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# MARINE-LIFE DATA AND ANALYSIS TEAM (MDAT) TECHNICAL REPORT ON THE METHODS AND DEVELOPMENT OF MARINE- LIFE DATA TO SUPPORT REGIONAL OCEAN PLANNING AND MANAGEMENT



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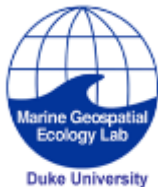
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## EXECUTIVE SUMMARY

In 2014, the Marine Geospatial Ecology Lab (MGEL) of Duke University began work with the Northeast Regional Ocean Council (NROC), the NOAA National Centers for Coastal Ocean Science (NCCOS), the NOAA Northeast Fisheries Science Center (NEFSC), and Loyola University Chicago, as part of the Marine-life Data and Analysis Team (MDAT), to characterize and map marine life in the Northeast region, at the request of the Northeast Regional Planning Body (NE RPB) to support the Northeast Ocean Plan. These research groups collaborated to produce “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 working groups and other experts, were kept closer to the original 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 products are annual and monthly or seasonal predictions and show predicted abundances of animals for the given time period. Avian relative abundance products are annual and seasonal, and can address the question of how abundant a given species is predicted to be in one area as compared to other areas. Fish biomass are represented in natural log kilograms per tow, and display expected biomass per tow, if a tow were to occur in the given area. Three map products include 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 this 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 individual base products. To address this gap and other potential management applications as identified by the NE RPB and others, MDAT has created several types of “synthetic”, or summary map products from these base layers. Summary products are comprised of data layers from multiple 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 nine mammal groups. Summary 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 modeled/sampled 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 groups. 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 (fish). These core area layers were then aggregated within each of 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 for three spatial extents: 1) the full US east coast; 2) the Northeast planning area and 3) the Mid-Atlantic area of interest. Because these products are dependent on the total extent of the input data, core area abundance/biomass products will differ at each extent.

At the time of publication of this document, base layer products for each taxon have been integrated into the Northeast Ocean Data Portal, are in the process of being integrated into the Mid-Atlantic Ocean Data Portal, and some select species are in the process of being integrated into the NOAA Marine Cadastre Portal. Some of the summary products have also been integrated into the Northeast and Mid-Atlantic Portals to support ocean planning, and others continue to be considered as part of different aspects of the ocean planning process. The Marine Cadastre also plans to integrate some of the summary products.

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

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# 1 INTRODUCTION

In 2014, the Marine Geospatial Ecology Lab (MGEL) of Duke University began work with the Northeast Regional Ocean Council (NROC), the NOAA National Centers for Coastal Ocean Science (NCCOS), the NOAA Northeast Fisheries Science Center (NEFSC), and Loyola University Chicago, as part of the Marine-life Data and Analysis Team (MDAT), to characterize and map marine life in the Northeast region at the request of the Northeast Regional Planning Body (NE RPB) to support the Northeast Ocean Plan. In 2015, the Mid-Atlantic Regional Council on the Ocean (MARCO) contracted with MDAT to build upon and expand this effort into the Mid-Atlantic planning area. 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 addressed much of the interest to characterize marine life in the region. The information, statements, and findings in this report are those of the MDAT.

## 1.1 MDAT MEMBERS

MDAT is comprised of four organizations working together to deliver the best available marine life data for marine mammals, 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 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 summary 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, Arliss Winship and Timothy White 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.

MDAT is supported by NROC staff, including Emily Shumchenia, who provided overall project management and facilitated communication with the NE RPB, agency staff, and scientific experts in the Northeast region. MDAT is also supported by MARCO staff, who facilitated communication with the Mid-Atlantic RPB, agency staff, and scientific experts in the Mid-Atlantic region.

## 1.2 SCIENTIFIC PEER REVIEW PROCESS

Critical, scientific review of all MDAT products is a central component to overall data development in multiple ways.

First, as stand-alone projects prior to the formation of MDAT, the individual species data products associated with each taxa are the result of multi-institution collaborations and were subject to expert review throughout development. The avian modeling methodology and results were reviewed and described in a 2016 Bureau of Ocean Energy Management (BOEM) report (Kinlan et al. 2016). The marine mammals modeling methodology and results were published in the journal *Nature Reports* (Roberts et al. 2016). The fish species datasets and mapping approaches were completed by NEFSC, who provide basic information on the ecosystem and spatial analysis products derived from their >40-year dataset available on the web at: <http://nefsc.noaa.gov/ecosys/>.



Second, as part of the MDAT project, NROC and the NE RPB assembled three Marine Life Work Groups (one each for marine mammals, avian species, and fish species) comprised of experts from federal government agencies, state government agencies, academia, research institutions, and Non-Governmental Organizations (NGOs), including experts from the Mid-Atlantic region. Each working group met via webinar three separate times over the course of seven months between August 2014 and March 2015 to review potential data sources, share expertise on species characteristics including life history and spatial and temporal distribution knowledge, and discuss potential products and product spatial extent. Following these calls, MDAT developed three work plans (one for each taxa), integrating the work groups' feedback and input, that describe the methods and approaches to developing data products to support ocean planning in the Northeast. Lists of invited work group participants, work group call agendas, work group call summaries, and final work plans are available online at <http://neoceanplanning.org/projects/marine-life/>. In 2015, the Mid-Atlantic RPB Data Synthesis Working Group (DSWG) was formed to provide guidance and oversight on the MDAT work in the Mid-Atlantic region. MDAT presented to the DSWG several times during the course of the project. Several in-person and web-based Mid-Atlantic RPB meetings, stakeholder workshops, and briefings were held with MDAT presenting spatial data products and methodologies, and incorporating feedback when possible.

Third, when the Northeast RPB convened the Ecosystem Based Management (EBM) Work Group in September 2015, they charged this work group with providing input to the NE RPB on many EBM-related issues, such as reviewing MDAT products and methods, including summary products. Since then, the EBM Work Group has discussed and provided feedback on MDAT products in each of their three meetings; the proceedings of these meetings are available online at <http://neoceanplanning.org/about/northeast-rpb>. In January of 2016, MDAT provided all base models/data products and all summary products to the NE RPB, three original Marine Life Work Groups and the EBM Work Group for a 4-week period of review. Numerous comments and feedback were received on topics including the need to characterize the extent of observation data, the need to make detailed documentation of methods accessible to users, and the number and types of species groups to include in the final products. As a result of this feedback, the NE RPB decided that supporting information would take the form of data layers depicting survey extents where possible; that infographics, and narrative descriptions would be included on the Northeast Ocean Data Portal; and that all summary products would be initially released on the Northeast Ocean Data Portal with a "Draft" stamp.

Finally, the base products, summary products, and all documentation associated with MDAT products were released for public and expert review on the Northeast Ocean Data Portal in May 2016 as part of the draft Northeast Ocean Plan public release. The EBM Work Group also continues to provide input and feedback on summary products.

### 1.3 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 individual species in specific locations at certain times of year.

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 summary 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 summary 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 summary products for all species in a taxon (avian, mammal, fish) or in a taxon group (i.e. ESA listed species). Summary products include total abundance or biomass, richness, and two common diversity indices.



**FIGURE 1 Marine-life data product pyramid from Northeast 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 work group, are representations of the original 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 of this Report.

For all three taxa, summary 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 created the abundance, species richness, core abundance/biomass area richness, and diversity data products (Figure 2, number 3). Summary products are described in more detail in section 3 of this Report.

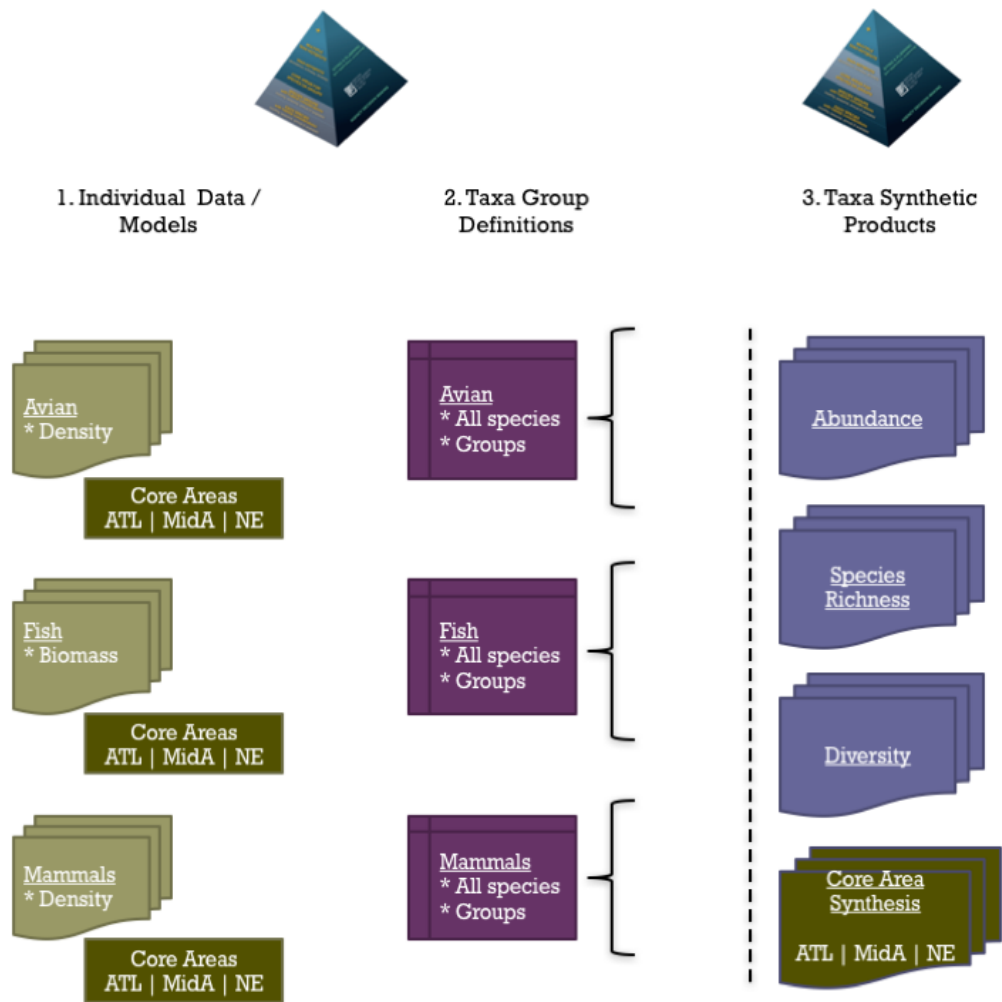


FIGURE 2 Break-down of the marine-life data product pyramid, from base layers to products for groups of species to multi-taxa products incorporating species across mammal, avian, and fish species.

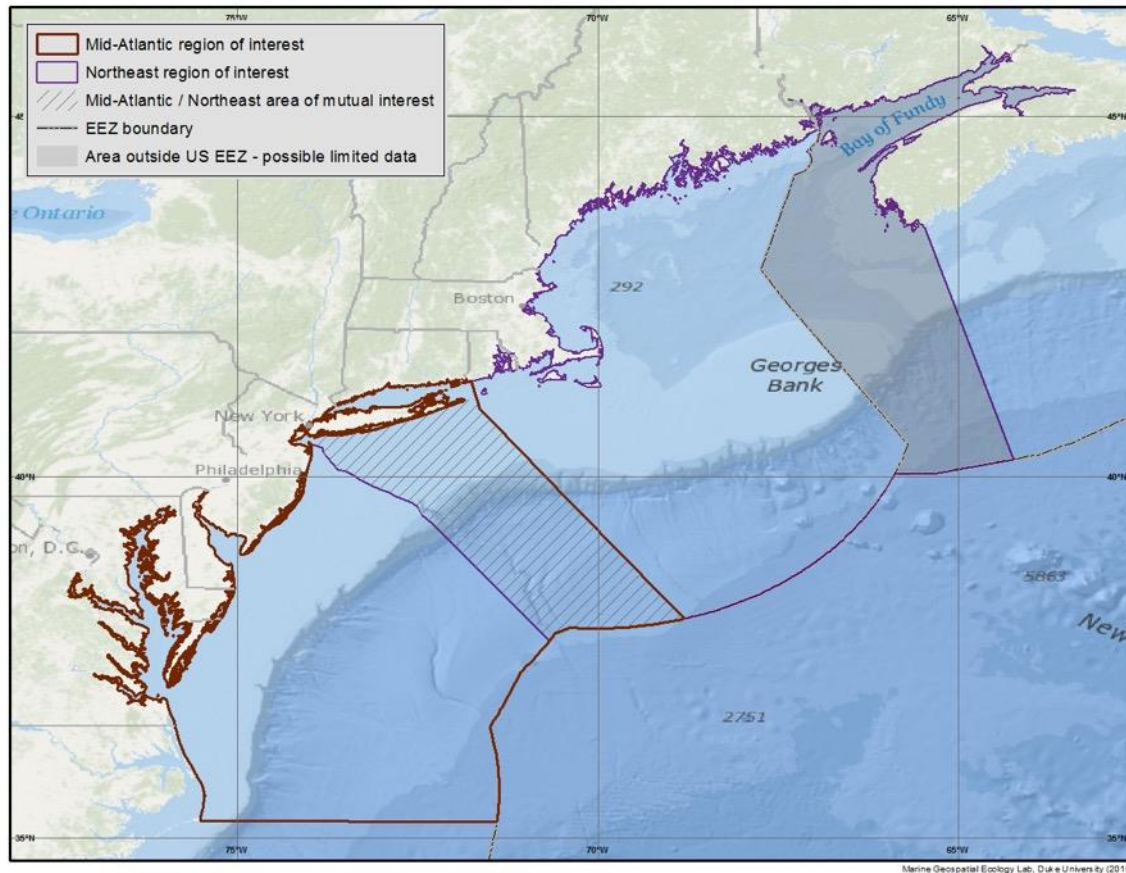


## 2 BASE MODELS AND DATA PRODUCTS

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 (RPBs), 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 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.



**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, it may be more useful to know how likely it is that a species of conservation interest 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

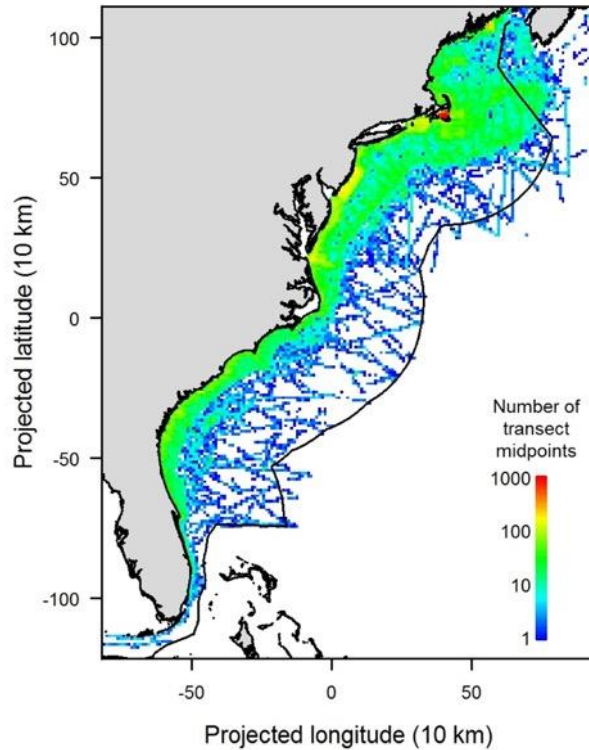
The full NCCOS report describing this work, along with model performance measures, and downloadable data can be accessed online at: <https://coastalscience.noaa.gov/projects/detail?key=279>.

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 summary products, base products (i.e., long-term average annual and seasonal relative abundance model results) were first normalized by their mean values. Thus, avian summary 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), which is greatest in areas with few survey data or sightings (e.g., further offshore). Predictions in areas with a lot of survey data and sightings were less impacted by this error. This error occurred because one of the spatial coordinate predictors was scaled incorrectly when making spatial predictions, which sometimes distorted spatial patterns. The error has been corrected, and incorporated into the next generation of models which are expected to be released and made available to users in the future. The calculated model performance metrics (see Technical Document/Appendix A, Table 3) reflect any distortion in predictions, so good performance indicates that the model predictions more closely matched the observed data in areas with survey effort. Maps that exhibit a vertical banding pattern should be interpreted with caution.

### 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). 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.'<sup>1</sup> 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, and recent surveys conducted by states, BOEM, and wind energy companies to inform energy siting off Rhode Island, Massachusetts, Maine, and elsewhere in the Northeast and Mid-Atlantic. Fewer data exist for the 1990s than for other decades.

<sup>1</sup>[www.data.boem.gov/PI/PDFImages/ESPIS/5/5209.pdf](http://www.data.boem.gov/PI/PDFImages/ESPIS/5/5209.pdf)



**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	<i>n</i>
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



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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
WHOISep2010*	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, 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 work 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
Surfscoter	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) led the MDAT effort in summarizing fish biomass and distribution, as part of their ongoing Ecosystem Assessment 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.

While the marine mammal and avian MDAT partners developed models to show abundance and distribution, the Work Group guiding the process for fish products decided on products that represent the original data. 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 among each state survey 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 data source, and not compared across sources.

### 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 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 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
BARNDOR 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

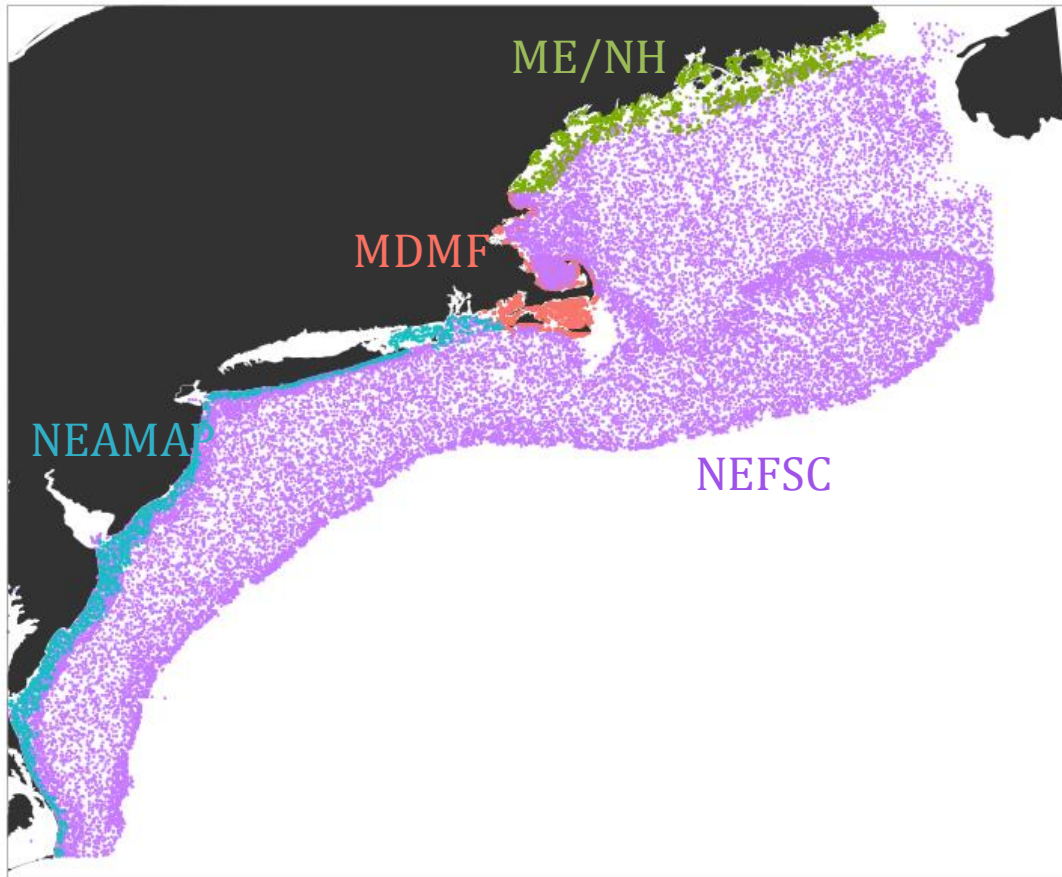


ROUGHTAIL STINGRAY	433	127	17	0
ROUND HERRING	1266	153	12	0
SAND TIGER	55	31	4	0
SCUP	3661	801	1636	87
SEA RAVEN	2828	19	497	306
SEA SCALLOP	3312	25	467	459
SILVER HAKE	9912	259	1352	1145
SMOOTH DOGFISH	2542	674	884	0
SMOOTH SKATE	1438	0	11	107
SOUTHERN STINGRAY	143	33	0	0
SPINY BUTTERFLY RAY	445	197	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 RPB, 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, sourced from Table 1 in Roberts et al. (2016)**

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

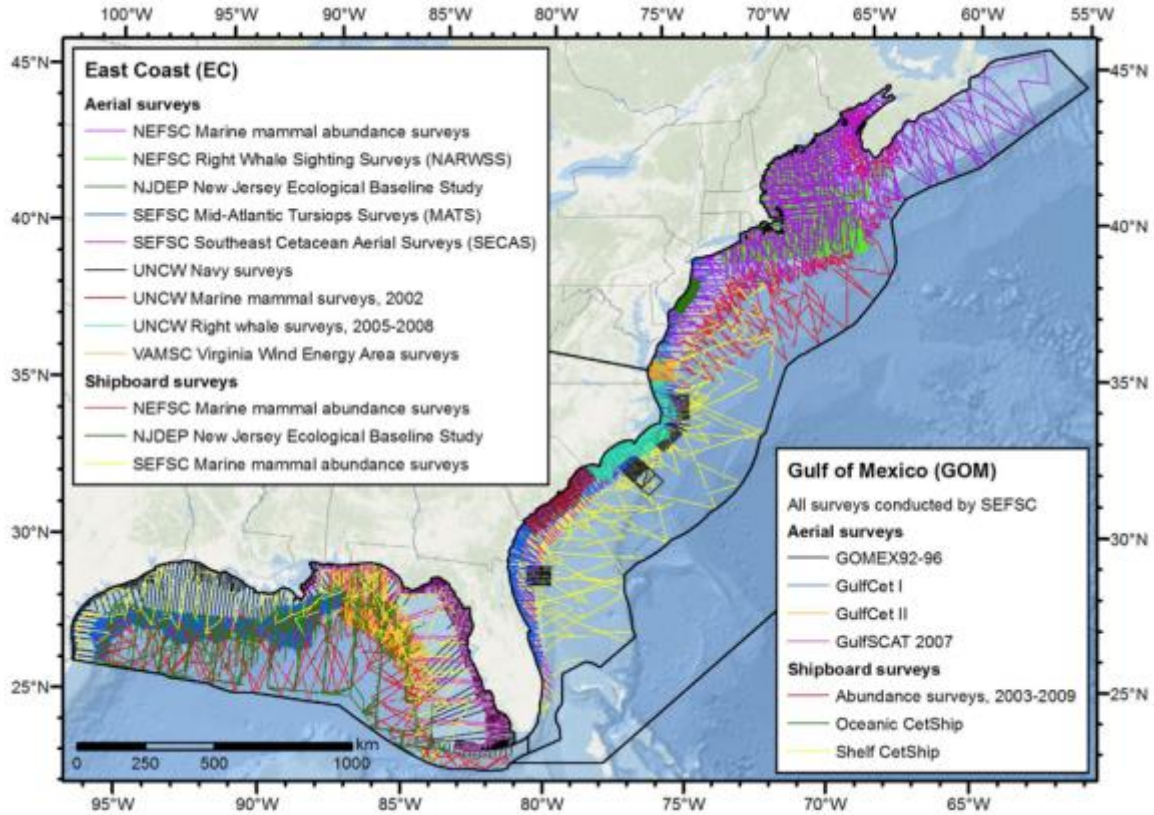


FIGURE 6 Marine mammal Survey effort and coverage for the US East Coast and Gulf of Mexico, Figure 1 from Roberts et al. (2016), based on the surveys listed in Table 5. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

**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. For full details see Supplementary Information Table S1 in Roberts et al. (2016).**

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



**TABLE 7** Sourced from Roberts et al. (2016). 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. For full details see Supplementary Information Table S3 in Roberts et al. (2016).

**Supplementary Table S3.** Candidate covariates for the spatial models. All covariates were rescaled to the 10 km Albers equal area map projection used for the analysis. Each model only considered the covariates that were appropriate for the modeled region and known ecology of the taxon.

Type	Covariates	Resolution	Time range	Description
Physiographic	Depth, Slope	30 arc sec		Seafloor depth and slope, derived from SRTM30-PLUS global bathymetry <sup>20</sup>
	DistToShore, DistTo125m, DistTo300m, DistTo1500m	30 arc sec		Distance to the closest shoreline, excluding Bermuda and Sable Island, and various ecologically-relevant isobaths <sup>20</sup>
	DistToCanyon, DistToCanyon OrSeamount	30 arc sec		Distance to the closest submarine canyon, and to the closest canyon or seamount <sup>21</sup>
SST & Winds	SST, DistToFront	0.2°, daily	1991-2014	Foundation sea surface temperature (SST), from GHR SST Level 4 CMC SST <sup>22</sup> , and distance to the closest SST front identified with the Canny edge detection algorithm <sup>23</sup>
	WindSpeed	0.25°, daily	1991-2014	30-day running mean of NOAA NCDC 1/4° Blended Sea Winds <sup>24</sup>
Currents	TKE, EKE	0.25°, daily	1993-2013	Total kinetic energy (TKE) and eddy kinetic energy (EKE), from Aviso 1/4° DT-MADT geostrophic currents
	DistToEddy, DistToAEddy, DistToCEddy	0.25°, weekly	1993-2013	Distance to the ring of the closest geostrophic eddy having any (DistToEddy), anticyclonic (DistToAEddy), or cyclonic (DistToCEddy) polarity, from Aviso 1/4° DT-MADT using a revision of the Chelton et al. algorithm <sup>25</sup> ; we tested eddies at least 9, 4, and 0 weeks old
Biological	Chl	9 km, daily	1997-2014	GSM merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll (Chl) <i>a</i> concentration <sup>26</sup> , smoothed with a 3D Gaussian smoother to reduce data loss to < 10%
	VGPM, CumVGPM45, CumVGPM90	9 km, 8 days	1997-2014	Net primary production (mg C m <sup>-2</sup> day <sup>-1</sup> ) derived from SeaWiFS and Aqua using the Vertically Generalized Production Model (VGPM) <sup>27</sup> ; we tested the original 8 day estimates as well as 45 and 90 day running accumulations
	PkPP, PkPB	0.25°, weekly	1997-2013	Zooplankton production (PkPP; g m <sup>-2</sup> day <sup>-1</sup> ) and biomass (PkPB; g m <sup>-2</sup> ) from the SEAPODYM ocean model <sup>28</sup>
	EpiMnkPP, EpiMnkPB	0.25°, weekly	1997-2013	Epipelagic micronekton production (EpiMnkPP; g m <sup>-2</sup> day <sup>-1</sup> ) and biomass (EpiMnkPB; g m <sup>-2</sup> ) from the SEAPODYM model <sup>28</sup>

### 2.4.3 SPATIAL COVERAGE, GRID SIZE, MODEL GAPS

Marine mammal models were created for the entire US East Coast and southeast Canada. 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. 5<sup>th</sup> 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. 95<sup>th</sup> percentiles – On the 95<sup>th</sup> 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 SUMMARY PRODUCTS

Marine-life data summary products are secondary or tertiary distillations of the abundance models or observation data. Summary products provide a means to distill hundreds of data layers and time period combinations into more simplified maps that supplement the base layer reference library, with the base layer 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 expert work groups, with other taxa-, model-, and regional experts, as well as the Northeast and Mid-Atlantic RPBs. Understanding the implications of applied thresholds and criteria is critical to appropriately interpret summary products. Higher-level, summary 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.

Summary 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 summary products were created at the scale and extent of the underlying base layer 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 North Carolina to the Gulf of Maine out to the shelf break.

#### 3.1 SPECIES SUMMARY PRODUCT CAVEATS AND CONSIDERATIONS

There are four main caveats when considering use of the higher-level summary 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 work 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 or biomass, 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 summary product development.
- Four species were not included in the summary analysis products because their maximum prediction values were too large: Audubon’s shearwater, black guillemot, black-capped petrel, and common eider.



Caveats specific to the fish summary products:

- Fish summary products were developed using the NEFSC fall survey data source only.
- 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, and RPB members. Additionally, an "all species" group was created for each of the three taxa: all modeled avian species, all sampled fish species, all modeled cetacean species (Table 8). "All species" groups might aid in early sighting or pre-screening activities in regional ocean planning.

The species groups described below were developed in collaboration with the NE RPB and the expert work groups. Data products representing each of these groups have been made publicly available by MDAT via map services (see Section 4.2), and have been integrated into the Northeast and Mid-Atlantic Ocean Data Portals at the discretion of the RPBs, experts, and Data Portal Working Groups.

**TABLE 8 "All species" groups for all modeled avian species, all sampled fish species and all modeled cetacean species. Avian species with (\*) were not included in summary products; see caveats in section 3.1.**

All modeled avian species	All sampled fish species	All modeled cetacean species
Arctic tern	Acadian redfish	Atlantic spotted dolphin
Atlantic puffin	Alewife	Atlantic white-sided dolphin
Audubon's shearwater*	American eel	Blainville's beaked whale
Band-rumped storm petrel	American lobster	Blue whale
Black-capped petrel*	American plaice	Bottlenose dolphin
Black guillemot*	American sand lance	Bryde's whale
Black scoter	American shad	



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Black-legged kittiwake	Atlantic cod	Clymene dolphin
Bonaparte's gull	Atlantic croaker	Cuvier's beaked whale
Brown pelican	Atlantic halibut	Dwarf sperm whale
Common eider*	Atlantic herring	False killer whale
Common loon	Atlantic mackerel	Fin whale
Common murre	Atlantic menhaden	Fraser's dolphin
Common tern	Atlantic sharpnose shark	Gervais' beaked whale
Cory's shearwater	Atlantic sturgeon	Harbor porpoise
Double-crested cormorant	Atlantic torpedo	Humpback whale
Dovekie	Atlantic wolfish	Killer whale
Great black-backed gull	Banded drum	Long-finned pilot whale
Great shearwater	Barndoor skate	Melon-headed whale
Herring gull	Bay anchovy	Minke whale
Horned grebe	Black sea bass	North Atlantic right whale
Laughing gull	Blackbelly rosefish	Northern bottlenose whale
Leach's storm petrel	Blueback herring	Pantropical spotted dolphin
Least tern	Bluefish	Pygmy sperm whale
Long-tailed duck	Bluntnose stingray	Risso's dolphin
Manx shearwater	Bullnose ray	Rough-toothed dolphin
Northern fulmar	Butterfish	Sei whale
Northern gannet	Capelin	Short-beaked common dolphin
Pomarine jaeger	Clearnose skate	Short-finned pilot whale
Razorbill	Cunner	Sowerby's beaked whale
Red phalarope	Cusk	Sperm whale
Red-necked phalarope	Fourspot flounder	Spinner dolphin
Red-throated loon	Goosefish	Striped dolphin
Ring-billed gull	Gulfstream flounder	True's beaked whale
Roseate tern	Haddock	White-beaked dolphin
Royal tern	Hickory shad	
Sooty shearwater	Horseshoe crab	
Surf scoter	Jonah crab	
White-winged scoter	Little skate	
Wilson's storm petrel	Longfin squid	
	Longhorn sculpin	
	Northern kingfish	
	Northern pipefish	
	Northern puffer	
	Northern sand lance	
	Northern searobin	
	Northern shortfin squid	
	Northern shrimp	
	Ocean pout	
	Pigfish	
	Pinfish	
	Pollock	
	Red hake	
	Rosette skate	
	Roughtail stingray	
	Round herring	
	Sand tiger	
	Scup	
	Sea raven	
	Sea scallop	
	Silver hake	
	Smooth dogfish	
	Smooth skate	
	Southern stingray	
	Spiny butterfly ray	
	Spiny dogfish	
	Spotted hake	
	Spot	



	Striped anchovy Striped bass Striped sea robin Summer flounder Tautog Thorny skate Tilefish Weakfish White hake Windowpane Winter flounder Winter skate Witch flounder Yellowtail flounder	
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### 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 summary 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 9). 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 9 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). Species with (\*) were not included in summary products; see caveats in section 3.1.**

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 tern	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 10) 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.asmfmc.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 could be derived from the base layer products using the same methodology.

**TABLE 10 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	
<b>NEFMC small mesh multispecies</b>		Northern shrimp	Monkfish	
Red hake		Sand tiger	Ocean pout	
Silver hake		Scup	Pollock	
		Smooth dogfish	Red hake	
<b>NEFMC monkfish</b>		Spiny dogfish	Rosette skate	
Goosefish		Spot	Scup	
		Striped bass	Sea scallop	
<b>NEFMC skates</b>		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 study area that have been modeled by Duke MGEL are listed as Endangered under the ESA (Table 11).

**TABLE 11 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 and RPB members.

Four categories of ecological or biological groupings were created for avian species: similar spatial patterns (Table 12), similar taxonomic identification (Table 13), common feeding strategies (Table 14), and common prey (Table 15). Additional groups were created classifying birds by how they use the region – breeding, feeding, migrating through, or resident (Table 16).

**TABLE 12 Groups for avian species based on similar spatial distribution. Species with (\*) were not included in summary products; see caveats in section 3.1.**

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 13 Groups for avian species based on similar taxonomic identification. Species with (\*) were not included in summary products; see caveats in section 3.1.**

<b>Coastal Waterfowl</b>
Black scoter
Common eider*
Common loon
Long-tailed duck
Red-breasted merganser
Red-throated loon
Surf scoter
White-winged scoter

**TABLE 14 Groups for avian species based on common feeding strategies. Species with (\*) were not included in summary products; see caveats in section 3.1.**

<b>Divers &amp; Pursuit Plungers</b>	<b>Benthic Feeders</b>	<b>Surface Feeders</b>	<b>Surface Plungers</b>
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 15 Groups for avian species based on prey type. Species with (\*) were not included in summary products; see caveats in section 3.1.**

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-rumped 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 16 Groups for avian species based on space use for the Mid-Atlantic and Northeast regions. Species with (\*) were not included in summary products; see caveats in section 3.1.**

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
<b>Resident</b>	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 17). 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 or near the seafloor. Several additional fish groups were identified but could not be reliably mapped using the NEFSC fall trawl as the sole data source. Work to map additional ecological/biological fish groups is continuing.

**TABLE 17 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 18). 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 and RPB members.

**TABLE 18 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 19).

**TABLE 19 Avian species groups based on sensitivity to collision or displacement due to offshore wind energy projects on the Atlantic Outer Continental Shelf. Group membership derived from BOEM OCS STUDY 2013-207 (Robinson Willmott et al. 2013). Species with (\*) were not included in summary products; see caveats in section 3.1.**

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 masking by 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. (2008) grouped marine mammals based on their hearing sensitivity to different sound frequencies (Table 20).

**TABLE 20 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. (2008).**

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	

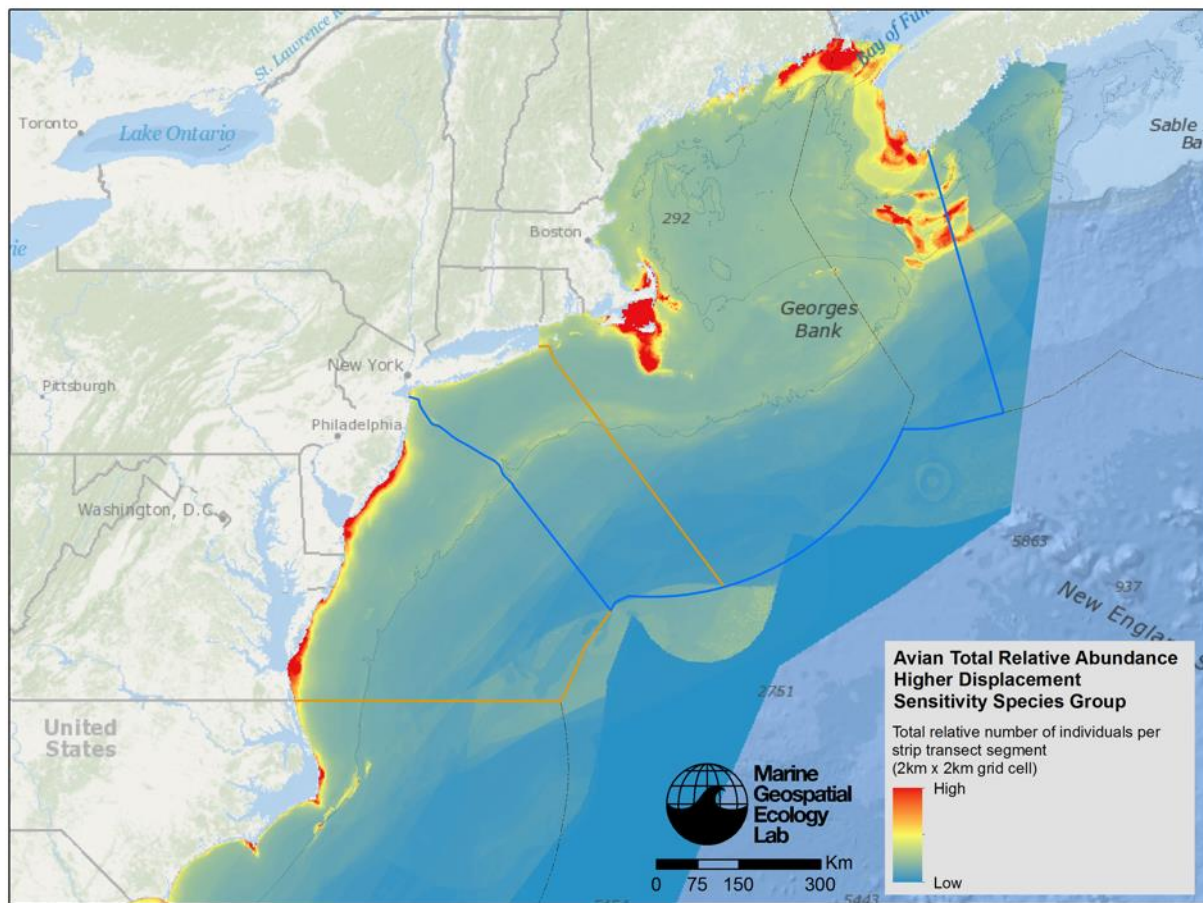
### 3.3 GROUP ABUNDANCE OR BIOMASS

Summed abundance products were created for every defined group including an “all modeled/sampled 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.

For example, the total avian relative abundance distribution map (Figure 7) for the Higher Displacement Sensitivity species group (see Table 19) shows areas with the highest relative abundances in red. This map shows where species that are most vulnerable to displacement due to offshore wind energy development (Robinson Willmott et al. 2013) tend to be most abundant in the study area.



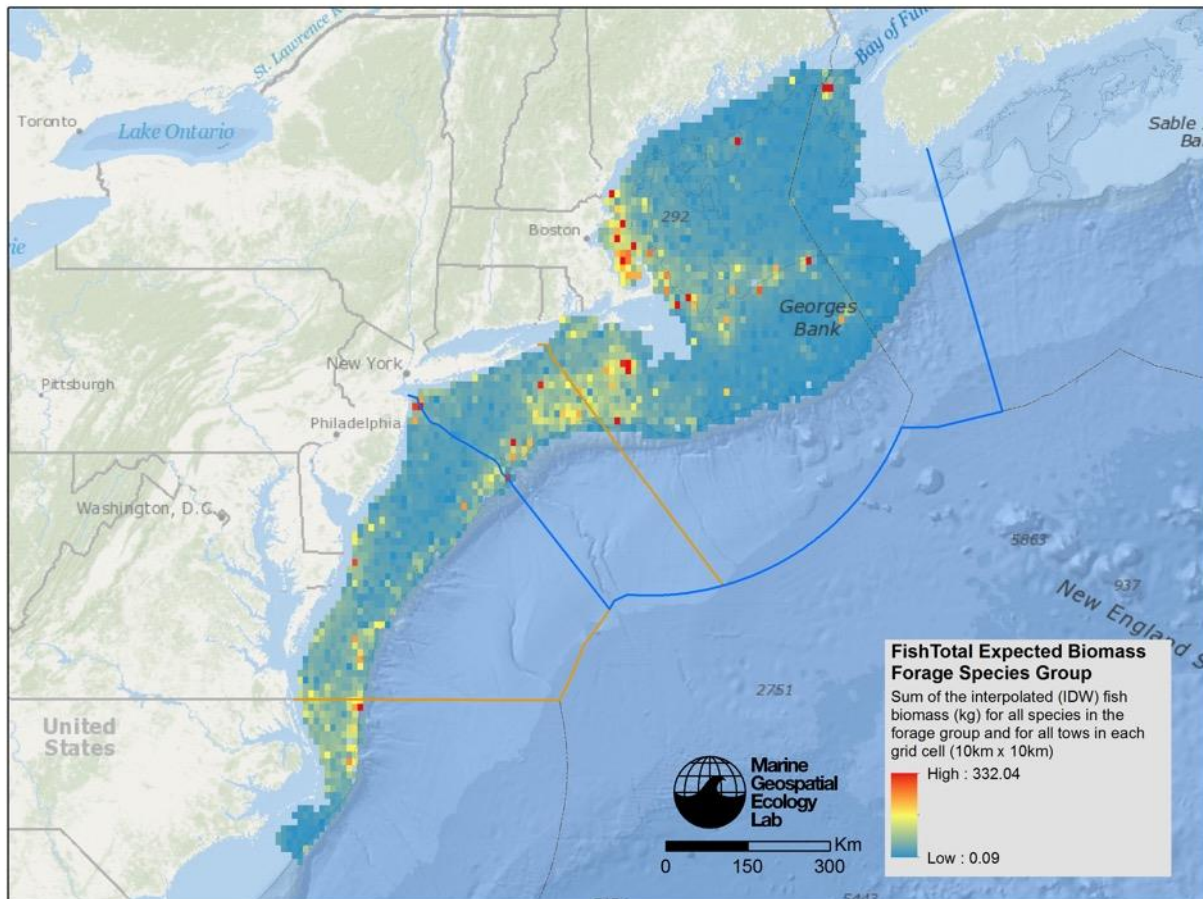
**FIGURE 7** Total avian relative abundance distribution map for the Higher Displacement Sensitivity species group (see Table 19). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.



### 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).

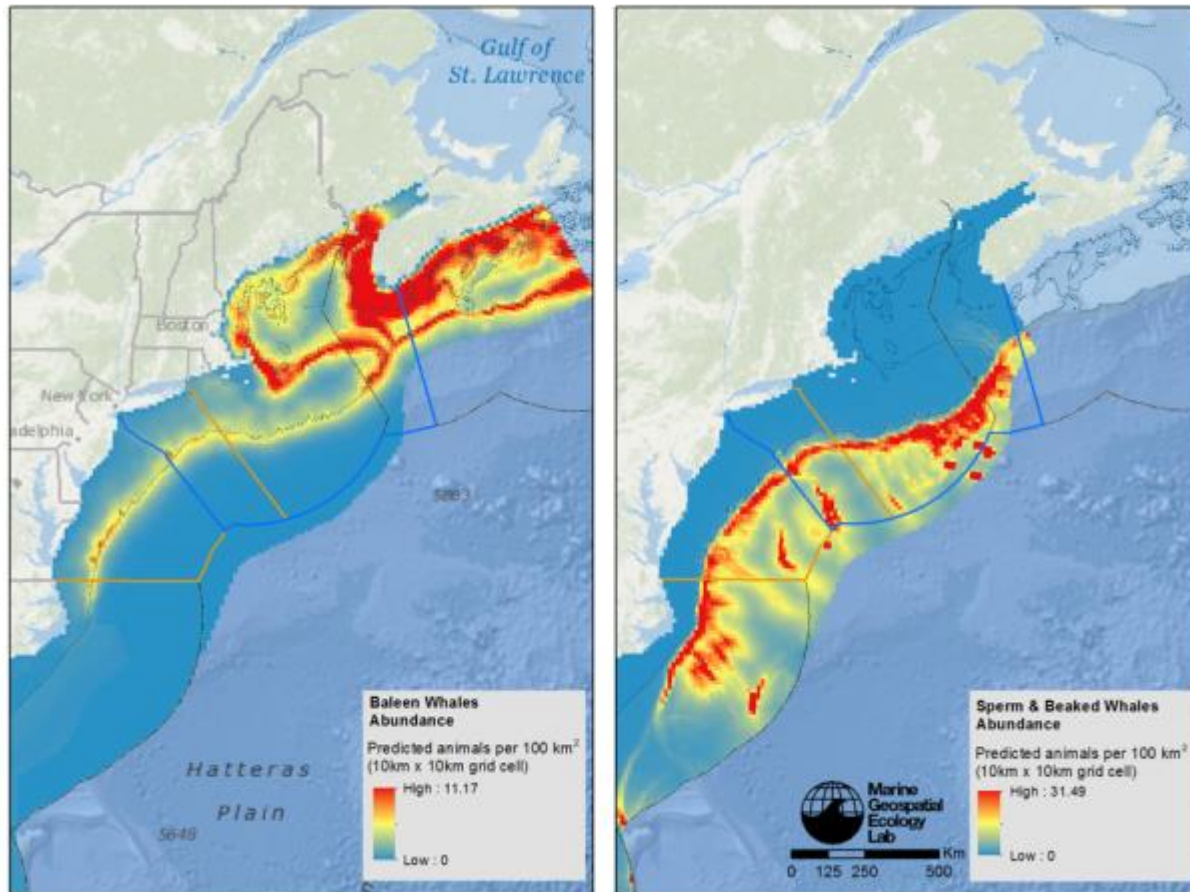
Note that individual fish species IDW maps calculate biomass on a natural logarithm scale, and these aggregate maps are raw biomass, in kilograms.



**FIGURE 8** Total fish biomass (kg) per tow for the forage fish group (see Table 17). The dotted grey line is the 150m isobath. 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.



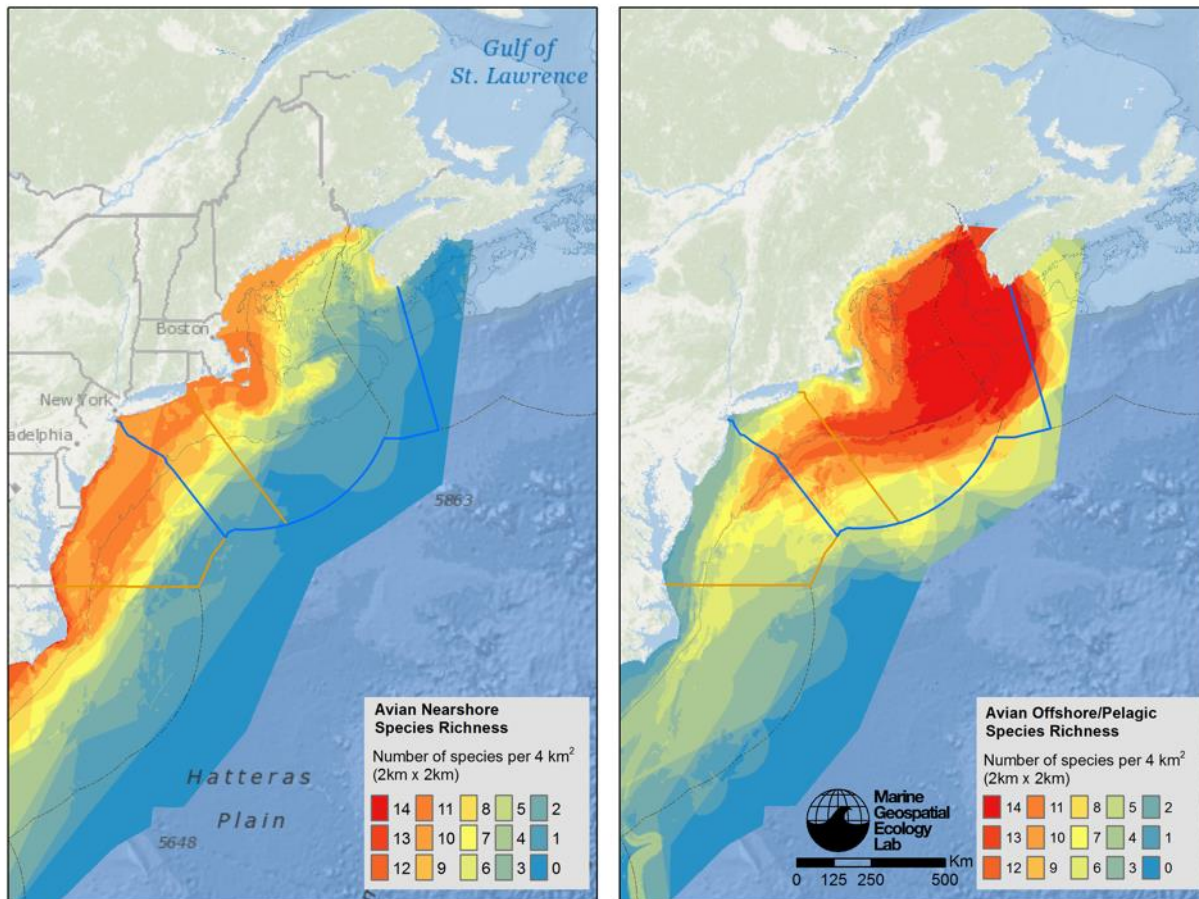
**FIGURE 9** Total predicted annual abundance for baleen whales (left) and sperm & beaked whales (right) (see Table 18). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.



## 3.4 SPECIES RICHNESS

### 3.4.1 AVIAN SPECIES RICHNESS

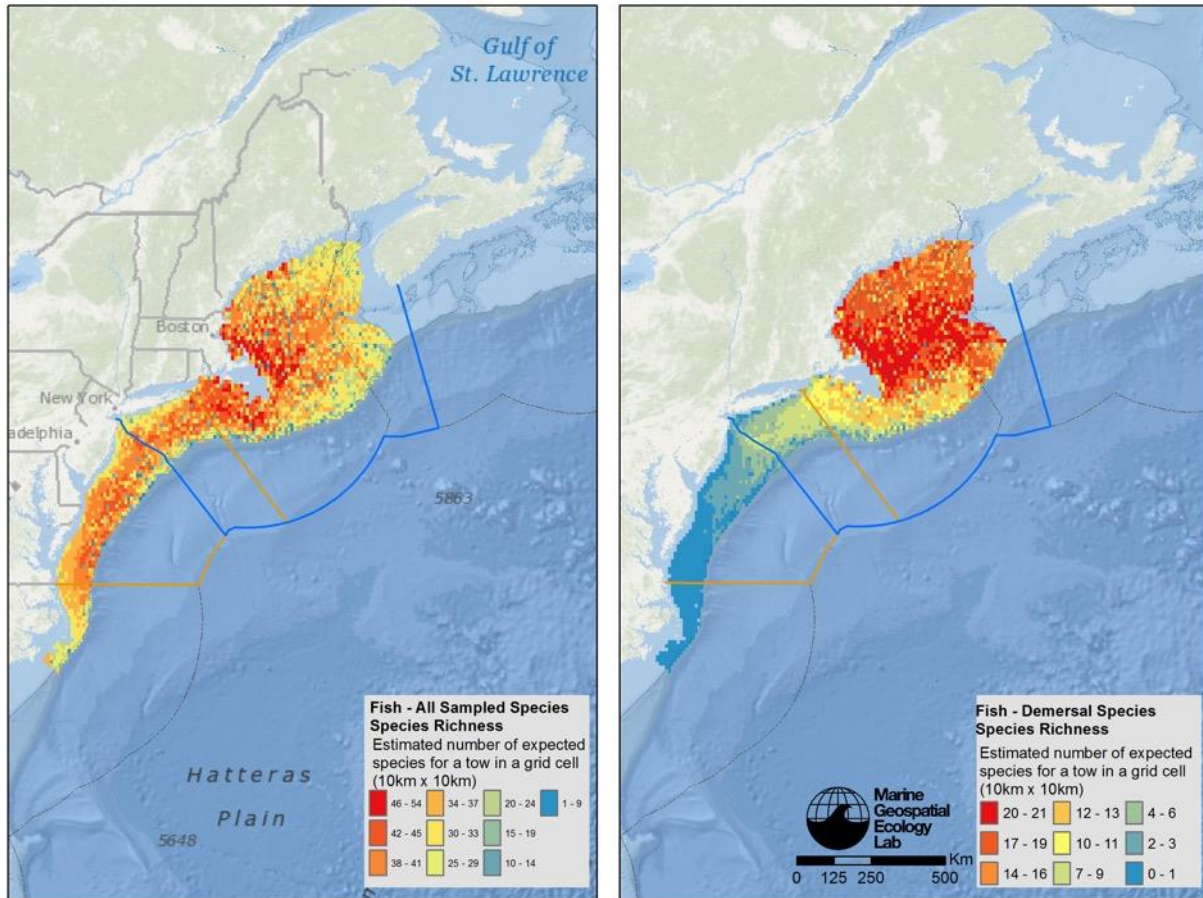
For all avian species together, and for each group of species defined in section 3.2 of this Report, total species richness maps are calculated in a GIS by stacking each individual species' predicted presence and counting the total number of species present in each cell. A species is considered present in a cell if that cell is included in the area holding 95% of the total predicted relative abundance for the species. 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). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

### 3.4.2 FISH SPECIES RICHNESS

For all sampled 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' sampled presence 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 95% of the total raw biomass for the species. Differences in the spatial patterns between “all sampled species” and species groups (e.g., demersal species) (Figure 11) indicate that species group maps may help reveal ecological patterns influencing fish species richness.



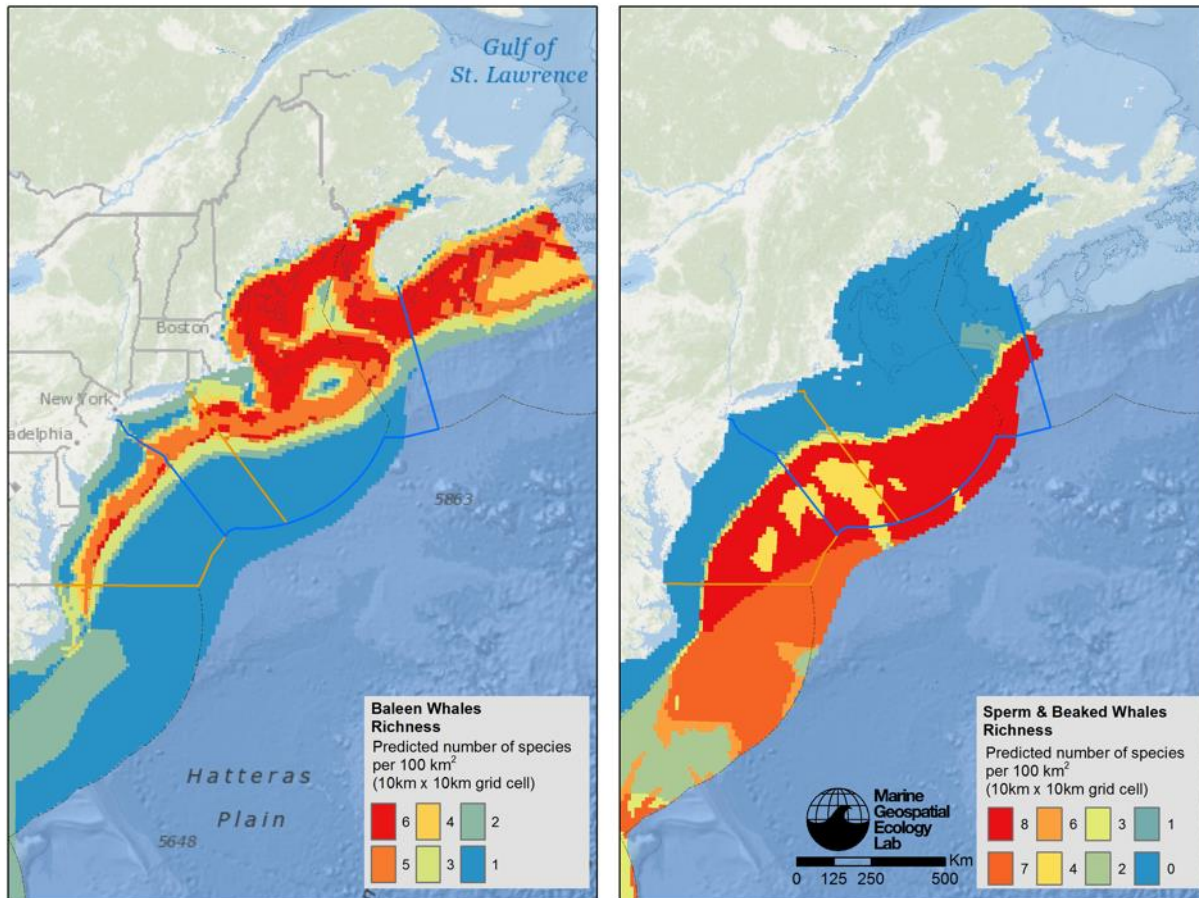
**FIGURE 11** Fish species richness, comparing all sampled fish species (left) with the demersal fish species group (right). The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

### 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 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 95% 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) suggest that in general, these biological groups of cetaceans occur in different ocean habitats.



**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

To create maps showing areas of high and low biodiversity, two indices of diversity were considered: the Shannon diversity index (Shannon & Weaver, 1949) and the Gini-Simpson diversity index (Gini 1912, Simpson 1949, Greenberg 1956, Berger & Parker 1970). Each index has strengths and weaknesses, depending on the question that the user is hoping to answer. The Shannon index is most sensitive to changes in rare species, whereas the Gini-Simpson index is most sensitive to changes in abundant (e.g., dominant) species (Peet, 1974).

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  $R$ ). The formula used to calculate the index, and the term definitions, 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

The Simpson index is simply a probability that any two individuals will belong to the same species. As the Simpson index approaches a maximum of 1, it indicates a maximum probability that all individuals belong to the same species; in other words, diversity is very low. The index is calculated by taking the proportion of individuals in one species relative to the total number of species, and summing these across all species. This number is essentially a measure of dominance, and as dominance increases, total diversity decreases. Because values of the Simpson index are not intuitive to map (i.e., high values equal low diversity) MDAT uses the Gini-Simpson index, which is 1 minus the Simpson index. As a result, areas with high Gini-Simpson index scores (approaching 1) have higher diversity (low dominance by a single species). Areas with low Gini-Simpson index scores (approaching 0) have lower diversity (high dominance by a single species). A drawback of this index is that species with few numbers of individuals will not impact the Gini-Simpson score. The formula used to calculate the index, and the term definitions, are given below:

$$D = 1 - \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

$n_i$  is the number of individuals belonging to the  $i$ th species

$N$  is the total number of individuals in the dataset

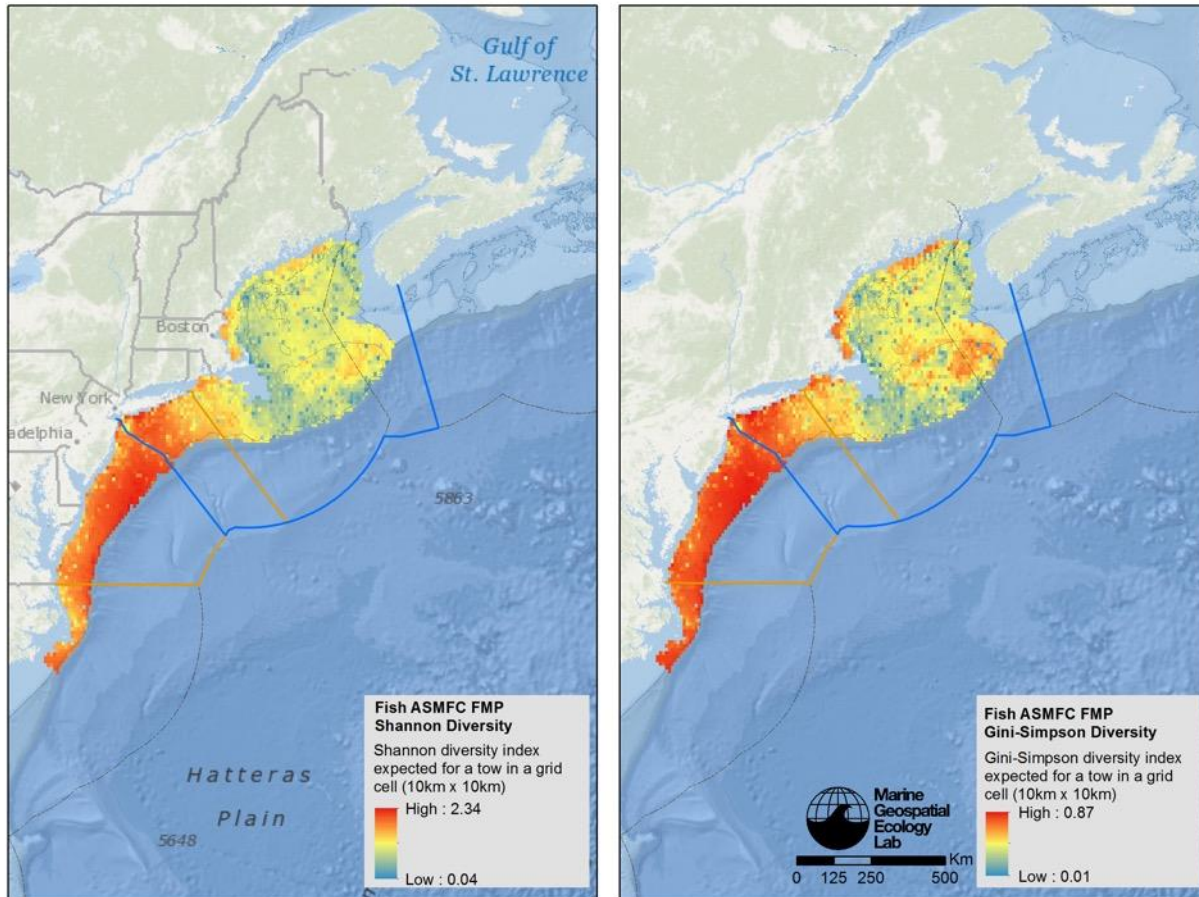


### 3.5.1 AVIAN DIVERSITY

Diversity metrics were not calculated for avian species. Avian model outputs are representations of *relative*—not absolute—abundance, and therefore it would be inappropriate to calculate diversity metrics, which rely on measures of absolute abundance.

### 3.5.2 FISH DIVERSITY

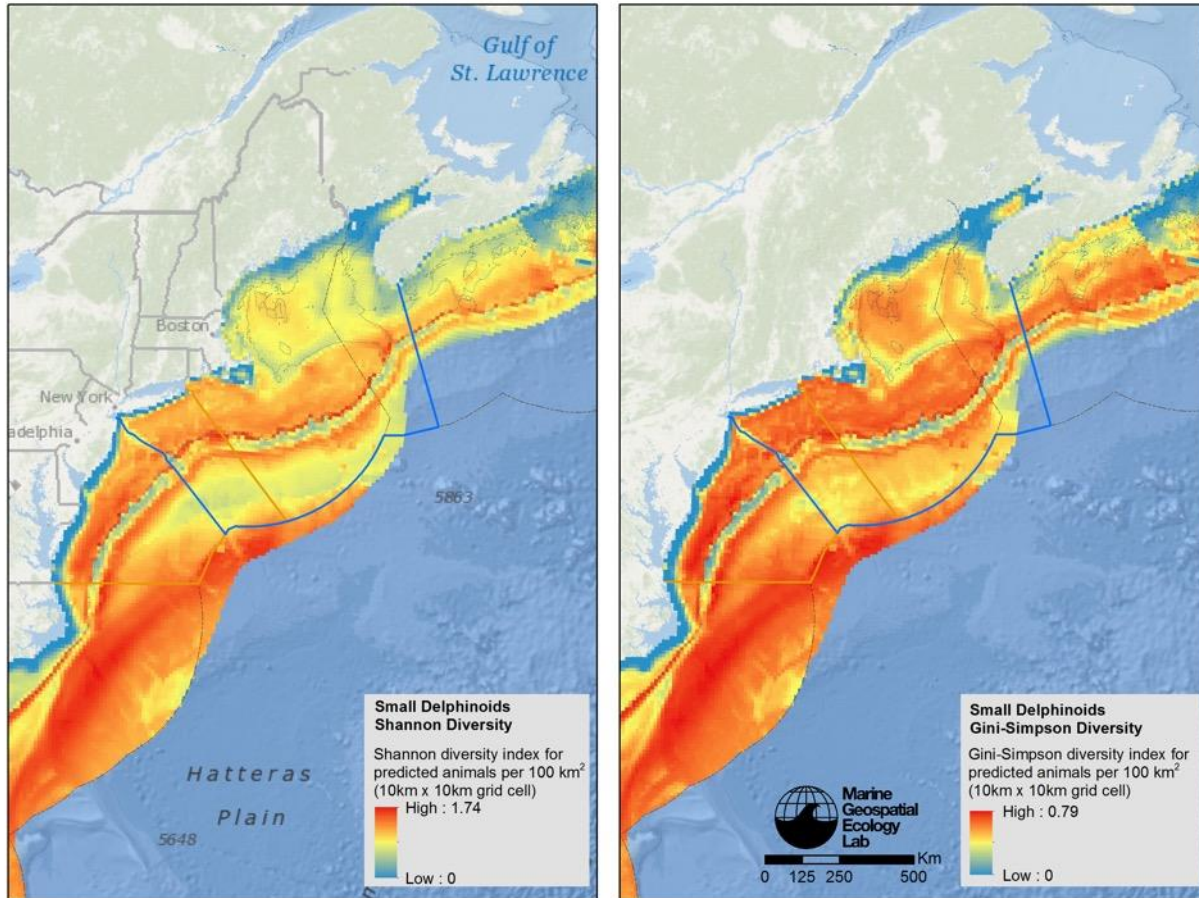
The maps below show Shannon diversity for fish species included in the Atlantic States Marine Fisheries Commission (ASMFC) fisheries management plans (Figure 13, left) and Gini-Simpson diversity for fish species included in the ASMFC fisheries management plans (Figure 13, right; see Table 11 for regulated species group definitions). Similar spatial patterns are observed between the two diversity indices examined here.



**FIGURE 13** Fish diversity for the Atlantic States Marine Fishery Commission (ASFMC) Fishery Management Plan (FMP) species. Both the Shannon diversity index (left) and the Gini-Simpson index (right) were calculated. The dotted grey line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

### 3.5.3 CETACEAN DIVERSITY

The maps below compare the Shannon diversity index (Figure 14, left) and the Gini-Simpson diversity index (Figure 14, right) of the small delphinoid species groups. Again, each index shows similar spatial patterns.



**FIGURE 14** Shannon diversity index (left) and Gini-Simpson index (right) of small delphinoid species. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

## 3.6 CORE ABUNDANCE OR BIOMASS 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.

In the summer of 2015, MDAT explored multiple methods that could be used to characterize areas with higher densities of each taxon. Examples of each method and a summary table describing the pros and cons of each method (Table 21) were presented to the work groups and agency staff for feedback. These methods ranged from simple classification methods applied to the abundance data (e.g., equal interval, quantile, natural breaks), to complex optimized thresholds that relied on abundance accumulation curves by individual month of the year.



**TABLE 21 Comparison of various methods considered for characterizing areas with higher densities. Selected method is in bold.**

	Simplicity	Comments
Equal Interval	Simple	Rudimentary
Quantiles	Simple	Rudimentary
Natural Breaks	Complex	Difficult to implement and explain
Recursive Means	Complex	Better data hierarchy than Natural Breaks, easier to implement
<b>Set population threshold</b>	<b>Simple</b>	<b>Apply consistently across taxa</b>
Optimized population threshold	Complex	Related to recursive means

After considering these options and balancing factors such as simplicity, representation of the distribution of the data, difficulty to implement, and difficulty to explain, the work groups and agency staff supported MDAT's choice to pursue the "Set population threshold." A major strength of this approach is the ability to apply it consistently across taxa and the ease of interpreting the resulting maps.

The set population approach calculates the smallest area that contains a certain percentage of the population. A cumulative sum plot could identify an optimal balance threshold between minimizing total area covered and maximizing percent of population included. Such an approach would identify thresholds that vary from species to species. In this effort, the focus was instead 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 a given species distribution prediction gives the total predicted abundance. Core area is calculated by ordering cells for a given species by their abundance value from greatest to least, then selecting cells starting with the highest abundance values and totaling those values until enough cells have been selected for the total to be equal to 50% of the total predicted abundance (or biomass for fish). This ensures that the cells selected represent the smallest area with 50% of the total predicted abundance. Cells that are in the core area are considered "presence" and cells outside that area are "absence". This process is repeated for each species in the group, and then all presence/absence grids are stacked in a GIS and each cell is summed, resulting in a count of species richness in each cell. Each cell count represent how many species include that cell as part of its 50% core area.

### 3.6.1 CORE ABUNDANCE / BIOMASS 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 of this Report for more details.

- Avian core relative abundance area richness products were calculated using the mean-normalized relative abundance individual species layers.
- The analysis extent matters. Because cells are ordered based on their abundance or biomass value, the cells that are included in that list – inside 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 area of interest, the Northeast planning area, and the full extent of the input data (i.e., US Atlantic Coast for mammals and birds, Northeast/Mid-Atlantic Continental Shelf for fish). This report includes examples of all three spatial extents.

### 3.6.2 AVIAN CORE RELATIVE ABUNDANCE AREA RICHNESS

Avian core relative abundance area richness for species of higher displacement sensitivity at the full US Atlantic coast extent (Figure 15, left) indicates medium species core area richness along the shoreline in the Mid-Atlantic and around Cape Cod Massachusetts. When calculated at the Mid-Atlantic regional extent (Figure 15, middle), 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, and similar higher densities of core area richness in the Northeast (Figure 15, right) when calculated at that extent.

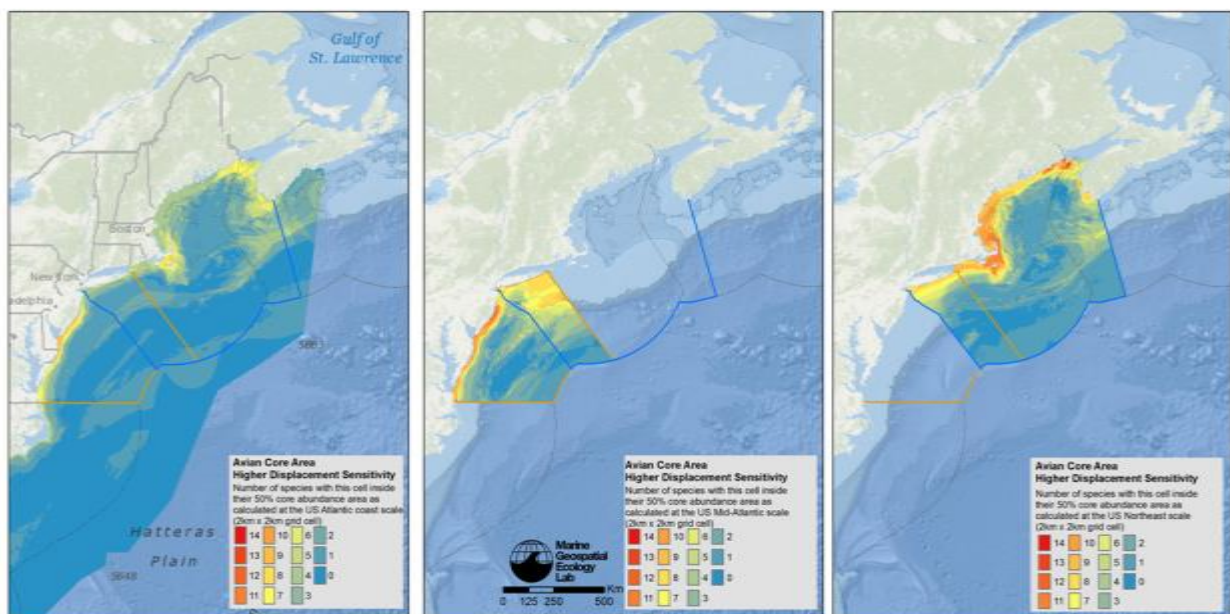


FIGURE 15 Avian core relative abundance area richness for species of higher displacement sensitivity at the full US Atlantic Coast scale (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

### 3.6.3 FISH CORE BIOMASS AREA RICHNESS

Fish core biomass area richness was calculated on the raw biomass values. NEFSC “all sampled species” group core biomass area richness at the US Northeast Shelf scale (Figure 16, left), the Mid-Atlantic region (Figure 16, middle), and the Northeast region extent (Figure 16, right). More cells with higher richness values are present in the regions of interest when the calculation is restricted to the smaller extents.

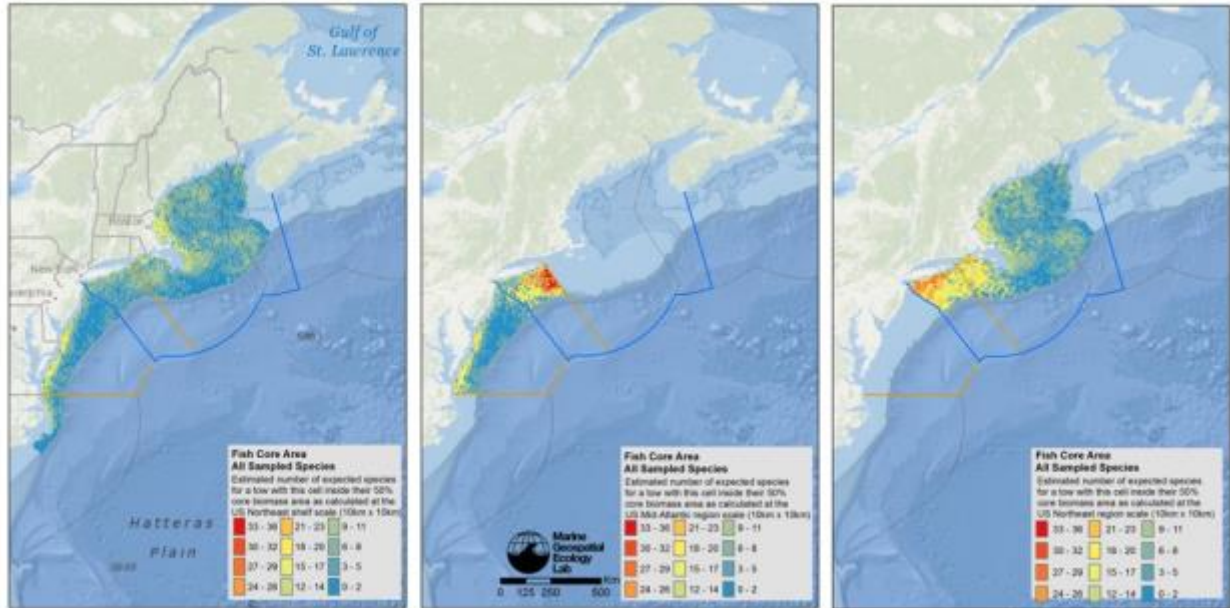
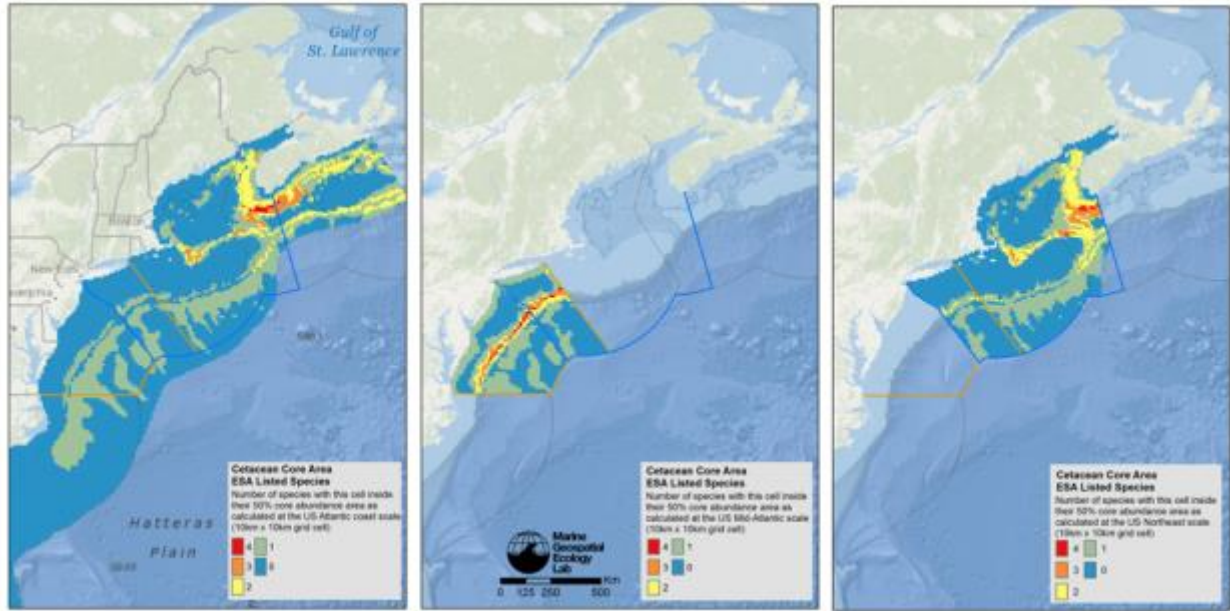


FIGURE 16 Fish core biomass area richness. NEFSC all sampled species core biomass area richness at the US east coast scale (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

### 3.6.4 CETACEAN CORE ABUNDANCE AREA RICHNESS

Cetacean species core abundance area richness is high along the shelf break in the Mid-Atlantic region (Figure 17, center) when calculated at that extent, but is shifted to the waters off Nova Scotia and in the Great South Channel when calculated at the full US Atlantic Coast extent (Figure 17, left). The latter pattern is repeated in the outputs for the Northeast region (Figure 17, right)



**FIGURE 17** Cetacean core abundance area species richness for the ESA species group calculated at the US Atlantic Coast (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.



## 4 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 summary products. A centralized data store of web services also allows the MDAT team to maintain the data through improvement and model update cycles. Web services for all products are accessed online at: <http://mgelmaps.env.duke.edu/mdat/rest/services/MDAT>.

### 4.1 BASE MODELS AND DATA PRODUCTS

A series of ArcGIS map services was created for the base layer data products. A separate service was created for each type of model, data, and associated uncertainty products (see the list below). MDAT has committed to host map services of the individual models and data over the next several years.

- 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

Use limitations for avian model products:

Please note: BOEM and NOAA make no warranty, expressed or implied, regarding these data, nor does the fact of distribution constitute such a warranty. BOEM and NOAA cannot assume liability for any damages caused by any errors or omissions in these data.

Use limitations for marine mammal model products:

This dataset is copyright 2015 by the Marine Geospatial Ecology Lab at Duke University and licensed under a Creative Commons Attribution 4.0 International License (CC-BY) (<http://creativecommons.org/licenses/by/4.0/>). If you use this dataset in a scientific publication or other formal publication, we request that you cite the Roberts et al. (2016) publication referenced in this report.

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 model products and avian model products are publicly distributed via a website. Marine mammal models are hosted by Duke University's Marine Geospatial Ecology Lab (see <http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/>). Avian model outputs and associated geospatial data are available for download at: <https://coastalscience.noaa.gov/projects/detail?key=279>.



## 4.2 SUMMARY PRODUCTS

Three ArcGIS map services were created to host the summary products, one for each MDAT taxonomic group. Within each taxonomic group, species groups (see section 3.2 of this Report) are the top level of organization. Within each species group, the full set of summary product layers are available, as outlined below. Services were not created for species groups containing only one species. MDAT has committed to host web services of summary products over the next several years.

Map service names for each taxonomic group:

- AvianModels\_SyntheticProducts
- Fish\_NEFSC\_SyntheticProducts
- Mammal\_SyntheticProducts

Within each service are the species group names, and within each species' group are the six available summary products:

- Abundance | Biomass
- Species Richness
- Gini-Simpson Diversity
- Core Abundance | Biomass Area – Northeast scale
- Core Abundance | Biomass Area – Mid-Atlantic scale
- Core Abundance | Biomass Area – Atlantic scale

Use limitations for all summary products:

If you use this dataset in a scientific publication or other formal publication, we request that you cite this report: Curtice, C., Cleary J., Shumchenia E., Halpin P. (2016) Marine-life Data and Analysis Team (MDAT) technical report on the methods and development of marine-life data to support regional ocean planning and management. Prepared on behalf of The Marine-life Data and Analysis Team (MDAT). Accessed at: [http://seamap.env.duke.edu/models/MDAT/MDAT-Technical-Report-v1\\_1.pdf](http://seamap.env.duke.edu/models/MDAT/MDAT-Technical-Report-v1_1.pdf).





## 5 ACKNOWLEDGEMENTS

### 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, [brian.kinlan@noaa.gov](mailto:brian.kinlan@noaa.gov)).

### 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 (NOAA NEFSC, [michael.fogarty@noaa.gov](mailto:michael.fogarty@noaa.gov)).

### 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](mailto:jason.roberts@duke.edu)).

### For the MDAT project and summary products

The Marine-life Data and Analysis Team developed and delivered the marine life base layer products and summary products as part of a collaboration with the Northeast Regional Ocean Council (NROC) and the Mid-Atlantic Regional Council on the Ocean (MARCO). Development of the summary products was guided by the Northeast Regional Planning Body (NERPB), NERPB expert work groups, the Mid-Atlantic Regional Planning Body, and the Mid-Atlantic Data Synthesis Work Group. Through NROC, this work was funded (in part) by cooperative agreement numbers NA12NOS4730010 and NA12NOS4730186 from the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies. For more information, please contact Jesse Cleary ([jesse.cleary@duke.edu](mailto:jesse.cleary@duke.edu)).

## 6 LITERATURE CITED

- Berger, W. H., & Parker, F. L. (1970). Diversity of planktonic foraminifera in deep-sea sediments. *Science*, 168(3937), 1345–1347.
- Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling estimating abundance of biological populations*. Oxford University Press.
- Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2004). *Advanced Distance Sampling: Estimating abundance of biological populations*. Oxford University Press.
- Gini, C. (1912). Variabilità e mutabilità, Studi economico-giuridici pubblicati per cura della Facoltà di Giurisprudenza della Regia Università di Cagliari, Anno III, parte 2.
- Greenberg, J. H. (1956). The Measurement of Linguistic Diversity. *Language*, 32(1), 109–115.  
<http://doi.org/10.2307/410659>
- Greene, J. K., Anderson, M. G., Odell, J., & Steinberg, N. (2010). The Northwest Atlantic marine ecoregional assessment: species, habitats and ecosystems. *Phase One. The Nature Conservancy, Eastern US Division, Boston, MA*.
- Kinlan, B. P., Menza, C., & Huettmann, F. (2012). Chapter 6: Predictive modeling of seabird distribution patterns in the New York Bight. *A Biogeographic Assessment of Seabirds, Deep Sea Corals and Ocean Habitats of the New York Bight: Science to Support Offshore Spatial Planning. NOAA Technical Memorandum NOS NCCOS, 141*, 87–224.
- Kinlan, B. P., Zipkin, E. F., O'Connell, A. F., & Caldow, C. (2012). Statistical analyses to support guidelines for marine avian sampling: final report. US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Herndon, VA. OCS Study BOEM 2012-101. *NOAA Technical Memorandum NOS NCCOS, 158*.
- Menza, C. W., Kinlan, B. P., Dorfman, D. S., Poti, M., & Caldow, C. (2012). *A biogeographic assessment of seabirds, deep sea corals and ocean habitats of the New York Bight: science to support offshore spatial planning*. US Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science.
- Peet, R. K. (1974). The Measurement of Species Diversity. *Annual Review of Ecology and Systematics*, 5(1), 285–307. <http://doi.org/10.1146/annurev.es.05.110174.001441>
- Roberts, J. J., Best, B. D., Mannocci, L., Fujioka, E., Halpin, P. N., Palka, D. L., ... Lockhart, G. G. (2016). Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Scientific Reports*, 6, 22615.  
<http://doi.org/10.1038/srep22615>
- Robinson Willmott, J. C., Forcey, G., & Kent, A. (2013). The relative vulnerability of migratory bird species to offshore wind energy projects on the Atlantic Outer Continental Shelf: An assessment method and database. *Final Report to the US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs. OCS Study BOEM, 207*, 275.
- Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois press.



- Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163, 688. <http://doi.org/10.1038/163688a0>
- Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr, C. R., ... others. (2008). Marine mammal noise-exposure criteria: initial scientific recommendations. *Bioacoustics*, 17(1-3), 273–275.
- Zipkin, E. F., Leirness, J. B., Kinlan, B. P., O'Connell, A. F., & Silverman, E. D. (2014). Fitting statistical distributions to sea duck count data: Implications for survey design and abundance estimation. *Statistical Methodology*, 17, 67–81.

## 7 APPENDIX A - MODEL PERFORMANCE

This appendix provides supplementary information regarding the model performance statistics for both avian and cetacean individual species models. Because fish biomass observations were mapped and not modeled, no additional information is provided for fish products in this appendix.

### 7.1 AVIAN MODEL PERFORMANCE

This section 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.

### References

Bodenhofner, U., Krone, M., and Klawonn, F. 2013. Testing noisy numerical data for monotonic association. *Information Sciences* 245:21-37.

Boudt, K., Cornelissen, J., and Croux, C. 2012. The Gaussian rank correlation estimator: robustness properties. *Statistics and Computing* 22:471-483.

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 <sup>1</sup>	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 $\geq 1$ ; 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

<sup>1</sup> Boudt et al. (2012) and Bodenhofner 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	$x < 0.1$	$0.1 \leq x < 0.2$	$0.2 \leq x < 0.4$	$0.4 \leq x < 0.6$	$x \geq 0.6$
AUC	$x < 0.6$	$0.6 \leq x < 0.7$	$0.7 \leq x < 0.8$	$0.8 \leq x < 0.9$	$x \geq 0.9$
RankRG_nz	$x < 0.1$	$0.1 \leq x < 0.2$	$0.2 \leq x < 0.4$	$0.4 \leq x < 0.6$	$x \geq 0.6$
MedianAE_nz_rel (CV)	$x \geq 2.0$	$2.0 > x \geq 1.0$	$1.0 > x \geq 0.5$	$0.5 > x \geq 0.25$	$x < 0.25$

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
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



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)
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
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

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)
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
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

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)
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
nof u	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
nof u	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
nof u	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
nof u	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
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

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)
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
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

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)
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

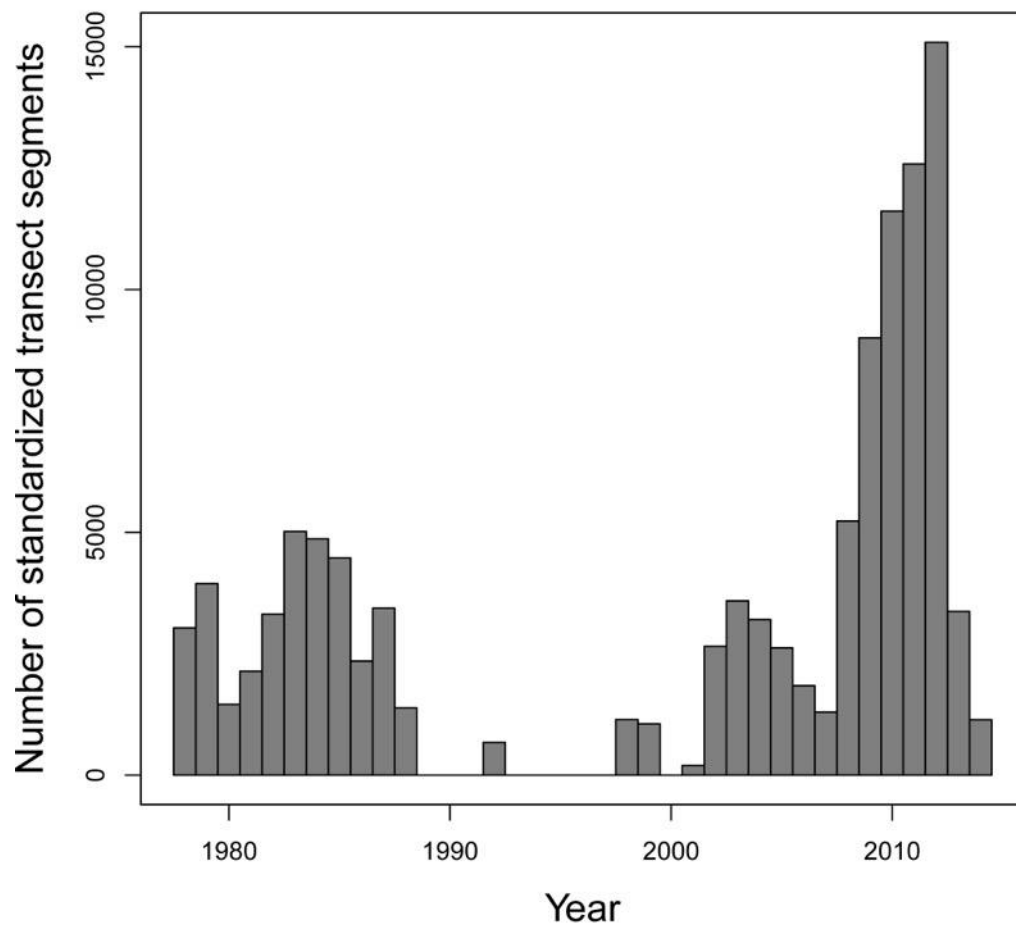


Figure 1. Number of survey transect segments by year.

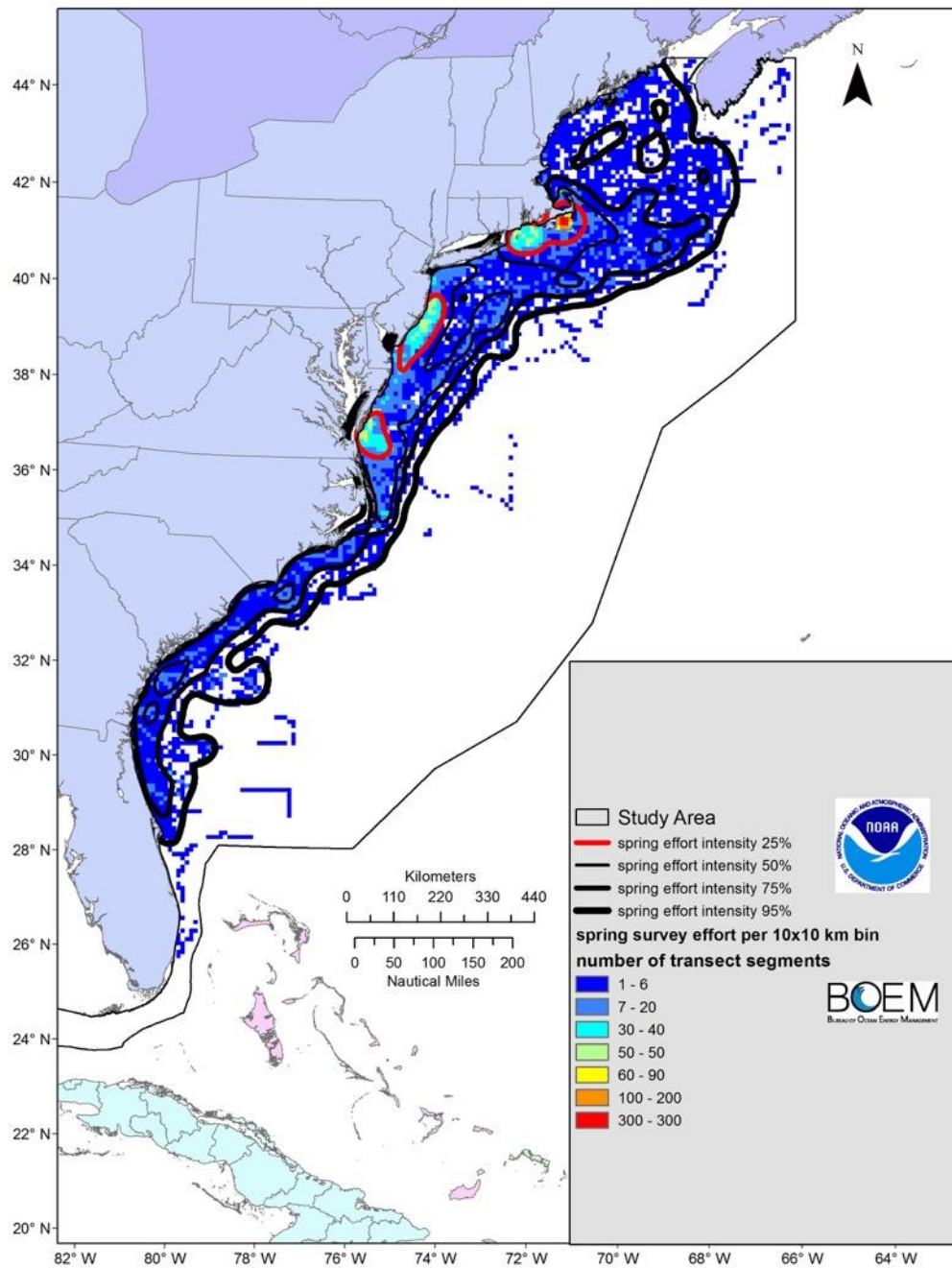


Figure 2. Map of survey effort in spring (March-May). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.



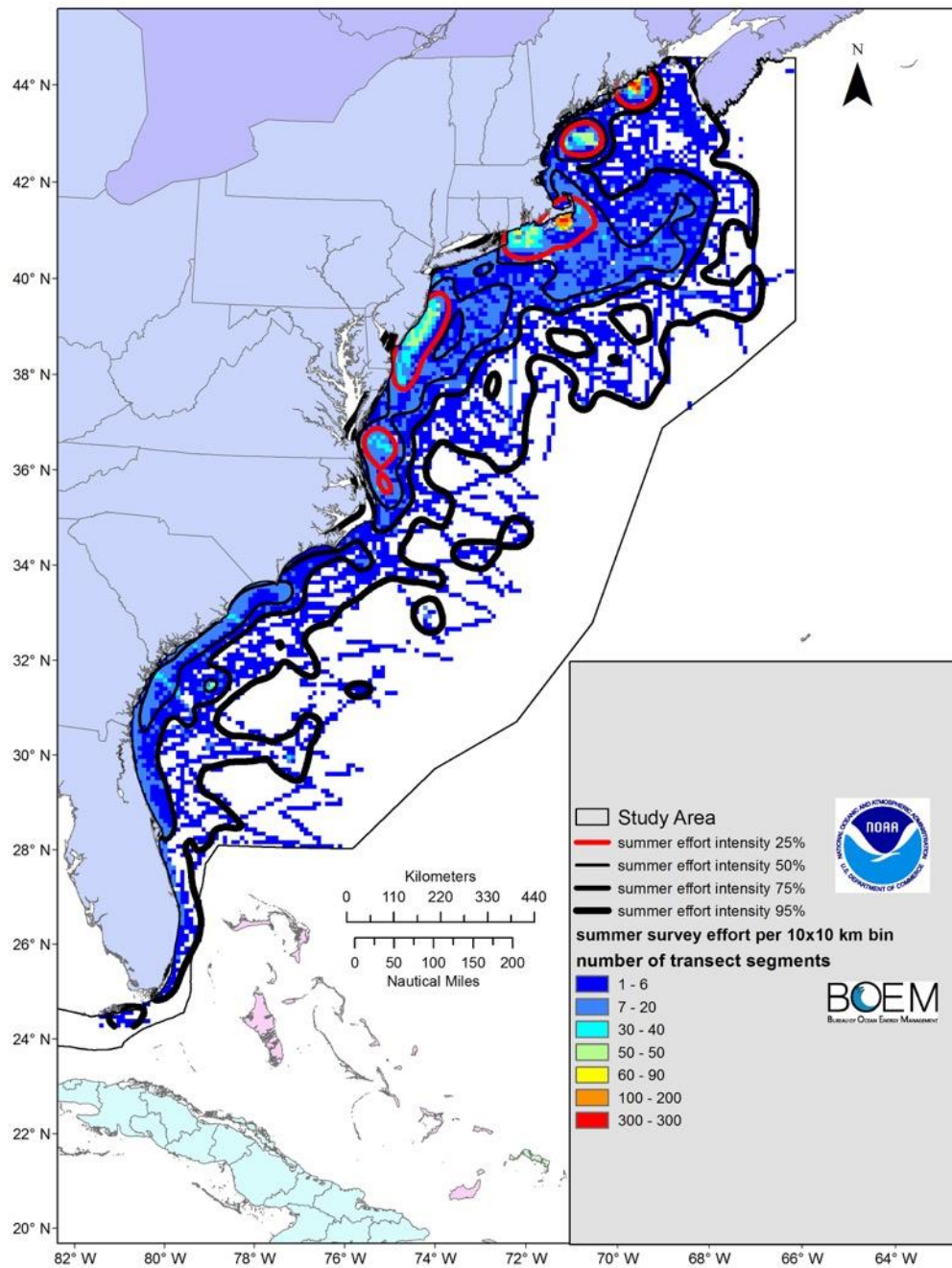


Figure 3. Map of survey effort in summer (June-August). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.

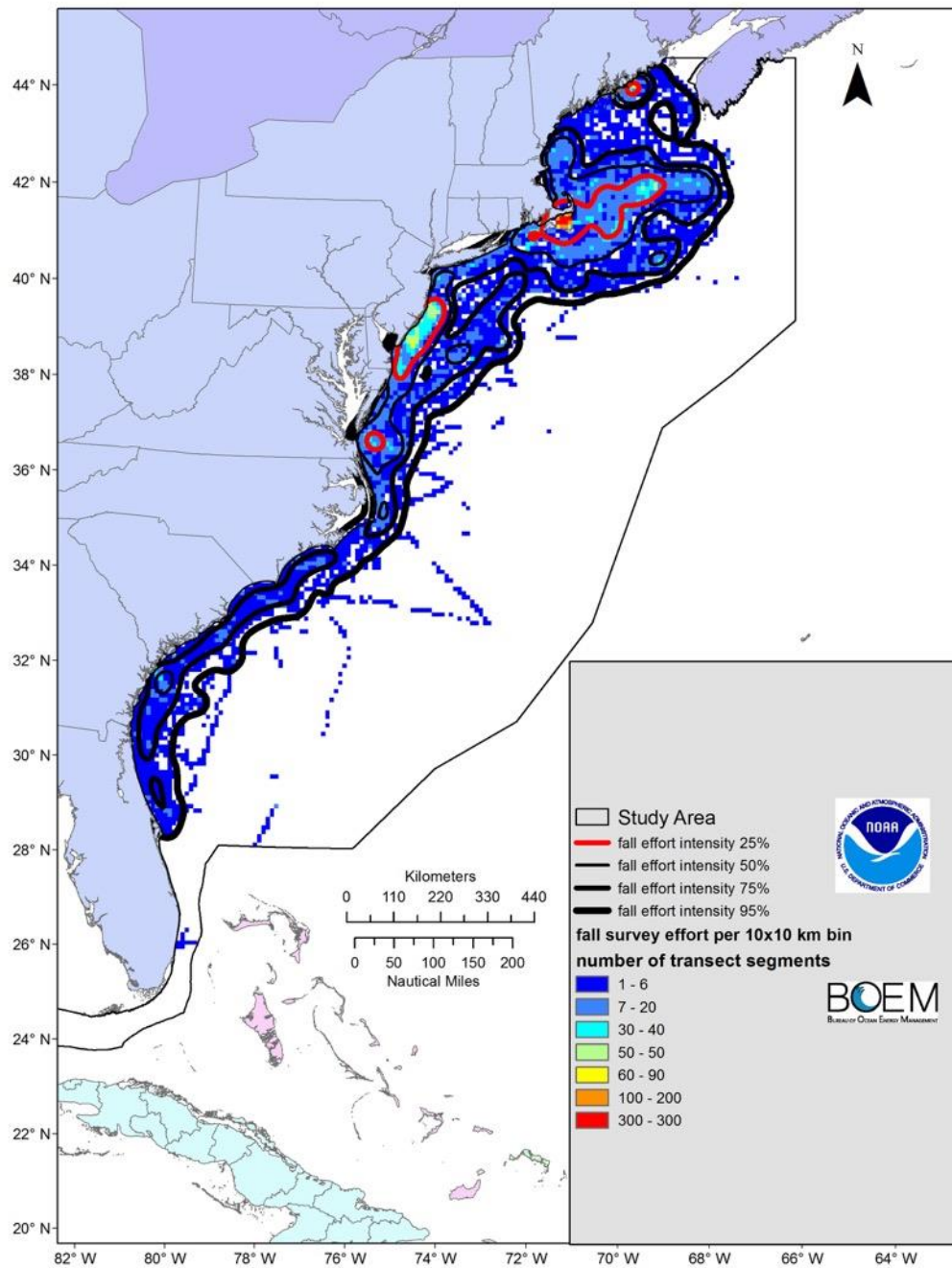


Figure 4. Map of survey effort in fall (September-November). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.

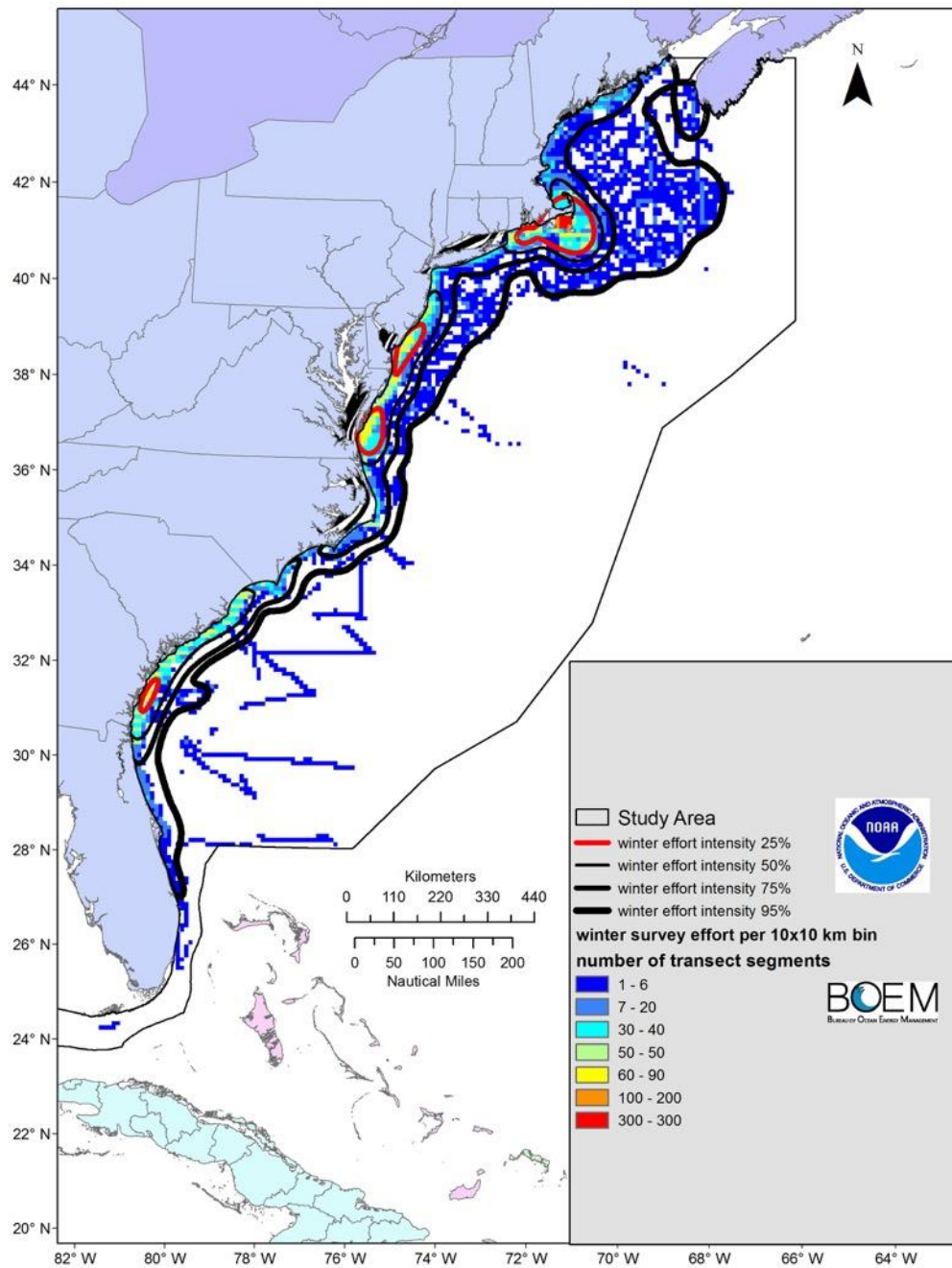


Figure 5. Map of survey effort in winter (December-February). The colored grid represents the number of survey transect segment midpoints in 10 x 10 km cells within the study area (outer thin black line). The overlaid thick red and black lines indicate different isopleths of survey effort density.



## 7.2 CETACEAN MODEL PERFORMANCE

Cetacean model performance metrics are reproduced here from the Supplementary information in Roberts et al. (2016), which is also available online here: <http://www.nature.com/article-assets/npg/srep/2016/160303/srep22615/extref/srep22615-s1.pdf>



**Supplementary Table S4.** Summary of results, by modeled taxon, region, and season. Model type “both” means one sub-region was modeled with a DSM and another was modeled with a stratified model. Prediction resolution gives the temporal resolution of the density surface predicted by the best model. % Area covered,  $\hat{N}$ , and CV give the percentage of the study area covered by the surface, total abundance of the surface averaged across the season, and coefficient of variation (CV) of the total abundance. The CV estimate only incorporates the uncertainty of the spatial model.

Group	Modeled taxon	Region	Season	Model type	Prediction resolution	% Area covered	$\hat{N}$	CV
Small delphinoids	Atlantic spotted dolphin	EC	Year-round	DSM	Year-round	100	55,436	0.32
		GOM	Year-round	DSM	Year-round	100	47,488	0.13
	Atlantic white-sided dolphin	EC	Year-round	DSM	Monthly	100	37,180	0.07
	Bottlenose dolphin	EC	Year-round	DSM	Monthly	100	97,476	0.06
		GOM	Year-round	DSM	Year-round	100	138,602	0.06
	Clymene dolphin	EC	Year-round	Stratified	Year-round	100	12,515	0.56
		GOM	Year-round	DSM	Year-round	100	11,000	0.16
	Fraser's dolphin	EC	Year-round	Stratified	Year-round	100	492	0.76
		GOM	Year-round	Stratified	Year-round	100	1,665	0.73
	Harbor porpoise	EC	Winter (Nov-May)	DSM	Monthly	56	17,651	0.17
			Summer (Jun-Oct)	DSM	Monthly	92	45,089	0.12
	Pantropical spotted dolphin	EC	Year-round	Stratified	Year-round	100	4,436	0.33
		GOM	Year-round	DSM	Year-round	100	84,014	0.06
	Rough-toothed dolphin	EC	Year-round	Stratified	Year-round	100	532	0.36
		GOM	Year-round	DSM	Year-round	100	4,853	0.19
	Short-beaked common dolphin	EC	Year-round	DSM	Monthly	100	86,098	0.12
	Spinner dolphin	EC	Year-round	Stratified	Year-round	100	262	0.93
		GOM	Year-round	DSM	Year-round	100	13,485	0.24
	Striped dolphin	EC	Year-round	DSM	Year-round	100	75,657	0.21
		GOM	Year-round	DSM	Year-round	100	4,914	0.17
	White-beaked dolphin	EC	Year-round	Stratified	Year-round	100	39	0.42

Large delphinoids	False killer whale	EC	Year-round	Stratified	Year-round	100	95	0.84
		GOM	Year-round	Stratified	Year-round	100	3,204	0.36
	Killer whale	EC	Year-round	Stratified	Year-round	100	11	0.82
		GOM	Year-round	DSM	Year-round	100	185	0.41
	Melon-headed whale	EC	Year-round	Stratified	Year-round	100	1,175	0.50
		GOM	Year-round	DSM	Year-round	100	6,733	0.30
	Pilot whales (guild)	EC	Year-round	DSM	Year-round	100	18,977	0.11
	Pygmy killer whale	GOM	Year-round	DSM	Year-round	100	2,126	0.30
Beaked and sperm whales	Risso's dolphin	EC	Year-round	DSM	Monthly	100	7,732	0.09
		GOM	Year-round	DSM	Year-round	100	3,137	0.10
	Short-finned pilot whales	GOM	Year-round	DSM	Year-round	100	1,981	0.18
	Beaked whales (guild)	EC	Year-round	Both	Year-round	100	14,491	0.17
		GOM	Year-round	DSM	Year-round	100	2,910	0.16
	Kogia whales (guild)	EC	Year-round	Stratified	Year-round	100	678	0.23
		GOM	Year-round	DSM	Year-round	100	2,234	0.19
	Northern bottlenose whale	EC	Year-round	Stratified	Year-round	85	90	0.63
Baleen whales	Sperm whale	EC	Year-round	DSM	Monthly	100	5,353	0.12
		GOM	Year-round	DSM	Year-round	100	2,128	0.08
	Blue whale	EC	Year-round	Stratified	Year-round	100	11	0.41
	Bryde's whale	EC	Year-round	Stratified	Year-round	100	7	0.58
		GOM	Year-round	DSM	Year-round	100	44	0.27
	Fin whale	EC	Year-round	DSM	Monthly	100	4,633	0.08
		GOM	Year-round	Stratified	Year-round	100	9	1.01
	Humpback whale	EC	Winter (Dec-Mar)	DSM	Monthly	100	205	0.16
			Summer (Apr-Nov)	DSM	Monthly	100	1,637	0.07
	Minke whale	EC	Winter (Nov-Mar)	Both	Monthly	54	740	0.23
			Summer (Apr-Oct)	Both	Monthly	100	2,112	0.05
	North Atlantic right whale	EC	Winter (Nov-Feb)	DSM	Monthly	80	535	0.45
			Spring (Mar-Apr)	DSM	Monthly	78	416	0.12
			Summer (May-Jul)	Both	Monthly	80	379	0.07
			Fall (Aug-Oct)	DSM	Monthly	93	334	0.25
	Sei whale	EC	Winter (Dec-Mar)	Stratified	Monthly	79	98	0.25
			Spring (Apr-Jun)	DSM	Monthly	80	627	0.14
			Summer (Jul-Sep)	DSM	Monthly	100	717	0.30
			Fall (Oct-Nov)	DSM	Monthly	11	37	0.19