Important Improvements of the Duke 2015 Density Models Over the 2007 Navy NODEs Models for the U.S. Atlantic

Jason Roberts and Pat Halpin, Duke Marine Geospatial Ecology Lab

Updated 23 February 2016

Navy OPAREA Density Estimates (NODEs) models

- Funded by the Navy to support development of the Atlantic Fleet Active Sonar Training (AFAST) EIS (finalized January 2009)
- Developed by Geo-Marine, Inc.
- Utilized NOAA NEFSC and SEFSC surveys spanning 1998-2005
- Final report issued in 2007
- Not submitted to a peer-reviewed scientific journal
- Reused for the Navy’s Atlantic Fleet Training and Testing (AFTT) Phase II EIS (finalized November 2013)
  - AFAST was AFTT Phase I

Duke 2015 density models (a.k.a. CetMap)

- Initial funding from NASA for certain methodological work
- Main funding from the Navy to support the AFTT Phase III EIS
  - Specifically intended to replace NODEs with models built with additional data and updated methodology
- Developed at Duke in consultation with NOAA and others
- Utilized surveys from five institutions
- Models finalized in January 2015
- Peer-reviewed paper accepted for publication in February 2016
  - http://dx.doi.org/10.1038/srep22615

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

NODEs study areas

Southeast NODE study area

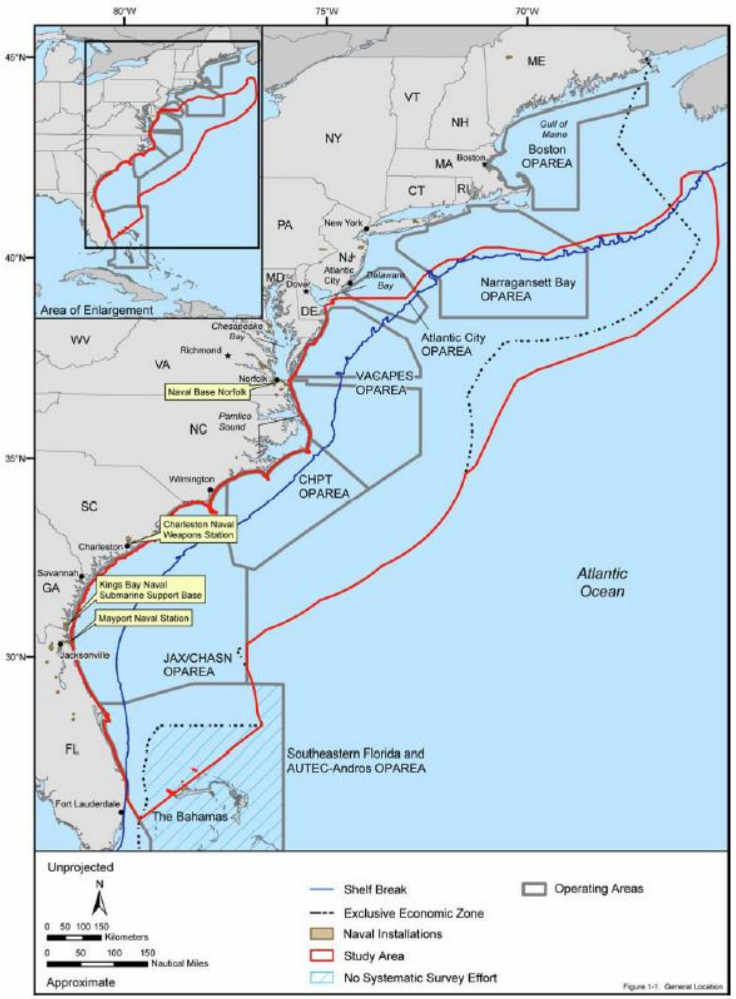


Figure 1-1. The Southeast study area located off the United States Atlantic Coast.

Northeast NODE study area

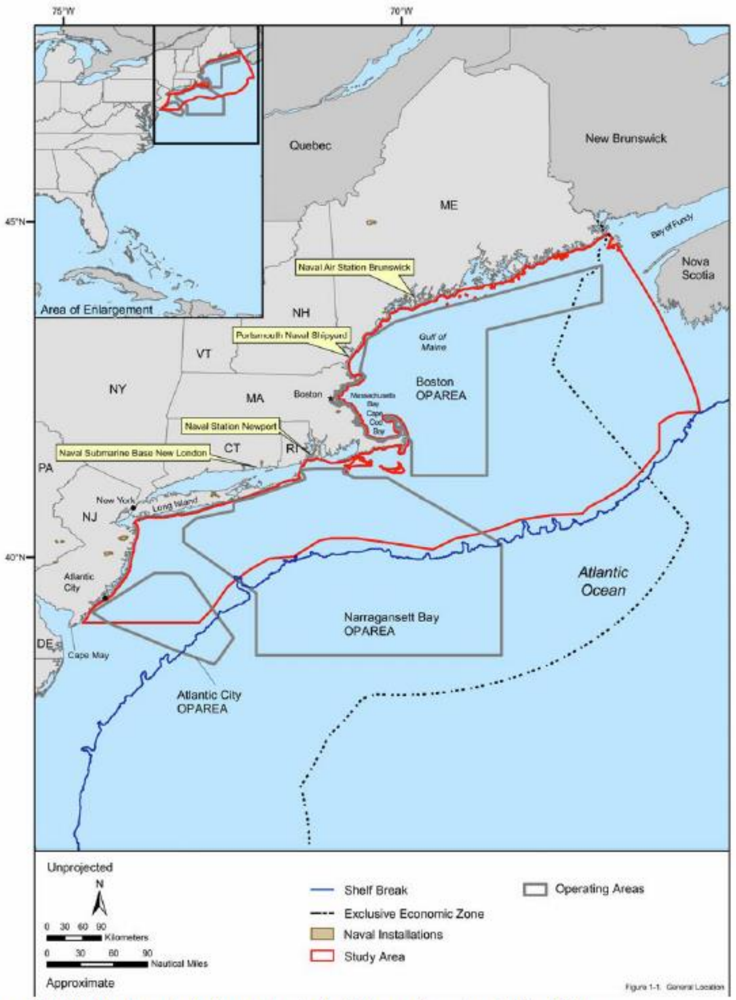
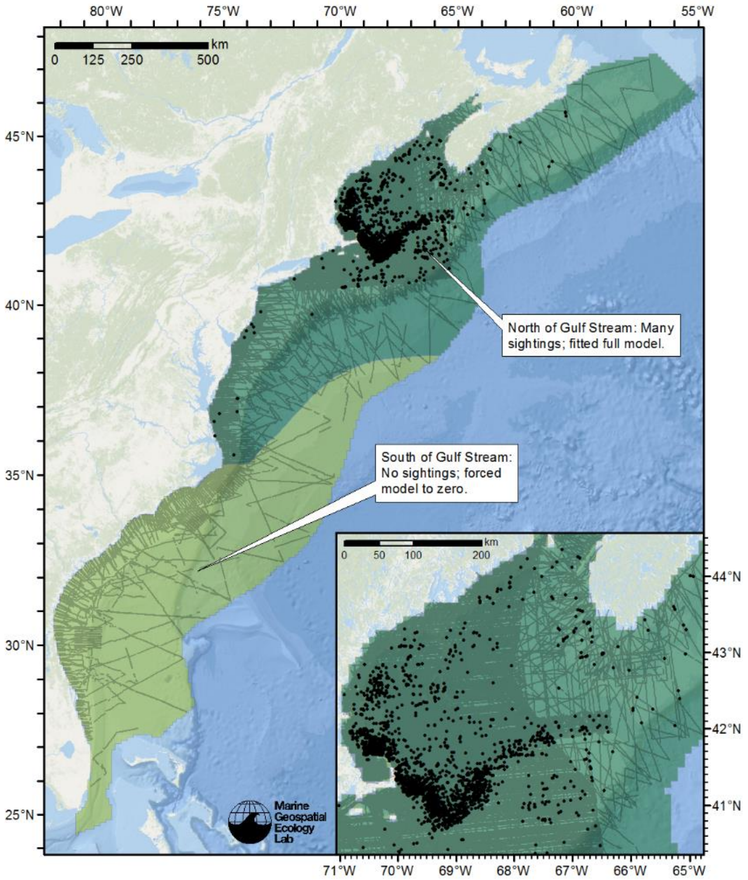


Figure 1-1. The Northeast study area located off the northeastern United States.

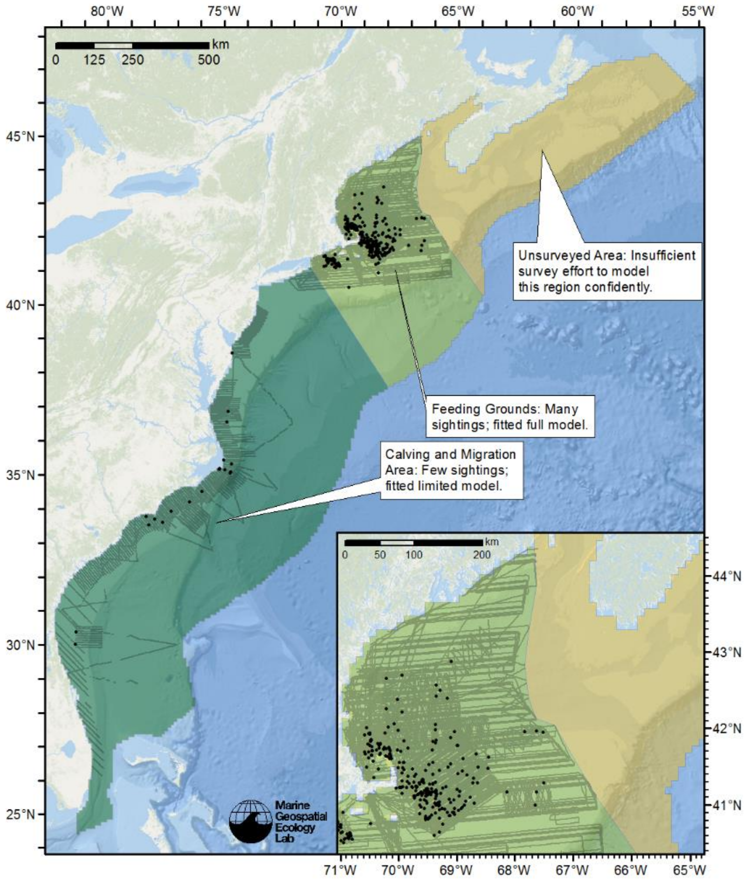
- NODEs effectively assumed that species are distributed mainly in one area or the other
- Species do not conform to these patterns
  - For example, humpbacks and harbor porpoises occur south of Cape May in winter
- For many species, Cape Hatteras is a more appropriate ecoregional boundary than Cape May

Duke study area

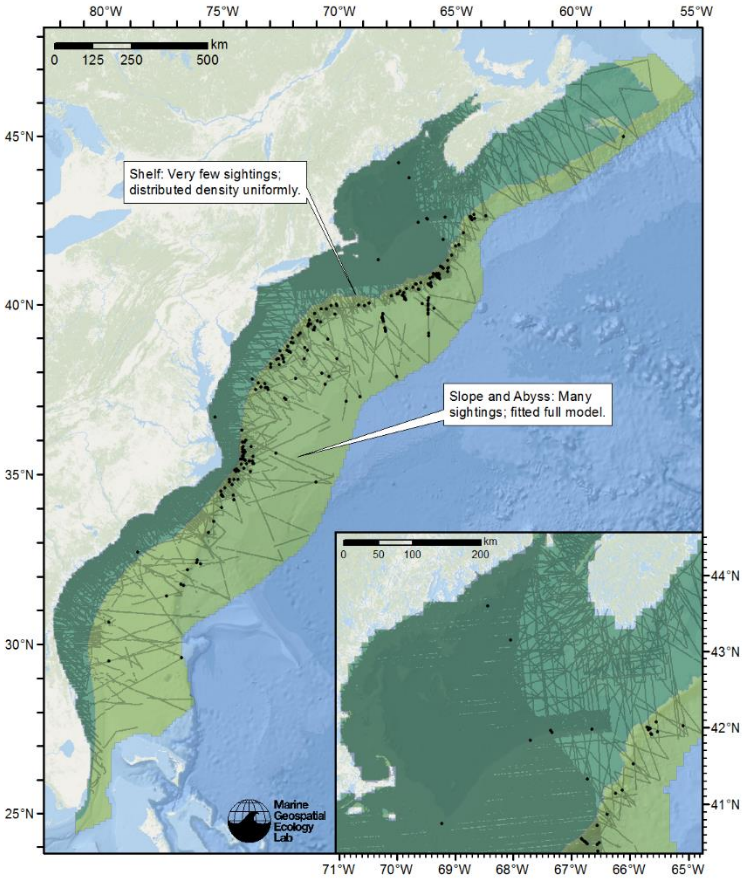
Humpback whale – summer



Right whale – spring



Beaked whales – year round



- We split the study area into taxon-specific seasonal model sub-regions according to the known ecology of each taxon
- We combined sub-region predictions into a full-region raster, for convenience

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Table 2. Comparison of the results of this analysis to the U.S. Navy NODE studies

Study	Study area	Survey effort (h)		Taxa with predictions that were:			
		Aerial	Shipboard	Seasonal or monthly	Year-round (DSMs)	Year-round (stratified)	Unmodeled taxa
This analysis	East coast	4622	3710	11	4	13	0
DoN 2007b	East coast north	177	0	1	5	10	5
DoN 2007c	East coast south	159	2352	5	6	7	11
This analysis	Gulf of Mexico	628	4965	0	16	3	0
DoN 2007	Gulf of Mexico	532	3096	4	6	8	0

Duke

NODEs

- We incorporated surveys spanning 1992-2014; NODEs spanned 1992-2005
- As a result, in the Atlantic we utilized 1276% more aerial and 58% more shipboard survey hours than NODEs

Region	Platform	Surveyor	Survey program	Years	Length (1000 km)	Hours
EC	Aerial	NEFSC	Marine mammal abundance surveys [15]	1995-2008	70	412
			Right Whale Sighting Survey (NARWSS) [51]	1999-2013	432	2330
			NARWSS harbor porpoise survey [51]	1999	6	36
		NJDEP	New Jersey Ecological Baseline Study [52,53]	2008-2009	11	60
		SEFSC	Mid-Atlantic Tursiops Surveys (MATS)	1995, 2004-5	35	196
			Southeast Cetacean Aerial Surveys (SECAS) [54]	1992, 1995	8	42
		UNCW	Cape Hatteras Navy surveys [55]	2011-2013	19	125
			Jacksonville Navy surveys [55]	2009-2013	66	402
			Marine mammal surveys, 2002 [26]	2002	18	98
			Onslow Bay Navy surveys [55]	2007-2011	49	282
			Right whale surveys, 2005-2008 [55]	2005-2008	114	586
		VAMSC	Virginia Wind Energy Area surveys [56]	2012-2014	9	53
			Total:	1992-2014	837	4622
	Shipboard	NEFSC	Marine mammal abundance surveys [15]	1995-2004	16	1143
		NJDEP	New Jersey Ecological Baseline Study [52,53]	2008-2009	14	836
		SEFSC	Marine mammal abundance surveys [57]	1992-2005	28	1731
			Total:	1992-2009	58	3710
GOM	Aerial	SEFSC	GOMEX92-96 [54]	1992-1996	27	152
			GulfCet I [58]	1992-1994	50	257
			GulfCet II [59]	1996-1998	22	124
			GulfSCAT 2007	2007	18	95
			Total:	1992-2007	117	628
	Shipboard	SEFSC	Oceanic CetShip [14]	1992-2001	49	3102
			Shelf CetShip [13]	1994-2001	10	707
			Marine mammal abundance surveys [60]	2003-2009	19	1156
			Total:	1992-2009	78	4965

Surveys used in Duke models

NODEs used a subset of the surveys boxed in red

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Table 2. Comparison of the results of this analysis to the U.S. Navy NODE studies

Study	Study area	Survey effort (h)		Taxa with predictions that were:			
		Aerial	Shipboard	Seasonal or monthly	Year-round (DSMs)	Year-round (stratified)	Unmodeled taxa
This analysis	East coast	4622	3710	11	4	13	0
DoN 2007b	East coast north	177	0	1	5	10	5
DoN 2007c	East coast south	159	2352	5	6	7	11
This analysis	Gulf of Mexico	628	4965	0	16	3	0
DoN 2007	Gulf of Mexico	532	3096	4	6	8	0

Northest NODE

Species for Which Abundance Estimates Do Not Exist
Blue whale (*Balaenoptera musculus*)
Spinner dolphin (*Stenella longirostris*)
White-beaked dolphin (*Lagenorhynchus albirostris*)
Pygmy killer whale (*Feresa attenuata*)
Killer whale (*Orcinus orca*)

Southeast NODE

Species for Which Abundance Estimates Are Not Available
Blue whale (*Balaenoptera musculus*)
Sei whale (*Balaenoptera borealis*)
Bryde's whale (*Balaenoptera brydei/edeni*)
Killer whale (*Orcinus orca*)
Pygmy killer whale (*Feresa attenuata*)
False killer whale (*Pseudorca crassidens*)
Melon-headed Whale (*Peponocephala electra*)
Spinner dolphin (*Stenella longirostris*)
Fraser's dolphin (*Lagenodelphis hosei*)
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)
Harbor porpoise (*Phocoena phocoena*)

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Table 2. Comparison of the results of this analysis to the U.S. Navy NODE studies

Study	Study area	Survey effort (h)			Taxa with predictions that were:				
		Aerial	Shipboard		Seasonal or monthly	Year-round (DSMs)		Year-round (stratified)	Unmodeled taxa
This analysis	East coast	4622	3710	Duke	11	4	15 total	13	0
DoN 2007b	East coast north	177	0		1	5	6 total	10	5
DoN 2007c	East coast south	159	2352	NODEs	5	6	11 total	7	11
This analysis	Gulf of Mexico	628	4965		0	16		3	0
DoN 2007	Gulf of Mexico	532	3096		4	6		8	0

- We modeled 15 cetacean taxa with density surface models
  - These are models in which density was modeled according to environmental covariates such as depth, sea surface temperature, and so on
- The northeast NODE modeled 6 taxa
- The southeast NODE modeled 11 taxa

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Seasonality in the NODEs models

NODEs used the same seasonal definitions for all species:

2.3.1.1 Seasonal Definitions

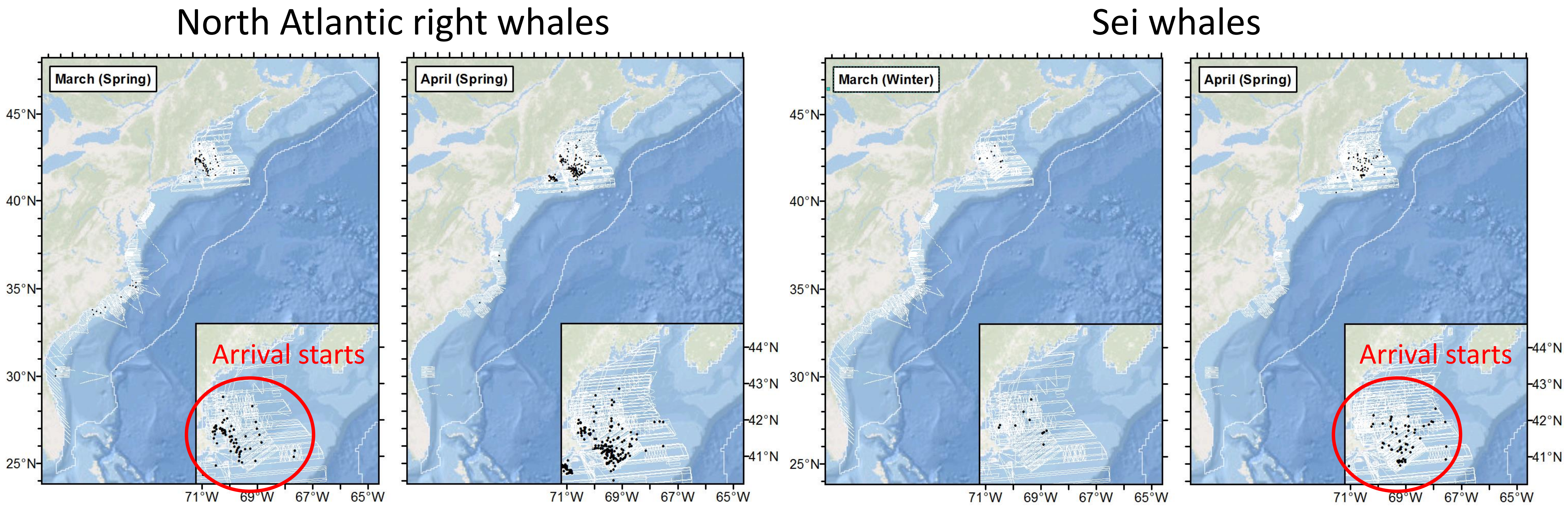
Since derived seasonal definitions based on sea surface temperature (SST) can be so disparate between the northern and southern portions of the U.S. Atlantic coastline, the seasons were instead based on three-month periods of time as follows:

- Winter—December, January, and February
- Spring—March, April, and May
- Summer—June, July, and August
- Fall—September, October, and November

(This is from the Northeast NODE report)

Evidence suggests different species migrate at different times

Right and sei whale arrival in the Great South Channel



- Right whales begin arriving in the Great South Channel in March
- Sei whales do not arrive in large numbers until April

Seasonality in the Duke density models

- Philosophy: define seasons on per-species basis, based on ecology
- We split data into separate seasonal models, on month boundaries, when:
  - Literature suggested species exhibits seasonality in which its relationship to the environment is expected to be different during different seasons (e.g. baleen whales feeding vs. breeding/calving), and:
  - We had sufficient sightings to model at least one of the seasons effectively, and:
  - The spatial pattern in the sightings resembled the expectation
- When any condition was false, we fit a "year-round" model

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Table 2. Comparison of the results of this analysis to the U.S. Navy NODE studies

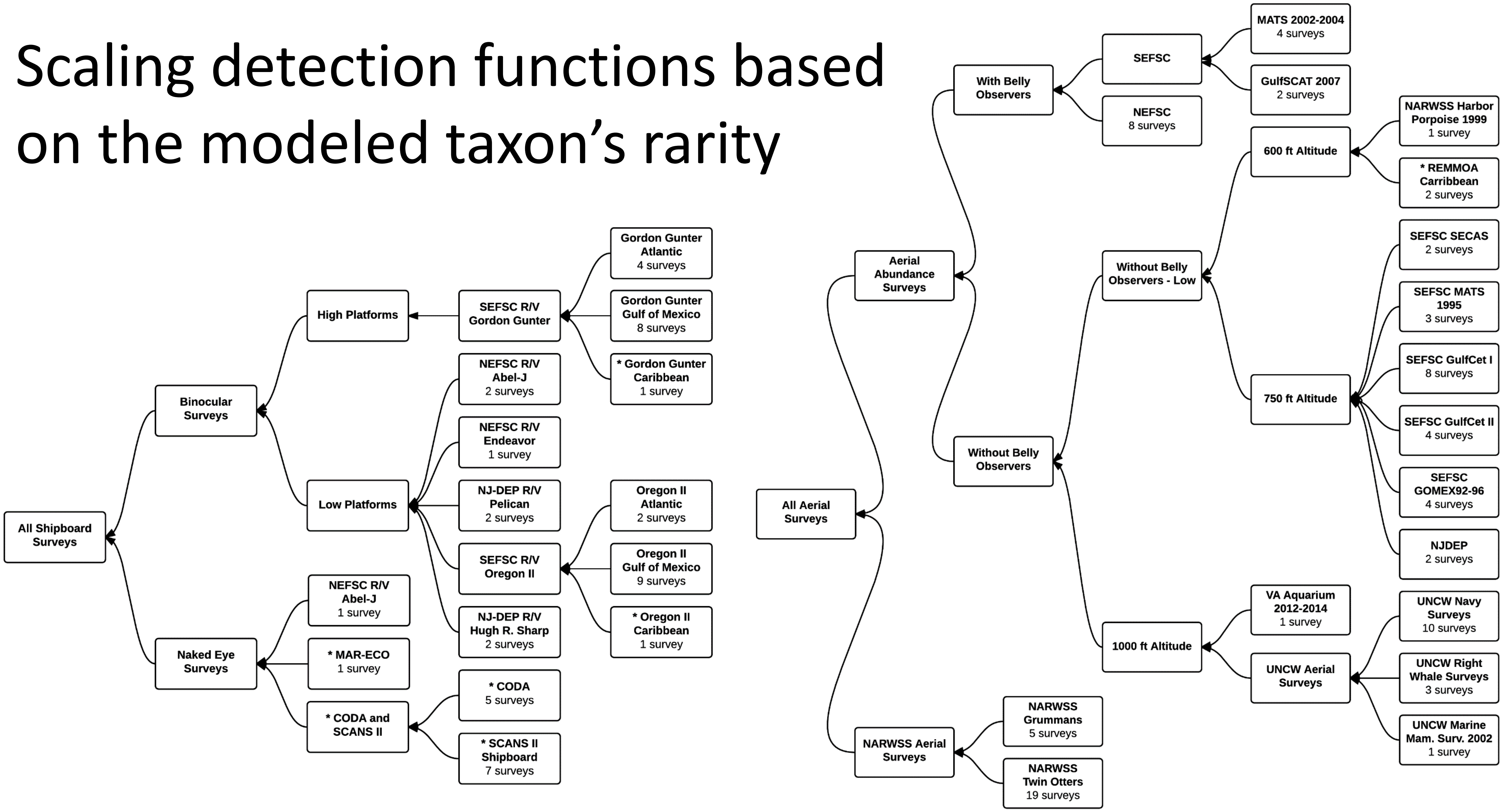
Study	Study area	Survey effort (h)			Taxa with predictions that were:			
		Aerial	Shipboard		Seasonal or monthly	Year-round (DSMs)	Year-round (stratified)	Unmodeled taxa
This analysis	East coast	4622	3710	Duke	11	4	13	0
DoN 2007b	East coast north	177	0	NODEs	7	5	10	5
DoN 2007c	East coast south	159	2352		5	6	7	11
This analysis	Gulf of Mexico	628	4965		0	16	3	0
DoN 2007	Gulf of Mexico	532	3096		4	6	8	0

- We predicted monthly maps for 11 taxa
- The northeast NODE predicted seasonal maps for 6 taxa and monthly maps for 1 taxon (right whales)
- The southeast NODE predicted seasonal maps for 4 taxa and monthly maps for 1 taxon (right whales)

Important improvements of Duke models over NODEs

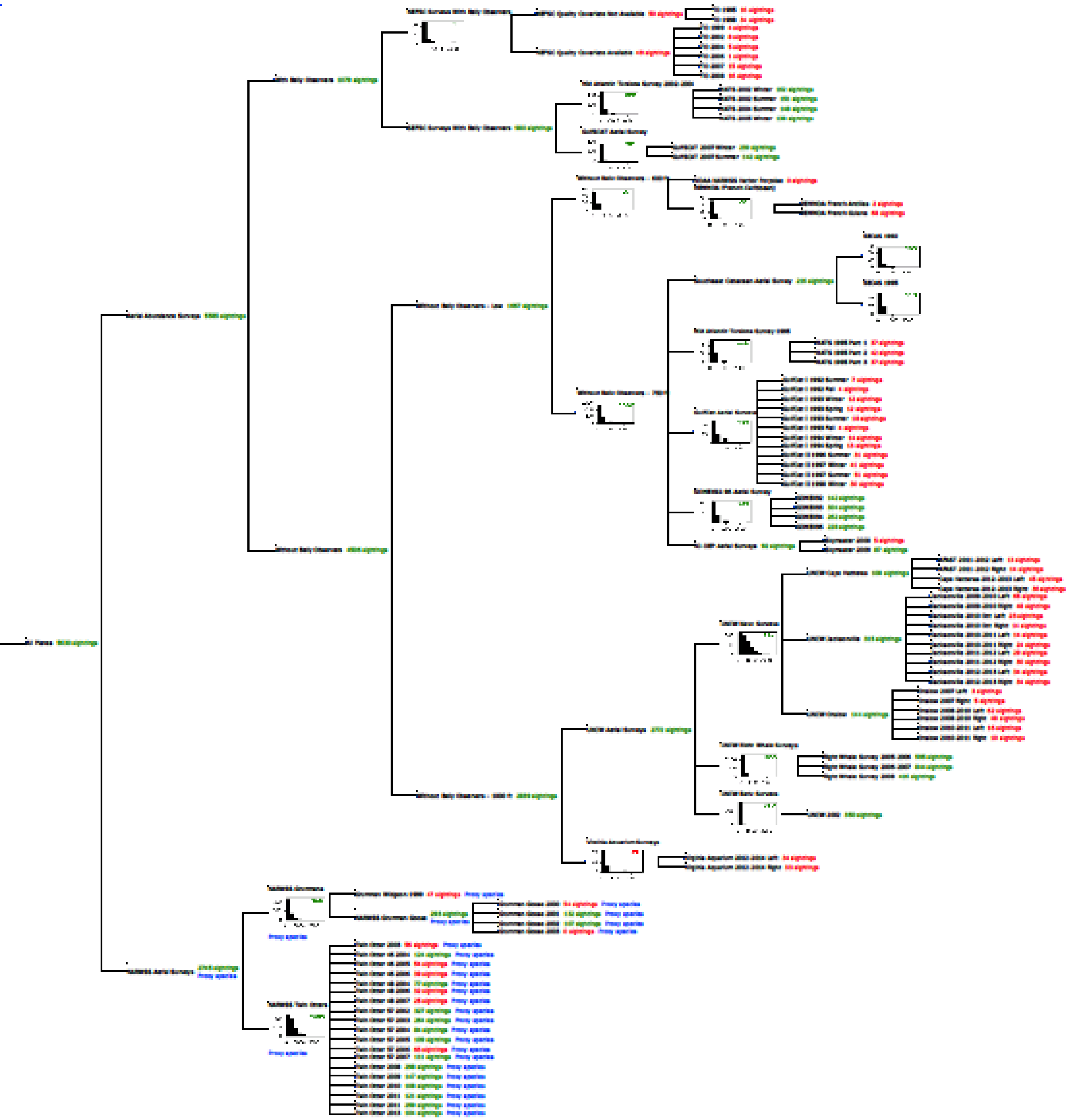
1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Scaling detection functions based on the modeled taxon's rarity

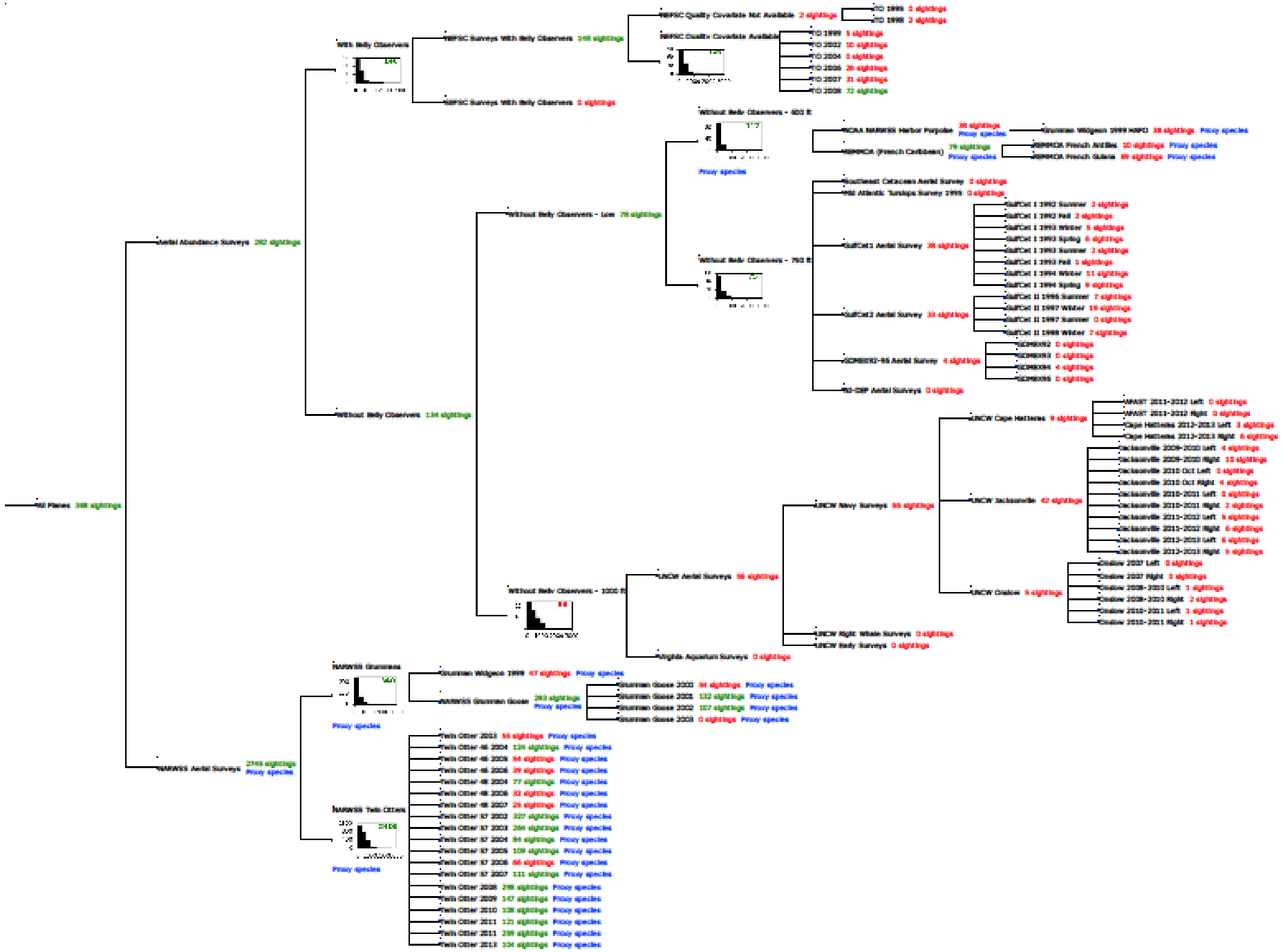


* Additional surveys from other regions used in detection functions only (not in the EC or GOM spatial models)

Bottlenose dolphin aerial detection hierarchy
5630 sightings, 17 detection functions



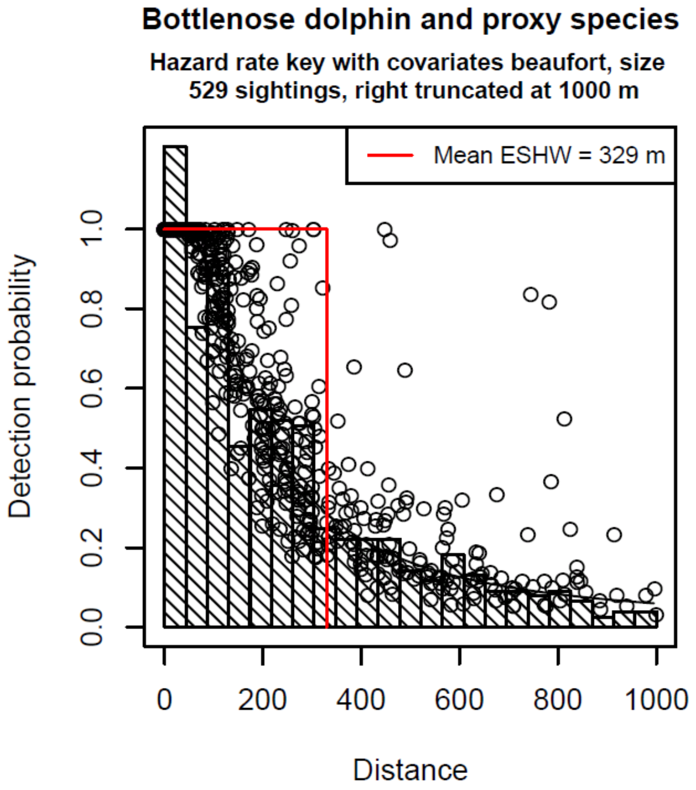
Risso's dolphin aerial detection hierarchy
368 sightings, 7 detection functions

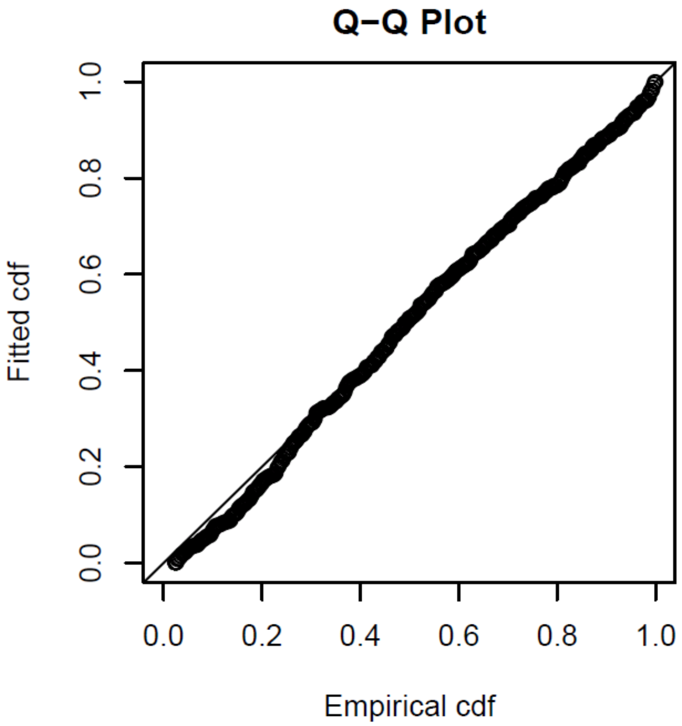


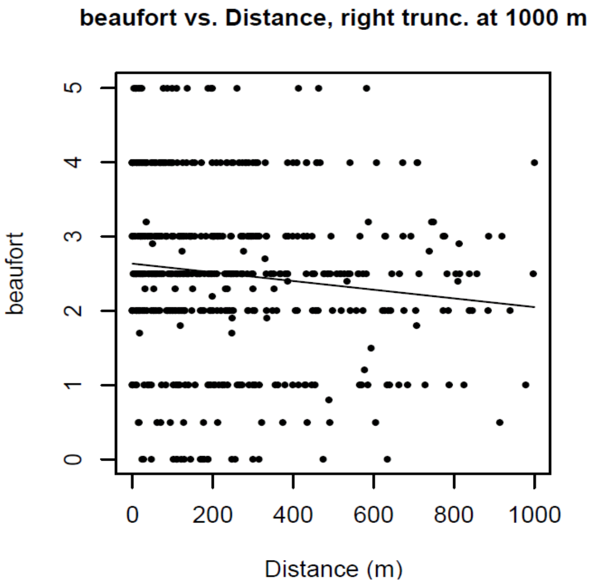
Important improvements of Duke models over NODEs

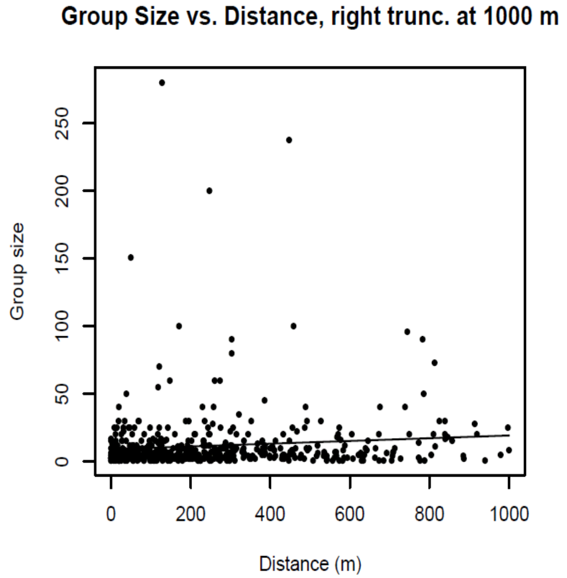
1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Example: dolphins on shipboard cruises that used naked eyes









Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Availability bias: not available to be seen (diving)

Perception bias: hard to see (e.g. the seal below)

Credit MAKY_OREL

Credit Minette Layne

NODEs did not address these biases for many species

For the purpose of this report, we assumed *g(0)* = 1. This is an unrealistic assumption for many of the species addressed in this report, particularly those with long dive times (i.e., beaked whales and the sperm whale) or that are difficult to detect as a result of their size or behavior (i.e., minke whale and harbor porpoise). However, estimates of *g(0)* were not calculated during the surveys which our analyses were based. As stated above, by assuming *g(0)* = 1 for these analyses, the abundance and density estimates for most of the species are underestimated. The magnitude of the bias is species-, area-, and platform-specific. The magnitude of *g(0)* variation is provided in a table of *g(0)* values from various areas, methods of calculations, and platforms for each of the species addressed in this report (**Table 2-2**).

(This is from the Northeast NODE report)

- By not addressing these biases, NODEs underestimated abundance, especially for long-diving animals such as beaked whales
  - They noted this in their report, as you can see above
- Both the NOAA SARs for the Atlantic and the Duke models *do* address these biases

Important improvements of Duke models over NODEs

1. Utilized a more flexible study area design
2. Incorporated much more survey data
3. Modeled more cetacean species
4. Modeled more species with density surface models (DSMs)
5. Used species-specific seasons
6. Predicted more species at high temporal resolution
7. Utilized more detection functions, when data allowed
8. Controlled for the influence of sea state, glare, group size and other factors on detection probability
9. Controlled for availability and perception bias
10. Considered many more environmental covariates in DSMs

Covariates used in Duke models

Type	Covariates	Resolution	Time range	Description
Physiographic	Depth, * Slope *	30 arc sec		Seafloor depth and slope, derived from SRTM30-PLUS global bathymetry[20]
	DistToShore, * DistTo125m, DistTo300m, * DistTo1500m	30 arc sec		Distance to the closest shoreline, excluding Bermuda and Sable Island, and various ecologically-relevant isobaths[20]
	DistToCanyon, DistToCanyon OrSeamount	30 arc sec		Distance to the closest submarine canyon, and to the closest canyon or seamount[21]
SST & Winds	SST, * DistToFront	0.2°, daily	1991-2014	Foundation sea surface temperature (SST), from GHRSST Level 4 CMC SST[22], and distance to the closest SST front identified with the Canny edge detection algorithm[23]
	WindSpeed	0.25°, daily	1991-2014	30-day running mean of NOAA NCDC 1/4° Blended Sea Winds[24]
Currents	TKE, EKE	0.25°, daily	1993-2013	Total kinetic energy (TKE) and eddy kinetic energy (EKE), from Aviso 1/4° DT-MADT geostrophic currents
	DistToEddy, DistToAEddy, DistToCEddy	0.25°, weekly	1993-2013	Distance to the ring of the closest geostrophic eddy having any (DistToEddy), anticyclonic (DistToAEddy), or cyclonic (DistToCEddy) polarity, from Aviso 1/4° DT-MADT using a revision of the Chelton et al. algorithm[25]; we tested eddies at least 9, 4, and 0 weeks old
Biological	Chl *	9 km, daily	1997-2014	GSM merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll (Chl) *a* concentration[26], 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)[27]; 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[28]
	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[28]

- Each model only considered the covariates that were appropriate for the modeled region and known ecology of the taxon
  - For example, we did not use distance to eddy covariates for on-shelf sub-regional models, because geostrophic eddies rapidly decohere when they reach the shelf break
  - We tried WindSpeed in the right whale calving area model, based on a suggestion from the literature (Good 2008) (it was not selected). We did not use it in any other models.
- NODEs used covariates marked with *

In conclusion

- The NODEs models utilize 10 year old data and methodology
- The Duke 2015 models incorporated many additional datasets and methodological improvements
- The Navy, NOAA OPR, NROC, and MARCO have adopted the Duke models as their baseline cetacean density maps
- The NODEs models should be considered obsolete and no longer be used