Abundance of Coastal and Continental Shelf Stocks of Common Bottlenose and Atlantic Spotted Dolphins in the Northern Gulf of Mexico: 2017-2018

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BACKGROUND AND STUDY OBJECTIVES

In this report, we describe the results of aerial visual line-transect surveys conducted by the National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center along the U.S. Gulf coast during 2017-2018. The primary objective of these surveys was to collect data to estimate abundance and characterize spatial distribution of marine mammals and sea turtles occupying coastal and continental shelf waters between the Florida Keys and the Texas/Mexico border. Three seasonal surveys were conducted: summer 2017, winter 2018, and fall 2018 as a part of the larger Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS). The collected data and resulting abundance estimates improve the assessment of marine mammal stocks as required under the Marine Mammal Protection Act (MMPA). The MMPA requires that stocks of marine mammal species in U.S. waters be maintained at or above their optimum sustainable population level (OSP), defined as the number of animals which results in the maximum net productivity. To meet this requirement, the NMFS conducts research to define stock structure, and for each stock, estimates annual human-caused mortality and potential biological removal (PBR), the maximum number of animals that may be removed from a stock due to human activities (*e.g.*, fisheries bycatch) while allowing the stock to reach or maintain its OSP. PBR is calculated following specific criteria using the estimated minimum abundance of the stock, its maximum net productivity rate (theoretical or estimated), and a recovery factor (Barlow et al*.*, 1995; Wade and Angliss, 1997). The NMFS is required to prepare a Stock Assessment Report (SAR) for each stock to update abundance, stock structure, human-caused mortality, PBR, and status (*e.g.*, Hayes et al., 2019). This study describes the results of the 2017-2018 aerial surveys and resulting abundance estimates for Gulf of Mexico stocks of common bottlenose dolphins and Atlantic spotted dolphins.

METHODS

Aerial Survey Methods

A DeHavilland DHC-6 Twin Otter was used to conduct aerial surveys, and transects were flown at an altitude of 183 m and an airspeed of 185 km/hr. The aircraft position was recorded at 10 second intervals, and environmental parameters were recorded including weather conditions, visibility, water color, water turbidity, sea state, and glare. Surveys were typically flown during favorable sighting conditions at Beaufort sea states less than or equal to 4 (surface winds <12 knots). Visual observers searched for marine mammals and sea turtles from directly beneath the aircraft out to a perpendicular distance of approximately 600 m from the trackline. Due to the bubble configuration of the observing windows and the position of the belly window observer, the trackline could be reliably visualized. Upon sighting a sea turtle or marine mammal, the observer measured the angle from the vertical to the animal (or group) using a digital inclinometer or estimated the angle based upon markings on the windows indicating 10-degree intervals. This sighting angle, θ, was converted to the perpendicular distance (PSD) from the trackline by PSD = tan(θ) x Altitude.

A two-team configuration was used that allows estimation of the probability of detection on the trackline. In this case, the forward team consisted of observers stationed in bubble windows on either side of the aircraft. The aft team consisted of a belly window observer and an observer stationed at a large bubble window on the right side of the aircraft. Both teams had independent data recorders and did not communicate with each other while actively surveying. Upon observation of a marine mammal group, the forward observer would allow the airplane to pass over the group giving the aft team the opportunity to see the group. Once the group passed the rear of the airplane, the pilots were notified, and the group was circled to verify species identification and group size. For each marine mammal sighting, it was determined if the sighting had been seen by the forward team only, the aft team only, or both teams at the time of data entry.

Survey Design

The 2017-2018 surveys covered waters over the continental shelf from Brownsville, TX (U.S./Mexico border) to north of the Dry Tortugas (Figure 1). Tracklines were oriented perpendicular to the shoreline and bathymetry gradient and spaced 20 km apart throughout most of the survey. Higher density lines (spaced 5 km apart) were surveyed within the main portion of Mississippi Sound. Survey tracklines followed uniform spacing from a random start point and were divided into strata to accommodate changes in the orientation of the coastline. The survey as planned encompassed approximately 14,600 km of survey effort, and surveys were conducted during summer 2017 (29 June – 17 August, 2017), winter 2018 (18 January – 14 March, 2018) and fall 2018 (12 October – 28 November, 2018). Due to weather conditions, not all planned tracklines were covered during each survey. In addition, only one survey team was used during the beginning of the winter survey, and the survey start was delayed resulting in limited effort. Survey effort was stratified into defined boundaries for the bottlenose dolphin stocks occupying the Northern Gulf of Mexico waters. These included three coastal stocks (Eastern, Northern, and Western), the continental shelf stocks, the Mississippi River Delta (MRD) estuarine stock, and the Mississippi Sound (MSS) stock (Figure 1). For Atlantic spotted dolphins, the abundance estimate is for the region corresponding to the continental shelf stock area (i.e., 20 m isobath to shelf break).

Data analysis

Abundance estimates were derived using the independent observer approach assuming point independence (Laake and Borchers, 2004) implemented in package mrds (version 2.21, Laake et al., 2020) in the R statistical programming language. 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 group is the product of two probability components. The first probability corresponds to the "standard" 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 [p(0)] which is modeled using a logistic regression approach and the "capture histories" of each sighting (i.e. seen by one or both teams).

The high speed of the aircraft and the resulting short viewing interval for each group means that sightings are essentially instantaneously available to both teams at the same time. Thus, p(0) in this case is an estimate of the likelihood of at least one team on the survey detecting the marine mammal group conditional on its being at the surface at the time the aircraft passed over its location. Because dolphins occur in groups of multiple animals and individual animals have relatively short dive durations, it is expected that negative bias due to all animals in a group being underwater simultaneously is small. Both model components can include factors that may affect the probability of detection such as viewing or weather conditions, and these factors are included in both components of the detection model. Details on the derivation, assumptions, and implementation of the estimation approach are provided in Laake and Borchers (2004).

As noted above, the aft survey team had limited visibility on the left side of the aircraft. Thus, mammal groups occurring at sighting angles more than 30 degrees from vertical on the left side were not available to the aft team and were therefore removed from the analysis of p(0). However, all sightings were included in the abundance estimates.

Covariates that may influence detection probability were evaluated for both components of the detection probability model including sea state, cloud cover, glare intensity (level of visual obstruction due to sea surface glare), glare coverage (proportion of viewing area obstructed), and turbidity. Group size was considered as a covariate, but there was no correlation between group size and detection distance for any survey. All combinations of variables were considered, and the best model was selected from the candidate models based on the lowest Akaike's Information Criterion (AIC). For the mark-recapture component of the model, a distance x observer interaction term was evaluated and included in the models when needed to allow for potential differences in detection probability estimates for the two survey teams. Model fit was evaluated using Chi-Square goodness of fit tests and the Cramer-von Mises test as implemented in mrds. Separate detection probability models were fit for each seasonal survey.

Prior Year Surveys

Similar aerial surveys were conducted during 2011-2012 as part of the Natural Resource Damage Assessment associated with the *Deepwater Horizon* oil spill (Garrison 2017). The aircraft and observer configurations were the same as those for the current surveys, and the survey design was similar. These data were reanalyzed to develop estimates that are directly comparable to those in the current analysis. The specific differences between this reanalysis and the estimates from Garrison (2017) are: 1) a broader suite of potential sighting condition variables was considered in the current analysis, and model selection was used to select the best model, 2) individual detection probability functions were fit to each survey whereas in Garrison (2017) a single function for detection probability on the trackline was used for all surveys, and 3) the Garrison (2017) analysis used a bootstrapping procedure to estimate variance, and the mean of the bootstrap distribution was used as the best estimate of abundance. In contrast, the current analysis uses analytical variances and means as implemented in the R packages mrds and dht.

Mississippi River Delta Estuarine Stock

The Mississippi River Delta (MRD) estuarine stock was not sampled during the 2017-2018 surveys, and therefore an abundance estimate cannot be developed directly from these data. However, the adjacent region of Chandeleur Sound was surveyed. During the winter 2012 aerial survey, both regions were surveyed sufficiently in winter months. The estimated density for Chandeleur Sound area in winter 2012 was 0.173 dolphins/km^2 (CV = 0.745), and the density for the MRD stock was 0.110 (CV = 0.933; Garrison 2017). These estimates are not significantly different from each other; however, the ability to detect significant differences between these density estimates is limited by the large uncertainty in both estimates. To estimate the abundance of the MRD stock in winter 2018, we assumed that the density within this area was the same as that for the adjacent Chandeleur Sound region and multiplied that density by the area of the MRD stock to obtain an updated abundance estimate.

Stock Specific Abundance Estimates and Trend Analysis

As in the prior estimate, the best abundance estimate for the coastal and continental shelf stocks was the inverse-variance weighted average of the seasonal estimates. However, due to the incomplete survey conducted in the winter of 2018, the eastern coastal, western coastal, and shelf stock estimates include only the summer 2017 and fall 2018 surveys. For the Mississippi Sound and Mississippi River Delta stocks, the best estimate is considered to be the winter survey estimate which is expected to reflect predominantly resident animals.

To assess the statistical significance of differences in abundance between the 2011-2012 and 2017-2018 estimates for each stock, a pairwise z-test was conducted on the log-transformed abundance estimates. Significance was interpreted at an alpha of p = 0.10.

RESULTS AND DISCUSSION

Survey Effort and Sightings

Total aerial survey effort accomplished and the number of bottlenose dolphin sightings are summarized in Table 1. The highest proportion of the planned tracklines was completed during the summer survey. In the winter survey, unavoidable delays in starting the survey and weather conditions precluded the completion of survey effort in both the eastern and western portions of the survey area. The spatial distribution of sightings during summer and fall were similar; however, there were fewer sightings in the eastern Gulf and more in the western Gulf during the fall survey compared to the summer survey (Figures 2-4). In the fine-scale surveys of Mississippi Sound, dolphin sightings were distributed broadly throughout the stock area, and dolphin density was much higher during the fall survey relative to the summer and winter seasons (Figure 5). Survey effort and the number of on-effort sightings of marine mammal groups and bottlenose dolphins within stock areas are summarized in Tables 2 and 3.

During the summer survey, there were sightings of Atlantic spotted dolphins over the west Florida shelf and concentrated in an area south of the Florida panhandle (Figure 2). While the west Florida shelf was not covered during the winter survey, there were no sightings during winter in the area south of the panhandle (Figure 3). During the fall survey, there were only 2 sightings of Atlantic spotted dolphins in the western Gulf and none in the eastern Gulf (Figure 4). These data suggest some variability in the seasonal distribution of Atlantic spotted dolphins and perhaps onshore-offshore movements.

Estimation of detection probability

The number of dolphin groups sighted by each survey team is summarized in Table 4. To estimate detection probability on the trackline [p(0)] a mark-recapture distance sampling (MRDS) model was fit to all of the survey data for each seasonal survey. All combinations of potential explanatory factors were evaluated, and the model with the lowest AIC was selected for both the distance sampling and mark-recapture component of the model. The selected models for each seasonal survey and associated estimates of detection probability are shown in Table 5. The models generally fit the data well as indicated by the Cramer von-Mises goodness of fit tests. There was a decline in the number of sightings detected near the trackline in some of the seasonal surveys. Left-truncation of the data was explored; however, this approach did not improve the model fit and resulted in much higher and less certain estimates of abundance. Plots showing the detection probability models and associated fits for each survey are shown in Figures 6-8. The detection probability on the trackline ranged from 0.657 to 0.801 across the surveys (Table 5). The overall detection probability ranged from 0.532 to 0.674 (Table 5).

Abundance Estimates

Abundance estimates and associated variance were derived for each surveyed bottlenose dolphin stock (Table 6). The abundance estimates for the eastern coastal, western coastal, and continental shelf stocks from the winter survey should be interpreted with caution since the strata were not completely surveyed in this season. For the Mississippi Sound stock, the fall abundance estimate was notably higher than the other two seasonal surveys. For Atlantic spotted dolphins, there was a large difference in the summer and fall abundance estimates associated with the low number of sightings during the fall in the eastern Gulf of Mexico (Table 7).

The best abundance estimates for each stock are shown in Table 8. For the coastal and continental shelf stocks, the abundance estimate is the inverse-variance weighted average of the valid seasonal abundance estimates. For the MSS and MRD estuarine stocks, the best abundance estimate is intended to represent the resident animals. Therefore, the winter estimate was used for these stocks as it presumably reflects animals that are most likely to be present year-round. These abundance estimates and the associated variance are used to estimate the N_{min} and PBR benchmarks in the MMPA Stock Assessment Reports.

Comparisons between abundance estimates from the 2017-2018 surveys for specific stocks to those from similar surveys conducted in 2011-2012 are shown in Table 8. Abundance estimates for bottlenose dolphin continental shelf, northern coastal, and eastern coastal stocks were significantly higher than those from 2011-2012 at the alpha = 0.10 level. While the relatively high uncertainty in the abundance estimates limits the power of these comparisons, the available estimates suggest possible increases in abundance for these stocks over the 6-year period between the surveys.

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Table 1. Survey effort (km) by season and stock area.

Stock	Summer 2017	Winter 2018	Fall 2018
Eastern Coastal	1843	597	814
MSS	487	515	750
Northern Coastal	583	431	489
Continental Shelf	9747	4804	6914
Western Coastal	1929	1698	1815
Total	14590	8046	10781

Table 2. Total on-effort unique marine mammal sightings by species and season.

Species	Summer 2017	Winter 2018	Fall 2018
Atlantic Spotted Dolphin	19	4	2
Bottlenose Dolphin	259	192	325
Bottlenose/Spotted Dolphin	6	0	4
Stenella sp.	1	0	0
Rough-toothed dolphin	1	0	0
Unid. Dolphin	1	1	1
Manatee	4	1	0
Total	291	198	332

Table 3. Unique on effort bottlenose dolphin sightings by season and stock area.

Stock	Summer	Winter	Fall
Eastern Coastal	48	14	27
MSS	16	19	83
Northern Coastal	11	23	18
Continental Shelf	143	48	108
Western Coastal	41	88	89
Total	259	192	325

Table 4. Number of on-effort dolphin groups (all species) by season seen by the forward team only, aft team only, or both teams. These counts exclude sightings that were not available to the aft team or when only one survey team was on effort.

Survey	Forward Only	Aft Only	Both Teams
Summer 2017	76	37	126
Winter 2018	25	23	61
Fall 2018	132	48	151

Table 5. Model parameters for Mark-Recapture Distance Sampling model for each survey. The selected explanatory variables for each model are shown: distance = distance from trackline, observer = observer team, ss = sea state, tb = turbidity, g = glare intensity, gc = glare coverage, cc = cloud cover. ~1 indicates a null model including no explanatory factors selected.

Parameter	Summer	Winter	Fall
Mark-Recapture Model (mr)	~distance * observer + ss+tb+g	~1	~distance * observer
Distance Model (ds)	~ cc+gc	~ cc	~ ss+gc+g
Detection probability on the trackline (p0)	0.657	0.719	0.801
Detection probability within survey strip (pds)	0.668	0.568	0.676
Survey Detection probability (pd)	0.559	0.523	0.634
Standard Error of pd	0.051	0.048	0.032
Cramer von-Mises GOF Test p-value	0.150	0.847	0.618

Table 6. Bottlenose dolphin abundance estimates within stock areas from seasonal aerial surveys. The coefficient of variation (CV) of each estimate is indicated in parentheses. The weighted average is the inverse variance weighted average of the seasonal estimates. For the eastern coastal, shelf, and western coastal stocks, the weighted average only includes the summer and fall estimates due to incomplete coverage in winter months.

Stock	Summer	Winter	Fall	Weighted Average
Mississippi Sound	2,145 (0.337)	1,265 (0.353)	4,337 (0.159)	3,078 (0.135)
Eastern Coastal	11,482 (0.232)	27,597 (0.401)	21,386 (0.235)	16,407 (0.173)
Northern Coastal	4,670 (0.493)	18,194 (0.240)	7,152 (0.318)	11,543 (0.186)
Western Coastal	18,600 (0.301)	58,542 (0.184)	21,765 (0.140)	20,759 (0.132)
Continental Shelf	74,959 (0.149)	58,349 (0.229)	52,090 (0.143)	63,280 (0.105)

Table 7. Atlantic spotted dolphin sightings and abundance estimates from seasonal aerial surveys.

Survey	Number of Groups	Average Group Size	Density (n/km^2)	Abundance (CV)	95% Confidence Interval
Summer 2017	19	14.4	0.0754	15929 (0.315)	8449 - 29336
Winter 2018	4	30.0	0.0778	16146 (0.559)	5780 - 46618
Fall 2018	2	22.0	0.0120	2529 (0.713)	704 - 9080

Table 8. Best abundance estimates for northern Gulf of Mexico bottlenose dolphin and Atlantic spotted dolphin stocks. For the northern, eastern, and western coastal stocks and the continental shelf stock, the estimate is an inverse-variance weighted average of the seasonal estimates. For the MRD and MSS stocks, the best estimate is the winter estimate which is likely to reflect resident animals. The Atlantic spotted dolphin estimate is from the summer 2017 survey.

Stock	Estimated Abundance	CV Estimate
Eastern Coastal	16,407	0.173
Northern Coastal	11,543	0.186
Western Coastal	20,759	0.132
Continental Shelf	63,280	0.105
MSS	1,265	0.353
MRD	1,446	0.186
Atlantic Spotted Dolphin	15,929	0.315

Table 9. Comparison of abundance estimates from the 2011-2012 aerial surveys to the 2017-2018 aerial surveys and tests of significant pairwise differences at alpha = 0.10. The estimates for the 2011-2012 surveys have been updated since Garrison (2017) [see methods above]. All comparisons are made across the same seasons or seasonal averages. † indicates significant differences between estimates.

Stock	**2011-2012 Abundance (CV)**	**2011-2012 Abundance 95% Confidence Interval**	**2017-2018 Abundance (CV)**	**2017-218 Abundance 95% Confidence Interval**	**z-test for difference of log-transformed means p-value**
Eastern Coastal	12180 (0.144)	9200 – 16126	16407 (0.173)	11720 - 22967	**0.091†**
Northern Coastal	7569 (0.221)	4936 – 11604	11543 (0.186)	8038 – 16576	**0.070†**
Western Coastal	19381 (0.200)	13148 – 28568	20759 (0.132)	16047 – 26852	0.386
Continental Shelf	48060 (0.113)	38540 – 59931	63280 (0.105)	51493 – 77764	**0.037†**
MSS	1104 (0.591)	377 - 3226	1265 (0.353)	646 – 2476	0.416
MRD*	332 (0.933)	70 – 1565	1446 (0.186)	1007-2075	NA
Atlantic Spotted Dolphin	12274 (0.434)	5585 - 28997	15929 (0.315)	8717 - 29107	0.307

*The MRD estimate is that reported in Garrison (2017). No comparison was made with the 2017-2018 estimate because the region was not surveyed during winter 2018. Please see methods section.

Figure 1. Planned aerial survey tracklines and bottlenose dolphin stock boundaries.

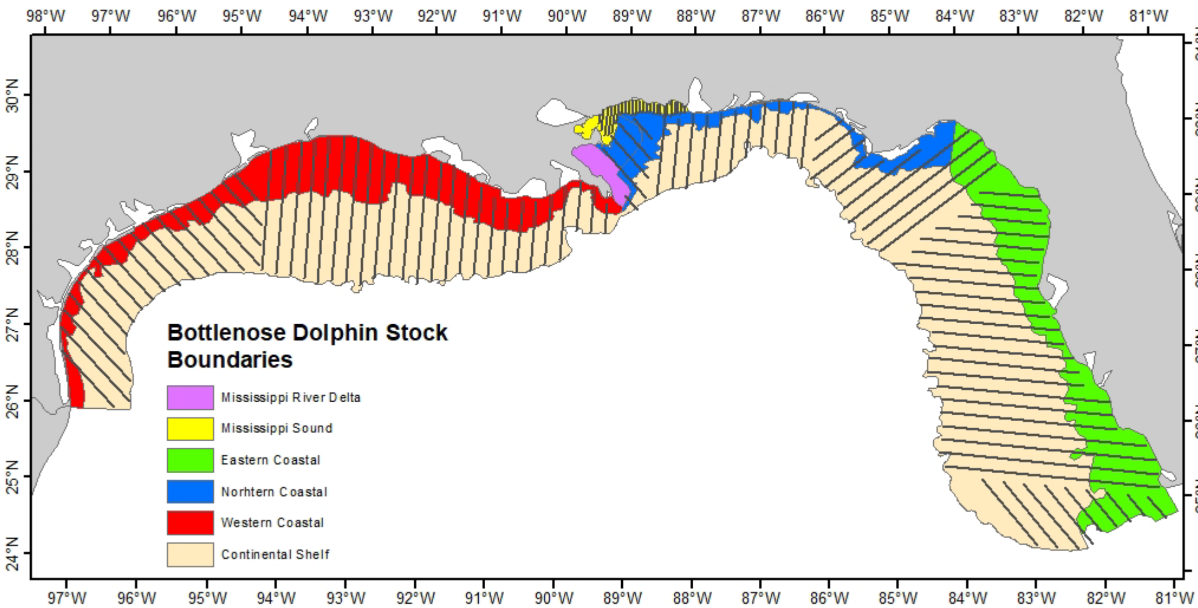

Figure 2. Tracklines completed and marine mammal sightings during the summer 2017 aerial survey.

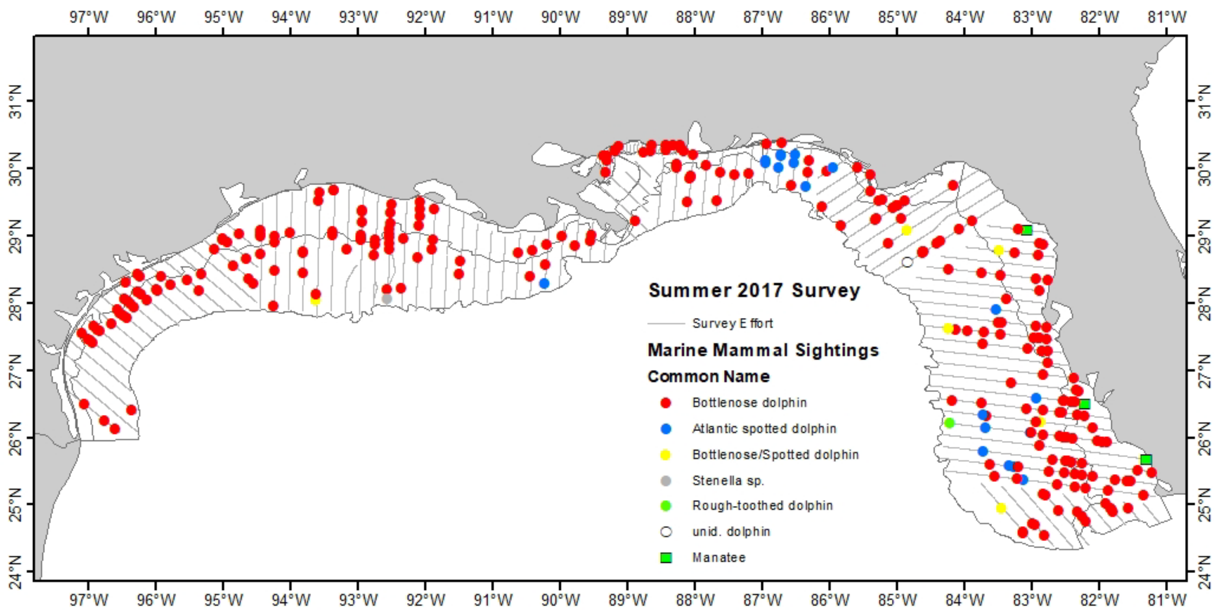

Figure 3. Tracklines completed and marine mammal sightings during the winter 2018 aerial survey.

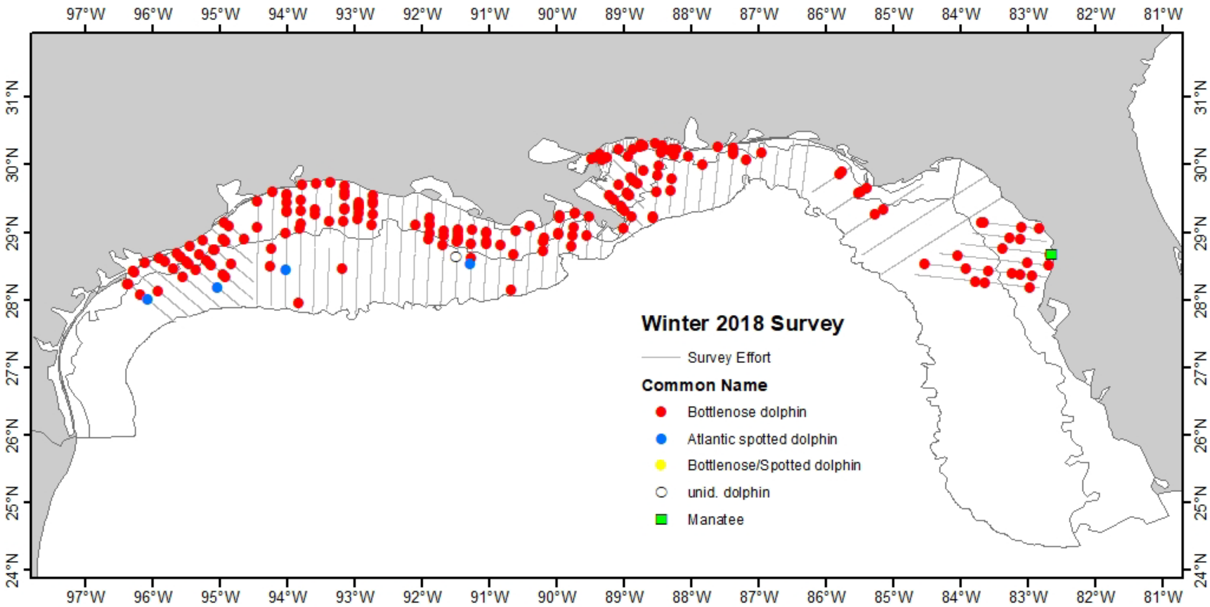

Figure 4. Tracklines completed and marine mammal sightings during the fall 2018 aerial survey.

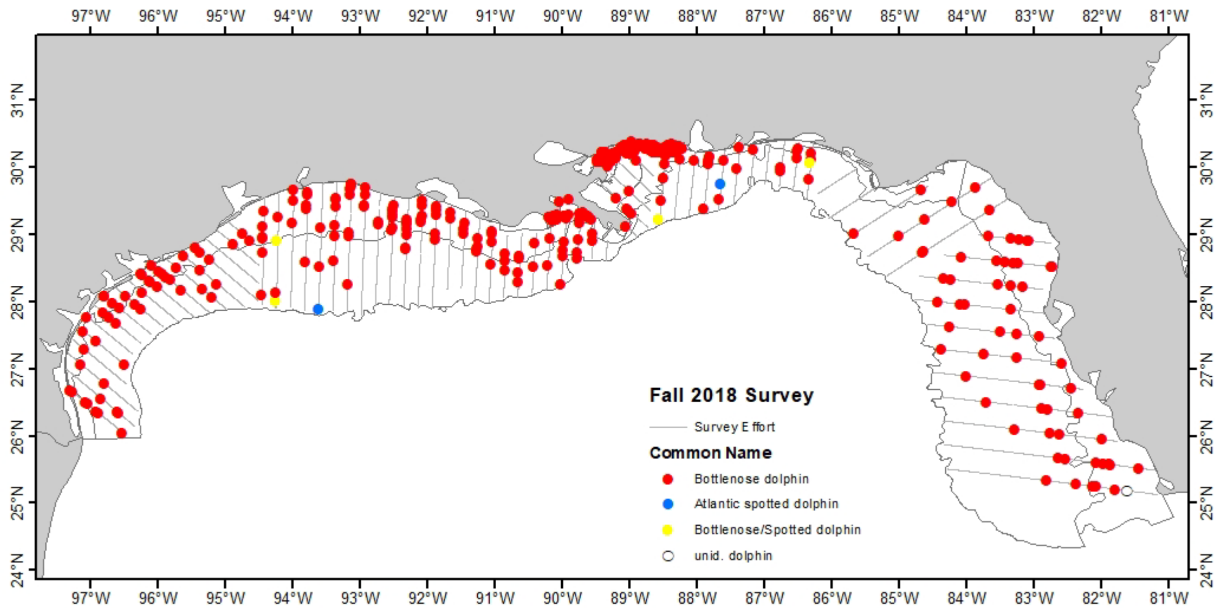

Figure 5. Tracklines completed and bottlenose dolphin sightings in Mississippi Sound during the 2017-2018 aerial surveys. Note that the survey effort in the fall survey was 750 km

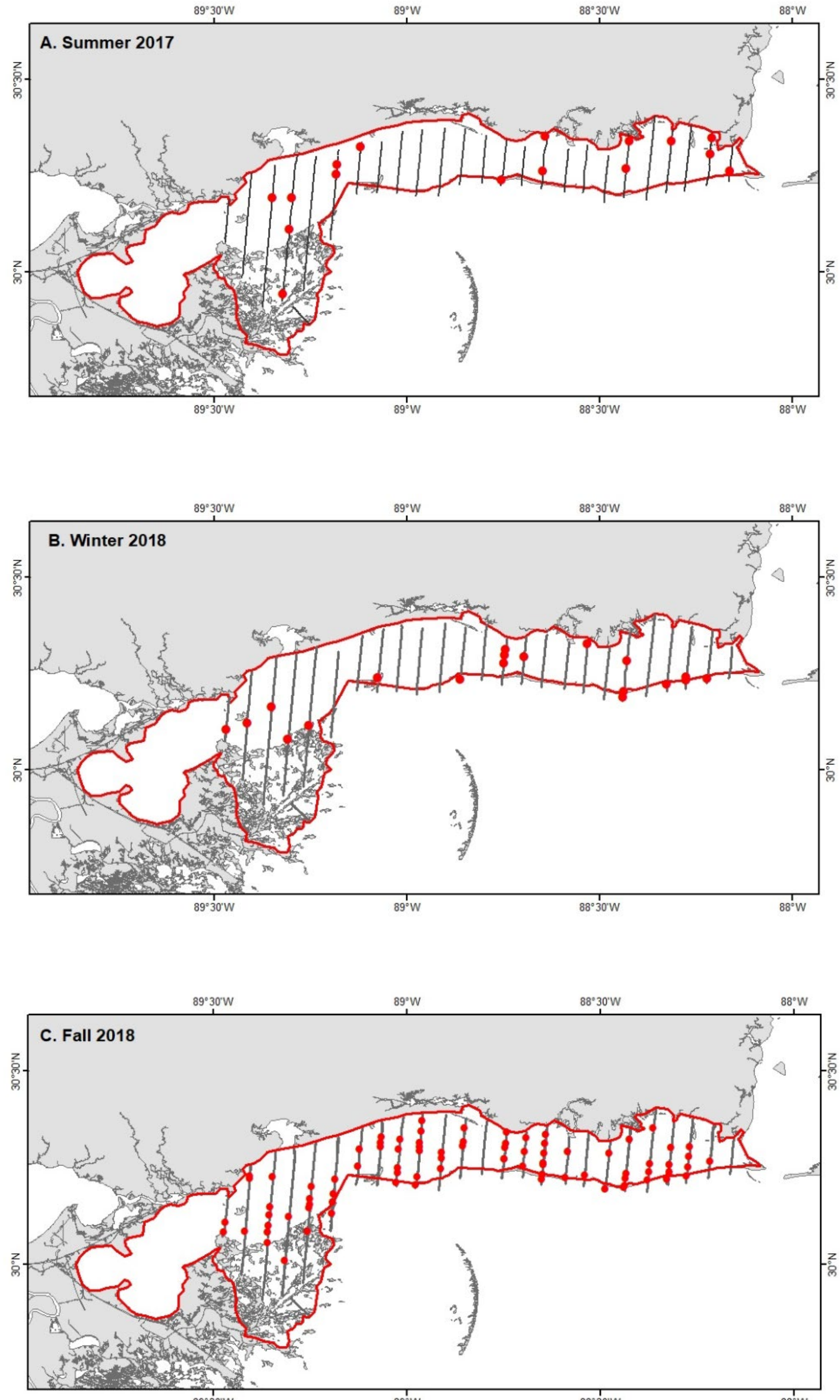

Figure 6. Detection probability plots for the selected MRDS model for the summer 2017 aerial survey.

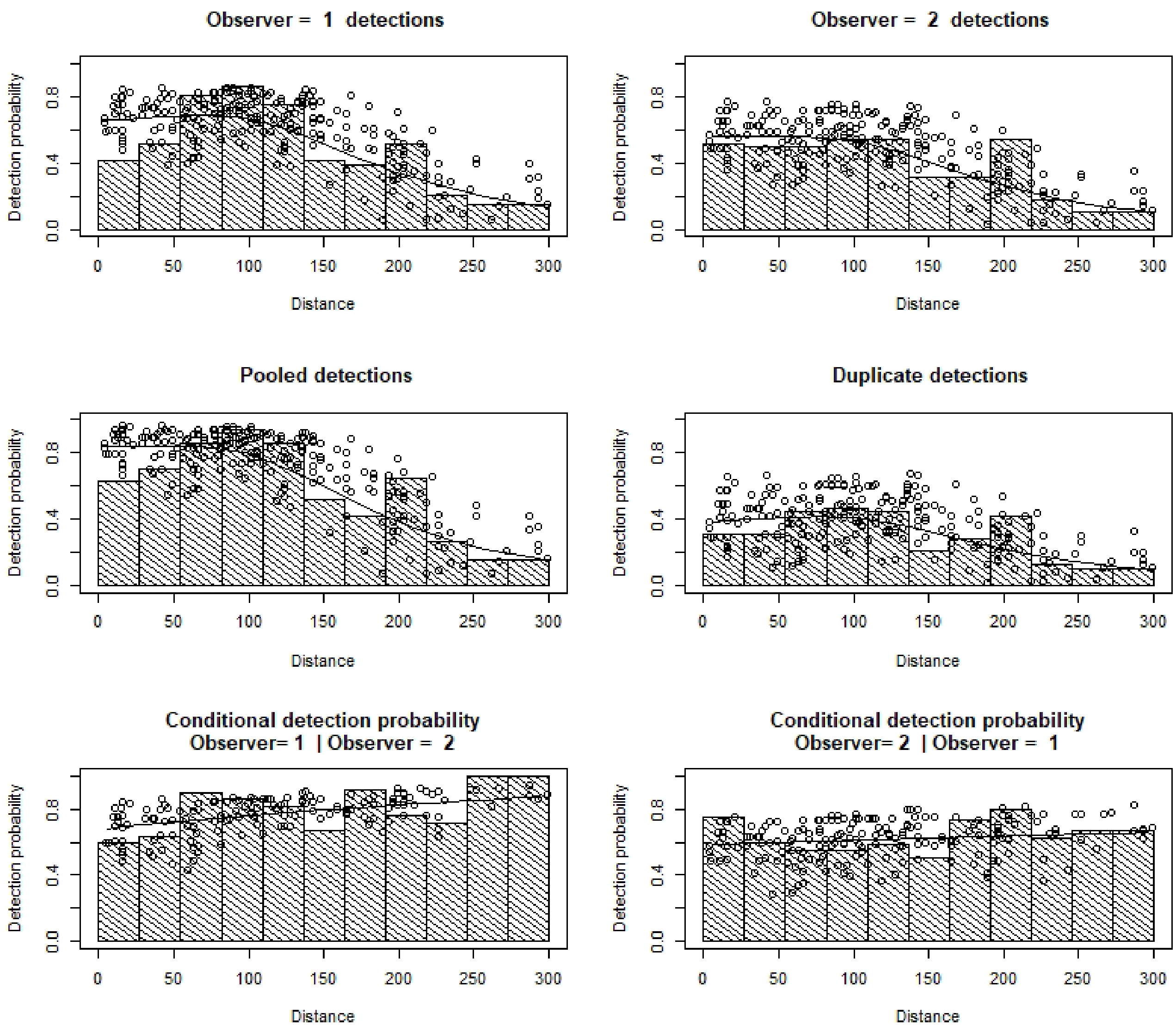

Figure 7. Detection probability plots for the selected MRDS model for the winter 2018 aerial survey.

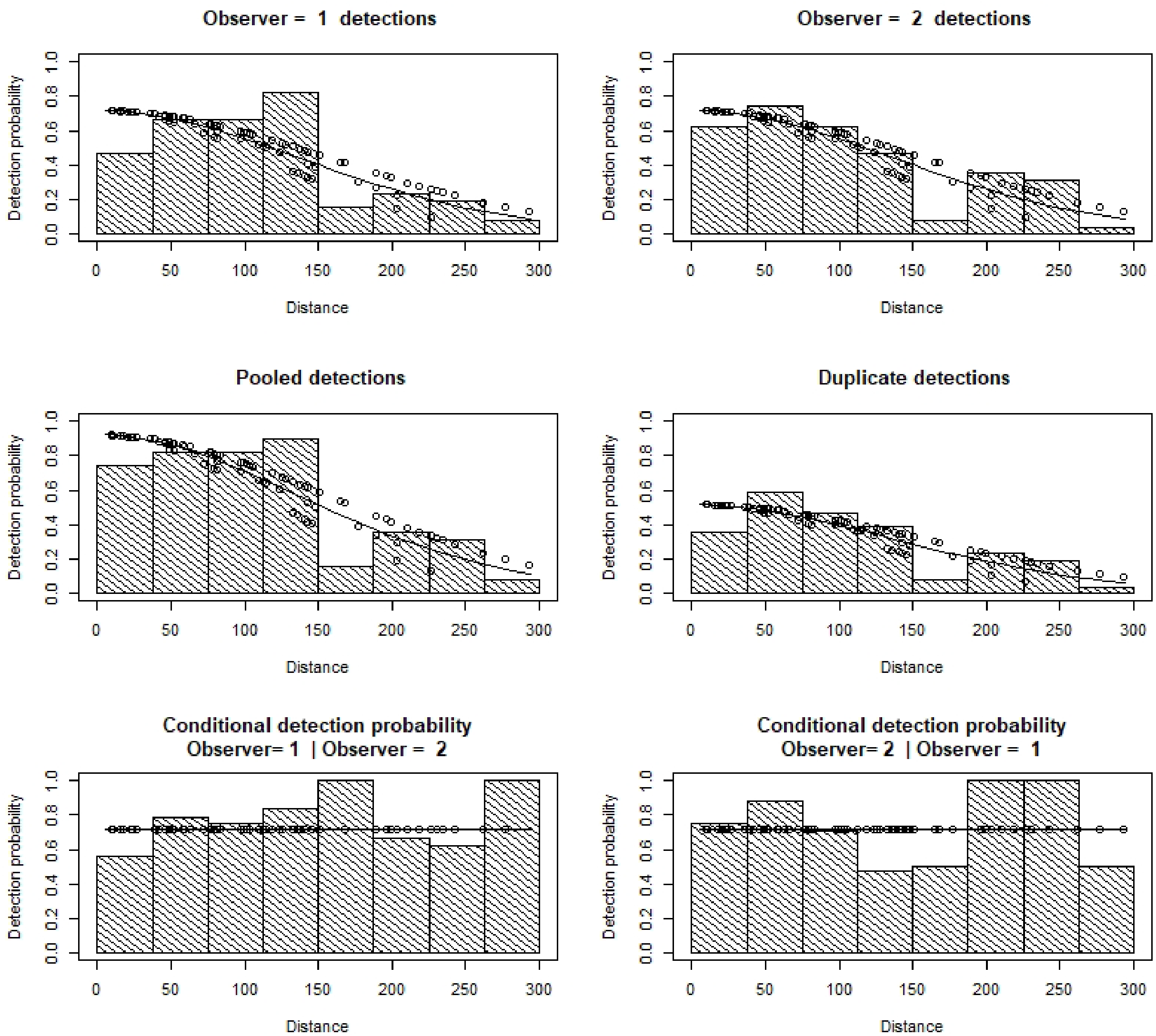

Figure 8. Detection probability plots for the selected MRDS model for the fall 2018 aerial survey.