Abundance and distribution of marine mammals in nearshore waters off New Jersey, USA

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ABSTRACT

Marine mammal abundance and distribution in New Jersey's nearshore waters are not well known due to limited dedicated studies. The first year-round systematic surveys were conducted to determine the spatial/temporal distribution and estimate the abundance of marine mammals in this region prior to wind power development. Eight marine mammal species were observed: North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), fin whale (*Balaenoptera physalus*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), harbour porpoise (*Phocoena phocoena*) and harbour seal (*Phoca vitulina*). Results indicate clear seasonal patterns in distribution and abundance. The fin whale, humpback whale and bottlenose dolphin were sighted during all seasons. The abundance of large whales in the study area was relatively low while the abundance of dolphin and porpoise species was high and largely seasonal. The bottlenose dolphin was the most abundant species; however, abundance was high only during spring and summer. Common dolphins and harbour porpoises were common in the study area during winter and spring. These baseline data will be used to assess potential environmental impacts of the construction and operation of offshore wind power facilities in this region.

KEYWORDS: ABUNDANCE ESTIMATE; MODELLING; DISTRIBUTION; CONSERVATION; SURVEY–AERIAL; SURVEY–VESSEL; ATLANTIC OCEAN; HABITAT; NORTH ATLANTIC RIGHT WHALE; HUMPBACK WHALE; MINKE WHALE; FIN WHALE; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; HARBOUR PORPOISE; HARBOUR SEAL

INTRODUCTION

Marine mammals are important marine resources in New Jersey's nearshore waters which are prime areas targeted for offshore renewable energy development, particularly wind power development, on the United States (US) Atlantic Outer Continental Shelf (OCS). In 2010, Geo-Marine, Inc. (GMI) successfully completed the US's first Ecological Baseline Study (EBS) specific to offshore wind planning for the New Jersey Department of Environmental Protection (NJDEP) (GMI, 2010). The EBS is a precursor to the initiation of the State of New Jersey's test project to obtain practical knowledge of the benefits and impacts of offshore wind turbine facilities off the coast of New Jersey. This study was conducted in accordance with the New Jersey Blue Ribbon Panel on Development of Wind Turbine Facilities in Coastal Waters formed by New Jersey State Executive Order 12. The EBS provided critical information on the marine resources that may be impacted by the construction and operation of these facilities. This paper describes the results of the marine mammal surveys which were an important component of the NJDEP EBS. The data collected from these baseline surveys were used to conduct an assessment of potential environmental impacts and to assist in the siting of offshore wind power facilities in nearshore waters off New Jersey.

The National Marine Fisheries Service (NMFS) and other organisations have been conducting marine mammal surveys along the US east coast for many years. Although several of these surveys have included waters surveyed during the EBS (e.g. mid-Atlantic *Tursiops* aerial surveys, *Delaware II* 97–05 shipboard survey, Cetacean and Turtle Assessment Program [CETAP] aerial and shipboard surveys), none has concentrated efforts specifically in New Jersey's nearshore waters with the exception of a photo-identification survey conducted by NMFS' Southeast Fisheries Science Center and the Rutgers University Marine Field Station in coastal waters off southern New Jersey from May through October in 2003, 2004 and 2005 (Blaylock, 1995; CETAP, 1982; Garrison and Yeung, 2001; NMFS-NEFSC, 1997; Toth Brown, 2007). In addition, no year-round survey efforts have been conducted in this region. The NJDEP EBS includes the first year-round systematic survey effort for marine mammals in this region.

MATERIALS AND METHODS

Field methods

Study area

The study area encompassed 5,259km^2 of nearshore waters from the shoreline to approximately 37km offshore between Wildwood Crest and northern Barnegat Bay, New Jersey (Fig. 1). The offshore boundary of the study area roughly followed the 30m isobath which is the maximum installation depth of the turbines that are planned for this region.

Aerial surveys

Aerial surveys were conducted once a month from February through May 2008 and twice a month (when possible) from January through June 2009. The surveys followed standard line-transect methods (see Buckland, 2001). In 2008, they were conducted from a twin-engine, high-winged Cessna *Skymaste*r 337 with bubble windows on each side of the

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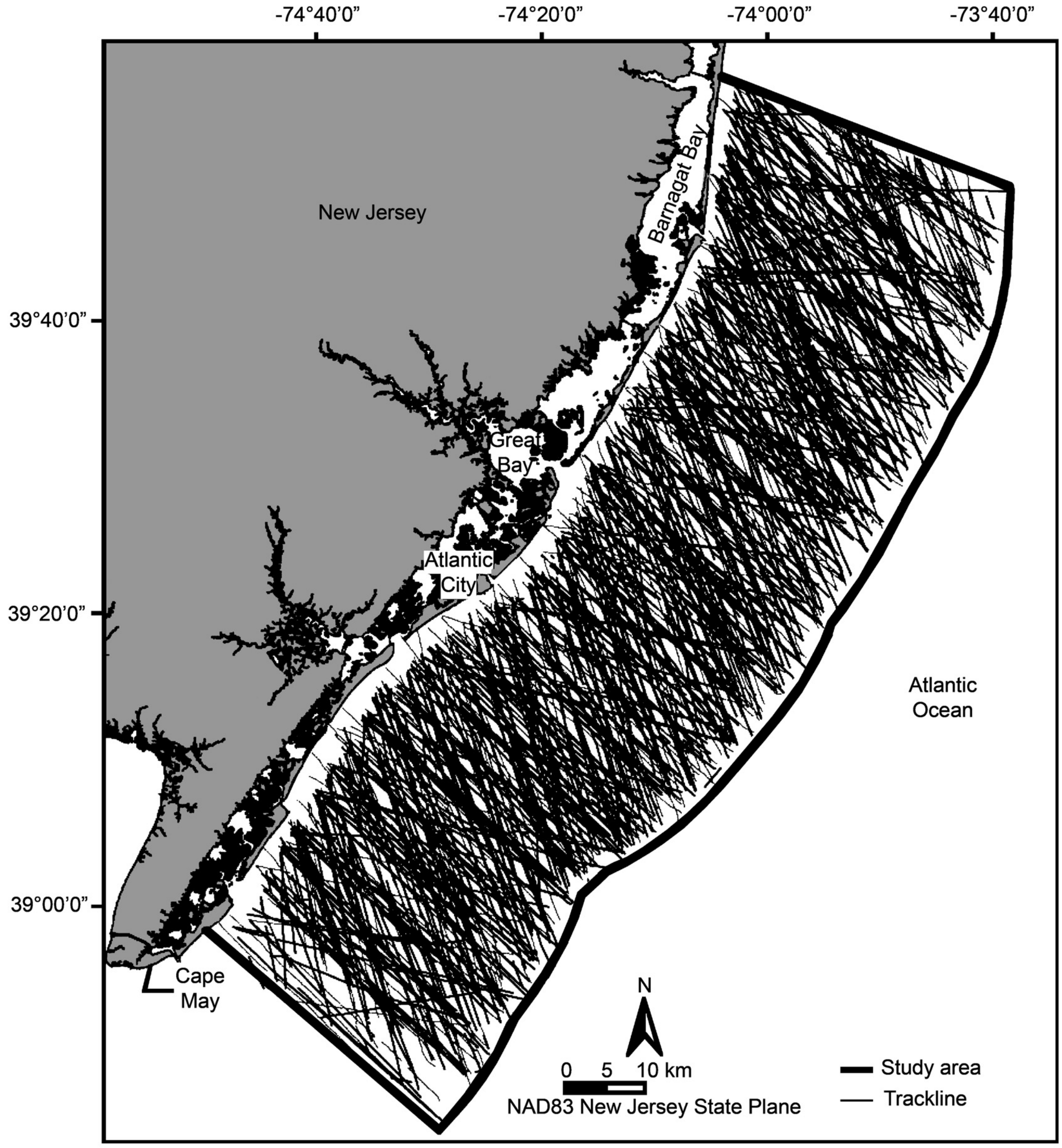

Fig. 1. Tracklines covered during the aerial and shipboard surveys.

aircraft to allow unobstructed views of the transect lines directly beneath the plane. During the 2009 surveys, a Cessna *Skymaster* without bubble windows was used, resulting in limited visibility below the aircraft. Surveys were flown at ~229m altitude and a speed of ~220km per hour (km/h) during daylight hours when there was at least 3.7km visibility and a Beaufort Sea State (BSS) less than 6.

For the February 2008 survey, randomly-generated transect lines (tracklines) were spaced 3.7km apart and orientated perpendicular to the coastline. Survey design was changed to a double saw-tooth pattern for the rest of the surveys to provide comparable spatial and temporal coverage of the entire study area and allow the entire study area to be surveyed in one day, thereby minimising the temporal variation. Tracklines were randomly generated in a double saw-tooth pattern for each survey using the program *Distance 5.0* (Buckland *et al.*, 2004; Thomas *et al.*, 2010).

Visual observations were recorded by a team of three people during the 2008 surveys. Two experienced observers searched for animals at the surface from directly beneath the aircraft out to a perpendicular distance of approximately 1,500m. The third person served as the data recorder and was stationed in the co-pilot seat. During the 2009 surveys, flight protocols followed those stated above with some modifications; a co-pilot was added so there was no room in the plane for a dedicated data recorder. Therefore, the two experienced observers positioned in the rear seats were responsible for observations and recording data. One observer recorded the time and position of each sighting on a laptop while the second observer recorded the sighting information on a digital tape recorder.

The aircraft's position along the trackline (in addition to all other survey information) was collected every 10s on a computer interfaced with the aircraft's global positioning system (GPS) *via* a custom data acquisition program. Environmental conditions (e.g. BSS, solar glare, water colour and transparency), which may affect the ability to detect animals, were recorded prior to the start of each trackline and updated as needed while on effort. All sightings data, including time, position, declination angle, group size, species and behaviour were recorded. Animals were identified to the lowest possible taxonomic group.

During the 2008 surveys, when an animal was sighted perpendicular to the aircraft along the trackline, the angle to the sighting (≤60°) was determined either using a digital inclinometer or 10° intervals (bins) marked on the aircraft windows for calculation of perpendicular sighting distances. During the 2009 surveys, the perpendicular sighting distances were calculated based on GPS locations.

During both the 2008 and 2009 surveys, the observers went into off-effort mode at the time of a sighting to verify species identification and estimate group sizes. The species identification, best estimate of group size, behaviour, time, position and associated animals were also recorded. A circle-back procedure was used if necessary to verify species identification and estimate group sizes.

Shipboard surveys

Shipboard surveys were conducted monthly from January 2008 through December 2009 on the University of Delaware's R/V *Hugh R. Sharp* using a single platform and following standard line-transect methods (Buckland *et al.*, 2001). The surveys were conducted at 18.5km/h along randomly-generated tracklines in a double saw-tooth pattern which crossed the bathymetry gradient and maximised uniform coverage of the study area. The starting point and time of each cruise was chosen based on the timing of high tide and weather conditions due to the docking criteria of the R/V *Hugh R. Sharp*. Tracklines were altered only if sea state, glare, or weather inhibited survey efforts.

Visual observations were recorded from the flying bridge (10m above water) during daylight hours when weather permitted at least 2km of visibility and BSS was 5 or less. The marine mammal observer team consisted of six individuals; three observers were actively on duty at any one time and rotated positions every 40 min. On-duty observers consisted of one observer searching with 25×150 power *Fujinon* binoculars ('bigeyes') mounted on a pedestal on the port side of the vessel while another observer searched through bigeye binoculars mounted on the starboard side. The third observer served as the data recorder and also searched the water with unaided eyes and 7× hand-held binoculars between the port and starboard bigeye observers. Each observer scanned out to the horizon from abeam (90°) on his/her side of the ship to 10° to the opposite side of the bow (100° in all). The 20° along the ship's trackline thus received overlapping coverage by the two bigeye observers.

Weather conditions (BSS, wind speed, swell height and direction, direction of sun, visibility, etc.), visual effort (on or off), sightings and other survey information were recorded. Weather conditions were recorded every 40 min (when observers rotated positions) and updated when conditions changed. The GPS position of the vessel, as well as the vessel's course and speed, was automatically recorded every 2 min *via* an integrated, stand-alone GPS unit on the flying bridge. The data fields recorded for all sightings included the time, position, initial bearing and distance, group size, species identification (or lowest identifiable taxonomic category) and behaviour. Three estimates of group size (best, maximum and minimum) were recorded for all sightings. Estimates of group size and the percent taxonomic composition were made independently by each observer without discussion to minimise observer bias.

Analytical methods

The following periods were used as seasonal designations in the analyses of sightings data: winter (18 December–09 April), spring (10 April–21 June), summer (22 June–27 September) and fall (28 September–17 December). These seasons were calculated based on three years (2007–2009) of sea surface temperature (SST) data. Winter and summer are the times of year with the lowest and highest temperatures, respectively, while spring and fall represent transitional periods between the two temperature extremes.

Data preparation

Sightings included in the density/abundance analyses met the following criteria: (1) sightings were recorded by on-duty observers while the team was searching in on-effort mode; (2) perpendicular sighting distances were able to be calculated and (3) sightings and effort were recorded in a BSS ≤5 for all species/groups except the harbour porpoise (*Phocoena phocoena*) which was analysed based on sightings and effort recorded in a BSS ≤2 due to the low detectability of this species in higher sea states (Polacheck, 1995).

Density estimation

Aerial and shipboard survey data could not be combined for density/abundance estimation because of the differences in survey techniques and perception bias. Therefore, separate analyses were conducted using the aerial and shipboard sightings data. The Conventional Distance Sampling (CDS) method was used to generate abundance/density estimates for the overall study area using *Distance 6.0*, release 2 (Thomas *et al.*, 2010). Based on line-transect theory (Buckland *et al.*, 2001), density was estimated as a function of (1) encounter rate n/L (where n = number of sightings and L = line-transect length), (2) probability density function at zero perpendicular distance $f(0)$, (3) mean group size $E(s)$ and (4) probability detection function at zero perpendicular distance [$g(0)$].

The estimated density (D) is given by the following equation:

$$D = N/A = n*E(s)*f(0)/2L*g(0)$$

where N = abundance, A = study area and the other parameters are as defined previously.

Density is estimated as the ratio of the number of animals sighted (n) to the survey coverage area (a), where $a = 2wL$, w = strip half-width (truncation distance) and L = transect length. The effective strip half-width (ESW), μ, is defined as the sighting distance such that the number of animals at distances less than μ that were missed by the observer is equal to the number of animals at distances greater than μ that were detected by the observer. The ESW μ is equal to $1/f(0)$.

For those species with sufficient sightings and covariate data, the Multiple Covariate Distance Sampling (MCDS) method was used to model probability of detection as a function of both distance and one or more covariates to increase the precision of density estimates (Marques and Buckland, 2003; Marques *et al.*, 2007). The included covariates were BSS, group size, and visibility which have all been shown to affect perpendicular sighting distances (Barlow *et al.*, 2001). These covariates were all treated as continuous variables.

The error or uncertainty associated with each estimated parameter [D, n/L, $f(0)$, $E(s)$] was quantified by the variance (Var), coefficient of variation (CV) and the 95% confidence interval (CI). The analytical variance of a density or abundance estimate was estimated using the delta method, and the log-normal 95% confidence limits were obtained using equations 3.71–3.74 of Buckland *et al*. (2001) except that t-based limits were calculated using degrees of freedom calculated using the Satterthwaite method given in formula 3.75. The nonparametric bootstrap method was used to estimate variance when group size was included as a covariate in the MCDS.

A discussion of factors affecting animal detectability and methods of accounting for detection bias are discussed in Thomsen *et al.* (2005). A $g(0)$ of 1 was assumed because estimates of $g(0)$ could not be calculated due to the limitations of the single platform observer configuration for both the ship and aerial surveys. During attempts to consistently implement the Hiby circle-back method (Hiby, 1999) during the aerial surveys, the additional data recording requirements of the team and the circle-back protocol resulted in unconfirmed or loss of sightings due to the multi-tasking of observers. In addition, the method of conducting simultaneous ship and aerial surveys to estimate $g(0)$ (Palka *et al.*, 2005) was not practical for this study due to the relatively low encounter rates in the study area. Previously estimated $g(0)$ values from similar surveys were not used in the current study since detection probability has been shown to vary substantially among observers, platforms, weather conditions, etc. (Borchers, 2005). Therefore, the density and abundance estimates calculated for this study are considered relative estimates and are not absolute and may be underestimated due to both perception and availability biases.

To account for group-size bias, an expected mean group size was estimated using a regression method in which the logarithm of group size of observation was regressed against the estimated detection probability. Mean group size in the population was estimated from the predicted mean size of detected groups in the region where the detection probability was 1 (at zero perpendicular distance from the trackline). This regression method corrected for size-biased detections and for the underestimation of size of detected groups (Buckland *et al.*, 2001). A statistical hypothesis test was applied to the regression of group size on distance, and the expected mean group size was only used in the analysis if it was significantly ($P<0.15$) smaller than the arithmetic mean group size.

The decrease in detection probability as a function of increasing perpendicular distance from the trackline was modelled using the uniform, half-normal, and hazard-rate key functions along with polynomial or cosine series expansion terms as required, except for the MCDS models which do not allow for the uniform key function. In most cases, the optimal model was chosen as that model which yielded the smallest value of the Akaike's Information Criterion (AIC) index (Buckland, 2001; 2004). In some cases where the behavioural observations indicated a problem with avoidance or attraction to the survey platform, the optimal model was subjectively chosen. For example, when a spike near the trackline was thought to be caused by the attraction of the animals to the platform, the optimal model chosen was the one that did not fit the detection function to the whole spike since fitting the spike near the trackline results in inflated abundance/density estimates.

This model optimisation analysis was conducted for each species/group in which there were around 20 sightings that met the criteria listed above. A sample size of at least 60 sightings is typically recommended for estimating a detection function (Buckland, 2001), and 15 sightings may be the absolute minimum number of sightings that can be used to fit a detection function (Barlow *et al.*, 2006). The sightings recorded during 2008 and 2009 were combined to maximise the number of sightings for each species/group for analysis. Species with fewer than 20 sightings were pooled into taxonomic groups with species of similar sighting characteristics, when possible, to model a group detection function. The data were then stratified by species to estimate abundance/density of individual species using the pooled detection function. For some species and groups, sufficient sightings data were recorded such that density/abundance estimates could be generated for different seasons while others were limited to annual analyses.

Histograms of the perpendicular distance data and selected various cutpoints were plotted to identify suitable truncation points for removal of spurious data and outliers. Right truncations were based on specific distances from the trackline which were determined on a case-by-case basis for the different species/groups. In some cases, spurious data can cause spikes of detections near the trackline. These spikes often arise when animals are attracted to the survey vessel and detections were not made before any responsive movement occurred (Thomas *et al.*, 2010). For the shipboard survey analyses, the spiked data were not removed with a left truncation so that data with a near-100% detection probability at short distances were not eliminated. A left truncation was used for the aerial survey data collected in 2009 not because of a spike near the trackline but because of the limited visibility of the trackline due to the lack of bubble and belly windows on the survey plane. In this case, a left truncation position was chosen where detection was certain.

RESULTS

Survey effort

The aerial surveys covered 12,222km of on-effort trackline between February 2008 and June 2009 (Fig. 1). The total amount of aerial survey effort that met the criteria (i.e. BSS 0 to 5) for the abundance/density analyses for all species/groups except the harbour porpoise was as follows: winter (6,188km), spring (4,084km) and summer (1,950km). No aerial surveys were conducted during the fall. The shipboard surveys covered 12,893km of on-effort trackline between January 2008 and December 2009 (Fig. 1). The total amount of shipboard survey effort that met the criteria (i.e. BSS 0 to 5) for the abundance/density analyses for all species or groups except the harbour porpoise was as follows: winter (3,696km), spring (2,704km), summer (3,830km) and fall (2,663km). The total survey effort included in the harbour porpoise analysis (BSS 0 to 2) for winter abundance/density was 1,150km. There were insufficient sightings data to model the abundance/density of this species during the other seasons or from the aerial surveys.

Distribution and abundance

Eight species of marine mammals were sighted in the study area during the study period: North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), fin whale (*B. physalus*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), harbour porpoise and harbour seal (*Phoca vitulina*). During the aerial and shipboard surveys, a total of 512 sightings (396 of which were on effort) were recorded (Figs 2–4). The sighting information and abundance/density estimates for each species are discussed below. Table 1 provides a summary of the sightings for each species/group. Both on-effort and off-effort sightings were assessed to describe species distribution in the study area; therefore, all sightings were included in the calculations of mean and range for group size, water depth, distance from shore, and SSTs for each species (Table 1). Given the relatively low number of sightings and associated variables, CDS was used to analyse the data for most species/groups. MCDS was attempted for the bottlenose dolphin analyses due to the larger number of sightings and associated covariates. Results of the analyses, including density/abundance estimates with corresponding 95% CIs and CVs, are summarised in Tables 2 and 3. Detection functions were also plotted versus perpendicular sighting distance in the form of histograms of the collected data overlaid by a curve describing the fit of the optimal model to the sightings data (Fig. 5).

Endangered marine mammals

North Atlantic right, humpback, and fin whales are all designated as endangered marine mammals under the US Endangered Species Act (ESA). These species were pooled to fit a detection function since they have similar sighting characteristics due to their large body sizes and distinct blows and because there were not enough sightings recorded for humpback or North Atlantic right whales to fit separate

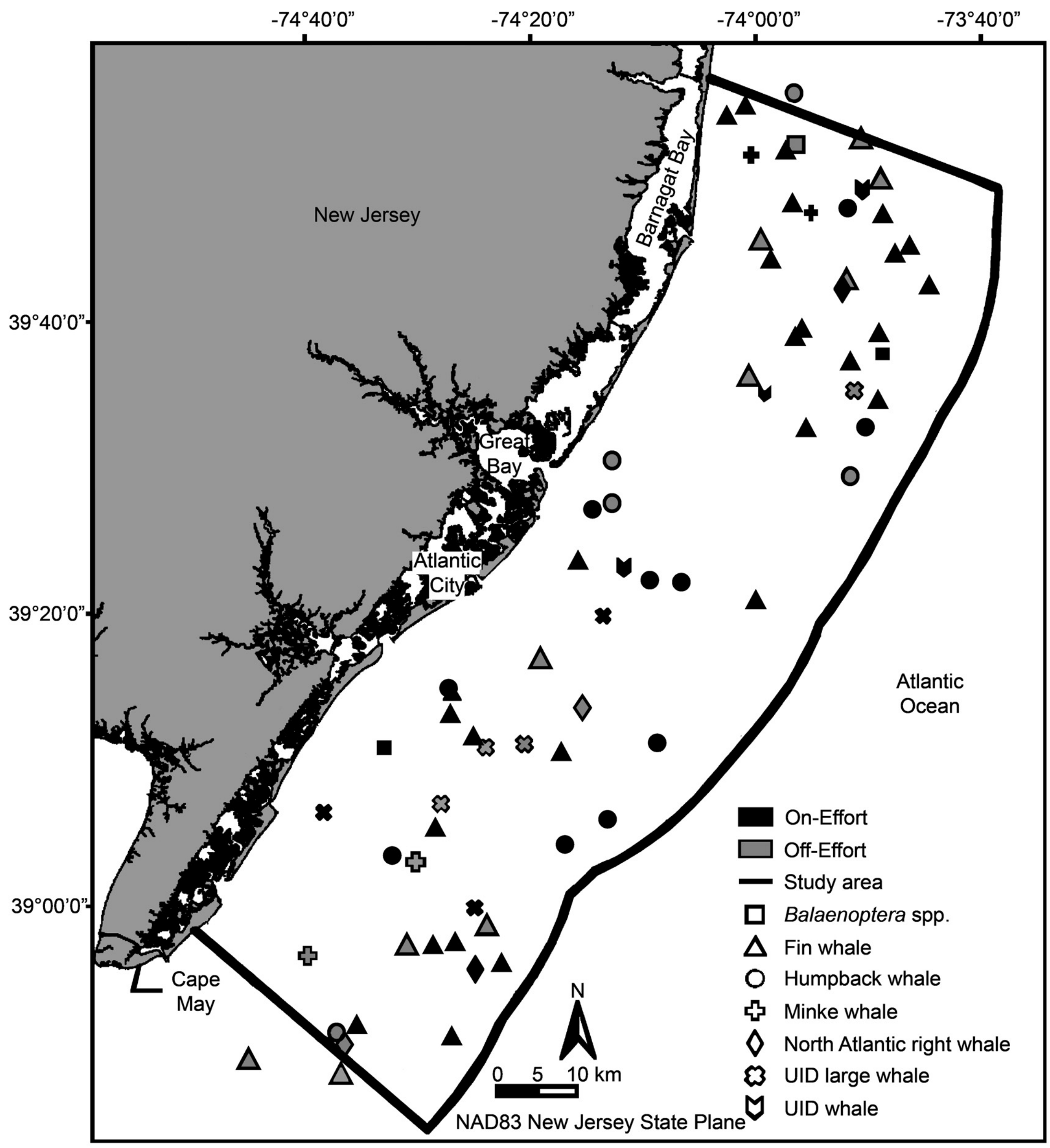

Fig. 2. Sightings of whales recorded during the shipboard and aerial surveys.

detection functions for these species. Sightings of this group were recorded throughout the year. Due to the overall low number of sightings of this group, abundance/density estimates were generated for the entire year and not for any specific seasons using the shipboard survey data. The distance data were truncated at 5,000m which left 33 sightings to be analysed; only one sighting was removed from the analysis based on the chosen truncation distance. A half-normal key function with no adjustments was chosen as the best model based on the lowest AIC value and the fit of the detection function (Fig. 5). The year-round abundance of endangered baleen whales was estimated to be three individuals (95% CI = 2–5; %CV = 29.49; Table 3). Therefore, at any given day of the year, three endangered baleen whales may be in the study area.

NORTH ATLANTIC RIGHT WHALE

Four sightings of North Atlantic right whales were recorded during the study period (Fig. 2, Table 1). Only two of these sightings were on effort; therefore, no estimates of abundance could be generated for this species. These sightings and the results of passive acoustic monitoring for right whales in the study area are discussed in detail in Whitt *et al*. (2013). North Atlantic right whales were sighted during winter, spring and fall and were acoustically detected year round (Whitt *et al.*, 2013). Three of the sightings were recorded during November, December and January when right whales are known to be on calving grounds off Georgia/Florida (Winn *et al.*, 1986) or in the Gulf of Maine (Cole *et al.*, 2013). In 2008, a cow-calf pair was sighted offshore Atlantic City in May and subsequently sighted in the Bay of Fundy in August (Whitt *et al.*, 2013). Photos of each right whale sighted were matched to the North Atlantic Right Whale Catalog maintained by researchers at the New England Aquarium (Whitt *et al.*, 2013).

HUMPBACK WHALE

Seventeen sightings of humpback whales were recorded throughout the study area; seven of these were off effort and 10 were on effort (Fig. 2, Table 1). Humpback whales were sighted during all seasons; the majority of sightings (nine) were recorded during winter. In mid-September 2008, a mixed species aggregation of a fin and humpback whale was recorded south of Atlantic City. The humpback whale was observed lunge feeding in the vicinity of the fin whale in water depths of 15m. A cow-calf pair was recorded in February 2008 just north of the study area boundary in 20m of water. This was the only sighting of a humpback calf during the study period. Breaching behaviour was observed during two sightings: one in May 2009 and the other in October 2009. Photographs were compared to the College of the Atlantic's North Atlantic Humpback Whale Catalog. One individual sighted in the August 2009 was matched to the catalog and had previously been observed in the Gulf of Maine in 2008 (M. Weinrich pers. comm.). The endangered marine mammal data were stratified by species so that an individual year-round abundance estimate could be generated for the humpback whale using the pooled detection function. Based on this analysis, one humpback whale may be in the study area on any given day of the year (95% CI = 0–2; %CV = 54.64; Table 3).

FIN WHALE

Fin whales were the most frequently sighted large whale species during the survey period with a total of 37 sightings recorded (27 were on effort) (Fig. 2). This species was sighted throughout the year. One mixed-species aggregation of a fin and humpback whale was observed in September 2008. While the humpback whale was lunge feeding, the fin whale surfaced multi-directionally but did not appear to be feeding. One calf was observed with an adult fin whale in August 2008. Photographs were compared to the North

Table 1

Summary of sightings data (combined aerial and shipboard survey data) by species/group.

	Sightings (no. of groups)			Group size (no. of animals)		Water depth (m)		Distance from shore (km)		SST* (°C)	
Common name	On effort	Off effort	Total	Mean	Range	Mean	Range	Mean	Range	Mean	Range
North Atlantic right whale	2	2	4**	1.5	1–2	22.5	17–26	23.7	19.9–31.9	10.0	5.5–12.2
Humpback whale	10	7	17	1.2	1–2	20.5	12–29	18.4	4.8–33.2	10.1	4.7–19.5
Minke whale	2	2	4	1.0	1	18.0	11–24	13.1	6.7–18.5	8.3	5.4–11.5
Fin whale	27	10	37	1.5	1–4	21.5	12–29	20.0	3.1–33.9	9.6	4.2–19.7
Bottlenose dolphin	257	62	319	15.3	1–112	16.6	1–34	11.3	0.4–37.7	16.3	4.8–20.3
Common dolphin	23	9	32	12.8	1–65	23.2	10–31	23.5	3.0–37.5	7.1	4.7–12.4
Harbour porpoise	42	9	51	1.7	1–4	21.5	12–30	19.5	1.5–36.6	5.8	4.5–18.7
Harbour seal	1	0	1	1.0	1	18.0	18	9.9	9.9	11.4	11.4
Unidentified cetacean	0	1	1	3.0	3	28.0	28	22.0	22.0	5.2	5.2
Unidentified small cetacean	3	0	3	1.0	1	21.0	14–25	19.5	9.3–32.3	5.3	4.5–6.0
Unidentified dolphin	13	8	21	5.0	1–20	22.2	12–32	19.4	5.0–37.6	11.2	5.3–19.6
Unidentified small delphinid	5	0	5	2.0	1–4	22.6	10–29	19.6	3.2–35.3	5.6	5.1–6.4
Balaenoptera spp.	2	1	3	1.0	1	20.3	17–23	16.2	8.6–27.7	9.6	4.4–18.9
Unidentified whale	3	0	3	1.0	1	22.0	17–25	17.0	12.7–21.1	13.9	11.3–18.9
Unidentified large whale	3	4	7	1.0	1	19.4	15–28	18.6	5.8–27.6	8.3	4.7–18.9
Unidentified pinniped	3	1	4	1.3	1–2	16.0	8–27	14.4	2.8–30.7	6.4	4.9–10.6

*SST data were remotely sensed. **Two sightings of North Atlantic right whales were recorded close together in both time and space on 12 December 2009. These sightings were originally recorded as two separate sightings and appear as such in GMI (2010). Subsequent photo-identification analyses indicated that these sightings were of the same individual North Atlantic right whale. Therefore, the first sighting of this individual is considered the original sighting, and the second sighting is considered a re-sight of the individual and, thus, is not included in this table.

Atlantic Finback Whale Catalogue managed by Allied Whale for possible matches, but no matches were made.

Enough sightings were recorded to fit an unpooled detection function for this species. A 5,000m truncation was chosen for the year-round analysis which resulted in the removal of only one sighting (Table 2). The remaining 24 sightings were described well by a half-normal model with no adjustments (Fig. 5). Based on the resulting year-round abundance estimate, two fin whales may be present in the study area on any given day of the year (95% CI = 1–4; %CV = 36.48; Table 3).

Minke whale

Four sightings of minke whales were recorded during the survey period (Fig. 2, Table 1). Sightings of minke whales occurred during the winter and spring. The winter sightings were recorded in February in the northern portion of the study area northeast of Barnegat Light. The two spring sightings were recorded in June in the southern portion of the study area southeast of Sea Isle City and northeast of Wildwood. The differing sighting characteristics of this species compared to the other whales sighted during this study prevented any pooling of sightings data to fit a detection function for this species. Therefore, no abundance estimates could be generated for the minke whale.

Delphinids

The common dolphin was the dominant delphinid species sighted during the winter surveys. There were insufficient sightings of this species to model a detection function; therefore, common dolphins were pooled with other delphinid sightings recorded during winter to model a detection function. Fourteen of the sightings included in this delphinids group for winter were common dolphins. The remaining seven sightings were likely common dolphins but were recorded as unidentified dolphins or unidentified small delphinids because species identifications could not be confirmed. A detection function was modeled for the pooled group of common dolphins, unidentified dolphins and unidentified small delphinids for the winter. Detections were truncated at 2,500m which left 18 sightings in the analysis (12 of which were common dolphins) (Table 2). The large spike of detections during the trackline is likely due to the attraction of this species to the ship; common dolphins often approached the ship to bow ride (Fig. 5). The hazard-rate key function had the lowest AIC value but also resulted in very high abundances because this model was fitting the spike of detections near the trackline. The half-normal key function provided a better fit for the data and did not include the entire spike (Fig. 5). The winter abundance estimate for the delphinids group was 92 individuals (95% CI = 38–218; %CV = 46.22; Table 3).

COMMON DOLPHIN

A total of 32 sightings (23 on effort) of this species were recorded during the survey period (Fig. 3, Table 1). The presence of calves was confirmed in 26% of the shipboard sightings. The mean water depth of sightings was 23.2m which is the deepest mean depth for all identified cetacean sightings. This may indicate a preference for deeper waters or may be a construct of the fact that the distribution of sightings of common dolphins during the study period was relatively far from shore (mean = 23.5km). Common dolphins were only sighted during fall and winter (late November through mid-March). The data were stratified by species so that a winter abundance estimate could be

Table 2

Number of sightings meeting the criteria for analysis (before and after truncation), truncation distance, mean group size used in the analysis (expected or observed), fitted detection function model, estimated probability density function evaluated at zero perpendicular sighting distance [$f(0)$] in km^{-1} and the corresponding percentage coefficient of variation (CV), effective strip width (*ESW*) and encounter rate of each species or group in km^{-1} analysed. All analyses, except those designated as ‘aerial’, were conducted with the shipboard survey data.

Common name or group	Sightings n_{Before}	Sightings n_{After}	Truncation distance w(m)	Mean group size***	$f(0)$	%CV $f(0)$	*ESW* (m)	Encounter rate (n/L)
Endangered marine mammals								
Year-round	34	33	5,000	1.303 (*e*)	0.000334	13.45	2991.9	0.002554
Humpback whale*								
Year-round	7	7	5,000	1.143 (*o*)	0.000418	37.84	2392.5	0.000542
Fin whale								
Year-round	25	24	5,000	1.381 (*e*)	0.000307	15.78	3253.8	0.001857
Delphinids								
Winter	21	18	2,500	9.000 (*o*)	0.000797	16.37	1254.9	0.004854
Common dolphin*								
Winter	14	12	2,500	12.333 (*o*)	0.000797	16.37	1254.9	0.003236
Bottlenose dolphin								
Spring	69	68	3,500	19.853 (*o*)	0.000582	9.45	1719.2	0.025074
Summer	98	97	3,500	10.448 (*e*)	0.000521	7.59	1919.9	0.025338
Summer (aerial)	72	40	10**	18.350 (*o*)	0.001554	12.61	643.63	0.020508
Harbour porpoise								
Winter	30	27	2,200	1.889 (*o*)	0.000848	16.10	1179.9	0.023254

*Species were pooled with others of similar detectability to model detection functions due to the limited number of sightings of the individual species. **Left truncation was chosen within 10m of the trackline due to the limited visibility of the trackline directly below the survey plane. ***(*e* = expected; *o* = observed).

Table 3

Estimates of abundance and density (individuals/km^2) and the corresponding 95% confidence intervals (CI) and percentage coefficient of variation (CV) for each species and group analysed. All estimates, except those designated as 'aerial', were generated from the shipboard survey data.

Common name or group	Abundance (*N*)	95% CI(*N*)	Density (*D*) per 1km^2	95% CI(*D*)	%CV
Endangered marine mammals					
Year-round	3	2–5	0.000560	0.000317–0.000988	29.49
Humpback whale					
Year-round	1	0–2	0.000130	0.000045–0.000370	54.64
Fin whale					
Year-round	2	1–4	0.000394	0.000197–0.000790	36.48
Delphinids					
Winter	92	38–218	0.017405	0.007301–0.041493	46.22
Common dolphin					
Winter	84	33–213	0.015901	0.006245–0.040487	50.15
Bottlenose dolphin					
Spring	761	362–1,600	0.144770	0.068903–0.304180	39.10
Summer	363	196–669	0.068942	0.037353–0.127250	31.93
Summer (aerial)	1,537	758–3,119	0.292350	0.144120–0.593050	36.97
Harbour porpoise					
Winter	98	35–272	0.018612	0.006704–0.051676	55.27

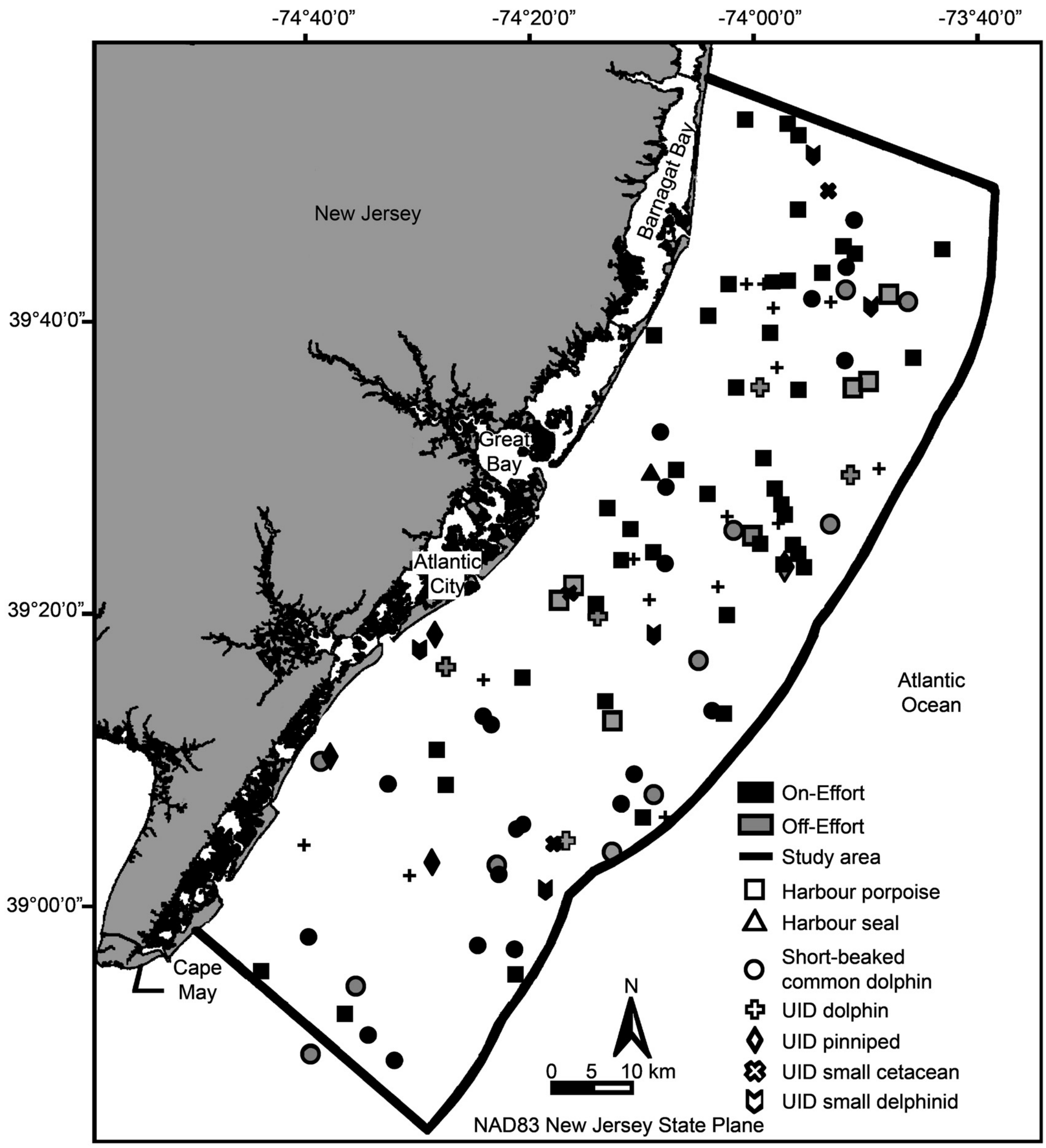

Fig. 3. Sightings of small cetaceans and pinnipeds recorded during the shipboard and aerial surveys.

generated for this species. This abundance estimate was 84 individuals (95% CI = 33–213; %CV = 50.15; Table 3). There were not enough sightings of this species to generate fall abundance/density estimates.

BOTTLENOSE DOLPHIN

Bottlenose dolphins were the most frequently sighted species during this study. A total of 319 sightings were recorded; most of these (257) were on effort (Fig. 4, Table 1). The presence of calves was confirmed in 24% of all sightings. This species was sighted during all seasons. Occurrence was documented as early as the beginning of March and as late as mid-October, but the vast majority of sightings were during the spring and summer. There were not enough sightings of this species to generate abundance/density estimates for the fall or winter seasons; therefore, only spring and summer analyses were conducted. The spring analysis using the shipboard survey data included a right truncation at 3,500m which resulted in 68 sightings left for analysis (Table 2). The half-normal key function was used although the hazard-rate actually resulted in a lower AIC value. A high number of detections of bottlenose dolphins within 250m of the trackline resulted in a spike near zero (Fig. 5); the hazard-rate key function fitted the detection function to this spike which resulted in a higher estimate of abundance. This spike was likely caused by the attraction of this species to the ship and the failure of observers to detect the animals before any responsive movement occurred. To minimise the influence of this spike, the half-normal key function with no adjustments was used to fit the detection function and resulted in a model with a flatter 'shoulder' to the detection function (Fig. 5). The spring abundance of bottlenose dolphins using the half-normal model was estimated to be 761 individuals (95% CI = 362–1,600; %CV = 39.10; Table 3).

The analysis of bottlenose dolphin sightings recorded from the shipboard surveys during the summer was based on a right truncation at 3,500m which resulted in 97 sightings left for analysis (Table 2; Fig. 5). The best model included BSS as a covariate and used a half-normal key function with no adjustments. This MCDS model provided a reasonable fit

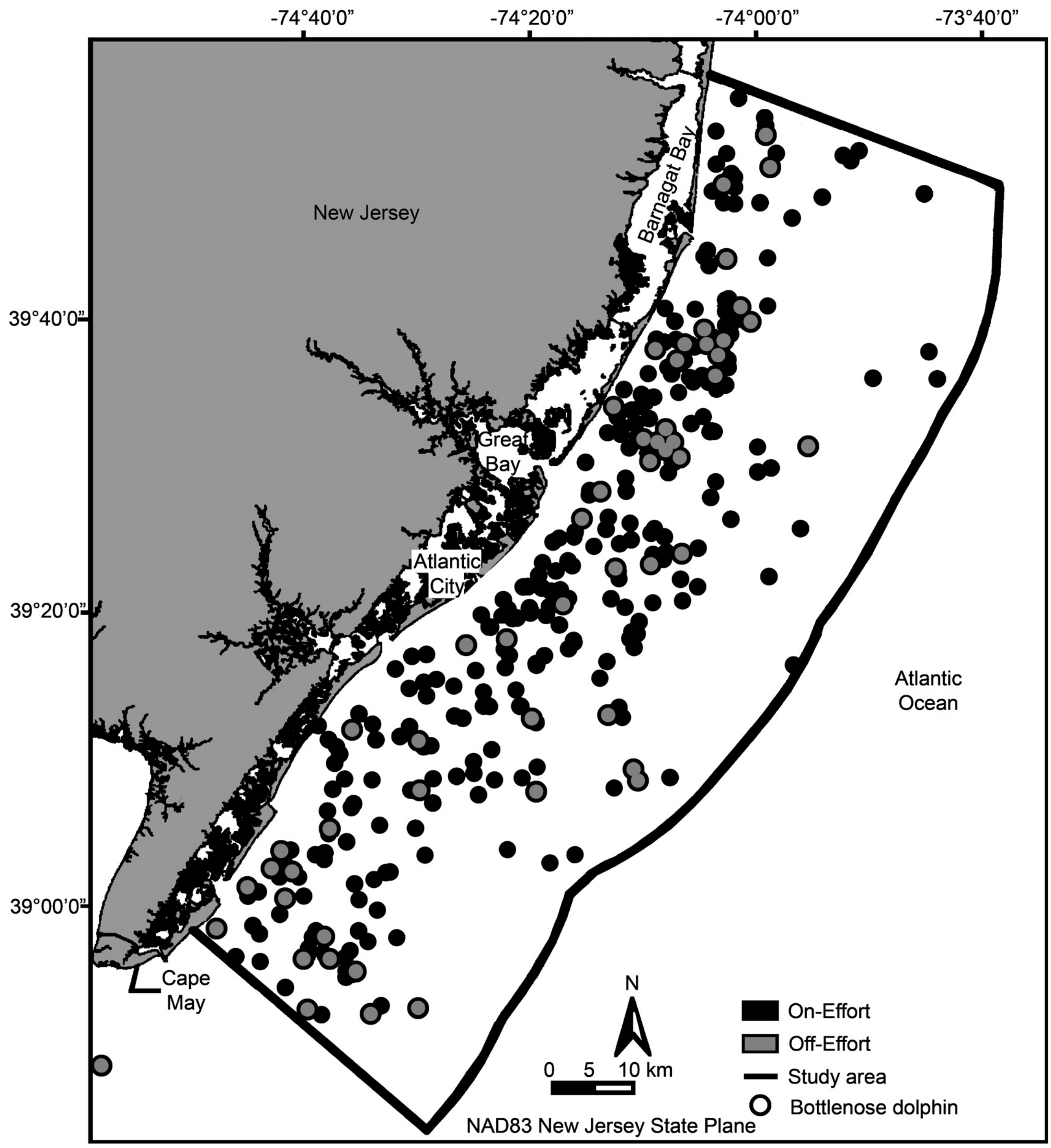

Fig. 4. Sightings of bottlenose dolphins recorded during the shipboard and aerial surveys.

to the data and provided a low AIC value. Note that we chose a model that did not fit the spike of detections near the trackline to minimise the influence of the likely attraction of bottlenose dolphins to the ship. The summer abundance estimated from this model was 363 individuals (95% CI = 196–669; %CV = 31.93; Table 3). The analysis of bottlenose dolphin sightings recorded from the aerial surveys during the summer was based on a left truncation at 10m (Table 2). Summer aerial surveys were only conducted in 2009 during which the survey plane did not include bubble or belly windows. Therefore, visibility below the aircraft directly on the trackline and within 10m on either side of the trackline was limited, violating the assumption that all animals on the trackline were detected. Therefore, the left truncation position was chosen to include only the portion of the trackline where detection of animals was certain. After the left truncation at 10m, 40 sightings were left for the analysis. A MCDS model with BSS as a covariate and the half-normal key function with no adjustments provided the best fit for the data (Fig. 5). The summer abundance estimated from these aerial survey data was 1,537 individuals (95%CI = 758–3,119; %CV = 36.97; Table 3).

Harbour porpoise

The harbour porpoise was the second most frequently sighted cetacean after the bottlenose dolphin. A total of 51 sightings were recorded (42 on effort) (Fig. 3, Table 1). Over 90% of harbour porpoise sightings were recorded during winter (mainly February and March). Three sightings occurred during spring (April and May), and one sighting was recorded during summer (July). The mean SST (5.8°C) for harbour porpoise sightings was the lowest value for all identified cetacean species. There were insufficient sightings of this species to conduct a fall, spring or summer analysis. A right truncation of 2,200m was chosen for the winter analysis to maximise the sample size. This truncation distance only removed three sightings; therefore, 27 sightings remained for the analysis (Table 2). A very small spike of detections was evident within 250m from the trackline which might suggest responsive movements to the presence of the vessel. No apparent attraction behaviour was documented for this species during the survey period; this species is known to move away from vessels (Barlow, 1988; Palka and Hammond, 2001; Polacheck and Thorpe, 1990). A half-normal key function with no adjustments was chosen as the best model based on the fit and the low AIC value (Fig. 5). The winter abundance of harbour porpoises in the study area was estimated to be 98 individuals (95% CI = 35–272; %CV = 55.27; Table 3).

Harbour seal

Only one harbour seal was recorded during the survey period; therefore, no abundance estimate could be generated for this species. This individual seal was observed in shallow

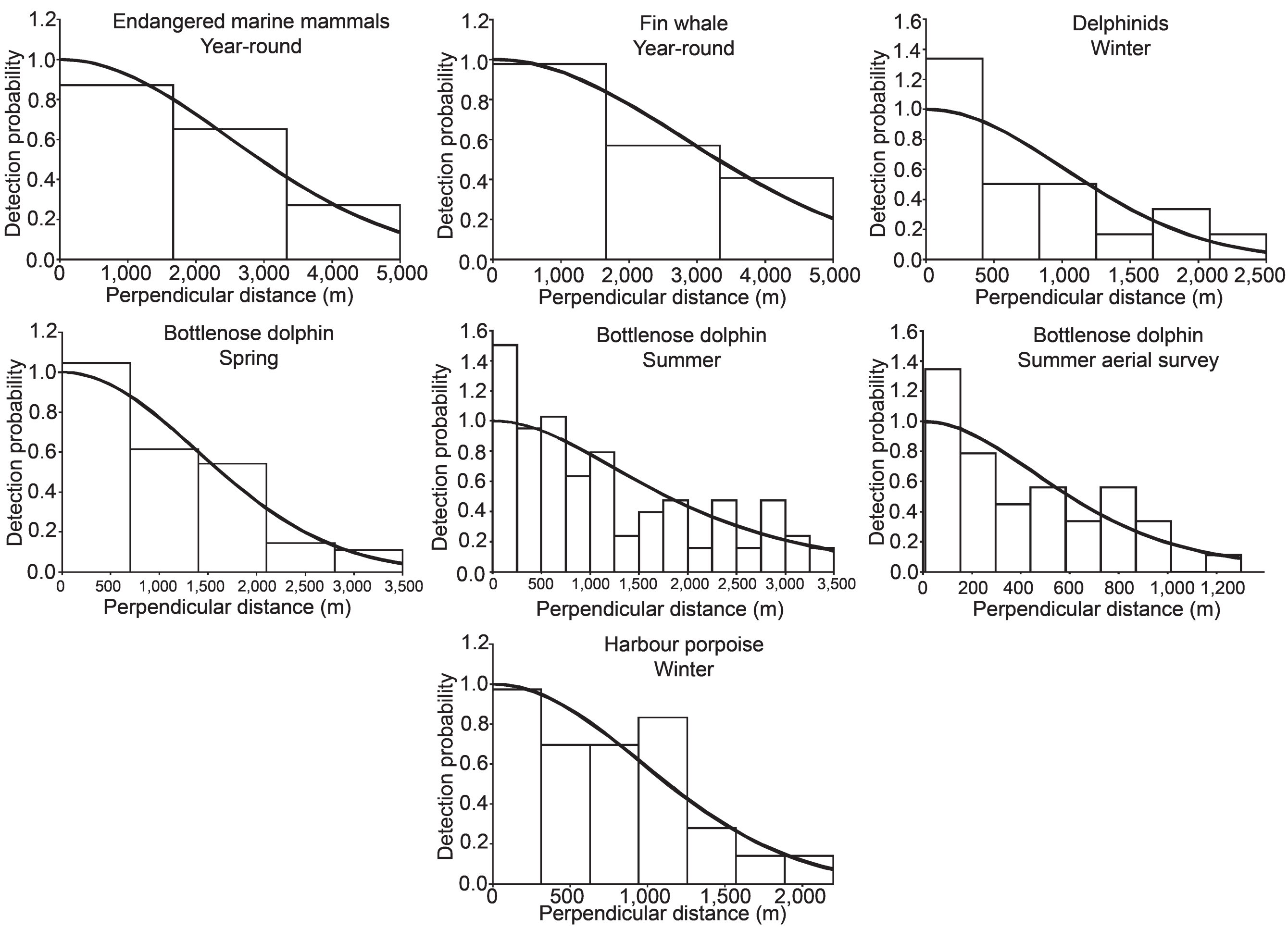

Fig. 5. Histograms of observed distances and fitted detection functions for the species and groups analysed.

waters (18m) 9.9km east of Little Egg Inlet in June 2008 (Fig. 3, Table 1). The three unidentified pinnipeds recorded in the study area were probably harbour seals but species identification could not be confirmed.

DISCUSSION

Baleen whales

Endangered baleen whales

The year-round detections of North Atlantic right, fin and humpback whales confirm the occurrence of these species in this portion of the Mid-Atlantic outside of 'typical' migratory periods (i.e. summers spent at high-latitude feeding grounds and winters spent at low-latitude breeding grounds) (Corkeron and Connor, 1999). The year-round presence of fin and humpback whales was visually confirmed. Although right whales were visually detected in all seasons except summer, they were acoustically detected during the summer months, which also confirms the year-round presence of this species (Whitt *et al.*, 2013). Humpback whales are known to migrate between summer feeding grounds from south of New England to northern Norway (Kenney and Winn, 1986; Stevick *et al.*, 2003b; Weinrich *et al.*, 1997; Whitehead, 1982) and winter calving grounds in the West Indies region (Smith *et al.*, 1999; Stevick *et al.*, 2003a; Whitehead and Moore, 1982). Similarly, North Atlantic right whales undertake a well-defined, strongly seasonal migration between their feeding grounds off the northeastern US and Canada and their calving grounds off the southeastern US (Kenney, 2001; Winn *et al.*, 1986). Fin whales are believed to follow the typical baleen whale migratory pattern consisting of movement between northern summer feeding grounds and southern winter calving grounds (Aguilar, 2009; Clark, 1995). However, not all humpback, right or fin whales in the western North Atlantic undergo these seasonal migrations (e.g. Aguilar, 2009; Charif *et al.*, 2001; Clapham, 2009; Clapham *et al.*, 1993; Dawbin, 1966; Kraus *et al.*, 1986; Swingle *et al.*, 1993). Although the abundance estimates for these whales were relatively low, the presence of even one humpback, right or fin whale in nearshore New Jersey waters is enough to trigger monitoring and mitigation measures given their endangered status.

The detections of these species in the study area, particularly during times of the year when individuals are known to be in other areas, demonstrate the potential year-round importance of this region as more than habitat for seasonal migrants. Based on the sightings and behavioural observations from the current study, the nearshore waters off New Jersey may provide important nursery and feeding habitat for endangered baleen whales. A right whale cow-calf pair sighted in the study area in May was presumably en route to the Bay of Fundy (Whitt *et al.*, 2013). During the encounter of a fin whale cow-calf pair in August, the calf circled our ship while the cow appeared to be making foraging dives several hundred meters from the calf. One of the humpback whales sighted exhibited lunge feeding behaviour, and the two juvenile right whales sighted together appeared to be skim feeding (Whitt *et al.*, 2013). The main feeding grounds for both species are north of the study area (Cole *et al.*, 2013; Nichols *et al.*, 2008; Weinrich *et al.*, 1997). Although feeding could not be confirmed for any of these whales, the observations of feeding behaviour suggest that New Jersey's nearshore waters may serve as additional feeding areas for these endangered species.

Minke whale

Minke whales are widespread throughout US waters but are most likely to occur in US Mid-Atlantic waters during winter. Sightings of this species in the study area during winter (February) are consistent with the known movement of minke whales southward from New England waters from November through March (Mellinger *et al.*, 2000; Mitchell, 1991). Occurrence of minke whales in New England waters increases during the spring and summer and peaks from July through September (Murphy, 1995; Risch *et al.*, 2013; Waring *et al.*, 2013). The June sightings recorded during the study period may have been of individuals moving back to New England waters for the summer.

Delphinids and harbour porpoise

The occurrence of delphinids and porpoises was largely seasonal. Although bottlenose dolphins were present during all seasons, abundance was highest in the spring and summer which coincides with the known movement of the Northern Migratory Coastal stock into the northern portion of their range (Waring *et al.*, 2010). Common dolphins and harbour porpoises were frequently seen in the study area during the winter and spring. The high winter abundance of common dolphins in the study area is consistent with their known seasonal movements to mid-Atlantic waters during colder months (Hamazaki, 2002; Payne *et al.*, 1984; Perrin, 2009). High abundances of harbour porpoises also occurred during the winter when the waters off New Jersey and in the New York Bight provide an important habitat for this species (Westgate *et al.*, 1998). The fall season appears to be a transitional period for these seasonal cetacean species. Few sightings of bottlenose dolphins and common dolphins were recorded during the fall despite the large amount of shipboard survey effort. It is likely that most bottlenose dolphins have already moved south of the study area, and most common dolphins and harbour porpoises are farther north during this time of year.

Bottlenose dolphin

The bottlenose dolphin was the most abundant and most frequently sighted species found in the study area. High abundances of bottlenose dolphins off New Jersey have been documented since the 19th century (True, 1885). New Jersey and Long Island, New York represent the northernmost range of coastal bottlenose dolphins in US waters (Waring *et al.*, 2010) with the exception of extralimital sightings in Cape Cod Bay (Wiley *et al.*, 1994). The bottlenose dolphins found in coastal waters off New Jersey are thought to belong to the Western North Atlantic Northern Migratory Coastal stock which occupies a small range between New York and North Carolina. This stock moves between the mouth of Chesapeake Bay and Long Island during summer (July–September) and between Cape Lookout, North Carolina and the North Carolina/Virginia border during winter (January–March) (Waring *et al.*, 2010). During our study, bottlenose dolphins were sighted during all seasons but were most abundant during the spring and summer months, particularly May through August, which coincides with the known movement of the coastal stock into the northern portion of their range. The sightings data also confirmed the presence of this species in New Jersey waters as early as March and as late as mid-October. Although no bottlenose dolphins were recorded in the study area between November and February, previous sightings have been recorded in December and January (CETAP, 1982). In addition, a group travelled into the Shrewsbury and Navesink Rivers in northern New Jersey in the summer of 2008 and remained there into the winter months[5]. In February 2010, a group of 8 to 15 animals, most likely bottlenose dolphins, was spotted in the Hackensack River far inland in northern New Jersey[6].

The seasonal occurrence of bottlenose dolphins off New Jersey is thought to be due to the presence of preferred prey species (sciaenid fishes) which occur off New Jersey during June through August (Able and Fahay, 1998; Gannon and Waples, 2004). Seasonal movements off New Jersey may also be indirectly influenced by water temperatures which affect the distribution of these sciaenid fishes (Toth *et al.*, 2011). Previous bottlenose dolphin surveys off New Jersey recorded average temperatures of the first and last sightings of the migration season between 14 and 16.3°C (Toth *et al.*, 2011). During the current study, bottlenose dolphins were recorded in SSTs ranging between 4.8 and 20.3°C (mean SST was 16.3°C) (Table 1), indicating that bottlenose dolphins off New Jersey can regularly withstand a wide range of temperatures, particularly low temperatures. They are also known to withstand water temperatures as low as 0.7°C based on the sightings of bottlenose dolphins that overwintered in the New Jersey rivers in January 2009 (A. Gorgone, pers. comm.). However, these sightings may represent extraordinary circumstances since coastal bottlenose dolphins do not typically overwinter this far north.

Bottlenose dolphins off New Jersey are known to prefer coastal habitat over estuarine habitat although they are found in Delaware Bay off the southern end of New Jersey (Toth *et al.*, 2011). Previous coastal studies focused on fine-scale distributions within 6km from shore (Toth Brown, 2007; Toth *et al.*, 2011). Toth Brown (2007) documented a significant break in the habitat usage of bottlenose dolphins in this range of New Jersey's nearshore waters, with one group using the waters within 2km of the shore and the other occupying waters outside of 2km of shore with very little overlap between the two groups. Toth *et al.* (2011) noted a 'core area' used by bottlenose dolphins, particularly cows and their calves between Brigantine and Little Beach. The current study covered a wide longitudinal range of the coast and resulted in sightings extending approximately 38km offshore with a mean distance of 11.3km from shore (Table 1). Sightings were scattered within this range along the coastline with slight concentrations detected north of Little Beach/Great Bay and between Great Bay and Atlantic City (Fig. 4).

Results indicate that the preferred coastal habitat for this migratory stock may extend offshore to approximately 38km off New Jersey. However, the bottlenose dolphins sighted during the current study could not be confirmed as belonging to the coastal stock or the Western North Atlantic Offshore stock, which is recognised seaward of 34km from the US coastline (Waring *et al.*, 2008). North of Cape Lookout, these two stocks are thought to be separated by bottom depth; the coastal form occurs in nearshore waters (<20m deep) while the offshore form is in deeper waters (>40m deep) (Garrison *et al.*, 2003). In addition, no offshore bottlenose dolphins have been detected within 40km from shore in this region (Garrison *et al.*, 2003). Because the bottlenose dolphin sightings were all within 38km from shore and in waters less than 35m deep, it is assumed that all of these sightings were of individuals from the coastal stock. Additional surveys and genetic sampling are required to confirm the current distribution patterns and any mixing or segregation of these stocks off New Jersey.

Common dolphin

Although common dolphins were confirmed in the study area during the fall and winter (November through March), they may occur year round. Previous sightings have been recorded in May and July just east and north of the study area (Canadian Wildlife Service, 2006; CETAP, 1982), and sightings farther offshore near the shelf break are common during the summer months (Jefferson *et al.*, 2009). Strandings have also been recorded along the New Jersey coastline during all seasons (NMFS Northeast Region Marine Mammal Stranding Network, unpublished data). Common dolphins primarily occur offshore in waters 200 to 2,000m in depth (Canadian Wildlife Service, 2006; CETAP, 1982; Jefferson *et al.*, 2009; Ulmer, 1981); however, they are known to occur in shallower waters in the Mid-Atlantic (Hamazaki, 2002; Payne *et al.*, 1984). During the current study, this species was sighted throughout the study area in waters 3 to 37km from shore and 10 to 31m in depth. Therefore, sightings support the occurrence of this species in shallow, coastal waters in this region.

Harbour porpoise

Harbour porpoises were most common in the study area in February and March, which is the time of year when New Jersey waters are known to be an important habitat for this species (Westgate *et al.*, 1998). However, harbour porpoises were also recorded in the study area in April, May and July, indicating that this species utilises this region during other times of the year. Strandings have also been recorded in the study area during winter, spring and summer (NMFS-NEFSC, 1997). No harbour porpoise sightings were recorded during the fall; however, weather conditions were often above a BSS 2 which makes sighting this species very difficult. The densest concentrations of harbour porpoises are thought to occur from New Jersey to Maine from October through December (NMFS-NEFSC, 2001). Therefore, harbour porpoises are likely to occur in the study area throughout the fall. Harbour porpoises are known to occur most frequently over the continental shelf and are most often found in waters cooler than 17°C (Read, 1999). Sightings data from the current study are consistent with these known habitat associations; harbour porpoises were recorded between 1.5 and 37km from shore in waters ranging from 12 to 30m in depth and 4.5 to 18.7°C.

[5] Information available at *http://www.nefsc.noaa.gov/njdolphins* and *http://usatoday30.usatoday.com/news/nation/2008-12-27-dolphins_N.htm*. Accessed 15 August 2013.

[6] Information available at *http://www.northjersey.com/news/021710_Dolphins_seen_in_Hackensack_River.html*. Accessed 15 August 2013.

Pinnipeds

Harbour seals may be found in the study area during any time of year and are known to make seasonal movements in New Jersey waters during the winter, specifically from late October to early May (Slocum, 2009). Only one harbour seal was recorded in the study area during the study period. This seal was sighted in shallow waters east of Little Egg Inlet in June. Other unidentified pinnipeds recorded near Ocean City in April were likely also harbour seals but could not be confirmed. Harbour seals regularly haul out inshore of the study area at three major sites: Great Bay, Barnegat Inlet, and Sandy Hook (Slocum, 2009). The harbour seal observed in June was likely from one of these sites.

Biases

The relative abundance/density estimates presented in this paper are most likely underestimates because they are not fully corrected for perception or availability biases. Perception bias results when an observer fails to detect an animal on the trackline when the animal is actually at the surface on the trackline. Factors that can influence perception bias include viewing conditions (e.g. BSS, glare, swell height, visibility), observer condition (e.g. experience, fatigue) and platform characteristics (e.g. pitch, roll, yaw, altitude). Perception bias was minimised by using experienced observers, allowing sufficient observer breaks to minimise fatigue, and conducting surveys during optimal sea conditions. However, because the goal was to record any marine mammal species in the study area, survey effort was not limited to near perfect detection conditions (e.g. BSS 0–2). Instead, survey effort was limited to the maximum sea conditions at which large blows could be detected (i.e. BSS 0–5).

Availability bias results when an animal is submerged or otherwise hidden from view while on the trackline and, hence, is unable to be detected. Factors that can affect availability bias include species-specific behaviour, group size, blow and dive characteristics and dive intervals. Availability bias was not fully accounted for, but inflated abundance/density estimates were minimised by not fitting detection functions to spikes in detections resulting from possible attractive animal movements toward the survey platform prior to detection. The factors tested in the MCDS models for bottlenose dolphins included BSS, visibility, and group size; BSS was the only factor chosen in the best MCDS models for bottlenose dolphins during the summer shipboard and aerial surveys. Further correction for perception and availability biases would provide absolute estimates of abundance/density which would be useful for determining the overall status of species, populations or stocks in the Mid-Atlantic but are not necessary for the purposes of the current study which was to generate relative baseline estimates which can be used for future trend and impact analyses.

Management implications

This study provides the first year-round abundance and density estimates for marine mammal species in nearshore waters off New Jersey. These relative estimates and the distribution and habitat utilisation information obtained from this study are critical for assessing the potential impacts of anthropogenic activities in this portion of the Mid-Atlantic Bight which is a prime region of future offshore renewable energy development on the OCS. These baseline data will provide the industry and regulators with the necessary details to inform the permitting and licensing of offshore renewable energy technologies and to determine potential monitoring and mitigation strategies for minimising impacts on marine mammals. The distribution and abundance information for the endangered North Atlantic right, fin and humpback whales will be particularly important for future construction and post-construction impact studies. Assuming the levels of bias remain constant for future surveys (e.g. use of similar protocols, platforms, observers, etc.), these relative abundance/density estimates provide a baseline that can be compared to estimates obtained during pre-construction, construction and post-construction activities to assess impacts and changes over time. The baseline estimates can also be used to determine site-specific take estimates for incidental take authorisations and may be used to inform the timing of construction activities to minimise potential impacts during known periods of marine mammal occurrence.

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