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Abundance of short-finned pilot whales along the U.S. east coast from summer 2016 vessel surveys.

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1 Introduction

In this report, we describe the data and analytical tools used to develop an abundance estimate for the Western North Atlantic Short-finned Pilot Whale (*Globicephala macrorhyncus*) stock based upon large vessel line-transect surveys conducted by the Northeast and Southeast Fisheries Science Centers during the summer of 2016. The primary objective of these surveys was to collect data and samples to support assessment of the abundance, habitats, and spatial distribution of cetaceans within U.S. waters. The survey was conducted as part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS), a comprehensive effort conducted jointly by the Bureau of Ocean Energy Management (BOEM), the U.S. Fish and Wildlife Service, and NOAA Fisheries' Northeast and Southeast Fisheries Science Centers. Its primary objective is to produce spatially explicit maps of marine mammal, sea turtle and sea bird density to support environmental impact assessments and planning. This document updates the abundance estimates for short-finned pilot whales. The most recent prior estimate was based upon vessel surveys conducted during the summer of 2011 (Garrison 2016; Garrison and Rosel 2017).

The Western North Atlantic Short-finned Pilot Whale stock has been a focus of assessment efforts during the last two decades due to the relatively high rate of observed interactions with the U.S. Atlantic and Gulf of Mexico Pelagic Longline Fishery. This species is frequently observed interacting with pelagic longline gear, and mortalities and serious injuries are documented by fisheries observers primarily due to the animals becoming hooked in the mouth (Garrison and Stokes 2017; Garrison 2007). The stock has been the focus of efforts to reduce mortality and serious injury by the Pelagic Longline Take Reduction Team since 2004.

Assessment of this stock is complicated by the fact that the short-finned and long-finned (*G. melas*) pilot whale species overlap spatially off the U.S. east coast between Virginia and New York during portions of the year. Detailed photographic data collection can be used to characterize distinctive coloration patterns between the two species; however, this requires both close approaches and light conditions that allow collection of high quality photographs (Rone and Pace 2012). This detailed data collection is not routinely possible during visual surveys for abundance estimation or during at-sea observations of pilot whales incidentally taken in commercial fisheries. Therefore, a habitat based model is used to predict the probability that any given vessel sighting is a short-finned pilot whale as a function of latitude, month of the year, and sea surface temperature (Garrison and Rosel 2017). This model was developed using tissue biopsy samples collected from pilot whales at sea and genetic analyses that identified sampled animals to species.

2 Methods

2.1 Survey Methods

The SEFSC survey was conducted aboard the NOAA Ship Gordon Gunter during 30 June – 19 August 2016 in waters off the southeast Atlantic coast of the U.S. The survey was conducted along "zig-zag" tracklines between central Florida and the Maryland/Delaware border and included shelf-break and inner continental slope waters within the U.S. EEZ (Figure 1). Survey effort was stratified into four geographic strata reflecting regional differences in hydrographic and bathymetric structure and spatial variation in the density and occurrence of different cetacean species.

The NEFSC survey was conducted aboard the NOAA Ship Henry Bigelow during 27 June – 25 August. The survey covered waters off of Southern New England deeper than the 100m isobath. Survey effort was stratified into a "shelf" stratum along the shelf break off of the southern Flank of Georges Bank and an "offshore" stratum covering waters deeper than the 2000m isobath to beyond the U.S. EEZ (Figure 2). The shelf stratum was divided into two substrata with higher ("shelf-hi") and lower ("shelf-lo") trackline density.

Standard ship-based, line-transect survey methods for cetaceans were used during both surveys. The surveys employed the "independent observer" methodology to improve estimates of sighting probability. This approach was similar to that used during the summers of 2004 (SEFSC, unpublished) and 2011 (Garrison 2016). The two observer teams were stationed at different positions on each vessel. The two teams were isolated from one another to avoid "cueing" each other to the presence of marine mammals. On the SEFSC survey, the upper team was stationed on the vessel's flying bridge (height above water = 13.7 m) and the lower team was on the bridge wings (height above water = 11.0 m). On the NEFSC survey, the upper team was on the flying bridge (height above water = 15.1 m) and the lower team was on the roll tank (height above water = 11.1 m). Observer teams consisted of four observers rotating through two positions at 30 min. intervals. Data on sightings by each team were recorded using a computerized data entry program interfaced with a global positioning system (GPS) receiver. For each team, the left and right side observers searched to the horizon in the arc from 10° right and left of the ship's bow to the left and right beams (90°), respectively, using 25x "bigeye" binoculars. Survey speed was usually 18 km hr-1 (~10 kt) but varied with sea conditions. The effectiveness of visual line transect survey effort is severely limited during high sea state and poor visibility conditions (e.g., fog, haze, rain). Survey effort was therefore suspended during heavy seas (Beaufort sea state > 5), fog, and rain.

For each cetacean sighting, time, position, bearing and reticle (a measure of radial distance) of the sighting, species, group size, behavior, bottom depth, sea surface temperature, and associated animals (e.g., seabirds, fish) were recorded. The bearing and radial distance for groups sighted without 25x binoculars and close to the ship were estimated. Survey effort data were automatically recorded every minute and included the ship's position and heading, effort status, observer positions, and environmental conditions which could affect the observers' ability to sight animals (e.g., Beaufort sea state, trackline glare, etc.).

2.2 Analytical Methods

Abundance estimates were derived using the independent observer approach assuming point independence (Laake and Borchers 2004) as implemented in the mrds package of the R statistical package (version 2.1.18, Laake et al 2017). Briefly, this approach is an extension of standard line-transect distance analysis that includes direct estimation of sighting probability on the trackline. The probability of sighting a particular cluster of animals is the product of two probability components. The first probability corresponds to the distance sampling sighting function such that the probability of detection declines with increasing distance from the trackline following a known functional form (typically the half-normal or hazard function). The second component is the likelihood of detection on the trackline which is modeled using a logistic regression approach and the "capture histories" of each sighting (i.e. seen by one or both teams). The logistic model can include factors that may affect the probability of detection such as viewing or weather conditions. Details on the derivation, assumptions, and implementation of the estimation approach are provided in Laake and Borchers (2004).

Detection probability was estimated separately for the SEFSC and NEFSC survey data. The perpendicular sighting distances were right-truncated to remove roughly 10% of the sightings with the farthest distances (Buckland et al. 2001) with the truncation distance equal to 6000m for both surveys. The form of the sighting function (hazard vs. half-normal) and the inclusion of covariates (including observer platform, group size, sea state, glare, swell height, wind speed, etc.) in the distance sampling and mark-recapture components of the models were evaluated using model selection from all possible model combinations based upon the minimum Akaike Information Criterion (AIC, Laake and Borchers 2004). For the SEFSC survey, sea state, glare, survey conditions (poor to excellent), visibility, wind speed, and percentage cloud cover were considered variables affecting both the distance and mark-recapture components of the detection probability model. For the NEFSC survey, variables included sea state, glare, survey conditions, and cloud cover. For both surveys, data were examined to determine if there was a significant correlation between group size and detection distance. There was no significant correlation ($p > 0.1$) in either case, and group size was therefore not included in the detection probability models. For the mark-recapture portion of the model for both surveys, terms were included for the observer team and the observer x distance interaction term. This allowed the selection of models that better account for differences in detection probability functions between the upper and lower survey teams. Density estimates were calculated for each stratum and combined to estimate total pilot whale abundance for each survey. Refer to appendix A for the summary output from MRDS analysis for SE and NE survey data.

2.3 Partitioning Estimates to Species

A habitat model based upon tissue biopsy samples collected from pilot whales along the U.S. east coast was applied to partition abundance estimates between short-finned and long-finned pilot whales (Garrison and Rosel 2017). For each pilot whale group observed, contemporaneous remotely-sensed SST data were obtained from the NASA MODIS-AQUA platform (https://oceancolor.gsfc.nasa.gov/data/aqua/). The spatial resolution was 4x4km. Products were downloaded in either 8-day or 30-day composites. For a given sighting location and date, the 8-day composite was used unless the pixel of interest was obscured by clouds, in which case the 30-day composite was used. The SST value, latitude, and month of observation were used to predict the probability that a sighting was short-finned pilot whales from the logistic regression model. This probability was integrated into the equations for estimating abundance (see Garrison and Rosel 2017). Based upon SST and location, all of the sightings during the SEFSC survey had a greater than 95% probability of being from short-finned pilot whales. Therefore, the partitioning was only applied to data collected from the NEFSC survey.

Variance for the estimates from the NEFSC survey included uncertainty in both the detection probability and logistic regression models using a bootstrapping approach. For each bootstrap iteration, a random value for each parameter in the detection probability model was drawn accounting for the variance/covariance structure among the estimates. Second, a random sample of tracklines (and associated sightings) was drawn to account for sampling variation. The bootstrap sample was designed such that the same number of transects was drawn from each latitudinal stratum as was included in the original design. Finally, a random value for the parameters in the logistic regression model was drawn allowing for uncertainty in model parameter estimates. Based on these sampled values, abundance estimates were calculated and stored. The bootstrap sample was drawn 1000 times. This bootstrap approach does not account for model selection uncertainty in either the detection probability or logistic regression models.

3 Results and Discussion

3.1 Southeast Survey

The southeast vessel survey included 4,400 km of trackline on effort and observed 64 groups of pilot whales totaling 944 animals (Table 1). The highest density of pilot whale sightings occurred along the shelf break north of Cape Hatteras, NC, but pilot whales were also observed in deeper waters throughout the survey range (Figure 1). Twenty-two of the pilot whale groups were seen by the upper team only, 24 by the lower team only, and 18 were seen by both teams.

The preferred distance sampling component of the detection probability model used the half-normal key function and included sea state, survey conditions, and glare. The mark-recapture component of the model included observer, survey conditions, and the observer x distance interaction term. Model fit was good with a non-significant goodness of fit test ($\chi 2=$ 5.49, df = 5, p = 0.359), Kolmogrov-Smirnov (KS = 0.0981, p = 0.250), and Cramer-von Mises (CvM = 0.288, p = 0.146) tests. The combined detection probability on the trackline (p(0)) for the two survey teams was 0.72 (CV = 0.16), and the average detection probability within the survey strip was 0.262 (CV = 0.18). Sighting functions are shown in Figure 3 and indicate monotonically decreasing detection probability moving away from the trackline and good fit overall.

The habitat model for separating short-finned from long-finned pilot whales indicated that all sightings during the SEFSC survey had a very high probability (>0.95) of being from short-finned pilot whales. The minimum water temperature for sightings from the SEFSC survey was 21.5ºC, and the majority of sightings occurred in water temperatures of 23ºC or higher. The resulting abundance estimates for short-finned pilot whales from the SEFSC surveys are shown in Table 2. The highest density and number of animals occurred in the shelf-break stratum north of Cape Hatteras, NC. The total estimated abundance estimate is 25,114 individuals (95% CI: 14,750 – 42,759).

3.2 Northeast Survey

The northeast vessel survey included 3,738 km of trackline on effort and observed 117 groups of pilot whales totaling 904 animals (Table 3). The pilot whale sightings occurred along the southern flank of Georges Bank in two notable clusters, one off of New York and the other at the tip of Georges Bank in Canadian waters (Figure 2). Sightings also occurred in deeper waters over the continental slope. Thirty-seven of the pilot whale groups were seen by the upper team only, 35 by the lower team only, and 45 were seen by both teams.

The preferred distance sampling component of the detection probability model used the hazard-rate key function, and environmental covariates were not selected in either the distance sampling or mark-recapture components of the model. The MR model included observer and the observer x distance interaction term. Model fit was good with a non-significant goodness of fit test ($\chi 2=$ 8,63, df = 14, p = 0.854) , Kolmogrov-Smirnov (KS = 0.0584, p = 0.839), and Cramer-von Mises (CvM = 0.061, p = 0.805) tests. The combined detection probability on the trackline (p(0)) for the two survey teams was 0.95 (CV = 0.03), and the average detection probability within the survey strip was 0.323 (CV = 0.19). Sighting functions are shown in Figure 4 and indicate monotonically decreasing detection probability moving away from the trackline and good fit overall. The resulting abundance estimates for total pilot whales (undifferentiated by species) are shown in Table 4.

Pilot whale sightings during the northeast survey occurred across a range of water temperatures with distinct clusters at temperatures between 17.4 - 22ºC and 22 - 28ºC (Figure 5).

The habitat model therefore predicted the occurrence of both short-finned and long-finned pilot whales during this survey. The predicted probability of being a short-finned pilot whale was generally highest in the southern and offshore portions of the survey, and the lowest probability was in the northernmost area at the tip of Georges Bank. Interestingly, one large cluster of sightings at approximately 41ºN latitude was predicted to have a high probably of being short-finned pilot whales while another at approximately the same latitude had a very low probability of being short-finned (Figure 6). The former cluster was observed in mid- to late-August at water temperatures from 23-26ºC, while the latter was observed in late June at water temperatures from 17-19ºC.

The resulting abundance estimates for short-finned pilot whales from the NEFSC surveys are shown in Table 5. The total estimated abundance estimate for short-finned pilot whales is 3,810.8 individuals (95% CI: 1,351 – 7,561).

3.3 Total Abundance and Previous Estimates

The total abundance for short-finned plot whales along the U.S. Atlantic coast between central Florida and Georges Bank is the sum of the estimates from the northeast and southeast vessel surveys: 28,924 individuals (CV = 0.24). Previous estimates from similar surveys are available from 2004 (N = 24,674; CV = 0.45) and 2011 (N = 21,515; CV = 0.36; Garrison 2016). In both cases, survey methods were similar to those during the summer of 2016 and both employed a habitat model to partition pilot whale sightings between species during the northeast portion of the survey. A weighted (by standard error) generalized linear model indicated no significant trend in these estimates (slope = 0.018 [SE = 0.024]; p = 0.593). The most recent abundance estimate from 2016 should be considered the best abundance estimate for the Western North Atlantic Short-finned Pilot Whale stock for the purpose of MMPA stock assessment reports.

4 Tables

Table 1 Survey effort and pilot whale sightings during the SEFSC survey.

Stratum	Total Sightings	Upper Team Sightings	Lower Team Sightings	Both Teams Sightings	Avg. Group Size	Survey Effort (km)
SAB-Inshore	7	2	1	4	14	1,356
SAB-Offshore	4	1	2	1	9	1,244
MAB-Inshore	44	17	17	10	16	389
MAB-Offshore	9	2	4	3	10	1,431
Total	**64**	**22**	**24**	**18**	**15**	**4,400**

Table 2 Estimated abundance of short-finned pilot whales from SEFSC survey.

Stratum	N	SE	CV	95% Confidence Interval
SAB-Inshore	4,999.3	3,393.4	0.679	1,420.2 – 17,598.4
SAB-Offshore	804.5	795.6	0.989	145.8 – 4,439.3
MAB-Inshore	13,998.6	4,449.8	0.321	7,379.6 – 26,554.6
MAB-Offshore	5,311.6	2,415.5	0.455	2,197.4 – 12,839.6
Total	**25,114.5**	**6,863.1**	**0.273**	**14,750.2 – 42,759.7**

Table 3 Survey effort and pilot whale sightings during the NEFSC survey.

Stratum	Total Sightings	Upper Team Sightings	Lower Team Sightings	Both Teams Sightings	Avg. Group Size	Survey Effort (km)
Shelf-Hi	71	24	23	24	8	1,369
Shelf-Low	31	11	8	12	7	639.5
Offshore	15	2	4	9	6	1,730
Total	**117**	**37**	**35**	**45**	**8**	**3,738**

Table 4 Estimated abundance of pilot whales (both short-finned and long-finned) from NEFSC survey.

Stratum	N	SE	CV	95% Confidence Interval
Shelf-Hi	3,482.6	1,786.8	0.513	1,291.6 – 9,390.3
Shelf-Low	1,968.7	879.6	0.447	793.1 – 4,887.5
Offshore	2,495.6	1,103.5	0.442	994.9 – 6,260.0
Total	**7,947.0**	**2,588.8**	**0.326**	**4,222.0 – 14,958.4**

Table 5 Estimated abundance of short-finned pilot whales from NEFSC survey.

Stratum	N	SE	CV	95% Confidence Interval
Shelf-Hi	1,710.2	1,187.2	0.694	92.2 – 4,618
Shelf-Low	280.0	217.0	0.775	8.7 – 820.1
Offshore	1,820.7	846.0	0.465	491.8 – 3,721.3
Total	**3,810.8**	**1,588.7**	**0.417**	**1,351.8 – 7,560.9**

5 Figures

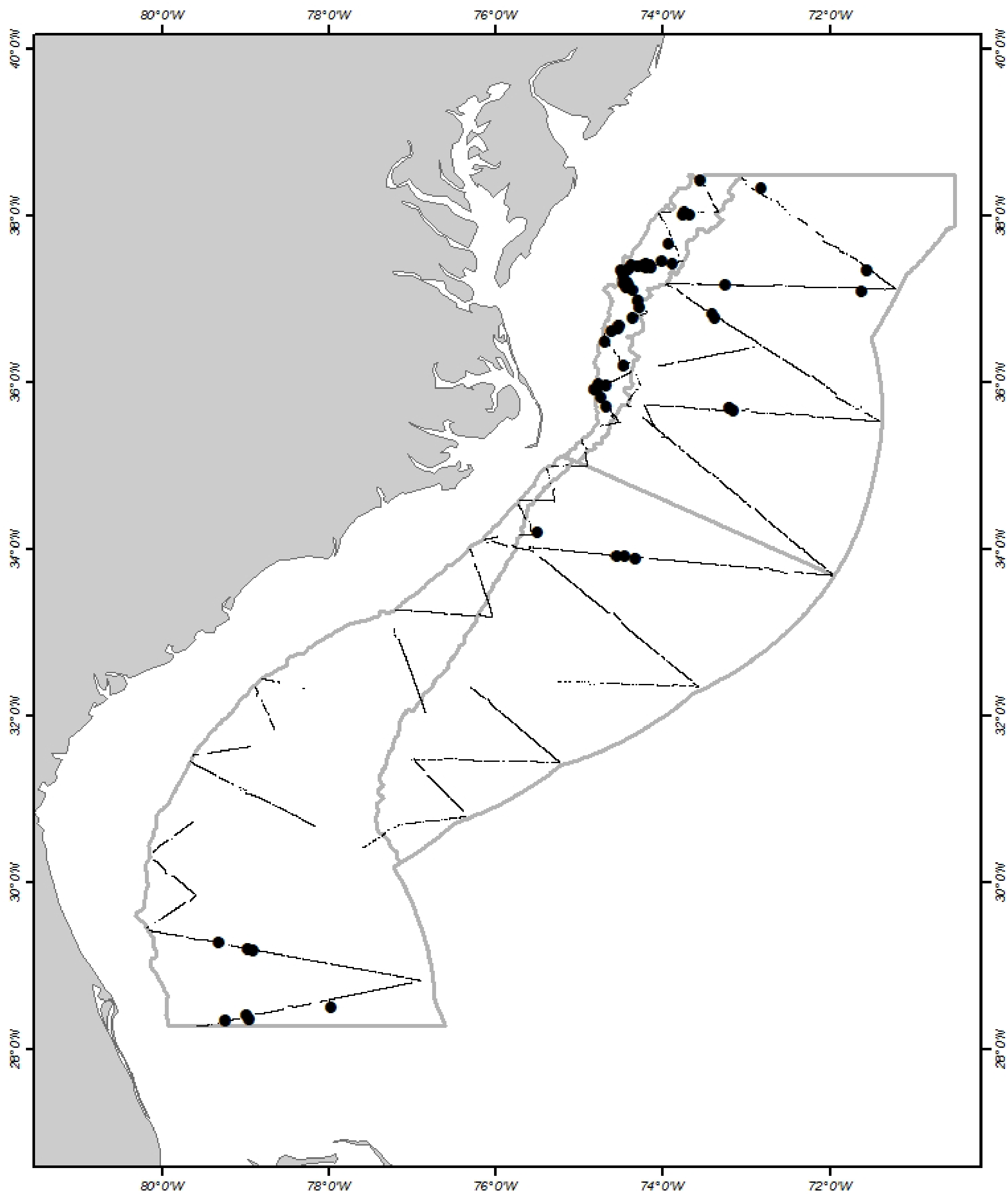

Figure 1 Summer 2016 SEFSC AMAPPS vessel survey effort, strata, and pilot whale sightings.

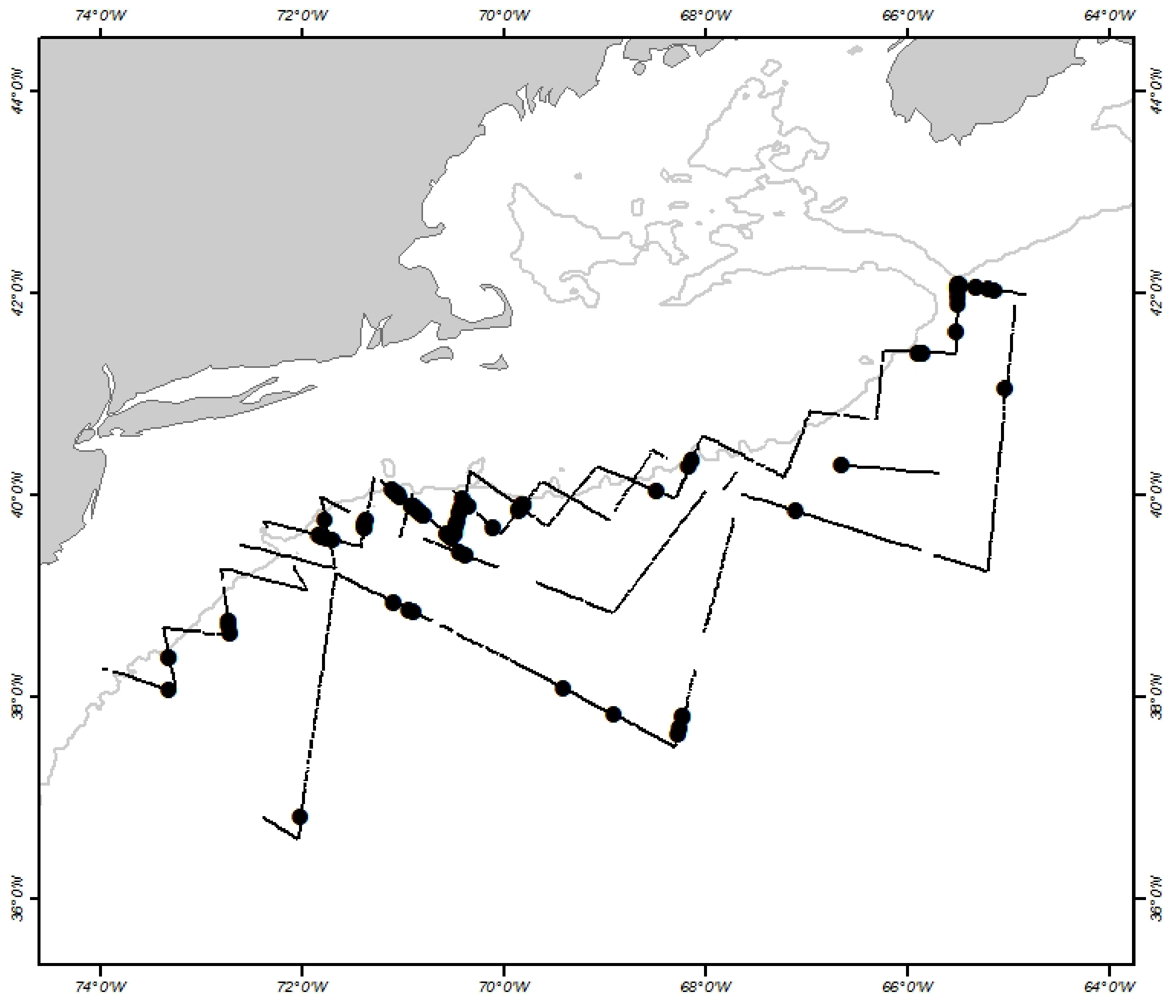

Figure 2 Summer 2016 NEFSC AMAPPS vessel survey effort and pilot whale sightings.

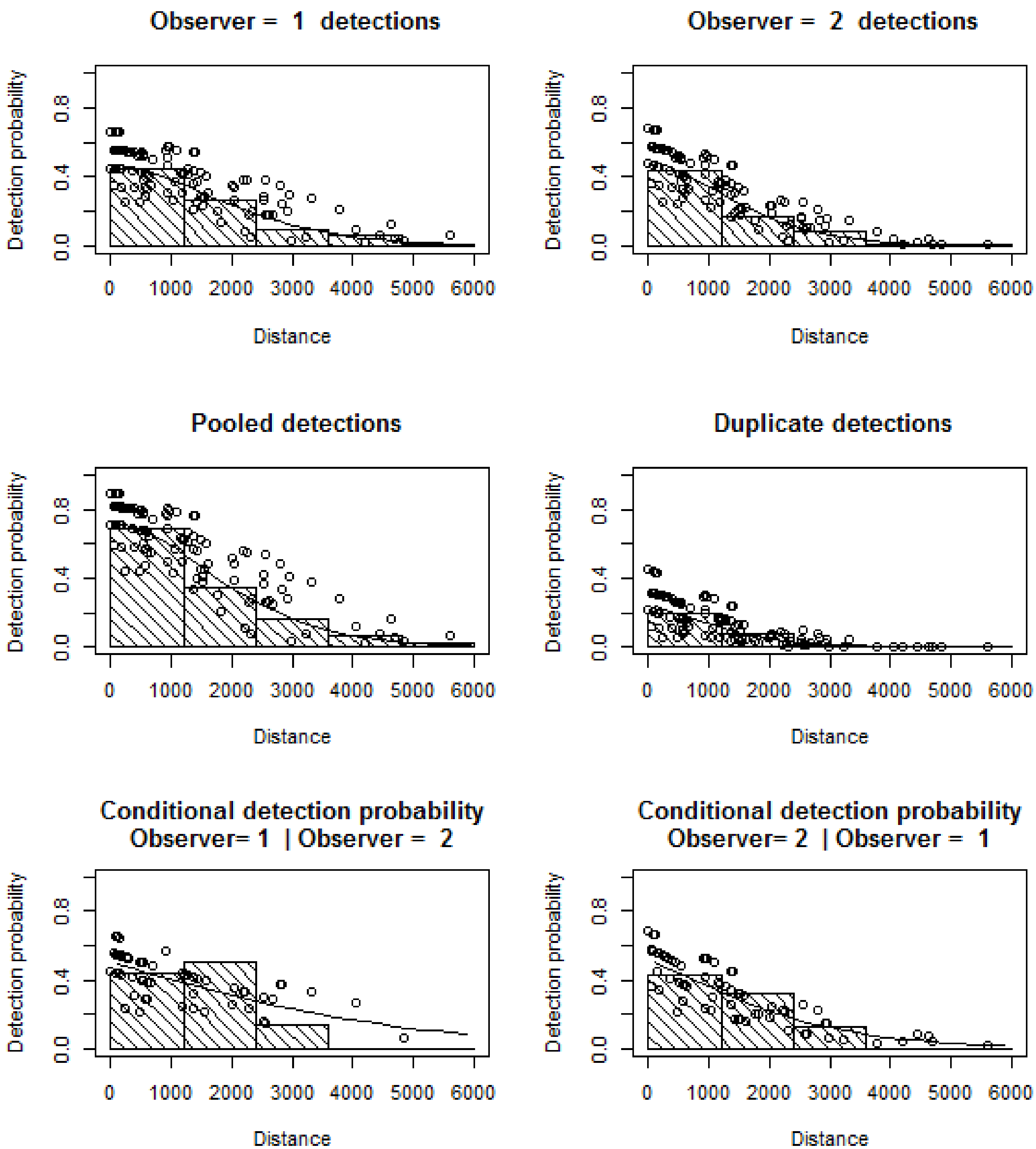

Figure 3 Detection probability functions for the SEFSC vessel survey.

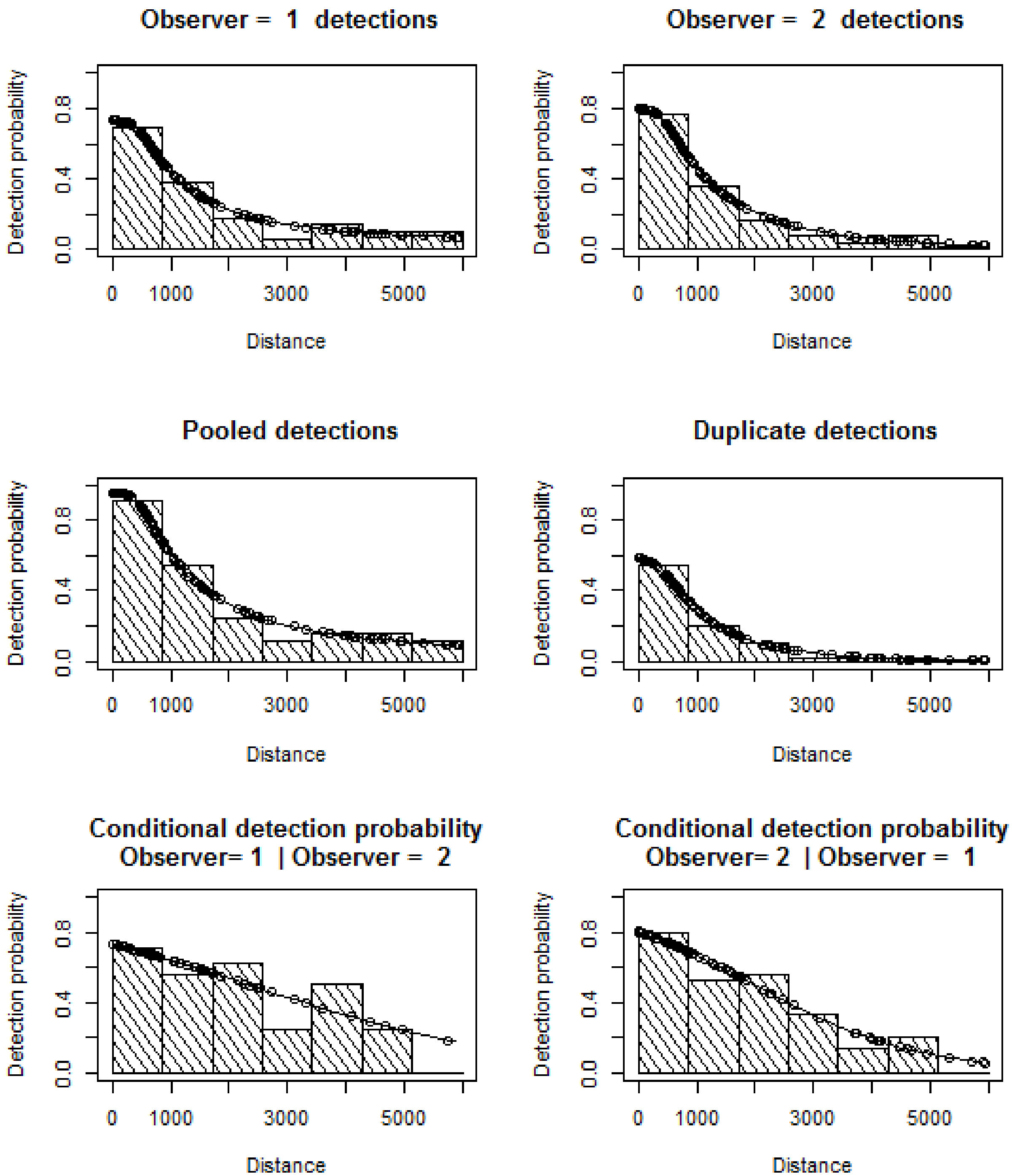

Figure 4 Detection probability functions for the NEFSC vessel survey.

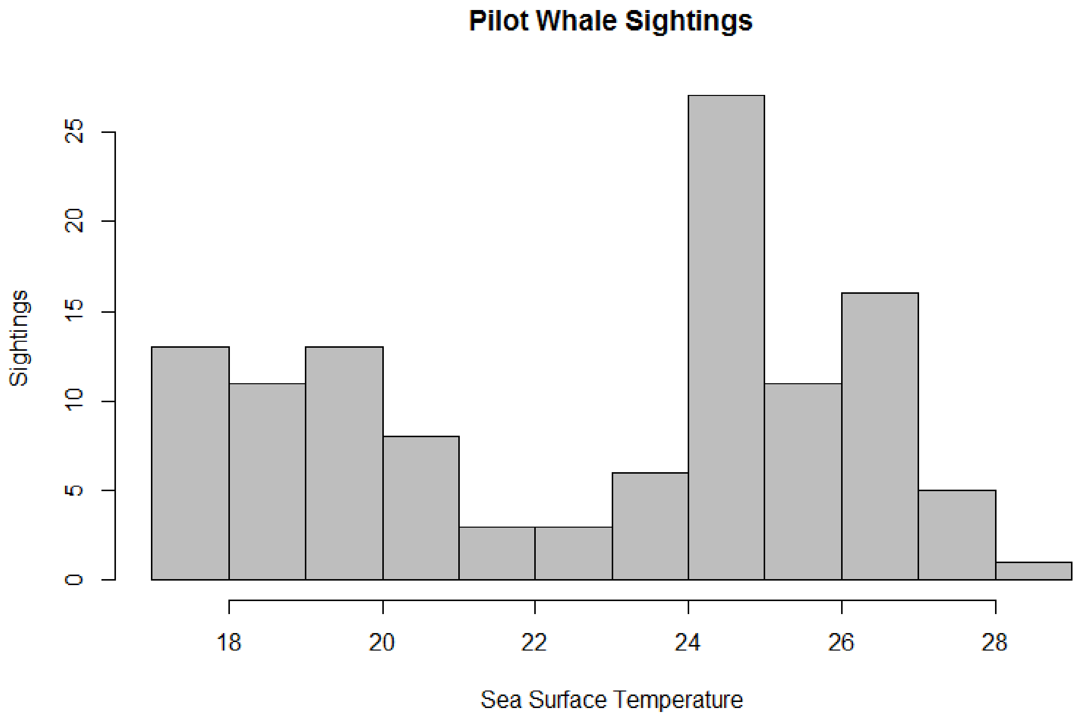

Figure 5 Sea surface temperature (based upon remote MODIS satellite data) at the locations of pilot whale sightings during the NEFSC survey.

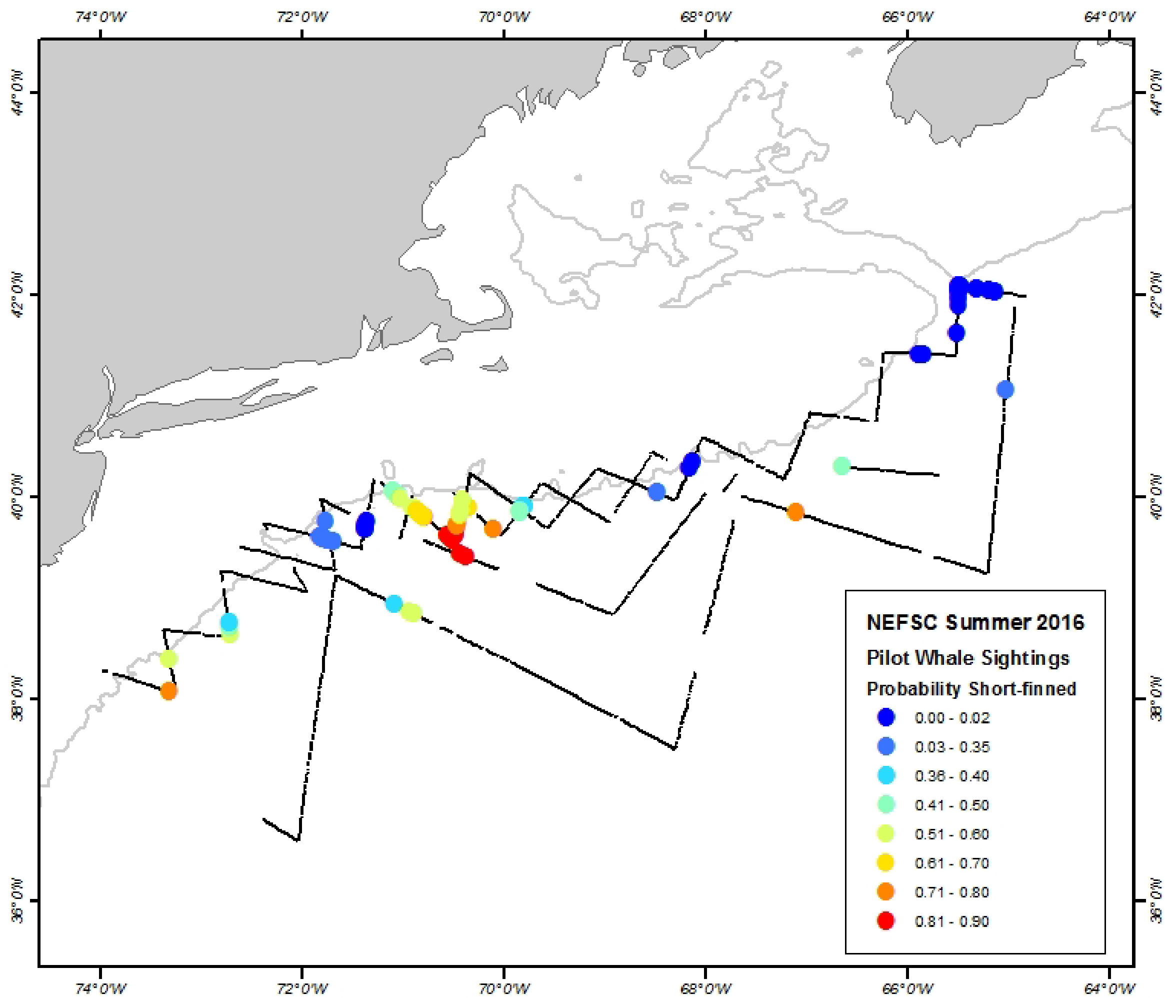

Figure 6 NEFSC survey pilot whale sightings and effort indicating the probability of each sighting being of short-finned pilot whales.

6 Acknowledgements

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Appendix A: Summary output from MRDS analysis for southeast and northeast survey data

Southeast Survey

```
Conditional detection function parameters:
                       estimate           se
(Intercept)       -1.1624386438 0.8558228944
distance          -0.0001233919 0.0003431908
observer           0.0998484065 0.2664060510
conditions         0.4323327223 0.254655414
distance:observer -0.0002932910 0.0001984879

                        Estimate        SE        CV
Average primary p(0)   0.4712015 0.1063712 0.2257445
Average secondary p(0) 0.4948477 0.1132831 0.2289251
Average combined p(0)  0.7200427 0.1159574 0.1610424


Summary for ds object
Number of observations :  108
Distance range         :  0  -  6000
AIC                    :  1780

Detection function:
 Half-normal key function

Detection function parameters
Scale coefficient(s):
              estimate         se
(Intercept)  8.0619788 0.20335528
seastate    -0.2250858 0.07633632
visibility   0.2210340 0.14095600
glare       -0.1847785 0.08379329

           Estimate         SE         CV
Average p 0.3627405 0.02604701 0.07180618


Summary for io object
Total AIC value :  2006.103

                       Estimate          SE        CV
Average p             0.2611886  0.04649951 0.1780304
N in covered region 413.4942538 81.51418523 0.1971350
```

Northeast Survey

```
Conditional detection function parameters:
                      estimate           se
(Intercept)        0.6217395122 0.5004875993
distance          -0.0001617245 0.0002547888
observer           0.3858058224 0.2806938129
distance:observer -0.0002679778 0.0001482484

                        Estimate         SE         CV
Average primary p(0)   0.7325395 0.06507360 0.08883289
Average secondary p(0) 0.8011267 0.05693798 0.07107238
Average combined p(0)  0.9468092 0.02576415 0.02721156


Summary for ds object
Number of observations :  112
Distance range         :  0  -  6000
AIC                    :  1890.584

Detection function:
 Hazard-rate key function

Detection function parameters
Scale coefficient(s):
            estimate        se
(Intercept) 6.927021 0.3647231

Shape coefficient(s):
             estimate        se
(Intercept) 0.2603678 0.2032531

           Estimate         SE        CV
Average p 0.3410578 0.06502517 0.1906573


Summary for io object
Total AIC value :  2121.442

                      Estimate          SE        CV
Average p            0.3229167  0.06219034 0.1925894
N in covered region 346.8386769 72.03570618 0.2076923
```