Occurrence, Distribution, and Density of Protected Marine Species in the Chesapeake Bay Near Naval Air Station Patuxent River: Final Report

Submitted to:

Naval Facilities Engineering Command Atlantic under Contract No. N62470-10-D-3011, Task Order 55, issued to HDR, Inc.

Prepared by

Michael Richlen[1], Tiffany Keenan-Bateman[2], Erin Cummings[2], Ryan McAlarney[2], William McLellan[2], D. Ann Pabst[2], Louise Burt[3], Len Thomas[3], Jessica Aschettino[1], Amy Engelhaupt[4], Daniel Murphy[5], Sarah Mallette[6], Sue Barco[6], and Dan Engelhaupt[1]

[1] HDR
Virginia Beach, Virginia

[2] Department of Biology and Marine Biology
University of North Carolina Wilmington
Wilmington, North Carolina

[3] University of St. Andrews
St. Andrews, Scotland

[4] Amy Engelhaupt Consulting
Virginia Beach, Virginia

[5] Daniel Murphy Software and Data Consultancy
Redruth, England

[6] Virginia Aquarium Foundation
Virginia Beach, Virginia

Submitted by:

HDR
Virginia Beach, VA

July 2018

Suggested Citation:

Richlen, M., T. Keenan-Bateman, E. Cummings, R. McAlarney, W. McLellan, D.A. Pabst, L. Burt, L. Thomas, J. Aschettino, A. Engelhaupt, D. Murphy, and D. Engelhaupt. 2018. *Occurrence, Distribution, and Density of Protected Marine Species in the Chesapeake Bay Near Naval Air Station Patuxent River: Final Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Order 55, issued to HDR, Inc., Virginia Beach, Virginia. June 2018.

Cover Photo Credit:

Common bottlenose dolphins (*Tursiops truncatus*) observed in the Chesapeake Bay. Photograph taken by Jessica Aschettino under National Marine Fisheries Service permit no. 16239.

This project is funded by Naval Air Systems Command and managed by Naval Facilities Engineering Command Atlantic as part of the U.S. Navy's Marine Species Monitoring Program.

Table of Contents

Appendices

Figures

Tables

Acronyms and Abbreviations

AIC	Akaike Information Criterion
CI95	95% confidence interval
DPM	detection-positive minutes
DPD	detection-positive days
km	kilometer(s)
km^2	square kilometer(s)
m	meter(s)
NAS	Naval Air Station
PAX	Patuxent River
photo-ID	photo identification
U.S.	United States

1. Summary

Aerial surveys and passive acoustic monitoring was conducted for protected marine species in the waters surrounding Naval Air Station (NAS) Patuxent River (PAX) beginning in April 2015 in support of environmental planning and regulatory compliance for United States (U.S.) Navy testing and training activities. These surveys provide data and information on the seasonal occurrence, distribution, and density of marine mammals and sea turtles in the waters near NAS PAX. The survey area extends from Drum Point, south to Smith Point along the western shore and over to the coastal waters of the eastern shore. Aerial surveys were initiated in April 2015 and the first deployment of C-PODs (passive acoustic data loggers; chelonia.co.uk) occurred in July 2015. The University of North Carolina Wilmington conducted monthly aerial line-transect surveys to document the occurrence and distribution of marine mammals and sea turtles within the study area from April 2015 through November 2016. Survey effort was then postponed until the spring of 2017 in an effort to capture the seasonal re-entry of protected species into the study site. Monthly aerial survey effort resumed in April 2017 and concluded on 4 June 2017. Upon completion of the study, U.S. Naval Air Systems Command personnel made a decision to extend and increase the NAS PAX aerial survey effort through October 2017 in an attempt to increase sample size and strengthen abundance estimates. Twice-monthly aerial surveys were conducted by the Virginia Aquarium beginning on June 25 through October 2017 using identical methods and standard operating protocols as previously outlined by the University of North Carolina Wilmington. HDR deployed and refurbished C-PODs on a four- to six-month cycle to document the occurrence and seasonality of cetaceans in the study area based upon echolocation clicks produced by dolphins. Additionally, HDR opportunistically collected photographs of common bottlenose dolphins (*Tursiops truncatus*) during C-POD servicing trips for photo-identification (photo-ID) analysis. The Centre for Research into Ecological and Environmental Modelling at the University of St. Andrews has operated in an advisory capacity on survey design for both the visual and passive-acoustic data, and has analyzed all sightings data from the line-transect surveys using standard statistical analysis methods.

This report represents a cumulative summary of the data collected over two and a half years of effort near NAS PAX, from April 2015 through November 2017. Both aerial survey and acoustic monitoring results indicate that dolphins and sea turtles are present seasonally in the study area. Observations of common bottlenose dolphins peak in June and July, and there were no detections documented in the months between November and March.

Abundances for common bottlenose dolphins and sea turtles were estimated for the two major geographic blocks within the survey area—the Chesapeake Bay block and the Potomac River block. Mean summer abundances in the Chesapeake Bay block were 104 common bottlenose dolphins (95% confidence interval [CI95=26–420]), and 14 loggerhead sea turtles (*Caretta caretta* [CI95=7–26]). Mean summer abundances in the Potomac River block were 19 common bottlenose dolphins (CI95=4–89). Loggerhead turtles were not detected in the Potomac River block, and neither of these species were detected in winter in either block.

2. Methods

2.1 Study Area

NAS PAX is located at the mouth of the Patuxent River on the Chesapeake Bay in Maryland (**Figure 1**). The area of interest was determined during discussions with U.S. Naval Air Systems Command personnel, who require protected marine species occurrence and density data for use in environmental planning and regulatory compliance efforts.

2.2 Passive Acoustic Methods

HDR deployed underwater acoustic monitoring devices (C-PODs, Chelonia Limited, Mousehole, UK; www.chelonia.co.uk) at six locations to document the presence of common bottlenose dolphins in the study area. The C-PODs can detect the presence of echolocating common bottlenose dolphins and other odontocetes, in addition to collecting a record of ambient water temperatures. Multiple deployment sites were included in the initial planning to allow for flexibility in case interest shifted to other areas over the course of the study. The C-PODs were bottom-mounted and an acoustic release (Sport MFE Push Off Release Transponder, Edgetech, West Wareham, MA) was used for retrieval. To ensure that the device will float to the surface upon release, a syntactic foam float was attached to the unit. The devices were first deployed on 11 July 2015 and recovered/redeployed at four to six month intervals through November 2017. Deployment locations remained constant with the exception of a shift from site PAX 6 to PAX 7 in July 2016 (**Figure 1**).

The raw click data were imported into custom analysis software and processed using the KERNO classifier (a custom function built into proprietary Chelonia Limited software) to detect click trains and classify their likely sources. A secondary encounter classifier called GENENC (also a custom function built into proprietary Chelonia Limited software), which uses a longer classification time window to improve detection performance, was also used on these data. Additionally, an experienced C-POD analyst conducted quality control and detection validation.

Common bottlenose dolphin occurrence was measured by the presence of clicks within 1-minute blocks of data (detection-positive minutes [DPM]). An additional measure, detection-positive days (DPD), was also used to describe occurrence more generally. The number of DPM may be misleading since the group sizes and durations of each encounter within the detectable range of each C-POD are unknown. DPD are days when one or more DPM have been recorded that day.

Visual validation was used to assess the overall rate of false positive dolphin DPM. For evaluating false detection rates, an inspection of the data showed that weak boat echo sounder trains and sediment transport noise were the source of false positives. Following the application of a suitable sound-level filter to remove weak trains, the files were sampled using stratified temporal sampling, to give 10 samples per file with start times spaced at approximately even time intervals through the files. The 10 detection positive minutes following the start of each sampling period were visually validated, so 100 DPM in total were sampled per file (or all DPM if fewer than 100 present in the file).

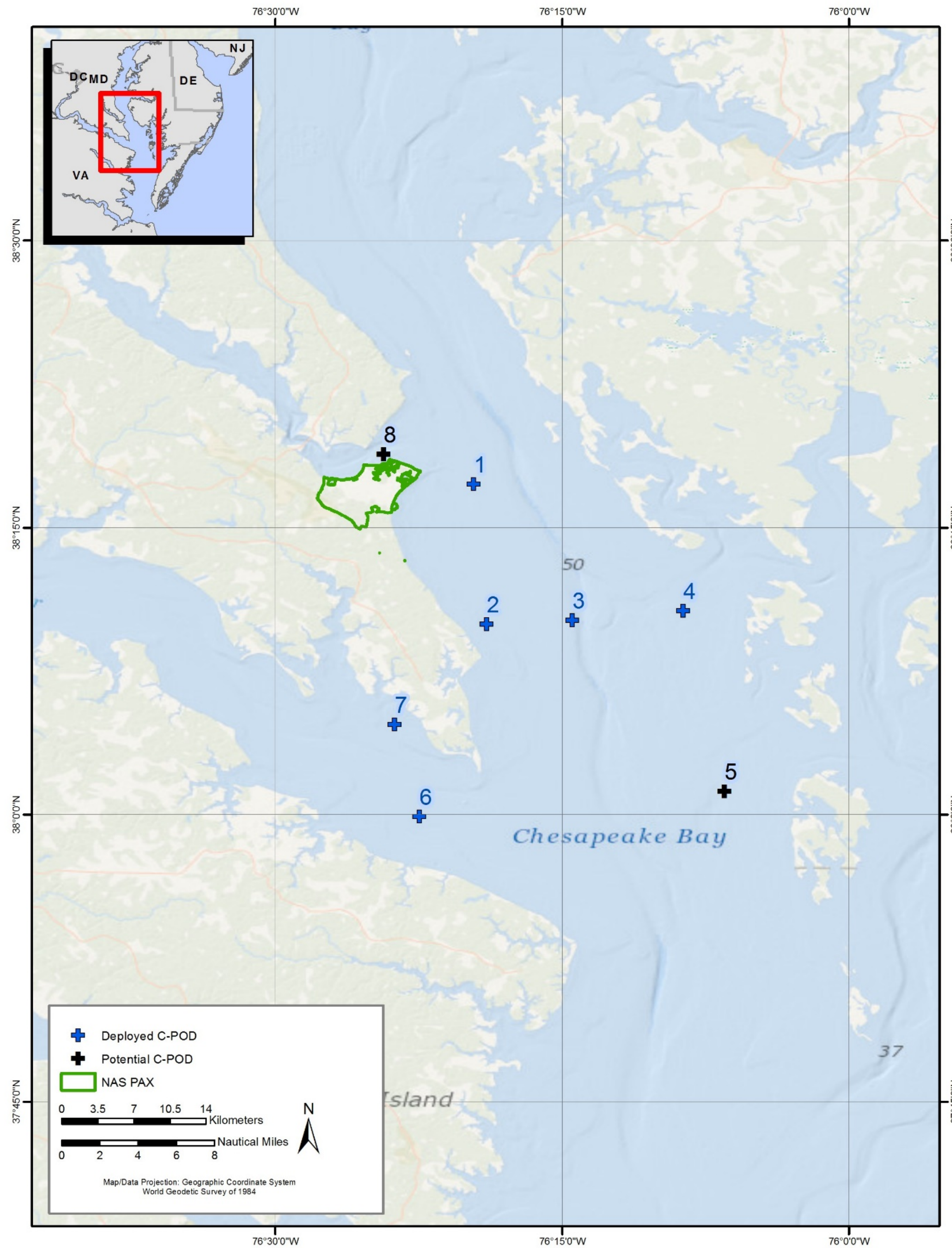


Figure 1. The NAS PAX study area, showing locations of C-POD deployments (blue +) and alternative deployment sites (black +).

2.3 Dolphin Photo-Identification and Visual Surveys

During each of the five C-POD deployment/recovery trips, HDR researchers maintained a visual lookout for dolphins while underway. These surveys were non-systematic and opportunistically conducted to maximize data collection while on the water. Time and weather permitting, efforts were made to obtain photographs to be used for photo-ID analysis. A collaboration was established with researchers from Georgetown University (Potomac-Chesapeake Dolphin Project), who are also conducting common bottlenose dolphin surveys in the Potomac River. Using the photo program ACDSee Pro (Versions 7-9), photographs of dolphins were digitally sorted and cropped to select the best image of each dolphin from the 2015 encounter and were subsequently shared with the Potomac-Chesapeake Dolphin Project and submitted to the Mid-Atlantic Bottlenose Dolphin Catalog (Urian et al. 1999), established by the National Marine Fisheries Service and curated by Duke University. Photos collected during the 2016 encounters have not been processed to date, but will be sorted and cropped as time allows and made available to the Potomac-Chesapeake Dolphin Project, Mid-Atlantic Bottlenose Dolphin Catalog, or any interested research group. Photo-ID comparisons with HDR's common bottlenose dolphin photo-ID catalog from Norfolk and Virginia Beach, Virginia (Engelhaupt et al. 2016) would also be of value, and will be initiated funding becomes available.

2.4 Aerial Surveys

2.4.1 Survey Methods

Aerial line-transect surveys were conducted in the waters of the Chesapeake Bay, and the mouth of the Potomac River, surrounding NAS PAX (**Figure 2, Table 1**). Surveys were flown in an over-wing, twin-engine Cessna 337 Skymaster, at an altitude of 305 meters (m) and groundspeed of 185 kilometers/hour. Two observers, one positioned on each side of the aircraft in the rear seats, carried out surveys. The goal of each monthly survey was to cover the full set of tracklines in a single day (**Table 1**). All dolphin and turtle sightings were logged. Additionally, cownose rays and ocean sunfish (*Mola mola*) were also recorded in the data.

For each detection, the observers recorded the vertical and horizontal angle to the detection, species, group size (minimum, maximum, and best estimate), sighting cue, and confidence of the species identification (reliability). The vertical angle (i.e., the angle of declination from the observer to the animal) was recorded in four intervals, with each interval representing approximately 16°. Environmental conditions were recorded along each trackline (e.g., glare, cloud cover, sea state, and visibility). On detecting a dolphin or dolphin group, search effort was suspended and the plane flew over the group to estimate group size and mark the exact location of the animal or group. Animals observed opportunistically between transect lines, or outside of the survey area, were classified as "off-effort" sightings.

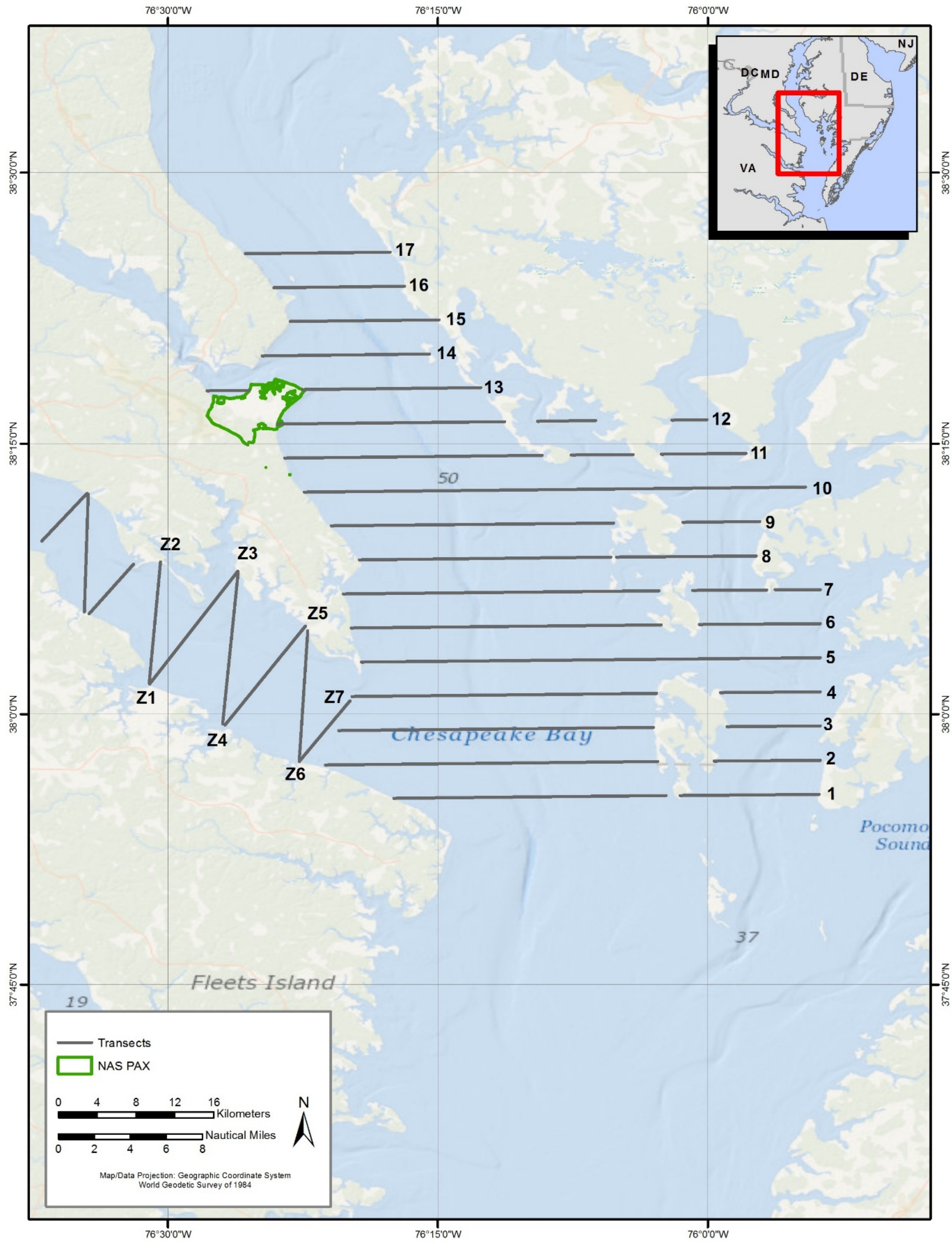


Figure 2. Aerial survey tracklines for the NAS PAX study area.

Table 1. Trackline endpoint coordinates for the Patuxent River study site. Note that the seven Z waypoints create a zigzag of nine trackline segments.

Transect	West Waypoint		East Waypoint		Transect Z Waypoints	Latitude (°N)	Longitude (°W)
	Latitude (°N)	Longitude (°W)	Latitude (°N)	Longitude (°W)			
1	37.92217	76.29089	37.92583	75.89691	Z1	38.14046	76.50664
2	37.95300	76.35423	37.95738	75.89579	Z2	38.02788	76.51701
3	37.98468	76.24193	37.98893	75.89582	Z3	38.13213	76.43518
4	38.01637	76.32963	38.02047	75.89584	Z4	37.99095	76.44934
5	38.04801	76.32098	38.05202	75.89587	Z5	38.07689	76.37031
6	38.07945	76.33015	38.08356	75.89590	Z6	37.95600	76.37821
7	38.11091	76.33740	38.11510	75.89593	Z7	38.01216	76.33126
8	38.14261	76.32279	38.14618	75.95522			
9	38.17386	76.34884	38.17775	75.95189			
10	38.20512	76.37349	38.20963	75.90946			
11	38.23644	76.39159	38.24073	75.96450			
12	38.26790	76.39853	38.27197	76.00080			
13	38.29972	76.37556	38.30154	76.21005			
14	38.33082	76.41266	38.33258	76.25759			
15	38.36267	76.38674	38.36422	76.24889			
16	38.39403	76.40185	38.39542	76.28056			
17	38.42525	76.42832	38.42681	76.29400			

2.4.2 Statistical Methods

The study region was divided into two survey strata ("blocks"): a block in Chesapeake Bay (CB; the seventeen parallel tracklines oriented east-west) covering an area of 1,784 square kilometers (km^2) and a block in the Potomac River (PR; the zigzag lines extending into the Potomac River) covering an area of 215 km^2. Line-transect Distance sampling analysis methods (Buckland et al. 2001) were used to estimate individual density (D) and abundance (N) as follows:

$$\hat{D} = \frac{n}{2wL\hat{p}} \cdot \hat{E}[s] \qquad \text{and} \qquad \hat{N} = A.\hat{D}$$

where

- n is the number of groups (a group can be one or more animals) detected within perpendicular truncation distance w. Detections recorded as opportunistic sightings were not included.
- L is total length of survey effort
- $\hat{p}$ is the estimated probability of detection in a strip of area $2wL$, where $2w$ is the width of the strip
- $\hat{E}[s]$ is the estimated population mean group size
- A is the area of the survey block.

Note that two alternative parameterizations are sometimes used to report probability of detection: effective strip half-width (ESW; denoted by $\hat{\mu}$) given by $\hat{p}w$, and $f(0)$ estimated by $1/\hat{\mu}$.

Details of the components of the density estimator are given below.

Survey Effort Statistics

Survey effort was calculated from the start and end locations of the effort that were recorded independently by each observer; for each transect the average effort recorded by the left and the right observer was used. Survey block CB includes many islands and search effort was not suspended over islands, except during the first survey. Distances travelled over islands were calculated from the waypoints of the designed transects and these distances were subsequently subtracted from search effort for relevant transects.

Perpendicular Distance Calculation

The calculation of the perpendicular distances of the detection to the trackline depended on the species of the detected animal (or group) following the methods of Read et al. (2014); exact distances were calculated for dolphins, and for other species distance intervals were estimated. When dolphins were detected, search effort was suspended, the plane left the trackline and flew over the animals to obtain an accurate location. The perpendicular distance, x_d, was calculated from the distance between the location at suspension of effort and the location of the detected group, r, and the horizontal angle from the bearing of the plane to the detected group when effort was suspended, θ, as follows:

$$x_d = r \cdot \sin\theta$$

Search effort was not suspended for other species and the vertical angle (i.e., angle of declination) from the observer to the detection was recorded. The vertical angle represents the angle to the detected animal when the plane was abeam and so perpendicular distance, x_o, was calculated from:

$$x_o = h \cdot \tan\alpha$$

where h is the height of the plane (taken to be 305 m) and α is the vertical angle. The vertical angle was measured in intervals (rather than an exact angle), with each interval being approximately 16°. The observers could not see directly below the plane and this region was excluded in the calculation of the binned perpendicular distances. **Table 2** shows the perpendicular distance intervals for a plane at an altitude of 305 m. For analysis, the data were divided into these perpendicular distance intervals and the detection function model was fitted to the binned data.

Table 2. Perpendicular distances (m) for each vertical angle interval assuming an altitude of 305 m.

Interval	Minimum	Maximum	Mid-point
1	0	125	57
2	125	337	213
3	337	899	530
4	899	3000[1]	1952

[1] This interval has been truncated for plotting and detection function estimation.

Probability of Detection

One critical assumption of standard or "conventional" distance sampling (CDS) methods is that all groups on the trackline (i.e., at zero perpendicular distance) are detected with certainty. Given this assumption, the distribution of perpendicular distances is used to model how the probability of detection decreases with increasing distance from the trackline.

A detection function model fitted to the observed distribution of perpendicular distances using either the exact distances for dolphins or binned distances for other species. Perpendicular distances were truncated (at w), where required, to avoid a long tail in the detection function (Buckland et al. 2001). An overall probability of detection, p, was obtained from the area under the detection function divided by the area assuming detection was certain out to w. The number of detections for each species/species group for each survey was small, so perpendicular distances from all surveys were combined to obtain one detection function per species or species group. Two models of the detection function were considered (without adjustment terms)—hazard rate and half normal—and the model that resulted in the smallest Akaike Information Criterion (AIC) was selected.

To boost the number of detections for loggerhead turtles, detections of unidentified turtles were included with detections of loggerhead turtles for detection function fitting (but excluded in the encounter rate).

Estimated Mean Group Size

Mean group size was estimated by regressing the natural logarithm of group size against detection probability for the group (estimated from the detection function at observed perpendicular distance for the group). This size-bias regression model was used to predict group size where detection probability is one (i.e., at the point where all groups are assumed to be detected) (Buckland et al. 2001). Best estimates of group sizes were used.

Density and Abundance

Detections and search effort were pooled within each season and survey block to obtain encounter rates (n/L), and hence average estimates of density and abundance, by season and survey block. Seasons were defined as winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November). Estimates were also obtained for each survey where detections were made.

The analyses were performed using the program Distance version 7.1 Release 1 (Thomas et al. 2010) using the CDS analysis engine. Coefficients of variation (CV) were obtained using the delta method (Buckland et al. 2001). The encounter rate variance was estimated using the 'R2' estimator of Fewster et al. (2009)—the default estimator in conventional DS analysis.

3. Results

3.1 Passive Acoustic Monitoring

Results Summary

Six deployments of five instruments each were made over the duration of the project, summarized in **Table 3**. C-PODs at all five locations (PAX 6 and 7 are combined as one site to represent Potomac River site) recorded good quality data during each deployment and were still logging data when recovered for refurbishment. The only C-POD failure was the fifth deployment at PAX 2. The memory card for this deployment became corrupted without any indication, and the issue was not noticed until after the unit was retrieved. The data were sent back to Chelonia to see if they could be recovered and, unfortunately, the data were unrecoverable.

Table 3. C-POD sampling summaries by site, with all deployments combined.

Site	Start	End	Logged Days	Total Dolphin DPM[1]	Total Dolphin DPD[2]	Percent DPD [3]	Percent False Positive[4]
1	07/11/2015	11/30/2017	872.08	1018	128	14.7%	3.3%
2	07/11/2015	11/29/2017	701.03	2476	171	24.4%	2.8%
3	07/11/2015	11/29/2017	849.3	1333	163	19.2%	3.1%
4	07/11/2015	11/30/2017	873.65	1561	96	11.0%	1.3%
6 & 7*	07/11/2015	11/30/2017	863.75	1845	100	11.6%	2.0%
Total			**4159.81**	**8233**	**658**	**15.8%**	**2.6%**

[1] Detection Positive Minutes (DPM) are minutes where one or more trains have been classified in that minute.
[2] Detection Positive Days (DPD) are days where one or more DPM have been recorded in that day.
[3] Percent DPD are calculated over the duration of the total recording time for each deployment.
[4] Percent False Positive is the number of false positive dolphin DPM as a percentage of total DPM
* Sites 6 and 7 are treated as the same location and are continuous and do not overlap.

When analyzing the data, the KERNO classifier was found to work better than the GENENC classifier, and the results were filtered for moderate- and high-quality click trains with specific sound pressure levels. This step was to remove weak vessel sonar that could otherwise be misclassified as dolphins. Common bottlenose dolphins were the only cetacean species detected.

Averaged across all deployments and sites, 15.8 percent of all logged days had dolphin detections (**Table 3**). The mean DPM per day across all deployments was 1.96 (standard deviation=9.86). PAX 2 had the highest percentage of monitored days with dolphin detections (at least 1 DPM) at 24.4 percent, followed in descending order by PAX 3, PAX 1, PAX 6/7, and PAX 4. The overall false positive rate across all sites and deployments was 2.6 percent, i.e., 97.4 percent of DPM were true detections after applying appropriate filters. For individual sites, false positive rates varied from 1.3 percent at PAX 4 to 3.3 percent at PAX 1 (**Table 3**).

Dolphin click trains were detected at every site during each deployment (**Table 4**). DPM ranged from 3 to 1492, and DPD from 2 to 75, with both maximum values at PAX 2 during deployment 6. The percent of days with dolphin detections during a deployment ranged from 1.47 (PAX 4, deployment 1) to 64.10 (PAX 2, deployment 3).

Table 4. Dolphin detection results from all of the C-POD deployments.

Site	Start	End	Logged Days	Dolphin DPM[1]	Dolphin DPD[2]	Percent DPD[3]
1	07/11/2015	11/23/2015	136.00	5	3	2.21%
1	11/24/2015	04/19/2016	147.07	11	5	3.40%
1	04/19/2016	07/19/2016	91.09	499	52	57.09%
1	07/19/2016	12/04/2016	137.97	167	9	6.52%
1	12/05/2016	05/23/2017	169.00	23	10	5.92%
1	05/23/2017	11/30/2017	190.95	313	49	25.66%
2	07/11/2015	11/23/2015	136.00	56	13	9.56%
2	11/24/2015	04/18/2016	146.04	5	4	2.74%
2	04/18/2016	07/19/2016	92.05	812	59	64.10%
2	07/19/2016	12/04/2016	138.00	111	20	14.49%
2	05/24/2017	11/29/2017	188.94	1492	75	39.70%
3	11/07/2015	11/23/2015	136.00	50	6	4.41%
3	11/24/2015	04/18/2016	146.11	10	7	4.79%
3	04/18/2016	07/19/2016	91.95	601	58	63.08%
3	07/19/2016	12/04/2016	138.00	103	20	14.49%
3	12/04/2016	05/01/2017	148.23	60	12	8.10%
3	05/24/2017	11/29/2017	189.01	509	60	31.74%
4	07/11/2015	11/23/2015	136.00	35	2	1.47%
4	11/23/2015	04/18/2016	146.92	6	3	2.04%
4	04/18/2016	07/19/2016	91.82	501	32	34.85%
4	07/19/2016	12/04/2016	137.99	22	4	2.90%
4	12/04/2016	05/23/2017	169.86	41	6	3.53%
4	05/23/2017	11/30/2017	191.06	956	49	25.65%
6*	07/11/2015	11/24/2015	128.00	45	10	7.81%
6*	11/24/2015	04/18/2016	145.98	3	2	1.37%
6*	04/18/20160	07/19/2016	91.95	465	35	38.06%
7*	07/19/2016	12/04/2016	138.01	51	7	5.07%
7*	12/04/2016	05/23/2017	169.87	3	3	1.77%
7*	05/24/2017	11/30/2017	189.94	1278	43	22.64%

[1] Detection Positive Minutes (DPM) are minutes where one or more trains have been classified in that minute.

[2] Detection Positive Days (DPD) are days where one or more DPM have been recorded in that day.

[3] Percent DPD are calculated over the duration of the total recording time for each deployment.

* Sites 6 and 7 are treated as the same location and are continuous and do not overlap.

Seasonal and Temporal Variations

Distinctive seasonal patterns can be seen at all sites with almost all dolphin activity occurring between early April and late August (**Figure 3**). This was seen in 2016 and 2017; however, the 2015 deployment began in July and missed a large portion of the peak season. In 2016 PAX 1, PAX 2, and PAX 3 recorded the highest number of total DPM and showed peaks in activity from the end of May until mid-June, then another peak from approximately the end of June until mid-July at PAX 1 and PAX 2. In 2017, PAX 2 showed peaks in activity from approximately the end of June until the third week of July, PAX 4 showed a strong peak at the end of May and PAX 6/7 showed a strong peak at the end of June/beginning of July then a smaller peak in the middle of July/third week of July.

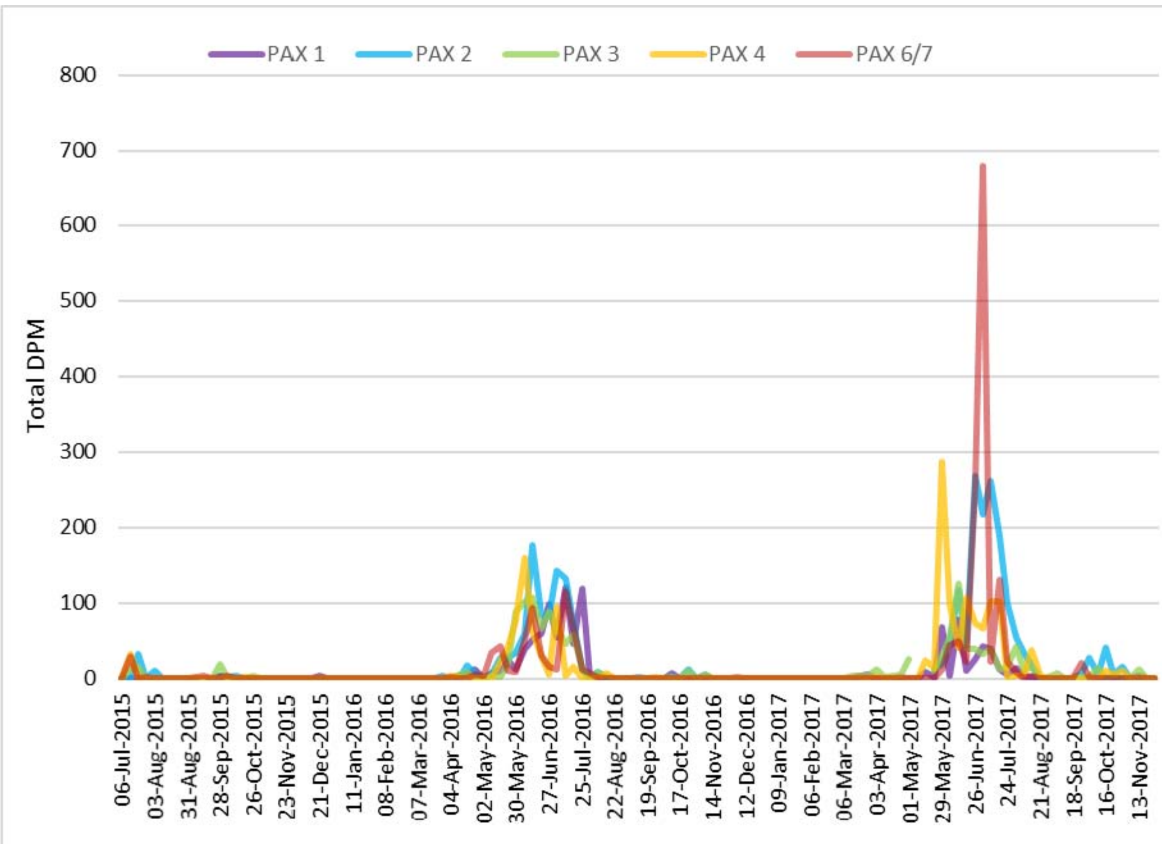


Figure 3. Weekly dolphin DPM for all PAX sites.

Interannual differences were assessed by summing DPM by site and calendar year across all deployments (**Table 5**). Few dolphin DPM were recorded in 2015; however, this was expected since the first deployment occurred very late in the peak season. In total, 38 percent more dolphin DPM were recorded across the entire study area in 2017 than in 2016. Comparing the 2016 and 2017 data for the individual sites, total dolphin DPM recorded in 2017 increased over 2016 at PAX 2 (60 percent increase), PAX 4 (88 percent increase) and PAX 6/7 (145 percent increase), but decreased at PAX 1 (50 percent decrease) and PAX 3 (20 percent decrease). Figures depicting the annual occurrence at each site can be seen in **Appendix B**.

Table 5. Total dolphin DPM per year per site

Year	PAX 1	PAX 2	PAX 3	PAX 4	PAX 6/7	Total
2015	8	55	50	35	46	**194**
2016	673	927	714	529	521	**3364**
2017	336	1492	569	997	1278	**4672**

All five sites showed similar seasonal patterns in mean weekly water temperatures (**Figure 4**). When summarizing the DPM into weekly intervals and comparing it to the temperature data, in both 2016 and 2017 the peak DPM occurred two to four weeks prior of the peaks in mean water temperature at all sites.

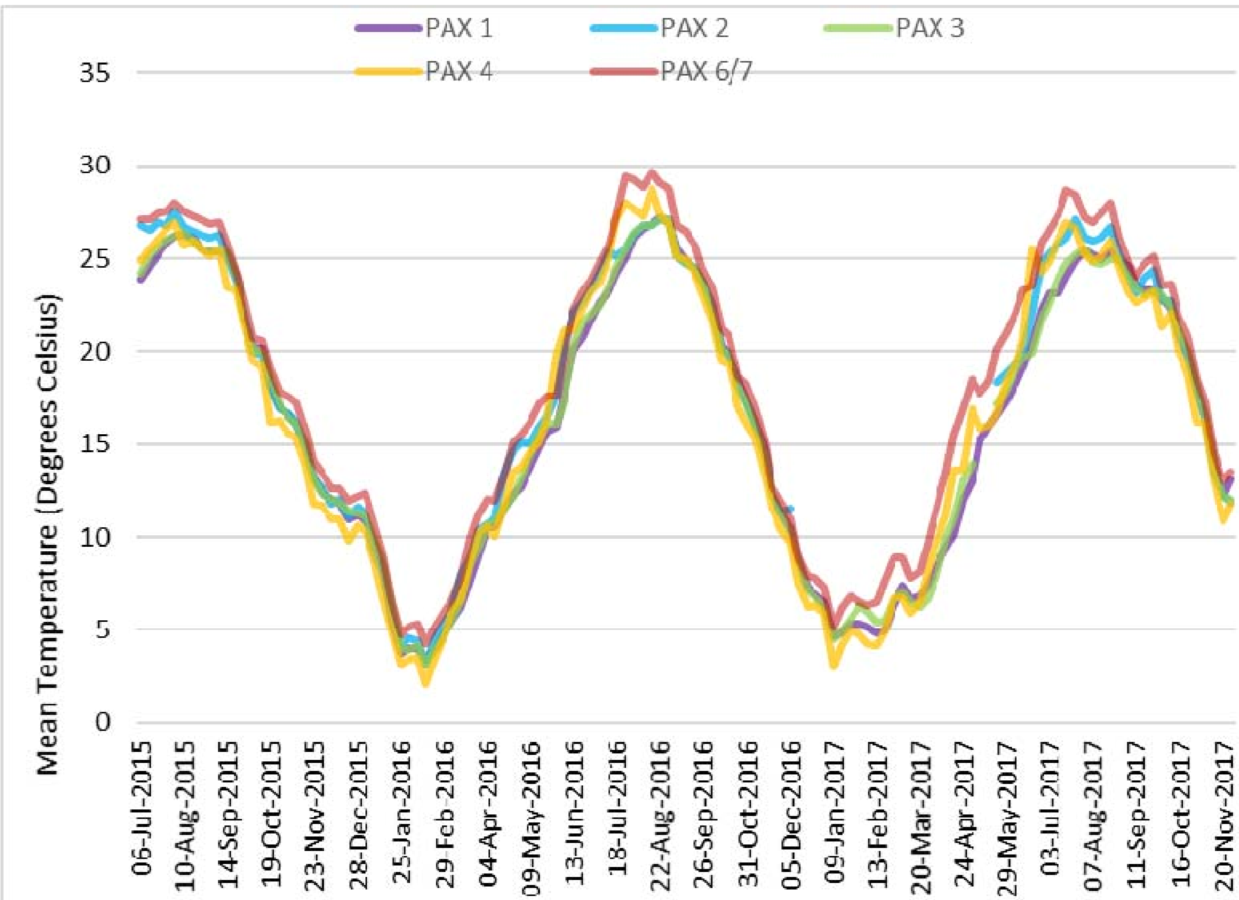


Figure 4. Weekly mean temperatures recorded by the C-PODs at each deployment location.

Diurnal activity was examined by summing DPM over each hour for all deployments. **Figure 5** shows the hourly occurrence data at each site. There is a high degree of variability within and between sites, but the general pattern shows that the highest acoustic activity occurs from 8pm until 6am (local time) with minimum activity around the middle of the day.

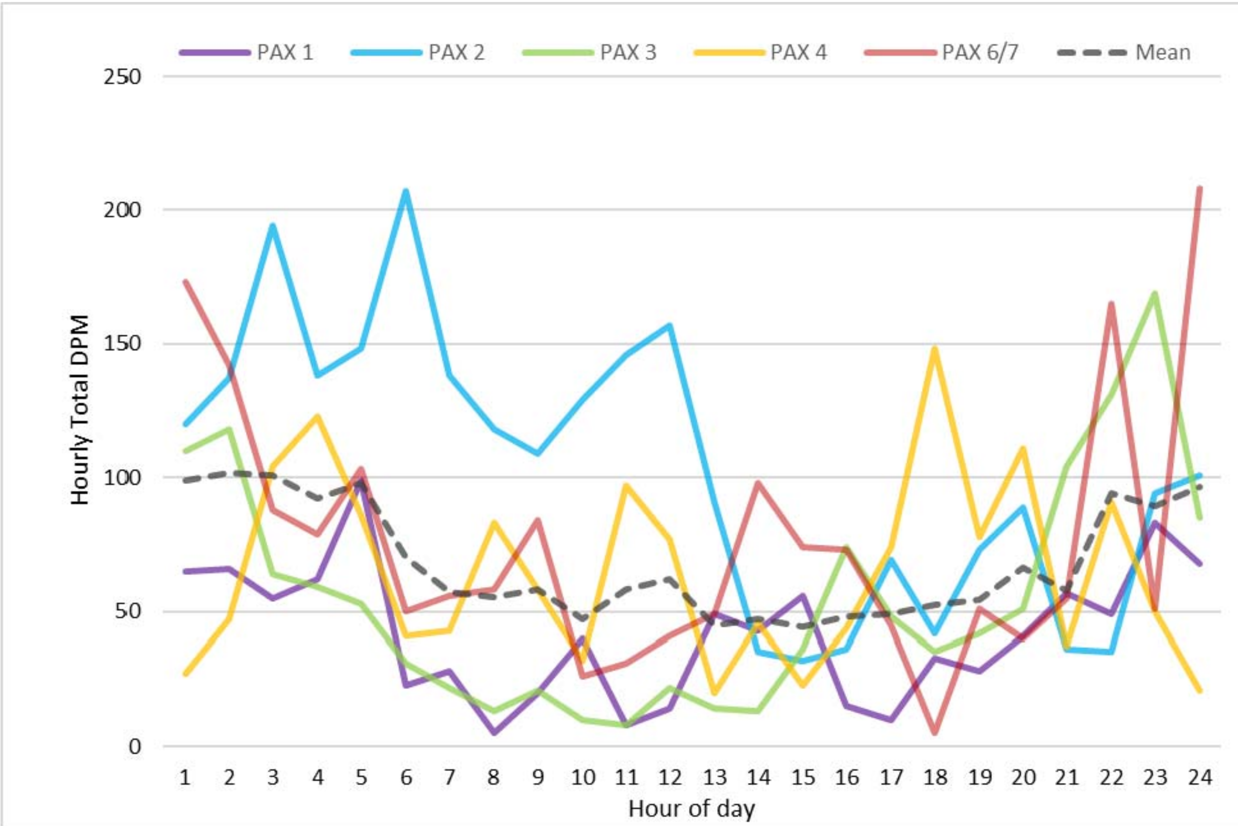


Figure 5. Summed hourly dolphin DPM for all deployments by site.

Potomac River C-PODs

The deployment sites in the Potomac River was shifted from PAX 6 to PAX 7 on the same day for the duration of the study on November 19, 2016. Summer occurrence in the Potomac in 2017 was higher than in 2016, with a large peak in late June and the first week of July (**Figure 6**). However, overall dolphin occurrence in the study area in 2017 was higher than in 2016 (**Table 5**) and a valid comparison between the two Potomac River sites would require additional years of data.

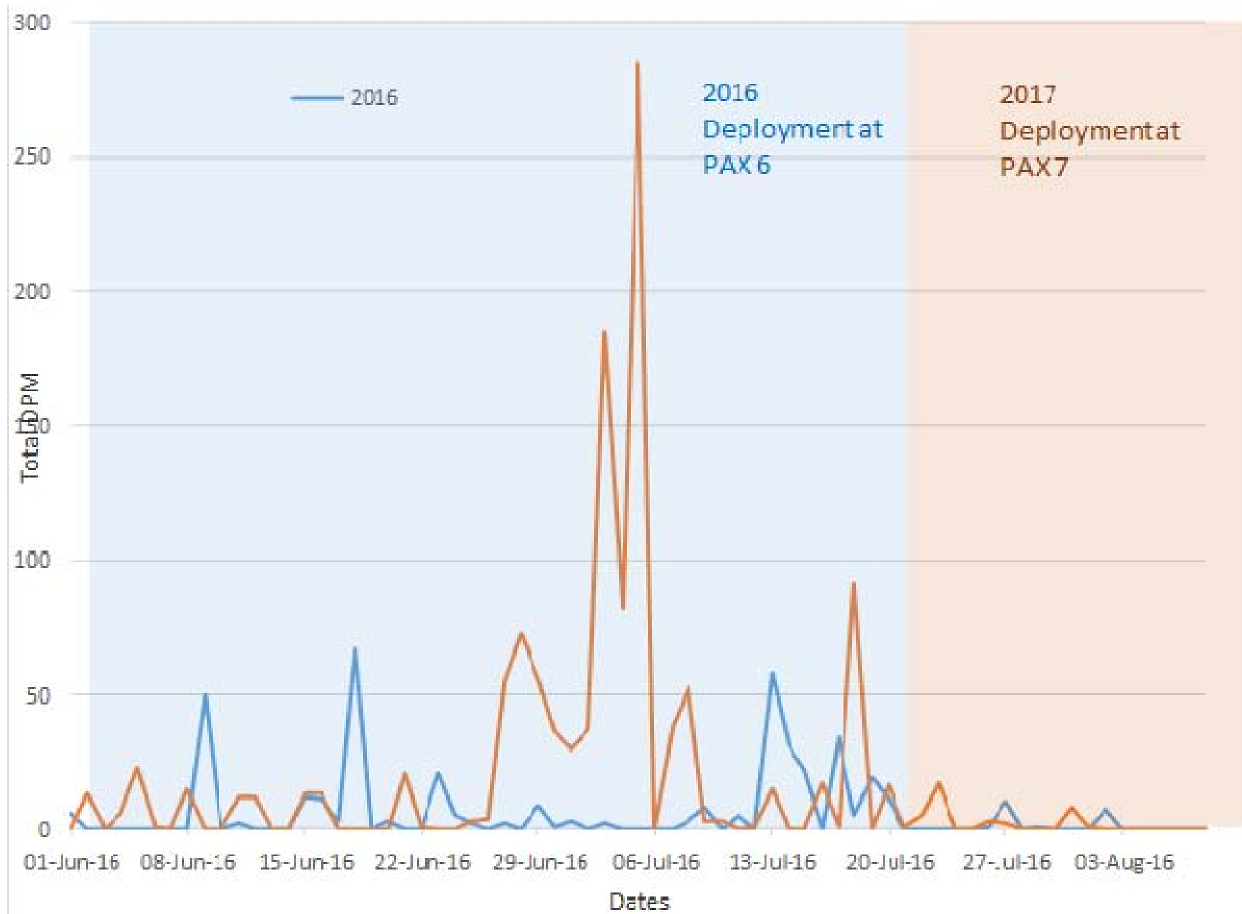


Figure 6. Dolphin DPM in the Potomac River during most of the summer season (01 June to 08 August) at PAX sites 6 and 7, comparing 2016 and 2017. The blue shading indicates the period that the C-POD was located at PAX 6 in 2016 and the orange shading is the period when the C-POD was shifted to PAX 7.

3.2 Photo-Identification

Four common bottlenose dolphin sightings were made during the C-POD refurbishment trips and vessel survey effort north of the study site and into the Patuxent River (**Figure 7, Table 6**). Identification photos were collected during three of the four sightings. Group size ranged from five to 70 individuals (mean=30). Approximately one-half of the photographs have been sorted and prepared for cataloging. These data will be archived and available for future analysis and/or collaboration with researchers from Georgetown University and the Mid-Atlantic Bottlenose Dolphin Catalog.

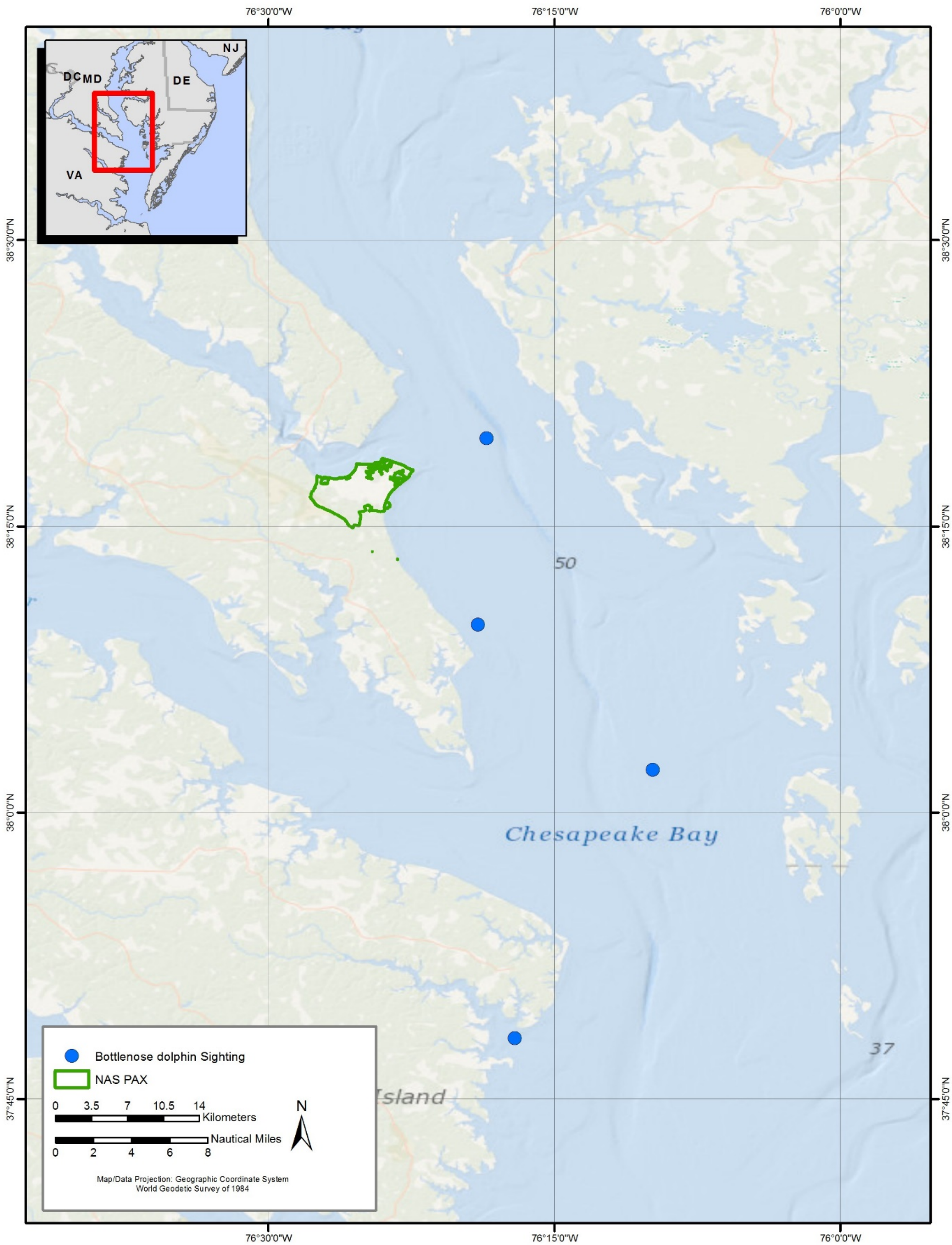


Figure 7. Common bottlenose dolphin sightings made opportunistically during the C-POD refurbishment trips.

Table 6. Summary of opportunistic sightings during C-POD refurbishment trips.

Date	Time (EDT)	Latitude (°N)	Longitude (°W)	Group Size	Number of Photos Taken
07/12/2015	08:52:08	38.327083	76.310200	35	1487
07/19/2016	11:01:13	38.037200	76.200100	10	274
07/19/2016	14:48:39	38.163916	76.316650	5	0
07/26/2016	12:43:57	37.802833	76.286400	70	752

3.3 Aerial Surveys

A total of 28 days of aerial survey effort was completed during the study period from April 2015 through October 2017 (**Table 7**). Concerted effort was made to schedule surveys when optimal weather and sea state conditions were forecast to maximize visibility and detectability (**Figure 8**). Monthly effort was conducted consistently and all tracklines were completed in all but three surveys. Tracklines were truncated for these individual surveys because of mechanical issues, weather, and site restrictions and closures, respectively. There were 24 sightings of common bottlenose dolphins, 20 on-effort (*n*=548 individuals) and four off-effort (*n*=30 individuals) during the entire study period, with estimated group sizes ranging from 2 to 90 individuals (**Tables 8 and 9, Figures 9 through 11**). All on-effort sightings occurred between April and August, with the peak numbers of sightings in June and July. Sightings were concentrated primarily in the southern portion of the survey area, near the confluence of the Potomac River and the Chesapeake Bay, with the exception of three sightings that occurred in the northern portion of the study site (**Figure 9**). All off-effort sightings occurred between September 2015 and April 2016. These sightings occurred outside of the study area, in the center of the Chesapeake Bay, during return transits to Norfolk.

There were 42 sea turtle sightings (*n*=51 individuals) at the PAX study site from April 2015 through October 2017 (41 on-effort, 1 off-effort), all occurring between the months of May and October (**Figures 12 and 13**, **Table 10**). Thirty-nine of the sightings were positively identified as loggerhead sea turtles (*Caretta caretta*), and three individuals were classified as unidentified sea turtles.

Cownose rays were also observed across the range of the study area from April through October (**Figure 13 Table 11**). This species was the most abundant identified species observed in the PAX study area.

Table 7. Summary of aerial survey effort conducted at the NAS PAX study site.

Date	Tracklines Flown AM	Tracklines Flown PM	Total km Flown	Hobbs Hours
26-Apr-2015	1 to 9	17 to 10, Z	579.3	5.2
23-May-2015	1 to 9	17 to 10, Z	583.4	5.7
28-Jun-2015	1 to 9	17 to 10, Z	573.6	5.6
19-Jul-2015	Z, 17 to 9	8 to 1	579.7	5.2
16-Aug-2015	1 to 9	17 to 10, Z	578.0	5.2
20-Sep-2015	Z, 9 to 17	8 to 1	573.0	5.0
31-Oct-2015	1 to 9	17 to 10, Z	581.2	5.2
15-Nov-2015	Z, 9 to 17	8 to 1	584.4	4.7
6-Dec-2015	1 to 9	17 to 10, Z	590.0	5.4
31-Jan-2016	Z, 9 to 17	8 to 1	586.5	5.5
21-Feb-2016	Z, 9 to 17	8 to 1	582.1	5.6
26-Mar-2016	1 to 9	17 to 10, Z	584.1	5.2
17-Apr-2016	1 to 8	17 to 9, Z	583.1	5.2
8-May-2016	Z, 9 to 17	8 to 1	574.9	6.3
12-Jun-2016	Z, 9 to 17	8 to 1	589.7	5.2
23-Jul-2016	1 to 9	17 to 10, Z	580.4	6.2
7-Aug-2016	Z, 9 to 17	8 to 1	584.7	5.8
2-Oct-2016	Z, 9 to 17	8 to 1	588.8	5.6
6-Nov-2016	1 to 9	17 to 10, Z	580.0	5.3
29-Apr-2017	1 to 9	N/A	332.0	3.9
3-Jun-2017	1 to 9	17 to 10, Z	578.3	5.2
4-Jun-2017	1 to 9	10 to 17, Z	580.1	4.7
25-Jun-2017	1 to 10	17 to 11, Z	568.7	5.7
22-Jul-2017	N/A	1 to 13	441.2	4.7
23-Jul-2017	1 to 9	17 to 10, Z	597.7	5.4
3-Sep-2017	N/A	1 to 17, Z	571.7	5.3
4-Sep-2017	1 to 17	Z	569.0	5.4
7-Oct-2017	1 to 9	17 to 10, Z	563.1	5.3
Totals			**15858.4**	**148.7**

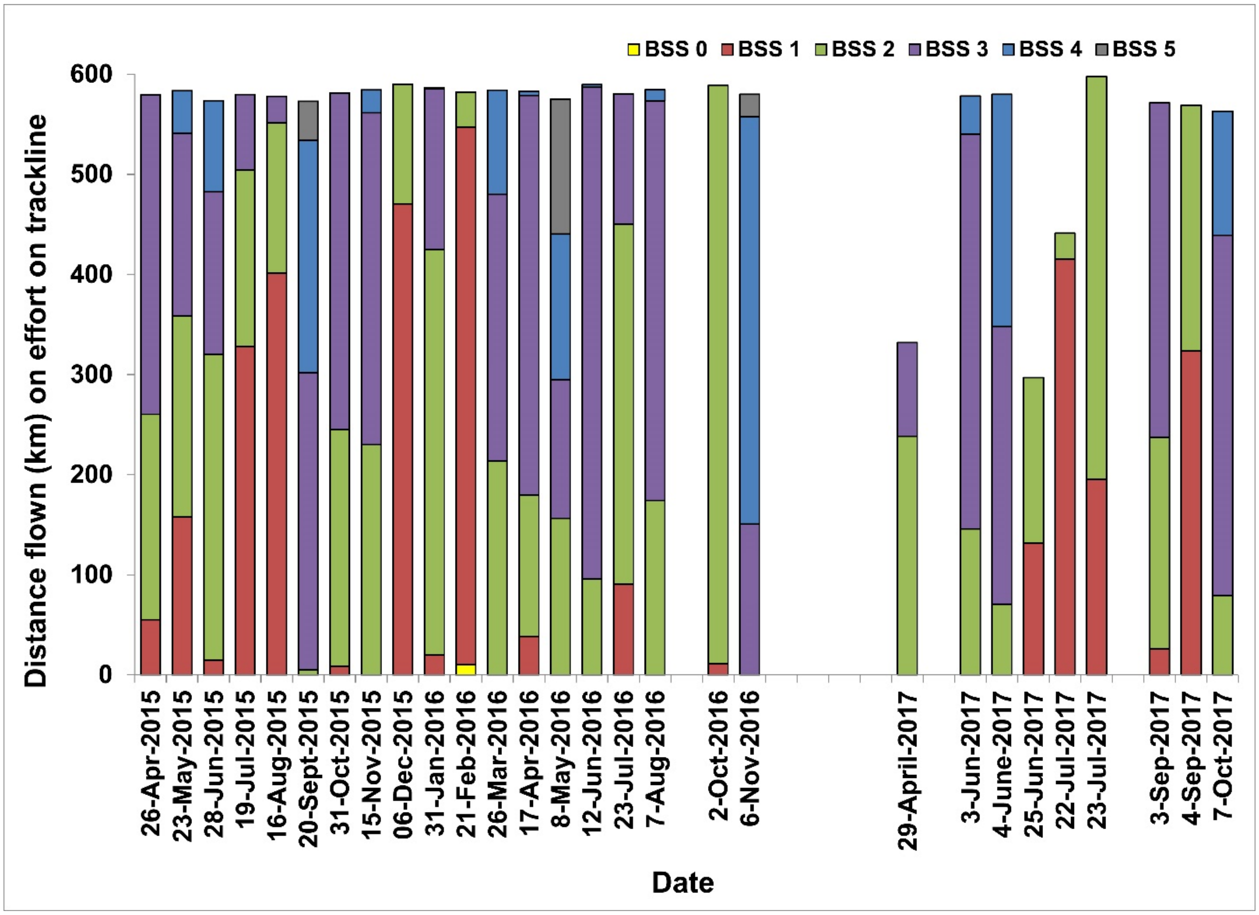


Figure 8. Summary of effort by Beaufort Sea State (BSS) for each survey at the NAS PAX study site. Blanks indicate the months in which no aerial surveys were conducted at the study site.

Table 8. Summary of aerial survey sightings at the NAS PAX study site (off-effort sightings in parentheses).

Common Name	Scientific Name	Number of Sightings	Number of Individuals
Common bottlenose dolphin	*Tursiops truncatus*	20 (4)	548 (30)
Loggerhead sea turtle	*Caretta caretta*	38 (1)	47 (1)
Unidentified sea turtle	N/A	3	3
Cownose ray	*Rhinoptera bonasus*	53	1607
Ocean sunfish	*Mola mola*	1	1

Table 9. Common bottlenose dolphin sightings from aerial surveys at the NAS PAX study site.

Date	Time (EDT)	On-/Off-Effort	Latitude (°N)	Longitude (°W)	Trackline	Group Size
26-Apr-15	10:32:48	On	37.952668	76.292179	2	3
28-Jun-15	09:35:18	On	37.92272	76.198775	1	16
28-Jun-15	10:06:14	On	37.950588	76.335386	2	6
28-Jun-15	10:15:00	On	37.976134	76.27539	3	3
19-Jul-15	09:26:48	On	38.060937	76.39591	Z	8
20-Sep-15	08:56:30	Off	37.5815	76.346893	N/A	8
15-Nov-15	10:06:00	Off	37.805033	76.28825	N/A	8
6-Dec-15	09:16:19	Off	37.811791	76.305475	N/A	12
17-Apr-16	15:03:43	Off	37.296368	76.16051	N/A	2
8-May-16	10:40:39	On	38.238632	76.118558	11	28
12-Jun-16	09:13:57	On	37.93714	76.322106	Z	70
23-Jul-16	09:34:21	On	37.920542	76.206547	1	23
23-Jul-16	09:41:39	On	37.912137	76.122343	1	5
23-Jul-16	09:55:40	On	37.967303	76.063693	2	32
23-Jul-16	10:20:28	On	37.984998	76.172077	3	2
23-Jul-16	10:45:19	On	38.047783	76.289443	5	3
23-Jul-16	11:14:19	On	38.081213	76.267852	6	13
23-Jul-16	15:19:40	On	37.963757	76.378748	Z	80
7-Aug-16	09:46:40	On	38.074078	76.475926	Z	45
3-Jun-17	10:29:31	On	38.07621	76.312405	6	31
3-Jun-17	14:48:32	On	38.235695	76.33883	11	28
4-Jun-17	09:02:08	On	37.951506	76.352919	2	22
22-Jul-17	13:53:50	On	37.955378	76.309014	2	90
23-Jul-17	14:16:20	On	38.290835	76.372693	13	40

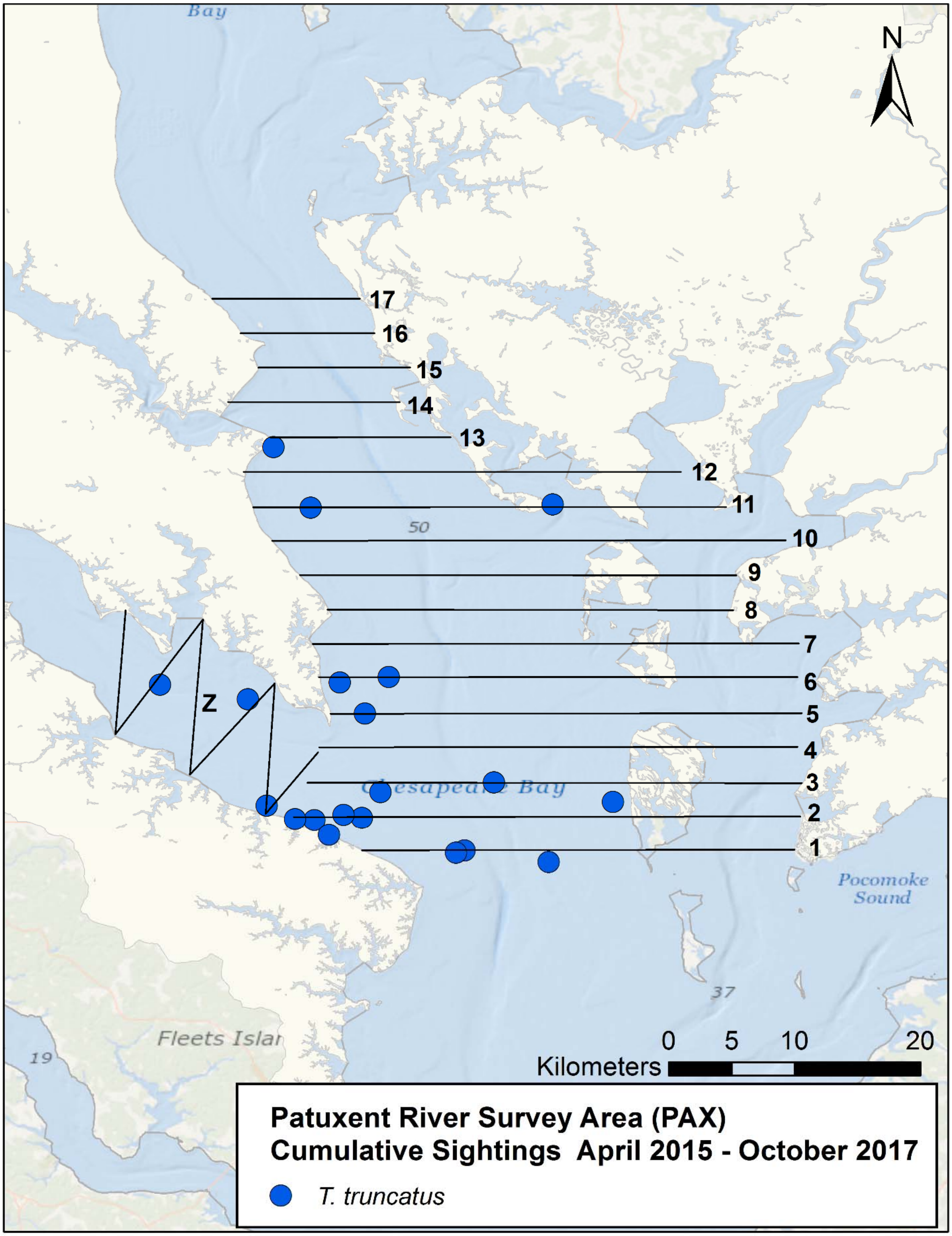


Figure 9. All on-effort common bottlenose dolphin sightings from aerial surveys at the NAS PAX study site.

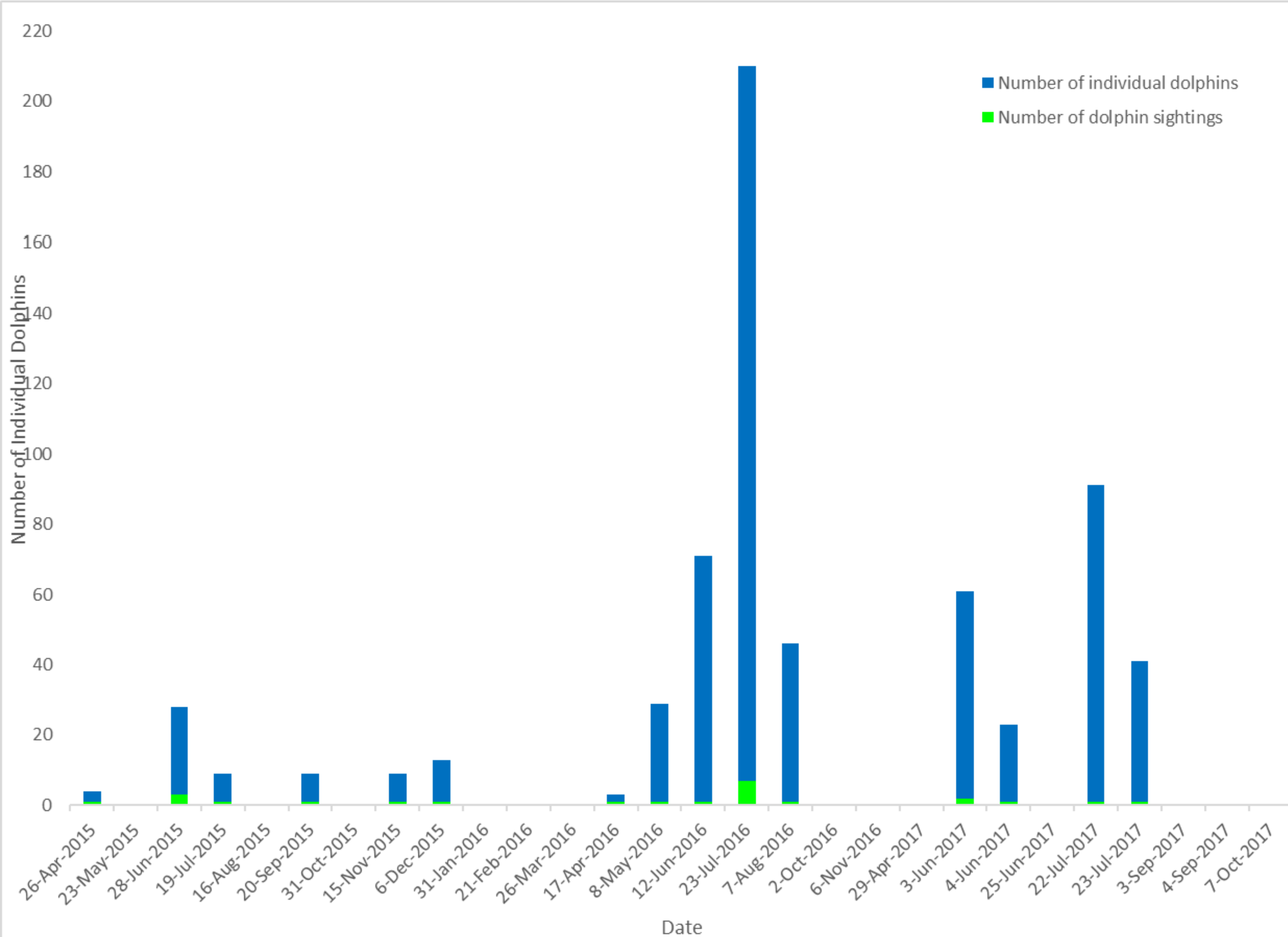


Figure 10. Number of individual common bottlenose dolphins observed per survey from aerial surveys at the NAS PAX study site during the study period from April 2015 through October 2017.

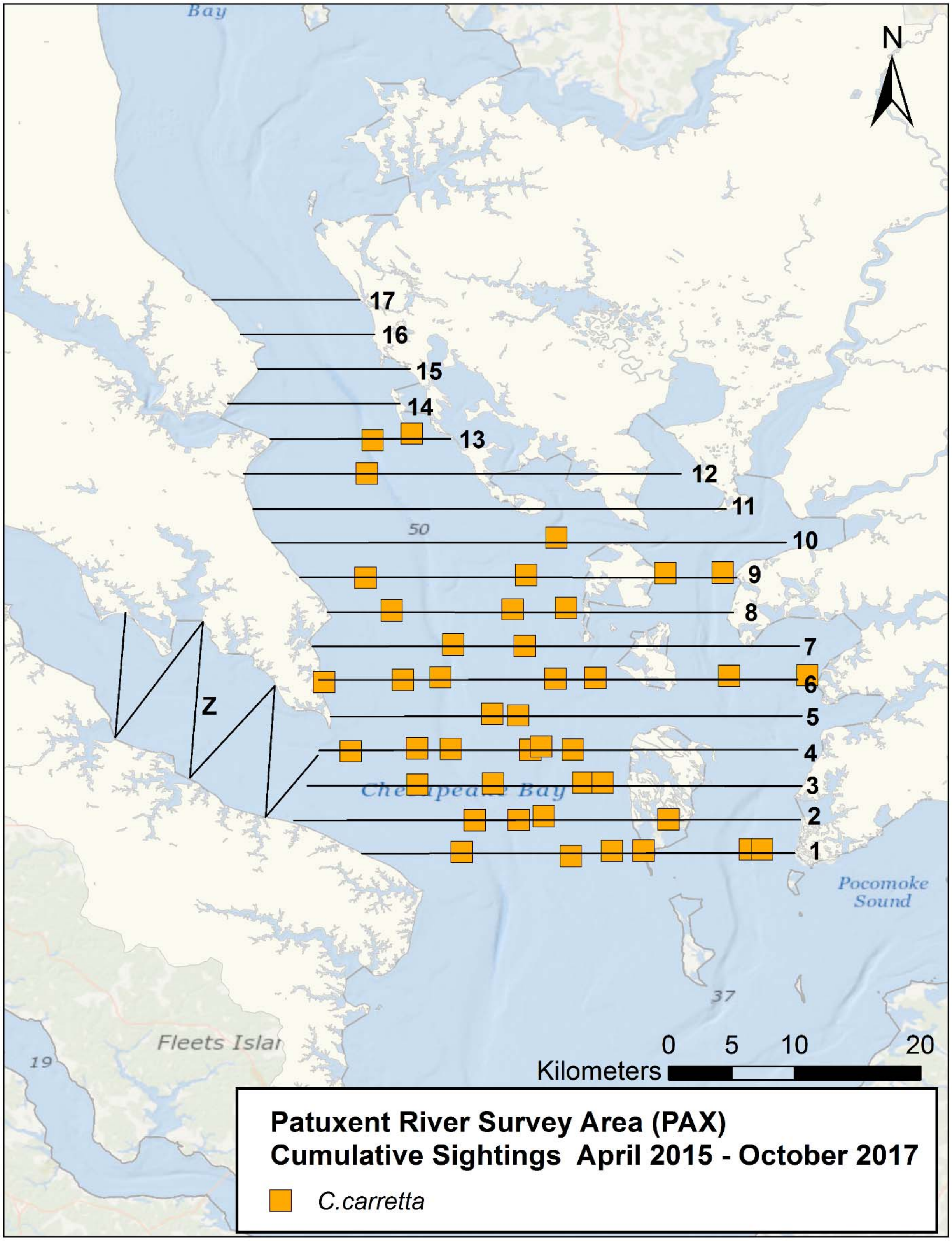


Figure 11. All on-effort sea turtle sightings from aerial surveys at the NAS PAX study site.

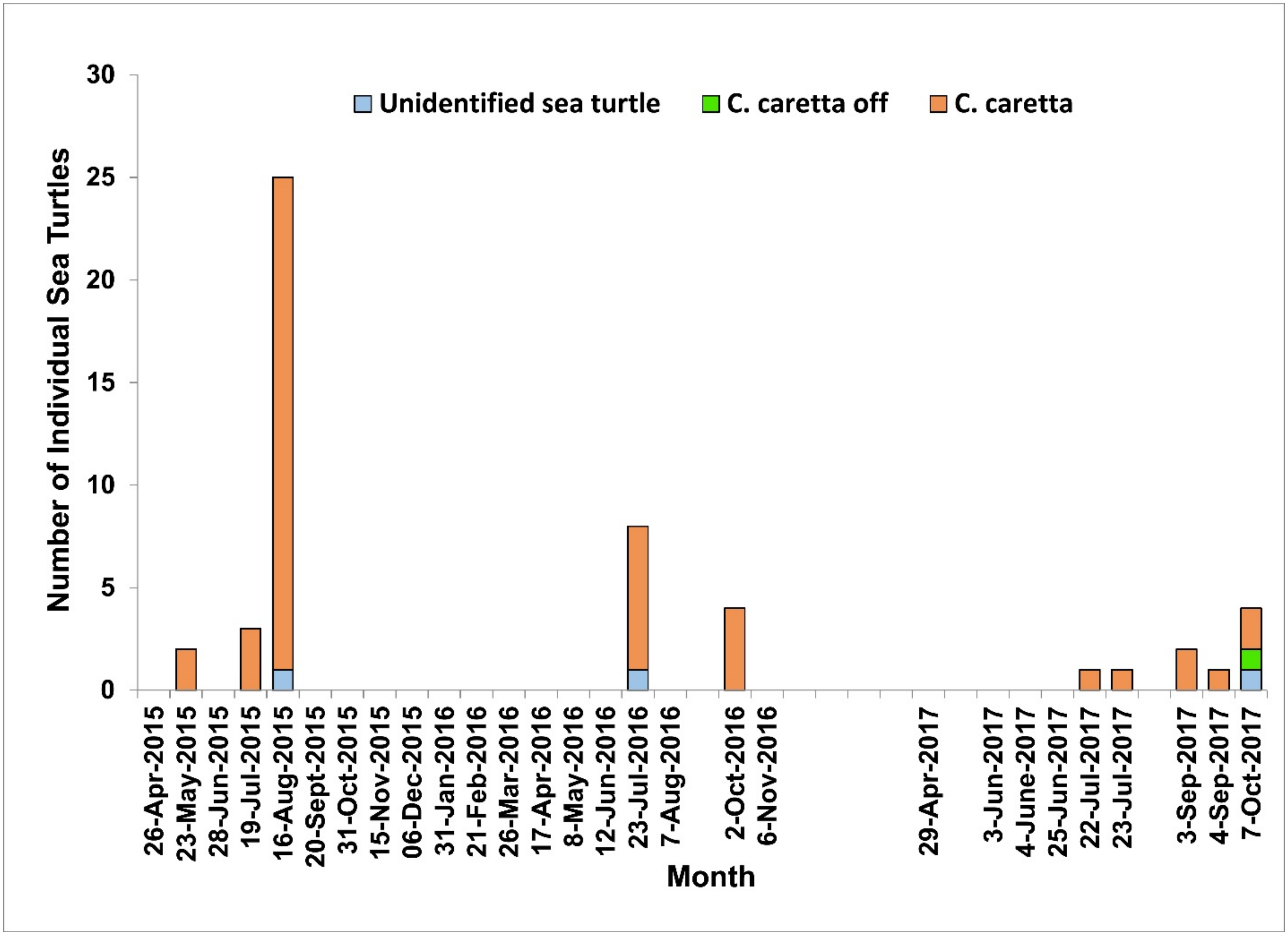


Figure 12. Numbers of individual sea turtles observed per month during aerial surveys at the NAS PAX study site. Blank labels indicate the months in which no aerial surveys were conducted at the study site.

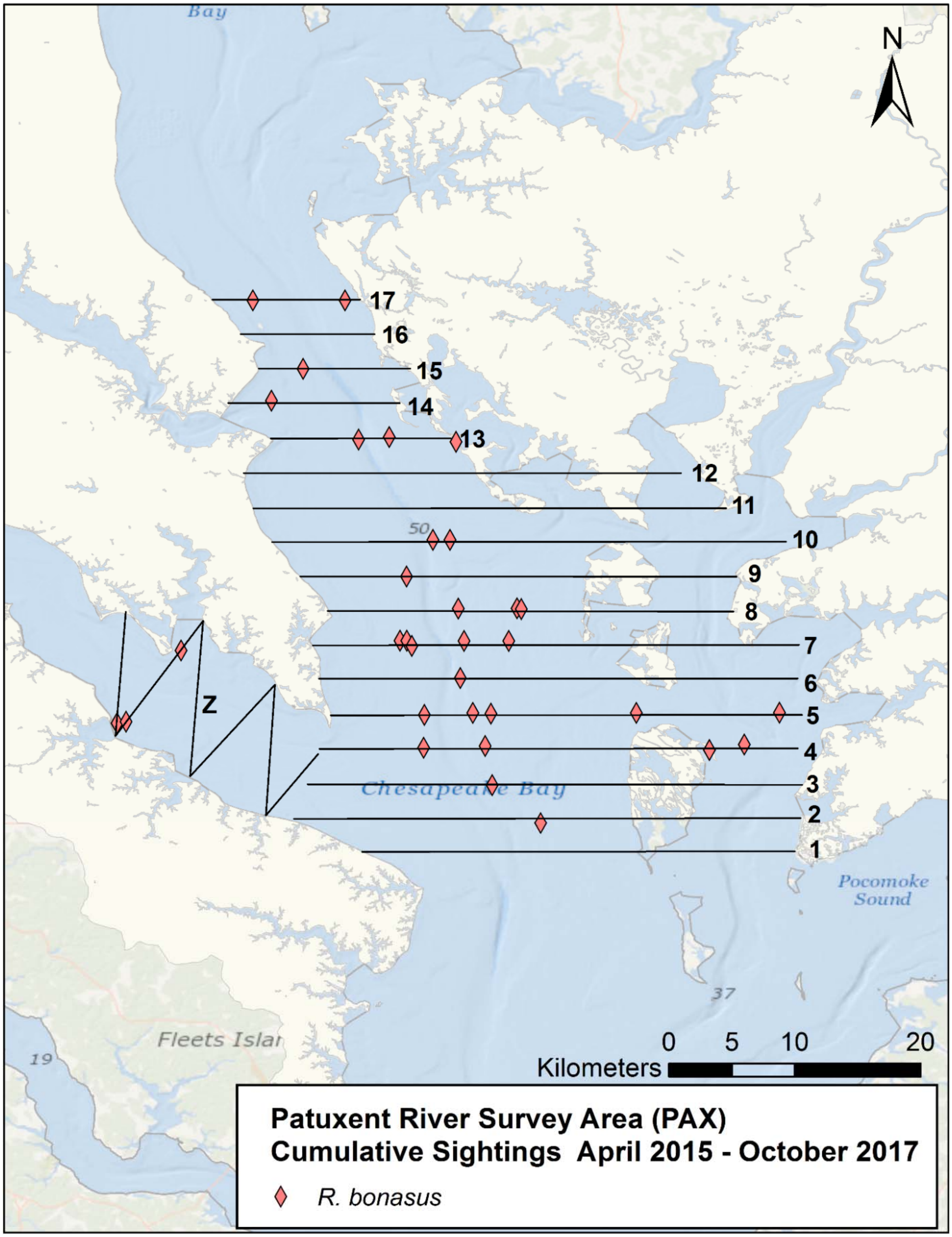


Figure 13. Cownose ray sightings from aerial surveys at the NAS PAX study site.

Table 10. Sea turtle sightings from aerial surveys at the NAS PAX study site.

Date	Time (EDT)	On-/ Off-Effort	Latitude (°N)	Longitude (°W)	Trackline	Species	Group Size
23-May-15	9:54:02	On	38.017747	76.138852	4	Loggerhead Sea Turtle	1
23-May-15	10:56:49	On	38.176567	76.142949	9	Loggerhead Sea Turtle	1
19-Jul-15	11:13:27	On	38.173935	76.288774	9	Loggerhead Sea Turtle	1
19-Jul-15	12:39:01	On	38.146655	76.106575	8	Loggerhead Sea Turtle	1
19-Jul-15	13:23:22	On	38.019009	76.241886	4	Loggerhead Sea Turtle	1
16-Aug-15	9:36:47	On	37.924578	76.201294	1	Loggerhead Sea Turtle	1
16-Aug-15	9:40:01	On	37.925556	76.064672	1	Loggerhead Sea Turtle	1
16-Aug-15	9:40:42	On	37.925789	76.035968	1	Loggerhead Sea Turtle	1
16-Aug-15	9:42:59	On	37.926904	75.939115	1	Loggerhead Sea Turtle	2
16-Aug-15	9:43:14	On	37.926918	75.928397	1	Loggerhead Sea Turtle	1
16-Aug-15	9:48:37	On	37.954512	76.013382	2	Loggerhead Sea Turtle	3
16-Aug-15	9:51:52	On	37.953888	76.149536	2	Loggerhead Sea Turtle	1
16-Aug-15	10:03:29	On	37.986236	76.241837	3	Loggerhead Sea Turtle	1
16-Aug-15	10:05:07	On	37.986977	76.172691	3	Unidentified Sea Turtle	1
16-Aug-15	10:07:03	On	37.987719	76.090750	3	Loggerhead Sea Turtle	1
16-Aug-15	10:07:28	On	37.987812	76.073116	3	Loggerhead Sea Turtle	1
16-Aug-15	10:18:23	On	38.018012	76.100328	4	Loggerhead Sea Turtle	1
16-Aug-15	10:23:11	On	38.016266	76.302422	4	Loggerhead Sea Turtle	4
16-Aug-15	10:29:11	On	38.050299	76.173800	5	Loggerhead Sea Turtle	3
16-Aug-15	10:47:42	On	38.079053	76.326557	6	Loggerhead Sea Turtle	1
16-Aug-15	11:26:45	On	38.178221	76.015981	9	Loggerhead Sea Turtle	1
16-Aug-15	11:27:56	On	38.178686	75.963921	9	Loggerhead Sea Turtle	1
23-Jul-16	10:03:23	On	37.953703	76.189552	2	Loggerhead Sea Turtle	1
23-Jul-16	10:38:12	On	38.018575	76.211452	4	Loggerhead Sea Turtle	1
23-Jul-16	11:08:35	On	38.082920	76.079766	6	Loggerhead Sea Turtle	1
23-Jul-16	11:09:28	On	38.082388	76.116128	6	Loggerhead Sea Turtle	1
23-Jul-16	11:12:55	On	38.081201	76.254733	6	Loggerhead Sea Turtle	1
23-Jul-16	11:39:41	On	38.145253	76.154868	8	Unidentified Sea Turtle	1
23-Jul-16	11:42:35	On	38.144247	76.265086	8	Loggerhead Sea Turtle	1
23-Jul-16	14:00:23	On	38.298955	76.282322	13	Loggerhead Sea Turtle	1
2-Oct-16	11:07:07	On	38.268872	76.287573	12	Loggerhead Sea Turtle	1
2-Oct-16	13:39:31	On	38.112069	76.143958	7	Loggerhead Sea Turtle	1
2-Oct-16	14:06:44	On	38.049042	76.150014	5	Loggerhead Sea Turtle	2
22-Jul-17	14:54:22	On	38.113441	76.209136	7	Loggerhead Sea Turtle	1
23-Jul-17	14:11:23	On	38.304844	76.246729	13	Loggerhead Sea Turtle	1
3-Sep-17	13:14:31	On	37.957451	76.126828	2	Loggerhead Sea Turtle	1
3-Sep-17	14:02:05	On	38.084781	75.957914	6	Loggerhead Sea Turtle	1
4-Sep-17	11:09:44	On	38.020549	76.129126	4	Loggerhead Sea Turtle	1
7-Oct-17	10:21:17	On	37.920792	76.102170	1	Loggerhead Sea Turtle	1
7-Oct-17	11:20:17	Off	38.085316	75.887080	1	Loggerhead Sea Turtle	1
7-Oct-17	11:28:59	On	38.083399	76.220695	6	Loggerhead Sea Turtle	1
7-Oct-17	14:55:53	On	38.210589	76.115100	10	Unidentified Sea Turtle	1

Table 11. Cownose ray sightings from aerial surveys at the NAS PAX study site.

Date	Time	On-/ Off-Effort	Latitude (°N)	Longitude (°W)	Trackline	Group Size
23-May-2015	14:29:44	On	38.426525	76.231811	17	6
23-May-2015	14:33:48	On	38.394528	76.333792	16	16
23-May-2015	14:50:05	On	38.301227	76.293318	13	3
28-Jun-2015	09:24:13	On	37.918460	76.258686	1	55
28-Jun-2015	09:57:21	On	37.952304	76.318524	2	10
28-Jun-2015	10:10:36	On	37.984476	76.232340	3	13
28-Jun-2015	10:18:35	On	37.987381	76.175172	3	6
28-Jun-2015	10:32:49	On	38.017861	76.106289	4	12
28-Jun-2015	10:34:50	On	38.016980	76.188668	4	25
28-Jun-2015	10:59:47	On	38.079702	76.240483	6	27
28-Jun-2015	11:04:50	On	38.112616	76.255126	7	8
28-Jun-2015	11:05:05	On	38.112713	76.244607	7	60
28-Jun-2015	11:20:17	On	38.143835	76.124996	8	30
28-Jun-2015	11:23:29	On	38.145208	76.242961	8	15
28-Jun-2015	11:29:55	On	38.176415	76.242037	9	14
28-Jun-2015	14:48:36	On	38.237232	76.262939	11	30
19-Jul-2015	10:02:10	On	38.425396	76.345038	17	70
16-Aug-2015	09:52:03	On	37.953896	76.157048	2	10
20-Sep-2015	10:01:07	On	38.208217	76.990547	10	15
17-Apr-2016	10:16:10	On	38.050208	75.912298	5	25
23-Jul-2016	10:31:24	On	38.021121	75.944208	4	11
23-Jul-2016	10:52:57	On	38.048000	76.235460	5	27
23-Jul-2016	10:54:27	On	38.049153	76.174843	5	25
23-Jul-2016	11:11:38	On	38.081695	76.202809	6	85
23-Jul-2016	11:20:28	On	38.116322	76.330073	7	55
23-Jul-2016	11:22:17	On	38.115690	76.257556	7	40
23-Jul-2016	11:22:26	On	38.115698	76.251413	7	55
23-Jul-2016	11:23:41	On	38.115359	76.199365	7	65
23-Jul-2016	11:24:41	On	38.115400	76.158585	7	22
23-Jul-2016	11:41:00	On	38.144868	76.204594	8	85
23-Jul-2016	11:48:34	On	38.174122	76.251628	9	40
23-Jul-2016	13:37:30	On	38.425638	76.391342	17	8
23-Jul-2016	13:39:38	On	38.425637	76.307563	17	25
23-Jul-2016	13:47:41	On	38.363253	76.345658	15	11
23-Jul-2016	13:54:45	On	38.334350	76.374389	14	35
23-Jul-2016	14:58:24	On	38.106782	76.456762	Z	25
7-Aug-2016	14:14:22	On	38.016066	75.976087	4	5
7-Aug-2016	14:26:29	On	37.984198	76.173693	3	85
7-Aug-2016	14:38:38	On	37.949486	76.129626	2	30
2-Oct-2016	09:38:08	On	38.040524	76.514971	Z	30
2-Oct-2016	09:40:43	On	38.041875	76.506666	Z	90
2-Oct-2016	11:15:21	On	38.301311	76.267336	13	40
2-Oct-2016	13:25:07	On	38.145203	76.151131	8	15
2-Oct-2016	13:42:08	On	38.110900	76.246730	7	11
2-Oct-2016	14:03:56	On	38.050009	76.042454	5	8
2-Oct-2016	14:15:49	On	38.018138	76.236060	4	11
25-Jun-2017	13:53:33	On	38.296900	76.206511	31	75
25-Jun-2017	13:55:47	On	38.298876	76.295223	32	15
25-Jun-2017	14:27:09	On	38.207539	76.227618	39	8
25-Jun-2017	14:27:32	On	38.207644	76.212023	40	25

3.4 Statistical Analyses

The aerial survey sighting data used for statistical analyses varied slightly from those reported above because one trackline (Z6 from June 2016) was excluded in the statistical analyses as it was in actually in the CB survey block. There was a sighting while on this transect and hence the disparity in the numbers reported below.

All 23 transects were covered during 26 of the 28 surveys for a total of nearly 14,800 km of survey effort flown (**Table 12**). For three surveys (survey numbers 3, 15 and 23) transects in the PR block were misaligned and fell in the CB block. These misaligned transects were excluded or truncated at the boundary between blocks. On two surveys (23 and 25), transect 9 was covered twice; only transects 1 to 9 were covered on survey 20; only transects 1 to 13 were covered on survey 24.

Table 12. Summary of surveys by season and block: total search effort (L) and number of detected groups (n) by species (no truncation).

Season	Block	*L* (km)	Number of groups detected (*n*)						
			Tt	Cc	UT	Rb	UR	Mm	Total
Spring	CB	2628.6	2	2	-	4	-	-	**8**
	PR	375.8	-	-	-	-	-	-	**-**
Summer	CB	5109.6	14	28	2	39	68	-	**151**
	PR	716.8	3	-		1	5	-	**9**
Autumn	CB	3727.3	-	8	1	7	-	1	**17**
	PR	590.3	-	-	-	2	-	-	**2**
Winter	CB	1403.8	-	-	-	-	2	-	**2**
	PR	225.8	-	-	-	-	-	-	**-**
Total		**14777.9**	**19**	**38**	**3**	**53**	**75**	**1**	**189**

Key: CB=Chesapeake Bay, PR=Potomac River, Tt=common bottlenose dolphin, Cc=loggerhead turtle, UT=unidentified turtle, Rb=cownose ray, UR=unidentified ray, Mm=ocean sunfish.

There were 189 groups of animals detected in total, with the unidentified elasmobranch (rays, sharks and skates) being the most frequently recorded (75 groups). Comments in the data suggested that all these detections were of rays and so this species group will be referred to as unidentified rays hereafter (**Table 12**). The next most frequently sighted species were cownose rays (53 groups), loggerhead turtles (38 groups), and common bottlenose dolphins (19 groups). In addition, three unidentified sea turtles and one ocean sunfish were detected. Turtles were not detected in the Potomac River survey block and there were no detections of animals at all during eight of the surveys. **Appendix A** presents estimates per season that have higher average densities because the encounter rates for each survey were higher than the average encounter rate per season.

Turtles were detected most frequently as single animals, but one group of four turtles was detected on 16 August 2015 (**Table 13**). The smallest group of dolphins detected consisted of two animals and the maximum was 90 animals on 22 July 2017. The smallest detected group of cownose rays was three animals, and the maximum was 90 rays. For unidentified rays, the smallest group detected consisted of one animal, and the maximum was 225 rays. The distributions of group size for each species is provided in **Table 13**.

Table 13. Distributions of recorded group sizes for each species observed.

Group size	Cc	UT	Tt	Rb	Ur	MM
1	33	3	-	-	2	1
2	2	-	1	-	-	-
3	2		3	1	1	-
4	1	-	-	-	-	-
5–9	-	-	3	7	13	-
10–19	-	-	2	15	11	-
20–49	-	-	8	18	31	-
50–99	-	-	2	12	11	-
≥ 100	-	-	-	-	6	-
Total number of groups	**38**	**3**	**19**	**53**	**75**	**1**
Maximum group size	**4**	**1**	**90**	**90**	**225**	**1**

Key: CB=Chesapeake Bay, PR=Potomac River, Tt=common bottlenose dolphin, Cc=loggerhead turtle, UT=unidentified turtle, Rb=cownose ray, UR=unidentified ray, Mm=ocean sunfish.

Probability of Detection

Although the numbers of detected groups were small for detection-function estimation, particularly for dolphins, detection functions were estimated separately for turtles, common bottlenose dolphins, and cownose rays.

The maximum distance at which a dolphin group was detected was 1,291 m and no further truncation was used because so few groups were detected. The hazard rate detection function had a slightly lower AIC than the half-normal detection function and so was selected (**Figure 14a; Table 14**). This resulted in a probability of detection of common bottlenose dolphin groups of 0.28 (CV=0.60) which was equivalent to an estimated effective strip half-width of 360 m.

Few detections of turtles occurred in the outermost distance interval, so the data were truncated at 899 m, leaving 40 groups of turtles. The hazard rate detection function was selected (**Figure 14b; Table 14**). The estimated probability of detection of turtles was 0.45 (CV=0.24).

Only one group of cownose rays were detected in the farthest distance bin; therefore, these data were truncated at 899 m, leaving 52 groups. A half-normal detection function had a lower AIC than a hazard rate detection function, so was selected (**Figure 14c; Table 14**). This resulted in a probability of detection of cownose ray groups of 0.40 (0.12).

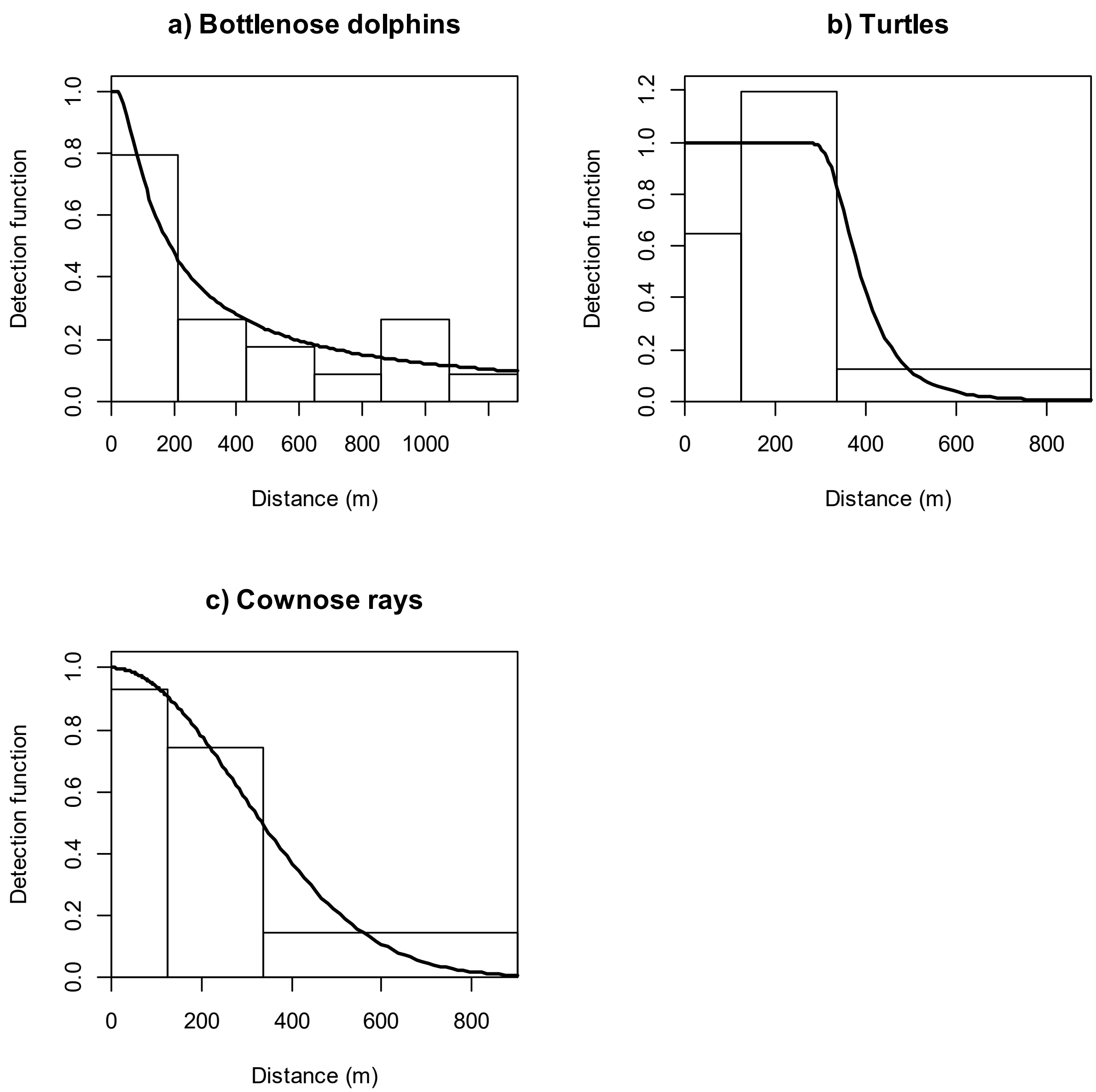


Figure 14. Estimated detection function (thick black line) overlaid onto the scaled perpendicular distance distributions for a) common bottlenose dolphin groups, b) turtle groups, and c) cownose ray groups.

Table 14. Summary of detection-function fitting and group-size estimation: number of groups used in detection function fitting (n); AIC values for the half-normal (HN) and hazard rate (HR) detection functions; and estimates of probability of detection ($\hat{p}$) for the selected function (shown in bold), $\hat{f}(0)$; effective strip half-width ($\hat{\mu}$; metres), average group size ($\bar{s}$), and regression-based ($\hat{E}[s]$) estimates. Coefficients of variation are given in parentheses.

Species or species group	n	AIC		$\hat{p}$	$\hat{f}(0)$	$\hat{\mu}$	$\bar{s}$	$\hat{E}[s]$
		HN	HR					
Common bottlenose dolphins	19	269.4	**266.9**	0.28 (0.60)	0.0028 (0.60)	360 (0.60)	25.2 (0.23)	15.3 (0.38)
Turtles	40	82.23	**80.28**	0.45 (0.24)	0.0024 (0.24)	406 (0.24)	1.23 (0.09)	1.17 (0.06)
Cownose rays	52	**112.80**	114.73	0.40 (0.12)	0.0028 (0.12)	356 (0.12)	29.7 (0.11)	28.7 (0.14)

Estimated Mean Group Sizes

The size-bias regression estimates accounted for the tendency of smaller groups being missed at larger distances and thus these estimates were lower than the observed average group sizes (**Table 14**), although the differences between the two estimates were small for turtles and cownose rays. The size-bias-adjusted estimate of mean group size for common bottlenose dolphins was 15.3 animals (CV=0.38), for turtles it was 1.17 animals (CV=0.06), and for cownose rays it was 28.7 animals (CV=0.14).

Density and Abundance Estimates

Average estimates by season and block were obtained by using encounter rates for each season and block and applying the detection probabilities and estimated group sizes estimates described above. Summaries of seasonal encounter rate, density and abundance for common bottlenose dolphins, loggerhead turtles and cownose rays in the survey blocks are given in **Table 15.** Cownose rays were the most abundant species, and for all these species the highest estimated average abundances occurred during summer: average summer abundances in the Chesapeake Bay block were 104 common bottlenose dolphins (95% confidence interval 26-420), 14 loggerhead turtles (7-26) and 536 cownose rays (334-860). Average summer abundances in the Potomac River block were 19 common bottlenose dolphins (4-89) and 12 cownose rays (1-99). Loggerhead turtles were not detected in the Potomac River block and none of these species were detected in winter.

Table 15. Summary of estimates by season and block: number of groups (n) after truncation, encounter rate of groups (n/L; groups per km), estimated density ($\hat{D}$, individuals per km^2), estimated abundance of individuals ($\hat{N}$), and 95% confidence intervals (CI) for $\hat{N}$. Coefficients of variation are in parentheses.

(a) Common bottlenose dolphins

Season	Block	*n*	*n*/*L*	$\hat{D}$	$\hat{N}$	95% CI
Spring	CB	2	0.00076 (0.67)	0.0162 (0.97)	29 (0.97)	6–150
	PR	0				
Summer	CB	14	0.00274 (0.34)	0.0582 (0.78)	104 (0.78)	26–420
	PR	3	0.00419 (0.51)	0.0889 (0.87)	19 (0.87)	4–89
Autumn	CB	0				
	PR	0				
Winter	CB	0				
	PR	0				

(b) Loggerhead turtles

Season	Block	*n*	*n*/*L*	$\hat{D}$	$\hat{N}$	95% CI
Spring	CB	2	0.00076 (0.67)	0.0011 (0.72)	2 (0.72)	1 ; 8
	PR	0				
Summer	CB	27	0.00528 (0.22)	0.0076 (0.33)	14 (0.33)	7 ; 26
	PR	0				
Autumn	CB	8	0.00215 (0.29)	0.0031 (0.38)	6 (0.38)	3 ; 11
	PR	0				
Winter	CB	0				
	PR	0				

(c) Cownose rays

Season	Block	*n*	*n*/*L*	$\hat{D}$	$\hat{N}$	95% CI
Spring	CB	4	0.00152 (0.51)	0.0615 (0.54)	110 (0.54)	38 ; 314
	PR	0				
Summer	CB	38	0.00744 (0.15)	0.3005 (0.24)	536 (0.24)	334 ; 860
	PR	1	0.00140 (0.98)	0.0564 (1.00)	12 (1.00)	1 ; 99
Autumn	CB	7	0.00188 (0.34)	0.0759 (0.39)	135 (0.39)	62 ; 294
	PR	2	0.00339 (0.63)	0.1369 (0.65)	29 (0.65)	7 ; 128
Winter	CB	0				
	PR	0				

4. Discussion

Cumulative results from effort conducted between April 2015 and October 2017 indicate that the occurrence of common bottlenose dolphins and sea turtles at the NAS PAX study site within the Chesapeake Bay is seasonally dependent, occurring primarily in the summer months. For all C-POD deployments, 15.8 percent of all logged days had dolphin acoustic detections, and the results demonstrate that common bottlenose dolphins first arrive in the study area in March, leave by November, and peak in June/July. This is supported by previous surveys in the area, which showed the same seasonal pattern (Baker 2000). When the study was initiated in 2015, the C-PODs were not deployed until after the peak of the season, so inter-annual comparisons are only valid for 2016 and 2017. In total, dolphin acoustic detections were 38 percent higher in 2017 than in 2016.

The C-POD sites were chosen to cover different habitats and coastlines in the Chesapeake Bay. Despite maximizing the coverage in the study area to examine habitat preferences or other factors influencing dolphin occurrence, no clear pattern emerged. PAX 2 had the highest dolphin occurrence with 171 DPD despite the fewest number of logged days because of a C-POD malfunction. PAX 3 had the next highest number of DPD with 163. This site was located in the shipping channel at the center of Chesapeake Bay and was the deepest deployment location (approximately 15 m, while all others were between 7 and 10 m). While deeper deployments may help facilitate sound detection from greater distances, it is likely not the case for this unit since the depth difference is not large enough. The site with the fewest DPD was PAX 4, on the eastern side of Chesapeake Bay; however, dolphins were still present 11 percent of the time.

Generally, over the course of the two-year study, each site had a wide range of total DPM (a proxy for dolphin occurrence and acoustic activity), as well as in the total DPD. There were increases in total dolphin DPM in 2017 compared to 2016 at PAX 2 (60 percent increase), PAX 4 (88 percent increase) and PAX 6/7 (145 percent increase); however, there were decreases in activity in 2017 at PAX 1 (50 percent decrease) and PAX 3 (20 percent decrease).

Peaks in dolphin DPM per week occurred 2 to 4 weeks ahead of peak mean water temperature at all sites in both 2016 and 2017. Previous studies demonstrated that dolphin occurrence is positively correlated with water temperature (Baker 2000; Barco et al. 1999). The assumption is that their return to these waters in summer is related to their prey. Common bottlenose dolphins along the mid-Atlantic have a diverse diet (Gannon and Waples 2004), and no directed studies of prey species have been conducted within the Chesapeake Bay further north than the lower bay and York River areas.

There was a diel pattern observed, with most echolocation clicks produced during the nighttime and peaking between 2200 and 0500 EDT. This may be indicative of peak foraging times for the dolphins. The increase in echolocation could also be a factor of nighttime darkness, although the peaks at specific times likely denote foraging activity.

Photographs were taken of common bottlenose dolphins opportunistically seen during transits between C-POD deployment sites on three different occasions. All sightings were made in the month of July, and the observed group sizes ranged from 5 to 75 individuals. Sightings of common bottlenose dolphins during aerial surveys occurred between April and August in all years, with peak occurrence in June and July. Mean group size for sightings of dolphins from aerial surveys (24.1, *n*=20) was similar to the groups seen during C-POD deployments (mean=30.0, *n*=4). Dolphin photographs will be shared with researchers conducting regular surveys in the Chesapeake Bay waters (www.pcdolphinproject.org/research/), and it will be interesting to note if photographic-identification data will reveal if there is site fidelity between years for individuals occurring inside the bay. Some matches have been discovered between HDR's Norfolk-Virginia Beach bottlenose dolphin catalog and the Potomac-Chesapeake Dolphin Project's catalog via the Mid-Atlantic Bottlenose Dolphin Catalog (Urian et al. 1999); however, those matched were not any of those identified in the processed photos from the July 2015 encounter during CPOD deployments. Further comparisons will hopefully reveal some matches that will aid in determining whether individuals from the coastal community are heading into the bay temporarily or if there is a discrete population that returns annually.

While the C-PODs had detections distributed throughout the study area, visual sightings of common bottlenose dolphins made during aerial surveys were predominantly in the southern end of the study area, with the highest number of sightings in and around the Potomac River. Twenty on-effort sightings were made between April 2015 and October 2017, and four off-effort observations were recorded outside of the survey site while the aircraft was transiting back to Norfolk, Virginia. Loggerhead sea turtles and cownose rays were also observed seasonally, in the summer months, and distributed throughout the study area (with the exception of sea turtles, which were never observed within the Potomac River).

Density and abundance estimates for each season and survey block were calculated for common bottlenose dolphins, loggerhead turtles, and cownose rays using line- transect Distance methods (Buckland et al. 2001). As a rule of thumb, approximately 60 detections are required to fit a detection function to obtain reliable estimates (Buckland et al. 2001) and even combining detections from all surveys, the numbers of detections, particularly for common bottlenose dolphins, fell short of this. Therefore, the abundance estimates cannot be considered reliable and so the confidence intervals, which provide a range of plausible values for the abundance, maybe more appropriate.

Due to the small number of observations, an average estimate of detection probability and estimated group size overall seasons were obtained for each species or species group. Both these values may change seasonally and geographically.

There were more detections of bottlenose dolphin common bottlenose dolphins close to the line (i.e., within 200 m) compared to further away resulting in a spiked detection function and correspondingly large CV (also due to the small number of detections). A detection function with a wider shoulder, perhaps by observers searching further out (while maintaining effort on the trackline) would result in a lower CV. One parameter in the selected hazard rate model was estimated to be at a lower bound of possible values for that parameter (although this was not necessarily a problem).

An assumption of line-transect sampling is that an animal on the trackline (i.e., at zero perpendicular distance) it is certain to be detected. If this is not the case, then the probability of detection will be overestimated and, hence, abundances will be underestimated. An estimate of the probability of detection on the trackline (perception bias) requires a different observer configuration and adds to the complexity of the search protocol (Burt et al. 2014). An estimate of the probability of an animal or group being at the surface at any given time (availability bias) also requires additional data. To adjust for availability, estimates of the proportion of time each species spend at, or close to, the surface are required. Any adjustment due to availability may be considerable and change; for example, the temperature of the water may affect the length of time animals are at, or close to, the surface and water temperature may change seasonally and geographically within the region of interest. The turbidity of water may also affect availability and again this may change seasonally and geographically.

The number of detections of turtles in the vertical angle bin closest to the (adjusted) trackline (bin 1) was smaller than the number of detections in bin 2 (after accounting for bin width). This may indicate an inadequate view of the trackline (even after adjusting for the region under the plane unseen by the observers) and hence uncertain detection on the trackline (or in the first bin). The same did not happen for cownose rays (which can be similar in size and colour as turtles) suggesting that observers do not have difficulty seeing this first bin. It should be noted that the smallest detected group of cownose rays consisted of three rays and detected turtles were generally singletons; however, it highlights the difficulty in detecting turtles close to the trackline.

The density estimates represent an average density for the survey block. Densities may change throughout the block and to model changes in density would require a method such as that described by Hedley and Buckland (2004).

These data provide a useful record of occurrence in the region of interest throughout different seasons but, due to the small number of detections for each species and given the above caveats, the estimates given here can provide, at best, approximate estimates of abundance and density of animals.

5. Acknowledgements

For collaborative efforts, we thank our colleagues at St. Andrews University (Charles Paxton). We thank Ed Coffman, owner and operator of Orion Aviation, and his highly skilled pilots: John Estes, Richard Waterman, Dave Huddle, Stan Huddle, Bob Stickle, and Rocky Walker for excellent survey flights and their professionalism. We also thank Billy Pipkin of Captain Billy's Charters and John Mayer from Marauder Charters for their assistance during C-POD deployments and recoveries. Kevin Warren from the Navy Atlantic Test Ranges was also extremely helpful for scheduling all field activities around range closures. We thank Jennifer Paulk and Joel Bell for their support of this work. Surveys were conducted under National Oceanic and Atmospheric Administration Scientific Permit No. 16473 held by the University of North Carolina Wilmington, and National Oceanic and Atmospheric Administration General Authorization Letter of Confirmation No. 16185.

6. Literature Cited

Baker, S.L.M. (2000) Population biology, residency status, and management of bottlenose dolphins, *Tursiops truncatus*, in the Eastern Bay and Choptank River areas of Chesapeake Bay. Ph.D. thesis, University of Maryland, College Park, MD. 183 pp.

Barco S.G., W.M. Swingle, W.A. McLellan, R.N. Harris, and D.A. Pabst. 1999. Local abundance and distribution of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Virginia Beach, Virginia. *Marine Mammal Science* 15:394–408

Buckland S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. *Introduction to distance sampling: estimating abundance of animal populations*. Oxford University Press, Oxford, United Kingdom.

Burt M.L., D.L. Borchers, K.J. Jenkins, and T.A. Marques. 2014. Using mark-recapture distance sampling on line transect surveys. *Methods in Ecology and Evolution* 5: 180–1191. doi: 10.1111/2041-210X.12294

Engelhaupt A., J. Aschettino, T.A. Jefferson, D. Engelhaupt, and M. Richlen. 2016. *Occurrence, Distribution, and Density of Marine Mammals Near Naval Station Norfolk and Virginia Beach, Virginia. Final Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Orders 03 and 043, issued to HDR Inc., Virginia Beach, Virginia. 12 October 2016

Fewster R.M., S.T. Buckland, K.P. Burnham, D.L. Borchers, P.E. Jupp, J.L. Laake, and L. Thomas. 2009. Estimating the encounter rate variance in distance sampling. *Biometrics* 65:225–236

Gannon D. P. and D. M. Waples. 2004. Diets of coastal bottlenose dolphins from the U.S. Mid-Atlantic coast differ by habitat. *Marine Mammal Science* 20(3): 527-545

Hedley S.L. and S.T. Buckland. 2004. Spatial models for line transect sampling. *Journal of Agricultural, Biological and Environmental Statistics* 9:181–199

Read A.J., S. Barco, J. Bell, D.L. Borchers, M.L. Burt, E.W. Cummings, J. Dunn, J. Fougeres, L. Hazen, L.E. Williams-Hodge, A-M. Laura, R.J. McAlarney, P. Nilsson, D.A. Pabst, C.G.M. Paxton, S.Z. Schneider, K. Urian, D.M. Waples, and W.A. McLellan. 2014. Occurrence, distribution and abundance of cetaceans in Onslow Bay, North Carolina, USA. *Journal of Cetacean Research and Management* 14:23–35

Thomas L., S.T. Buckland, E.R. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques, and K.P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14. DOI: 10.1111/j.1365-2664.2009.01737.x

This page intentionally left blank.

A

Density Estimates by Survey and Survey Block

This page intentionally left blank.

Appendix A: Density Estimates by Survey and Survey Block

The estimates in this appendix are higher than the average estimates provided for each season (**Table 12**) because the encounter rate per survey is higher than the average encounter rate per season. In the tables below, only surveys where detections occurred are shown.

Table A-1. Summary of estimates by survey and block: number of groups (n) after truncation, encounter rates (n/L; groups per km), density ($\hat{D}$, individuals per km^2), abundance of individuals ($\hat{N}$) and 95% confidence intervals (CI) for $\hat{N}$. Coefficients of variation are in parentheses. There were no detections of these species during other surveys.

(a) Common bottlenose dolphins

Year	Survey number	Month	Block	*n*	*n/L*	$\hat{D}$	$\hat{N}$	95% CI
2015	1	May	CB	1	0.0021 (0.99)	0.0449 (1.21)	80 (1.21)	12 ; 555
	3	June	CB	3	0.0065 (0.52)	0.1383 (0.87)	247 (0.87)	54 ; 1128
	4	July	PR	1	0.0134 (1.02)	0.2843 (1.24)	61 (1.24)	7 ; 528
2016	14	May	CB	1	0.0022 (0.99)	0.0462 (1.22)	82 (1.22)	12 ; 575
	16	July	CB	6	0.0131 (0.39)	0.2778 (0.81)	496 (0.81)	119 ; 2065
			PR	1	0.0136 (1.09)	0.2893 (1.30)	62 (1.30)	7 ; 574
	17	October	PR	1	0.0134 (1.02)	0.2893 (1.24)	61 (1.24)	7 ; 518
2017	21	June 3	CB	2	0.0043 (0.67)	0.0921 (0.98)	164 (0.98)	32 ; 855
	22	June 4	CB	1	0.0022 (0.99)	0.0459 (1.22)	82 (1.22)	12 ; 568
	24	July 22	CB	1	0.0024 (0.99)	0.0511 (1.21)	91 (1.21)	13 ; 579
	25	July 23	CB	1	0.0020 (1.04)	0.0428 (1.25)	76 (1.25)	11 ; 555

(b) Loggerhead turtles (there were no detections in the Potomac River block)

Year	Survey number	Month	*n*	*n*/*L*	$\hat{D}$	$\hat{N}$	95% CI
2015	2	May	2	0.0043 (0.68)	0.0053 (0.72)	11 (0.72)	3 ; 43
	4	July	3	0.0065 (0.53)	0.0080 (0.58)	17 (0.58)	5 ; 51
	5	August	16	0.0349 (0.34)	0.0429 (0.42)	90 (0.42)	40 ; 204
2016	16	July	6	0.0131 (0.41)	0.0161 (0.47)	34 (0.47)	13 ; 85
	18	October	3	0.0064 (0.53)	0.0079 (0.58)	16 (0.58)	5 ; 50
2017	24	July 22	1	0.0024 (0.99)	0.0030 (1.02)	6 (1.02)	1 ; 38
	25	July 23	1	0.0020 (1.04)	0.0025 (1.07)	5 (1.07)	1 ; 32
	26	September 3	2	0.0043 (0.67)	0.0053 (0.71)	11 (0.71)	3 ; 42
	27	September 4	1	0.0021 (0.99)	0.0026 (1.02)	6 (1.02)	1 ; 33
	28	October	2	0.0043 (0.67)	0.0053 (0.71)	11 (0.71)	3 ; 42

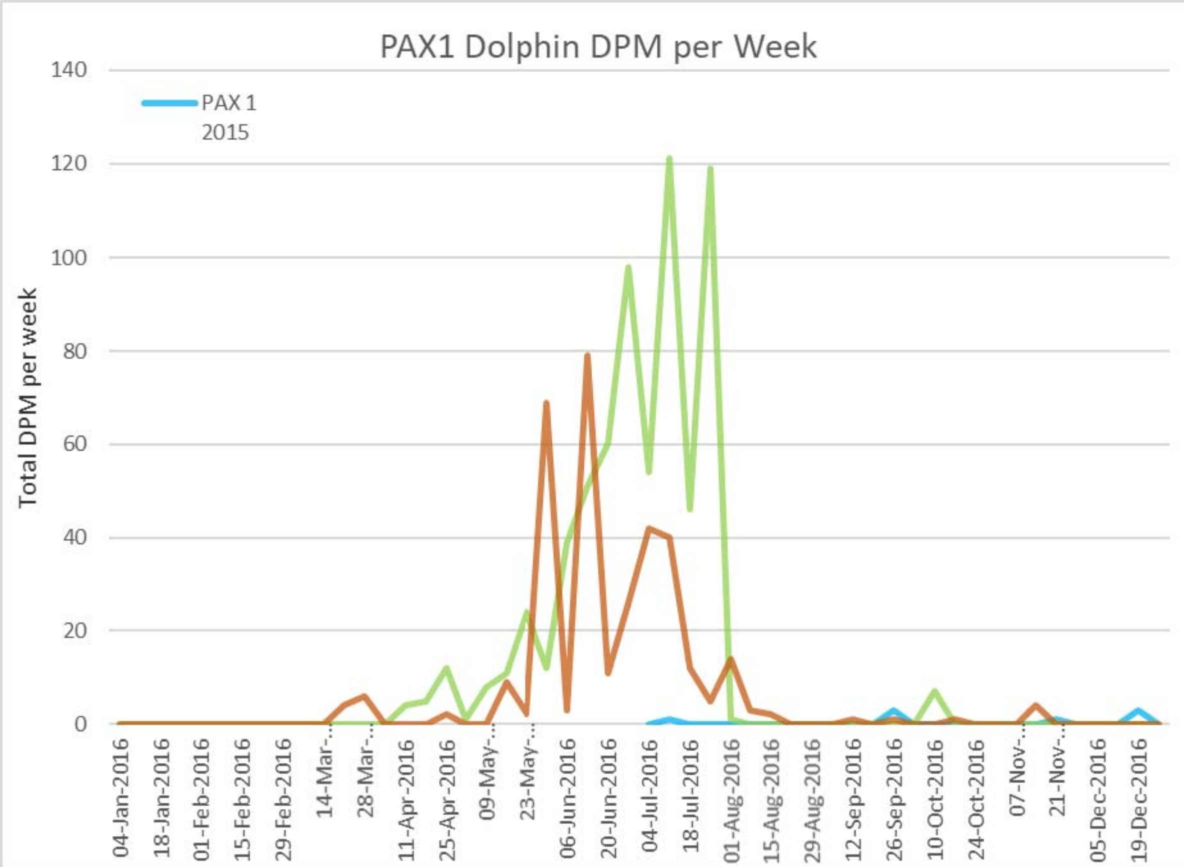
(c) Cownose rays

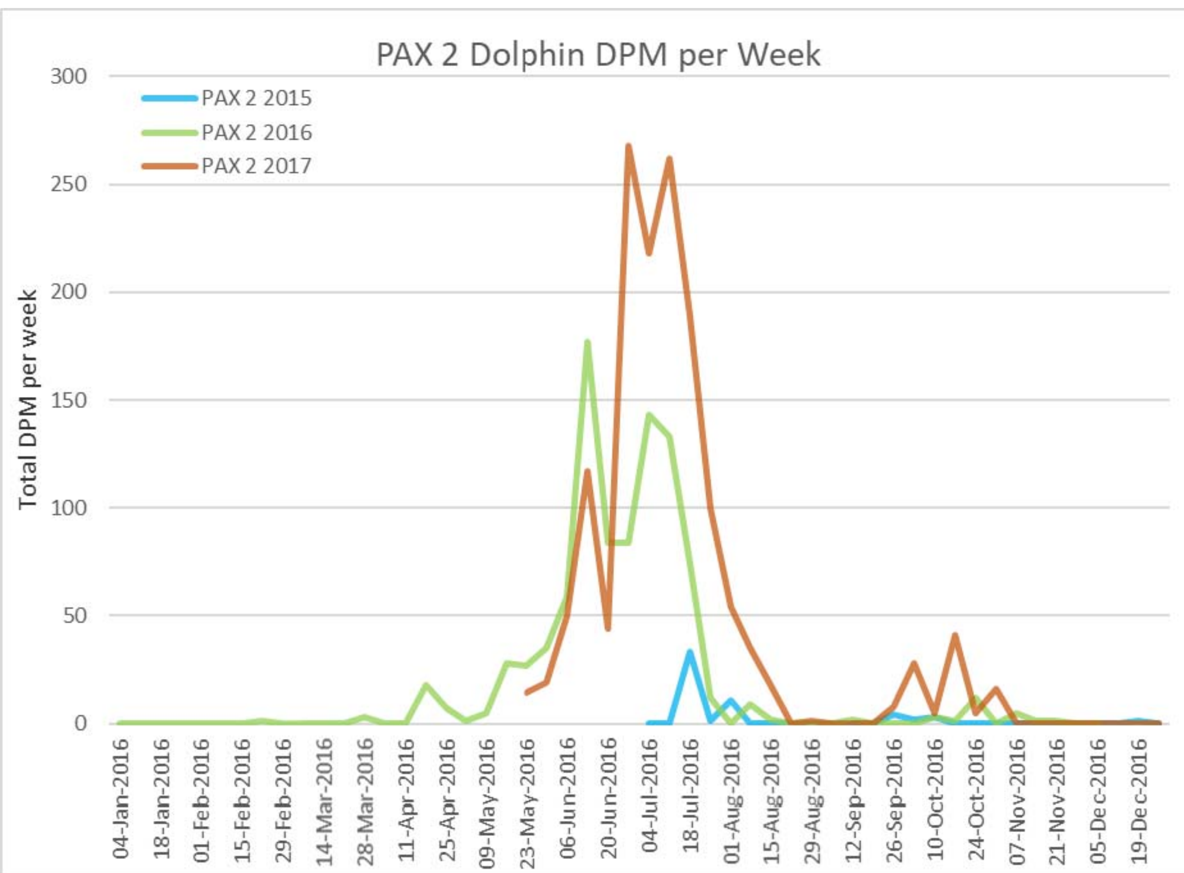
Year	Survey number	Month	Block	*n*	*n*/*L*	$\hat{D}$	$\hat{N}$	95% CI
2015	2	May	CB	3	0.0065 (0.61)	0.2614 (0.63)	466 (0.63)	138 ; 1573
	3	June	CB	13	0.0282 (0.22)	1.1401 (0.29)	2034 (0.29)	1146 ; 3610
	4	July	CB	1	0.0022 (1.04)	0.0873 (1.06)	156 (1.06)	25 ; 967
	5	August	CB	1	0.0022 (0.98)	0.0880 (1.00)	157 (1.00)	27 ; 911
	6	September	CB	1	0.0021 (0.97)	0.0866 (0.99)	155 (0.99)	27 ; 884
2016	13	April	CB	1	0.0022 (0.98)	0.0870 (1.00)	155 (1.00)	27 ; 897
	16	July	CB	14	0.0305 (0.32)	1.2333 (0.37)	2200 (0.37)	1052 ; 4603
			PR	1	0.0136 (0.98)	0.5505 (1.00)	118 (1.00)	14 ; 964
	17	August	CB	3	0.0064 (0.52)	0.2598 (0.55)	464 (0.55)	159 ; 1354
	18	October	CB	5	0.0106 (0.38)	0.4303 (0.42)	768 (0.42)	335 ; 1759
			PR	2	0.0263 (0.63)	1.0627 (0.66)	229 (0.66)	53 ; 996
2017	23	June 25	CB	4	0.0081 (0.70)	0.326 (0.72)	582 (0.72)	149 ; 2268
	24	July 22	CB	2	0.0048 (0.67)	0.1946 (0.70)	347 (0.70)	90 ; 1337
	26	September 3	CB	1	0.0021 (0.99)	0.0864 (1.01)	154 (1.01)	26 ; 902

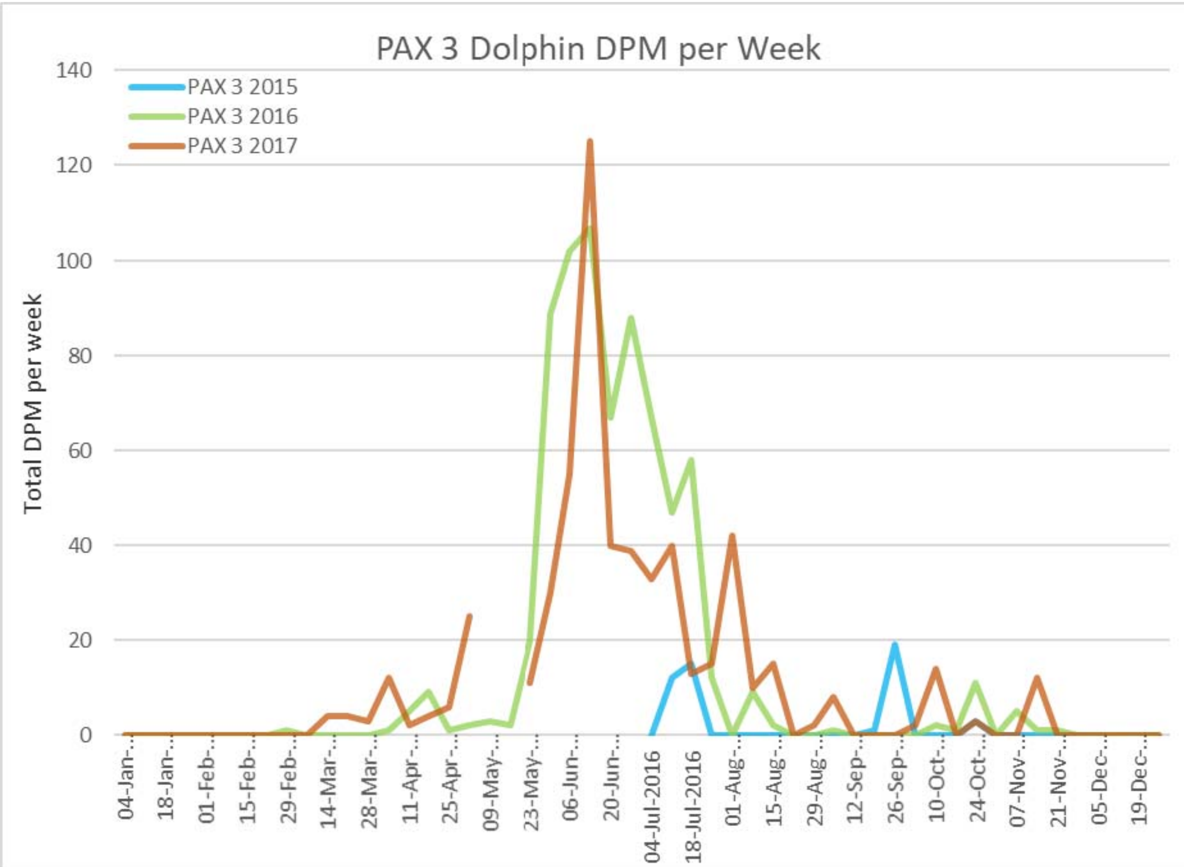
B

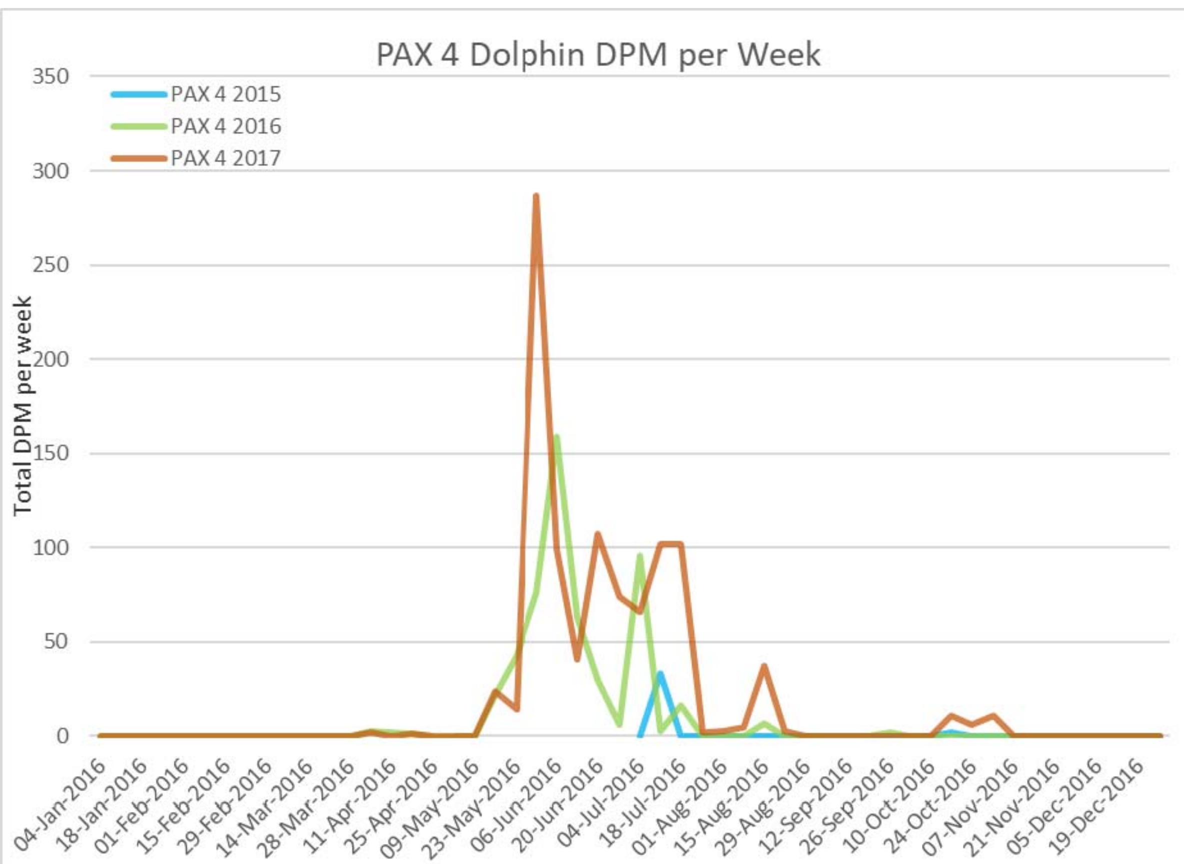
Additional C-POD Figures

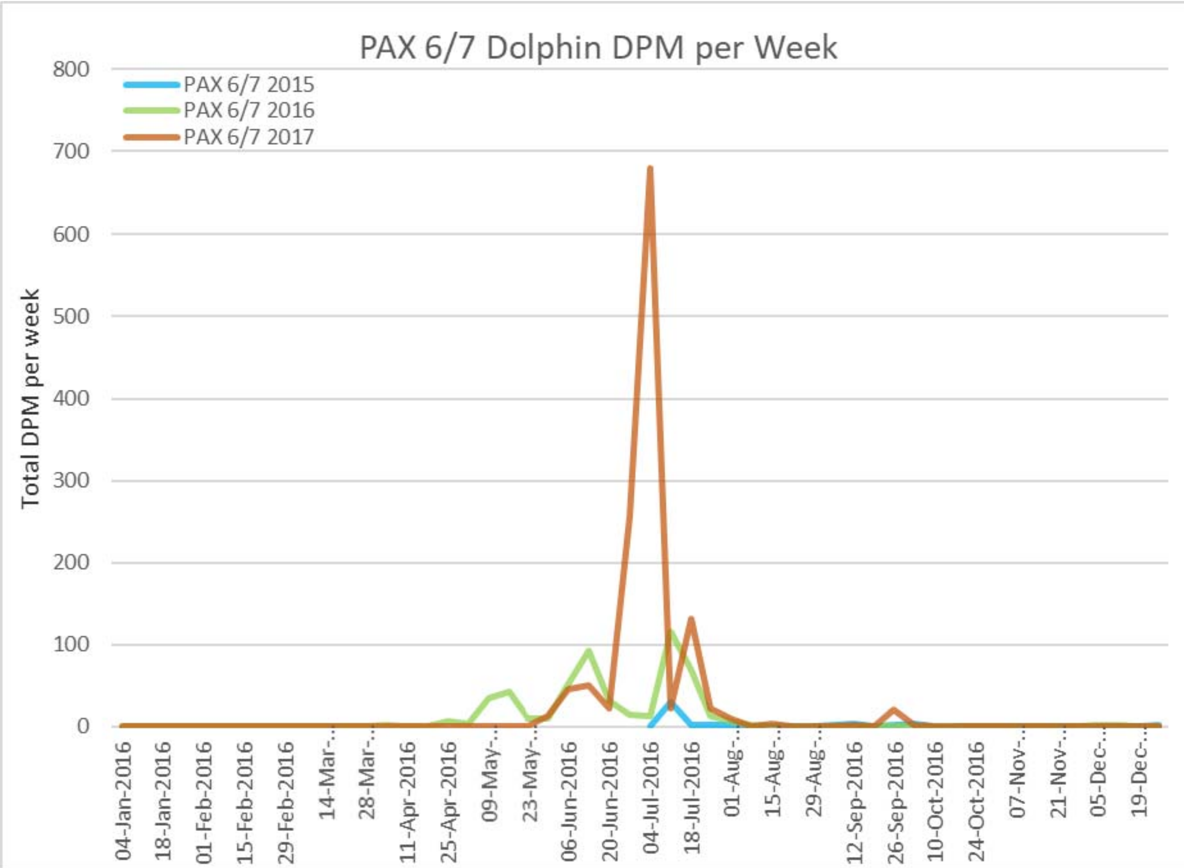
This page intentionally left blank.


PAX1 Dolphin DPM per Week
PAX 1 2015
Total DPM per week
140
120
100
80
60
40
20
0
04-Jan-2016
18-Jan-2016
01-Feb-2016
15-Feb-2016
29-Feb-2016
14-Mar-...
28-Mar-...
11-Apr-2016
25-Apr-2016
09-May-...
23-May-...
06-Jun-2016
20-Jun-2016
04-Jul-2016
18-Jul-2016
01-Aug-2016
15-Aug-2016
29-Aug-2016
12-Sep-2016
26-Sep-2016
10-Oct-2016
24-Oct-2016
07-Nov-...
21-Nov-...
05-Dec-2016
19-Dec-2016


PAX 2 Dolphin DPM per Week
PAX 2 2015
PAX 2 2016
PAX 2 2017
Total DPM per week
300
250
200
150
100
50
0
04-Jan-2016
18-Jan-2016
01-Feb-2016
15-Feb-2016
29-Feb-2016
14-Mar-2016
28-Mar-2016
11-Apr-2016
25-Apr-2016
09-May-2016
23-May-2016
06-Jun-2016
20-Jun-2016
04-Jul-2016
18-Jul-2016
01-Aug-2016
15-Aug-2016
29-Aug-2016
12-Sep-2016
26-Sep-2016
10-Oct-2016
24-Oct-2016
07-Nov-2016
21-Nov-2016
05-Dec-2016
19-Dec-2016


PAX 3 Dolphin DPM per Week
PAX 3 2015
PAX 3 2016
PAX 3 2017
Total DPM per week
0
20
40
60
80
100
120
140
04-Jan-...
18-Jan-...
01-Feb-...
15-Feb-...
29-Feb-...
14-Mar-...
28-Mar-...
11-Apr-...
25-Apr-...
09-May-...
23-May-...
06-Jun-...
20-Jun-...
04-Jul-2016
18-Jul-2016
01-Aug-...
15-Aug-...
29-Aug-...
12-Sep-...
26-Sep-...
10-Oct-...
24-Oct-...
07-Nov-...
21-Nov-...
05-Dec-...
19-Dec-...


PAX 4 Dolphin DPM per Week
PAX 4 2015
PAX 4 2016
PAX 4 2017
Total DPM per week
0
50
100
150
200
250
300
350
04-Jan-2016
18-Jan-2016
01-Feb-2016
15-Feb-2016
29-Feb-2016
14-Mar-2016
28-Mar-2016
11-Apr-2016
25-Apr-2016
09-May-2016
23-May-2016
06-Jun-2016
20-Jun-2016
04-Jul-2016
18-Jul-2016
01-Aug-2016
15-Aug-2016
29-Aug-2016
12-Sep-2016
26-Sep-2016
10-Oct-2016
24-Oct-2016
07-Nov-2016
21-Nov-2016
05-Dec-2016
19-Dec-2016


PAX 6/7 Dolphin DPM per Week
PAX 6/7 2015
PAX 6/7 2016
PAX 6/7 2017
Total DPM per week
800
700
600
500
400
300
200
100
0
04-Jan-2016
18-Jan-2016
01-Feb-2016
15-Feb-2016
29-Feb-2016
14-Mar-...
28-Mar-...
11-Apr-2016
25-Apr-2016
09-May-...
23-May-...
06-Jun-2016
20-Jun-2016
04-Jul-2016
18-Jul-2016
01-Aug-...
15-Aug-...
29-Aug-...
12-Sep-2016
26-Sep-2016
10-Oct-2016
24-Oct-2016
07-Nov-...
21-Nov-...
05-Dec-...
19-Dec-...

This page intentionally left blank.