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ORIGINAL PAPER

Abundance and distribution of cetaceans in the Gulf of Alaska

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Abstract To effectively protect and manage marine mammals, contemporary information on their abundance and distribution is essential. Several factors influence present-day insight including the accessibility of the study area and the degree of difficulty in locating and studying target species. The offshore waters of the Gulf of Alaska are important habitat to a variety of cetaceans yet have remained largely unsurveyed due to its remote location, vast geographic area, and challenging environmental conditions. Between 2009 and 2015, three vessel surveys were conducted using line-transect sampling methods to estimate cetacean abundance and density. Here, we present results on the distribution for all species encountered and density and abundance for six species, including humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), sperm whales (*Physeter macrocephalus*), blue whales (*B. musculus*), killer whales (*Orcinus orca*), and Dall's porpoise (*Phocoenoides dalli*). Fin whales, humpback whales, and Dall's porpoise were the most abundant species. Beaked whales were documented only in 2015. Prior to this study, recent sightings of blue whales were rare, likely related to the lack of offshore survey coverage. No North Pacific right whales (*Eubalaena japonica*) were sighted, underscoring the critically endangered status of this species in a formerly populous habitat. Although these results provide the first estimates from offshore waters, additional effort is necessary to assess trends and to obtain baseline data for the rare and cryptic species in order to better inform conservation and management actions.

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Introduction

Historically, large whales were extensively targeted by commercial whaling. As the numbers dramatically diminished globally, protective measures were implemented. These included regulations administered by the League of Nations in 1935, the creation of the International Whaling Commission (IWC) in 1946, and the passage of the Marine Mammal Protection Act (MMPA) of 1972 and the Endangered Species Act (ESA) of 1973. Whereas some species were protected from commercial whaling at the onset, others were managed by the IWC. The IWC set restrictions on catch and minimum size limits, seasons and areas. Whaling fleets were required to carry inspectors to enforce international regulations (Ivashchenko et al. 2011). The true extent of the shortcomings of these international efforts has only recently been revealed. Land-based Japanese whaling stations underreported sperm whale catches (Kasuya 1999) with recent research further revealing systematic falsification of catch data for this species in the North Pacific (Ivashchenko and Clapham 2015). Driven by economics, the former USSR conducted a large-scale global operation of illegal whaling that went completely unchecked for over

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30 years (Berzin 2008; Clapham and Ivashchenko 2009; Ivashchenko et al. 2011). In 1982, an international moratorium on commercial whaling was imposed, although Japan continues to hunt whales in the North Pacific under the IWC's 'special permit' provision, purportedly for scientific research.

The consequences of this global whaling campaign on the great whales (defined as 12–14 species of baleen whales and the sperm whale) remain evident today. While some whale populations have shown signs of recovery, others remain a concern. The eastern North Pacific gray whale (*Eschrichtius robustus*) was removed from the US List of Endangered and Threatened Wildlife in 1994, with abundance comparable to pre-whaling estimates (NMFS 1994). Fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) in western Alaska and the central Aleutian Islands are increasing (Zerbini et al. 2006). The Bering-Chuckchi-Beaufort Seas bowhead whale (*Balaena mysticetus*) stock shows an annual increase estimated at 3.7% with the abundance tripling from 1978 to 2011 (Givens et al. 2013). North Pacific humpback whales have continued to increase with some estimates showing greater numbers than pre-whaling abundance (Barlow et al. 2011). Humpback whales have recently been divided into 14 Distinct Population Segments (DPS) (NMFS 2016). While many of the world's humpbacks have recovered (9 no longer warrant listing), 5 remain listed as either 'threatened' or 'endangered' (NMFS 2016). The western North Pacific gray whale was so depleted it was once thought to be extinct (Bowen 1974). It remains listed as critically endangered (Reilly et al. 2008c) due to a small population size and slow rate of increase (Bradford et al. 2008). Both the western and eastern stocks of North Pacific right whales (*Eubalaena japonica*) are endangered. While the western stock is comprised of a couple hundred individuals (Brownell et al. 2001), the eastern stock is estimated at 30 individuals (Wade et al. 2011a) and is listed as critically endangered (Reilly et al. 2008d).

Movement patterns can vary considerably within and among species. It is well known that many baleen whales undertake extensive seasonal migrations between productive summer feeding grounds and tropical or subtropical areas for reproduction and calving (e.g., Kraus et al. 1986; Kennedy et al. 2014a). Migrations of mature male sperm whales to tropical waters are motivated by reproduction (Whitehead 2002a). Long-range movements for many species can occur within seasons likely driven by the search for productive foraging areas (Kennedy et al. 2014b). From spring to fall, an influx of whales into the Gulf of Alaska (GoA) occurs as it is an important feeding destination for migratory baleen whales (Dawbin 1966; Aguilar 2002; Jones and Swartz 2002; Kenney 2002; Sears 2002). It is important to recognize that many species demonstrate high mobility and frequent movements across international boundaries in this and other areas. Environmental changes are occurring in the world's oceans as a result of human activity that may threaten populations (Davidson et al. 2012; Parsons et al. 2015). When assessing stocks and identifying anthropogenic risks, it is important to obtain multi-regional information to reflect the cosmopolitan nature of many species of cetaceans.

In a global analysis of line-transect surveys, Kaschner et al. (2012) determined that <25% of the oceans were surveyed and only 6% were surveyed frequently enough to assess trends; survey coverage was biased toward the Northern Hemisphere, and specifically US and northern European waters. While some Alaskan waters have been surveyed extensively (e.g., Clarke et al. 2013, 2015), large gaps remain including waters off the continental shelf in the GoA (Ferguson et al. 2015). Abundance and distribution data for some cetacean species in nearshore areas have been collected since the mid-1980s (Brueggeman et al. 1987, 1988; Forney and Brownell 1996; Zerbini et al. 2006, 2007; Hobbs and Waite 2010). Five nearshore Biologically Important Areas have been identified within the GoA region as important feeding or migratory corridors for four baleen and one toothed whales (Ferguson et al. 2015). In contrast, knowledge of cetacean distribution in offshore areas throughout the GoA is derived mainly from whaling records (Townsend 1935; Berzin and Rovnin 1966; Nishiwaki 1966; Rice 1974; Wada 1979; Ivashchenko and Clapham 2012; Ivashchenko et al. 2014). Bottom-mounted hydrophones in offshore waters have been used to record calls from blue, humpback, fin, right (Mellinger et al. 2004b; Stafford et al. 2007), and sperm (Mellinger et al. 2004a) whales throughout the area providing some information on seasonal occurrence patterns. In recent years, some effort in offshore areas has provided limited information on cetacean distribution and abundance (Barlow et al. 2011; Matsuoka et al. 2012, 2013).

The GoA is an extension of the Pacific Ocean and defined by the southern coast of Alaska. It is dominated by two current systems, the subarctic gyre in the basin and the Alaska Coastal Current (Stabeno et al. 2004). The topography is diverse and complex, comprised of a continental shelf, slope, and pelagic waters with canyons and seamounts (Fig. 1). The GoA is characterized by strong storm systems which in turn impact ocean circulation and nutrients resulting in a rich ecosystem. Changes in the system are further influenced by global warming, decadal variability patterns, El Nińo and interannual variability which in turn influence nutrients and plankton (Stabeno et al. 2004).

This complex GoA ecosystem attracts a variety of cetacean species. A minimum of 15 species occur seasonally or year-round within these waters. Species range from shallow water harbor porpoise (*Phocoena phocoena*) to offshore

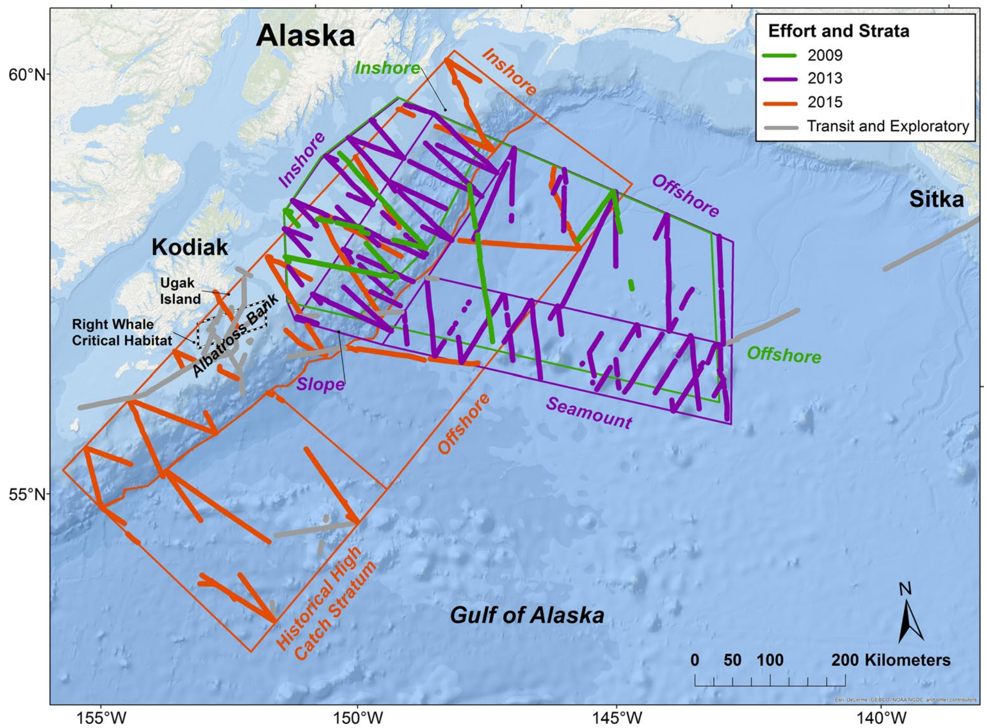

Fig. 1 Survey strata and realized effort by year. For 2009, the survey strata (*green*) were confined to the boundaries of the Temporary Maritime Activities Area (TMAA). In 2013, the survey strata (*purple*) extended slightly south of the TMAA to encompass seamounts located on the southern boundary of the TMAA. In 2015, the survey strata (*orange*) encompassed historical North Pacific right whale habitat. Strata overlap occurred between all 3 years. For all years, transit and exploratory effort (*light gray*) was used in estimation of detection probability and distribution only. Produced with ArcGis 10.3.1

pelagic species such as blue whales (*B. musculus*) (Carretta et al. 2016; Muto et al. 2016). Seven species are ESA-listed by the US. Eleven are data deficient with regard to US regional stock assessments pertaining to abundance and trends, reproductive rates, and potential biological removal calculations (Wade and Angliss 1997; Carretta et al. 2016; Muto et al. 2016). In this paper, we describe the distribution, density, and abundance of cetaceans from 3 surveys conducted during 2009–2015 in the GoA. The motivation for these surveys originated from two objectives: to provide data on marine mammals for an assessment of potential impacts related to US Navy training exercises and to conduct research on North Pacific right whales. Surveys conducted in 2009 and 2013 were designed to document and estimate abundance and densities of marine mammals within the Navy Maritime Activities Area (TMAA) (Fig. 1). This was necessary in order to conduct an environmental impact statement in relation to US Navy activity. In 2015, the first survey of historical North Pacific right whale habitat within the GoA was conducted (Fig. 1). While there are differences in timing, location, and survey design, there is geographic overlap across all years and comparable habitat surveyed (Fig. 1). All surveys encompassed the diverse habitat that characterizes the GoA. It was expected that each survey design would potentially capture all species that can be encountered within these waters. Although estimates were calculated for only two surveys, all 3 years are included here in order to present the best depiction of cetaceans within this region. Here, we present the most current information on cetaceans in the offshore waters of the GoA.

Methods

Field methods, survey area, and survey design

Visual observers worked in rotating teams of three people to collect sighting data using standard line-transect methods during on-effort mode. For all three surveys, the starboard and port observers and the recorder were stationed on the same level. In 2009 and 2015, observations were conducted on the flying bridge (platform + observer height = 15.2 m), and in 2013 on the bridge wings (platform + observer height = 6.9 m). Observers used 25× 'big-eye' binoculars with reticles to scan from 10 degrees past the bow on the opposite side to 90 degrees abeam. The data recorder surveyed the trackline with 7 × 50 binoculars while scanning through the viewing areas of the 2 primary observers. When a sighting was made, the primary observer conveyed to the recorder the horizontal angle and number of reticles from the horizon to the initial sighting. Additional information collected included sighting cue, course and speed, species identity, and best, high, and low estimates of group size. Computer data-logging programs (2009 and 2015 = *Wincruz* available at http://swfsc.nmfs.noaa.gov/PRD/softwares/software.html; 2013 = *Mysticetus* available at www.mysticetus.com) were used to record

Table 1 Strata, area, tracklines, and proposed and realized effort by year

Stratum	Area (km^2)			Number of track-lines			Proposed effort (km)			Realized effort (km)		
	2009	2013	2015	2009	2013	2015	2009	2013	2015	2009	2013	2015
Inshore	47,411	22,749	106,133	12	18	18	1905	1296	2511	460	673	1399
Offshore	98,253	60,051	81,457	10	11	5	1944	1752	963	300	926	425
Seamount	–	45,377	–	–	25	–	–	2610	–	–	1160	–
Slope	–	36,776	–	–	18	–	–	1986	–	–	1191	–
HHC	–	–	64,521	–	–	6	–	–	1526	–	–	884
Total	145,664	164,953	252,111	22	72	29	3849	7644	5000	760	3950	2708

all sighting and environmental data (e.g., sea state, swell height, glare, precipitation, and visibility).

During daylight hours, a visual watch was always maintained; the degree of effort was determined by weather conditions. On-effort was defined as a visible horizon, Beaufort sea state ≤5, survey speed of 8–10 kts, and a 3-observer team using 25× and 7 × 50 binoculars. Only on-effort data were used for density and abundance estimates. On-effort line-transect methods were also conducted on transit legs between transects to increase the sighting sample size to improve estimation of detection probability. During inclement weather (poor visibility and/or Beaufort sea state ≥ 6), off-effort visual watches were conducted. This would occur either temporarily by the 3-person team until conditions improved or with a single data recorder/observer primarily to monitor for improvements in conditions. Off-effort sightings were used for distribution information only.

In 2009, the survey area was limited to the boundaries of the TMAA (Fig. 1, green strata). In 2013, the survey was designed to include all of the TMAA with a slight extension of the southern boundary to encompass the seamounts located on the southern boundary of the TMAA (eastern boundary 57°21′N, 141°01′W; northern boundary 148°11′N, 59°38′W; western boundary 57°16′N, 151°03′W; southern boundary 55°14′N, 141°48′W) (Fig. 1, purple strata). Additional distribution data were collected on transit legs from Sitka, Alaska in the eastern GoA (2013 only) and to/from Kodiak, Alaska, in the western GoA (2009 and 2013). The 2009 survey was conducted from 10 to 20 April aboard the NOAA ship *Oscar Dyson*, a 63-m fisheries research vessel. Tracklines were designed to provide uniform coverage of the TMAA including the continental shelf/slope or 'inshore' stratum and pelagic 'offshore' stratum (Fig. 1, green strata). The effort per unit of area allocated to the inshore stratum was twice that of the offshore stratum (Table 1). The 2013 survey was conducted from 23 June to 18 July aboard the R/V *Aquila*, a 50-m chartered crab fishing vessel. Because of the relatively short period of time dedicated for the 2009 survey and, consequently, the relatively low survey coverage achieved, additional time was allocated for the 2013 survey. The survey area was partitioned into four survey strata created to stratify effort across four distinct habitats within the TMAA: continental shelf or 'inshore' stratum, 'slope' stratum, pelagic or 'offshore' stratum, and 'seamount' stratum (Fig. 1, purple strata). The effort per unit of area allocated to the inshore, slope, and seamount strata was twice that allocated to the offshore stratum (Table 1).

The focus of the 2015 survey was the historical habitat of North Pacific right whales in the western GoA (eastern boundary 58°14′N, 143°02′W; northern boundary 146°44′N, 60°07′W; western boundary 55°18′N, 155°52′W; southern boundary 53°06′N, 152°03′W) (Fig. 1, orange strata). This area was chosen based upon historical whale catch data (Townsend 1935; Ivashchenko and Clapham 2012). Survey effort presented here was conducted from 10 August to 8 September 2015 aboard the NOAA ship *Reuben Lasker*. Tracklines for this survey were designed to provide uniform coverage within three strata that included continental shelf and slope or 'inshore' stratum, a pelagic 'offshore' stratum, and a 'historical high catch' (HHC) stratum (Fig. 1, orange strata). Seamounts were located within the HHC stratum. The HHC stratum was designed to encompass the area of high density whaling catches as outlined in Doroshenko (2000). The effort per unit of area allocated to the inshore and HHC strata were twice that of the offshore stratum (Table 1). Additional distribution data were collected on transit legs to and from Kodiak, Alaska, between transect lines, and during visual and acoustic exploratory transects.

For all surveys, effort allocation followed a systematic sampling design with a random starting point (Strindberg et al. 2004). Tracklines were designed to provide near-uniform sampling coverage within each stratum using an equal-spaced zigzag sampler configuration (Strindberg et al. 2004). Transects were designed around a 24-h operation: simultaneous visual and acoustic methods during daylight hours and acoustic only during inclement weather and after dark. There was geographic overlap across all 3 years (Fig. 1).

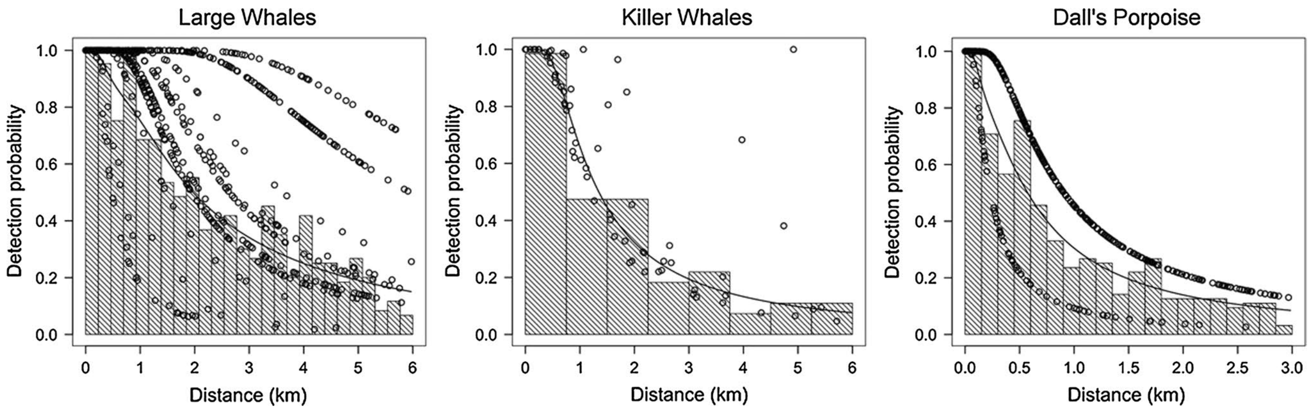

Fig. 2 Histograms of perpendicular distance (km) and fitted detection functions for the best AIC selected model (*dots* represent detection probability for each individual sighting). Produced with R (R Development Core Team 2011)

Data analysis

Detection probability was estimated using the hazard-rate or the half-normal models within Conventional Distance Sampling (CDS) or Multiple Covariate Distance Sampling (MCDS) frameworks (Table 3) (Buckland et al. 2001; Marques and Buckland 2003). The approach to fitting detection functions varied by species (Fig. 2). Dall's porpoise (*Phocoenoides dalli*) sample size was sufficient to fit using 2013 and 2015 data only. For killer whales (*Orcinus orca*), perpendicular distance data were collected during all 3 years and a previous killer whale study was conducted in the GoA (Zerbini et al. 2007) in order to increase sample size. For blue (*B. musculus*), fin, humpback, sperm (*Physeter macrocephalus*), and unidentified large baleen whales (referred to as unidentified large whales hereafter), perpendicular distances were pooled across all 'large whale' species (all mysticetes except minke whales [*B. acutorostrata*] plus sperm whales). Pooling provided greater sample size for fitting the detection functions (Fig. 2), allowing for density to be computed for species with relatively low number of detections and for improving precision of these estimates. Pooling across species with insufficient sample sizes (e.g., blue and sperm whales in this study) is a relatively common practice (e.g., Barlow et al. 1997; Forney and Barlow 1998) as long as pooling includes species with similar detection characteristics. In this study, perpendicular distance data were combined across species detected at similar average distances (e.g., Barlow et al. 2001). Sightings collected in 'on-effort' mode during transit legs to and from the survey strata and between transects were used in the estimation of detection probability but not for density and abundance estimates. Modeling of perpendicular distance was conducted with ungrouped data truncated at 6 km for all whale species and at 3 km for Dall's porpoise. Truncation was set at these distances after exploratory analyses were conducted to assess best truncation points (i.e., balance between sample size and appropriate fit model). The procedures and values selected for truncation are consistent with the literature (e.g., Buckland et al. 2001; Zerbini et al. 2006; Friday et al. 2013).

Covariates included in the analysis are presented in Table 2. More than one covariate was used in an additive approach for species or group of species with sufficient sample sizes. Covariate models that did not conform to the detection probability hypothesis being tested were excluded from the analysis. For example, detection probability is expected to increase as group size increases; models that indicated otherwise were removed from the set of candidate models for any given species or group of species before model selection was performed (e.g., Zerbini et al. 2006). Model selection was conducted following the Akaike Information Criterion (AIC, Akaike 1973).

Because survey conditions (sea state, weather, and visibility) and survey coverage were substantially better in 2013 than in 2009 (Fig. 1), density and abundance were only computed for the 2013 survey of the TMAA survey area. Survey effort was sufficient to calculate estimates for 2015. Stratum-specific density and abundance estimates were calculated using the detection probability model that received the most support from the data (i.e., the 'best' model) according to AIC. Variance of the combined estimates was approximated by the delta method assuming the estimates were independent.

For CDS models, expected group size was estimated by the simple mean within each stratum. For MCDS models, group size was estimated by dividing the estimated density of individuals by the estimated density of groups (Marques and Buckland 2003). Encounter rate and its variance were estimated as proposed by Innes et al. (2002). The variance of group size estimates and the variance of the estimated detection probability were computed following Buckland et al. (2001) and Marques and Buckland (2003). For the

Table 2 Summary of covariates used in modeling the detection probability of cetacean species

Covariate	Covariate type	Observation
Beaufort	Numerical (ranging from 0 to 5)	Models included either Beaufort or Beaufort Category, but not the two covariates together
Beaufort Category	Factor: two levels, 'low' (Beaufort states 0–2) and 'high' (Beaufort states 3–5)	Models included either Beaufort or Beaufort Category, but not the two covariates together
Group Size	Numerical	
Method	Factor: two levels, 'A' (naked eye and 7 × 50 binoculars) and 'B' (big-eye binoculars)	The sample of sightings collected with naked eye was small ($n = 16$), and they were pooled with those collected with 7 × 50 binoculars
Ship	Factor: two to four levels depending on the analysis.	Only used in estimating detection probability for perpendicular data collected from multiple ships
Species	Factor: with five levels (blue, fin, humpback, sperm, and unidentified large whale)	Only used in estimating detection probability for the 'large whale group' and applied in the estimation of abundance of blue whales, sperm whales, and unidentified large whales

purpose of this analysis, detection probability on the trackline was assumed to be $g[0] = 1$. For Dall's porpoise, no attempts were made to correct for responsive movements. Estimates of quantities of interest were computed using the package *mrds* version 2.1.0 (Laake et al. 2012) for software R (R Development Core Team 2011). For species with very small sample sizes (Baird's and Cuvier's beaked whales, minke whales, harbor porpoise, and Pacific white-sided dolphins), no density and abundance estimates were computed. Estimates were not corrected for the proportion of animals missed on the trackline.

It is important to note the differences between the 2009 and 2013 surveys. In 2009 and 2013, the 2 surveys were conducted during different seasons: spring in April 2009 versus summer in June/July 2013. There was also a substantial difference in survey effort: 11 days in 2009 and 26 days in 2013. The survey design was changed from 2 strata and 22 transects in 2009 to 4 strata and 72 transects in 2013 (Table 1). This change in survey design occurred for two reasons: (1) increased survey days in 2013 allowed additional search effort and (2) additional strata were identified to increase probability of beaked whale detections (addition of slope and seamount strata).

Survey constraints, animal behavior, and weather play a major role in the identification of large whales. With a clear horizon, a blow can be detected at >13 km when using 25× binoculars positioned 15 m above the water; survey objectives and related time constraints, however, limit the ability for all sightings to be investigated for all surveys. In 2015, the primary focus of the survey was to locate North Pacific right whales. Given the vast survey area and finite number of survey days, time was not dedicated to identifying distant animals when the characteristics of the blow were indicative of a non-target large baleen whale (i.e., fin and blue whales).

When evaluating estimates between 2013 and 2015, survey objectives must be considered. In 2013, the primary objective was to obtain density and abundance estimates for all marine mammals documented in the TMAA. Time was allocated to identify species whenever feasible. In 2015, contributions toward density and abundance estimates were a secondary objective. Limitations in the timeframe of the survey prohibited the ability to survey the expansive historical North Pacific right whale range in the western GoA and suspend effort to identify distant non-target unidentified large whales. This difference in survey objectives is fundamental when assessing interannual estimates for humpback, fin and blue whales.

Results

In 2009, 20% of the trackline was surveyed with a total of 87 sightings (422 individuals) of 8 cetacean species and 28 sightings (38 individuals) of unidentified large whales (Tables 1, 3; Figs. 1, 3, 4). In 2013, 52% of the trackline was surveyed with 708 sightings (1898 individuals) of 11 cetacean species documented with an additional 122 sightings (160 individuals) of unidentified large whales and 5 sightings (8 individuals) of unidentified beaked whales (Tables 1, 3; Figs. 1, 3, 4). In 2015, 54% of the trackline was surveyed. There were 317 sightings (1889 individuals) of 10 species with an additional 151 sightings (209 individuals) of unidentified large whales (Tables 1, 3; Figs. 1, 3, 4).

Distribution

Mysticetes

Fin whales were the most frequently sighted large whale in 2009 and 2013, and second most frequently sighted in

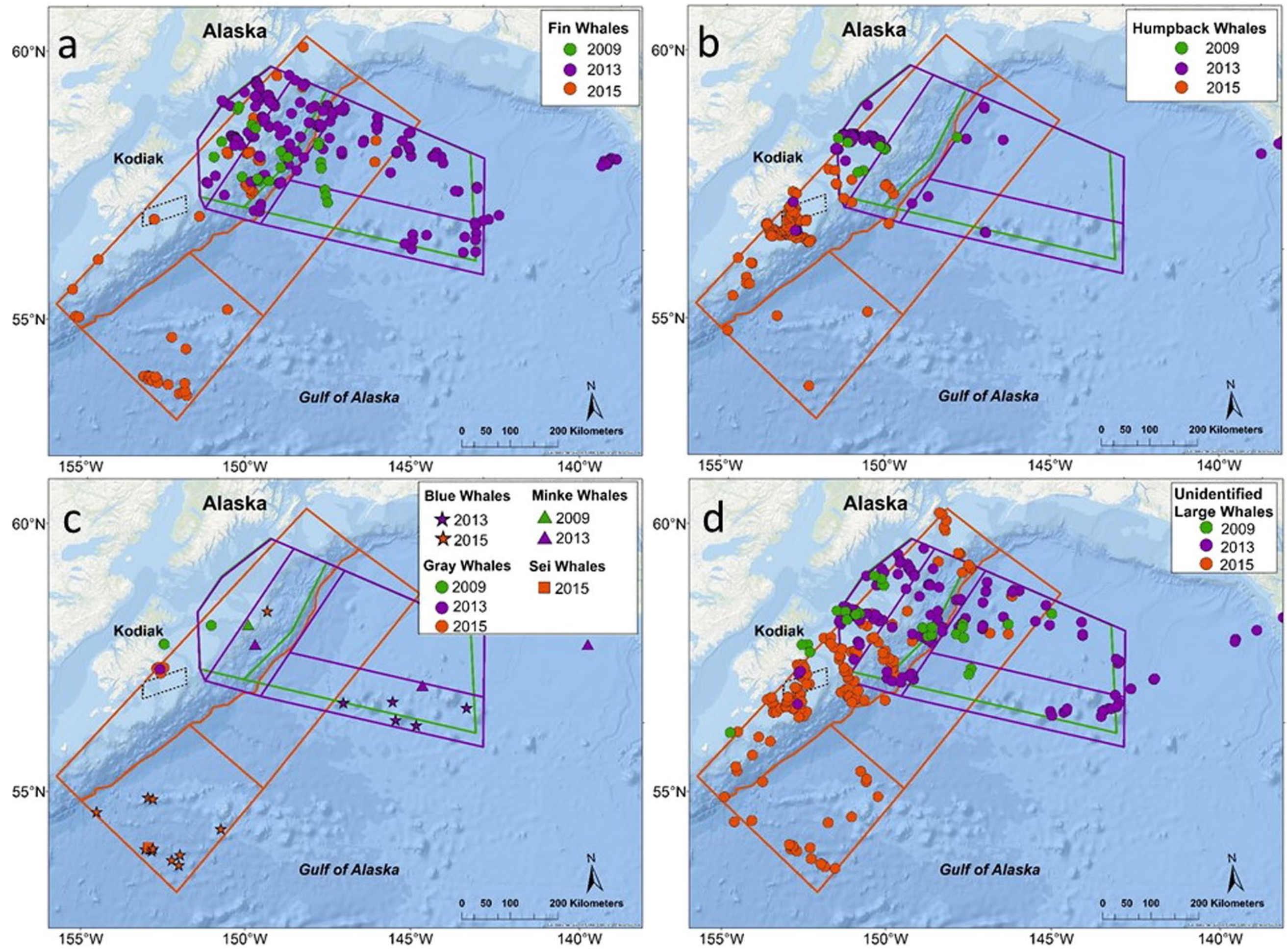

Fig. 3 Visual sightings of mysticetes in the Gulf of Alaska for all years. Produced with ArcGis 10.3.1

2015. Sightings occurred throughout the entire study area, on the continental shelf, slope and within pelagic waters in all 3 years (Fig. 3a). Sightings were scattered throughout most of the area surveyed in 2009. In 2013, sightings were concentrated mainly in the northern half of the study area, particularly over the slope and shelf; there was a second concentration located at the southeast corner of the study area. There was a notable absence of sightings in the western half of the seamount stratum. In 2015, an aggregation was documented in the southern end of the HHC stratum (Fig. 3a). Additional sightings were scattered throughout the inshore stratum and sparse within the offshore stratum.

The majority of humpback whales were documented on the continental shelf within the inshore stratum. Scattered sightings occurred in the pelagic waters of the offshore and seamount strata in 2009 and 2013 (Fig. 3b). The main aggregations in both years were located east of Kodiak Island in the same general region. In 2015, sightings were sparse within the HHC and offshore strata. The main aggregation was located on Albatross Bank within and in the general locale of the North Pacific right whale Critical Habitat (Fig. 3b).

There were no blue whales sighted in 2009. In 2013, all 5 blue whale sightings were dispersed within the pelagic waters of the seamount stratum (Fig. 3c). In 2015, there was one blue whale sighting in the inshore stratum along the shelf break. The additional 12 sightings occurred within the HHC stratum in pelagic waters and near seamounts (Fig. 3c). The main concentration of sightings was located at the southern end of the survey area (Fig. 3c) which was the same area as the 2015 fin whale aggregation (Fig. 3a.) Blue whale sightings were documented over a 4-day period within the HHC stratum. The majority of these sightings ($n = 8$) occurred on August 13, 2015; the survey returned to this area on September 8, 2015, and no blue whales were sighted.

In 2009 and 2013, sightings of gray, minke, and sei whales were sparse (Fig. 3c). In 2009, several gray whales were sighted in the inshore stratum and close to shore on the east side of Kodiak Island (Fig. 3c). In 2013, gray

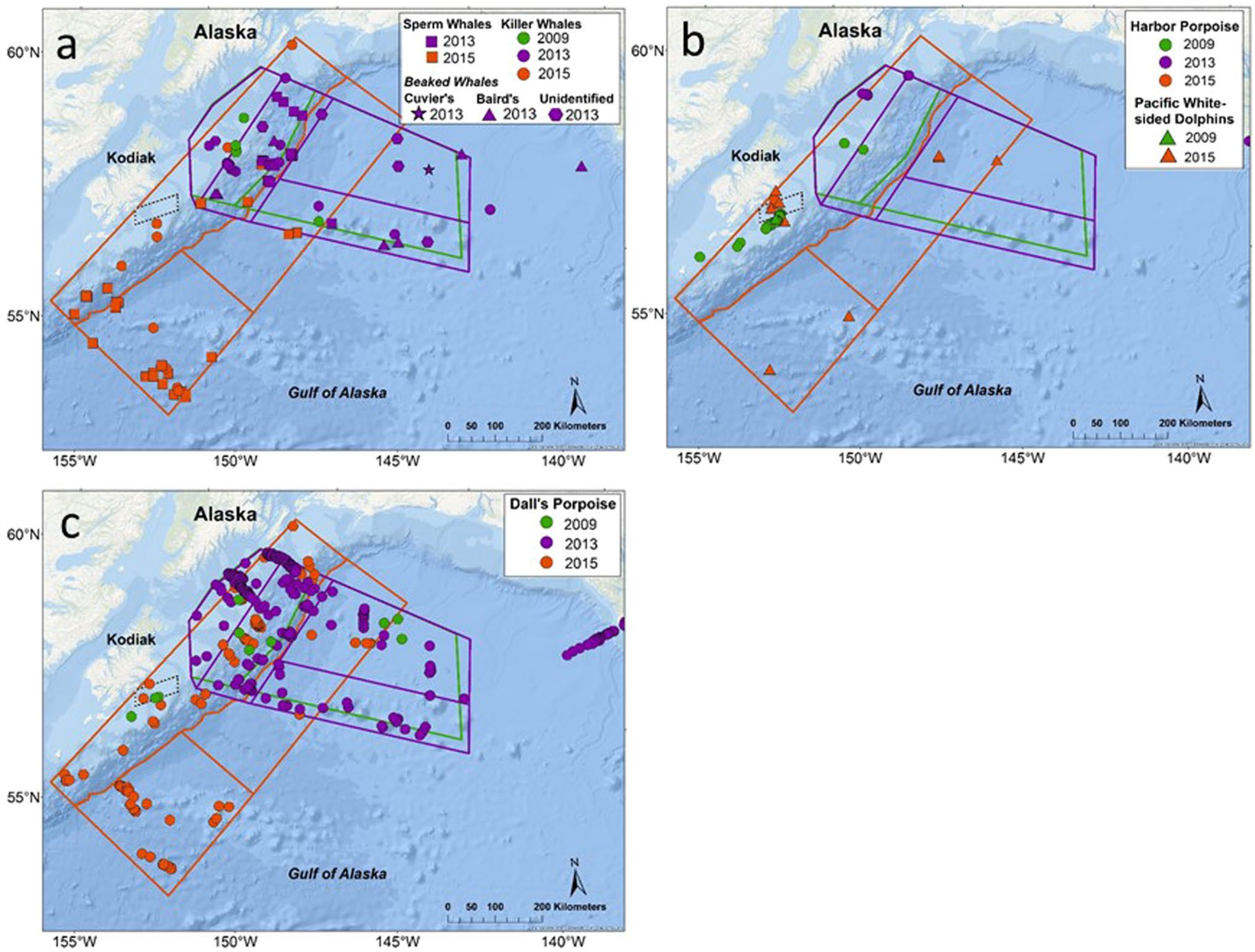

Fig. 4 Visual sightings of odontocetes in the Gulf of Alaska for all years. Produced with ArcGis 10.3.1

whales were only sighted in a concentration of ~25 individuals near Ugak Island, Kodiak (Fig. 3c). In 2015, gray whales were again only sighted by Ugak Island (Fig. 3c), but animals were not concentrated as in 2013. Two sightings of minke whales in 2009 and 2013 were documented in the slope stratum (Fig. 3c). A mother/calf minke whale pair was sighted in pelagic waters in the seamount stratum in 2013. There were no minke whale sightings in 2015. The only confirmed sightings of sei whales were in 2015 (Fig. 3c); one sighting occurred within the aggregation of fin and humpback whales on Albatross Bank and the second within the HHC stratum.

Sightings of unidentified large baleen whales occurred on transit legs to and from the survey area, near Kodiak Island, and within all strata of the study areas in all years (Fig. 3d). Although sightings were scattered, there were concentrations in the inshore stratum in 2009, in the inshore, slope, and seamount strata in 2013, and in the inshore and HHC strata in 2015. These unidentified sightings coincided with both fin and humpback whale hot spots in all 3 years and blue whales in 2015.

Odontocetes

Killer whales were seen throughout the survey area in 2009 and 2013 (Fig. 4a), most frequently on the continental shelf, slope, and in pelagic waters. In 2015, sightings occurred within the inshore and HHC strata. A majority of the sightings occurred near the aggregation of large whales on Albatross Bank and within the HHC. Sperm whales were not sighted in 2009. In 2013, all sperm whale sightings occurred on the continental shelf break and slope with the exception of one sighting near a seamount (Fig. 4a). In 2015, sperm whales occurred on the continental shelf break and slope within the inshore stratum and the pelagic waters and seamounts of the offshore and HHC strata. The highest numbers occurred near the fin/humpback/unidentified large whale concentrations in the southern end of the HHC

Table 3 Summary of groups sighted (with the total number of individuals in parentheses) during on-effort and off-effort survey modes by year

Species	On-Effort			Off-Effort			Total		
	2009	2013	2015	2009	2013	2015	2009	2013	2015
Beaked whales									
Baird's beaked whale	0	6 (49)	0	0	1 (9)	0	0	7 (58)	0
Cuvier's beaked whale	0	1 (1)	0	0	0	0	0	1 (1)	0
Unidentified beaked whale	0	5 (8)	0	0	0	0	0	5 (8)	0
Mysticetes and Unidentified large whales									
Blue whale	0	5 (7)	10 (10)	0	0	3 (3)	0	5 (7)	13 (13)
Fin whale	20 (56)	172 (317)	42 (60)	4 (8)	28 (75)	6 (9)	24 (64)	200 (392)	48 (69)
Gray whale	1 (2)	0	1 (10)	2 (6)	1 (25)	5 (14)	3 (8)	1(25)	6 (24)
Humpback whale	10 (19)	91 (295)	64 (145)	1 (1)	15 (36)	39 (141)	11 (20)	106 (331)	103 (286)
Minke whale	2 (3)	3 (6)	0	0	0	0	2 (3)	3 (6)	0
Sei whale	0	0	1 (1)	0	0	0	0	0	1 (1)
Unidentified large whale	22 (31)	109 (142)	114 (138)	6 (7)	13 (18)	37 (71)	28 (38)	122 (160)	151 (209)
Odontocetes									
Dall's porpoise	10 (59)	320 (859)	93 (364)	0	17 (48)	5 (27)	10 (59)	337 (907)	98 (391)
Harbor porpoise	30 (89)	8 (11)	1 (1)	0	0	0	30 (89)	8 (11)	1 (1)
Killer whale	6 (119)	21 (138)	9 (66)	0	0	1(7)	6 (119)	21 (138)	10 (73)
Pacific white-sided dolphin	1 (60)	0	6 (374)	0	0	4 (612)	1 (60)	0	10 (986)
Sperm whale	0	19 (22)	25 (37)	0	0	2 (8)	0	19 (22)	27 (45)

stratum (Fig. 4a). The largest sighting of individual sperm whales in this area was comprised of 11 animals, including one calf. Beaked whales were only sighted in 2013 (Fig. 3a). Sightings occurred within pelagic waters, near seamounts, and on the continental slope.

Dall's porpoise were sighted in all years within all strata on the continental shelf, slope, and in pelagic waters; they were the most frequently sighted cetacean in 2013 (Table 3; Fig. 4c). Although sighted throughout the survey area in 2013, over half (55%) of the Dall's porpoise sightings were observed within the inshore and slope strata. A few harbor porpoise sightings occurred in the shallow waters of the continental shelf in all 3 years (Table 3; Fig. 4b). There was a noticeable disparity in sightings of Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) sightings. There was only 1 sighting (60 individuals) documented in 2009, versus 10 sightings (986 individuals) in 2015. These sightings occurred within shallow and deep pelagic waters (Table 3; Fig. 4b). There were no sightings in 2013.

Density and abundance

Mysticetes

Fin and humpback whales were the most abundant large whales sighted in all 3 years (Table 4). Highest densities occurred inshore for both species in 2013 and 2015 with 0.0680 and 0.0070 whales/km^2 for fin whales and 0.0930 and 0.0050 whales/km^2 for humpback whales, respectively (Table 6). The fin whale survey encounter rates were 0.0230 (2013) and 0.0050 (2015) groups/km (Table 5). Total density and abundance for the survey areas were 0.0082 whales/km^2 and 3168 whales (CV = 0.26) (2013) and 0.0020 whales/km^2 and 916 whales (CV = 0.39) (2015) (Table 6). The overall humpback whale encounter rates were 0.0120 (2013) and 0.0030 (2015) groups/km (Table 5). Total density and abundance for the survey areas were 0.0057 whales/km^2 and 2215 whales (CV = 0.26) (2013) and 0.0027 whales/km^2 and 605 whales (CV = 0.30) (2015) (Table 6).

Blue whales were documented in both 2013 and 2015. In 2013, they were only sighted within the seamount stratum, where density was 0.0014 whales/km^2 (Table 6). The survey encounter rate was 0.0010 groups/km (Table 5) with an overall density of 0.0002 whales/km^2 and abundance of 63 whales (CV = 0.76) (Table 6). In 2015, blue whales were documented in the inshore and HHC strata with densities of 0.0001 and 0.0014 whales/km^2, respectively (Table 5). The survey encounter rate was 0.0010 groups/km (Table 5) with an overall density of 0.0002 whales/km^2 and abundance of 59 whales (CV = 0.58) (Table 6).

Odontocetes

Killer whales were sighted in all 3 years. In 2013, the greatest density of killer whales occurred over the slope stratum

Table 4 Parameter estimates (SE in parenthesis) for the most supported detection probability models fitted to perpendicular distance data for large whales, killer whales, and Dall's porpoise P = average detection probability

Model	Species/group of species		
	Large whales	Killer whale	Dall's porpoise
	Hazard rate + Beaufort category + Method + Species	Hazard rate + Group size	Hazard rate
Covariate model coefficients			
Intercept	−2.02 (0.67)	−0.20 (0.42)	−1.73 (0.30)
Beaufort category (Low)	0.30 (0.16)		1.36 (0.27)
Method (Big eye)	1.39 (0.20)		
Species (Fin whale)	−0.32 (0.52)		
Species (Humpback whale)	−0.23 (0.52)		
Species (Sperm whale)	0.01 (0.57)		
Species (Unidentified large whale)	0.80 (0.54)		
Group size		0.04 (0.25)	
Shape parameter (Hazard-rate models)	0.56 (0.11)	0.47 (0.24)	0.30 (0.11)
Average detection probability (*P*)	0.43 (0.03)	0.33 (0.07)	0.30 (0.03)
Effective half strip width (km)	2.58	2.0	0.91

with 0.0190 whales/km^2 (Table 6). The survey encounter rate was 0.0030 whales/km^2 (Table 5) with an abundance of 899 whales (CV = 0.72) (Table 6). In 2015, the greatest density of killer whales occurred in the HHC stratum with 0.0090 whales/km^2 (Table 6). The survey encounter rate was 0.0010 groups/km^2 (Table 5) with an overall density of 0.0022 whales/km^2 and an abundance of 690 whales (CV = 0.54) (Table 6).

In 2013, sperm whales were almost exclusively located in the slope stratum. Density within that stratum was 0.0030 whales/km^2 (Table 6). The survey encounter rate was 0.0030 groups/km (Table 5) with an overall density of 0.0003 whales/km^2 and an abundance of 129 whales (CV = 0.44) (Table 6). In 2015, sperm whales were documented in all three survey stratums. The survey encounter rate was 0.0030 groups/km (Table 5) with an overall density of 0.0016 whales/km^2 and abundance of 345 whales (CV = 0.43) (Table 6).

Dall's porpoise were documented in all 3 years and were the most abundant cetacean in both 2013 and 2015 (Table 6). Densities were greatest in the inshore stratum in both years with 0.2180 and 0.0880 porpoises/km^2, respectively. In 2013, the survey encounter rate was 0.0360 groups/km (Table 5) with an overall density of 0.0398 porpoises/km^2 and abundance of 15,423 porpoises (CV = 0.28) (Table 6). In 2015, the survey encounter rate was 0.0110 groups/km (Table 5) with an overall density of 0.0340 whales/km^2 and abundance of 13,110 porpoises (CV = 0.22) (Table 6).

Unidentified large whales

In 2013 and 2015, there were 122 sightings (160 individuals) and 151 sightings (209 individuals) of large baleen whales, respectively (Table 4; Fig. 3d) that could not be identified to species mainly due to time constraints and environmental conditions. The estimates of abundance and density corrected by pro-rating the unidentified large whales according to relative proportions of identified species (e.g., Calambokidis and Barlow 2004; Zerbini et al. 2006) are not presented in this study; sighting data are provided by stratum to allow for such estimates. There are caveats to pro-rating unidentified large whales. As stated in Zerbini et al. (2006), this correction assumes that all large baleen whales (blue, fin, and humpback whales) are equally identified which we know is false; for example, humpback whales are easier to detect given their frequency of high arching dives with flukes raised. Additionally, some of the whales designated as unidentified may correspond to additional species not identified during this survey; however, allocation to other species not confirmed during this survey is not feasible.

Discussion

In order to assess interannual variability and trends, surveys need comparable effort, location and to be conducted across multiple years (e.g., Zerbini et al. 2006, 2007).

Table 5 Number of sightings after truncation (*n*), encounter rates (ER, groups/km), encounter rate coefficient of variation (ER CV), estimated group size (ES), and estimated group size coefficient of variation (ES CV) by stratum and year

Stratum	2013					2015				
	n	ER	ER CV	ES	ES CV	*n*	ER	ER CV	ES	ES CV
Blue whales										
Inshore	0	0	0	0	0	1	0.0010	1.01	1.0	0.00
Offshore	0	0	0	0	0	0	0	0	0	0
Seamount	4	0.0030	0.45	1.7	0.14	–	–	–	–	–
Slope	0	0	0	0	0	–	–	–	–	–
HHC	–	–	–	–	–	9	0.0100	0.57	1.0	0.00
Total	4	0.0010	0.50	1.7	0.14	10	0.0010	0.63	1.0	0.00
Dall's porpoise										
Inshore	136	0.2020	0.50	2.4	0.15	44	0.0130	0.42	4.5	0.16
Offshore	24	0.0260	0.54	2.5	0.20	5	0.0120	0.66	3.4	0.14
Seamount	19	0.0160	0.38	1.5	0.06	–	–	–	–	–
Slope	90	0.0760	0.38	4.2	0.30	–	–	–	–	–
HHC	–	–	–	–	–	31	0.0350	0.24	4.2	0.15
Total	269	0.0360	0.33	2.9	0.17	80	0.0110	0.30	4.3	0.11
Fin whales										
Inshore	76	0.1130	0.41	2.5	0.22	25	0.0180	0.34	1.3	0.06
Offshore	36	0.0390	0.22	1.9	0.10	1	0.0020	0.97	2.0	0.00
Seamount	11	0.0090	0.35	1.7	0.08	–	–	–	–	–
Slope	48	0.0400	0.14	1.3	0.04	–	–	–	–	–
HHC	–	–	–	–	–	12	0.0140	0.40	1.6	0.25
Total	171	0.0230	0.23	2.0	0.12	38	0.0050	0.32	1.4	0.06
Humpback whales										
Inshore	82	0.1220	0.56	3.6	0.16	21	0.0150	0.28	1.1	0.06
Offshore	3	0.0030	0.73	1.0	0.00	1	0.0020	0.90	1.0	0.00
Seamount	4	0.0030	0.59	1.3	0.19	–	–	–	–	–
Slope	1	0.0010	1.01	1.0	0.00	–	–	–	–	–
HHC	–	–	–	–	–	4	0.0050	0.46	1.0	0.00
Total	90	0.0120	0.55	3.3	0.21	26	0.0030	0.30	1.1	0.05
Killer whales										
Inshore	3	0.0040	0.53	3.6	0.21	3	0.0020	0.54	6.5	0.47
Offshore	0	0	0	0	0	0	0	0	0	0
Seamount	2	0.0020	0.71	4.9	0.30	–	–	–	–	–
Slope	15	0.0130	0.81	5.5	0.20	–	–	–	–	–
HHC	–	–	–	–	–	4	0.0050	0.71	7.4	0.20
Total	20	0.0030	0.62	5.1	0.18	7	0.0010	0.50	6.9	0.29
Sperm whales										
Inshore	0	0	0	0	0	8	0.0060	0.42	1.2	0.16
Offshore	0	0	0	0	0	2	0.0050	0.90	1.0	0.00
Seamount	1	0.0010	1.00	2.0	0.00	–	–	–	–	–
Slope	18	0.0150	0.39	1.1	0.04	–	–	–	–	–
HHC	–	–	–	–	–	10	0.0110	0.51	2.1	0.45
Total	19	0.0030	0.45	1.2	0.05	20	0.0030	0.36	1.3	0.19
Unidentified large whales										
Inshore	31	0.0460	0.30	1.4	0.16	64	0.0460	0.23	1.2	0.05
Offshore	19	0.0210	0.24	1.4	0.09	4	0.0090	0.61	1.2	0.17
Seamount	15	0.0130	0.43	1.3	0.07	–	–	–	–	–
Slope	21	0.0180	0.27	1.0	0.04	–	–	–	–	–
HHC	–	–	–	–	–	13	0.0150	0.46	1.3	0.11
Total	86	0.0110	0.20	1.3	0.06	81	0.0110	0.28	1.2	0.05

Estimates were not calculated for 2009. Refer to Table 1 for area per stratum by year

HHC historical high catch

Table 6 Number of sightings (*n*), estimated density (*D*, individuals/km^2), estimated abundance (*N*), and coefficient of variation (CV) by stratum and year

Stratum	2013				2015			
	n	*D*	*N*	CV	*n*	*D*	*N*	CV
Blue whales								
Inshore	0	0	0	0	1	0.0001	10	1.06
Offshore	0	0	0	0	0	0	0	0
Seamount	4	0.0014	63	0.76	–	–	–	–
Slope	0	0	0	0	–	–	–	–
HHC	–	–	–	–	9	0.0014	49	0.64
Total	4	0.0002	63	0.76	10	0.0002	59	0.58
Dall's porpoise								
Inshore	136	0.2180	4961	0.39	44	0.0880	9293	0.26
Offshore	24	0.0370	2192	0.42	5	0.0160	1307	0.79
Seamount	19	0.0240	1076	0.45	–	–	–	–
Slope	90	0.1960	7194	0.48	–	–	–	–
HHC	–	–	–	–	31	0.0730	2510	0.28
Total	269	0.0398	15,423	0.28	80	0.0340	13,110	0.22
Fin whales								
Inshore	76	0.0680	1556	0.48	25	0.0070	708	0.49
Offshore	36	0.0160	971	0.23	1	0.0010	61	0.98
Seamount	11	0.0030	145	0.37	–	–	–	–
Slope	48	0.0130	496	0.20	–	–	–	–
HHC	–	–	–	–	12	0.0040	147	0.36
Total	171	0.0082	3168	0.26	38	0.0020	916	0.39
Humpback whales								
Inshore	82	0.0930	2107	0.74	21	0.0050	543	0.32
Offshore	3	0.0010	65	0.85	1	0.0000	36	0.91
Seamount	4	0.0010	37	0.59	–	–	–	–
Slope	1	0.0000	6	1.01	–	–	–	–
HHC	–	–	–	–	4	0.0010	26	0.48
Total	90	0.0057	2215	0.70	26	0.0027	605	0.30
Killer whales								
Inshore	3	0.0050	107	0.59	3	0.0040	390	0.67
Offshore	0	0	0	0	0	0	0	0
Seamount	2	0.0020	107	0.77	–	–	–	–
Slope	15	0.0190	685	0.92	–	–	–	–
HHC	–	–	–	–	4	0.0090	300	0.84
Total	20	0.0023	899	0.72	7	0.0022	690	0.54
Sperm whales								
Inshore	0	0	0	0	8	0.0020	190	0.58
Offshore	0	0	0	0	2	0.0010	49	0.92
Seamount	1	0.0000	12	1.03	–	–	–	–
Slope	18	0.0030	117	0.46	–	–	–	–
HHC	–	–	–	–	10	0.0030	106	0.70
Total	19	0.0003	129	0.44	20	0.0016	345	0.43
Unidentified large whales								
Inshore	31	0.0060	143	0.39	64	0.0060	650	0.27
Offshore	19	0.0030	174	0.29	4	0.0020	124	0.61
Seamount	15	0.0020	89	0.48	–	–	–	–
Slope	21	0.0020	81	0.38	–	–	–	–
HHC	–	–	–	–	13	0.0020	76	0.54
Total	86	0.0013	487	0.20	81	0.0020	850	0.24

Estimates were not calculated for 2009

HHC historical high catch

While these assessments are hindered by the 2-year dataset and the differences in survey design, essential new information on cetacean abundance, density, and distribution data from this study provides an important baseline for the GoA where few data have previously been collected. Overall, humpback whale, fin whale, and Dall's porpoise were sighted across all years and were the most abundant species. Beaked whales were only documented in 2015. Sightings of gray (all years), minke (2009 and 2013), and sei (2015 only) whales were infrequent. Blue whales were sighted in both 2013 and 2015 including a concentration of animals (8 sightings) occurring on 1 day in 2015. Density and abundance estimates were comparable for both years. Density and abundance of sperm whales were greater in 2015 versus 2013. This included a sighting of 10 individuals and one calf. Killer whales were sighted across all habitat in all years. Harbor porpoise were sighted in the shallow waters of the continental shelf in all 3 years. Pacific white-sided dolphins were sighted in 2009 and 2015 with a markedly higher number in the latter year. No North Pacific right whales were sighted in this study.

Survey objectives and designs previously described likely contributed to the differences in fin and humpback whale results. Whereas fin whales were the most commonly sighted species in 2013, humpback whales were the most commonly sighted in 2015. In 2015, fin whale sightings were only 25% of the total sightings documented in 2013. In 2013, the survey objective was to obtain density and abundance estimates of all marine mammals within the TMAA. Time was allocated to identify all species when possible. In 2015, the objective was to locate right whales. This likely biased effort toward identifying humpback whales. Their blows can be similar to right whales and were frequently investigated throughout the survey. For other large whales such as fin and blue whales, the blows are easy to distinguish from right whales. Another possible explanation for the differences in fin whale sightings between the 2 years is the location of realized effort. In looking at the overlapping area of the inshore and slope strata of 2013 and the inshore stratum of 2015 located northeast of Kodiak Island (Fig. 1; Table 1), there was considerably less trackline surveyed in 2015 as a result of both survey design (fewer transects in 2015) and realized effort. In a visual analysis of sightings on the trackline, there are a sizeable number of unidentified large whales (Fig. 3d) sighted in 2015. If effort had been comparable in both 2013 and 2015 within this overlapping region, it is plausible there may have been a substantial number of additional fin whale sightings. Location of effort likely contributed to differences between years. It is well documented that humpback whales concentrate in large numbers around and in close proximity to Kodiak Island, as it is an important feeding ground for this species during summer months (Waite et al. 1999; Zerbini et al. 2006; Barlow et al. 2011; Witteveen et al. 2011; Ferguson et al. 2015; Wright et al. 2015). Whereas the inshore stratum in 2015 encompassed all of the eastern side of the island, the inshore stratum of 2013 was largely offshore and northeast of the island. These differences in transect effort and location provide plausible explanations for the greater number of fin whales in 2013 and humpback whales in 2015.

It is possible that results from 2015 may not be representative of a typical year in the GoA if a 'typical' year even exits. Beginning in late 2013, a large patch of warm water formed in the GoA and by the end of 2015 had stretched from Mexico to Alaska with temperatures 1–4 °C above average (Bond et al. 2015; Cavole et al. 2016). This warm water mass weakened winter storms and wind patterns, increased ocean stratification, and affected location and timing of up- and downwellings. This led to a series of impacts throughout the food web (Cavole et al. 2016). Short-term changes in abundance, species, and distribution of cetaceans may be observed as a result of changes in primary productivity. There were a markedly higher number of blue whales sighted in 2015 versus 2013. The sighting of 11 sperm whales, likely comprised of females, juvenile males, and one calf (no mature males present), is interesting. Such groups have traditionally been thought to typically occur in lower latitudes during the summer, although this view of sperm whale distribution has recently been challenged (Ivashchenko et al. 2014). There were no beaked whales despite excellent coverage within known habitat. It is difficult to provide a definitive explanation for these occurrences. However, it is important to note that a warm water anomaly was occurring during the 2015 survey that may have contributed to these differences.

Analysis Caveats

The visual estimates of abundance presented in this study assumed that no cetaceans were missed on the trackline ($g[0] = 1$). Failure to meet this assumption (referred to as 'visibility bias') is common in marine mammal surveys and causes negative biases in density estimates (Laake 1999; Buckland et al. 2001). Marsh and Sinclair (1989) coined the terms 'perception' and 'availability' bias to differentiate two forms of visibility bias. Perception bias occurs when marine mammal groups are available to be seen but are missed by the observers, while availability bias corresponds to animals that are missed because they are submerged and not visible to the observer. Except for long-diving species such as sperm whales and beaked whales and for species that are only seen at close ranges such as harbor porpoise, availability bias is typically not as important an issue as perception bias in ship surveys since animals are often at the surface and within the visual range of observers due to the relatively slow speed of the vessel (see discussion in Barlow 1995). Studies to assess the proportion of whales missed on the trackline have shown that nearly 90–100% of humpback and blue whales are detected during ship surveys, depending on visibility conditions and group size (Barlow and Gerrodette 1996; Calambokidis and Barlow 2004). Visibility bias is more substantial for species that are more difficult to detect (e.g., harbor porpoise) or for deep-diving species (e.g., sperm whales) and may lead to more severe negative bias in their estimates. The magnitude of this bias is unknown in this study. Experiments to estimate g(0) (e.g., double platform surveys) are needed to estimate correction factors for the abundance estimates.

In this study, no attempt was made to correct for the responsive movements of Dall's porpoise. This species tends to show a positive response to ships (i.e., approach to the vessel for bow-riding). Typically, detection occurs after the group responds to and are already moving toward the vessel or when the group is already at the bow, violating one of the basic assumptions of the line-transect theory (Turnock and Quinn 1991). Positive responsive movements will cause overestimation of abundance, the magnitude of which is difficult to estimate given the sampling methods used in this study. Future surveys could conduct experiments (e.g., Palka and Hammond 2001) to assess the proportion of animals approaching the vessel and apply a correction factor to estimate abundance of Dall's porpoise more accurately.

Small sample sizes typically result in high uncertainty around abundance estimates. Estimates were calculated for blue, sperm, and killer whales despite small numbers of visual detections in order to provide a baseline for predictions on presence. The effects of the small sample sizes are reflected in the relatively high CVs for these species.

Three ecotypes of killer whales have been described in the eastern North Pacific: 'transient,' 'resident,' and 'offshore' (Bigg et al. 1990; Ford et al. 2000; Dahlheim et al. 2008). Killer whale estimates from this survey are not stratified by ecotype. Sightings of transient (2013) and resident (2013, 2015) ecotypes were confirmed through photo-identification and the presence of the offshore ecotype by acoustics (2013) (Rone et al. 2014). Only 29% (2013) (Rone et al. 2014) and 10% (2015) (Rone et al. 2015) of the killer whale sightings were identified to ecotype; therefore, the proportion of each ecotype could not be inferred from the data collected.

Beaked whales

Collectively, members of the family Ziphiidae are difficult to research due to their cryptic nature. They spend a majority of their time submerged (Tyack et al. 2006; Arranz et al. 2011), regularly dive to deep depths (Schorr et al. 2014; Tyack et al. 2006) and often occur singly or in small groups; therefore, excellent sighting conditions and a significant amount of time are required to locate these cetaceans. The International Union for Conservation of Nature and Natural Resources (IUCN) estimates the worldwide population of Cuvier's beaked whales at well over 100,000 (Taylor et al. 2008c). Evidence from photo-identifications and satellite telemetry suggests that discrete populations exist in several areas including Hawaii (McSweeney et al. 2007; Baird et al. 2009) and San Clemente Island, California (Falcone et al. 2009). No trends are available for this species. Far less is known about Baird's and Stejneger's beaked whales; both are classified as data deficient by the IUCN (Taylor et al. 2008a, 2008b). There are three recognized subpopulations of Baird's beaked whales in the western North Pacific with a minimum estimate of 7000 (Miyashita 1986; Kasuya 2002; Barlow et al. 2006). Abundance is estimated at 1000 in the eastern North Pacific including 228 off the US west coast (Barlow et al. 2006). The Stejneger's is endemic to the cold waters of the North Pacific (Muto et al. 2016). Much of what is known is inferred by stranding records (Loughlin and Perez 1985; Mead 1989; Walker and Hanson 1999).

Little is known about beaked whale distribution and abundance in the GoA. This is a result of limited survey effort confounded by the difficulties in obtaining visual sightings due to factors discussed above. These factors likely explain the lack of sightings in 2009 which was characterized by limited survey days and stormy spring conditions. However, despite acoustic coverage within beaked whale habitat, the continental slope, and near seamounts (Ohsumi 1983; Kasuya and Ohsumi 1984; Kasuya 2002), no acoustic detections were documented (Rone et al. 2010) for reasons that cannot be determined. In 2013, the survey design doubled the dedicated effort within beaked whale habitat and resulted in 13 sightings (Table 3; Fig. 4a). Of the beaked whales that were identified to species, all sightings were comprised of Baird's beaked whales with the exception of one sighting of a single Cuvier's beaked whale (Table 3; Fig. 4a). A greater number of Baird's beaked whale sightings may be explained by their relatively large size, visible blow, and the fact that they often travel in large groups (58 individuals were encountered). In 2015, survey effort covered comparable beaked whale habitat (slope, seamounts, and pelagic water) with some overlap with the 2013 effort. Although weather conditions (sea state, swell height, visibility) could have played a role in this, no beaked whales were sighted. Unlike 2013, the 2015 survey did not have a towed-hydrophone array, so there is no way to determine beaked whale presence and whether animals were simply missed due to availability or perception bias. It is worth noting that a seaglider survey was conducted in

July and August of 2015 along the slope within the same general area and only recorded possible Stejneger's beaked whale vocalizations (Klinck et al. 2016).

As expected, beaked whales were associated with seamounts and the slope. Additionally, they were documented throughout the offshore stratum (Fig. 4a). Although there were only 13 visual sightings of beaked whales in 2013, this is probably a skewed representation of the overall presence of beaked whales in the GoA. During the 2013 survey, acoustic effort was conducted 24 h with a towed-hydrophone array (Rone et al. 2014). There were 50 beaked whale acoustic encounters of which 35 were localized. These localizations included Baird's and Cuvier's beaked whales, both species sighted by visual observations. Additionally, Stejneger's beaked whales were detected based on spatiotemporal patterns of beaked whale echolocation signals described by Baumann-Pickering et al. (2012, 2013). There were an additional five sightings of unidentified beaked whales during this survey. Two sightings were possible Stejneger's based on the description and sketches from the visual observer; however, no photographs were collected and neither encounter was sighted by a second observer for confirmation, so these sightings remained unidentified. Of the 13 visual sightings, there were 5 acoustic detections matched to visual sightings. The stratum and trackline design, along with a combination of visual and acoustic effort for the 2013 survey, was successful in capturing beaked whale detections.

Blue whales

Although their distribution spans the Atlantic, Pacific, and Indian Oceans, there are only a few contemporary abundance estimates. According to the IUCN, a plausible worldwide estimate for blue whales is in the range of 10,000–25,000 and increasing (Reilly et al. 2008a). Eastern North Pacific blue whales are estimated at 1647 (CV = 0.07) (Calambokidis and Barlow 2013). Prior to this present study, contemporary information on blue whale distribution was scarce and no abundance estimates were available within Alaskan waters. The most recent information was derived from two IWC surveys where three sightings were documented near the southern boundary of the GoA in both 2011 and 2012 (Matsuoka et al. 2012, 2013).

Stafford et al. (2001), Stafford (2003) suggest that two blue whale stocks, eastern and western, occur in the North Pacific with geographic overlap in the GoA based on the detection of two distinct call types. Although once abundant throughout the North Pacific, their numbers plummeted as a result of commercial whaling. In the waters northeast and southwest of Kodiak, Alaska, 102 blue whales were reported caught by Japanese whaling between 1960 and 1962 (Nishiwaki 1966). Blue whales were not sighted in the GoA during surveys conducted in 1980 leading to the conclusion that they were severely depleted in this region (Rice and Wolman 1982).

It is not clear whether the increase in sightings in recent years is a reflection of effort, a temporary shift in distribution (e.g., resulting from ocean anomalies), a sign of recovery, or some other factor. Monnahan et al. (2014) suggest numbers within the eastern North Pacific are reaching pre-exploitation levels. The occurrence of blue whales in the GoA in recent years may be linked to a reestablishment of migration patterns or in response to oceanographic changes and prey shift (Calambokidis et al. 2009). The GoA abundance estimates for 2013 and 2015 were comparable, 63 (CV = 0.76) and 59 (CV = 0.59), respectively. The aforementioned restrictions on identifying large whales in the distance in 2015 likely resulted in a low estimation of abundance. If this is correct, it is possible that if there was an influx of animals as a result of prey shift from the warm water anomaly, it was not detected. Results do support a belief that blue whales are regularly returning to the GoA. The infrequency of sightings prior to this study is likely explained by the lack of offshore survey effort.

Fin whales

Although they remain highly depleted in the Southern Ocean, fin whales are generally considered to be abundant in the Northern Hemisphere. In the North Pacific, the California, Oregon, and Washington stock is estimated at 3051 (Carretta et al. 2016) and is showing a positive trend in abundance (Moore and Barlow 2011). A discrete subpopulation has been identified in the Gulf of California (Reilly et al. 2008b). Abundance estimates of the Northeast Pacific stock are not available (Muto et al. 2016). Surveys conducted between June and August in 1980 within the GoA resulted in a survey total of only 33 individuals sighted. In the early 2000s, surveys on the eastern Bering Sea shelf in 2002, 2008, and 2010 yielded regional estimates of 419 (CV = 0.33), 1368 (CV = 0.34), and 1061 (CV = 0.34) (Friday et al. 2013). Zerbini et al. (2006) estimated fin whale abundance along the Aleutian Islands and the Alaska Peninsula at 1652 (CV = 0.19). Analysis indicated a positive trend with an annual rate of increase of 4.8% (95% CI 4.1–5.4%) (Zerbini et al. 2006).

Much of what was known about fin whale distribution in recent years was derived from acoustic studies. Stafford et al. (2007) demonstrated that fin whales were present year-round in the GoA. There were seasonal peaks in call rates in fall and winter with fewer calls recorded during summer months. It was proposed that fewer calls during summer months may be explained by a collective movement inshore out of range of the hydrophones as well as an absence in long series of pulses (Stafford et al. 2007).

Historically, fin whales were present throughout the GoA in large numbers (Mizroch et al. 2009). Sighting data from this study demonstrate that fin whales are common within former whaling grounds of the GoA in spring and summer. Although fin whales were present in offshore pelagic waters, there were higher concentrations within the shelf/slope waters (Fig. 3a). The proposed seasonal shift inshore is possible to some degree, but this cannot be determined when comparing the one moored hydrophone (Fig. 1 in Stafford et al. 2007) located within this study area.

Humpback whales

As previously stated, humpback whales have recently been divided by the US National Marine Fisheries Service into 14 DPSs. Collectively worldwide, humpback whale populations have generally been recovering well from historical whaling. Nine of the DPSs have been delisted by the US. Five exceptions remain, Mexico, Arabian Sea, Cape Verde Islands/Northwest Africa, Central America, and western North Pacific, which continue to warrant concern (NMFS 2016).

Surveys conducted between June and August in 1980 within the GoA resulted in a survey total of 191 individual humpback whales sighted (Rice and Wolman 1982). Zerbini et al. (2006) estimated humpback whale abundance along the Aleutian Islands and the Alaska Peninsula in the early 2000s at 2644 (CV = 0.17) and predicted an annual growth rate of 6.6% annually. Results from this study were conflicting. Summer abundance from the 2013 survey was estimated at 2214 (CV = 0.70) compared to 605 (CV = 0.30) in 2015. According to the Zerbini et al. (2006) growth rate estimation, one would have expected a similar or higher abundance estimation in 2015. The estimate in 2015 is likely a result of one or a combination of reasons described above and not true a decline in GoA humpback whales given current estimates (Barlow et al. 2011).

The structure of GoA humpback whale stocks documented within this study is complex. The central and western North Pacific stocks overlap within this study area; therefore, the stock to which these humpbacks belong to is unclear (Muto et al. 2016). Furthermore, three regional feeding aggregations with subregions have been identified (Witteveen et al. 2011; Wright et al. 2015). Witteveen et al. (2011) demonstrated that GoA humpback whales have a high site fidelity and exhibit genetic and trophic distinctions between feeding aggregation regions. This study overlaps both the 'North' and 'South' feeding aggregations of the Kodiak Archipelago (Fig. 3b; Fig. 1 in Wright et al. 2015; Fig. 1 in Witteveen et al. 2011) and the inshore and offshore subregions of the Prince William Sound, Kenai Fjords, and lower Cook Inlet feeding aggregation (Fig. 3b, Fig. 1 in Witteveen et al. 2011). Feeding structure should be considered when evaluating anthropogenic impacts and management actions.

The main aggregations in all years were located on the eastside of Kodiak Island (Fig. 3b), encompassing both the 'North' and 'South' Kodiak Archipelago feeding aggregation (Witteveen et al. 2011; Wright et al. 2015). Humpback whale presence also coincides with findings from previous line-transect surveys in this area that described typical water depths for humpback whales as between 50 and 200 m (Brueggeman et al. 1988). In 2013, lower densities occurred within the slope, offshore, and seamount strata indicating these areas are not likely preferred habitat and may be used only during migration and not during the feeding season. However, many of the 2015 sightings may be duplicates due to the survey effort overlap during the 3 days spent in the North Pacific right whale Critical Habitat.

Killer whales

Killer whales have a cosmopolitan distribution (Leatherwood and Dahlheim 1978) and are currently treated as one species (Rice 1998). Evidence strongly suggests that a split into different species or subspecies is warranted (Mikhalev et al. 1981; Berzin and Vladimirov 1983; Pitman and Ensor 2003). According to the IUCN, they are estimated at 50,000 worldwide (Taylor et al. 2013). As previously mentioned, three ecotypes occur in the eastern North Pacific. There are eight stocks recognized within US Pacific waters: three resident, three transient, one offshore, and the Hawaii stock (Carretta et al. 2016). Of the eight stocks, the southern resident killer whales are of greatest concern. This stock has been declining since 1995 and was listed as endangered in 2005 under the ESA (NMFS 2005). The AT1 transient stock is considered 'depleted' under the MMPA with no recruitment into the stock since 1984 (Muto et al. 2016). The range extends into Alaskan waters for all, but the Hawaii stock (Carretta et al. 2016; Muto et al. 2016). Killer whale populations have been well studied over the years for southeastern Alaska and Prince William Sound (e.g., Dahlheim et al. 1997; Matkin et al. 1999a, b). For the coastal waters of the GoA and the Aleutian Islands, transient killer whales have been estimated at 345 (95% CI 255–487) (Durban et al. 2010) and 251 (CV = 0.51) (Zerbini et al. 2007) and resident killer whales estimated at 991 (CV = 0.52) (Zerbini et al. 2007). Differences in transient killer whale estimates may be explained by seasonal occurrence and analysis methods (Durban et al. 2010).

Within this study, both transient and resident ecotypes were documented during these surveys; however, not all sightings were photographed to determine ecotype due to time constraints; therefore, estimates cannot be made at the ecotype and stock level or compared with other regions within Alaska waters (e.g., Zerbini et al. 2007; Durban et al. 2010). Evidence suggests there are multiple subpopulations within the North Pacific resident (Fearnbach et al.

2013; Parsons et al. 2013) and transient killer whale stocks (Parsons et al. 2013); the GoA indicates multiple genetic clusters (Parsons et al. 2013). A reevaluation of stock structure is necessary to thoroughly assess status and management implications.

North Pacific right whales

The long-term persistence of the eastern stock remains of grave concern. To date, there have been no matches between the few animals photographed in the GoA with the Bering Sea animals (Wade et al. 2011a, b). The lack of connection between the two regions suggests they may be subpopulations. Identifying habitat use and stressors for these few individuals is critical to their long-term survival.

Despite the lack of sightings during 3 years of surveys, North Pacific right whales were present within the study area in 2013 and 2015. In all years, there was an acoustic component conducted in concert with visual operations: towed-array (2009 and 2013) and sonobuoys (2013 and 2015) (methods described in Rone et al. 2010, 2014, 2015). Sonobuoys are an essential component needed for consistently locating North Pacific right whales (Rone et al. 2012). In 2013, exploratory transects using sonobuoys (Rone et al. 2014) were conducted in Barnabas Trough, located on Albatross Bank, which bisects the right whale Critical Habitat (Fig. 1). Localizations were obtained on two right whales (upcalls and gunshots) with a third unique detection (no localization obtained) north of the two other calling animals (Rone et al. 2012). The animals could not be visually located, likely due to the limited visibility at the time of detection. In 2015, vocalizations (upcalls and gunshots) were detected on 2 days resulting in 4 distinct localization of calling animals (two localizations on each day). Calls were faint and infrequent; despite an extensive, systematic search, visual confirmation was not obtained and the number of calling animals could not be confirmed (Rone et al. 2015).

Overall, the extreme paucity of sightings of right whales in the GoA stands in sharp contrast to their former abundance in this region, as evidenced by the extensive catches made throughout the GoA by both nineteenth century whalers (Townsend 1935) and by former USSR whaling fleets operating illegally in the 1960s (Ivashchenko and Clapham 2012).

Sperm whales

Pre-exploitation numbers for sperm whales were estimated at 1,260,000 (Rice 1989). Today, abundance is estimated at 100,000 worldwide (Whitehead 2002b). Their population structure is not adequately defined. Sperm whales are widely distributed throughout the North Pacific. Currently, there are three defined stocks recognized within US North Pacific waters: Alaska, California/Oregon/Washington, and Hawaii (Carretta et al. 2016; Muto et al. 2016). An abundance of 2106 (CV = 0.58) is estimated within the California Current (Moore and Barlow 2014). The best available estimate for the Hawaii stock is 3354 (CV = 0.34) (Bradford et al. 2013). Mizroch and Rice (2013) suggest there is no apparent division between stocks in the North Pacific. Barlow and Taylor (2005) reported a continuous distribution from California out to Hawaii. However, recent genetic analyses indicate differences in matrilineal groups from the California/Oregon/Washington stock from the central and eastern tropical Pacific and mixing of males in the subarctic from the three regions (Mesnick et al. 2011).

Until this study, there were no abundance estimates for sperm whales in Alaska waters. Visual surveys conducted by MML between 2001 and 2006 found sperm whales to be the most frequently sighted large cetacean (Muto et al. 2016). They are present year-round within the GoA with higher occurrence during summer months (Mellinger et al. 2004a). Both females and males have broad ranging long-distance movement as demonstrated by discovery marks (Mizroch and Rice 2013). Although sperm whales found at the highest latitudes are often mature males that are generally solitary, whaling catch data confirmed that females were found in waters north of 50 N (see Fig. 2b in Mizroch and Rice 2013). Fearnbach et al. (2012) documented a rare winter sighting of approximately 50 individuals comprised of females and immatures in the Bering Sea near the Aleutian Islands, confirming that present-day movements of these subgroups are not confined to the tropics and subtropics. Similarly, analysis of former USSR catch records shows females and immatures occurring in high latitudes a far as 60 N (Ivashchenko et al. 2014). Mizroch and Rice (2013) noted that although Mesnick et al. (2011) reported that few adult females inhabit Alaska waters, it cannot be assumed that there are no females within this area given the lack of contemporary survey effort. During 2015, a large group of 11 individuals including 1 calf were documented; no mature males were observed. This 2015 sighting demonstrates that both sexes and mixed age classes can occur in the GoA.

As with right whales, a combination of visual and acoustic platforms can increase detections of species such as sperm whales that are often difficult to detect due to their deep-dives. While no sperm whales were visually detected in 2009, there were 28 localized detections from the towed-hydrophone array (Rone et al. 2010) compared to 19 sightings and 174 acoustic localizations (Rone et al. 2014) in 2013. A towed-array was not used in 2015. This disparity in sperm whale detections between 2009 and 2013 may be attributed to differences in seasons, inclement weather (for visual), a significantly reduced survey effort (2009), and location of realized effort. In 2013, acoustic estimates

(N = 215, D = 0.001; CV = 0.18) were nearly twice the visual estimates (N = 129, D = 0.00031; CV = 0.44) (Rone et al. 2014; Table 6). The estimates derived from acoustic localizations were more robust than those from visual detection due to the larger sample size.

Dall's porpoise

Dall's porpoise are distributed across the North Pacific Ocean (Hammond et al. 2012) and are known to inhabit the continental shelf, slope, and pelagic waters and demonstrate seasonality in movements (Hall 1979). Abundance is estimated at 1.2 million (Buckland et al. 1993). In the eastern North Pacific, they are documented in all months (Muto et al. 2016). Abundance for the Alaska stock was estimated at 417,000 (Hobbs and Lerczak 1993) for data collected over 25 years ago. Turnock and Quinn (1991) suggest estimates are inflated as much as five times as a result of vessel attraction. A revised estimated would put a minimum abundance estimate at 83,400 (Muto et al. 2016). More recent estimates in the eastern Bering Sea resulted in 35,303 (CV = 0.53) in 2002, 14,543 (CV = 0.32) in 2008, and 11,143 (CV = 0.32) in 2010. There was no significant difference between years. Estimates were not corrected for biases and do not represent the minimum estimates (Friday et al. 2013).

Although sighted throughout the survey area, there were two substantial concentrations of Dall's porpoise within the inshore and slope strata in 2013 that accounted for a significant portion (55%) of the sightings (Fig. 4b). Estimates for 2013 and 2015, 15,423 (CV = 0.28) and 13,111 (CV = 0.22), respectively, did not differ significantly. These estimates do not include a correction factor and are not considered the minimum estimates. No trends can be determined from these data. They are currently not considered a species of concern (Hammond et al. 2012).

Conclusion

This study provides the most detailed information to date on distribution, abundance, and densities of cetaceans within offshore waters of the GoA. The absence of North Pacific right whale sightings within this historically important habitat continues to underscore the precarious status of this critically endangered whale. Management and conservation of this species continues to be greatly hindered by the lack of basic information regarding this population, and further research should be a high priority. Beaked whales and blue whales have demonstrated behavioral responses to mid-frequency active sonar (MFAS) (Tyack et al. 2011; DeRuiter et al. 2013; Goldbogen et al. 2013). Although beaked whales have been documented stranding concurrent with MFAS exposure during military exercises, the connection between strandings and sonar remains unclear (Cox et al. 2006; D'Amico et al. 2009). The occurrence of beaked whales (2013) and blue whales (2013, 2015), detected both visually and acoustically (Rone et al. 2014, 2015), suggests the GoA represents important habitat. Additional research should be devoted to obtaining rigorous abundance and density estimates and a better understanding of habitat use in order to assess potential impacts from military activity.

Although acoustic results conducted during these surveys were not detailed, they were nevertheless discussed to provide a better depiction of the presence of some of the more cryptic species documented in the GoA. As in the case of beaked whales, using both visual and acoustic methods increased the number of beaked whale detections and species identified. The presence of right whales would not have been documented without the contribution of acoustic effort. Results demonstrate the importance of utilizing compatible platforms of data collection to detect rare and elusive species and underscore the importance of considering all data collected when conducting analyses, particularly when assessing anthropogenic impacts.

As our oceans continue to change under a myriad of impacts from human pressures, it is essential to fill in the data gaps and obtain contemporary information on endangered, recovering, and data-deficient species. In a time where funding is becoming increasingly difficult to obtain, now more than ever, it is essential to conduct recurrent, dedicated regional surveys in order to assess status, detect trends, and predict habitat use.

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Compliance with ethical standards

Conflict of interest Brenda K. Rone declares that she has no conflict of interest. Alexandre N. Zerbini declares that he has no conflict of interest. Annie B. Douglas declares that she has no conflict of interest. David W. Weller declares that he has no conflict of interest. Phillip J. Clapham declares that he has no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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