalinae subfamily) and small delphinoids (small dolphins and harbor porpoise). Group definitions for cetaceans were reviewed and agreed upon by expert work group members, DSWG members, and RPB members.

TABLE 17 Groups for cetaceans based on biological or ecological similarities.

Baleen Whales	Sperm & Beaked Whales	Small Delphinoids	Large Delphinoids
Blue whale	Blainville’s beaked whale	Atlantic spotted dolphin	False killer whale
Bryde’s whale	Cuvier’s beaked whale	Atlantic white-sided dolphin	Killer whale
Fin whale	Dwarf sperm whale	Bottlenose dolphin	Long-finned pilot whale
Humpback whale	Gervais’ beaked whale	Clymene dolphin	Melon-headed whale
Minke whale	Northern bottlenose whale	Fraser’s dolphin	Risso’s dolphin
North Atlantic right whale	Pygmy sperm whale	Harbor porpoise	Short-finned pilot whale
Sei whale	Sowerby’s beaked whale	Pantropical spotted dolphin	
	Sperm whale	Rough-toothed dolphin	
	True’s beaked whale	Short-beaked common dolphin	
		Spinner dolphin	
		Striped dolphin	
		White-beaked dolphin	

3.2.3 STRESSOR SENSITIVITY-BASED GROUPS

Maps of species grouped by their sensitivity to specific stressors enable a better understanding of special co-occurrence between marine life and human activities and the potential effects of ecosystem changes. Stressor sensitivity-based products provide the opportunity to understand where species could be directly affected by a particular human use or stressor when a specific interaction is suspected or known. As a result, these products can inform impact analyses and an assessment of the potential tradeoffs associated with a particular regulatory or management decision. We sought to develop groups based on known relationships between species and stressors, and as a result the development of stressor sensitivity-based species groups has been limited. The species membership of stressor sensitivity based groups was determined using peer-reviewed literature and federal agency research and policy.

Marine birds have the potential to be impacted by offshore wind energy development through displacement and collision. Robinson Willmott et al. (2013) ranked the sensitivity of Atlantic Outer Continental Shelf (OCS) marine bird species to these factors, and we used their 'higher' sensitivity qualitative categories for these two factors to form corresponding species groups (Table 18).

TABLE 18 Avian species groups based on stressor sensitivity. Higher collision sensitivity species are potentially the most vulnerable to collision risk, while higher displacement sensitivity species are potentially the most vulnerable to displacement and its effects (Robinson Willmott et al. 2013).

Avian		
Higher collision sensitivity		**Higher displacement sensitivity**
Arctic tern	Laughing gull	Arctic tern
Atlantic puffin	Leach's storm petrel	Atlantic puffin
Audubon's shearwater	Long-tailed duck	Black guillemot
Black guillemot	Manx shearwater	Black scoter
Black scoter	Northern fulmar	Common eider
Black-legged kittiwake	Northern gannet	Common loon
Common eider	Pomarine jaeger	Common murre
Common loon	Razorbill	Common tern
Common murre	Red phalarope	Great black-backed gull
Common tern	Red-necked phalarope	Long-tailed duck
Cory's shearwater	Red-throated loon	Manx shearwater
Double-crested cormorant	Roseate tern	Northern gannet
Great black-backed gull	Sooty shearwater	Razorbill
Great shearwater	Surf scoter	Red-throated loon
Herring gull	White-winged scoter	Roseate tern
Horned grebe	Wilson's storm petrel	Surf scoter
		White-winged scoter

Whales and dolphins are sensitive to anthropogenic noise in the ocean. Increasing ship traffic, construction, mining, and military activities all generate background and/or acute noise events that can disrupt the animal's ability to communicate with each other, to hear predators or prey, or in general cause them to avoid an area they otherwise would occupy or pass through. Southall et al. (2007) grouped marine mammals based on their hearing sensitivity to different sound frequencies (Table 19).

TABLE 19 Cetacean sound sensitivity groups. Each group is sensitive to a different frequency of noise in the ocean, indicated by the range of estimated auditory bandwidth as reported in Table 2 in Southall et al. (2007).

Marine Mammal Sound Sensitivity			
Low frequency 7 Hz to 22 kHz	**Mid frequency 150 Hz to 160 kHz**		**High frequency 200 Hz to 180 kHz**
Blue whale	Atlantic spotted dolphin	Northern bottlenose whale	Dwarf sperm whale
Bryde's whale	Atlantic white-sided dolphin	Pantropical spotted dolphin	Harbor porpoise
Fin whale	Blainville's beaked whale	Risso's dolphin	Pygmy sperm whale
Humpback whale	Bottlenose dolphin	Rough-toothed dolphin	
North Atlantic right whale	Clymene dolphin	Short-beaked common dolphin	
Sei whale	Cuvier's beaked whale	Short-finned pilot whale	
	False killer whale	Sowerby's beaked whale	
	Fraser's dolphin	Sperm whale	
	Gervais' beaked whale	Spinner dolphin	
	Killer whale	Striped dolphin	
	Long-finned pilot whale	True's beaked whale	
	Melon-headed whale	White-beaked dolphin	

3.3 GROUP ABUNDANCE OR BIOMASS

Summed abundance products were created for every defined group including an "all species" group in each taxon. There are slight differences in interpretation among the avian, fish and mammal products, summarized below with example maps and descriptions.

3.3.1 AVIAN TOTAL RELATIVE ABUNDANCE

For all avian species together, and for each group of species defined in Section 3.2 of this report, total relative abundance maps are calculated in a Geographic Information System (GIS) by stacking each individual species' predicted annual long-term average relative abundance layers and summing the values of the cells in each resulting "column". The result is the total predicted long-term average relative abundance of all individuals (of the included species in the group) in that cell. **It is important to note these products represent and reflect *relative* abundance, not predicted absolute abundance.** This caveat is based on the properties of the base-layer products being aggregated – the base-layer avian products do not predict absolute abundance. In addition, individual species base-layers were normalized to their mean prior to summation. This type of group product informs where areas of higher abundances of groups of species may be found relative to other areas.

The total avian relative abundance distribution map (Figure 7) for the High Displacement Sensitivity species group (see Table 18) shows areas with the highest relative abundances in red. These species are at risk of being displaced from their feeding / breeding / migration areas when human activities occur in these areas, and might be considered areas of concern for this group of species.

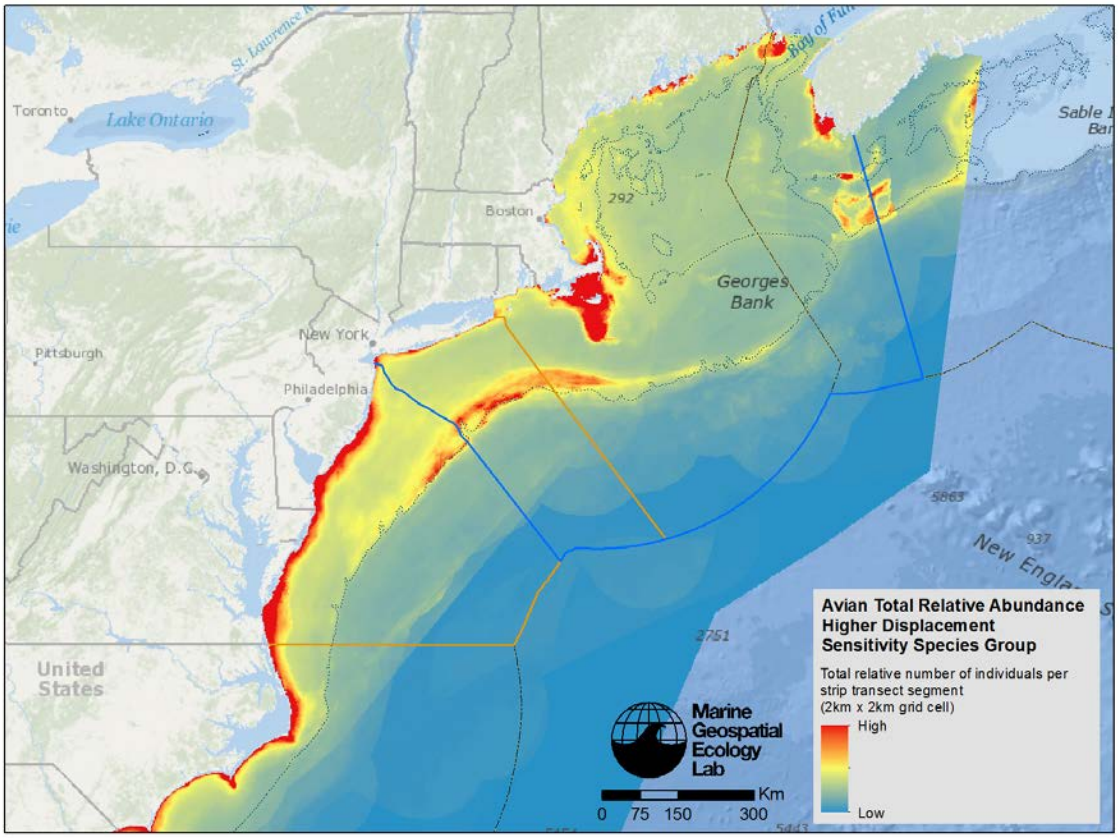

FIGURE 7 Total avian relative abundance distribution map for the High Displacement Sensitivity species group (see Table 18). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.3.2 FISH TOTAL BIOMASS

For all fish species together, and for each group of species defined in Section 3.2 of this report, total biomass maps are calculated in a GIS by stacking each individual species' Inverse Distance Weighted (IDW) interpolation layers and summing the values of the pixels in each resulting "column". The result is the total interpolated biomass of all individuals of the included species in that cell, for example forage fish (Figure 8; see Table 16 for complete list of species in this group).

Note that individual fish species IDW maps calculate biomass on a natural logarithm scale, and these aggregate maps are raw biomass, in kilograms.

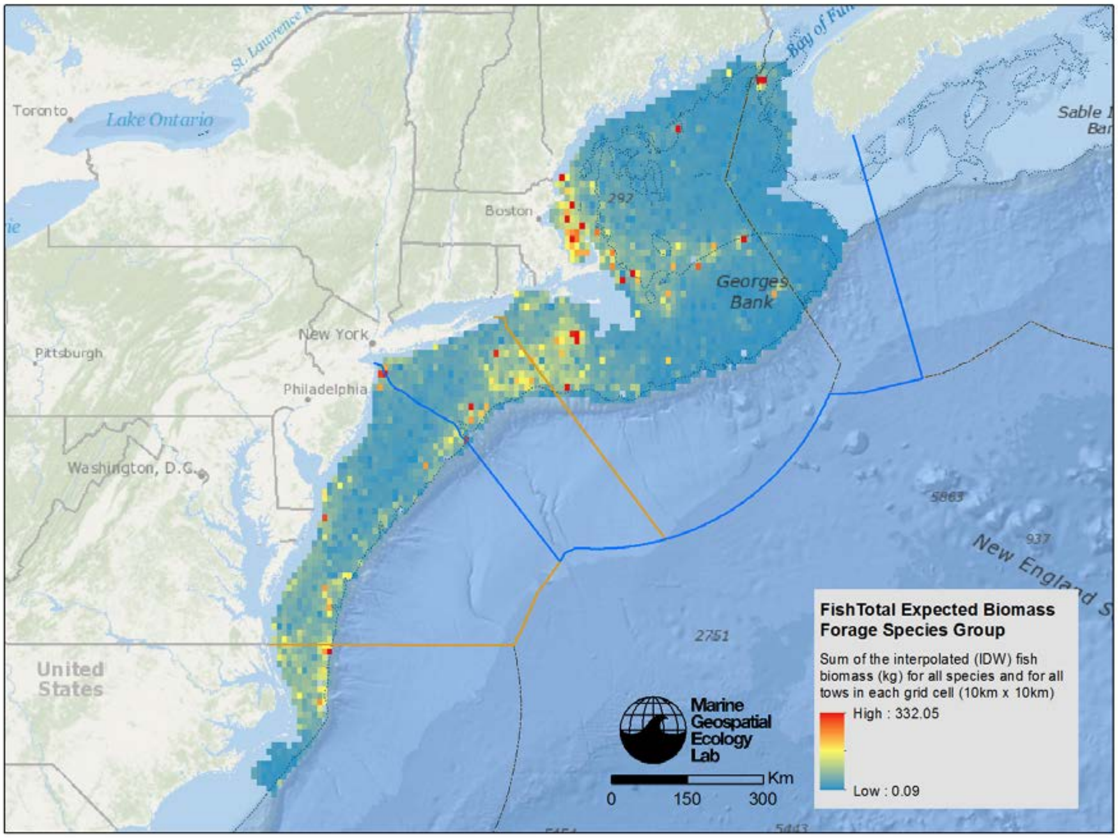

FIGURE 8 Total expected fish biomass per tow for the forage fish group (kg). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.3.3 CETACEAN TOTAL ABUNDANCE

For all cetacean species together, and for each group of species defined in Section 3.2 of this report, total abundance maps are calculated in a GIS by stacking each individual species' predicted annual abundance layers and summing the values of the pixels in each resulting "column". The result is the total predicted abundance of all individuals of the included species in that cell. For example, total predicted annual abundance for baleen whales (Figure 9, left) are most abundant north of Cape Hatteras, along the shelf break, around the Gulf of Maine and in Cape Cod Bay, Stellwagen Bank, and Jeffreys Ledge, while sperm & beaked whales (Figure 9, right) have higher abundance on the shelf break and in deeper waters, around canyons.

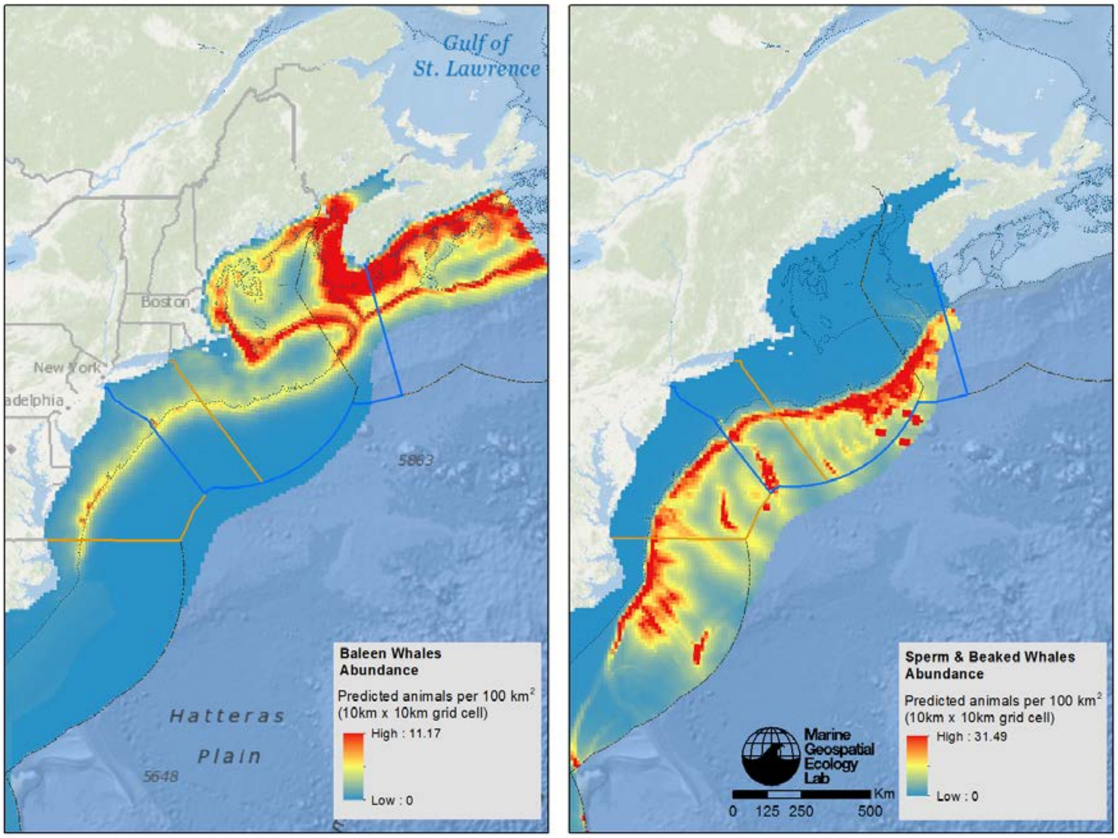

FIGURE 9 Total predicted annual abundance for baleen whales (left) and sperm & beaked whales (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.4 SPECIES RICHNESS

3.4.1 AVIAN SPECIES RICHNESS

For all avian species together, and for each group of species defined in Section 3.2 of this report, total species richness maps are calculated in a GIS by stacking each individual species' predicted presence or absence and counting the total number of species present in each cell. Comparing nearshore (Figure 10, left) and offshore species (Figure 10, right), the nearshore group has the highest richness along the coastline from about Cape Hatteras to New Jersey, while the offshore/pelagic group has the highest richness offshore in the Gulf of Maine and over Georges Bank.

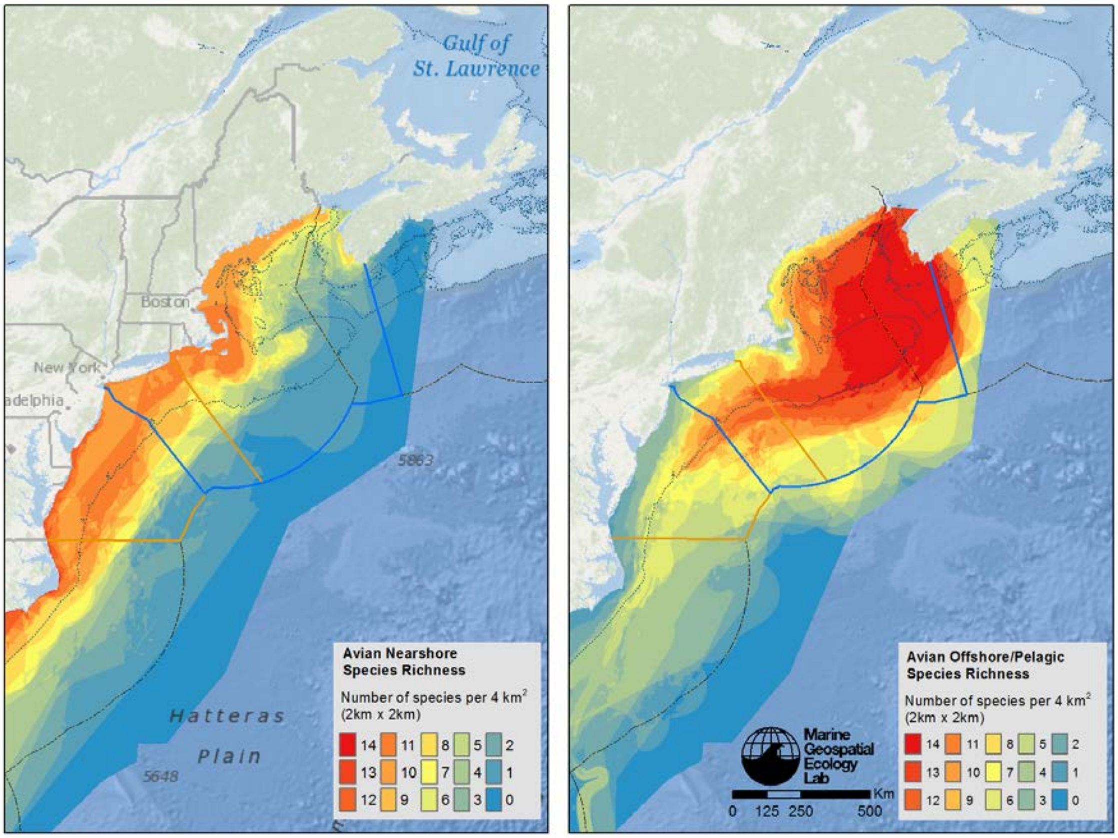

FIGURE 10 Species richness for two groups of avian species: nearshore (left) and offshore/pelagic (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.4.2 FISH SPECIES RICHNESS

For all fish species together, and for each group of species defined in Section 3.2 of this report, total richness maps are calculated in a GIS by stacking each individual species' predicted presence or absence and counting the total number of species present in each cell. Comparing "all species" group with the demersal species group, the highest richness value is 25 species for all (Figure 11, left), and 14 for demersal (Figure 11, right). Similarities can be seen in the pattern of high richness in the Gulf of Maine along the shore and through the Great South Channel and above Georges Bank. Differences in richness are highlighted south of Cape Cod, with far less richness in demersal species than there is in overall richness. A filter of 1.5 kg was applied to determine species presence or absence – the species is considered present if the raw biomass value is greater than 1.5 kg.

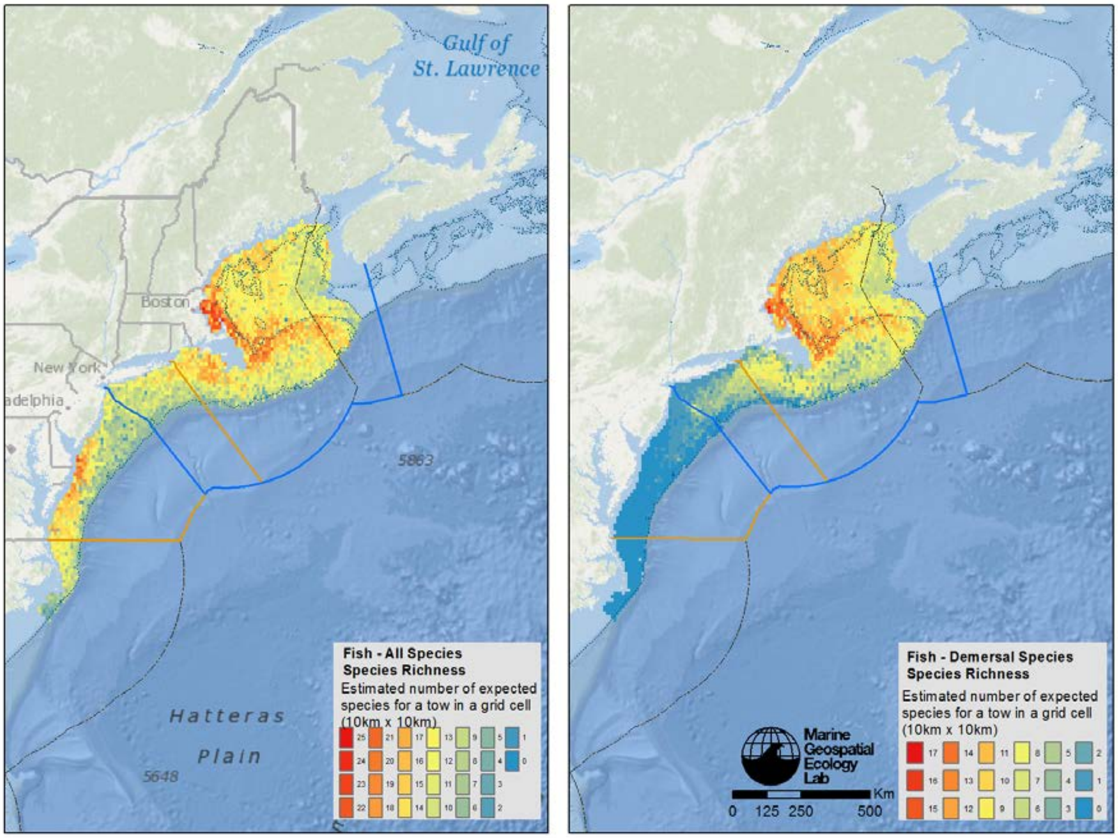

FIGURE 11 Fish species richness, comparing all fish species (left)with the demersal fish species group (right). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.4.3 CETACEAN SPECIES RICHNESS

For all cetacean species together, and for each group of species defined below, total richness maps are calculated in a GIS by stacking each individual species' predicted presence or absence and counting the total number of species present in each cell. A species is considered present in a cell if that cell is included in the area holding 99% of the total predicted abundance for the species.

Some of the individual models for mammal species were for species groups or guilds. For example, the beaked whale model is based on data from five beaked whale species (Blainville's beaked whale, Cuvier's beaked whale, Gervais' beaked whale, Sowerby's beaked whale, and True's beaked whale). This was done to create the best available model at the guild level when not enough data were available to create robust models at the individual species level. To better reflect true species counts in the richness map products, these guild density maps were counted as multiple species. Each beaked whale cell counted as five species (Blainville's beaked whale, Cuvier's beaked whale, Sowerby's beaked whale, and True's beaked whale).

A comparison of cetacean richness for baleen whales (Figure 12, left) and sperm & beaked whales (Figure 12, right) shows baleen whales have the highest richness on the shelf, in waters shallower than 150m, and the deep diving sperm and beaked whales have the highest richness off the shelf.

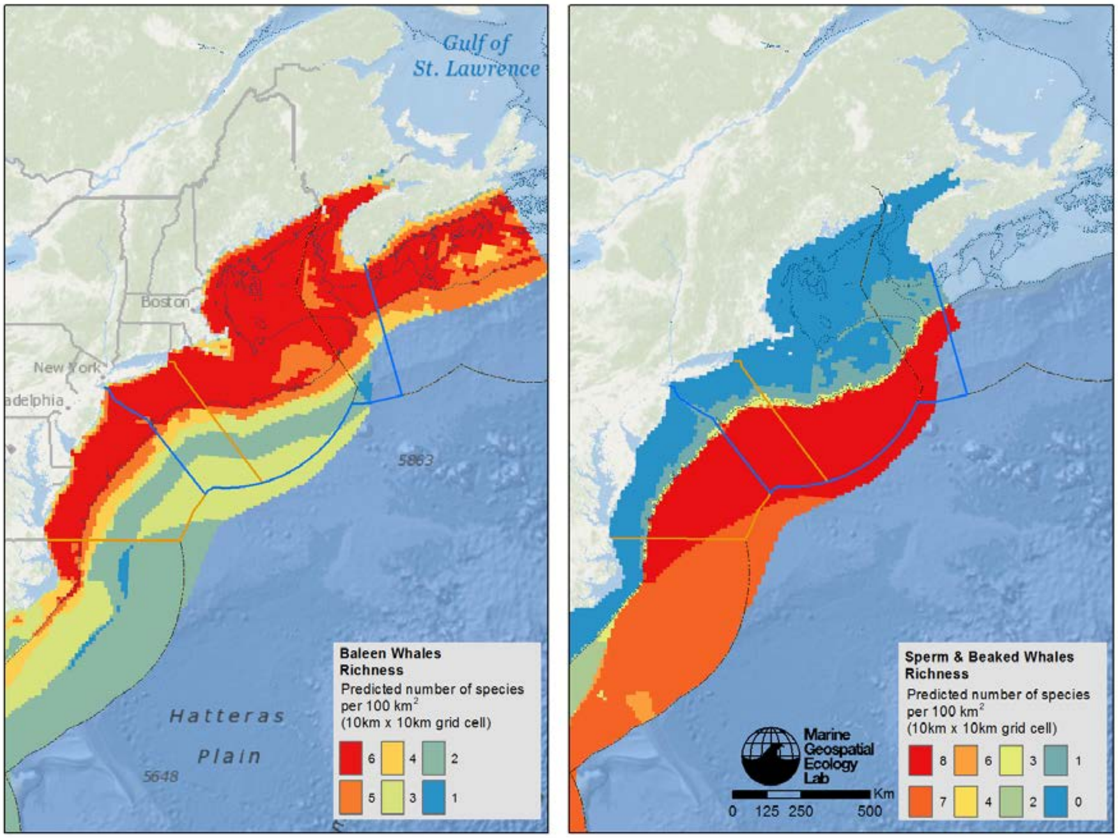

FIGURE 12 Comparison of mammal richness for baleen whales (left) and sperm & beaked whales (right). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.5 DIVERSITY

The Shannon diversity index (Shannon & Weaver, 1949) was used to create maps showing areas of high and low biodiversity. The Shannon index considers both abundance and evenness of species in an area in the calculation of diversity. Areas with high Shannon index scores have a large number of species (relative to the total number of species being considered in the area), as well as overall similar abundances (or biomass for fish) of these species. Areas that have a large number of species, but are dominated in abundance or biomass by only a few species, will not score as high on the Shannon index. The index approaches zero if the abundance is dominated by one species, regardless of how many other rare species occur in the area. The index is maximized when all the species evaluated have equal abundances, and it then equals the natural log of the species richness value (the number of species, or R). For fish biomass diversity products, cells with less than 2kg of biomass were excluded. The formula used to calculate the index, and the term definition, are given below:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

p_i is the number of individuals belonging to the *i*th species

R is richness, equal to the total number of species

3.5.1 AVIAN DIVERSITY

Avian diversity for the “all species” group and for the state-listed species group (Figure 13; see table 8 for species group definition) differ in their patterns of high diversity, with the “all species” group having more areas of higher diversity in the nearshore mid-Atlantic region, and the state-listed species group having high diversity areas occurring in a narrower band offshore of the mid-Atlantic region.

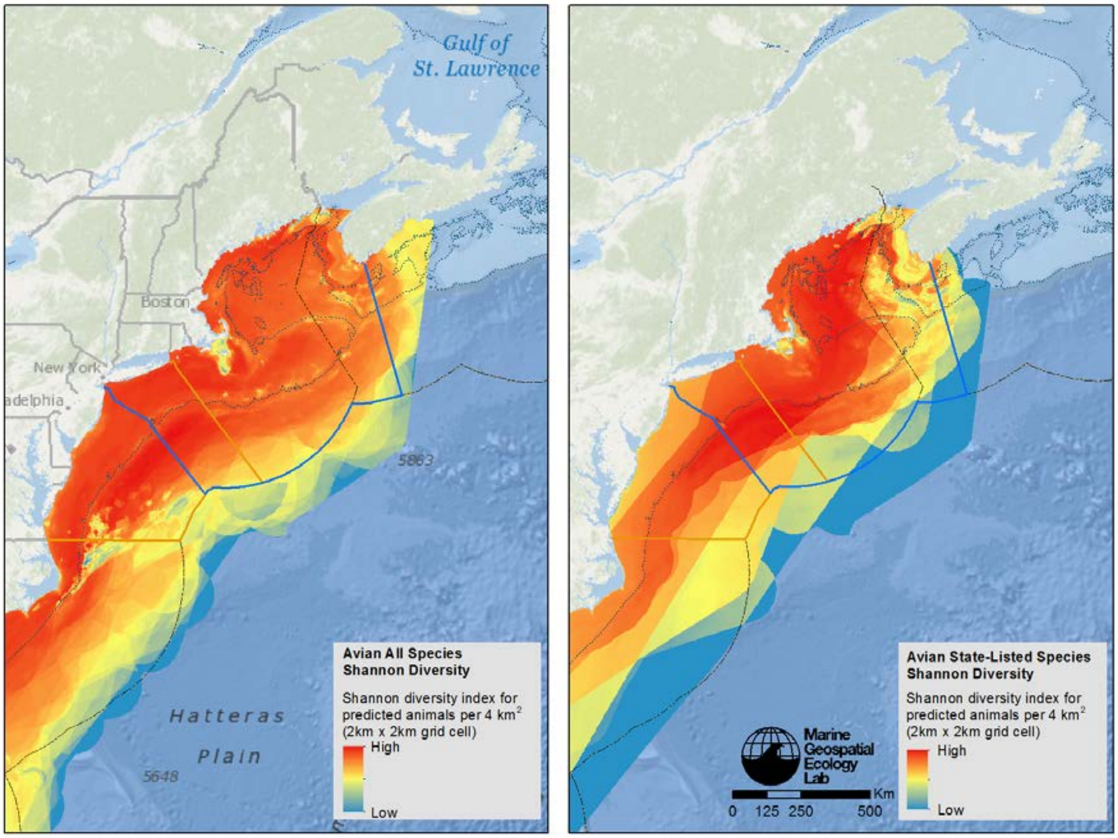

FIGURE 13 Diversity for avian species, comparing all species (left) and only state listed species (right; see table 8 for species group definition). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.5.2 FISH DIVERSITY

Fish diversity for species included in the Atlantic States Marine Fisheries Commission (ASMFC) fisheries management plans (Figure 14, left) and species managed under the Northeast Multispecies (Groundfish) Fishery Management Plan (Figure 14, right; see Table 10 for regulated species group definitions). The species managed by the mid-Atlantic have higher diversity along the mid-Atlantic coastal states, while the species included in the northeast plans have higher diversity in the Gulf of Maine.

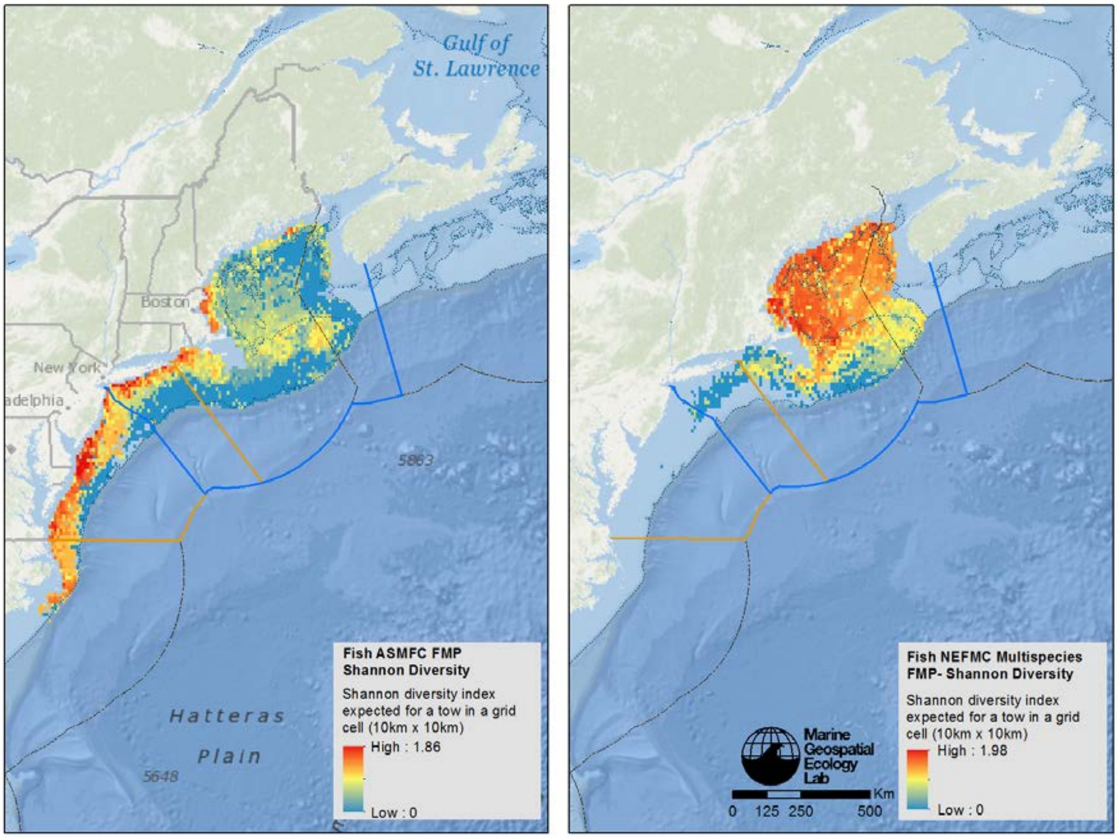

FIGURE 14 Fish diversity for two regulated species groups (see Table 10 for regulated species group definitions). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.5.3 CETACEAN DIVERSITY

Cetacean diversity, comparing small (Figure 15, left) and large (Figure 15, right) delphinoid species groups. Small delphinoids are dominated by short-beaked common dolphins along the shelf break, lowering the overall species diversity in that region for that group. Similarly, for large delphinoids the diversity is lower in a narrow band along the shelf break due to the high abundances of Risso's dolphins and, to a lesser degree, long-finned pilot whales.

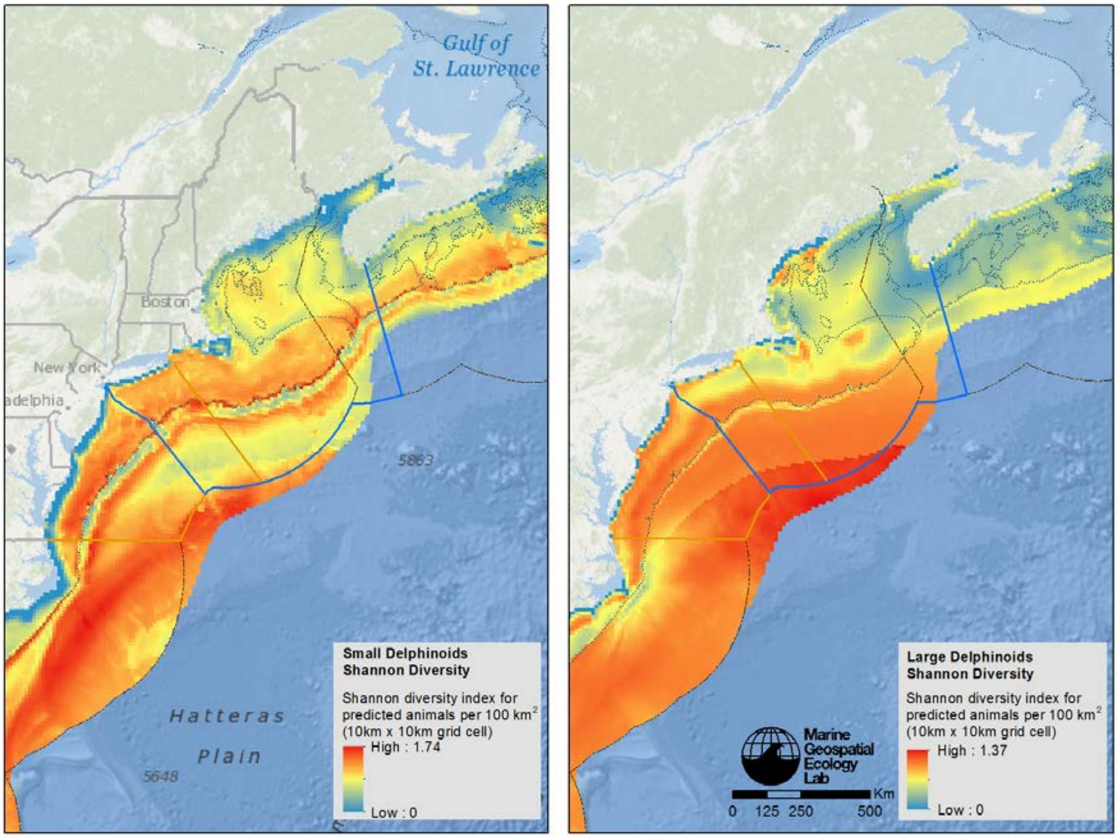

FIGURE 15 Cetacean diversity, comparing small and large delphinoid species groups. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.6 ABUNDANCE OR BIOMASS CORE AREA RICHNESS

Mammal and avian models predict animal density or relative abundance over a particular spatial extent, but the animals are not evenly distributed across this extent. Sometimes it is helpful to more clearly visualize areas with higher densities. One way to do this is to calculate the smallest area that contains a certain percentage of the population. A cumulative distribution function plot can show optimal balance between total area covered and percent of population included. In this effort, the focus was on the ability to easily convey the method and concept to a wide audience with varying levels of statistical and technical backgrounds. A population threshold of 50% visually conveys two areas, each of which contains half the predicted population. This is an easy to understand threshold: half the population falls within the identified core area, and half the population occurs outside of it.

Summing all the cells in the species distribution prediction gives the total predicted abundance. Core area is calculated by ordering cells by their abundance value from greatest to least, then selecting cells with the highest abundance values and totaling those values until enough cells have been selected for the total to be equal to or greater than 50% of the total predicted abundance.

3.6.1 CORE AREA RICHNESS CAVEATS AND CONSIDERATIONS

- Calculations for marine mammal core abundance area richness did not include uniformly distributed models. So-called stratified models showing uniform density were created when there were not enough sightings to create a habitat-based density model. For some species, there was enough information in the literature to have the models be bounded by geographic or biological features, such as the Gulf Stream or a particular depth contour. See section 2.4.1 for more details.
- Avian core relative abundance area richness products were calculated using the mean-normalized relative abundance individual species layers.
- Extent matters. Because cells are ordered based on their abundance or biomass value, the cells that are included in that list – in the area of interest – will make up the total abundance or biomass that the threshold is applied to. For this effort, core abundance areas were created for the mid-Atlantic region, the Northeast region, and the full US Atlantic Coast scale. Included in this report is a subset of the mid-Atlantic and full US Atlantic Coast scale results.

3.6.2 AVIAN CORE AREA RICHNESS

Avian relative abundance 50% core area richness for species of higher collision sensitivity at the full US Atlantic coast scale (Figure 16, left) indicates high species core area richness along the shoreline in the mid-Atlantic area. When calculated at the mid-Atlantic regional scale extent (Figure 16, right), more areas of localized high core area richness are present in a wider area of the shoreline and along the shelf break in the northern portion of the region.

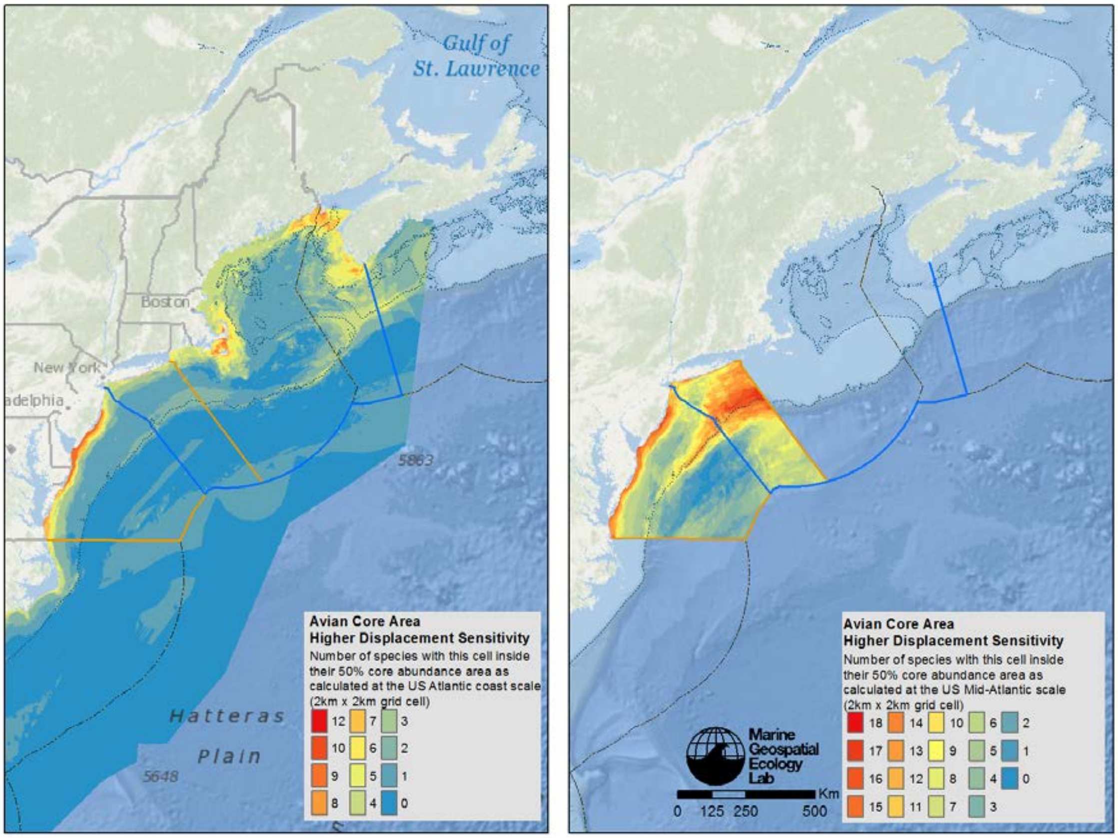

FIGURE 16 Avian core relative abundance area richness for species of higher collision sensitivity at the full US Atlantic Coast scale (left), and at the mid-Atlantic regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.6.3 FISH CORE AREA RICHNESS

Fish core biomass area richness was calculated on the raw biomass values. NEFSC “all species” group 50% biomass core area species richness at the US Northeast Shelf scale (Figure 17, left) and calculated for the mid-Atlantic region (Figure 17, right). More cells with higher richness values are present in the region of interest when the calculation is restricted to that extent.

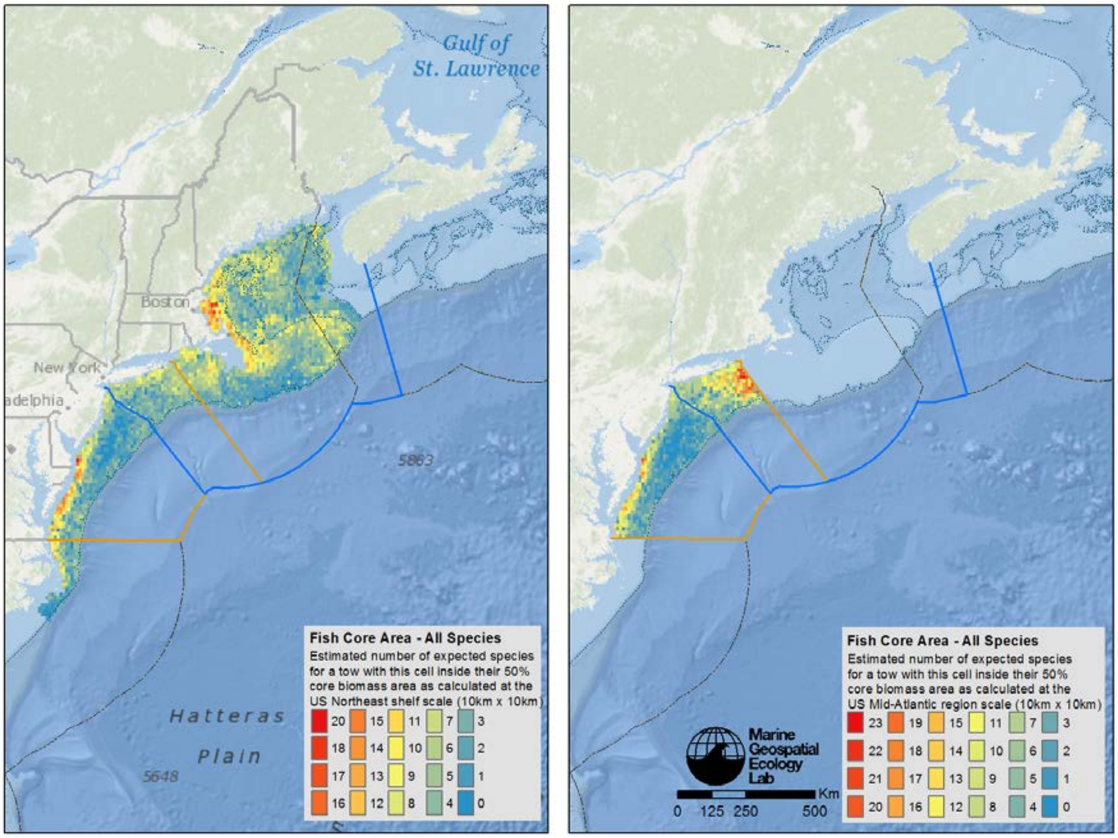

FIGURE 17 Fish core biomass area richness. NEFSC all species 50% core biomass area species richness at the US east coast scale (left) and calculated for the mid-Atlantic region (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.6.4 CETACEAN CORE AREA RICHNESS

Cetacean species core area richness is high along the shelf break in the mid-Atlantic region (Figure 18, right) when calculated at that extent, but is shifted to the waters off Newfoundland and in the Great South Channel when calculated at the full US Atlantic Coast extent (Figure 18, left).

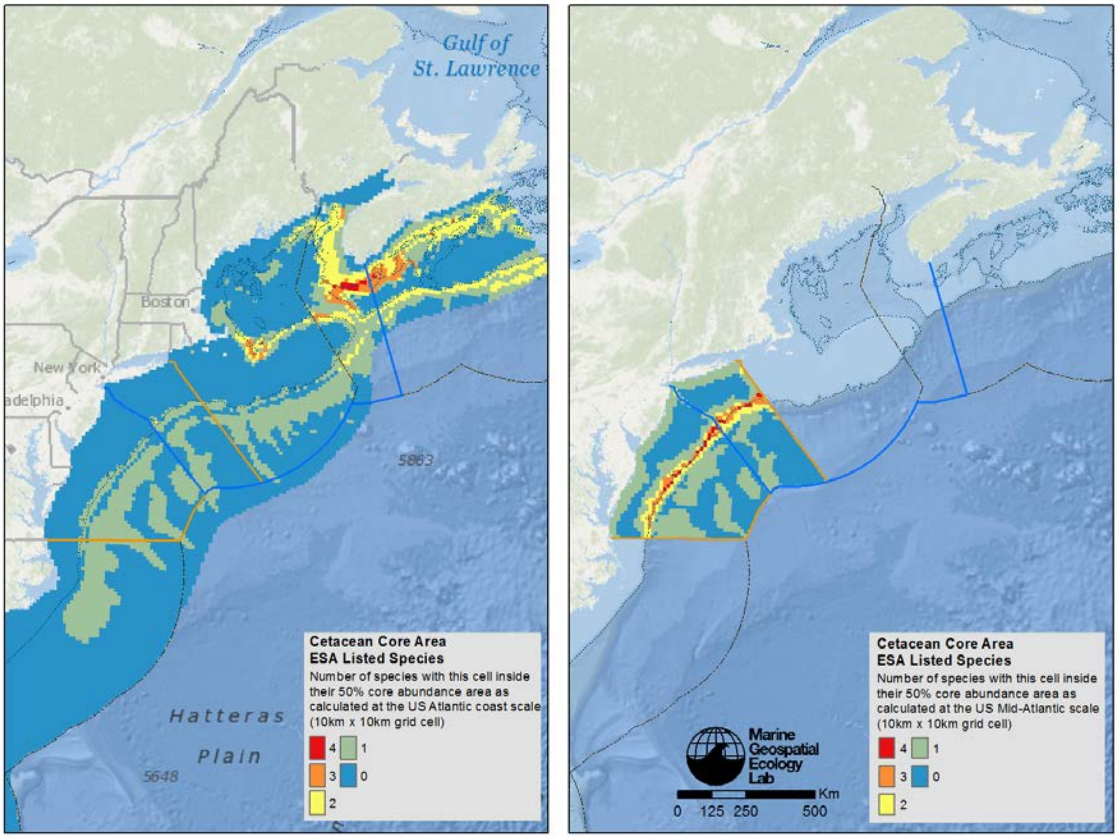

FIGURE 18 Cetacean core abundance area species richness for the ESA species group calculated at the US Atlantic Coast (left) and calculated for the mid-Atlantic region (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

4 ECOLOGICALLY RICH AREAS

Individual species density predictions and data summaries as described in Section 2 are directly useful for a wide range of existing ocean management applications. Creating species group summaries (Section 3) further distills these many layers into synthetic products that might address more comprehensive marine spatial planning needs. However, the sheer number of synthetic datasets can still be overwhelming. Additional data summarization can contribute to broader efforts to address regional ocean planning and to an across-taxa identification of areas of high abundance, richness or diversity.

MDAT deliverables included an exploratory analysis on the challenges to identify core species abundance areas or "ecologically rich areas" (ERAs) in the Mid-Atlantic Region. Such an approach contributes to recommendations from the US Interagency Ocean Policy Task Force to describe "important ecological areas, such as areas of high productivity and biological diversity; areas and key species that are critical to ecosystem function and resiliency; areas of spawning, breeding, and feeding; areas of rare or functionally vulnerable marine resources; and migratory corridors." (Interagency Ocean Policy Task Force & Council on Environmental Quality (U.S.), 2010)

The central challenges to describing ERAs are as follows:

1. Identify and define the set of criteria to define an Ecologically Rich Area
2. Identify appropriate datasets to address each criterion and capture data gaps
3. Identify the combinatorial rules and approach for analyzing these relevant data to describe ERA boundaries or occurrence

The MDAT work described in this section highlights some approaches on challenges 1 and 2 above and frames the discussion for challenge 3. Work on all 3 challenges is ongoing, with the guidance of the Mid-Atlantic RPB, regional stakeholders and from similar processes in adjacent regions (US Northeast, US Southeast).

4.1 DATA CAVEATS AND CONSIDERATIONS

Initial challenges that MDAT focused on were related to the definition of the ERA concept. There remains some fluidity in the use of this term across the Mid-Atlantic region, but efforts described below narrowed the conversation and highlighted the decisions needed to address ERA description. Additional focus emerged from presentations on the specific utility of the abundance and biomass data products described in section 2, which helped the RPB and regional stakeholders better understand the limitations and possible applications of these data to the ERA concept. Exploring the ERA concept as described herein was an effort to take a simple initial approach that would highlight both possibilities and challenges and to solicit guidance from the region.

It is important to reinforce that the MDAT products alone will not fully or directly address all measures of ecological richness. Additional marine-life, habitat, and productivity data will improve regional understanding of species and habitat richness.

Map products in this section do not represent an endpoint, but rather an in-progress exploration of how existing data may inform the ERA description process in the region under the auspices of the Mid-Atlantic RPB. Follow-on MDAT work in 2016 will build additional information toward a more comprehensive evaluation of the ERA description process through these and possibly other datasets.

4.2 EXPLORATORY APPROACH

As a starting point, the synthetic products for Core Abundance/Biomass Area Richness for the "All Species" groups for each taxon group were considered. These Core Area products focus on areas with the highest abundance or biomass for individual species, and then combine those areas for each taxon (see section 3.6 above for more detail) into a species richness count. As discussed in section 3 above, the choice of the extent over which to perform the Core Area analysis directly affects the results. The extent is a "spatial denominator" over which a regional population is totaled and percentages calculated. Two extents were used for the exploratory analysis, the full extent of each dataset (Figures 4, 5 - NEFSC, & 6) and the Mid-Atlantic planning area (Figure 3).

A four class system was used with a Jenks Natural Break algorithm to determine the class split levels for each taxon's Core Abundance/Biomass Area Richness product. The Jenks approach is malleable to the distribution of the data and seeks to minimize within class variance and maximize between class variance (Jenks 1967). Of the 4 richness classes, the cells contained within the top class were extracted, to be visualized with other potential ERA datasets (Figures 19-21).

A suite of other classification options was also considered (Equal Interval, Quantiles, and Head-Tails Breaks) and may yet be used for the final approach. In addition, classification of the other synthetic data products might also prove useful.

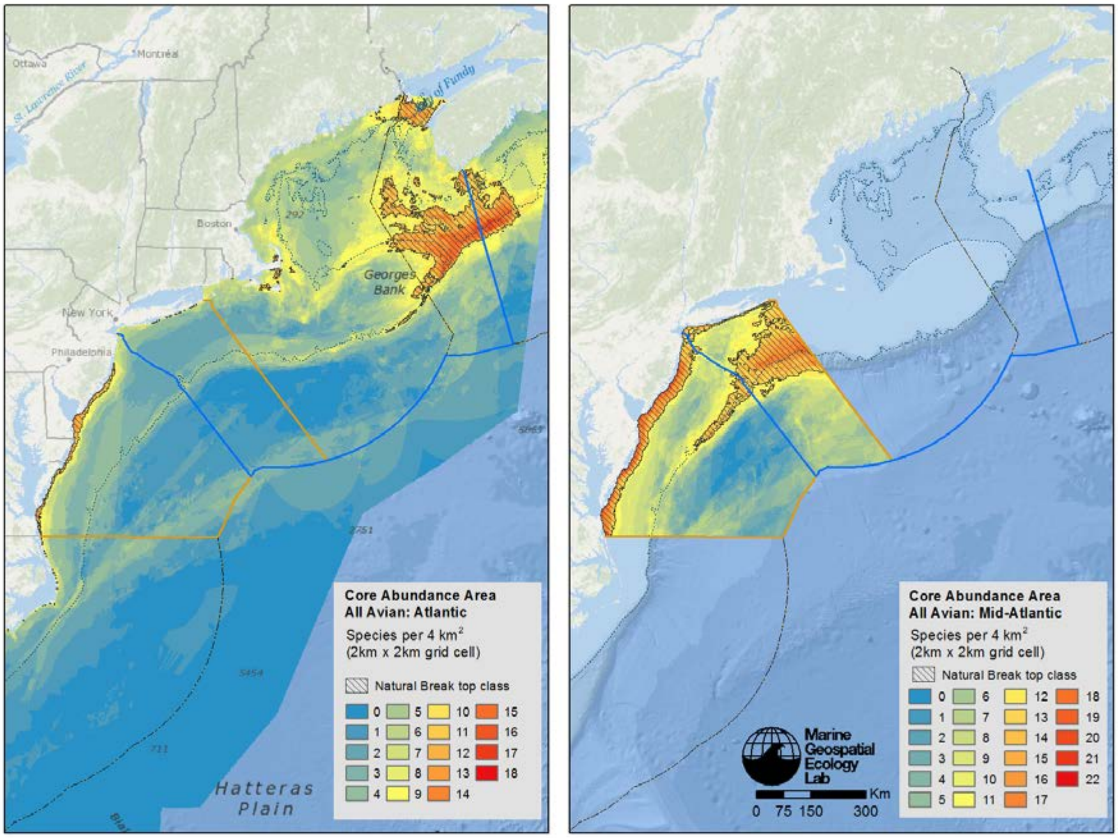

FIGURE 19 Core abundance area richness for the avian "all species" group, with the top Jenks Natural Break class identified.

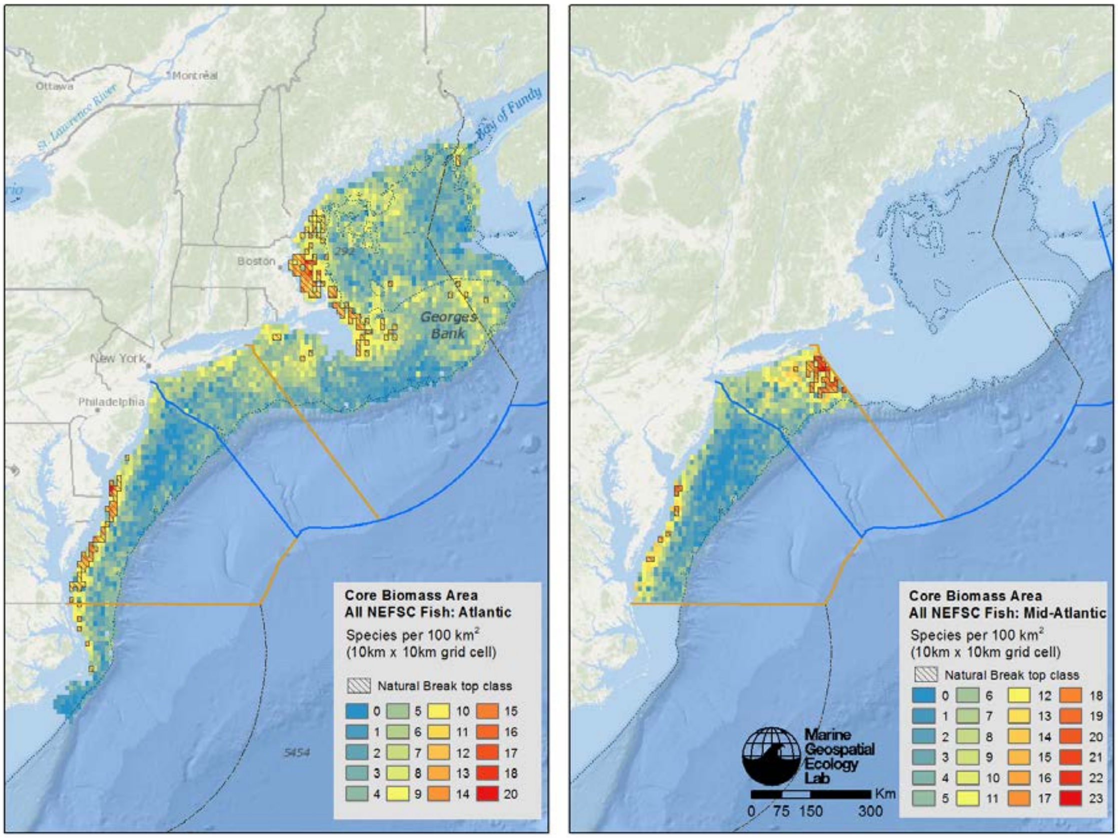

FIGURE 20 Core biomass area for the fish "all species" group from the NEFSC data source, with the top Jenks Natural Break class identified.

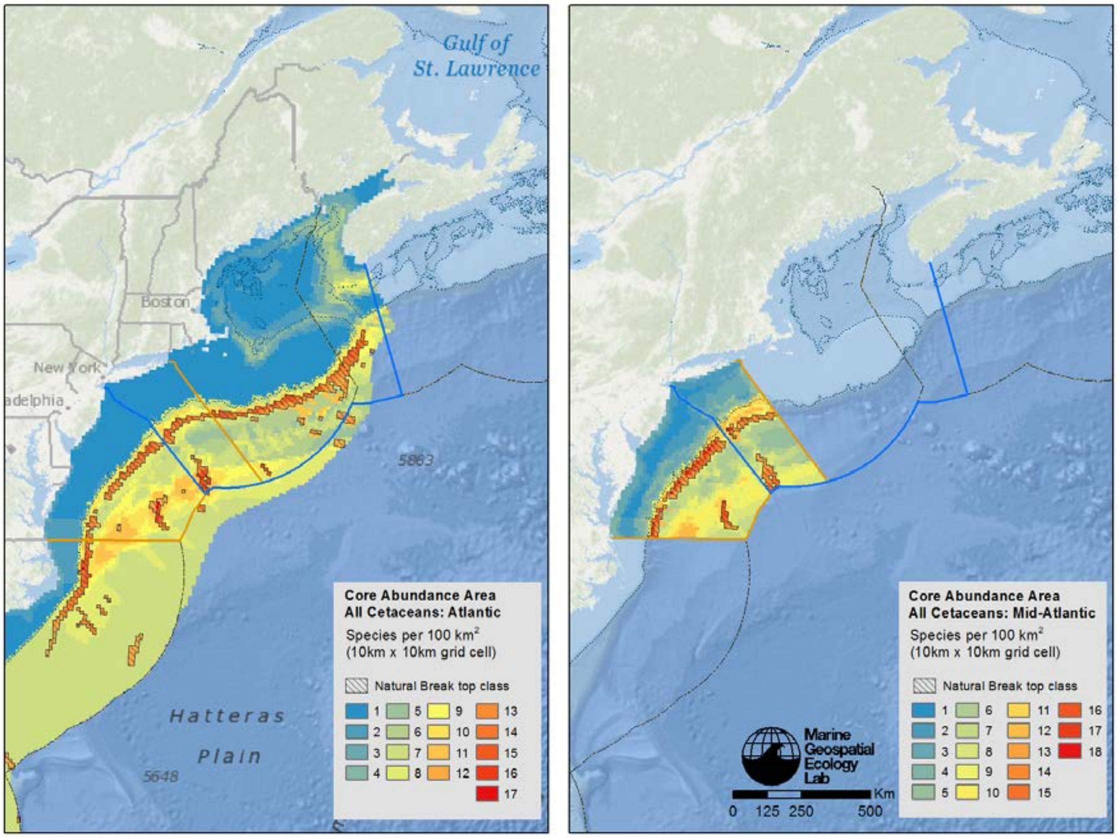

FIGURE 21 Core abundance area richness for the cetacean "all species" group, with the top Jenks Natural Break class identified.

Another regionally important dataset to help identify potential ERAs is the habitat model for deep-sea coral species, because deep-sea corals grow slowly, are long lived, provide habitat for many other species and are easily impacted by human activities. The deep-sea coral input was derived from habitat suitability modeling done by NOAA NCCOS (Kinlan et al. 2010). For each coral model (at the taxonomic level of "order"), the class of "Very High" habitat suitability was extracted. These areas were then combined, resulting in a count of the number of models with "Very High" predicted habitat suitability. (Figure 22)

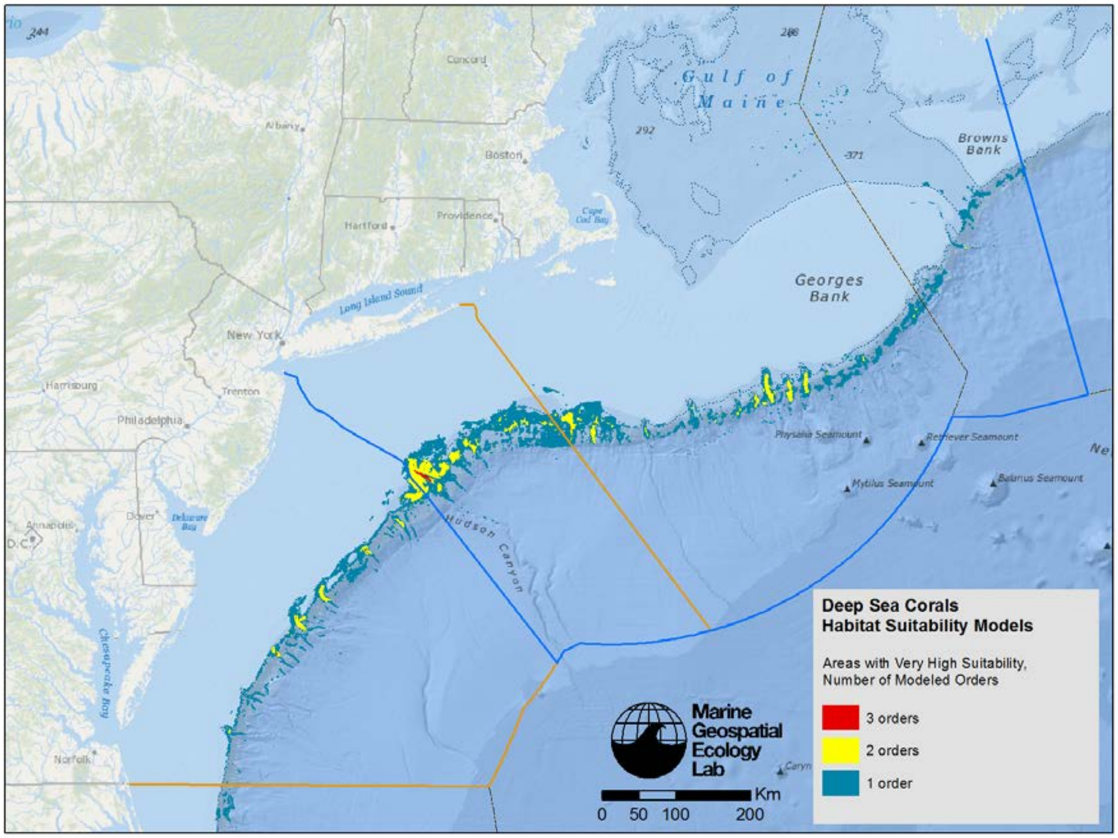

FIGURE 22 Number of overlapping areas of "Very High" predicted suitability for deep sea coral habitat.

Marine canyons cutting into the shelf break and slope are another important input for potential ERA description. During this initial exploration phase, the location and extent of the canyons in the Mid-Atlantic were included as an input dataset (Figure 23). Careful consideration needs to be given in how to include canyons in ERA description process, because canyons are also used as a predictor in several of the marine mammal models and are a feature in the habitat suitability models for deep-sea corals. A recent publication on global marine geomorphology provided the latest detailed dataset on marine canyons (Harris et al. 2014).

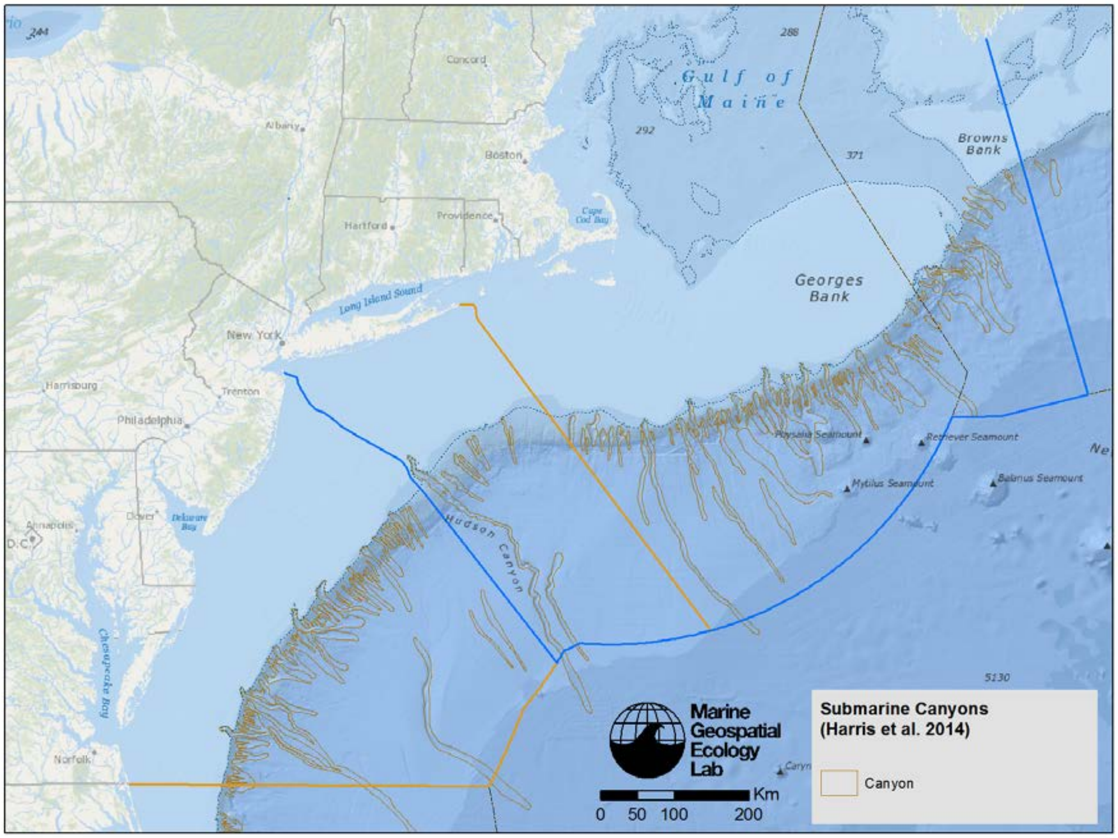

FIGURE 23 Submarine canyons

An additional dataset that might provide additional context for described ERAs is the benthic habitat dataset from the "Northwest Atlantic Marine Ecoregional Assessment" (NAMERA; Figure 24; Greene et al. 2010). These data were included in the initial set of exploratory map products.

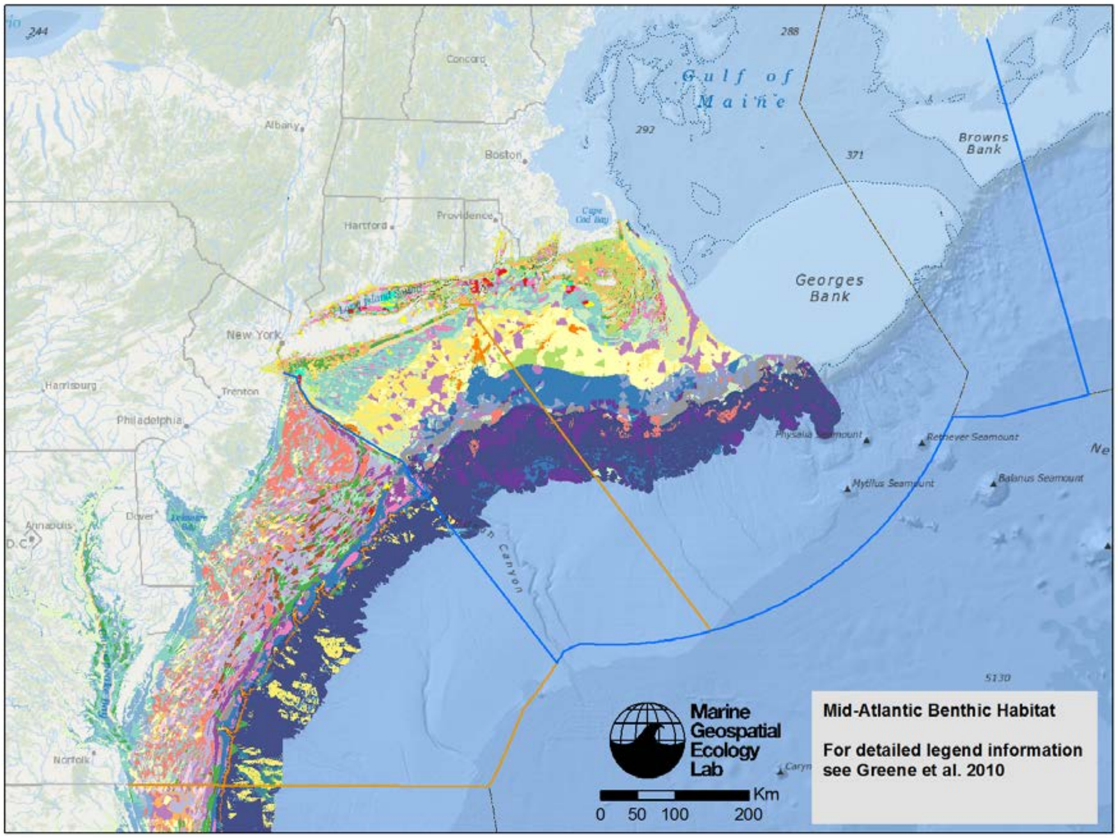

FIGURE 24 NAMERA Mid-Atlantic benthic habitat dataset

Once the datasets were created and assembled, a series of maps were created to stimulate discussion on outstanding ERA approach topics; how to define ERA criteria, what data should be included as inputs to an ERA description approach and how to combine disparate datasets to best inform and describe ERAs.

4.3 NEXT STEPS

The MDAT work stopped at the point of identifying potential input datasets to ERA description, leaving the work to describe ERAs for a follow-on project. Further consideration by the RPB, and other regional stakeholders is suggested to refine the definition of ecologically rich areas, consider which datasets to include, and refine the approach to combine input datasets. In addition, future work could consider if other existing important area descriptions (Biologically Important Areas (Van Parijs et al. 2015, LaBrecque et al. 2015), critical habitat, essential fish habitat) might help inform the ERA description process.

The MDAT team is reviewing comments received from public meetings, RPB discussions, and regional scientists about the ERAs, and is linking this process with analogous discussions with the Northeast RPB. Follow-on funding from MARCO is secured for the MDAT team to create a first iteration of regional ERAs and to continue to engage with regional stakeholders and scientists. Work in 2016 will be conducted to support the Mid-Atlantic Regional Planning Body.

5 DATA ACCESS

Given the multi-region scope of the MDAT work and potential interest from national data portals, a web service approach was identified as the most appropriate and efficient way to provide access to the MDAT data, models and synthetic products. This approach is generally compatible with the existing MARCO Ocean Data Portal. A centralized data store of web services also allows the MDAT team to maintain the data through improvement and model update cycles. The collation of metadata for MDAT products is ongoing, with the focus on existing documentation for models and data at the individual species level and developing new metadata for the synthetic products.

5.1 BASE MODELS AND DATA PRODUCTS

A series of ArcGIS Server REST web services were created for the base models and data products. A separate service was created for each type of model, data, and associated uncertainty products (see the list below). The MDAT team has committed to host web services of the individual models and data over the next several years. Discussion with the MARCO Ocean Data Portal team on ingestion of these services is ongoing.

- **Avian Abundance CI90**
- **Avian Abundance CV**
- **Avian Abundance**
- **Avian Occurrence CI90**
- **Avian Occurrence CV**
- **Avian Occurrence**
- **Fish Biomass MDMF Species**
- **Fish Biomass MENH Species**
- **Fish Biomass NEAMAP Species**
- **Fish Biomass NEFSC Species**
- **Mammal 5 Percent**
- **Mammal 95 Percent**
- **Mammal Abundance**
- **Mammal CV**
- **Mammal Standard Error**

The individual models and datasets contributed by MDAT collaborators may also be distributed by those individuals as a required deliverable from the original funders of those products. At present, only the marine mammal models are publicly distributed via a website hosted by Duke University's Marine Geospatial Ecology Lab (see http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/)

5.2 SYNTHESIS PRODUCTS

An ArcGIS Server REST web service was created for each MDAT generated synthetic product. Within each taxonomic group, species groups (see Section 3.2) are the top level of organization. The full set of synthetic product layers are available within each species group, as outlined below. MDAT has committed to host web services of synthetic products over the next several years. Discussion with the MARCO Ocean Data Portal team on ingestion of these services is ongoing.

- **Avian | Fish | Mammals Synthetic Products**
    - **Species Group 1**
        - Abundance | Biomass
        - Species Richness
        - Diversity
        - Core Abundance | Biomass Area – Northeast scale
        - Core Abundance | Biomass Area – Mid-Atlantic scale
        - Core Abundance | Biomass Area – Atlantic scale
    - **Species Group 2**
        - …

6 SCIENCE AND RESEARCH NEEDS

MDAT will continue to work with the Mid-Atlantic Regional Planning Body to update existing marine-life data products, to increase products, and to continue exploration of the Ecologically Rich Areas (ERAs). Listed below are some potential areas of future work under this partnership.

6.1 AVIAN

MGEL will continue to coordinate with NCCOS in their efforts to update the avian models, and will continue to work with Loyola University Chicago to incorporate their extreme abundance models in the MDAT framework.

6.1.1 UPDATED RELATIVE ABUNDANCE AND OCCURRENCE MODELS

- Update models by including additional survey data from multiple sources
- Update models by revising and/or adding environmental predictor variables
- Potentially refine statistical modelling framework

6.1.2 EXTREME ABUNDANCE MODELS

Relative abundance and occurrence models are complemented by a collaboration with MDAT member Loyola University Chicago, through which predictive maps of persistence and probability of very large aggregations of marine birds are being developed. Extreme abundance analysis is especially important for assessing potential risks of offshore activities to seaducks and other highly aggregative species. Loyola University will analyze a subset of the Compendium datasets (Table 1) for the “Priority 1” species (Table 2). The statistical models developed for this project used a Bayesian hierarchical approach to properly account for potential bias in offshore survey efforts, and to examine spatial extremes of count distributions (i.e., the large aggregations often reported in sea bird surveys and avoided in the analysis of such data). These model products are a grid of 4km x 4km cells, and used only two environmental co-variates: SST and chlorophyll. This tradeoff of larger cell size and few predictors results in temporal gain - the models predict monthly. Monthly predictions allow the assessment of the persistence of extreme aggregations. Loyal models will predict in embayments where survey data are available, however predictions will not be produced in the Bay of Fundy, or in offshore areas beyond the 400m isobath.

6.2 FISH

MGEL will continue to coordinate with the NEFSC to improve the fish dataset in the MDAT framework.

- MDAT may work with the NEFSC to understand if methods can be developed to normalize data across the different sources (NEFSC, NEAMAP, MDMF, ME/NH).
- MDAT will work with MARCO to obtain and process alternative data sources that reflect commercial and recreational fishery data.

6.3 MARINE MAMMALS AND SEA TURTLES

MGEL is already engaged and continuing improvements to the suite of marine mammal models, including additional, more recent, data sources and adding sea turtle models.

- Incorporate AMAPPS Phase I data into marine mammal models, where applicable
- Evaluate and potentially include the Massachusetts Clean Energy Center data
- Evaluate new data and create sea turtle models

6.4 ECOLOGICALLY RICH AREAS

The MDAT team is reviewing comments received from public meetings, RPB discussions, and regional scientists about the ERAs, and is linking this process with analogous discussions with the Northeast RPB. Follow-on funding from MARCO is secured for the MDAT team to create a first iteration of regional ERAs and to continue to engage with regional stakeholders and scientists.

- Create the first iteration of Ecologically Rich Areas (ERAs) using available data and criteria developed in coordination with Northeast ocean planning partners and Mid-Atlantic scientists and stakeholders.
- Identify additional data needs to advance ERA mapping over the long term.
- Engage experts as needed through meetings and correspondence to:
    - Evaluate synthetic products and Biologically Important Areas (BIAs) from NOAA's Cetacean and Sound Mapping Project
    - Supplement and verify model outputs with additional information on additional life history factors not characterized by abundance data (e.g. migratory corridors, nursery habitat, etc).

7 ACKNOWLEDGEMENTS

Sources for avian base-layer products

NOAA National Centers for Coastal Ocean Science. This study was funded in part by the U.S. Department of the Interior, Bureau of Ocean Energy Management through Interagency Agreement M13PG00005 with the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), National Centers for Coastal Ocean Science (NCCOS). This product represents results of predictive modelling applied to data from the 'Compendium of Avian Occurrence Information for the Continental Shelf waters along the Atlantic Coast of the U.S.' database developed and maintained by USGS and USFWS. For more information, please contact Brian Kinlan (NCCOS Biogeography Branch, Silver Spring, MD).

Sources for fish base-layer products

Northeast Fisheries Science Center (NEFSC) Ecosystem Assessment Program. Data sourced from fall bottom trawl surveys performed by NEFSC (1970-2014), Northeast Area Monitoring and Assessment Program (2007-2014), Massachusetts Division of Marine Fisheries (1978-2014), and the Maine Department of Marine Resources and New Hampshire Fish and Game Department (2000-2014). These products represent the results of aggregating and interpolating trawl point data along the US east coast from North Carolina to Maine. For more information, please contact Michael Fogarty.

Sources for marine mammal base-layer products

Marine Geospatial Ecology Lab (MGEL) at Duke University. This product was developed by MGEL in collaboration with colleagues at the National Oceanographic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS), the University of North Carolina, Wilmington (UNCW), and the Virginia Aquarium & Marine Science Center (VAMSC). It was derived from habitat-based density models for marine mammals built from shipboard and aerial line transect surveys conducted at sea between 1992-2014 by the NMFS Northeast and Southeast Fisheries Science Centers, UNCW, VAMSC, and the New Jersey Department of Environmental Protection. The UNCW surveys were funded by U.S. Navy Fleet Forces Command and NOAA. The VAMSC surveys were funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Task 1 of Grant NA12NOS4190027 and Task 95.02 of Grant NA13NOS4190135 from NOAA, under the Coastal Zone Management Act of 1972, as amended. The density models were initially developed with funding from the National Aeronautics and Space Administration and U.S. Navy Fleet Forces Command, and further elaborated with funding from the Northeast Regional Ocean Council. For more information, please contact Jason Roberts (jason.roberts@duke.edu).

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9 APPENDIX A - AVIAN MODEL PERFORMANCE

This appendix provides three types of supplementary information about the quality of the avian seasonal model predictions.

First, the temporal and spatial distribution of survey effort is presented in Figs 1-5. Most of the data were collected during the late 1970s, 1980s, and after 2000 (Fig. 1), and there was more survey effort nearshore than offshore (Figs 2-5). Model predictions in areas with few or no data should be interpreted with caution. Areas beyond the 95% survey effort density isopleth (Figs 2-5) are indicated on the seasonal species maps.

Second, the statistical performance of the model for each species-season combination was evaluated from a suite of performance metrics (Table 1). Then to provide an indication of the overall statistical performance of each model, four of the performance metrics were converted to numeric performance categories (Table 2), and the categories were averaged across these four metrics to provide a single numeric performance category for each model (5=highest to 1=lowest). The model performance metrics and categories for each species-season model are presented in Table 3. It is important to recognize that the model performance metrics and categories only reflect *the statistical fit of the models to the data*. They reflect only the data that were analyzed, and they do not necessarily reflect the quality of model predictions away from the data. For example, the survey data did not cover everywhere within the study area (Figs 2-5), so some model predictions are essentially interpolations/extrapolations from data in other parts of the study area. The accuracy of those predictions is not necessarily reflected by the model performance metrics. Nevertheless, the performance metrics and categories give an indication of how accurately a model was able to predict the observed data, and good performance provides a measure of confidence in the modelled distributions, especially within the temporal and spatial coverage of the observed survey data.

As a third assessment of model quality the maps were reviewed by a marine bird ecologist with substantial knowledge of and firsthand experience with the study area and species (Dr. Timothy White, NOAA National Centers for Coastal Ocean Science). For each species and season the correspondence between the modeled distributions of relative occurrence and abundance and what is known about the species' distribution was assigned a quality class: 'good', 'fair', or 'poor'. The quality class for each species-season model is presented in Table 3.

It is important to note that some model predictions exhibit a distortion that is evident as a dominant east-west trend in predicted relative occurrence and abundance, especially in offshore areas (i.e., vertical banding in the maps). This distortion is due to a bug in the computer code where one of the spatial coordinate predictors was scaled incorrectly when making spatial predictions, which sometimes distorted spatial patterns. It is difficult to quantify the amount of distortion in the predictions for any given model, but maps that exhibit a vertical banding pattern should be interpreted with caution, especially in areas with little survey effort. The performance metrics reflect the potentially distorted predictions, so good performance indicates that the model predictions more closely matched the observed data in areas with survey effort. The bug has been corrected in the next generation of models which are expected to be released in the future.

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Table 1. Model performance metrics.

Abbreviation	Performance metric	Interpretation
PDE	percent deviance explained	Percentage of deviance explained by the model; higher values indicate better performance; to calculate PDE, the saturated likelihood was assumed to be the maximum possible likelihood value, and the null likelihood was calculated from an intercepts-only zero-inflated model fit to the data (unpublished)
AUC	area under the receiver operating characteristic (ROC) curve	Ability of a model to classify transect segments with at least one sighting versus segments with no sightings (i.e., occurrence); higher values indicate better performance
AUC_nz	area under the receiver operating characteristic (ROC) curve	Ability of a model to classify the number of individuals counted as below or above the median count on transect segments with sightings; higher values indicate better performance
RankR_nz	Spearman's rank correlation coefficient	Correlation between observed and predicted counts on transect segments with sightings; higher values indicate better performance
RankRG_nz	Gaussian rank correlation coefficient[1]	Correlation between observed and predicted counts on transect segments with sightings; higher values indicate better performance
MedianAE_nz_rel	median absolute residual error	Absolute difference between observed and predicted counts relative to the mean count on transect segments with sightings; lower values indicate better performance
MedianBias_nz_rel	median residual error	Difference between observed and predicted counts relative to the mean count on transect segments with sightings; values closer to zero indicate better performance
CRPS_0	Brier score	Accuracy of the model when predicting the occurrence of a count ≥1; lower values indicate better performance
CRPS_Zinf	thresholded continuous rank probability score	Accuracy of the model when predicting a count in intervals defined by 150 equally spaced quantiles of the observed values; lower values indicate better performance

[1] Boudt et al. (2012) and Bodenhofer et al. (2013)

Table 2. Performance metric thresholds used to define model performance categories. Performance metrics are defined in Table 1. CV indicates that the metric was calculated with respect to test data during cross-validation (CV) tuning of the number of boosting iterations.

Performance metric	Performance category				
	1	2	3	4	5
PDE	x < 0.1	0.1 ≤ x < 0.2	0.2 ≤ x < 0.4	0.4 ≤ x < 0.6	x ≥ 0.6
AUC	x < 0.6	0.6 ≤ x < 0.7	0.7 ≤ x < 0.8	0.8 ≤ x < 0.9	x ≥ 0.9
RankRG_nz	x < 0.1	0.1 ≤ x < 0.2	0.2 ≤ x < 0.4	0.4 ≤ x < 0.6	x ≥ 0.6
MedianAE_nz_rel (CV)	x >= 2.0	2.0 > x ≥ 1.0	1.0 > x ≥ 0.5	0.5 > x ≥ 0.25	x < 0.25

Table 3. Model performance for all species and seasons. All model performance metrics (Table 1) were calculated on the full dataset, except for columns divided into 'Fit' and 'CV', which denote metrics calculated separately for the full dataset and for test data during cross-validation (CV) tuning of the number of boosting iterations, respectively. The overall model performance category is the rounded average of performance categories across four performance metrics (PDE, AUC, Rank RG_nz, and MedianAE_nz_rel (CV); Table 2). Particularly poor performance in terms of individual performance metrics is indicated in red.

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		**Overall model performance category**	**Model quality (expert opinion)**
							Fit	CV	Fit	CV	Fit	CV	Fit	CV		
arte	summer	0.11	0.94	0.74	0.44	0.41	0.36	0.41	-0.32	-0.37	0.000	0.000	0.000	0.000	**4**	**FAIR**
atpu	spring	0.34	0.93	0.71	0.41	0.4	0.44	0.44	-0.44	-0.44	0.010	0.010	0.010	0.010	**4**	**GOOD**
atpu	summer	0.53	0.98	0.7	0.41	0.47	0.44	0.46	-0.44	-0.46	0.010	0.010	0.010	0.010	**4**	**GOOD**
atpu	fall	0.4	0.96	0.7	0.32	0.37	0.69	0.7	-0.69	-0.7	0.000	0.000	0.000	0.000	**4**	**FAIR**
atpu	winter	0.4	0.95	0.58	0.17	0.22	0.55	0.55	-0.55	-0.55	0.010	0.010	0.010	0.010	**4**	**FAIR**
aush	spring	0.41	0.99	0.7	0.44	0.49	0.43	0.38	-0.16	-0.26	0.000	0.000	0.000	0.000	**4**	**FAIR**
aush	summer	0.51	0.95	0.73	0.44	0.46	0.32	0.32	-0.3	-0.31	0.020	0.020	0.020	0.020	**4**	**GOOD**
aush	fall	0.53	0.95	0.76	0.52	0.54	0.29	0.3	-0.29	-0.29	0.010	0.010	0.010	0.010	**4**	**FAIR**
aush	winter	0.76	1	0.84	0.61	0.63	0.38	0.48	-0.32	-0.45	0.000	0.000	0.000	0.000	**5**	**FAIR**
bcpe	spring	0.54	0.99	0.79	0.51	0.49	0.5	0.5	-0.32	-0.48	0.000	0.000	0.000	0.000	**4**	**GOOD**
bcpe	summer	0.63	0.98	0.78	0.53	0.54	0.34	0.35	-0.32	-0.35	0.010	0.010	0.010	0.010	**5**	**GOOD**
bcpe	fall	0.33	1	0.82	0.59	0.59	0.36	0.38	-0.17	-0.38	0.000	0.000	0.000	0.000	**4**	**GOOD**
bcpe	winter	0.28	1	0.95	0.84	0.81	0.39	0.66	-0.28	-0.39	0.000	0.000	0.000	0.000	**4**	**GOOD**
blgu	summer	0.33	0.99	0.58	-0.17	-0.17	1.7E+9	9.9E+8	1.7E+9	9.9E+8	0.000	0.000	0.000	0.000	**3**	**FAIR**
blki	spring	0.45	0.93	0.59	0.18	0.22	0.19	0.2	-0.19	-0.19	0.020	0.020	0.020	0.020	**4**	**FAIR**
blki	fall	0.58	0.94	0.69	0.38	0.4	0.18	0.19	-0.09	-0.1	0.050	0.050	0.040	0.050	**5**	**GOOD**
blki	winter	0.57	0.95	0.75	0.51	0.53	0.18	0.18	-0.06	-0.07	0.060	0.060	0.050	0.050	**5**	**GOOD**
blsc	spring	0.43	0.94	0.61	0.3	0.33	0.18	0.17	-0.11	-0.12	0.010	0.020	0.010	0.020	**4**	**FAIR**
blsc	fall	0.47	0.96	0.55	0.18	0.21	0.23	0.26	-0.09	-0.13	0.010	0.010	0.010	0.010	**4**	**FAIR**

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		Overall model performance category	Model quality (expert opinion)
blsc	winter	0.38	0.91	0.64	0.26	0.28	0.11	0.1	-0.05	-0.06	0.030	0.030	0.030	0.030	**4**	**FAIR**
bogu	spring	0.27	0.9	0.54	0.08	0.11	0.12	0.13	-0.11	-0.13	0.020	0.020	0.020	0.020	**4**	**POOR**
bogu	fall	0.4	0.92	0.67	0.34	0.39	0.25	0.26	-0.22	-0.24	0.010	0.010	0.010	0.010	**4**	**POOR**
bogu	winter	0.44	0.87	0.68	0.39	0.43	0.18	0.18	-0.13	-0.14	0.030	0.030	0.030	0.030	**4**	**FAIR**
brpe	spring	0	0.98	0.66	0.13	0.15	0.24	0.43	-0.21	-0.37	0.000	0.000	0.000	0.000	**3**	**FAIR**
brpe	summer	0	0.92	0.58	0.23	0.31	0.28	0.28	-0.28	-0.28	0.000	0.000	0.000	0.000	**3**	**POOR**
brpe	fall	0.48	0.99	0.65	0.29	0.3	0.3	0.33	-0.29	-0.3	0.000	0.000	0.000	0.000	**4**	**GOOD**
brpe	winter	0	0.93	0.65	0.35	0.35	0.45	0.34	-0.45	-0.34	0.000	0.000	0.000	0.000	**3**	**POOR**
brsp	summer	0.52	0.96	0.7	0.39	0.46	0.46	0.47	-0.46	-0.47	0.010	0.010	0.010	0.010	**4**	**GOOD**
coei	winter	0.55	0.97	0.55	0.1	0.1	0.33	0.35	0.24	0.27	0.030	0.040	0.030	0.030	**4**	**FAIR**
colo	spring	0.42	0.9	0.7	0.4	0.41	0.35	0.36	-0.32	-0.34	0.060	0.070	0.060	0.070	**4**	**FAIR**
colo	summer	0.36	0.95	0.63	0.21	0.25	0.73	0.73	-0.73	-0.73	0.000	0.000	0.000	0.000	**4**	**FAIR**
colo	fall	0.41	0.94	0.68	0.33	0.33	0.4	0.41	-0.37	-0.39	0.030	0.030	0.030	0.030	**4**	**FAIR**
colo	winter	0.36	0.83	0.65	0.29	0.31	0.32	0.33	-0.32	-0.32	0.080	0.080	0.070	0.070	**4**	**FAIR**
comu	spring	0.24	0.95	0.69	0.4	0.46	0.48	0.36	-0.48	-0.36	0.000	0.010	0.000	0.010	**4**	**FAIR**
comu	winter	0.34	0.96	0.74	0.52	0.53	0.5	0.61	-0.45	-0.61	0.000	0.010	0.000	0.010	**4**	**FAIR**
cosh	spring	0.48	0.98	0.66	0.27	0.27	0.43	0.44	-0.43	-0.44	0.000	0.000	0.000	0.000	**4**	**GOOD**
cosh	summer	0.33	0.87	0.66	0.33	0.34	0.2	0.21	-0.18	-0.19	0.060	0.070	0.060	0.070	**4**	**GOOD**
cosh	fall	0.46	0.91	0.72	0.46	0.48	0.22	0.23	-0.19	-0.19	0.040	0.050	0.040	0.040	**5**	**GOOD**
cote	spring	0.53	0.97	0.6	0.23	0.24	0.34	0.38	-0.29	-0.35	0.010	0.010	0.010	0.010	**4**	**GOOD**
cote	summer	0.44	0.93	0.62	0.26	0.3	0.27	0.29	-0.2	-0.21	0.030	0.030	0.030	0.030	**4**	**FAIR**
cote	fall	0.44	0.93	0.66	0.38	0.39	0.24	0.21	-0.15	-0.18	0.020	0.020	0.020	0.020	**4**	**FAIR**
dcco	spring	0.26	0.93	0.55	0.08	0.11	0.17	0.24	-0.15	-0.22	0.000	0.010	0.000	0.010	**4**	**POOR**
dcco	summer	0.06	0.92	0.56	0.18	0.24	0.2	0.2	-0.2	-0.2	0.000	0.010	0.000	0.010	**4**	**FAIR**
dcco	fall	0.42	0.88	0.63	0.27	0.3	0.08	0.08	-0.04	-0.06	0.010	0.010	0.010	0.010	**4**	**POOR**

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		**Overall model performance category**	**Model quality (expert opinion)**
dcco	winter	0.34	0.92	0.72	0.47	0.52	0.13	0.09	-0.07	-0.07	0.000	0.000	0.000	0.000	**4**	**FAIR**
dove	spring	0.41	0.93	0.75	0.56	0.58	0.26	0.27	-0.26	-0.26	0.010	0.010	0.010	0.010	**4**	**GOOD**
dove	fall	0.62	0.99	0.71	0.46	0.47	0.28	0.28	-0.1	-0.13	0.010	0.010	0.010	0.010	**5**	**GOOD**
dove	winter	0.49	0.93	0.68	0.45	0.49	0.22	0.23	-0.14	-0.17	0.020	0.020	0.020	0.020	**5**	**GOOD**
gbbg	spring	0.6	0.87	0.69	0.41	0.44	0.17	0.17	-0.09	-0.09	0.090	0.100	0.090	0.090	**5**	**GOOD**
gbbg	summer	0.47	0.91	0.67	0.34	0.35	0.26	0.26	-0.21	-0.21	0.060	0.070	0.060	0.060	**4**	**GOOD**
gbbg	fall	0.37	0.84	0.67	0.36	0.38	0.2	0.2	-0.07	-0.08	0.130	0.130	0.110	0.120	**4**	**GOOD**
gbbg	winter	0.53	0.9	0.73	0.45	0.48	0.13	0.13	-0.07	-0.07	0.070	0.070	0.070	0.070	**5**	**FAIR**
grsh	spring	0.72	0.98	0.78	0.59	0.62	0.19	0.21	-0.08	-0.09	0.010	0.010	0.010	0.010	**5**	**FAIR**
grsh	summer	0.56	0.92	0.72	0.44	0.45	0.1	0.09	0.01	0	0.080	0.090	0.080	0.080	**5**	**GOOD**
grsh	fall	0.59	0.95	0.72	0.47	0.48	0.26	0.26	0.05	0.04	0.080	0.080	0.080	0.080	**4**	**GOOD**
grsh	winter	0.71	0.98	0.85	0.65	0.66	0.23	0.23	-0.23	-0.23	0.000	0.000	0.000	0.000	**5**	**FAIR**
herg	spring	0.41	0.84	0.71	0.47	0.49	0.18	0.18	-0.05	-0.06	0.130	0.140	0.120	0.120	**4**	**FAIR**
herg	summer	0.48	0.91	0.68	0.37	0.39	0.25	0.25	-0.21	-0.2	0.060	0.060	0.050	0.060	**4**	**FAIR**
herg	fall	0.38	0.84	0.67	0.39	0.41	0.21	0.21	-0.03	-0.03	0.150	0.150	0.130	0.130	**4**	**GOOD**
herg	winter	0.43	0.87	0.69	0.41	0.44	0.17	0.16	-0.1	-0.1	0.100	0.100	0.090	0.090	**4**	**FAIR**
hogr	winter	0.24	0.95	0.71	0.32	0.33	0.57	0.58	-0.57	-0.58	0.000	0.000	0.000	0.000	**4**	**POOR**
lagu	spring	0.47	0.94	0.67	0.32	0.36	0.38	0.39	-0.38	-0.39	0.020	0.020	0.020	0.020	**4**	**FAIR**
lagu	summer	0.53	0.95	0.72	0.44	0.47	0.29	0.29	-0.27	-0.28	0.030	0.030	0.030	0.030	**4**	**FAIR**
lagu	fall	0.52	0.94	0.68	0.42	0.45	0.25	0.27	-0.16	-0.17	0.040	0.040	0.040	0.040	**4**	**GOOD**
lagu	winter	0.42	0.98	0.74	0.51	0.54	0.34	0.37	-0.34	-0.34	0.000	0.000	0.000	0.000	**4**	**FAIR**
lesp	spring	0.53	0.97	0.69	0.34	0.37	0.28	0.28	-0.27	-0.28	0.010	0.010	0.010	0.010	**4**	**GOOD**

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		**Overall model performance category**	**Model quality (expert opinion)**
lesp	summer	0.54	0.94	0.7	0.43	0.47	0.26	0.28	-0.2	-0.21	0.040	0.040	0.040	0.040	**4**	**GOOD**
lesp	fall	0.59	0.97	0.72	0.45	0.47	0.33	0.34	-0.31	-0.33	0.010	0.010	0.010	0.010	**4**	**GOOD**
lete	summer	0.03	0.91	0.62	0.29	0.36	0.27	0.27	-0.27	-0.27	0.000	0.000	0.000	0.000	**3**	**FAIR**
ltdu	spring	0.64	0.98	0.75	0.55	0.55	0.13	0.14	0.03	0.03	0.020	0.020	0.020	0.020	**5**	**GOOD**
ltdu	fall	0.72	0.99	0.81	0.62	0.62	0.16	0.15	0.01	0	0.010	0.010	0.010	0.010	**5**	**GOOD**
ltdu	winter	0.6	0.97	0.73	0.47	0.48	0.23	0.23	0.1	0.08	0.040	0.040	0.040	0.040	**5**	**GOOD**
mash	spring	0.2	0.89	0.6	0.16	0.25	0.65	0.65	-0.65	-0.65	0.000	0.000	0.000	0.000	**3**	**GOOD**
mash	summer	0.25	0.83	0.68	0.29	0.33	0.34	0.34	-0.34	-0.34	0.010	0.010	0.010	0.010	**4**	**FAIR**
mash	fall	0.31	0.9	0.74	0.38	0.41	0.57	0.57	-0.57	-0.57	0.010	0.010	0.010	0.010	**4**	**GOOD**
nofu	spring	0.62	0.96	0.76	0.57	0.58	0.14	0.14	-0.03	-0.04	0.050	0.050	0.040	0.050	**5**	**GOOD**
nofu	summer	0.7	0.98	0.72	0.48	0.52	0.07	0.07	-0.04	-0.05	0.010	0.010	0.010	0.010	**5**	**GOOD**
nofu	fall	0.61	0.95	0.77	0.58	0.59	0.19	0.19	-0.15	-0.15	0.040	0.040	0.040	0.040	**5**	**GOOD**
nofu	winter	0.62	0.98	0.73	0.49	0.52	0.18	0.17	-0.03	-0.05	0.020	0.020	0.020	0.020	**5**	**GOOD**
noga	spring	0.39	0.85	0.7	0.44	0.46	0.2	0.19	-0.07	-0.08	0.140	0.150	0.120	0.130	**4**	**GOOD**
noga	summer	0.47	0.93	0.72	0.41	0.45	0.43	0.45	-0.42	-0.44	0.030	0.030	0.020	0.030	**4**	**POOR**
noga	fall	0.52	0.91	0.72	0.48	0.52	0.21	0.22	-0.14	-0.14	0.080	0.090	0.070	0.080	**5**	**GOOD**
noga	winter	0.55	0.85	0.72	0.45	0.48	0.16	0.18	-0.07	-0.07	0.120	0.130	0.110	0.110	**4**	**GOOD**
poja	spring	0.31	0.93	0.69	0.27	0.31	0.76	0.76	-0.76	-0.76	0.000	0.000	0.000	0.000	**4**	**FAIR**
poja	summer	0.12	0.83	0.63	0.17	0.2	0.83	0.83	-0.83	-0.83	0.000	0.000	0.000	0.000	**3**	**FAIR**
poja	fall	0.29	0.89	0.66	0.26	0.28	0.66	0.66	-0.66	-0.66	0.030	0.030	0.020	0.020	**3**	**GOOD**
razo	spring	0.4	0.94	0.7	0.4	0.44	0.35	0.37	-0.33	-0.32	0.020	0.030	0.020	0.030	**4**	**FAIR**
razo	summer	0.44	0.98	0.8	0.6	0.63	0.71	0.71	-0.6	-0.6	0.000	0.000	0.000	0.000	**4**	**GOOD**

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		**Overall model performance category**	**Model quality (expert opinion)**
razo	fall	0.51	0.97	0.74	0.54	0.57	0.26	0.24	-0.2	-0.15	0.010	0.010	0.010	0.010	**5**	**FAIR**
razo	winter	0.44	0.93	0.72	0.45	0.47	0.29	0.31	-0.24	-0.24	0.040	0.040	0.040	0.040	**4**	**GOOD**
rbgu	spring	0.31	0.91	0.67	0.3	0.32	0.41	0.41	-0.41	-0.41	0.010	0.010	0.010	0.010	**4**	**POOR**
rbgu	fall	0.36	0.9	0.75	0.46	0.5	0.28	0.28	-0.28	-0.28	0.010	0.010	0.010	0.010	**4**	**POOR**
rbgu	winter	0.28	0.86	0.61	0.2	0.23	0.24	0.24	-0.24	-0.24	0.020	0.020	0.020	0.020	**4**	**FAIR**
reph	spring	0.48	0.96	0.66	0.35	0.39	0.1	0.09	0	-0.01	0.010	0.020	0.010	0.010	**4**	**GOOD**
reph	summer	0.51	0.96	0.73	0.45	0.45	0.04	0.05	-0.01	-0.01	0.000	0.000	0.000	0.000	**5**	**GOOD**
rnph	summer	0.33	0.93	0.65	0.33	0.38	0.31	0.33	-0.26	-0.3	0.000	0.000	0.000	0.000	**4**	**GOOD**
rnph	fall	0	0.87	0.6	0.2	0.23	0.29	0.31	-0.28	-0.31	0.010	0.010	0.010	0.010	**3**	**FAIR**
rost	spring	0	0.97	0.56	0.08	0.13	0.31	0.52	-0.31	-0.52	0.000	0.000	0.000	0.000	**3**	**POOR**
rost	summer	0.45	0.96	0.58	0.25	0.31	0.48	0.48	-0.22	-0.23	0.000	0.010	0.000	0.010	**4**	**FAIR**
rost	fall	0.54	0.97	0.61	0.27	0.31	0.29	0.29	-0.16	-0.27	0.000	0.000	0.000	0.000	**4**	**FAIR**
royt	spring	0.49	0.96	0.57	0.15	0.2	0.35	0.36	-0.35	-0.35	0.010	0.010	0.010	0.010	**4**	**FAIR**
royt	summer	0.52	0.97	0.74	0.47	0.51	0.42	0.43	-0.42	-0.43	0.010	0.010	0.010	0.010	**4**	**GOOD**
royt	fall	0.44	0.96	0.68	0.39	0.4	0.41	0.41	-0.41	-0.41	0.010	0.010	0.010	0.010	**4**	**GOOD**
rtlo	spring	0.41	0.9	0.69	0.39	0.42	0.3	0.31	-0.29	-0.3	0.050	0.060	0.050	0.060	**4**	**FAIR**
rtlo	fall	0.51	0.96	0.72	0.48	0.51	0.26	0.26	-0.25	-0.26	0.010	0.010	0.010	0.010	**4**	**FAIR**
rtlo	winter	0.34	0.87	0.69	0.39	0.43	0.3	0.31	-0.3	-0.31	0.050	0.050	0.050	0.050	**4**	**FAIR**
sosh	spring	0.45	0.95	0.67	0.38	0.41	0.17	0.17	-0.11	-0.12	0.020	0.020	0.020	0.020	**5**	**GOOD**
sosh	summer	0.56	0.93	0.72	0.45	0.48	0.05	0.06	-0.04	-0.04	0.030	0.030	0.030	0.030	**5**	**GOOD**
sosh	fall	0.22	0.9	0.65	0.29	0.34	0.36	0.36	-0.36	-0.36	0.000	0.000	0.000	0.000	**4**	**GOOD**

Species code	Season	PDE	AUC	AUC_nz	RankR_nz	RankRG_nz	MedianAE_nz_rel		MedianBias_nz_rel		CRPS_0		CRPS_Zinf		Overall model performance category	Model quality (expert opinion)
susc	spring	0.54	0.97	0.62	0.24	0.27	0.22	0.23	-0.06	-0.08	0.020	0.020	0.020	0.020	**4**	**FAIR**
susc	fall	0.62	0.97	0.7	0.42	0.38	0.34	0.32	0.07	0.07	0.010	0.010	0.010	0.010	**4**	**FAIR**
susc	winter	0.6	0.97	0.73	0.44	0.45	0.28	0.3	0.02	-0.01	0.020	0.030	0.020	0.020	**5**	**FAIR**
wisp	spring	0.61	0.97	0.69	0.39	0.4	0.21	0.2	-0.01	-0.03	0.040	0.040	0.030	0.040	**5**	**GOOD**
wisp	summer	0.46	0.86	0.68	0.4	0.42	0.2	0.2	0	-0.01	0.130	0.130	0.110	0.120	**4**	**FAIR**
wisp	fall	0.5	0.96	0.63	0.3	0.31	0.21	0.21	-0.11	-0.13	0.030	0.040	0.030	0.030	**4**	**GOOD**
wwsc	spring	0.44	0.95	0.59	0.22	0.24	0.11	0.14	-0.08	-0.12	0.010	0.020	0.010	0.020	**4**	**FAIR**
wwsc	fall	0.54	0.97	0.74	0.51	0.54	0.21	0.2	-0.07	-0.1	0.010	0.010	0.010	0.010	**5**	**FAIR**
wwsc	winter	0.5	0.95	0.63	0.29	0.29	0.2	0.18	-0.01	-0.03	0.030	0.030	0.030	0.030	**4**	**FAIR**

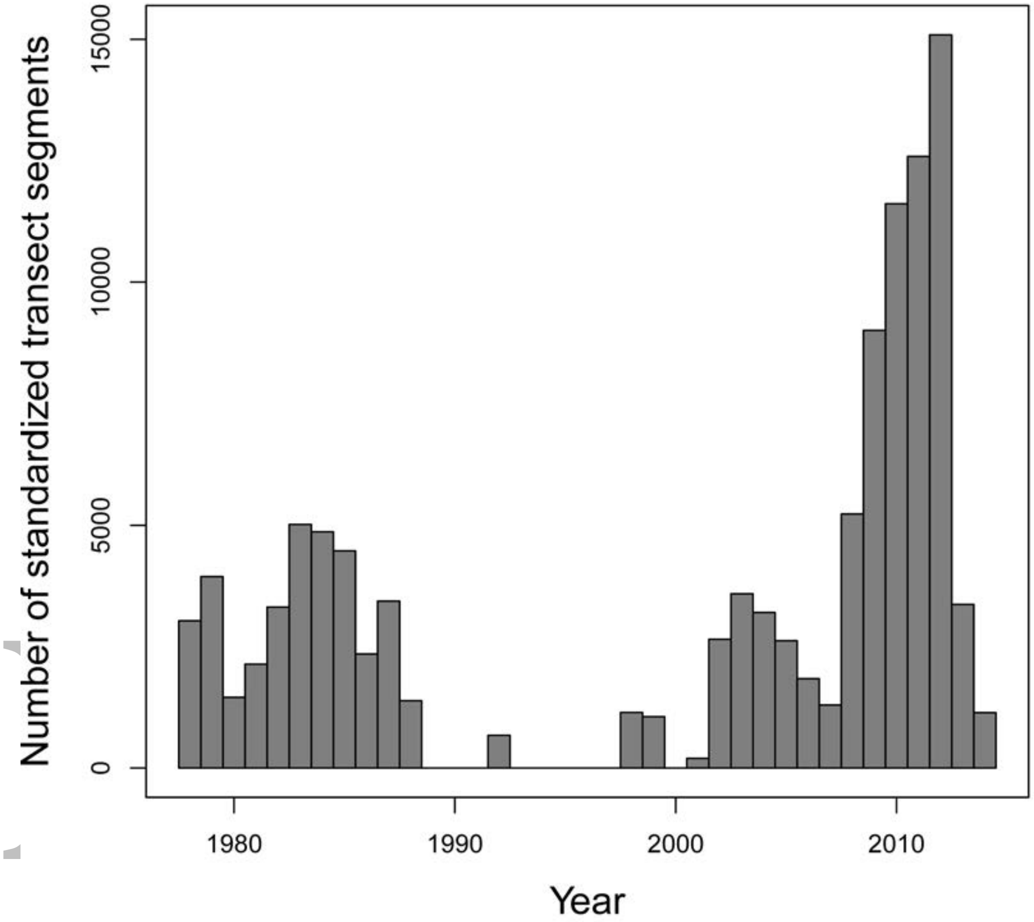

Figure 1. Number of survey transect segments by year.

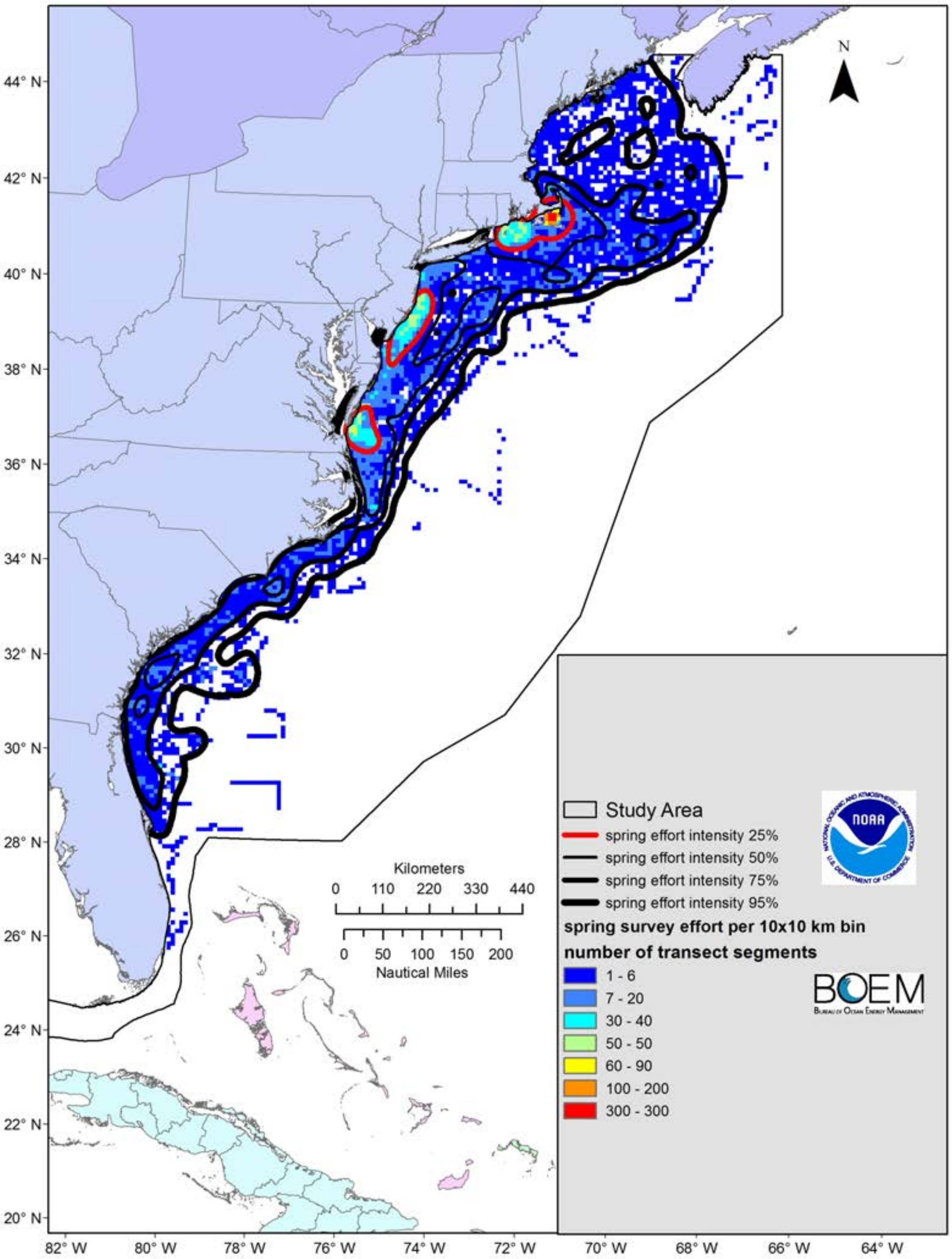

Figure 2. Map of survey effort in spring (March-May). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.

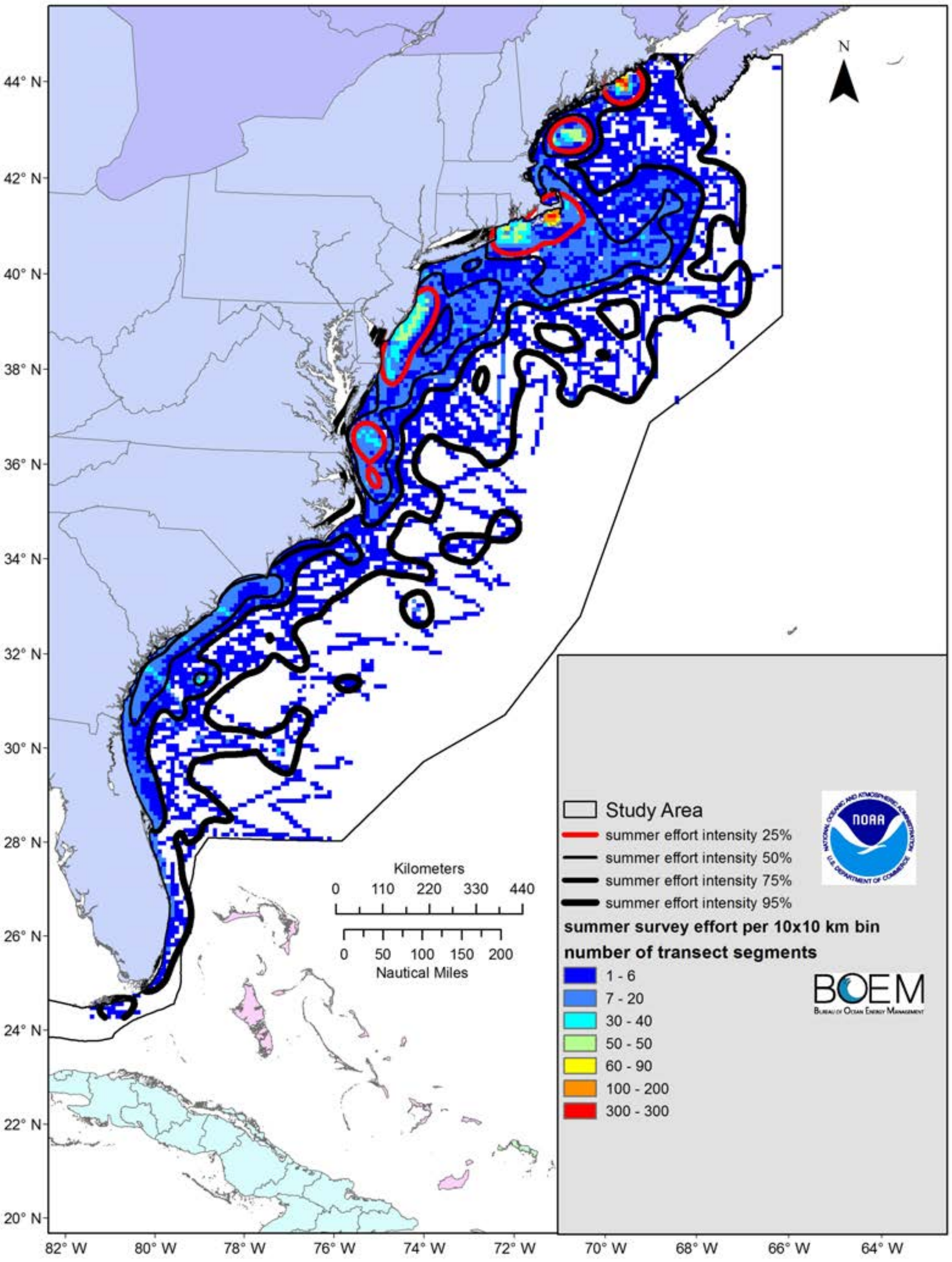

Figure 3. Map of survey effort in summer (June-August). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.

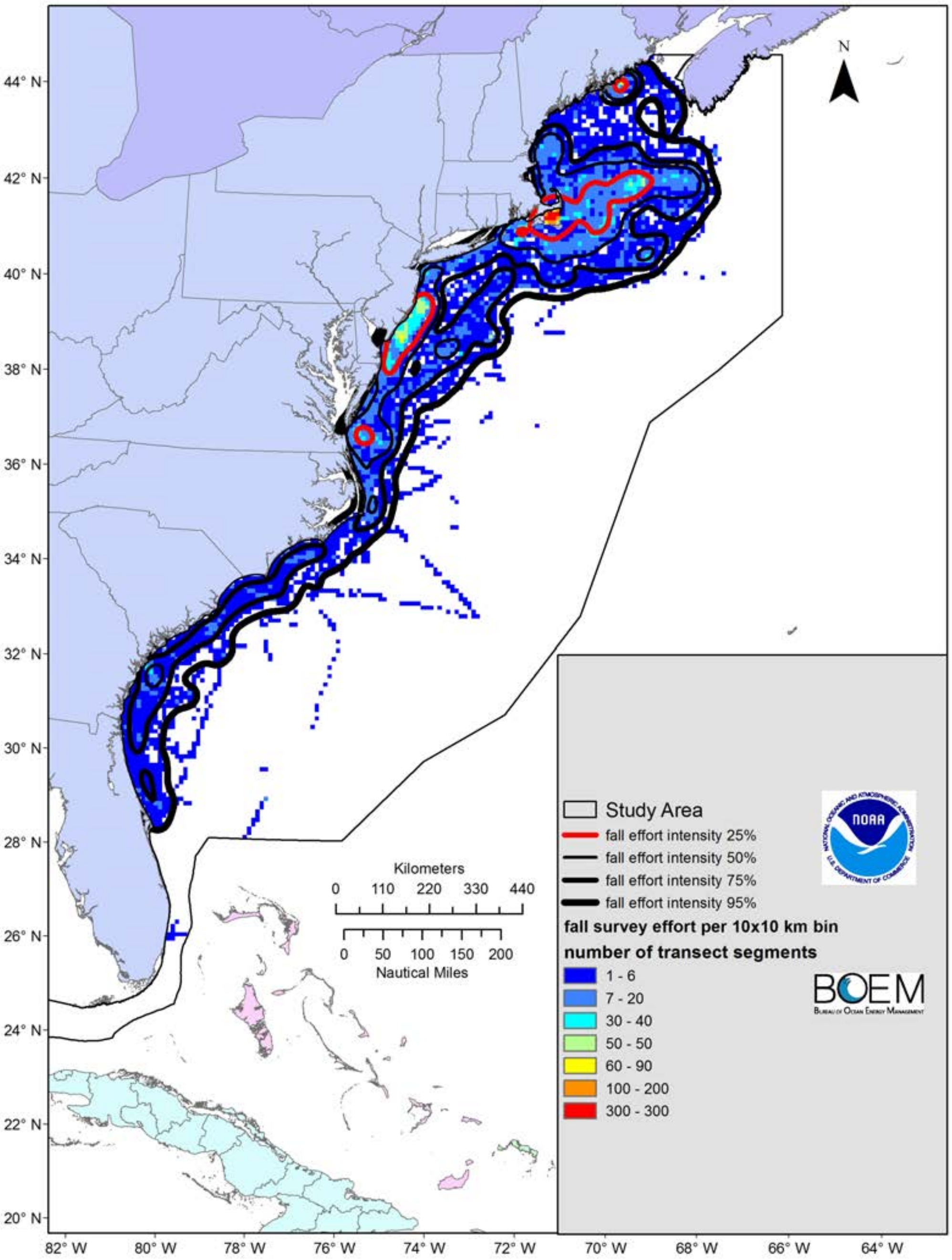

Figure 4. Map of survey effort in fall (September-November). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.

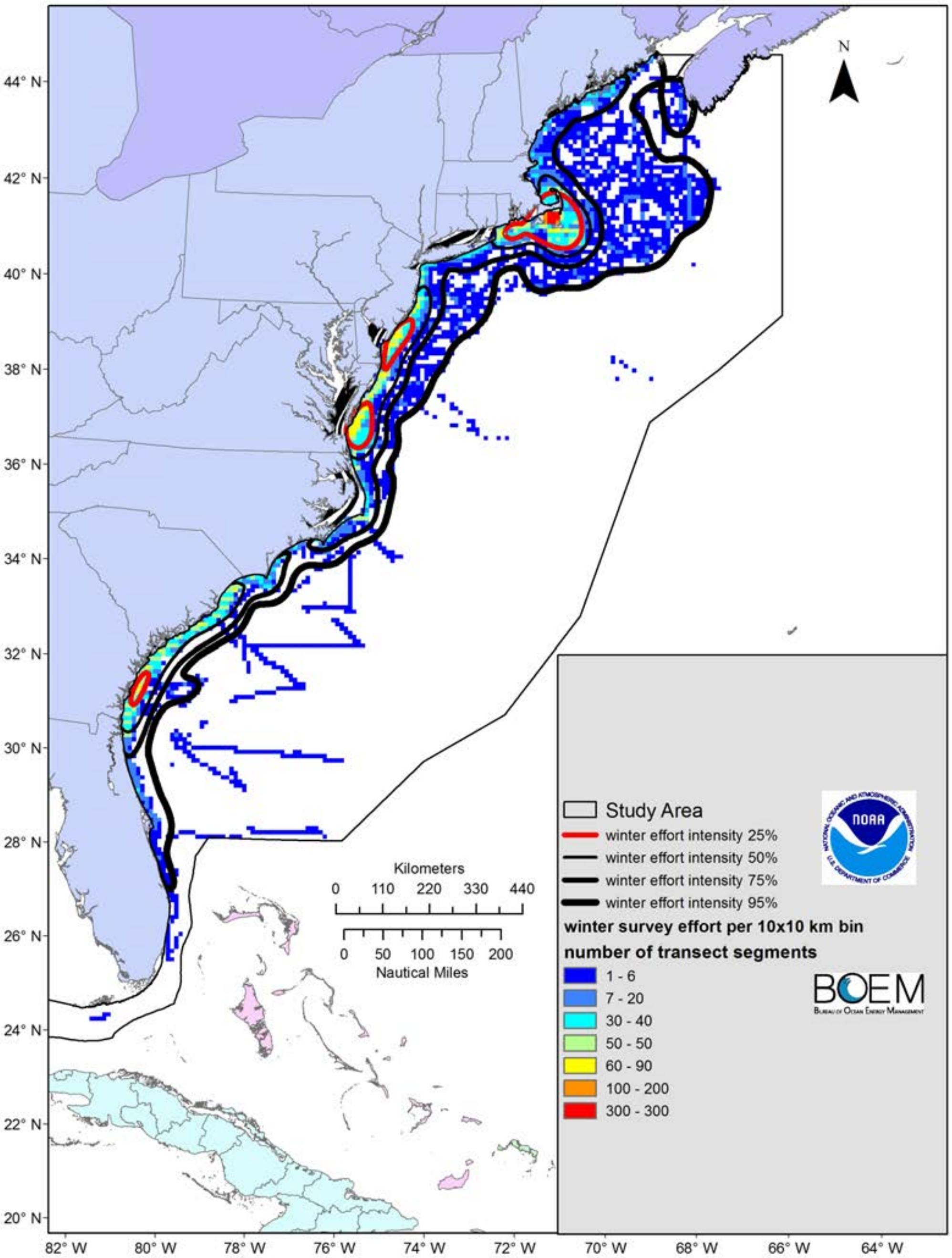

Figure 5. Map of survey effort in winter (December-February). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.