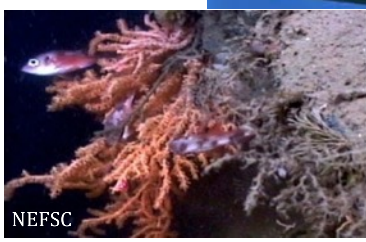
Marine-life Data and Analysis Team (MDAT) Technical Report on the Methods and Development of Marine-life Data to Support Regional Ocean Planning and Management



Authors: Corrie Curtice, Jesse Cleary, Emily Shumchenia, Patrick Halpin

Prepared on behalf of The Marine-life Data and Analysis Team (MDAT):

Patrick Halpin (Principal Investigator, Duke University), Earvin Balderama (Co-I, Loyola University Chicago), Jesse Cleary (Duke University), Corrie Curtice (Duke University), Michael Fogarty (Co-I, NOAA/NEFSC), Brian Kinlan† (NOAA/NCCOS), Charles Perretti (NOAA/NEFSC), Marta Ribera (TNC), Jason Roberts (Duke University), Emily Shumchenia (NROC), Arliss Winship (Co-I, NOAA/NCCOS)

Date published: 24 June 2019

Project manager and point of contact:

Jesse Cleary, Marine Geospatial Ecology Lab, Duke University, Durham, NC 27708
em: jesse.cleary@duke.edu ph: 919-684-3660 w: mgel.env.duke.edu

Accessible from: http://seamap.env.duke.edu/models/MDAT/MDAT-Technical-Report.pdf

† Deceased January 27, 2017

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" distribution products for cetacean, avian, and fish species. Cetacean 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.

Cetacean abundance products are annual and monthly or seasonal predictions and show predicted abundances of animals for the given time period. Avian relative density 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 for fall and spring seasons are represented in kilograms per tow (transformed using cubic root), and display expected biomass per tow, if a tow were to occur in the given area. Two map products include raw observations (bubble 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 taxon 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 multiple groups for avian, fish and cetacean species. 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 (cetaceans), 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.

Base layer products for each taxon have been integrated into the Northeast Ocean Data Portal and the Mid-Atlantic Ocean Data Portal, and some select species are hosted by MarineCadastre.gov, a BOEM/NOAA partnership. Selections 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. MarineCadastre.gov also hosts a selection 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 taxon and each type of product.

Recommended citation for this report:
Curtice, C., Cleary J., Shumchenia E., Halpin P.N. 2019. 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.pdf.

CHANGES FROM PREVIOUS VERSIONS

September 2016 – Original version

August 2018 – Updated individual species layers for avian and cetacean species; discontinued avian individual species occurrence products; new group summary products for all three taxa, including changes to algorithms for fish diversity products, and cetacean diversity, richness and core area abundance richness products; new species groups for fish species; minor corrections and edits to text.

June 2019 – Updated NEFSC methods and included new data (through 2016/2017) for fish species base layer products for NEFSC trawl data; for the NEFSC trawl data, added spring trawl products; based on NEFSC review, added Offshore Hake, removed Capelin, and merged American Sand Lance and Northern Sand Lance into a generic "Sand Lance" species. Twelve cetacean species or species guild models were updated with the same additional data and improved methodologies as the August 2018 update, with some additional improved methodologies. Summary products for both fish and cetaceans were recalculated to incorporate the updated base layer products, but no changes were made to the methods for the summary products. No changes were made to avian species products in this update.

Table of Contents

List of Figures

LIST OF TABLES

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 cetacean 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. MDAT released initial products in 2016, with selected updates in 2018 and 2019.

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 cetaceans, avian species, and fish species. Duke University's Marine Geospatial Ecology Lab (Duke MGEL) handled overall project coordination, as well as model products for cetaceans for the US East Coast. Beginning in 2011, MGEL worked with NOAA's Fisheries Science Centers, the Cetacean & Sound Mapping Working Group, partners at universities and non-governmental research organizations, and the Navy to create comprehensive cetacean habitat-based density surface 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.

Arliss Winship and Timothy White with the Marine Spatial Ecology Division 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). Brian Kinlan was the original Principal Investigator for the NCCOS work, and his work is greatly valued, and he is missed. NCCOS worked with Earvin Balderama of Loyola University to create models of extreme avian aggregations.

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

Marta Ribera of The Nature Conservancy (TNC) used independent bottom trawl survey data from NEFSC, along with methods developed by OceanAdapt (a collaboration between the Pinsky Lab at Rutgers University and the National Marine Fisheries Service) to produce spatial data products for fish species from spring and fall bottom trawl surveys.

MDAT has been supported by NROC and NROC staff, including Emily Shumchenia, who provides overall project management and facilitated communication with the NROC Ocean Planning Committee, agency staff, and scientific experts, since 2014. MDAT was also supported by MARCO staff, who facilitated communication with MARCO, the Mid-Atlantic RPB, agency staff, and scientific experts, from 2015-2018.

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 are reviewed and described in a 2016 Bureau of Ocean Energy Management (BOEM) report (Kinlan et al., 2016), and updated in a 2018 BOEM report (Winship et al., 2018). The cetacean modeling methodology and results were published in the journal *Scientific Reports* (Roberts et al. 2016), and subsequent updates are documented in Roberts et al. (2017, 2018). The fish species datasets and mapping approaches were completed by NEFSC and TNC. NEFSC provides 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 from 2014-2018, NROC and the NE RPB assembled three Marine Life Work Groups (one each for cetaceans, 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 in May 2016 on the Northeast Ocean Data Portal as part of the draft Northeast Ocean Plan public release, the Mid-Atlantic Ocean Data Portal as part of the draft Mid-Atlantic Regional Ocean Plan public release, and on the MarineCadastre.gov data portal. Both the Northeast and Mid-Atlantic ocean plans were certified by the National Ocean Council in December 2016.

In early 2018, NOAA NCCOS released updates to all the avian species model products, and MGEL released updates to selected cetacean species model products. Both updates included expert review processes prior to release. MDAT subsequently updated the avian and cetacean summary products to include these new individual species products. Additional expert reviews were conducted by the original avian (April 2018) and cetacean (May 2018) Marine Life Work Groups for the individual species and species group products. These reviews also included additional experts and Regional Planning Body members from both the Northeast and Mid-Atlantic.

In 2019, MDAT built on work being done by NEFSC and TNC for updated NEFSC fish bottom trawl survey products, with the notable addition of the spring bottom trawl data. MDAT member MGEL also provided updates to selected cetacean species at this time. Both updates included expert review processes prior to release. MDAT updated the group summary products to reflect these changes, and released all the updated layers in the summer of 2019.

1.3 Suite of Products

MDAT produced "base layer" predictive model products with associated uncertainty products for 30 cetacean species or species guilds (34 total species represented) and 47 avian species, and geospatial products for 81 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 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, cetacean, 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. Cetacean 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 cetacean 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.

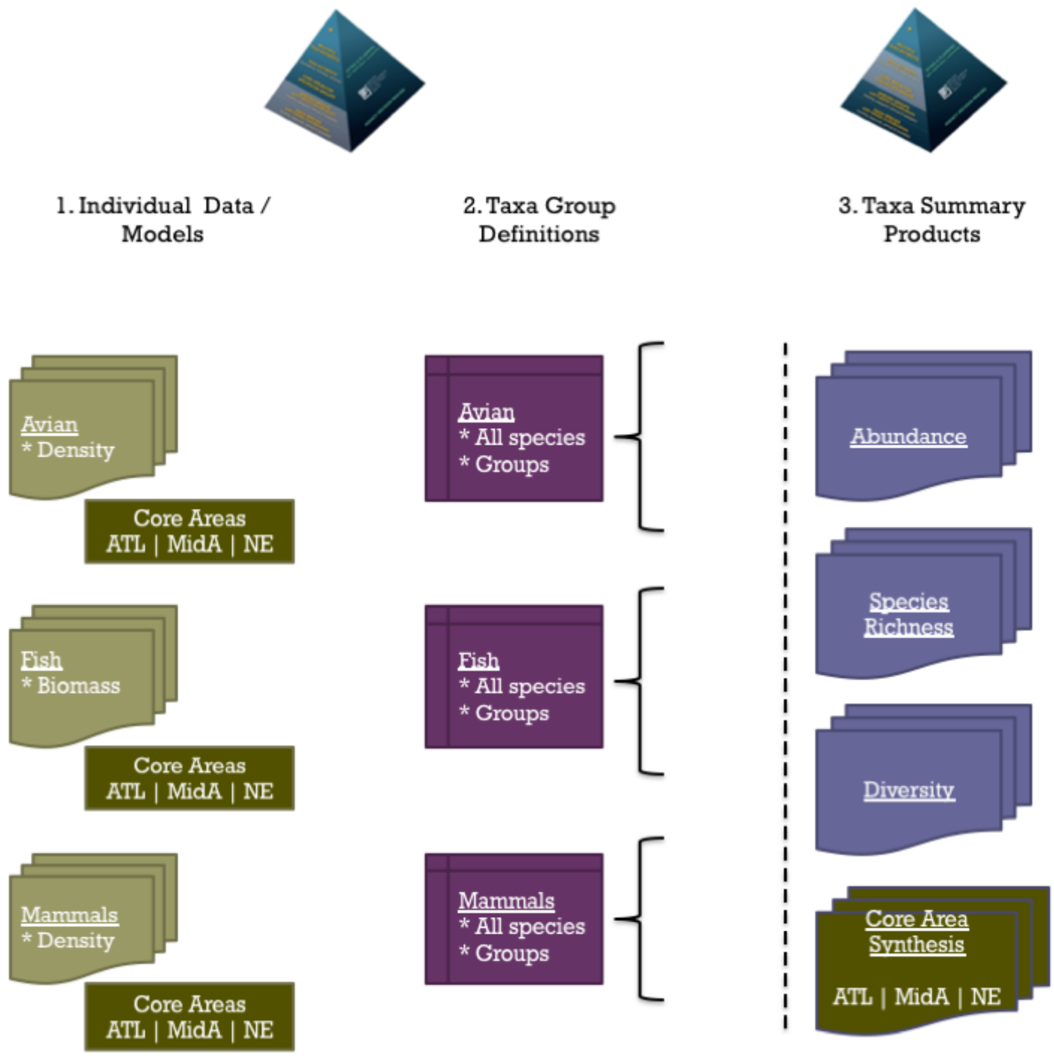


FIGURE 2 Break-down of the marine-life data product pyramid, from base layers to products for groups of species to multi-taxa products incorporating species across avian, cetacean, and fish species.

2 BASE MODELS AND DATA PRODUCTS

MDAT collectively produced over 3,000 map products for models of individual avian and cetacean 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 cetacean 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.

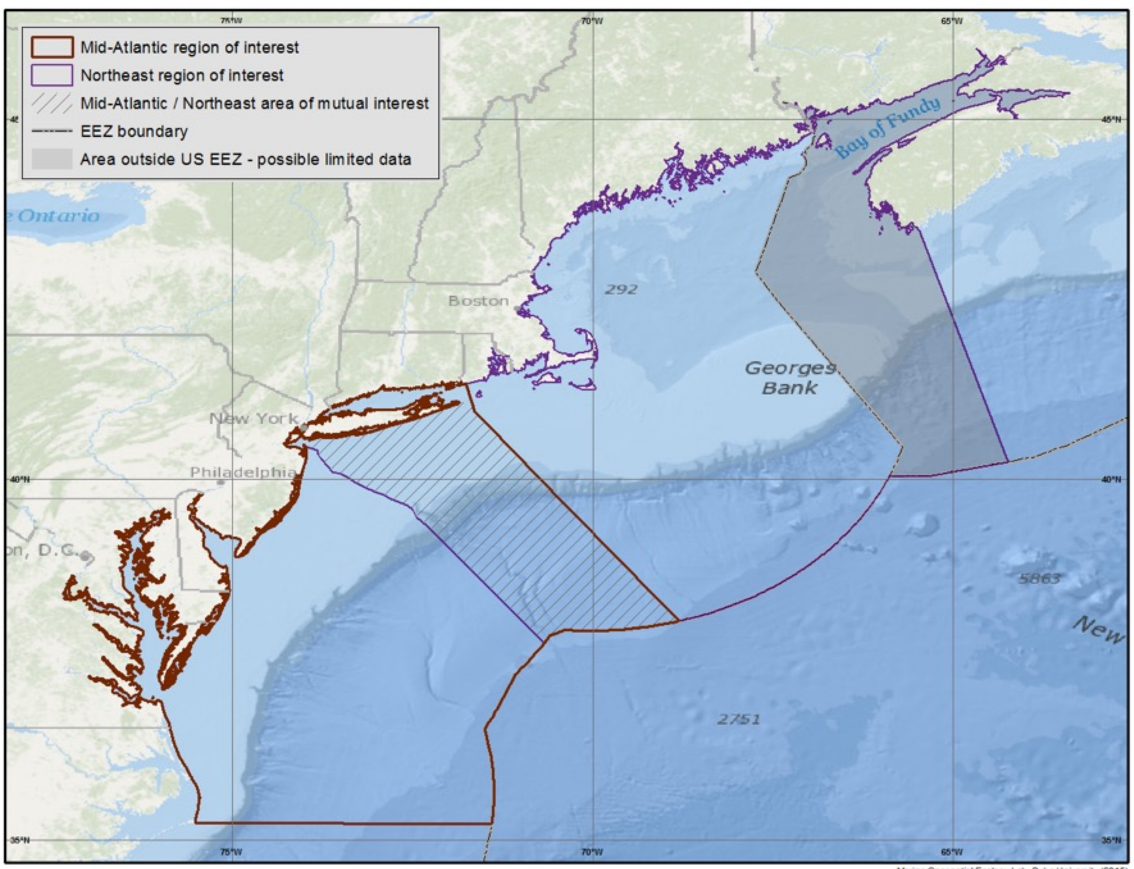


FIGURE 3 Geographic boundaries for marine life mapping in the Mid-Atlantic and Northeast regions of interest. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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 density 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).

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

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/data_reports/modeling-at-sea-density-of-marine-birds-to-support-atlantic-marine-renewable-energy-planning-final-report/

1. It is important to recognize that the model predictions *do not represent absolute density*, rather they are indices of density. 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?"
2. When calculating summary products, base products (i.e., long-term average annual and seasonal relative density 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. Masks showing areas with no survey effort are provided to aid the user in understanding where caution should be used when interpreting model results. Model predictions in areas with no 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.

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. 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.

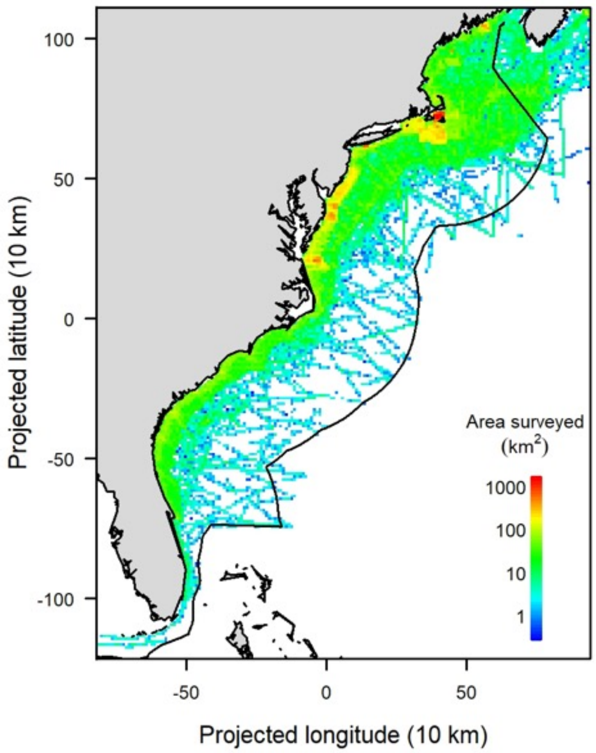


FIGURE 4 Survey effort coverage for the avian modeling effort along the US east coast. Model source data are from the Northwest Atlantic Seabird Catalog (US Fish and Wildlife Service) and the Eastern Canada Seabirds at Sea database (Canadian Wildlife Service, Environment and Climate Change Canada)spanning the years 1978-2016. Effort is mapped as total area surveyed (km^2) per 10 x 10 km cell.

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 21 April 2017 version of the United States Fish and Wildlife Service (USFWS) Northwest Atlantic Seabird Catalog and the Canadian Wildlife Service (Environment and Climate Change Canada) Eastern Canada Seabirds at Sea database, along with 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

These models incorporate virtually all known science-quality at-sea seabird surveys from 1978-2016 (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 (Fig. 1 in Appendix A).

TABLE 1 Analyzed datasets for the MDAT avian modeling effort. The number of transect segments within the study area is indicated by *n*, and the total area surveyed within the study area (km^2) is indicated by 'Area'. Datasets with an asterisk are not publicly available, but have been or are expected to be made available for use in modeling under a restricted usage agreement with the data owner or manager.

Code	Platform	Dates	Geographic range	*n*	Area
AMAPPS_FWS_Aerial_Fall2012	aerial	Sep-Oct 2012	entire coast	2,986	4,765
AMAPPS_FWS_Aerial_Fall2013	aerial	Sep 2013	entire coast	4,629	7,395
AMAPPS_FWS_Aerial_Fall2014	aerial	Oct 2014	ME to GA	2,876	4,608
AMAPPS_FWS_Aerial_Preliminary_Summer2010	aerial	Aug 2010	NC to FL	1,131	1,802
AMAPPS_FWS_Aerial_Spring2012	aerial	Mar 2012	entire coast	2,962	4,739
AMAPPS_FWS_Aerial_Summer2011	aerial	Jul-Aug 2011	entire coast	3,442	5,502
AMAPPS_FWS_Aerial_Winter2010-2011	aerial	Dec 2010 – Jan 2011	NJ to NC	513	823
AMAPPS_FWS_Aerial_Winter2014	aerial	Jan-Feb 2014	entire coast	3,073	4,914
AMAPPS_NOAA/NMFS_NEFSCBoat2011	boat	Jun-Jul 2011	offshore MA to NC	1,537	1,794
AMAPPS_NOAA/NMFS_NEFSCBoat2013	boat	Jul-Aug 2013	offshore MA to NC	1,577	1,853
AMAPPS_NOAA/NMFS_NEFSCBoat2014	boat	Mar-Apr 2014	offshore MA to NC	1,023	1,219
AMAPPS_NOAA/NMFS_NEFSCBoat2015	boat	Jun 2015	offshore MA	261	308
AMAPPS_NOAA/NMFS_SEFSCBoat2011	boat	Jun-Jul 2011	offshore MD to FL	982	1,155
AMAPPS_NOAA/NMFS_SEFSCBoat2013	boat	Jul-Sep 2013	offshore MD to GA	978	1,149
BarHarborWW05	boat	Jun – Oct 2005	ME	1,057	1,265
BarHarborWW06	boat	Jun – Oct 2006	ME	1,152	1,393
CapeHatteras0405	boat	Aug 2004 – Feb 2005	NC	363	374
CapeWindAerial*	aerial	Mar 2002 – Feb 2004	MA	4,676	7,492
CapeWindBoat*	boat	Apr 2002 – Sep 2003	MA	255	1,644
CDASMidAtlantic	aerial	Dec 2001 – Mar 2003	NJ to VA	1,604	766
CSAP	boat	Apr 1980 – Oct 1988	entire coast	26,125	33,545
DOEBRIAerial2012	camera	Mar-Dec 2012	DE to VA	4,596	3,669
DOEBRIAerial2013	camera	Feb-Dec 2013	DE to VA	5,300	4,250
DOEBRIAerial2014	camera	Jan-May 2014	DE to VA	2,370	1,896
DOEBRIBoatApr2014*	boat	Apr 2014	DE to VA	164	195
DOEBRIBoatApril2012*	boat	Apr 2012	DE to VA	165	197
DOEBRIBoatAug2012*	boat	Aug 2012	DE to VA	164	197
DOEBRIBoatAug2013*	boat	Jul–Aug 2013	DE to VA	166	199
DOEBRIBoatDec2012*	boat	Dec 2012 – Jan 2013	DE to VA	162	194
DOEBRIBoatDec2013*	boat	Dec 2013	DE to VA	170	202
DOEBRIBoatJan2013*	boat	Jan–Feb 2013	DE to VA	164	198
DOEBRIBoatJan2014*	boat	Jan–Feb 2014	DE to VA	164	197
DOEBRIBoatJune2012*	boat	Jun 2012	DE to VA	166	200
DOEBRIBoatJune2013*	boat	Jun 2013	DE to VA	168	200
DOEBRIBoatMar2013*	boat	Mar 2013	DE to VA	166	201
DOEBRIBoatMay2013*	boat	May 2013	DE to VA	168	201
DOEBRIBoatNov2012*	boat	Nov 2012	DE to VA	165	197
DOEBRIBoatOct2013*	boat	Oct 2013	DE to VA	170	201
DOEBRIBoatSep2012*	boat	Sep 2012	DE to VA	168	201
DOEBRIBoatSep2013*	boat	Sep 2013	DE to VA	168	201
DominionVirginia_VOWTAP	boat	May 2013 – Apr 2014	VA	78	250
EcoMonAug08	boat	Aug 2008	ME to NC	480	575
EcoMonAug09	boat	Aug 2009	ME to NC	458	547
EcoMonAug10	boat	Aug–Sep 2010	Gulf of ME and offshore	492	588
EcoMonAug2012	boat	Aug 2012	ME to NC	656	782

EcoMonFeb10	boat	Feb 2010	ME to VA (not northern Gulf of ME)	334	398
EcoMonFeb2012	boat	Feb 2012	ME to NC	549	661
EcoMonFeb2013	boat	Feb 2013	ME to VA	521	620
EcoMonJan09	boat	Jan–Feb 2009	ME to NC	391	474
EcoMonJun2012	boat	May–Jun 2012	MA to VA	544	651
EcoMonMay07	boat	May–Jun 2007	ME to NC	505	606
EcoMonMay09	boat	May–Jun 2009	ME to NC	621	746
EcoMonMay10	boat	May–Jun 2010	ME to NC	644	770
EcoMonNov09	boat	Nov 2009	ME to NC	441	528
EcoMonNov10	boat	Nov 2010	ME to NC	418	500
EcoMonNov2011	boat	Oct–Nov 2011	ME to NC	454	542
EcoMonOct2012	boat	Oct–Nov 2012	ME to MD	498	598
ECSAS	boat	Mar 2006 – Oct 2016	ME to NC, Canada	13,016	6,727
FLPowerLongIsland_Aerial	aerial	Oct 2004 – Mar 2006	NY	311	466
FLPowerLongIsland_Boat	boat	Apr 2004 – Jun 2006	NY	1,213	1,374
FWS_MidAtlanticDetection_Spring2012	aerial	Mar 2012	VA	177	283
FWS_SouthernBLSC_Winter2012	aerial	Feb 2012	SC to GA	904	1,500
FWSAtlanticWinterSeaduck2008	aerial	Feb 2008 – Feb 2011	entire coast	8,389	13,419
GeorgiaPelagic	boat	Nov 1982 – Jun 1985	SC to FL (also Gulf of ME and offshore)	2,186	2,569
HatterasEddyCruise2004	boat	Aug 2004	NC	131	117
HerringAcoustic06	boat	Sep 2006	Gulf of ME	287	341
HerringAcoustic07	boat	Oct 2007	Gulf of ME	334	395
HerringAcoustic08	boat	Sep–Oct 2008	Gulf of ME	822	990
HerringAcoustic09Leg1	boat	Sep 2009	Gulf of ME	127	151
HerringAcoustic09Leg2	boat	Sep–Oct 2009	Gulf of ME	289	341
HerringAcoustic09Leg3	boat	Oct 2009	Gulf of ME	263	315
HerringAcoustic2010	boat	Sep–Oct 2010	Gulf of ME	555	670
HerringAcoustic2011	boat	Sep–Oct 2011	Gulf of ME	808	950
HerringAcoustic2012	boat	Sep–Oct 2012	Gulf of ME	772	917
MassAudNanAerial	aerial	Aug 2002 – Mar 2006	MA	5,226	3,814
MassCEC2011-2012	aerial	Jan 2011 – Nov 2012	MA	2,511	4,016
MassCEC2013	aerial	Jan-Dec 2013	MA	2,248	3,596
MassCEC2014	aerial	Jan 2014 – Jan 2015	MA	1,512	2,421
NewEnglandSeamount06	boat	Oct 2006 – Jun 2007	east of Gulf of ME	65	36
NJDEP2009	aerial & boat	Jan 2008 – Dec 2009	NJ	4,971	5,967
NOAA/NMFS_NEFSCBoat2004	boat	Jun–Aug 2004	offshore MA to MD	1,207	1,422
NOAA/NMFS_NEFSCBoat2007	boat	Aug 2007	Gulf of ME	633	746
NOAAMBO7880	boat	Jan 1978 – Nov 1979	mostly ME to NC, but also GA and FL	6,965	6,417
PlattsBankAerial	aerial	Jul 2005	Gulf of ME	869	1,178
RISAMPAerial	aerial	Dec 2009 – Aug 2010	RI	2,466	2,953
RISAMPBoat	boat	Jul 2009 – Aug 2010	RI	781	1,022
SEFSC1992	boat	Jan–Feb 1992	NC to FL	783	938
SEFSC1998	boat	Jul–Aug 1998	MD to FL	1,365	1,596
SEFSC1999	boat	Aug–Sep 1999	NJ to FL	1,254	1,475
StatoilMaine	boat	May 2012 – Oct 2013	ME	400	480
WHOIJuly2010*	boat	Jul 2010	offshore NY Bight	86	102
WHOISept2010*	boat	Sep 2010	Gulf of ME	85	99

NCCOS developed models for species-season combinations for which there were at least 50 transect segments with a sighting of that species (Table 2). Non-modeled seasons are not included in annual averages (annual averages assume zero abundance in non-modeled seasons).

TABLE 2 Avian species sample sizes. Sample sizes are the number of transect segments with a sighting. Cells shaded in gray indicate species-season combinations with insufficient samples sizes for modeling.

Species	Number of transect segments with sightings			
	Spring	Summer	Fall	Winter
Arctic Tern		170		
Atlantic Puffin	362	287	124	342
Audubon's Shearwater	134	916	297	170
Black-capped Petrel	159	371	93	90
Black Guillemot		90		
Black-legged Kittiwake	741		2,239	4,066
Black Scoter	516		444	1,330
Bonaparte's Gull	467		329	1,585
Brown Pelican	66	127	164	76
Band-rumped Storm-Petrel		276		
Bridled Tern		101	65	
Common Eider	907	146	641	2,173
Common Loon	2,933	212	1,474	3,825
Common Murre	212			268
Cory's Shearwater	137	3,380	1,944	
Common Tern	642	1,807	777	
Double-crested Cormorant	158	187	278	157
Dovekie	664	61	468	1,252
Great Black-backed Gull	3,882	3,513	6,155	3,902
Great Shearwater	682	7,351	7,531	140
Great Skua			196	
Herring Gull	6,384	3,202	8,612	5,300
Horned Grebe				103
Laughing Gull	742	1,750	1,871	134
Leach's Storm-Petrel	279	2,540	591	
Least Tern		126	98	
Long-tailed Duck	1,336		539	3,565
Manx Shearwater	107	353	344	
Northern Fulmar	2,678	956	2,171	2,061
Northern Gannet	6,729	1,358	5,532	7,932
Parasitic Jaeger	53	77	191	
Pomarine Jaeger	112	155	830	
Razorbill	1,066	87	193	1,987
Ring-billed Gull	211	53	414	745
Red-breasted Merganser	69			112
Red Phalarope	480	250	338	
Red-necked Phalarope	143	182	201	
Roseate Tern	59	212	83	
Royal Tern	270	289	352	
Red-throated Loon	1,747		413	2,608
Sooty Shearwater	916	1,812	119	
Sooty Tern	60	119		
South Polar Skua		92	142	
Surf Scoter	846		848	1,918
Thick-billed Murre	315			151
Wilson's Storm-Petrel	1,750	9,271	1,481	
White-winged Scoter	569		668	1,535

Specific features of the NCCOS modeling approach include:

- NCCOS employed a statistical modeling framework that relates density to environmental predictor variables (Table 3)
- Seasonal climatologies of dynamic 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 (x direction)	spatial	yes
wind stress (y direction)	spatial	yes
wind divergence	spatial	yes
Depth	spatial	no
slope (2 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 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 density 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 coverage of the 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 density 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 coverage masks. Hatched masks indicate areas without survey effort at a 10 x 10 km spatial resolution. Model predictions in masked areas should be interpreted cautiously as there were no survey data to support them.

2.3 Fish Species

NOAA's Northeast Fisheries Science Center (NEFSC) led the original 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. The Ecosystem Considerations website (http://nefsc.noaa.gov/ecosys) 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. In 2019, TNC worked with MDAT, OceanAdapt, and NEFSC to create updated products for the fall bottom trawl survey data, and to add the spring bottom trawl data products, based on recent advances in the analysis methods developed by NEFSC, and requests from users.

While the cetacean 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, which conducts trawls across the Northeast US Shelf Ecosystem, and three coastal trawls: 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. Furthermore, beginning in 2019, NEFSC data products were separately updated with new analysis methods and the latest data; NEAMAP, MDMF, and ME/NH data products were not updated at this time. For these reasons, each trawl is 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

NEFSC bottom trawl

NEFSC bottom trawl data were obtained from OceanAdapt (http://oceanadapt.rutgers.edu/). Using code developed by the OceanAdapt team at Rutgers University, and available through their website, records were aggregated by station, year, season, and species. For the NEFSC fall and spring trawl data, two outputs were created for each species:

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 kilograms per tow.
2. Inverse-distance weighted (IDW) interpolation plot: biomass values are established by interpolation using inverse distance weighting and modified depending on the bathymetry. With this approach bottom depth differences between the interpolated points and observed data serve as a third dimension of distance, with a parameter converting depth differences to horizontal differences. Prior to interpolation, the biomass values were transformed using a cubic root to ensure normality. Strata that were not surveyed were removed from the interpolations. Methods and code for the interpolation were developed by NEFSC and modified slightly by TNC and MDAT to improve computational efficiency and output products for each species/season and each year of data (2010-2016 for fall and 2010-2017 for spring). Products for individual years were averaged to produce a final spring and fall plot for each species.

All NEFSC trawl products were reviewed by NEFSC staff.

Coastal trawls

NEAMAP, MDMF, and ME/NH trawl data were obtained by NEFSC. For the NEAMAP, MDMF, and ME/NH data, 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=81) 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). Trawls for all surveys occurred during the fall (September – December), except for NEFSC Spring which occurred primary from February – April..

Common Name	NEFSC		NEAMAP	MDMF	ME/NH
	Spring 2010-2017	Fall 2010-2016	Fall 2007-2014	Fall 2005-2014	Fall 2005-2014
ACADIAN REDFISH	629	532	0	32	396
ALEWIFE	1265	476	44	100	782
AMERICAN EEL	0	0	12	0	4
AMERICAN LOBSTER	1061	1162	151	464	800
AMERICAN PLAICE	848	554	0	170	560
AMERICAN SHAD	556	272	31	39	257
ATLANTIC COD	746	347	0	100	226
ATLANTIC CROAKER	44	301	576	0	0
ATLANTIC HALIBUT	88	72	0	6	169
ATLANTIC HERRING	1672	767	84	117	732
ATLANTIC MACKEREL	934	344	10	16	287
ATLANTIC MENHADEN	35	28	176	14	41
ATLANTIC SHARPNOSE SHARK	19	39	42	0	0
ATLANTIC STURGEON	13	1	0	0	0
ATLANTIC TORPEDO	40	37	21	17	8
ATLANTIC WOLFFISH	59	28	0	0	2
BANDED DRUM	11	74	146	0	0
BARNDOOR SKATE	706	642	5	8	12
BAY ANCHOVY	40	113	409	132	0
BLACK SEA BASS	437	525	432	286	2
BLACKBELLY ROSEFISH	368	380	2	0	1
BLUEBACK HERRING	828	259	34	37	335
BLUEFISH	56	347	851	103	8
BLUNTNOSE STINGRAY	18	83	156	0	0
BULLNOSE RAY	12	126	0	0	0
BUTTERFISH	991	1676	1096	741	657
CAPELIN	#N/A	#N/A	0	0	7
CLEARNOSE SKATE	335	390	954	13	2
CUNNER	117	96	7	112	89
CUSK	60	38	0	0	0
FOURSPOT FLOUNDER	1221	1399	0	272	0
GOOSEFISH	1299	1233	14	55	397
GULF STREAM FLOUNDER	862	945	39	4	10
HADDOCK	1011	929	6	91	338
HICKORY SHAD	0	1	13	0	0
HORSESHOE CRAB	217	187	477	47	0
JONAH CRAB	726	808	14	289	552
LITTLE SKATE	1565	1220	701	679	134
LONGFIN SQUID	1436	1944	1107	836	665
LONGHORN SCULPIN	913	505	2	241	547
NORTHERN KINGFISH	41	148	0	62	0
NORTHERN PIPEFISH	18	16	2	68	2
NORTHERN PUFFER	23	225	387	39	0
NORTHERN SEAROBIN	857	778	293	176	8
NORTHERN SHORTFIN SQUID	546	1323	0	87	453

NORTHERN SHRIMP	146	275	0	8	424
OCEAN POUT	927	445	0	129	0
OFFSHORE HAKE	142	163	#N/A	#N/A	#N/A
PIGFISH	13	59	179	0	0
PINFISH	25	30	202	0	0
POLLOCK	324	229	1	17	75
RED HAKE	1761	1328	75	361	640
ROSETTE SKATE	241	297	1	0	0
ROUGHTAIL STINGRAY	43	99	127	9	0
ROUND HERRING	12	362	153	3	0
SAND LANCE	122	57	6	60	7
SAND TIGER	5	3	31	2	0
SCUP	315	608	799	478	25
SEA RAVEN	565	359	19	105	167
SEA SCALLOP	921	934	25	149	291
SILVER HAKE	2372	1771	258	368	778
SMOOTH DOGFISH	237	345	672	243	0
SMOOTH SKATE	546	451	0	0	59
SOUTHERN STINGRAY	9	8	33	0	0
SPINY BUTTERFLY RAY	23	69	197	0	0
SPINY DOGFISH	1646	1063	76	362	273
SPOT	34	245	545	13	0
SPOTTED HAKE	1222	1239	664	70	37
STRIPED ANCHOVY	13	169	559	8	4
STRIPED BASS	71	11	66	15	3
STRIPED SEAROBIN	160	343	428	139	0
SUMMER FLOUNDER	939	651	1036	405	0
TAUTOG	7	17	40	72	0
THORNY SKATE	399	301	0	42	116
TILEFISH	22	21	0	0	0
WEAKFISH	70	211	724	34	0
WHITE HAKE	728	704	1	148	774
WINDOWPANE	1006	781	769	426	420
WINTER FLOUNDER	859	606	205	551	671
WINTER SKATE	1322	678	423	390	36
WITCH FLOUNDER	959	525	0	68	409
YELLOWTAIL FLOUNDER	797	473	5	287	147

2.3.3 Spatial coverage, grid size, model gaps

NEFSC trawl

Interpolated (IDW) products use code initially developed by NEFSC to create animations of species biomass change over time (see https://www.nefsc.noaa.gov/ecosys/spatial-analyses/). The interpolation considers both depth differences and horizontal distances between the interpolated location and sampled locations. Interpolations only occur within strata that were sampled on a survey (survey strata shown in Figure 5). The results are 2km x 2km grid-cell interpolations of fish biomass informed by bathymetry. Interpolated biomass products represent the average biomass for each species during each season for the examined years (2010-2017 for fall and 2010-2016 for spring).

Coastal trawls

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 NEAMAP and state sources are 10km x 10km. Coastal trawl products cover smaller and more coastal areas than the NEFSC trawl.

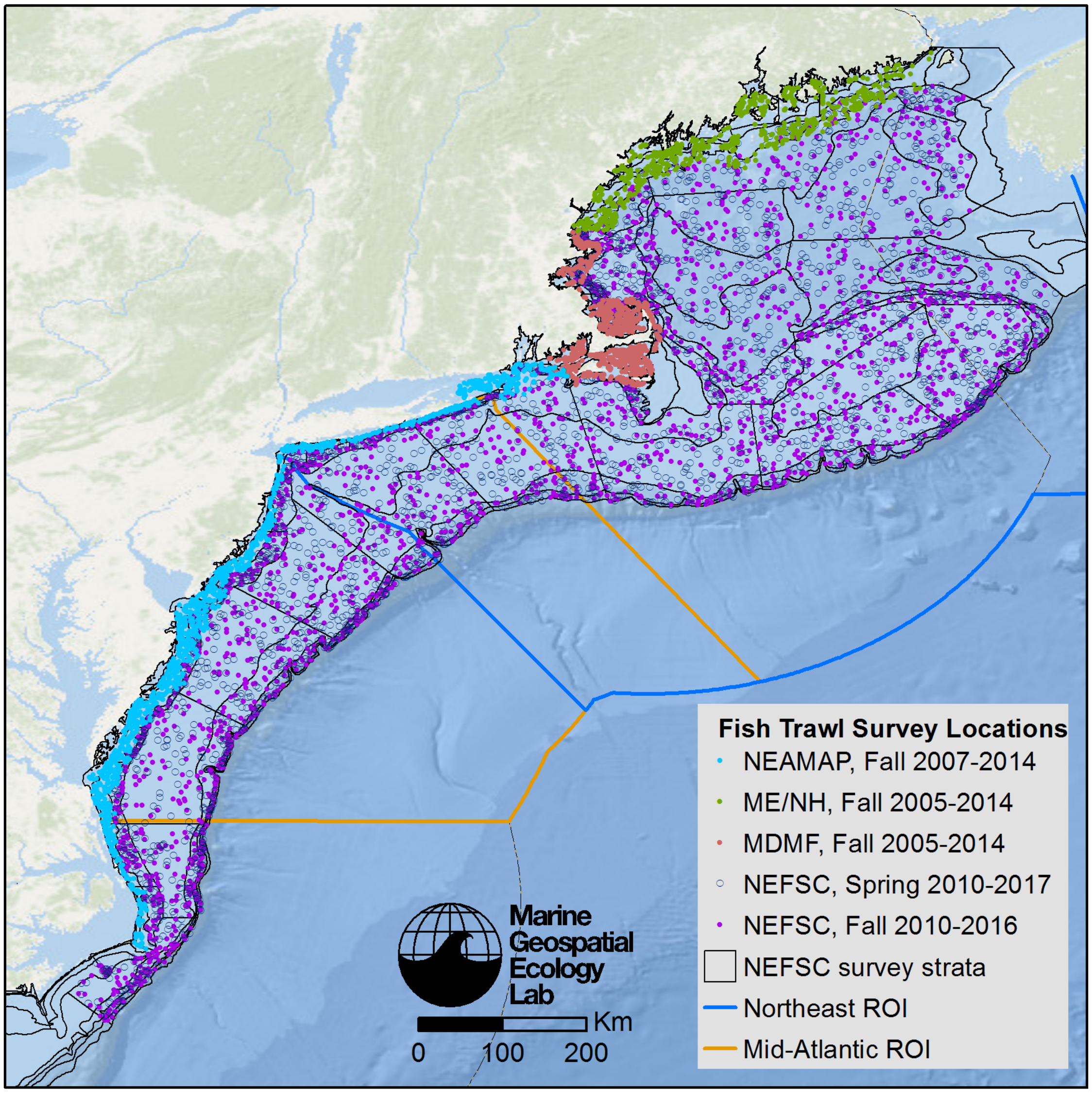


FIGURE 5 Federal and state bottom fish trawl survey locations.

2.3.4 Temporal coverage, assessment windows

NEFSC trawl

Fall survey samples were collected primarily in September and October, with some in November and a small number in December. Spring surveys were collected from February to April. Records for fall 2017 were removed due to incomplete coverage of the survey area, as recommended by NEFSC.

To address user feedback, products were produced for the available surveys in the most recent decade (e.g., since 2010). Users expressed that data products representing recent species distribution and biomass were most relevant to ocean planning activities and decision-making.

- NEFSC Spring 2010 - 2017
- NEFSC Fall 2010 – 2016

The symbology and legends for spring and fall products for each species and group were standardized so that biomass patterns between seasons could be more easily compared within each species and group.

Coastal trawls
Fall survey samples were collected primarily in September and October, with some in November and a small number in December.

When sufficient data were available, products were produced for two time periods for the coastal trawls, possibly highlighting spatial changes that have occurred in the recent past. For the NEAMAP survey, data products represent all available data since the survey commenced in 2007.

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

2.3.5 Characterization(s) of uncertainty

NEFSC trawl
Uncertainty was not quantified in a set of separate data products for the NEFSC IDW maps.

Coastal trawls
For NEAMAP and state level products, uncertainty is estimated as the variance of the total fish biomass per tow within each hexagon (units are log-kilograms).

2.4 Cetaceans

Duke MGEL worked with NOAA's Fisheries Science Centers, the Cetacean & Sound Mapping Working Group, partners at universities and non-governmental research organizations, and the Navy to create comprehensive cetacean habitat-based density surface models for the US east coast. Models were created for all species sighted at least once during NOAA broad-scale marine mammal abundance surveys of the US east coast conducted since 1992. Depending on the data available for a species and what is known about it, the species was modeled either individually or as part of a species guild.

2.4.1 Cetacean Model Caveats and Considerations

Many trade-offs and decisions were made by MDAT in the creation of the cetacean 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, 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.

1. Species with too few sightings available to model a density surface from environmental predictors were instead fitted with a so-called *stratified density model*, in which abundances for one or more geographic strata were estimated with traditional distance sampling methodology (Buckland et al. 2001) and then used to derive a density estimate that was assumed to be uniform throughout each stratum. Based on scientific literature reviews, some of these models were split into two or more strata, and models were fit to each of those areas. For species that are known to only occupy certain habitats, the study area was split into strata that reflected this, based on knowledge available in the literature. When no sightings were reported in an unoccupied stratum (which was usually the case) the resulting density estimate was zero for that stratum. An example of this is Fraser's dolphin, which is believed to be absent north of the Gulf Stream.

2. Several species had too few sightings to fit individual detection functions to them. In these cases, sightings were pooled with sightings from other species believed to exhibit similar detectability ("proxy species").

Full documentation for the original individual models released in 2016 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). These are known as the MDAT v1.1 collection of models, and are the first delivered by MDAT for use in regional ocean planning. Additional documentation is provided by Roberts et al. (2017) for the MDAT v2.0 collection of updated models, and in Roberts et al. (2018) for the MDAT v2.1 collection of updated models.

2.4.2 Cetacean Model Overview

Models were created by applying distance sampling (Buckland et al. 2001, Buckland et al. 2004) and density surface modeling methods (Miller et al. 2013) to visual line transect surveys (Table 5) with sighting data for 30 cetacean 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 – 2016) 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 or yearly temporal resolution. When possible, fitted seasonal models used species-specific season definitions, based on known ecology. See Roberts et al. (2016, 2017, 2018) for model specifics.

2.4.3 Cetacean Model Versioning

The cetacean models have been under development since 2011 and continue to be updated as new data and improved methodology become available. Not all models are updated in synchrony. To facilitate the tracking of updated models provided to regional ocean data portals, the Navy, and other users, each cetacean model has its own version number. These individual model version numbers, shown in Table 6, should not be confused with the MDAT version number (1.1, 2.0, or 2.1) that refers to the *collection* of models packaged together at a certain point in time and delivered for use in regional ocean planning processes.

The cetacean model version numbers follow a MAJOR.MINOR version numbering scheme. The MAJOR version number is incremented whenever any part of the predicted density surface changes. Typically, this happens every year or two when new data are integrated and the model is refitted and re-predicted, producing an updated density surface. But it can also happen more frequently when a smaller adjustment is made to the model, based on new information or expert feedback, without introduction of new data.

The MINOR number is incremented whenever something other than the predicted density surface changes. Most often, this will only be documentation, but it also includes changes to the model uncertainty products. In this latter case, model uncertainty might be estimated with an improved method, resulting in no change to the density surface, but changes to the standard error, coefficient of variation, 5th percentile or 95th percentile uncertainty surfaces.

TABLE 5 Northwest Atlantic line-transect surveys used in cetacean density models, sourced from Table 1 in Roberts et al. (2016) and updated to reflect additional survey effort incorporated in 2017 (see Roberts et al. 2017 for details).

Surveys	Start	End	On Effort Length (1000s km)	Effort Hours
NEFSC AMAPPS Aerial Surveys	2010	2014	42	220
NEFSC AMAPPS Shipboard Surveys	2011	2014	12	682
NEFSC North Atlantic Right Whale Sighting Survey	1999	2016	527	2757
NEFSC Pre-AMAPPS Aerial Surveys	1995	2008	71	363
NEFSC Pre-AMAPPS Shipboard Surveys	1995	2004	16	963
NJDEP Aerial Surveys	2008	2009	11	56
NJDEP Shipboard Surveys	2008	2009	14	728
SEFSC AMAPPS Aerial Surveys	2010	2015	66	345
SEFSC AMAPPS Shipboard Surveys	2011	2013	11	658
SEFSC Mid Atlantic Tursiops Aerial Surveys	1995	2005	35	181
SEFSC Pre-AMAPPS Atlantic Shipboard Surveys	1992	2006	33	1875
SEFSC Southeast Cetacean Aerial Surveys	1992	1995	8	40
SEUS North Atlantic Right Whale Aerial Surveys	2003	2016	1380	7286
UNCW Cape Hatteras Aerial Surveys (Navy)	2011	2016	35	172
UNCW Early Marine Mammal Aerial Surveys	2002	2002	18	93
UNCW Jacksonville Aerial Surveys (Navy)	2009	2016	87	417
UNCW Onslow Bay Aerial Surveys (Navy)	2007	2011	49	238
UNCW Norfolk Canyon Aerial Surveys (Navy)	2015	2016	12	56
UNCW Right Whale Aerial Surveys	2005	2008	114	574
Virginia Aquarium MD DNR Aerial Surveys	2013	2015	16	83
Virginia Aquarium VA CZM Aerial Surveys	2012	2015	21	102

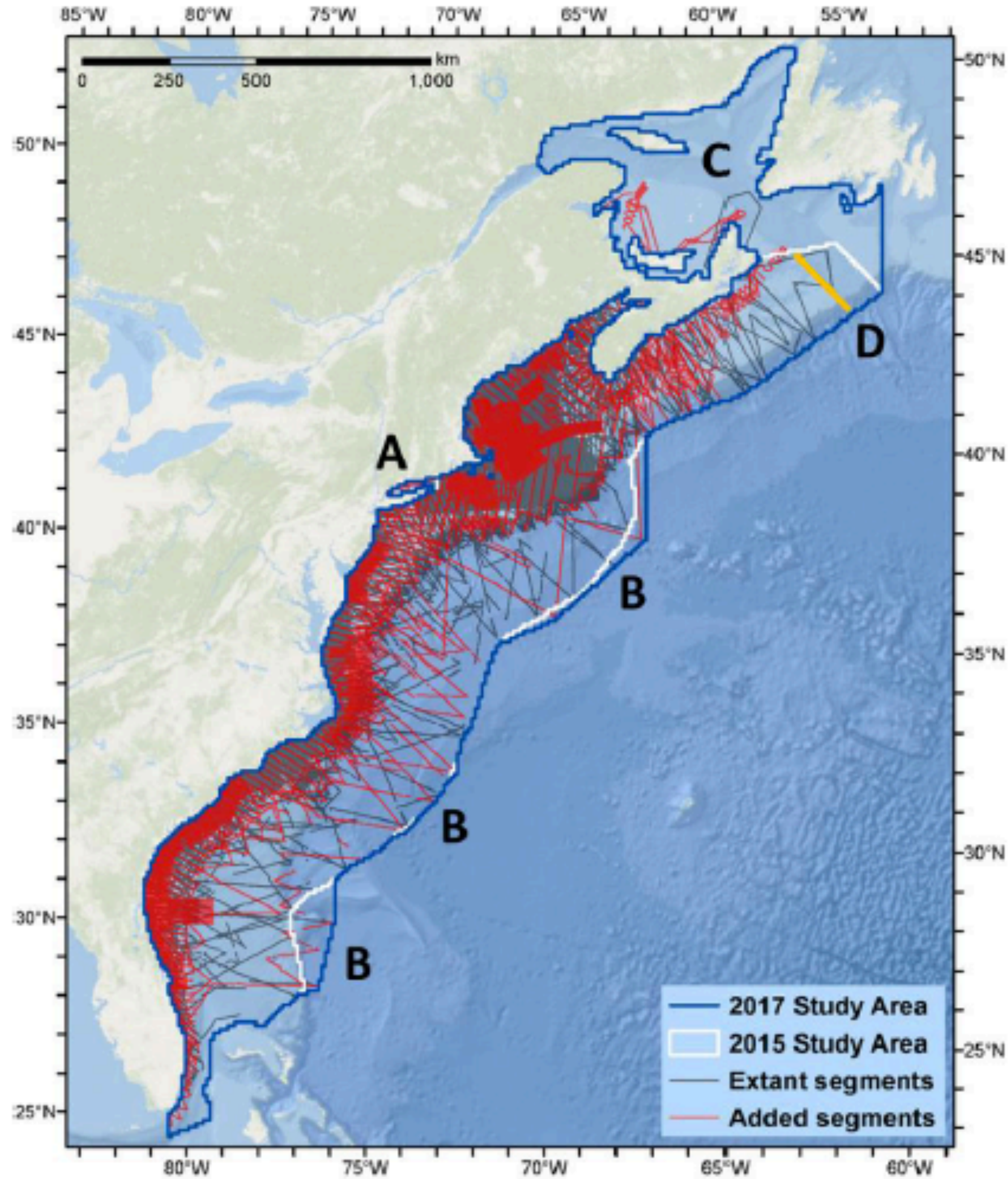


FIGURE 6 Cetacean Survey effort and coverage for the US East Coast with updated 2017 study area and added survey segments (both shipboard and aerial). Figure 3 from Roberts et al. (2017), based on the surveys listed in Table 5. Highlights include added AMAPPS added coverage to Long Island Sound (A) and several new offshore segments (B). New North Atlantic Right Whale Sightings Surveys effort in parts of the Gulf of St. Lawrence (C). Updated 2017 models now terminate at the south edge of the Laurentian Channel (line D). Previous models' predictions extended further north. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

TABLE 6 Cetacean sightings from the available datasets that are suitable for density modeling. n = number of groups sighted along the full US east coast extent used in the model. Density surface prediction Temporal Resolution is monthly 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) and updated information in Roberts et al. (2017).

Scientific Name	Common Name	Updated in 2018	n	Temporal Resolution	Model Guild	Model Version
Balaenoptera acutorostrata	Minke whale	No	1367	Monthly		9.0
Balaenoptera borealis	Sei whale	Yes	946	Monthly		8.0
Balaenoptera edeni	Bryde's whale	No	4	Year-round		1.3
Balaenoptera musculus	Blue whale	No	8	Year-round		1.3
Balaenoptera physalus	Fin whale	Yes	2513	Monthly		11.0
Delphinus delphis	Short-beaked common dolphin	Yes	1189	Monthly		4.0
Eubalaena glacialis	North Atlantic right whale	No	4084	Monthly		7.0
Globicephala	Unidentified pilot whale	No	1146	Year-round	Pilot whales	6.0
Globicephala macrorhynchus	Short-finned pilot whale	No	202	Year-round	Pilot whales	6.0
Globicephala melas	Long-finned pilot whale	No	2	Year-round	Pilot whales	6.0
Grampus griseus	Risso's dolphin	Yes	721	Monthly		4.0
Hyperoodon ampullatus	Northern bottlenose whale	No	4	Year-round		1.2
Kogia	Unidentified small sperm whale	Yes	24	Year-round	Dwarf and pygmy sperm whales	4.0
Kogia breviceps	Pygmy sperm whale	Yes	3	Year-round	Dwarf and pygmy sperm whales	4.0
Kogia sima	Dwarf sperm whale	Yes	4	Year-round	Dwarf and pygmy sperm whales	4.0
Lagenodelphis hosei	Fraser's dolphin	No	2	Year-round		1.2
Lagenorhynchus acutus	Atlantic white-sided dolphin	Yes	2266	Monthly		3.0
Lagenorhynchus albirostris	White-beaked dolphin	No	12	Year-round		2.2
Megaptera novaeangliae	Humpback whale	No	3297	Monthly		10.0
Mesoplodon	Unidentified mesoplodont beaked whale	No	94	Year-round	Mesoplodont beaked whales	5.0
Mesoplodon bidens	Sowerby's beaked whale	No	37	Year-round	Mesoplodont beaked whales	5.0
Mesoplodon densirostris	Blainville's beaked whale	No	5	Year-round	Mesoplodont beaked whales	5.0
Mesoplodon europaeus	Gervais' beaked whale	No	12	Year-round	Mesoplodont beaked whales	5.0
Mesoplodon mirus	True's beaked whale	No	4	Year-round	Mesoplodont beaked whales	5.0
Orcinus orca	Killer whale	No	4	Year-round		1.2
Peponocephala electra	Melon-headed whale	No	4	Year-round		1.2
Phocoena phocoena	Harbor porpoise	No	2381	Monthly		4.0
Physeter macrocephalus	Sperm whale	No	763	Monthly		7.0
Pseudorca crassidens	False killer whale	No	2	Year-round		1.2
Stenella attenuata	Pantropical spotted dolphin	Yes	17	Year-round		3.0
Stenella clymene	Clymene dolphin	Yes	11	Year-round		2.0
Stenella coeruleoalba	Striped dolphin	Yes	195	Year-round		4.0
Stenella frontalis	Atlantic spotted dolphin	Yes	838	Monthly		8.0
Stenella longirostris	Spinner dolphin	No	2	Year-round		1.1
Steno bredanensis	Rough-toothed dolphin	Yes	11	Year-round		2.0
Tursiops truncatus	Common bottlenose dolphin	Yes	4657	Monthly		5.0
Ziphiidae	Unidentified beaked whale	No	171	Year-round	Unidentified beaked whales	5.0
Ziphius cavirostris	Cuvier's beaked whale	No	164	Year-round		6.0

TABLE 7. Sourced from Roberts et al. (2017). 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
Static	Depth, Slope	30 arc sec		Seafloor depth and slope, derived from SRTM30-PLUS global bathymetry[1]
	DistToShore, DistTo125m, DistTo300m, DistTo1500m	30 arc sec		Distance to the closest shoreline, excluding Bermuda and Sable Island, and various ecologically-relevant isobaths[1]
	DistToCan, DistToCanOrSmt	30 arc sec		Distance to the closest submarine canyon, and to the closest canyon or seamount[2]
Physical oceanographic	SST, DistToFront	0.2°, daily	1991-2016	Foundation sea surface temperature (SST), from GHRSST Level 4 CMC SST[3], and distance to the closest SST front identified with the Canny edge detection algorithm[4]
	TKE, EKE	0.25°, daily	1993-2016	Total kinetic energy (TKE) and eddy kinetic energy (EKE), from Aviso 1/4° DT-MADT/MSLA geostrophic currents
	DistToEddy, DistToAEddy, DistToCEddy	0.25°, weekly	1993-2016	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[5]; we tested eddies at least 9, 4, and 0 weeks old
	FSLE	0.04°, 5-day	1994-2015	Backward-in-time Finite Size Lyapunov Exponents (FSLE)[6] from AVISO 1/4° sea surface altimetry
	Salinity	0.08°, daily	1993-2016	Sea surface salinity from the HYCOM ocean model[7]
	WindSpeed	0.25°, 6-hour	1991-2016	Wind speed from L3.0 Cross-Calibrated Multi-Platform (CCMP) Version 2.0 gridded surface vector winds[8]; we tested 1-day, 5-day, 15-day, and 30-day running means
Biological	Chl	9 km, daily	1997-2014	GSM merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll (Chl) *a* concentration[9], 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^{-2} day^{-1}) derived from SeaWiFS and Aqua using the Vertically Generalized Production Model (VPGM)[10]; 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^{-2} day^{-1}) and biomass (PkPB; g m^{-2}) from the SEAPODYM ocean model[11]
	EpiMnkPP, EpiMnkPB	0.25°, weekly	1997-2013	Epipelagic micronekton production (EpiMnkPP; g m^{-2} day^{-1}) and biomass (EpiMnkPB; g m^{-2}) from the SEAPODYM model[11]

References

1. Becker, J. J. et al. Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS. Mar. Geod. 32, 355–371 (2009).
2. Harris, P. T., Macmillan-Lawler, M., Rupp, J. & Baker, E. K. Geomorphology of the oceans. Mar. Geol. 352, 4–24 (2014).
3. Brasnett, B. The impact of satellite retrievals in a global sea-surface-temperature analysis. Q. J. R. Meteorol. Soc. 134, 1745–1760 (2008).
4. Canny, J. F. A computational approach to edge detection. IEEE Trans. Pattern Anal. Mach. Intell. 8, 679–698 (1986).
5. Chelton, D. B., Schlax, M. G. & Samelson, R. M. Global observations of nonlinear mesoscale eddies. Prog. Oceanogr. 91, 167–216 (2011).
6. d'Ovidio, F., Fernández, V., Hernández-García, E. & López, C. Mixing structures in the Mediterranean Sea from finite-size Lyapunov exponents. Geophys. Res. Lett. 31, n/a-n/a (2004).
7. Bleck, R. An oceanic general circulation model framed in hybrid isopycnic-Cartesian coordinates. Ocean Model. 4, 55–88 (2002).

8. Atlas, R. et al. A Cross-calibrated, Multiplatform Ocean Surface Wind Velocity Product for Meteorological and Oceanographic Applications. Bull. Am. Meteorol. Soc. 92, 157–174 (2011).
9. Maritorena, S., d'Andon, O. H. F., Mangin, A. & Siegel, D. A. Merged satellite ocean color data products using a bio-optical model: Characteristics, benefits and issues. Remote Sens. Environ. 114, 1791–1804 (2010).
10. Behrenfeld, M. J. & Falkowski, P. G. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr. 42, 1–20 (1997).
11. Lehodey, P., Murtugudde, R. & Senina, I. Bridging the gap from ocean models to population dynamics of large marine predators: a model of mid-trophic functional groups. Prog. Oceanogr. 84, 69–84 (2010).

2.4.4 Spatial coverage, grid size, model gaps

Cetacean 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 1/4°. Spatial gaps for base model products include various inshore areas: New York/New Jersey Harbor, 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.

2.4.5 Temporal coverage, assessment windows

Data sources ranged from 1992 – 2016. Model results are on a monthly basis when the data support that resolution, and when they don't the output is on an annual basis (Table 6).

2.4.6 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 many sightings were available for the model, how well the environmental conditions that occurred there correlated with species density, and how variable conditions were throughout the modeled period.

1. 5th and 95th percentiles – The units of these are the same as density. These are the lower and upper limits of a 90% confidence interval estimated for the modeling procedure. This means, roughly speaking, that there is a 90% probability that the true density value is between these limits.
2. 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.)
3. 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 cetacean 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 density distributions. The overall mean value of the relative distribution was used to normalize the predicted relative density distribution values. This normalization helps reduce the impact of very large predicted populations in the subsequent summary product development.

Caveats specific to the fish summary products:

- Fish summary products were developed using the NEFSC spring and fall survey data and are available via the map services, data portals, and download distribution file. Fish summary products developed from the NEAMAP fall survey data are available as map services only at this time.
- 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 spring and 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 cetacean summary products:

- Cetacean group richness, diversity, and core area abundance richness summary products now exclude all models which were created as stratified 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. Stratified models have uniform density in each individual stratum. Because these species are rarely sighted, their distribution and habitat are less well understood than the cetacean species or species guilds modeled with habitat-based density models. MDAT summary products are used to show variation across different habitats, and we lack the information to include these species at that level of variation. Sightings data of these rare species do show differences, but we lack enough data to say anything more detailed.

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 Portals.

TABLE 8 "All species" groups for all modeled avian species, all sampled fish species and all modeled cetacean species.

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 guillemot	American plaice	Bottlenose dolphin
Black scoter	American shad	Bryde's whale
Black-capped petrel	Atlantic cod	Clymene dolphin
Black-legged kittiwake	Atlantic croaker	Cuvier's beaked whale
Bonaparte's gull	Atlantic halibut	Dwarf sperm whale
Bridled tern	Atlantic herring	False killer whale
Brown pelican	Atlantic mackerel	Fin whale
Common eider	Atlantic menhaden	Fraser's dolphin
Common loon	Atlantic sharpnose shark	Gervais' beaked whale
Common murre	Atlantic sturgeon	Harbor porpoise
Common tern	Atlantic torpedo	Humpback whale
Cory's shearwater	Atlantic wolffish	Killer whale
Double-crested cormorant	Banded drum	Long-finned pilot whale
Dovekie	Barndoor skate	Melon-headed whale
Great black-backed gull	Bay anchovy	Minke whale
Great shearwater	Black sea bass	North Atlantic right whale
Great skua	Blackbelly rosefish	Northern bottlenose whale
Herring gull	Blueback herring	Pantropical spotted dolphin
Horned grebe	Bluefish	Pygmy sperm whale
Laughing gull	Bluntnose stingray	Risso's dolphin
Leach's storm petrel	Bullnose ray	Rough-toothed dolphin
Least tern	Butterfish	Sei whale
Long-tailed duck	Clearnose skate	Short-beaked common dolphin
Manx shearwater	Cunner	Short-finned pilot whale
Northern fulmar	Cusk	Sowerby's beaked whale
Northern gannet	Fourspot flounder	Sperm whale
Parasitic jaeger	Goosefish	Spinner dolphin
Pomarine jaeger	Gulf stream flounder	Striped dolphin
Razorbill	Haddock	True's beaked whale
Red phalarope	Hickory shad	White-beaked dolphin
Red-breasted merganser	Horseshoe crab	
Red-necked phalarope	Jonah crab	
Red-throated loon	Little skate	
Ring-billed gull	Longfin squid	
Roseate tern	Longhorn sculpin	
Royal tern	Northern shrimp	
Sooty shearwater	Northern kingfish	
Sooty tern	Northern pipefish	

South polar skua	Northern puffer	
Surf scoter	Northern searobin	
Thick-billed murre	Northern shortfin squid	
White-winged scoter	Ocean pout	
Wilson's storm petrel	Offshore hake	
	Pigfish	
	Pinfish	
	Pollock	
	Red hake	
	Rosette skate	
	Roughtail stingray	
	Round herring	
	Sand lance	
	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 searobin	
	Summer flounder	
	Tautog	
	Thorny skate	
	Tilefish	
	Weakfish	
	White hake	
	Windowpane	
	Winter flounder	
	Winter skate	
	Witch flounder	
	Yellowtail flounder	

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).

State listed	ESA listed	BCR30 Priority	AMBCC High	AMBCC Medium	AMBCC Low
Arctic tern	Roseate tern	Audubon's shearwater	Atlantic puffin	Arctic tern	Bridled tern
Atlantic puffin		Black scoter	Audubon's shearwater	Band-rumped storm-petrel	Laughing-gull
Leach's storm-petrel		Common eider	Black-capped petrel	Black scoter	Sooty tern
Least tern		Common tern	Common eider	Black-legged kittiwake	
Razorbill		Cory's shearwater	Common loon	Brown pelican	
Roseate tern		Great shearwater	Common murre	Cory's shearwater	
		Horned grebe	Least tern	Great shearwater	
		Least tern	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-necked phalarope	White-winged scoter		
		Red-throated loon			
		Roseate tern			
		Royal tern			
		Surf 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.asmfc.org/), species with identified Essential Fish Habitat (EFH), and species managed under the Atlantic Highly Migratory Species Management Division (http://www.nmfs.noaa.gov/sfa/hms/). Other groups may be identified as important 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	
Atlantic wolffish	Longfin squid	Atlantic croaker	Atlantic herring	
Haddock	Northern shortfin squid	Atlantic herring	Atlantic mackerel	
Ocean pout	Scup	Atlantic menhaden	Atlantic wolffish	
Offshore hake	Spiny dogfish	Atlantic sharpnose shark	Barndoor skate	
Pollock	Summer flounder	Atlantic sturgeon	Black sea bass	
White hake	Tilefish	Black sea bass	Bluefish	
Windowpane		Blueback herring	Butterfish	
Winter flounder		Bluefish	Clearnose skate	
Witch flounder		Horseshoe crab	Goosefish	
Yellowtail flounder		Jonah crab	Haddock	
NEFMC small mesh multispecies		Northern shrimp	Little skate	
Red hake		Sand tiger	Longfin squid	
Silver hake		Scup	Northern shortfin squid	
		Smooth dogfish	Ocean pout	
NEFMC monkfish		Spiny dogfish	Offshore hake	
Goosefish		Spot	Pollock	
		Striped bass	Red hake	
NEFMC skates		Summer flounder	Rosette skate	
Barndoor skate		Tautog	Scup	
Clearnose skate		Weakfish	Sea scallop	
Little skate		Winter flounder	Silver hake	
Rosette skate			Smooth skate	
Smooth skate			Spiny dogfish	
Thorny skate			Summer flounder	
Winter skate			Thorny skate	
			Tilefish	
			White hake	
			Windowpane	
			Winter flounder	
			Winter skate	
			Witch flounder	
			Yellowtail flounder	

All cetaceans are managed by NOAA/NMFS under the Marine Mammal Protection Act (MMPA, 1972, http://www.nmfs.noaa.gov/pr/laws/mmpa/). Some cetacean species are also listed as endangered under the Endangered Species Act (ESA), and have additional management actions also under authority of the NMFS. Six cetacean 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 cetacean 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.

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

TABLE 13 Groups for avian species based on similar taxonomic identification.

Coastal Waterfowl
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.

Divers & Pursuit Plungers	Surface Feeders	Surface Plungers
Atlantic puffin	Black-capped petrel	Arctic tern
Audubon's shearwater	Band-rumped storm-petrel	Bridled tern
Black guillemot	Black-legged kittiwake	Brown pelican
Common loon	Bonaparte's gull	Common tern
Common murre	Great black-backed gull	Least tern
Cory's shearwater	Herring gull	Northern gannet
Double-crested cormorant	Laughing gull	Roseate tern
Dovekie	Leach's storm-petrel	Royal tern
Great shearwater	Northern fulmar	
Horned grebe	Parasitic jaeger	
Manx shearwater	Red phalarope	
Razorbill	Red-necked phalarope	
Red-breasted merganser	Ring-billed gull	
Red-throated loon	Sooty tern	
Sooty shearwater	South polar skua	
Thick-billed murre		

TABLE 15 Groups for avian species based on prey type.

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

TABLE 16 Groups for avian species based on space use for the Mid-Atlantic and Northeast regions.

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

	Ring-billed gull	Red phalarope
	Sooty shearwater	Red-breasted merganser
	Sooty tern	Red-necked phalarope
	South polar skua	Red-throated loon
	Surf scoter	Ring-billed gull
	Thicke-billed murre	Roseate tern
	White-winger scoter	Sooty shearwater
	Wilson's storm-petrel	Sooty tern
		South polar skua
		Surf scoter
		Thick-billed murre
		White-winged scoter
		Wilson's storm-petrel

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	Pollock
American eel	American shad	American plaice	Red hake
American shad	Atlantic herring	Atlantic cod	Rosette skate
Atlantic sturgeon	Atlantic mackerel	Atlantic halibut	Scup
Blueback herring	Atlantic menhaden	Atlantic wolffish	Sea raven
Hickory shad	Bay anchovy	Barndoor skate	Silver hake
	Blueback herring	Black sea bass	Smooth skate
	Butterfish	Clearnose skate	Spotted hake
	Hickory shad	Cunner	Summer flounder
	Round herring	Fourspot flounder	Tautog
	Sand lance	Goosefish	Thorny skate
	Striped anchovy	Haddock	White hake
		Little skate	Windowpane
		Longhorn sculpin	Winter flounder
		Ocean pout	Witch flounder
		Offshore hake	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).

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

Cetacean 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	*Note: This species group was not implemented because 2 of the 3 species included only had stratified models produced for them.* * *Dwarf sperm whale* * *Pygmy sperm whale* * *Harbor porpoise*
Bryde's whale	Atlantic white-sided dolphin	Pantropical spotted dolphin	
Fin whale	Blainville's beaked whale	Risso's dolphin	
Humpback whale	Bottlenose dolphin	Rough-toothed dolphin	
Minke whale	Clymene dolphin	Short-beaked common dolphin	
North Atlantic right whale	Cuvier's beaked whale	Short-finned pilot whale	
Sei 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	

Hare et al. (2016) reviewed 82 fish and invertebrate species in the Northeast US Shelf for vulnerability to climate change in terms of both species abundance and distribution changes. Each species received overall scores of low, moderate, high or very high. MDAT produced summary products for all species in the high and very high categories for both types of sensitivity (Table 21).

Table 21 Fish species climate vulnerability groups. Fish that scored as high and very high based on Hare et al. (2016) climate vulnerability assessment for changes in abundance and distribution.

Very high and high vulnerability to climate related changes in abundance	Very high and high vulnerability to climate related changes in distribution
Alewife	Acadian redfish
American eel	American eel
American shad	American lobster
Atlantic halibut	American plaice
Atlantic sturgeon	Atlantic cod
Atlantic wolffish	Atlantic croaker
Black sea bass	Atlantic halibut
Blueback herring	Atlantic herring
Cusk	Atlantic mackerel
Hickory shad	Atlantic menhaden
Horseshoe crab	Barndoor skate
Northern shrimp	Black sea bass
Ocean pout	Butterfish
Sand tiger	Goosefish
Sea scallop	Haddock
Striped bass	Little skate
Tautog	Longfin squid
Thorny skate	Northern kingfish
Tilefish	Northern shortfin squid
Winter flounder	Northern shrimp
Witch flounder	Offshore hake
	Pollock
	Red hack
	Rosette skate
	Sand tiger
	Scup
	Silver hake
	Smooth dogfish
	Spiny dogfish
	Spot
	Striped bass
	Summer flounder
	Thorny skate
	Weakfish
	White hake
	Windowpane
	Winter flounder
	Winter skate
	Witch flounder
	Yellowtail flounder

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 cetacean products, summarized below with example maps and descriptions.

3.3.1 Avian Total Relative Density

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 density 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.

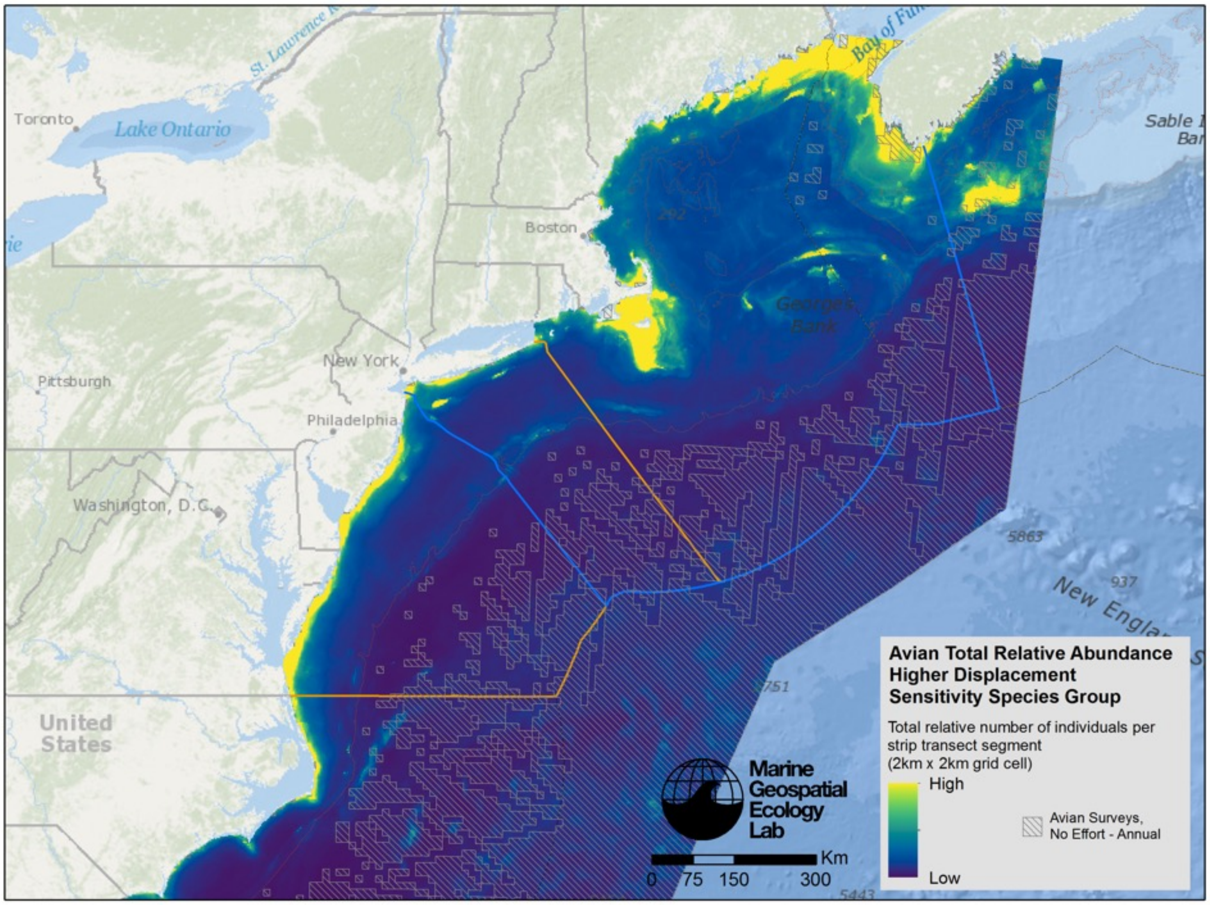
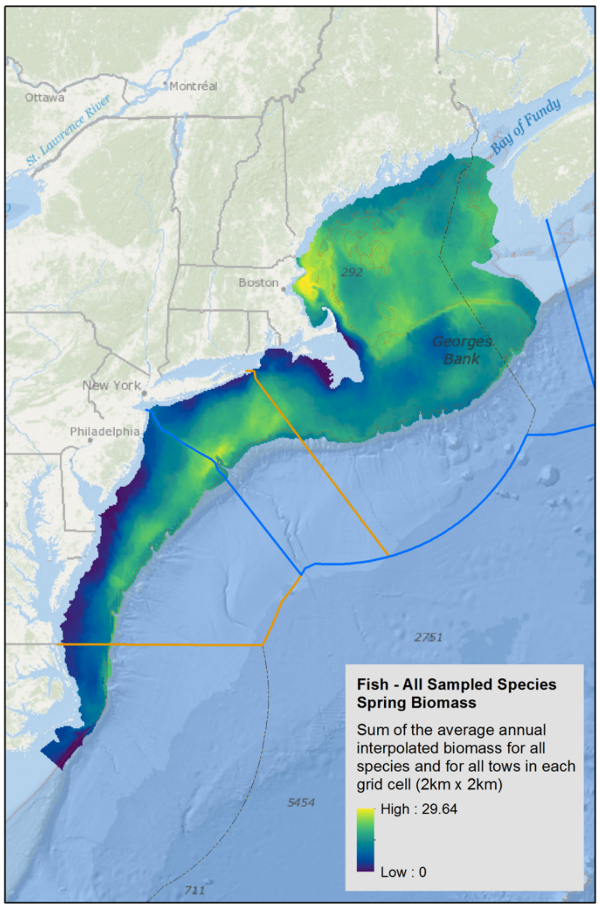


FIGURE 7 Total avian relative abundance distribution map for the Higher Displacement Sensitivity species group (see Table 19). The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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 all sampled fish species (Figure 8; see Table 8 for complete list of species in this group).

Note that individual fish species IDW maps calculate biomass as a cube root scale, and these aggregate maps sum those values.



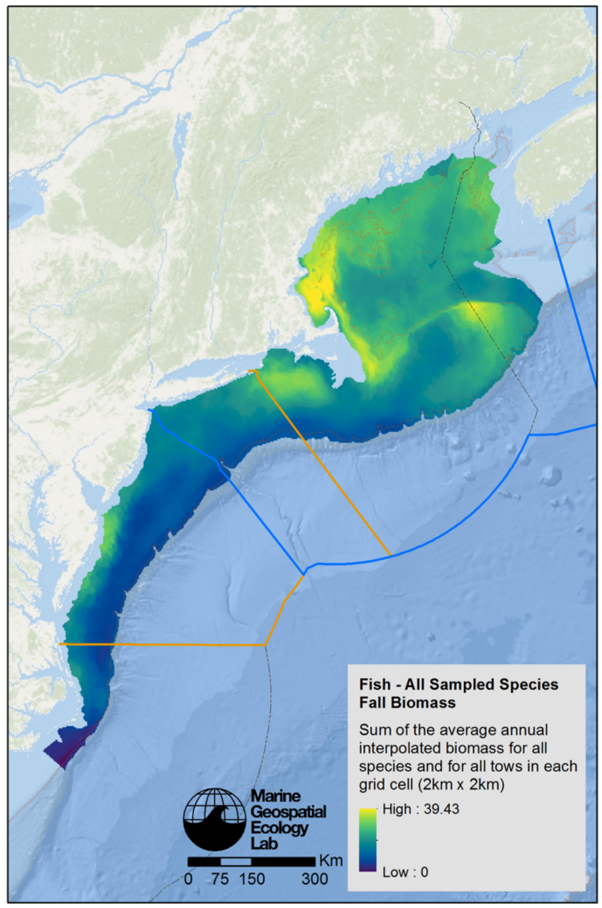


FIGURE 8 Total fish biomass per tow for the all fish species group (see Table 8), spring vs fall seasons. The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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 cells 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.

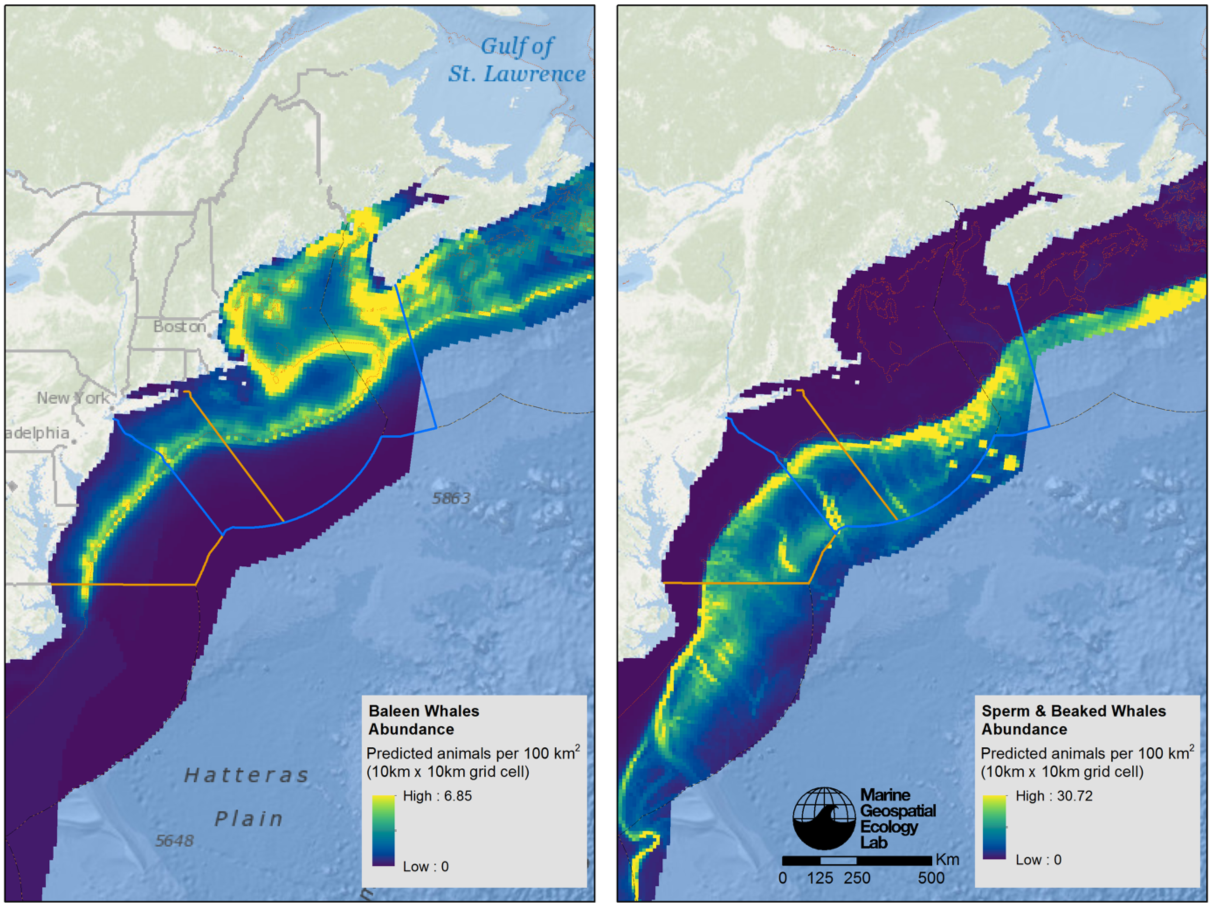


FIGURE 9 Total predicted annual abundance for baleen whales (left) and sperm & beaked whales (right) (see Table 18). The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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 consistently high richness along the coast, while the offshore/pelagic group has consistently low richness along the coast, and higher richness values offshore.

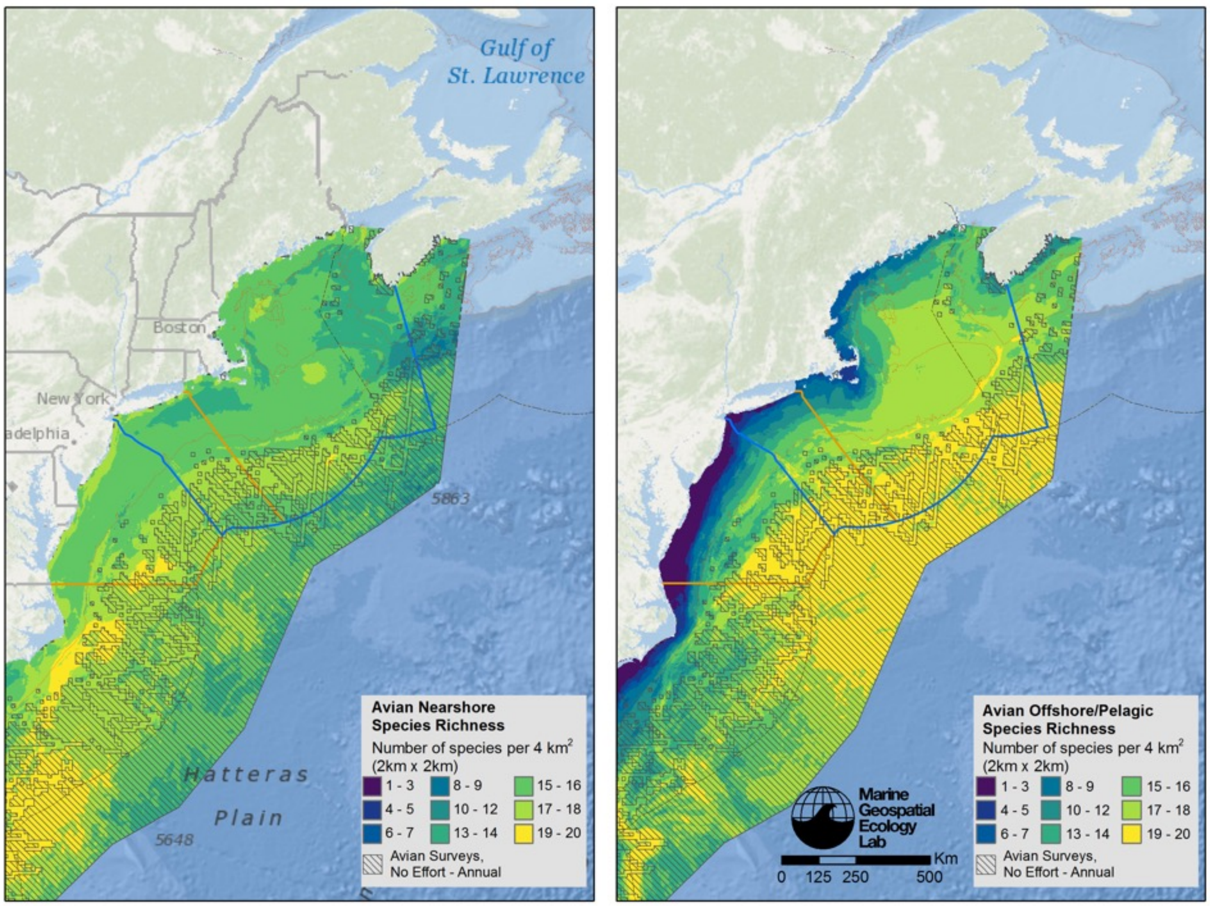


FIGURE 10 Species richness for two groups of avian species: nearshore (left) and offshore/pelagic (right). The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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.

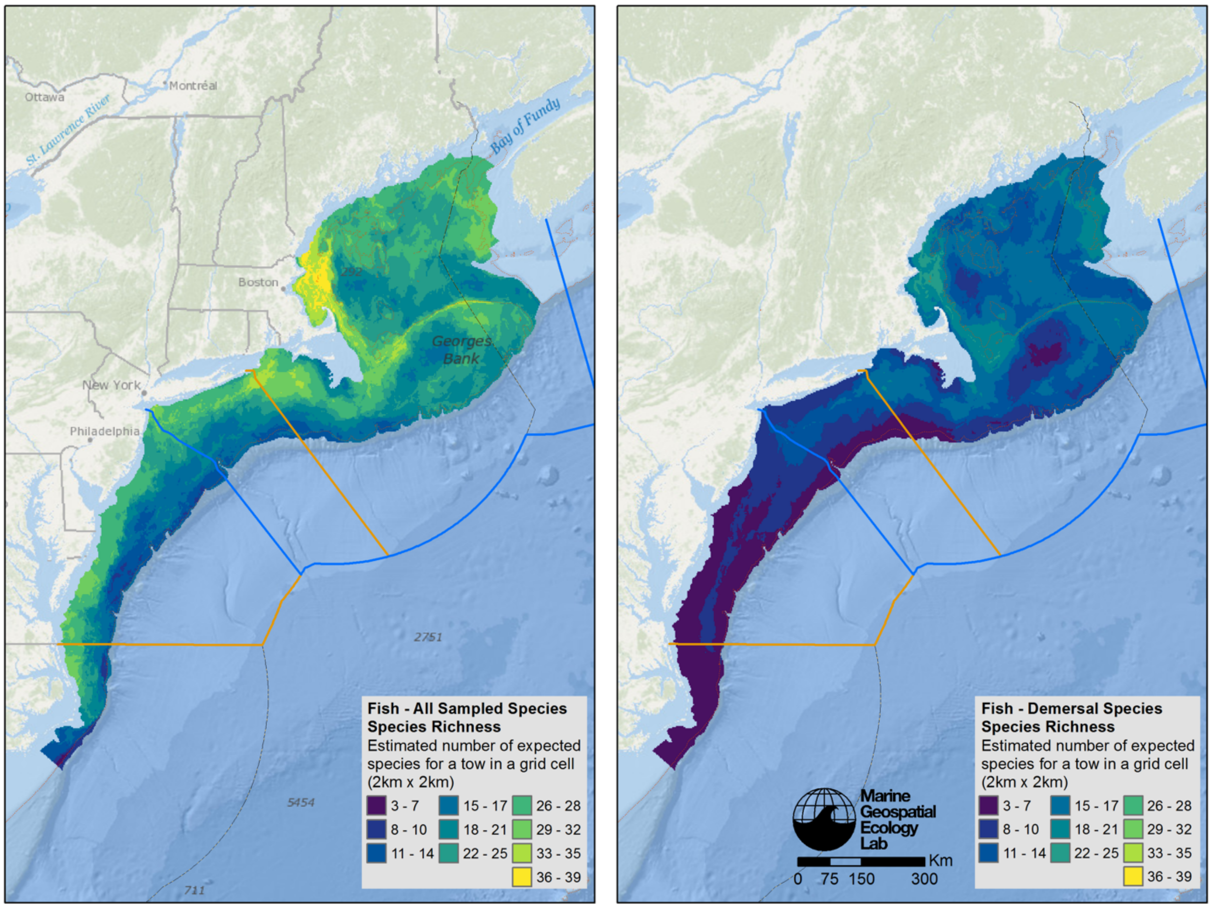


FIGURE 11 Fish species richness, comparing all sampled fish species (left) with the demersal fish species group (right) for fall season trawls. The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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. Species that were modeled as habitat-based density models are considered present in a cell if that cell is included in the area holding 95% of the total predicted abundance for the species. Species that were modeled as stratified models are not included in the species richness calculations.

Some of the individual models for cetacean species are for species groups or guilds. For example, the Mesoplodont beaked whale model is based on data from four beaked whale species (Blainville'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 Mesoplodont beaked whale cell counts as four species (Blainville'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.

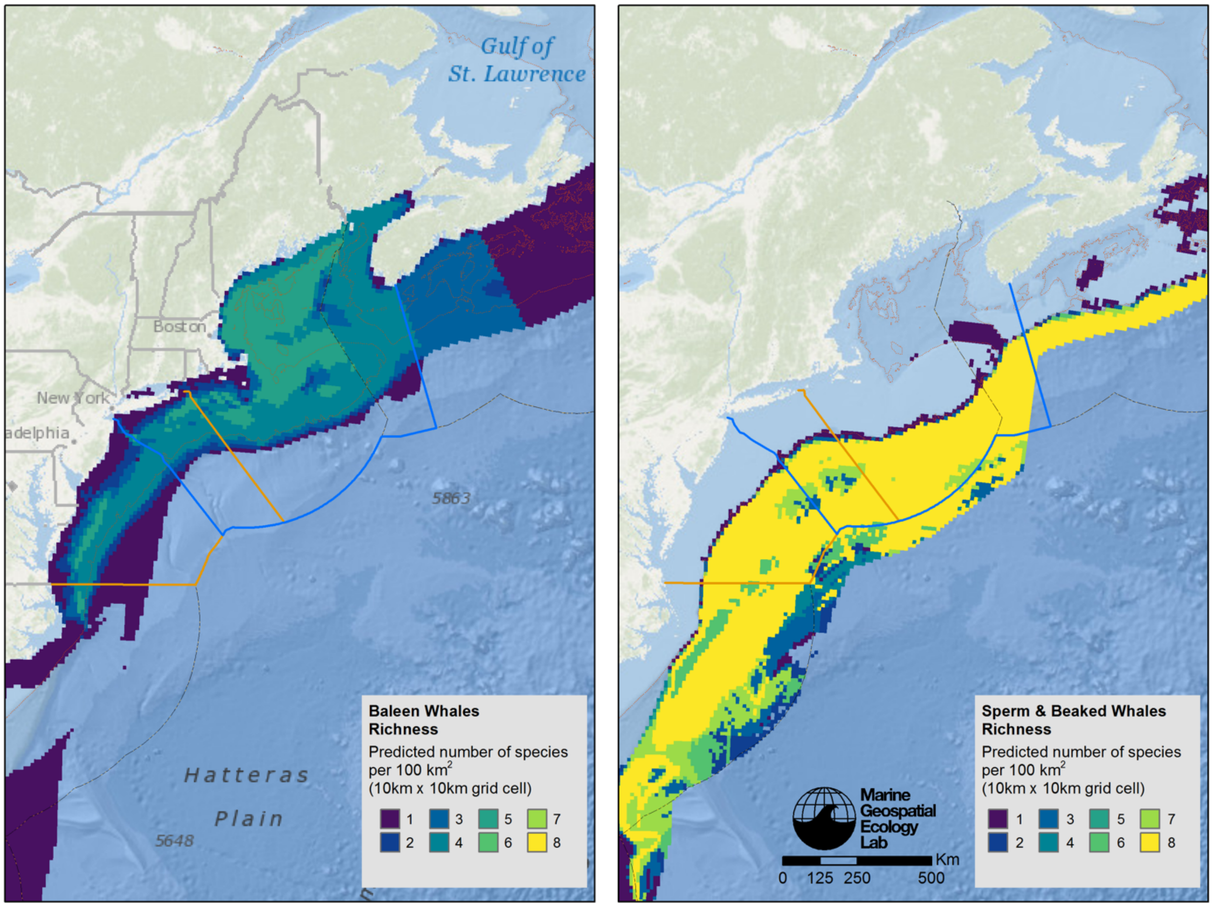


FIGURE 12 Comparison of species richness for baleen whales (left) and sperm & beaked whales (right). The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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 proportion of total individuals belonging to the ith 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:

$$\lambda = 1 - \sum_{i=1}^{R} p_i^2$$

p_i is the proportion of total individuals belonging to the ith species
R is richness, equal to the total number of species

3.5.1 Avian Diversity

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

3.5.2 Fish Diversity

For NEAMAP group diversity calculations, each individual species layer is pre-filtered to contain only the cells that are included in the area holding 95% of the total predicted biomass for the species. Due to the improved interpolation method in the 2019 update, this pre-filtering is not needed for NESFC diversity summary products.

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.

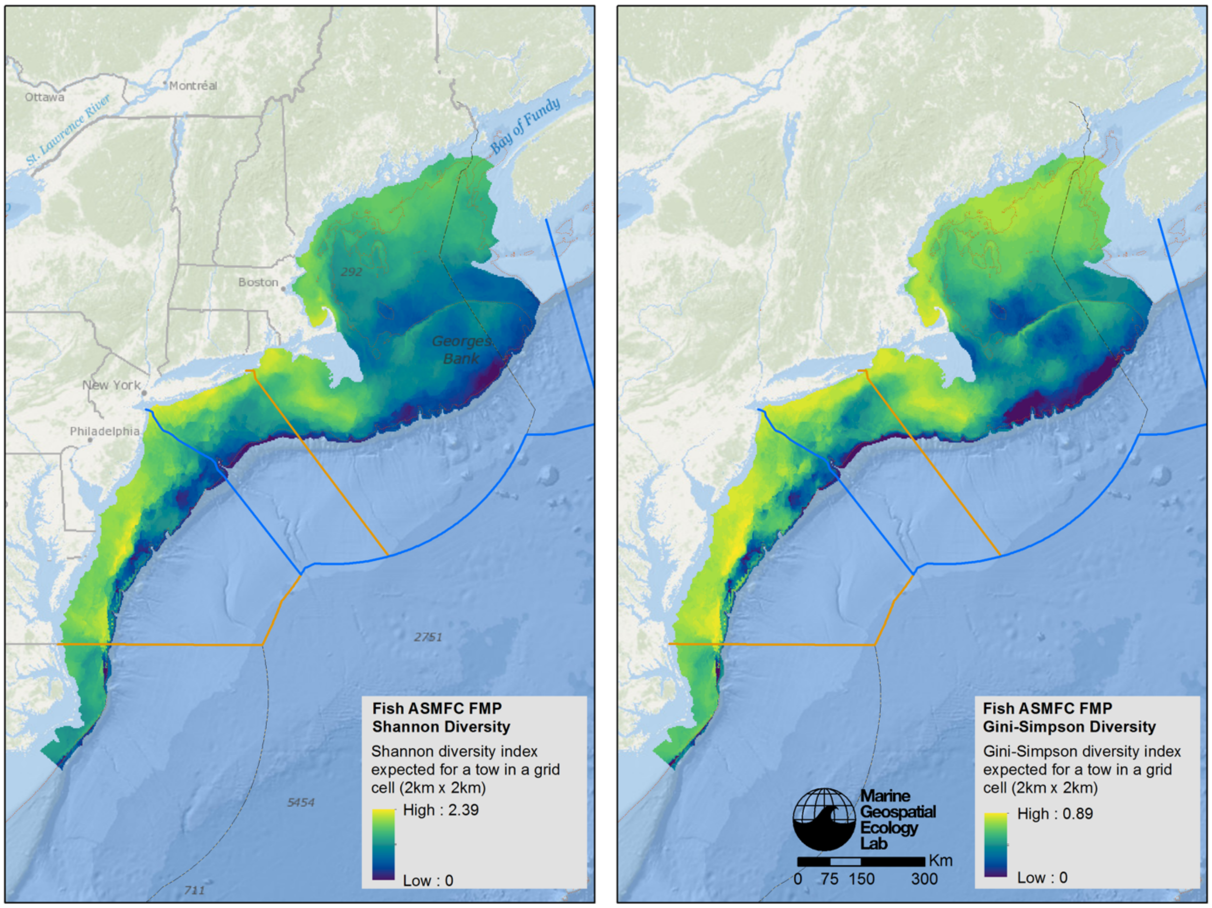


FIGURE 13 Fish diversity for the Atlantic States Marine Fishery Commission (ASFMC) Fishery Management Plan (FMP) species. Both the Shannon diversity index (left) and the Gini-Simpson index (right) were calculated. The dotted red line is the 150m isobath. Background map credits: Esri, DeLorme, GEBCO,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

3.5.3 Cetacean Diversity

Prior to group diversity calculations, species that were modeled as habitat-based density models are pre-filtered to contain only the cells that are included in the area holding 95% of the total predicted abundance for the species. Species that were modeled as stratified models are excluded from the group diversity products.

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.

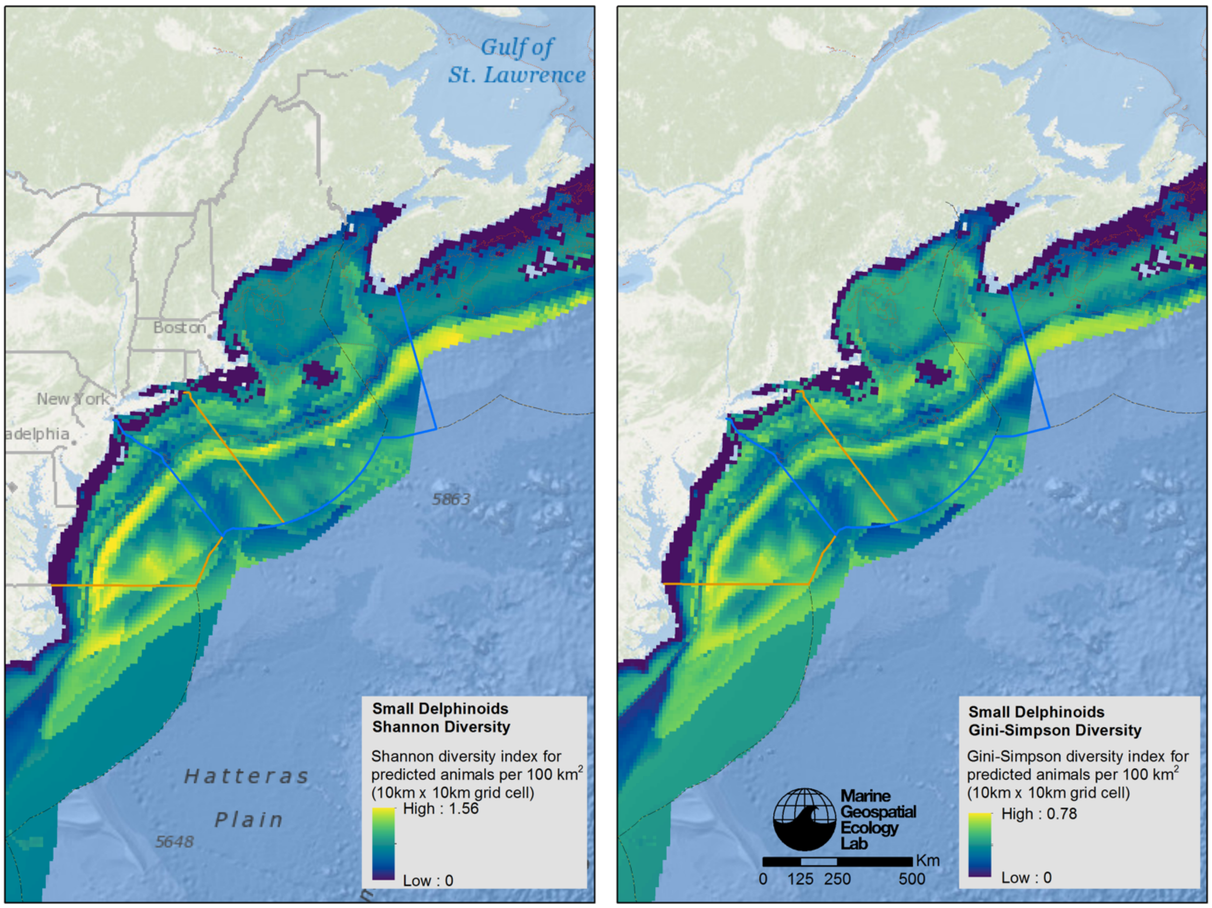


FIGURE 14 Shannon diversity index (left) and Gini-Simpson index (right) of small delphinoid species. Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

3.6 Core Abundance or Biomass Area Richness

Cetacean and avian models predict animal density or relative density 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 22) 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 22 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
Set population threshold	**Simple**	**Apply consistently across taxa**
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 represents 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 cetacean 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 density 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 cetaceans 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.

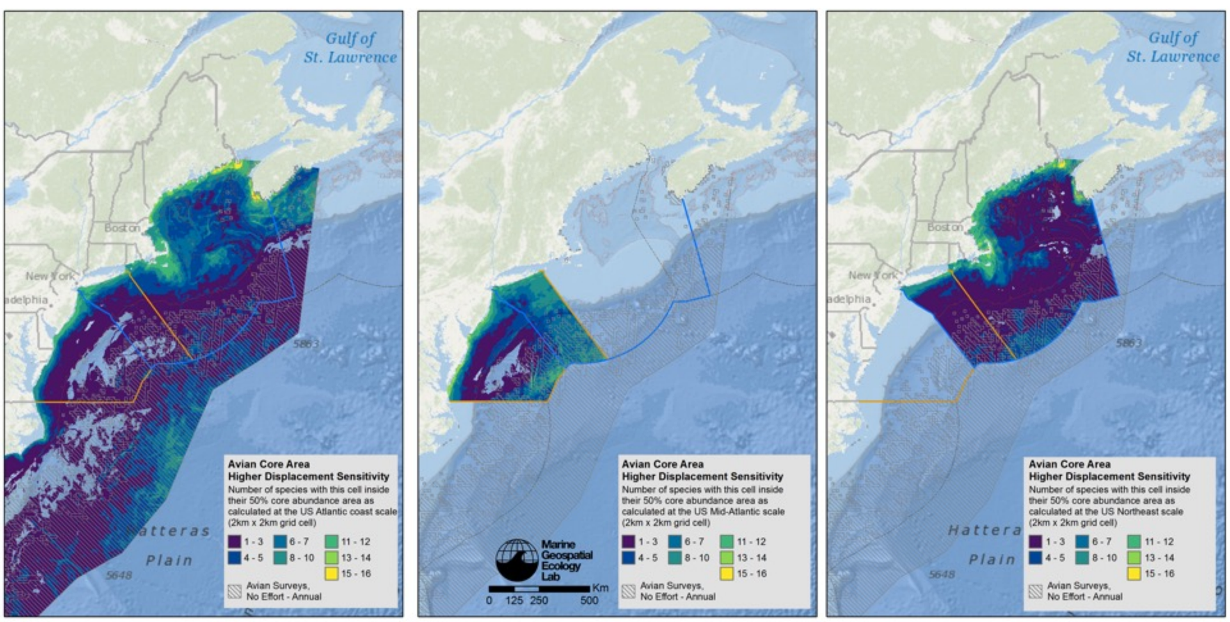


FIGURE 15 Avian core relative abundance area richness for species of higher displacement sensitivity at the full US Atlantic Coast scale (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other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

3.6.3 Fish Core Biomass Area Richness

Fish core biomass area richness was calculated on the interpolated biomass results for individual species. 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.

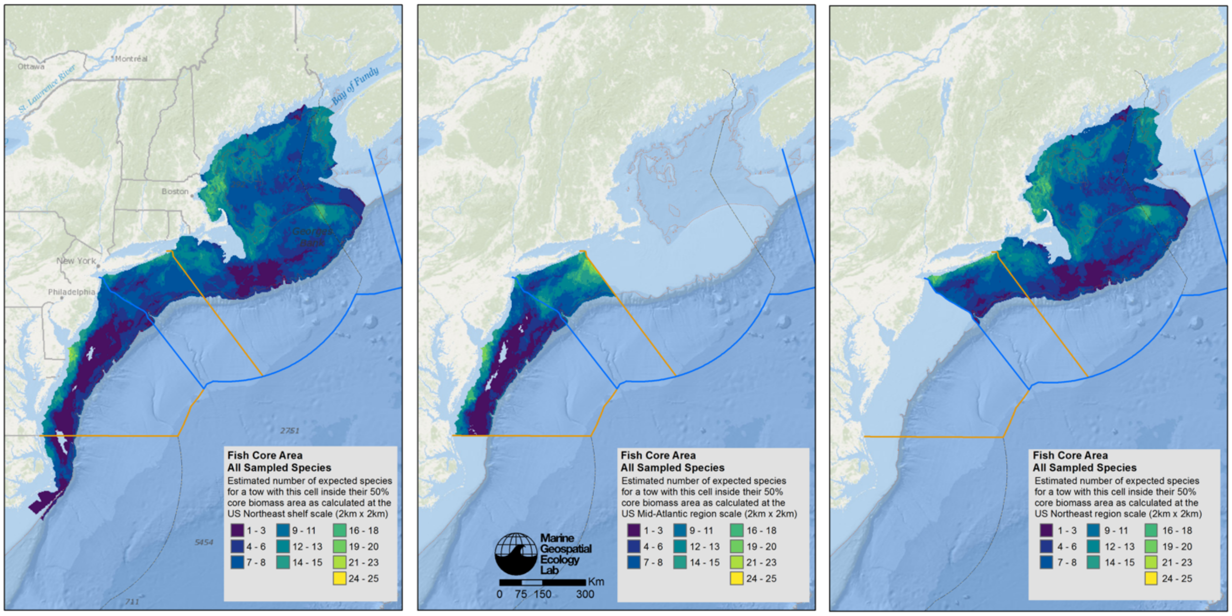


FIGURE 16 Fish core biomass area richness. NEFSC all sampled species for fall season trawls core biomass area richness at the US east coast scale (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and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

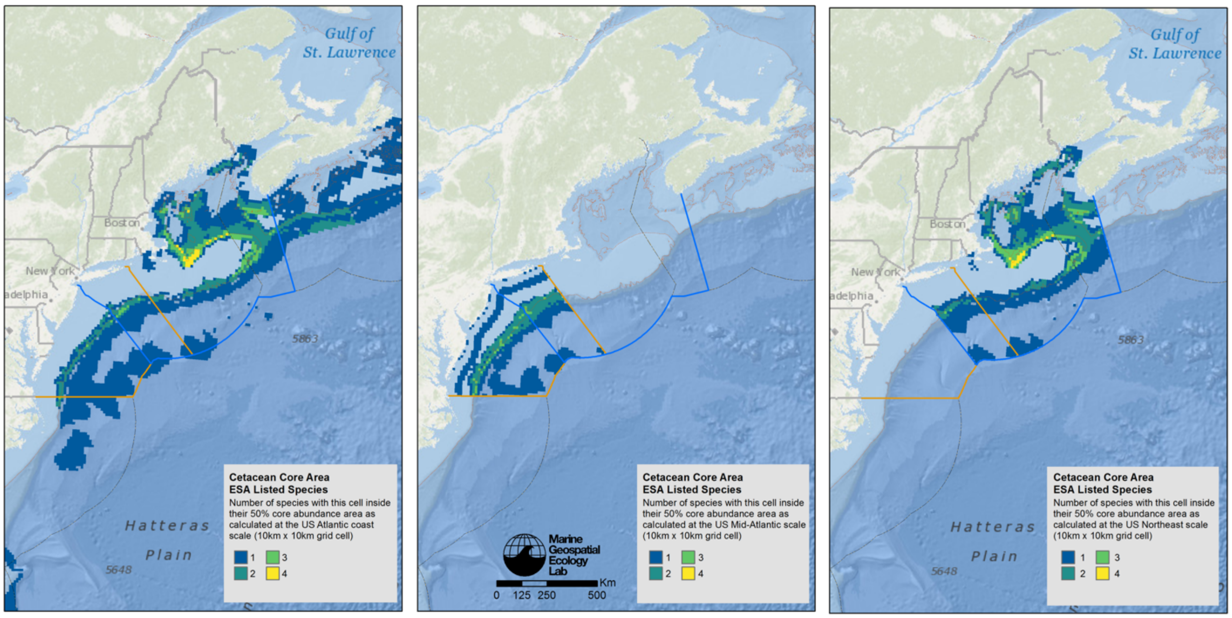


FIGURE 17 Cetacean core abundance area species richness for the ESA species group calculated at the US Atlantic Coast (left), at the Mid-Atlantic regional scale (middle) and at the Northeast regional scale (right). Background map credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

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
- 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 cetacean 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 cetacean model products and avian model products are publicly distributed via a website. Cetacean 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/data_reports/modeling-at-sea-density-of-marine-birds-to-support-atlantic-marine-renewable-energy-planning-final-report/

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:

- Avian_SummaryProducts
- Fish_SummaryProducts_NEAMAP
- Fish_SummaryProducts_NEFSC
- Mammal_SummaryProducts

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

  - Abundance | Biomass
  - Species Richness
  - Shannon Diversity Index
  - Gini-Simpson Diversity Index
  - 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. (2019) 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.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 'Northwest Atlantic Seabird Catalog' database maintained by USFWS and the 'Eastern Canada Seabirds at Sea' database maintained by the Canadian Wildlife Service, Environment and Climate Change Canada. For more information, please contact Arliss Winship (NCCOS Biogeography Branch, arliss.winship@noaa.gov).

For fish base layer products

Northeast Fisheries Science Center (NEFSC) Ecosystem Assessment and Dynamic Branch and The Nature Conservancy (TNC). Data sourced from fall (2010-2016) and spring (2010-2017) bottom trawl surveys performed by NEFSC Ecosystem Surveys Branch, 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 about NEAMAP, MDMF, MENH map products, please contact Michael Fogarty (NOAA NEFSC, michael.fogarty@noaa.gov). For information about the mapping procedure for the NEFSC base-layer products, please contact David Richardson (NOAA NEFSC, david.richardson@noaa.gov).

For cetacean 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), the Virginia Aquarium & Marine Science Center (VAMSC), the Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission, and the Atlantic Marine Conservation Society. It was derived from habitat-based density models for cetaceans built from shipboard and aerial line transect surveys conducted at sea between 1992-2016 by the NMFS Northeast and Southeast Fisheries Science Centers, UNCW, VAMSC, the New Jersey Department of Environmental Protection, the Riverhead Foundation for Marine Research & Preservation, and multiple teams surveying for North Atlantic right whales in the southeast U.S., including those led by FWRI, New England Aquarium, and Wildlife Trust / EcoHealth Alliance / Sea to Shore Alliance. The UNCW surveys were funded by U.S. Navy Fleet Forces Command and NOAA. VAMSC surveys in Virginia 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 southeast U.S. right whale surveys were funded by NOAA, the U.S. Army Corps of Engineers, the U.S. Coast Guard, the U.S. Navy, the Georgia Department of Natural Resources, the South Carolina State Port Authority, and the National Fish and Wildlife Foundation. 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).

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 (NE RPB), NE RPB 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).

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*.

Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., et al. (2016) A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756. https://doi.org/10.1371/journal.pone.0146756

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*.

Kinlan, B.P., Winship A.J., White T.P., & Christensen J. 2016. Modeling At-Sea Occurrence and Abundance of Marine Birds to Support Atlantic Marine Renewable Energy Planning: Phase I Report. U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of

Renewable Energy Programs, Sterling, VA. OCS Study BOEM 2016-039. xvii+113 pp. Accessed at: https://www.data.boem.gov/PI/PDFImages/ESPIS/5/5512.pdf

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.

Miller, D.L., Burt, M.L., Rexstad, E.A., Thomas, L. (2013). Spatial models for distance sampling data: recent developments and future directions. *Methods in Ecology and Evolution 4*, 1001–1010.

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

Roberts J.J., Mannocci L., Halpin P.N. 2017. Final Project Report: Marine Species Density Data Gap Assessments and Update for the AFTT Study Area, 2016-2017 (Opt. Year 1). Document version 1.4. Report prepared for Naval Facilities Engineering Command, Atlantic by the Duke University Marine Geospatial Ecology Lab, Durham, NC.

Roberts J.J., Mannocci L., Schick R.S., Halpin P.N. 2018 Final Project Report: Marine Species Density Data Gap Assessments and Update for the AFTT Study Area, 2017-2018 (Opt. Year 2). Document version 1.2. Report prepared for Naval Facilities Engineering Command, Atlantic by the Duke University Marine Geospatial Ecology Lab, Durham, NC.

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.

Winship, A.J., Kinlan, B.P., White, T.P., Leirness, J.B. and Christensen, J. (2018) Modeling At-Sea Density of Marine Birds to Support Atlantic Marine Renewable Energy Planning: Final Report. U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA. OCS Study BOEM 2018-010. 67 pp.

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 two 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 and 2. 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 (Fig. 2). Model predictions in areas with few or no data should be interpreted with caution. Areas without survey effort 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). The model performance metrics for each species-season model are presented in Table 2. 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 (Fig. 2), 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 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.

References

Bodenhofer, 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.

Performance metric	Interpretation
Percent deviance explained (PDE)	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; higher values indicate better performance
Spearman rank correlation coefficient	Rank correlation between observed and predicted counts; higher values indicate better performance
Gaussian rank correlation coefficient[1]	Rank correlation between observed and predicted counts; higher values indicate better performance
Median absolute error	Median absolute difference between observed and predicted counts relative to the mean count; lower values indicate better performance
Mean absolute error	Mean absolute difference between observed and predicted counts relative to the mean count; values closer to zero indicate better performance
Median bias	Median difference between observed and predicted counts (predicted minus observed) relative to the mean count; values closer to zero indicate better performance
Mean bias	Mean difference between observed and predicted counts (predicted minus observed) relative to the mean count; values closer to zero indicate better performance
Root mean square error	Square root of the average squared difference between observed and predicted counts; lower values indicate better performance

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

Table 2. Model performance (Table 1) for all species and seasons.

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
ARTE	summer	0.49	0.95	0.10	0.14	0.08	1.66	0.08	-0.11	0.36
ATPU	fall	0.46	0.96	0.09	0.13	0.15	1.76	0.15	0.07	0.08
ATPU	spring	0.41	0.92	0.15	0.19	0.14	1.69	0.14	-0.09	0.27
ATPU	summer	0.49	0.98	0.14	0.18	0.08	1.58	0.08	0.01	0.24
ATPU	winter	0.41	0.95	0.15	0.20	0.12	1.59	0.11	-0.05	0.22
AUSH	fall	0.64	0.98	0.14	0.20	0.16	1.36	0.16	-0.21	0.82
AUSH	spring	0.71	0.98	0.11	0.17	0.09	1.06	0.09	-0.31	0.33
AUSH	summer	0.52	0.95	0.22	0.28	0.06	1.40	0.06	-0.11	1.39
AUSH	winter	0.78	1.00	0.12	0.20	0.00	0.88	0.00	-0.10	0.11
BCPE	fall	0.83	1.00	0.08	0.14	0.00	0.49	0.00	-0.01	0.07
BCPE	spring	0.74	1.00	0.12	0.19	0.00	0.75	0.00	-0.01	0.12
BCPE	summer	0.67	0.99	0.16	0.22	0.00	1.35	0.00	-0.19	0.59
BCPE	winter	0.86	0.99	0.09	0.16	0.00	0.39	0.00	-0.01	0.05
BLGU	summer	0.59	0.99	0.08	0.13	0.15	1.50	0.15	0.09	0.09
BLKI	fall	0.56	0.95	0.35	0.40	0.02	1.17	0.02	-0.28	14.91
BLKI	spring	0.51	0.91	0.22	0.25	0.05	1.43	0.05	-0.32	2.82
BLKI	winter	0.58	0.93	0.48	0.51	0.10	1.07	0.06	-0.07	9.05
BLSC	fall	0.48	0.96	0.16	0.21	0.05	1.46	0.05	-0.30	6.33
BLSC	spring	0.58	0.94	0.19	0.24	0.01	1.25	0.01	-0.54	24.88
BLSC	winter	0.42	0.92	0.27	0.28	0.05	1.74	0.04	-0.03	74.80
BOGU	fall	0.46	0.90	0.11	0.14	0.19	1.95	0.19	0.14	1.49
BOGU	spring	0.39	0.92	0.17	0.18	0.12	1.63	0.11	-0.27	8.79
BOGU	winter	0.52	0.87	0.25	0.29	0.23	1.40	0.20	-0.15	5.08
BRPE	fall	0.43	0.99	0.10	0.16	0.02	1.25	0.02	-0.24	0.67
BRPE	spring	0.45	0.99	0.08	0.13	0.20	1.51	0.20	-0.01	0.45
BRPE	summer	0.28	0.99	0.09	0.14	0.00	1.11	0.00	-0.40	0.48

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
BRPE	winter	0.59	0.98	0.08	0.12	0.00	1.43	0.00	-0.29	0.51
BRSP	summer	0.53	0.96	0.13	0.19	0.08	1.42	0.08	-0.07	0.18
BRTE	fall	0.60	1.00	0.07	0.12	0.30	1.70	0.30	0.33	0.10
BRTE	summer	0.60	0.95	0.08	0.11	0.10	1.66	0.10	-0.21	0.19
COEI	fall	0.66	0.97	0.20	0.26	0.00	1.65	0.00	0.02	129.75
COEI	spring	0.45	0.96	0.21	0.26	0.33	2.00	0.32	0.40	266.07
COEI	summer	0.62	0.99	0.10	0.15	0.00	2.38	0.00	0.98	29.17
COEI	winter	0.41	0.94	0.37	0.40	0.02	1.54	0.02	-0.23	425.30
COLO	fall	0.42	0.94	0.28	0.34	0.11	1.33	0.09	-0.05	0.54
COLO	spring	0.40	0.91	0.41	0.44	0.21	1.24	0.14	-0.06	1.08
COLO	summer	0.49	0.94	0.11	0.14	0.09	1.75	0.09	-0.13	0.11
COLO	winter	0.35	0.83	0.36	0.39	0.46	1.41	0.32	-0.09	3.72
COMU	spring	0.38	0.92	0.12	0.15	0.22	1.64	0.22	-0.22	0.38
COMU	winter	0.49	0.95	0.14	0.19	0.02	1.42	0.02	-0.09	0.37
COSH	fall	0.40	0.90	0.29	0.34	0.20	1.43	0.17	-0.04	2.81
COSH	spring	0.67	0.97	0.11	0.15	0.11	1.69	0.11	-0.11	0.18
COSH	summer	0.36	0.83	0.31	0.33	0.29	1.38	0.20	-0.32	5.43
COTE	fall	0.55	0.94	0.20	0.24	0.16	1.44	0.15	-0.03	3.63
COTE	spring	0.39	0.97	0.23	0.30	0.05	1.45	0.05	-0.01	1.30
COTE	summer	0.45	0.94	0.30	0.34	0.13	1.48	0.11	-0.03	2.54
DCCO	fall	0.37	0.89	0.10	0.13	0.23	1.54	0.22	-0.42	4.77
DCCO	spring	0.46	0.95	0.11	0.13	0.06	1.48	0.06	-0.43	7.43
DCCO	summer	0.53	0.91	0.09	0.11	0.24	1.79	0.24	-0.10	2.45
DCCO	winter	0.65	0.91	0.10	0.13	0.09	1.22	0.09	-0.73	3.57
DOVE	fall	0.62	0.98	0.18	0.25	0.02	1.07	0.02	-0.20	1.85
DOVE	spring	0.53	0.94	0.21	0.28	0.08	1.21	0.07	-0.18	1.39
DOVE	summer	0.67	0.98	0.06	0.10	0.01	1.36	0.01	-0.30	0.10

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
DOVE	winter	0.43	0.91	0.27	0.33	0.08	1.17	0.07	-0.34	4.18
GBBG	fall	0.40	0.88	0.46	0.47	0.15	1.30	0.09	-0.13	12.13
GBBG	spring	0.48	0.86	0.41	0.43	0.13	1.24	0.10	-0.33	18.20
GBBG	summer	0.47	0.90	0.38	0.40	0.09	1.35	0.05	-0.12	4.36
GBBG	winter	0.66	0.89	0.42	0.45	0.10	1.12	0.07	-0.04	11.69
GRSH	fall	0.50	0.95	0.59	0.60	0.03	1.08	0.01	-0.13	22.02
GRSH	spring	0.72	0.98	0.24	0.32	0.00	1.00	0.00	-0.22	3.36
GRSH	summer	0.78	0.90	0.50	0.50	0.08	1.03	0.06	-0.04	129.86
GRSH	winter	0.59	0.98	0.11	0.16	0.02	1.21	0.02	-0.33	0.71
GRSK	fall	0.33	0.95	0.11	0.13	0.20	1.92	0.20	0.01	0.08
HERG	fall	0.42	0.87	0.51	0.52	0.20	1.21	0.10	-0.12	14.84
HERG	spring	0.42	0.86	0.48	0.51	0.20	1.20	0.13	-0.21	22.70
HERG	summer	0.50	0.90	0.37	0.40	0.07	1.35	0.04	-0.13	3.92
HERG	winter	0.46	0.85	0.43	0.45	0.30	1.25	0.18	-0.04	10.69
HOGR	winter	0.41	0.94	0.09	0.12	0.26	1.71	0.26	-0.08	0.15
LAGU	fall	0.55	0.94	0.31	0.36	0.06	1.34	0.05	0.00	3.41
LAGU	spring	0.52	0.95	0.23	0.29	0.08	1.43	0.07	-0.15	0.75
LAGU	summer	0.58	0.95	0.30	0.36	0.06	1.24	0.05	-0.13	1.38
LAGU	winter	0.58	0.97	0.10	0.16	0.09	1.42	0.09	-0.17	0.24
LESP	fall	0.60	0.97	0.19	0.26	0.05	1.29	0.05	-0.23	0.59
LESP	spring	0.52	0.96	0.15	0.19	0.14	1.47	0.13	-0.06	0.81
LESP	summer	0.50	0.94	0.36	0.40	0.05	1.21	0.04	-0.18	2.92
LETE	fall	0.62	0.97	0.08	0.11	0.00	1.99	0.00	0.12	1.22
LETE	summer	0.36	0.94	0.08	0.11	0.18	1.76	0.18	-0.02	0.48
LTDU	fall	0.71	0.99	0.19	0.27	0.00	1.29	0.00	0.04	15.74
LTDU	spring	0.48	0.97	0.28	0.34	0.27	1.51	0.23	-0.13	224.81
LTDU	winter	0.57	0.96	0.49	0.52	0.00	1.22	0.00	-0.26	99.69

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
MASH	fall	0.29	0.89	0.12	0.15	0.26	1.73	0.25	-0.18	0.27
MASH	spring	0.36	0.93	0.09	0.12	0.32	1.67	0.32	-0.10	0.11
MASH	summer	0.56	0.84	0.10	0.11	0.39	1.68	0.38	-0.26	1.97
NOFU	fall	0.62	0.96	0.35	0.42	0.00	1.18	0.00	0.13	9.88
NOFU	spring	0.66	0.94	0.43	0.48	0.01	1.08	0.01	-0.26	24.71
NOFU	summer	0.68	0.98	0.24	0.32	0.01	0.94	0.00	-0.45	21.93
NOFU	winter	0.67	0.98	0.39	0.46	0.01	0.98	0.00	-0.28	15.23
NOGA	fall	0.51	0.91	0.48	0.51	0.12	1.09	0.05	-0.13	4.10
NOGA	spring	0.44	0.85	0.50	0.52	0.24	1.13	0.12	-0.24	14.42
NOGA	summer	0.45	0.94	0.27	0.32	0.07	1.39	0.06	-0.07	0.58
NOGA	winter	0.41	0.81	0.46	0.47	0.29	1.19	0.16	-0.33	20.58
PAJA	fall	0.25	0.83	0.08	0.08	0.51	1.97	0.50	-0.01	0.11
PAJA	spring	0.14	0.86	0.05	0.06	0.51	2.01	0.50	0.02	0.05
PAJA	summer	0.23	0.87	0.05	0.06	0.56	1.97	0.56	-0.01	0.06
POJA	fall	0.37	0.90	0.19	0.21	0.13	1.77	0.11	-0.06	0.22
POJA	spring	0.53	0.96	0.09	0.13	0.27	1.68	0.27	-0.15	0.08
POJA	summer	0.23	0.84	0.07	0.08	0.53	1.96	0.53	-0.02	0.08
RAZO	fall	0.43	0.97	0.11	0.15	0.09	1.52	0.09	-0.01	1.03
RAZO	spring	0.41	0.95	0.27	0.32	0.08	1.44	0.07	-0.03	1.76
RAZO	summer	0.40	0.97	0.07	0.11	0.30	1.92	0.30	0.22	0.15
RAZO	winter	0.48	0.91	0.33	0.36	0.12	1.37	0.10	-0.07	4.81
RBGU	fall	0.41	0.90	0.14	0.17	0.15	1.49	0.15	-0.34	1.20
RBGU	spring	0.46	0.94	0.12	0.16	0.21	1.70	0.21	-0.08	0.36
RBGU	summer	0.54	0.96	0.06	0.08	0.20	1.44	0.20	-0.54	0.21
RBGU	winter	0.41	0.88	0.19	0.23	0.30	1.71	0.29	-0.02	2.24
RBME	spring	0.51	0.93	0.07	0.10	0.11	1.59	0.11	-0.33	0.43
RBME	winter	0.31	0.89	0.07	0.07	0.53	1.68	0.53	-0.31	1.48

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
REPH	fall	0.38	0.95	0.14	0.17	0.19	1.69	0.19	-0.16	1.45
REPH	spring	0.74	0.96	0.19	0.23	0.01	1.23	0.01	-0.27	90.82
REPH	summer	0.31	0.94	0.11	0.16	0.22	1.29	0.22	-0.63	96.77
RNPH	fall	0.32	0.89	0.09	0.11	0.48	1.93	0.48	-0.02	0.87
RNPH	spring	0.31	0.93	0.10	0.13	0.21	1.86	0.20	-0.04	3.18
RNPH	summer	0.36	0.94	0.10	0.13	0.15	1.56	0.15	-0.27	1.98
ROST	fall	0.23	0.96	0.07	0.11	0.39	2.04	0.39	0.41	0.64
ROST	spring	0.57	0.98	0.07	0.10	0.12	1.56	0.12	-0.35	0.25
ROST	summer	0.61	0.97	0.11	0.16	0.00	1.57	0.00	-0.12	0.69
ROYT	fall	0.53	0.97	0.15	0.20	0.05	1.61	0.05	-0.08	0.36
ROYT	spring	0.68	0.98	0.15	0.22	0.00	1.21	0.00	-0.28	0.58
ROYT	summer	0.65	0.98	0.14	0.20	0.01	1.32	0.01	-0.15	0.23
RTLO	fall	0.44	0.96	0.16	0.21	0.05	1.50	0.05	-0.07	0.61
RTLO	spring	0.48	0.93	0.34	0.38	0.08	1.34	0.06	-0.02	1.66
RTLO	winter	0.42	0.86	0.33	0.37	0.31	1.38	0.22	-0.09	1.90
SOSH	fall	0.39	0.92	0.08	0.09	0.27	1.85	0.27	-0.12	0.50
SOSH	spring	0.53	0.95	0.26	0.32	0.02	1.22	0.02	-0.32	5.06
SOSH	summer	0.71	0.93	0.30	0.34	0.01	1.17	0.01	-0.52	57.21
SOTE	spring	0.63	1.00	0.07	0.13	0.00	1.14	0.00	-0.06	0.84
SOTE	summer	0.56	0.98	0.09	0.12	0.03	1.67	0.03	-0.07	0.50
SPSK	fall	0.38	0.96	0.09	0.13	0.16	1.78	0.16	-0.07	0.09
SPSK	summer	0.35	0.92	0.07	0.10	0.32	1.85	0.32	-0.02	0.06
SUSC	fall	0.66	0.98	0.23	0.31	0.04	1.14	0.04	-0.16	10.93
SUSC	spring	0.47	0.97	0.26	0.33	0.08	1.28	0.07	-0.15	8.03
SUSC	winter	0.61	0.97	0.37	0.44	0.06	1.09	0.05	-0.20	16.58
TBMU	spring	0.44	0.95	0.15	0.20	0.06	1.43	0.06	-0.20	0.90
TBMU	winter	0.50	0.97	0.11	0.15	0.16	1.52	0.16	0.03	0.24

Species	Season	Percent deviance explained	AUC	Spearman rank correlation	Gaussian rank correlation	Median absolute error	Mean absolute error	Median bias	Mean bias	Root mean square error
WISP	fall	0.55	0.96	0.29	0.35	0.02	1.31	0.02	-0.24	3.77
WISP	spring	0.54	0.97	0.37	0.42	0.02	1.26	0.02	-0.09	10.14
WISP	summer	0.42	0.87	0.52	0.52	0.25	1.33	0.15	-0.04	27.22
WWSC	fall	0.55	0.97	0.20	0.27	0.01	1.32	0.01	-0.01	6.81
WWSC	spring	0.42	0.95	0.19	0.24	0.15	1.56	0.15	-0.14	29.15
WWSC	winter	0.55	0.94	0.31	0.36	0.04	1.24	0.03	-0.44	20.28

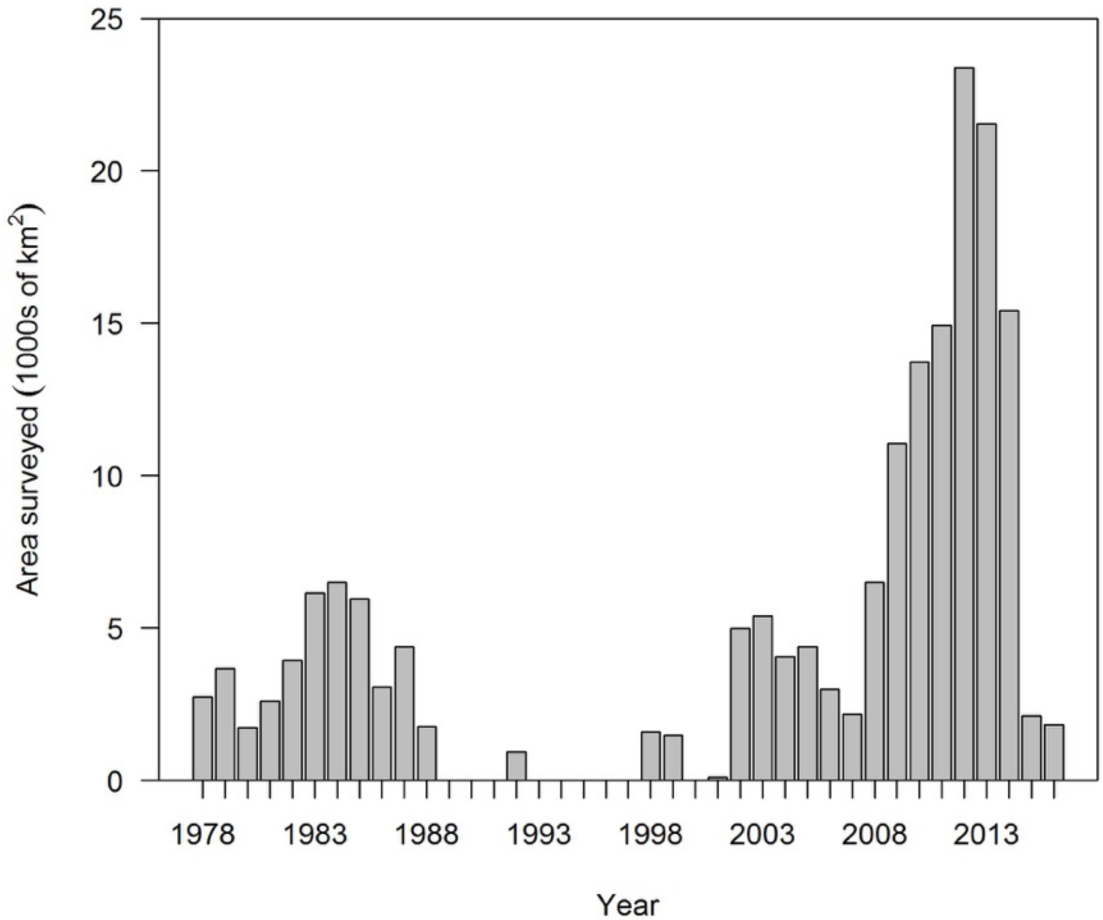


Figure 1. Total area surveyed by year.

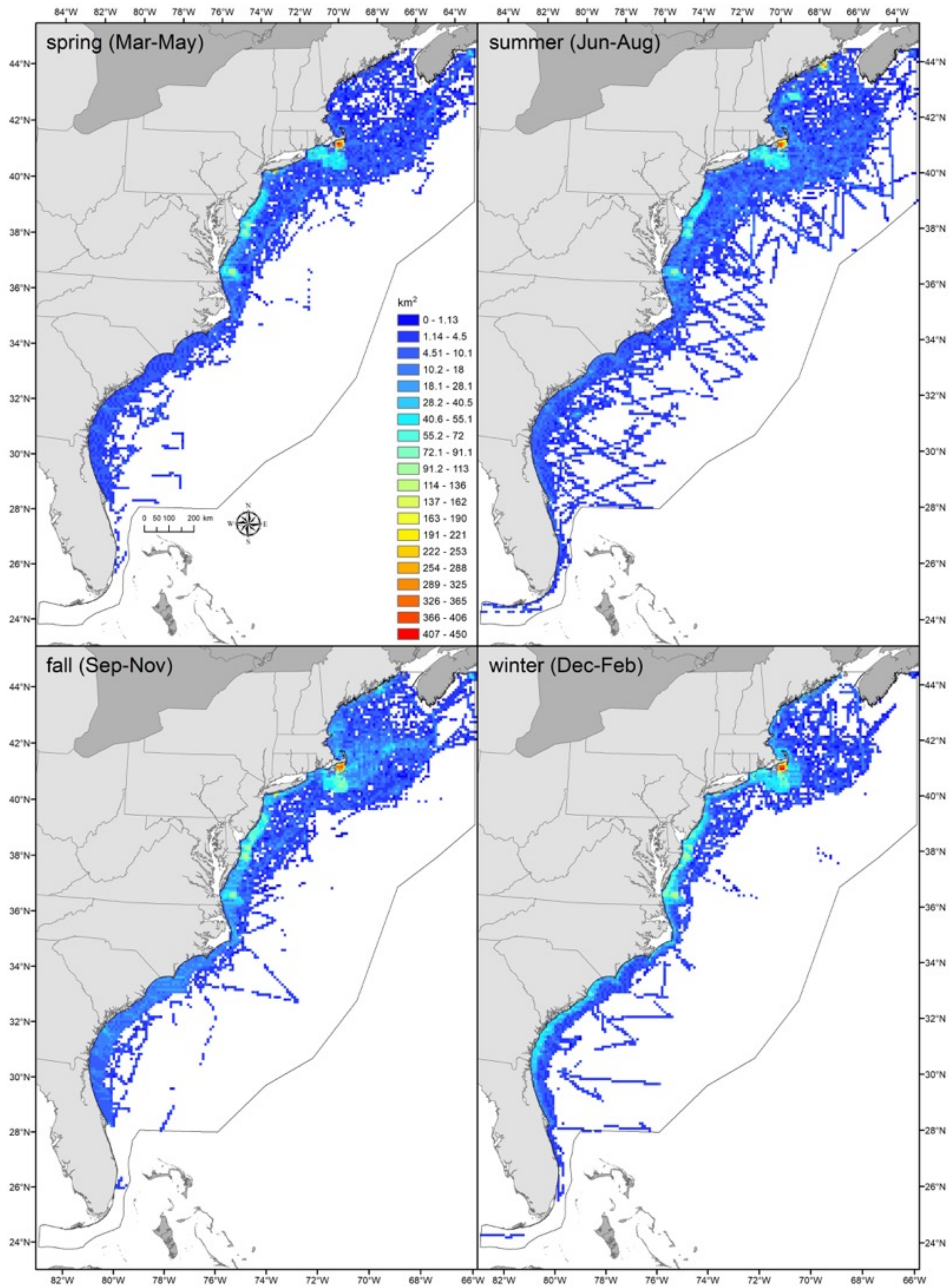


Figure 2. Map of survey effort in each season. The colored grid represents the total area surveyed in 10 x 10 km cells within the study area (outer thin black line).

7.2 Cetacean Model Performance

Cetacean model performance metrics for v1 models are available from the Supplementary information in Roberts et al. (2016), online here:
http://www.nature.com/article-assets/npg/srep/2016/160303/srep22615/extref/srep22615-s1.pdf

Model performance metrics for v2 and v2.1 model updates are available upon request.