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Cetacean Distrib. and Abundance Eastern Bering Sea. Deep-Sea Research II (in press)

N. Friday, A. Zerbini, J. Waite, S. Moore, P. Claphan

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Cetacean distribution and abundance in relation to oceanographic domains on the eastern Bering Sea shelf, June and July of 2002, 2008, and 2010

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ARTICLE INFO

Keywords:
Abundance
Cetacean
Distribution
Eastern Bering Sea shelf
Spatial variations
Temporal variations

ABSTRACT

As part of the Bering Sea Project, cetacean surveys were conducted to describe distribution and estimate abundance on the eastern Bering Sea shelf. Three marine mammal observers conducted visual surveys along transect lines sampled during the Alaska Fisheries Science Center walleye pollock assessment survey in June and July of 2008 and 2010. Distribution and abundance in 2008 and 2010 (cold years) are compared with results from a similar survey conducted in 2002 (a warm year), as the only three years that the entire survey area was sampled; patterns largely match those previously observed. Abundance estimates for comparable areas in 2002, 2008 and 2010 were as follows: humpback whales (*Megaptera novaeangliae*): 231 (CV=0.63), 436 (CV=0.45), and 675 (CV=0.80); fin whales (*Balaenoptera physalus*): 419 (CV=0.33), 1368 (CV=0.34), and 1061 (CV=0.38); minke whales (*Balaenoptera acutorostrata*): 389 (CV=0.52), 517 (CV=0.69), and 2020 (CV=0.73); Dall's porpoise (*Phocoenoides dalli*): 35,303 (CV=0.53), 14,543 (CV=0.32), and 11,143 (CV=0.32); and harbor porpoise (*Phocoena phocoena*): 1971 (CV=0.46), 4056 (CV=0.40), and 833 (CV=0.66). It should be noted that these abundance estimates are not corrected for biases due to perception, availability, or responsive movement. Estimates for humpback, fin and minke whales increased from 2002 to 2010, while those for harbor and Dall's porpoise decreased; trends were significant for fin whales. It is likely that changes in estimated abundance are due at least in part to shifts in distribution and not just changes in overall population size. Annual abundance estimates were examined by oceanographic domain. Humpback whales were consistently concentrated in coastal waters north of Unimak Pass. Fin whales were broadly distributed in the outer domain and slope in 2008 and 2010, but sightings were sparse in 2002. Minke whales were distributed throughout the study area in 2002 and 2008, but in 2010 they were concentrated in the outer domain and slope. In 2002, Dall's porpoise were sighted on the western edge of the middle domain and in the outer domain and slope, but shifted west out of the middle domain in 2008 and 2010. In 2002 and 2008, harbor porpoise were consistently found in the middle domain with scattered sightings in the outer domain and slope. In 2010, there was a multi-species aggregation between Navarin and Pervenets canyons.

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1. Introduction

The eastern Bering Sea (EBS) shelf is a highly productive ocean region, which supports large-scale commercial fishing and regional community-based subsistence activities, and also sustains numerous seabirds and marine mammals. The EBS responds rapidly to changes in the physical environment at seasonal, interannual, and decadal time scales (Napp and Hunt, 2001; Stabeno et al., 2007, 2012b). Because it is such an important ecosystem and is sensitive to climate change, the U.S. National Science Foundation's Bering Ecosystem STudy (BEST) and the North Pacific Research Board's (NPRB) Bering Sea Integrated Ecosystem Research Program (BSIERP) combined to form the Bering Sea Project to study the impacts of climate change and dynamic sea ice cover on the ecosystem of the EBS (Wiese et al., 2012). As part of the Bering Sea Project, we collected cetacean sightings data to assess distribution, estimate abundance, and estimate trends in abundance of cetaceans, particularly fin (*Balaenoptera physalus*) and humpback (*Megaptera novaeangliae*) whales, on the eastern Bering Sea shelf.

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0967-0645/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.dsr2.2013.03.011

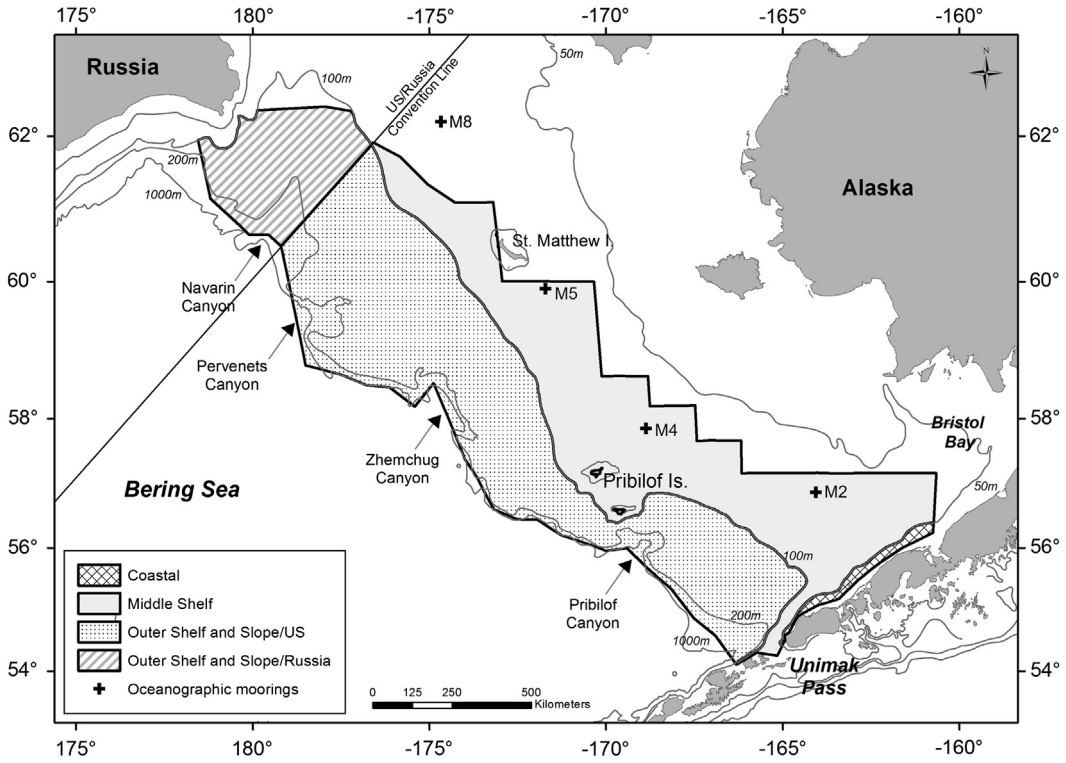

Fig. 1. Map of the study area and oceanographic domains. Also indicated are the NOAA's oceanographic moorings: M2, M4, M5, and M8.

The extent and duration of sea ice over the EBS shelf is largely controlled by atmospheric forcing and is a driving factor for many of the characteristics observed on the EBS shelf (Stabeno et al., 2007, 2012a) including the overall summertime productivity of the EBS ecosystem (Hunt et al., 2002, 2010, 2011; Stabeno et al., 2001, 1998). A revised Oscillating Control Hypothesis predicts that late sea ice retreats are associated with early, ice-associated spring blooms, which results in higher abundance of the medium sized, lipid-rich shelf copepod *Calanus* spp. and euphausiids *Thysanoessa raschii* and *T. inermis*. Availability of these zooplankton prey is critical for a strong pollock year class and for other planktivores such as baleen whales. In contrast, early sea ice retreats are associated with late spring blooms in warmer water, which lead to lower abundance of *Calanus* and *Thysanoessa* spp. (Hunt et al., 2011; Hunt and Stabeno, 2002; Stabeno et al., 2001). The frequency and duration of summer storms also affects the EBS shelf ecosystem (Sambrotto et al., 1986). Summer storms temporarily weaken the pycnocline and bring nutrients from the deep water into the upper water layer (Sambrotto et al., 1986; Whitledge et al., 1986) where it is available for phytoplankton production. However, a balance between storm mixing and stratification is needed for blooms where storms increase mixing and phytoplankton production, but water column stratification and stability is high enough that phytoplankton remain above the compensation depth (Coyle et al., 2008).

The EBS shelf is comprised of three oceanographic domains, separated by fronts or transition zones, as described by Coachman (1986): coastal (shore to the 50 m isobath), middle shelf (50–100 m), and outer shelf (100-180 m) (Fig. 1). The inner front (50 m) divides the coastal and middle domains, and the middle front (100 m) divides the middle and outer shelf domains. A salinity front at the shelf break (180 m) divides the outer domain from the slope waters. Each domain has defining characteristics in terms of their summer structure and zooplankton composition (Cooney and Coyle, 1982; Coyle et al., 1996; Coyle and Pinchuk, 2002; Hunt et al., 2002; Smith, 1991; Smith and Vidal, 1986). The coastal domain is characterized by a single well-mixed layer or two weakly stratified layers. The middle domain is a strongly stratified two-layer system: a wind-mixed surface layer and a nutrient rich, tidally-mixed lower layer. The coastal and middle domains are populated by shelf zooplankton species such as *Thysanoessa raschi*, *Pseudocalanus* spp., *Acartia* spp., and *Calanus marshallae*, but biomass is lower in the coastal domain than the middle domain (Napp et al., 2002). The outer domain has a wind-mixed surface layer and a tidally-mixed bottom layer with a transition layer in between, and is populated by oceanic zooplankton species such as *Thysanoessa inermis*, *Neocalanus plumchrus*, *Neocalanus cristatus*, *Eucalanus bungii*, and *Metridia pacifica*.

Environment has a profound effect on summer zooplankton composition in the middle domain. Coyle et al. (2008) found that the zooplankton composition shifted from large to small species and the water column stability increased three-fold when comparing a colder year, 1999, to a warmer year, 2004. Stabeno et al. (2012b) examined water temperature and temperature anomalies on the southeastern Bering Sea shelf at mooring M2 from 1995 to 2010. They were able to assign years to three categories: cold (1995, 1997, 1999, and 2007-2010), average (1996, 2000, and 2006) and warm (1998 and 2001-2005). Stabeno et al. (2012b) also examined interannual variability in sea ice cover at M2 during the same time period. They found three different temporal patterns in the variability of sea ice extent: high interannual variability (1995-1999), low variability with minimal ice coverage (2000-2006), and low variability with maximum ice coverage (2007-2010). They described a relationship between the species and abundance of zooplankton and the warm/cold year category; this relationship was less evident during periods of high interannual variability. Stabeno et al. (2012b) also found that the relative abundance of fin whales sighted during aerial surveys was 7–12 times higher in 1999, a cold year, compared to 2002, a warm year, suggesting that feeding conditions were better in cold conditions.

Since cetacean distribution in high latitudes is assumed to be driven primarily by the distribution of their prey, cetaceans are

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indicators of variability of zooplankton and forage fish prey. We expect cetacean distribution to change temporally and spatially with the composition and energetic value of the zooplankton and forage fish communities. Therefore, the differences in zooplankton community among the domains should be to be reflected in the distribution of cetaceans. If climate change shifts the pattern of variability toward prolonged periods of warmer conditions, this could have a profound effect on the composition of the lower trophic levels, which could then affect the abundance and distribution of upper trophic level species, including cetaceans.

Historical information on the distribution and abundance of cetacean species on the EBS shelf is limited. Leatherwood et al. (1983) conducted aerial surveys in the Bering Sea in the early 1980s, but they did not estimate abundance. Brueggeman et al. (1987) conducted aerial surveys in 1985 in the southeastern Bering Sea and estimated abundance for two areas divided along the 165°W longitude line; the North Aleutian Basin to the east and the St. George Basin to the west. Because surveys to determine distribution and abundance in the EBS are costly, the Alaska Fisheries Science Center's (AFSC) National Marine Mammal Laboratory (NMML) teamed with the Center's Resource Assessment and Conservation Engineering (RACE) Division to conduct visual surveys for cetaceans during RACE's biennial echo integration-trawl survey for walleye pollock on the EBS shelf (Friday et al., 2012; Moore et al., 2000, 2002; Tynan, 2004; Waite et al., 2002). Biologists from NMML were able to join the RACE surveys in 1997, 1999, 2000, 2002, 2004, 2008, and 2010, providing an opportunity to describe cetacean distribution and calculate abundance over a broad area of the EBS shelf. It was possible to place observers on the entire acoustic trawl survey in only 2002, 2008, and 2010, the last two surveys being part of the Bering Sea Project.

Friday et al. (2012) presented cetacean distribution and estimates of abundance by species and oceanographic domain for the 1999, 2000, 2002, and 2004 surveys. They found that the abundance of baleen whales tended to be greater in cold years (1999) than warm years (2002 and 2004), but no clear relationship was found for porpoise in regard to warm and cold years. Here, we compared the distribution and abundance of cetaceans on the EBS shelf in a warm year (2002) to two cold years (2008 and 2010), allowing us to compare estimates of abundance and to determine if the distribution patterns reported in Friday et al. (2012) persist.

2. Materials and methods

Visual surveys for cetaceans were conducted as a secondary study in association with the RACE echo integration-trawl (EIT) surveys for walleye pollock in June and July of 2002, 2008 and 2010 (Table 1). Because of the time constrains and requirements of the EIT surveys (e.g., maintaining the trackline during echo integration and conducting fish trawls to verify acoustic backscatter), visual surveys for cetaceans were conducted along the EIT transect lines in passing model only. Searches for cetaceans were conducted from the flying bridge of the NOAA ship *Miller Freeman* in 2002 and the NOAA ship *Oscar Dyson* in 2008 and 2010 at a platform height of 12 m and 15.5 m, respectively, above the sea surface and a survey speed of 18.5–22 km/h (10–12 kts). North-south transect lines were spaced 37 km apart and defined by the historical acoustic survey for walleye pollock. In 2008 and 2010, AFSC received permission to survey on the Russian side of the U.S./Russia Convention Line resulting in a 10% increase in the survey area in these years. Realized visual survey effort varied due to weather conditions, and the requirements of the pollock survey. Survey effort was divided into on-effort (during transect legs) and additional-effort (other times when the survey protocol was being used, such as transit to, from, and between transect legs).

Table 1
Sighting effort by year and domain: area (km^2) covered in each domain and on-effort (km) surveyed.

Domain	Area (km^2)		Effort (km)		
	2002	2008/2010	2002	2008	2010
Dates			6/6–7/28	6/3–7/30	6/6–8/5
Coastal	5097	5097	43	43	26
Middle shelf	150,749	150,749	1623	1092	353
Outer shelf U.S.	181,906	181,906	2086	1693	1015
Outer shelf Russian	0	33,531	0	424	245
Total on-effort	**337,752**	**371,283**	**3752**	**3253**	**1638**

Standard line transect survey protocols were followed with two observers using Fujinon[1] 25× (Big Eye) reticle binoculars at port and starboard stations on the flying bridge. The port observer scanned for cetaceans from 10° right to 90° left of the trackline, and the starboard observer from 10° left to 90° right. A third observer focused on the trackline, but scanned the entire 180° area forward of the ship by eye or Fujinon 7 × 50 reticle binoculars and recorded data in a laptop computer using the program WINCRUZ (available at: http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=147&id=1446). Effort data included date, time, latitude and longitude of the vessel, an observers' code, and observer positions. Environmental variables relating to sightability were recorded (e.g., sea state, glare, visibility, etc.). Species, radial distance (calculated from reticles in the binoculars), angle relative to the ship's heading (measured with an angle board or an angle ring on the binocular mount), group size (estimated number of animals in the sighted group), and sighting method (whether a sighting was made with the Big Eye binoculars or not) were recorded for each sighting. For group size, "best", "high" and "low" estimates were made by the observer who sighted the group; best estimates of group size were used in this analysis. Sighting effort was suspended when the sea state was estimated to be above Beaufort 5.

The study area was post-stratified into three oceanographic domains, separated by two fronts (Coachman, 1986): the coastal domain (shore to inner front), middle shelf domain (inner front to middle front), and outer shelf domain (middle front to western edge of the survey area) (Fig. 1). Although the locations of the inner and middle fronts vary, we have used standard front locations along the 50 m and 100 m isobaths, respectively, to demarcate the domains (Coachman, 1986). Using isobaths as proxies for the fronts is a common procedure and allows the cetacean abundances, and not just the densities, to be compared between years. The slope is separated from the outer shelf domain by a salinity front at the shelf break (200 m), but was combined with the outer shelf domain (combination is hereafter referred to as the outer stratum) for this analysis because the zooplankton communities are similar and only the eastern edge of the slope was sampled. In 2008 and 2010, the outer stratum was divided at the U.S./Russia Convention Line creating an outer U.S. stratum, matching 2002, and an outer Russian stratum. Cetacean distribution, sighting rates, and abundances were examined by oceanographic domain to investigate possible trends in species occurrence and density.

Abundance estimates were computed using conventional (CDS) and multi-covariate (MCDS) distance sampling methods

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

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Table 2
Number of groups sighted (with the total number of animals in parentheses) during on-effort and additional-effort survey modes by year.

	On-effort			Additional-effort		
	2002	**2008**	**2010**	**2002**	**2008**	**2010**
Mysticetes						
Humpback whale	6 (14)	16 (30)	7 (12)	12 (38)	29 (94)	24 (99)
Fin whale	16 (48)	47 (137)	33 (70)	12 (25)	25 (51)	23 (39)
Sei whale	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (1)
Minke whale	12 (13)	4 (5)	19 (28)	10 (11)	2 (2)	2 (2)
Gray whale	0 (0)	0 (0)	0 (0)	0 (0)	1 (7)	0 (0)
Odontocetes						
Sperm whale	2 (3)	1 (1)	0 (0)	0 (0)	3 (4)	5 (7)
Baird's beaked whale	0 (0)	0 (0)	0 (0)	0 (0)	2 (11)	1 (3)
Stejneger's beaked whale	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
Killer whale	8 (124)	21 (143)	10 (38)	12 (85)	9 (33)	9 (51)
Pacific white-sided dolphin	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (19)
Dall's porpoise	108 (535)	64 (298)	41 (141)	72 (348)	106 (529)	46 (175)
Harbor porpoise	49 (73)	47 (99)	8 (16)	8 (10)	9 (15)	1 (1)
Unidentified sightings						
Un-ID large whale	3 (3)	33 (49)	8 (9)	7 (27)	20 (27)	8 (8)
Un-ID baleen whale	6 (13)	10 (11)	26 (32)	10 (14)	1 (1)	21 (29)
Un-ID small whale	9 (9)	6 (6)	0 (0)	2 (4)	1 (1)	0 (0)
Un-ID dolphin/porpoise	24 (42)	32 (53)	6 (9)	17 (33)	13 (23)	5 (16)
Un-ID cetacean	4 (5)	7 (7)	3 (3)	1 (1)	2 (5)	4 (7)

(Buckland et al., 2001, 2004) as implemented in the Mark-Recapture Distance Sampling (mrds) package (Laake et al., 2012) for R (R Development Core Team, 2012). To increase the sample size when fitting the detection function, sightings from 2002, 2008 and 2010 were combined with three other data sources: (1) additional-effort sightings from the transit legs which were not part of the uniform coverage of the study area, (2) sightings from similar surveys on the EBS shelf on the NOAA ship *Miller Freeman* from early June to early July in 2000 and 2004 and from early July to early August in 1999 (Friday et al., 2012), and (3) a similar echo integration-trawl survey for walleye pollock on the NOAA ship *Miller Freeman* in the Gulf of Alaska in June and July of 2003 (Guttormsen and Yasenak, 2007) that used the same survey protocols. Sightings from these additional data sources were collected using the same visual observation protocols as the on-effort sighting, thus species should have the same probability of sighting. Including these additional data sources improves the fit of the detection function and improves the precision of the resulting estimates. To improve the fit of the detection functions, the perpendicular distance data for minke whales (*Balaenoptera acutorostrata*) were truncated at 2 km and were binned, and the perpendicular distance data for fin whales, Dall's porpoise (*Phocoenoides dalli*), and harbor porpoise (*Phocoena phocoena*) were truncated at 7, 5, and 4.5 km, respectively, but were not binned. It was not necessary to truncate or bin the perpendicular distance data for humpback whales. Two numeric covariates (sea state and group size) and two factor covariates (vessel and sighting method) were explored. Including the ship covariate accounted for differences in sightability between the NOAA ship *Miller Freeman* and the NOAA ship *Oscar Dyson*, if such differences were significant, so that comparisons could be made between vessels/years. To improve model fitting for species with a few outlying large groups, estimates of group size were transformed. The square root of group size was used for humpback and minke whales, and Dall's porpoise group sizes were divided by the maximum group size. Hazard-rate and half-normal models were fit with and without covariates, but without interactions, resulting in 32 proposed models for each species. Interactions might improve the fit of the detection functions, but are not merited by the sample sizes and would not greatly improve the precision of the density and abundance estimates given the other sources of variability.

The best-fit detection probability model was selected using Akaike's Information Criteria (AIC) (Burnham and Anderson, 2002). Models with $\Delta AIC \leq 2$ are considered well-supported by the data and are presented here for comparison, but density and abundance were computed with the best-fit model. On-effort sightings were separated by oceanographic domain and year for estimating group size, sighting rates, density, and abundance; additional-effort sightings were not used for these estimates. Because of the limitations of the survey, data were not collected to determine animals missed on the trackline (perception bias) or animals submerged when the ship passed (availability bias). Therefore, corrections were not made for these biases and $g(0)$, the sighting probability on the trackline, was assumed to be 1.0. This assumption likely causes underestimation of small cetaceans and minke whales (Barlow, 1995). However, estimates of fin and humpback whales are likely accurate because $g(0)$ was estimated as close to unity for ship surveys on comparable vessels in the North Pacific (Barlow, 1995; Calambokidis and Barlow, 2004). Estimates were not corrected for responsive movement (avoidance of, or attraction to, the vessel), which is an important factor in estimating abundance of some cetacean species (e.g., Dall's porpoise; Turnock and Quinn, 1991).

Annual rates of change were estimated for each species by fitting an exponential growth model to the log of the abundance estimates for the U.S. area only because they were comparable across years. The abundance in the starting year, the annual rate of change, and a term for additional variance were estimated by maximum likelihood methods, and the 95% confidence intervals for the rate of change were estimated using likelihood profiling (Branch, 2007; Hilborn and Mangel, 1997). The negative log likelihood was minimized using the optim function in R (R Development Core Team, 2012).

3. Results

The transect survey effort ranged from 1638 km in 2010 to 3752 km in 2002 (Table 1). Distribution patterns were examined

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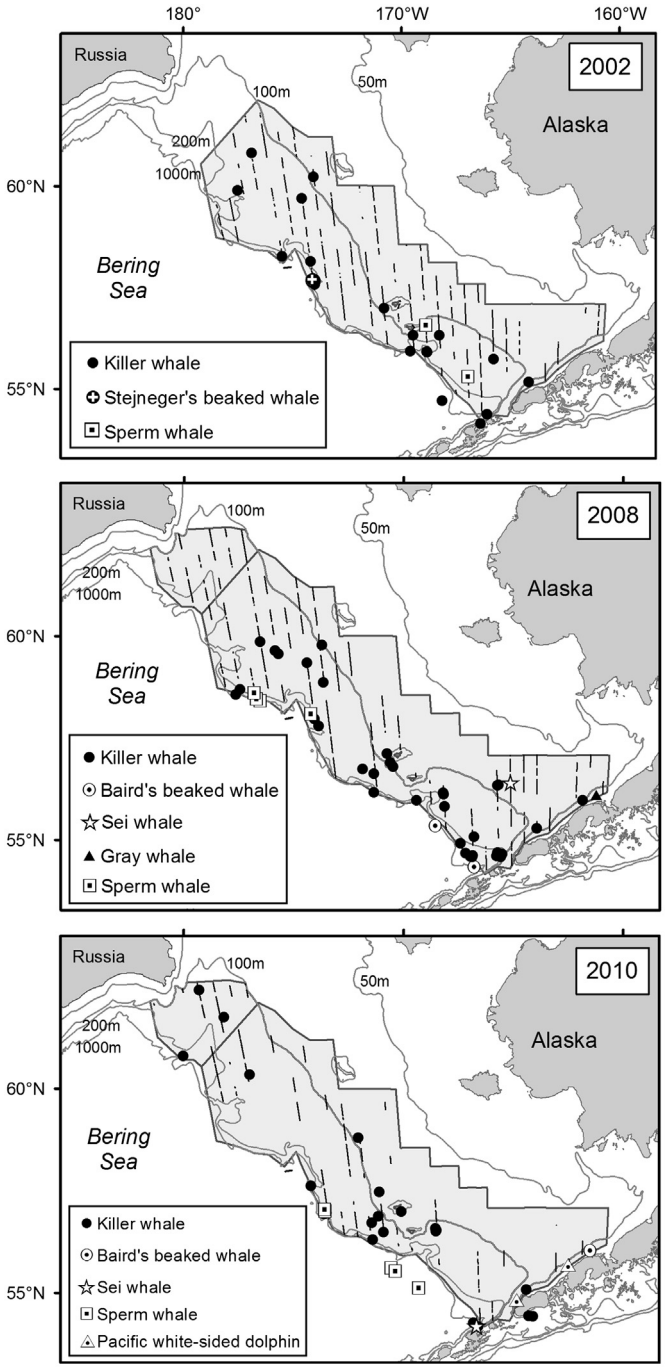

Fig. 2. Sightings of sei, gray, sperm, Baird's beaked, Stejneger's beaked, and killer whales by year; all sightings are plotted.

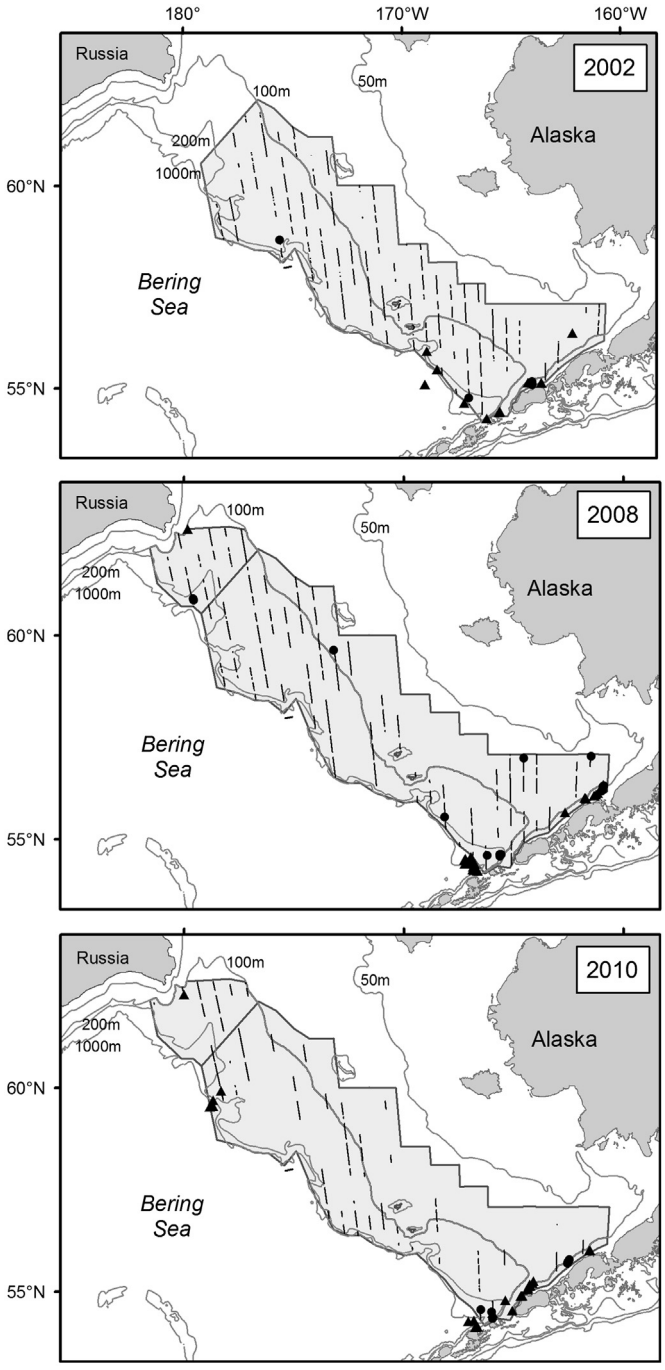

Fig. 3. Sightings of humpback whales by year. On-effort sightings are indicated by circles (●) and additional-effort and off-effort sightings are indicated by triangles (▲).

and abundance estimated for species with five or more sightings per year: humpback, fin, and minke whales, and Dall's and harbor porpoise (Table 2). Killer whales (*Orcinus orca*) also had five or more sighting per year and are widely distributed (Table 2, Fig. 2), but were excluded from further analysis because sightings were not identified to ecotype ("resident", "transient" or "offshore"; Ford et al., 2000). Other species sighted less frequently include sei (*Balaenoptera borealis*), gray (*Eschrichtius robustus*), sperm (*Physeter macrocephalus*), Baird's beaked (*Berardius bairdii*), and Stejneger's beaked (*Mesoplodon stejnegeri*) whales, and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), as well as sightings that were not identified to species (Table 2, Fig. 2). Fin whales were the most common large whale and Dall's porpoise were the most common small cetacean sighted in all years (Table 2).

3.1. Distribution

Distribution patterns for each species were similar among years, although differences in realized sampling effort in some regions of the study area confound interannual comparisons. Humpback whales were consistently concentrated in coastal waters north of Unimak Pass and along the Alaska Peninsula, with only scattered sightings along the slope (Fig. 3). Fin whales were well distributed

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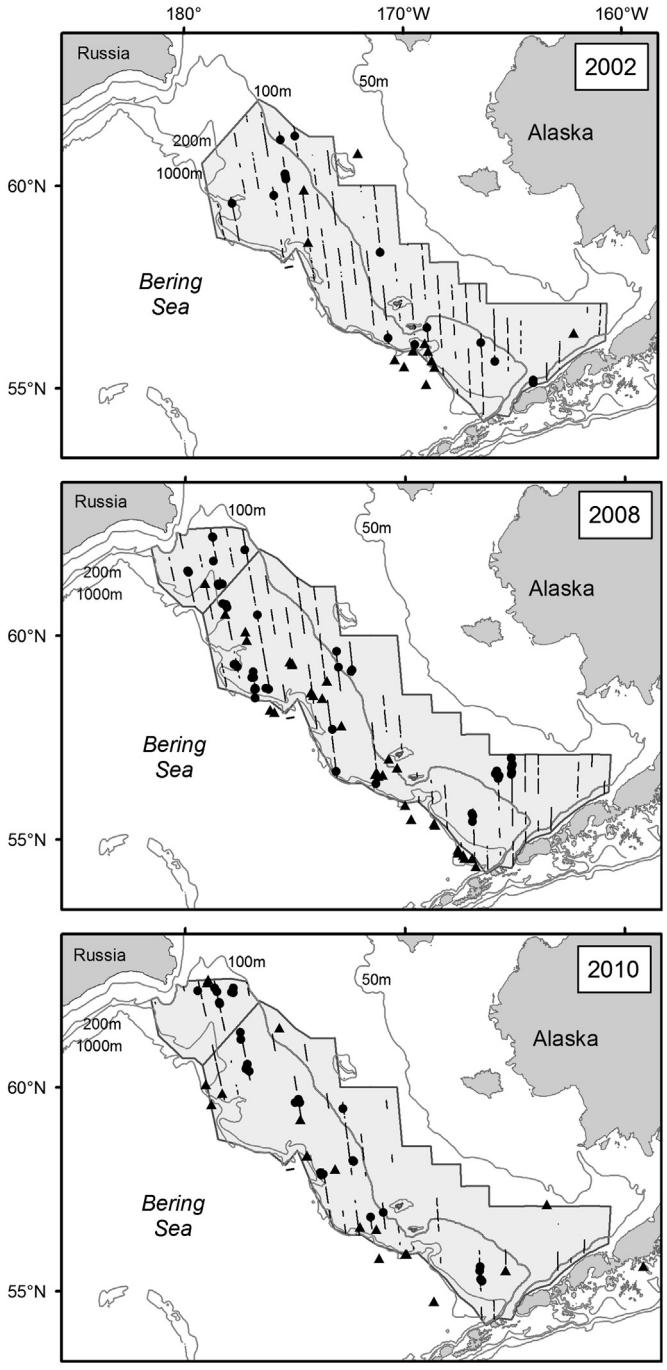

Fig. 4. Sightings of fin whales by year. On-effort sightings are indicated by circles (●) and additional-effort and off-effort sightings are indicated by triangles (▲).

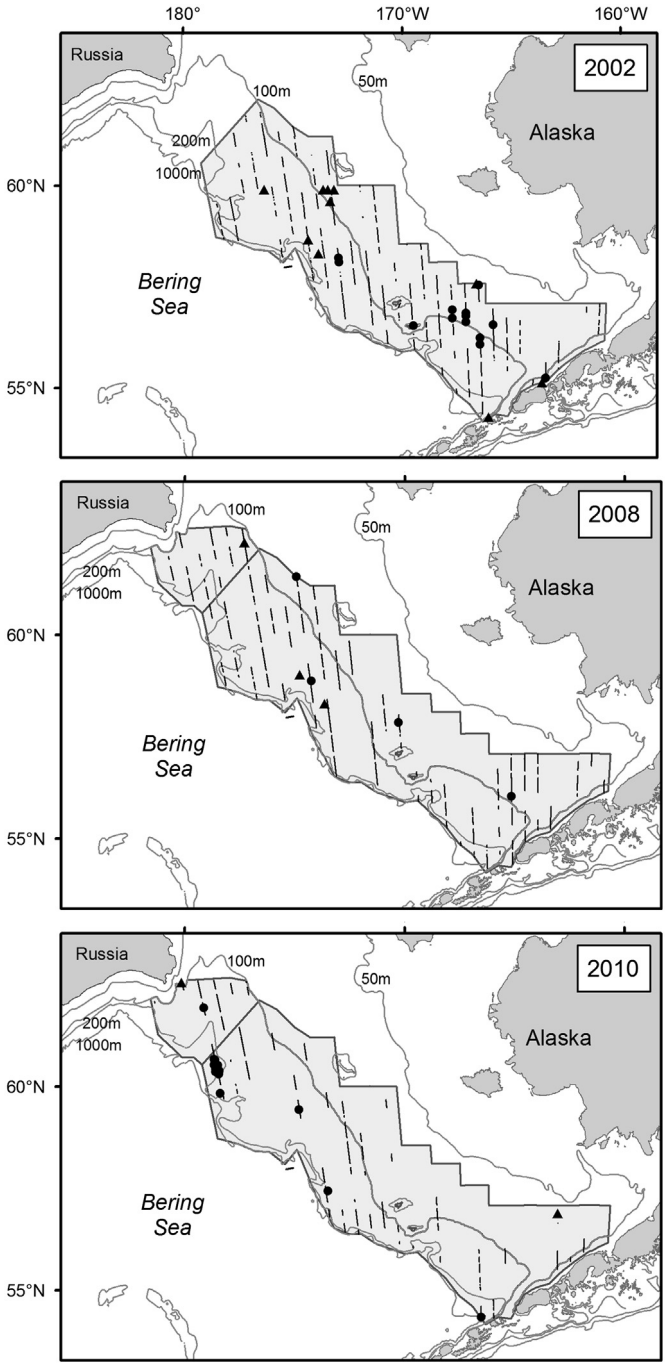

Fig. 5. Sightings of minke whales by year. On-effort sightings are indicated by circles (●) and additional-effort and off-effort sightings are indicated by triangles (▲).

in the outer stratum in all years, but were sparse in 2002, except for a cluster of sightings around Pribilof Canyon (Fig. 4). There were scattered sightings in the middle domain in all years and a cluster of sightings around 57°N, 165°W in 2008. In 2008 and 2010, fin whales were sighted in the Russian waters of the outer stratum indicating that the extension of the survey area over the U.S./Russia Convention Line may include more of the important habitat for fin whales. Overall, the distribution of humpback and fin whales seems to be consistent among all three years, with increased number of sightings of these species in 2008 and 2010 compared to 2002.

The distributions of minke whales and porpoise were more variable. Minke whales were seen throughout the study area in all domains (Fig. 5). In 2002 and 2008, sightings were scattered, while in 2010, sightings were concentrated in the outer stratum in Navarin Canyon. There were roughly equal numbers of sightings in 2002 and 2010, but few in 2008. The area east of the Pribilof Islands was an area of high sightings in 2002, but was not well sampled in 2008 and 2010. Dall's porpoise were sighted on the western edge of the middle domain along the 100 m isobath and in the outer stratum in 2002, while in 2008 and 2010, all of the on-effort and most of the additional-effort sightings occurred in the outer stratum (Fig. 6). In 2002, harbor porpoise were found in the middle domain, east of the Pribilof Islands, with scattered sightings in the outer stratum (Fig. 7). In 2008, harbor porpoise

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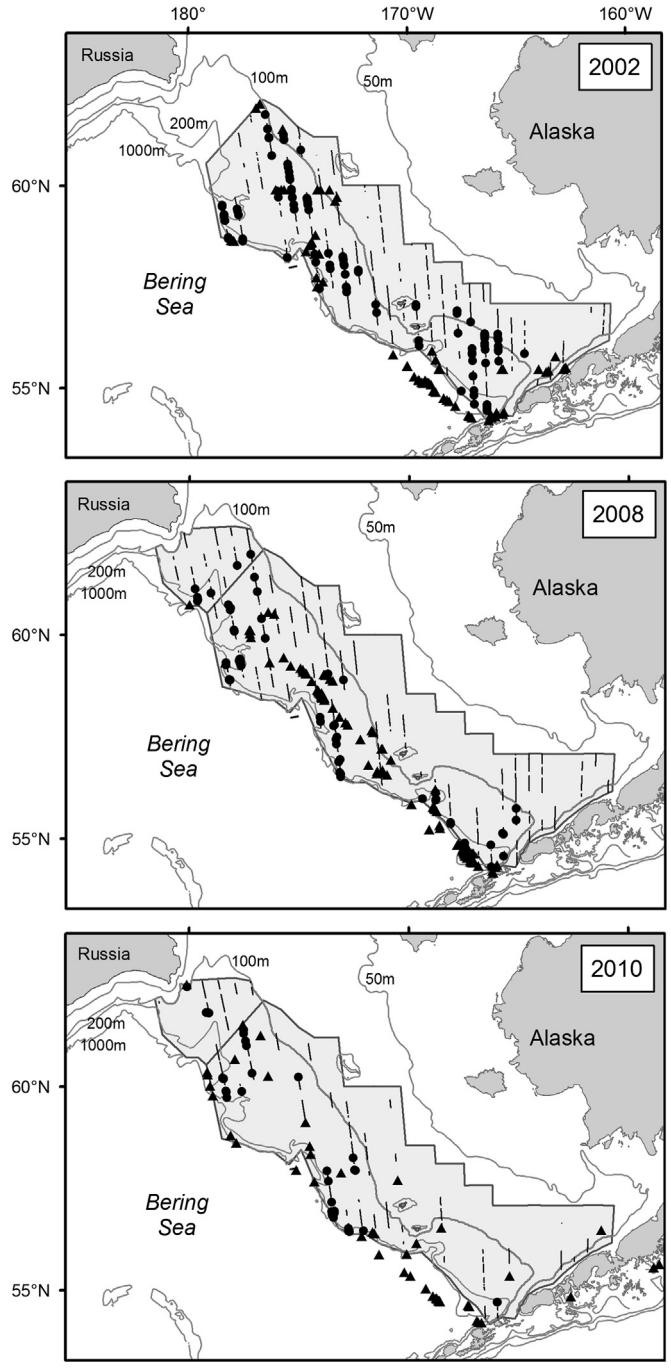

Fig. 6. Sightings of Dall's porpoise by year. On-effort sightings are indicated by circles (●) and additional-effort and off-effort sightings are indicated by triangles (▲).

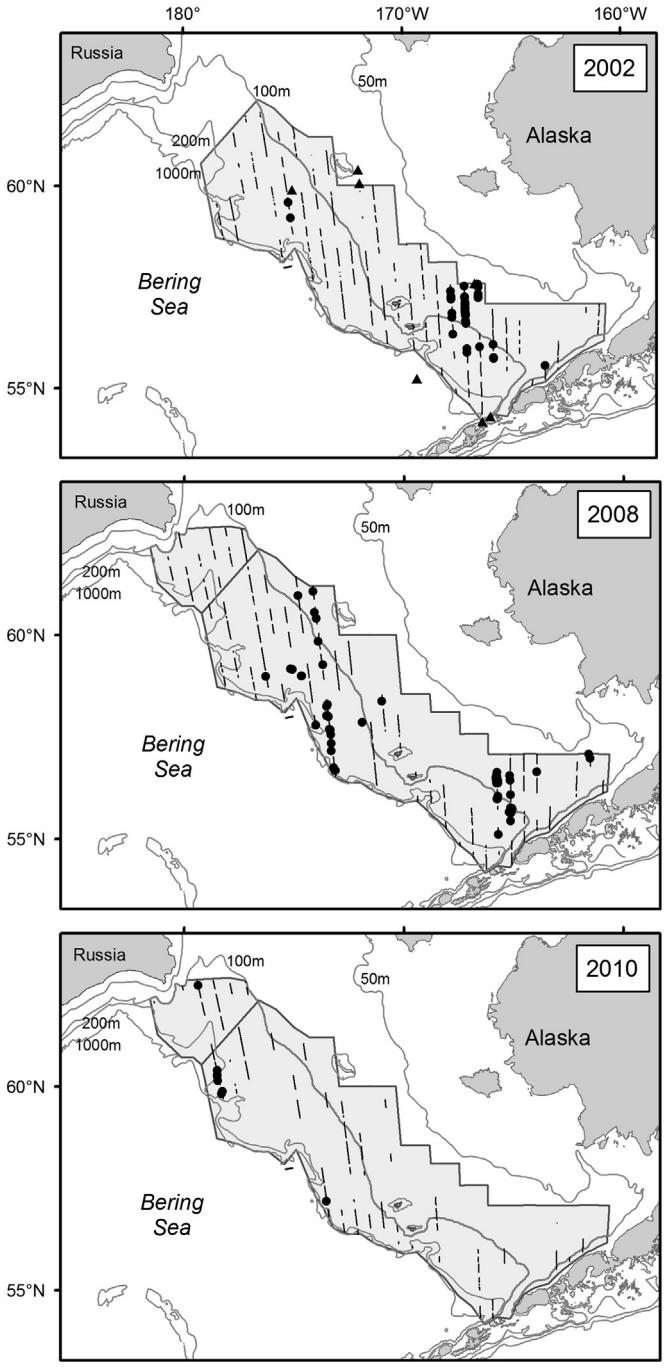

Fig. 7. Sightings of harbor porpoise by year. On-effort sightings are indicated by circles (●) and additional-effort and off-effort sightings are indicated by triangles (▲).

were found in the middle domain and outer stratum. In 2010, there were very few harbor porpoise sightings, and they all occurred in the outer stratum, with most around Pervenets and Navarin Canyons. In 2010, there was an atypical multi-species mix, including sightings of fin, humpback, and minke whales and Dall's and harbor porpoise between Navarin and Pervenets Canyons.

3.2. Abundance

The detection functions for the best-fit models (minimum AIC) for each species are illustrated in Fig. 8. All well-supported models for the detection function ($\Delta AIC \leq 2$) are presented in Table 3. Although the covariates in the well-supported models varied by species, the sighting method covariate was included in all well-supported models. The sea state covariate was included in all well-supported models for fin whales, Dall's porpoise and harbor porpoise. The need to truncate the minke whale data at 2 km from the trackline may have made sea state less important in this analysis even though sea state is often a factor for minke whales. Encounter rate, group size, density and abundance were estimated using the best-fit detection function model and are presented in Tables 4 and 5 for each species by year and oceanographic domain. General patterns for each species are discussed below.

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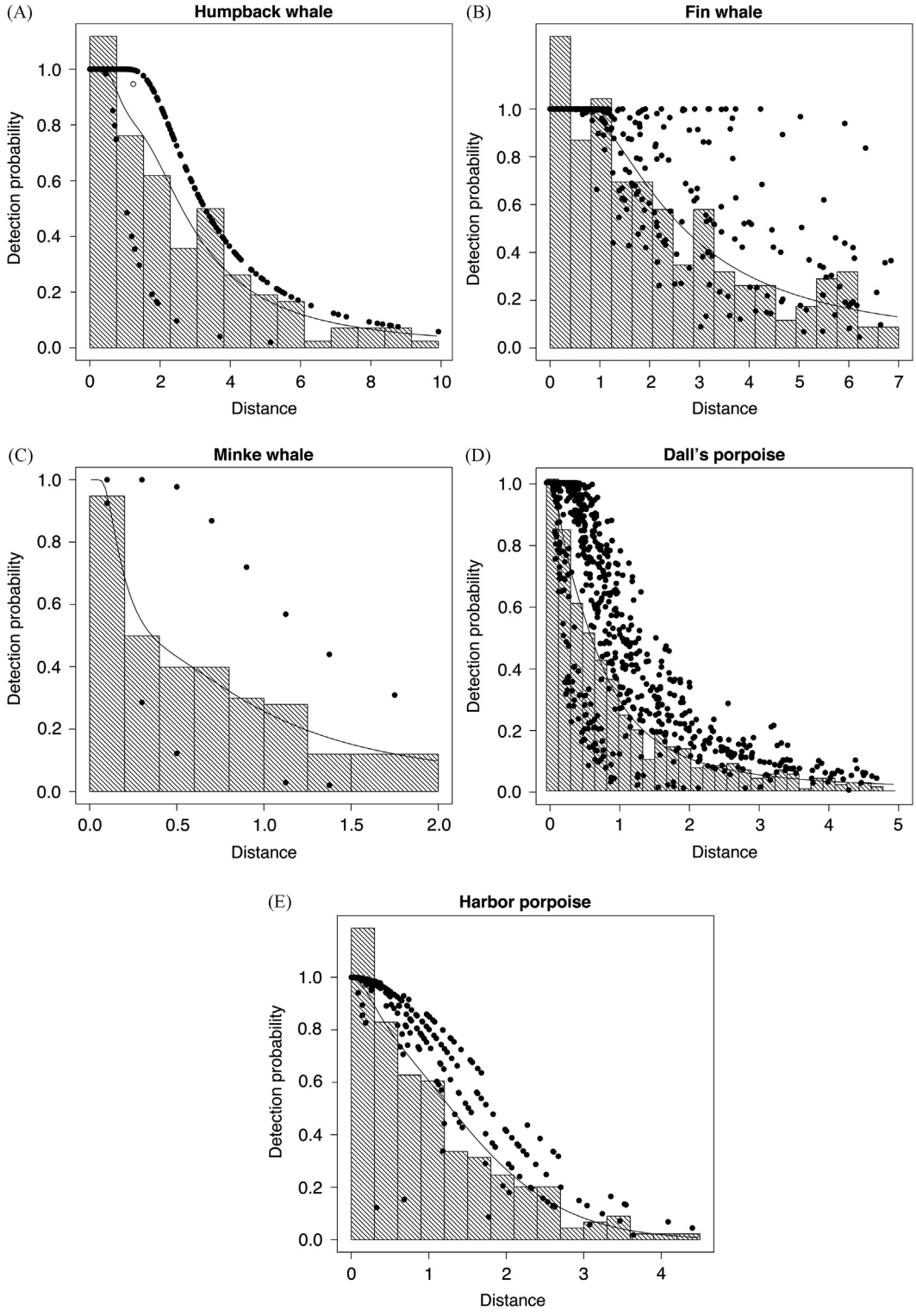

Fig. 8. Histograms of perpendicular distance (km) and fitted detection functions for best-fit model selected by Akaike's Information Criteria (dots represent detection probability for each individual sighting) for (A) humpback whales, (B) fin whales, (C) minke whales, (D) Dall's porpoise, and (E) harbor porpoise.

Estimated encounter rates for humpback whales were highest in the coastal domain, and were higher in 2008 and 2010 than in 2002, but group sizes were similar across years and oceanographic domains (Table 4). Density was highest for humpback whales in the coastal domain in all years: 0.029 whales/km^2 (CV=0.89) in 2002, 0.032 (CV=0.73) in 2008, and 0.029 (CV=0.95) in 2010 (Table 5). Domain-specific estimates were relatively imprecise (CVs > 0.7) due to small sample sizes, but yearly estimates are more precise than the corresponding domain-specific estimates. Point estimates of yearly abundance in the U.S. section of the study area increased from 231 (CV=0.63) in 2002 to 672 (CV=0.80) in 2010, but the three estimates are not significantly different from each other.

Estimated encounter rates for fin whales were higher in 2008 and 2010 than in 2002, except in the coastal domain, but group sizes were smaller in 2010 (Table 4). In 2008 and 2010, fin whale

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Table 3
Summary of model selection for well-supported models, with ΔAIC ≤ 2 compared to the best-fit model, proposed to fit perpendicular distance data for humpback, fin, and minke whales and Dall's and harbor porpoise.

Model, covariates	ΔAIC	w_i	Par. no.	P	CV
Humpback whales					
hz, method	0.00	0.243	3	0.33	0.10
hz, ship+method	0.04	0.238	4	0.31	0.11
hz, ship+sea state+method	1.95	0.091	5	0.30	0.11
hz, size+method	1.97	0.091	4	0.33	0.10
hz, sea state+method	2.00	0.089	4	0.33	0.10
Fin whales					
hz, sea state+size+method	0.00	0.283	5	0.47	0.08
hz, sea state+size	0.64	0.205	4	0.47	0.08
hn, sea state+size+method	1.48	0.135	4	0.50	0.04
hz, ship+sea state+size+method	2.00	0.104	6	0.47	0.08
Minke whales					
hz, method	0.00	0.228	3	0.33	0.30
hz, ship+method	0.58	0.171	4	0.32	0.32
hz, size+method	1.03	0.136	4	0.30	0.44
hz, ship+size+method	1.32	0.118	5	0.26	0.52
hz, sea state+method	1.70	0.098	4	0.33	0.32
hz, ship+sea state+method	2.00	0.084	5	0.31	0.36
Dall's porpoise					
hz, ship+sea state+size+method	0.00	0.571	6	0.19	0.06
Harbor porpoise					
hn, sea state+method	0.00	0.364	3	0.32	0.07
hn, ship+sea state+method	0.57	0.273	4	0.32	0.07
hn, sea state+size+method	2.00	0.134	4	0.32	0.07

hz—hazard rate, hn—half-normal, ship—vessel covariate, sea state—Beaufort numeric covariate, size—group size covariate, method—sighting method covariate, w_i—Akaike weight, P—average detection probability, CV—coefficient of variation of the average detection probability.

densities were highest in the outer stratum, with Russian waters in 2010 being the highest: 0.004 whales/km^2 (CV=0.48) in U.S. waters in 2008, 0.005 (CV=0.57) in Russian waters in 2008, 0.005 (CV=0.42) in U.S. waters in 2010, and 0.012 (CV=0.68) in Russian waters in 2010 (Table 5). In 2002, densities were highest in the coastal domain (0.009 whales/km^2, CV=0.89). Abundance was highest for fin whales in the U.S. waters of the outer stratum in all years: 295 whales (CV=0.41) in 2002, 802 (CV=0.48) in 2008 and 911 (CV=0.42) in 2010. Yearly abundances in the U.S. section of the study area were higher in 2008 (1368 whales, CV=0.34) and 2010 (1061 whales, CV=0.38) than in 2002 (419 whales, CV=0.33).

Minke whales were encountered at a higher rate in 2010 than in 2002 and 2008, but the oceanographic domains where they were seen varied among the years (Table 4). Minke whales were generally sighted as single animals except for 2010 when there were seven sightings of pairs and a sighting of a group of three in the outer stratum (Table 4). The highest density and highest abundance were found in the U.S. waters of the outer stratum in 2010 (0.011 whales/km^2, 2020 whales, CV=0.73, Table 5). The yearly abundance in the U.S. section of the study area was highest in 2010 (2020 whales, CV=0.73) and low, but not significantly different, in 2002 and 2008 (389, CV=0.52 and 517, CV=0.69, respectively).

Estimated encounter rates for Dall's porpoise were highest in the U.S. outer stratum, but were generally consistent across years (Table 4). Group sizes were similar across years and oceanographic domains (Table 4). The highest density and highest abundance of Dall's porpoise were found in the U.S. waters of the outer stratum in 2002 (0.175 porpoise/km^2, 31,868 porpoise, CV=0.58, Table 5). In 2008 and 2010, Dall's porpoise densities and abundances were also highest in the outer stratum: 0.080 porpoise/km^2 and 14,543 porpoise (CV=0.32) in U.S. waters in 2008, 0.077 porpoise/km^2 and 2570 porpoise (CV=0.60) in Russian waters in 2008, 0.061 porpoise/km^2 and 10,143 porpoise (CV=0.32) in U.S. waters in 2010, and 0.010 porpoise/km^2 and 333 porpoise (CV=0.72) in Russian waters in 2010. The yearly abundance in the U.S. section of the study area was highest in 2002 (35,303 porpoise, CV=0.53) and low in 2008 and 2010 (14,543 porpoise, CV=0.32 and 11,143 porpoise, CV=0.32, respectively).

Estimated encounter rates for harbor porpoise were generally higher in 2002 and 2008 than in 2010, but group sizes were similar across years and oceanographic domains (Table 4). The highest density and highest abundance of harbor porpoise were found in the U.S. waters of the outer stratum in 2008 (0.013 porpoise/km^2, 2421 porpoise, CV=0.60, Table 5). The middle domain in 2002 and 2008 also had relatively high densities and abundances (0.010 porpoise/km^2, 1479 porpoise, CV=0.58 and 0.011 porpoise/km^2, 1635 porpoise, CV=0.41, respectively). Yearly abundance in the U.S. section of the study area was lowest in 2010 (833 porpoise, CV=0.66) and higher, but not significantly different, in 2002 and 2008 (1971 porpoise, CV=0.46, and 4056 porpoise, CV=0.40, respectively).

3.3. Annual rate of change

The estimated annual rate of change in abundance of humpback (12.0%, 95% CI=−9.8% to 34.0%), fin (14.0%, 95% CI=1.0 to 26.5%), and minke (15.6%, 95% CI=−6.2% to 38.6%) whales increased between 2002 and 2010. The increase for fin whales is statistically significant, while those for humpback and minke whales are not. In contrast, the estimated annual rate of change in abundance of Dall's (−14.4%, 95% CI=−29.0% to 1.0%) and harbor (−0.7%, 95% CI=−33.6% to 24.9%) porpoise decreased during this same period; neither are statistically significant.

4. Discussion

This paper provides a broad-scale assessment of cetacean distribution and abundance in the EBS and compares results over a nine-year period. Overall, distribution patterns for each species largely match those previously reported (Friday et al., 2012). Humpback whales were consistently concentrated 'on the margins' of the study area: northern Alaska Peninsula (along the 50 m and 100 m isobaths), Aleutian Islands, the coastal waters north of Unimak Pass, southeastern middle domain near Bristol Bay, and Pervenets Canyon (Fig. 3). Humpback distribution north of the Alaska Peninsula corresponds with the middle and inner fronts, which are areas of nutrient upwelling (Kachel et al., 2002) and potential prey aggregation. Ortiz et al. (this issue) characterized this area north of the Alaska Peninsula as having high fishing activity; another indication that this is a highly productive area. Fin whales were consistently distributed both in the 'green belt' of the outer stratum, an area of high productivity along the edge of the EBS continental shelf (Springer et al., 1996), and in the middle domain (Fig. 4). Minke whales were scattered throughout the study area except for 2010, when they were concentrated mainly in the outer stratum (Fig. 5). In 2002, Dall's porpoise were sighted on the western edge of the middle domain and in the outer stratum, but shifted west out of the middle domain in 2008 and 2010 (Fig. 6). In 2002 and 2008, harbor porpoise were consistently found in the middle domain with scattered sightings in the outer stratum (Fig. 7).

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Table 4
Number of sightings (n), encounter rates (ER, #/km), encounter rate coefficient of variation (ER CV), estimated group size (ES), and estimated group size coefficient of variation (ES CV) for humpback, fin, and minke whales and Dall's and harbor porpoise by domain and year.

Domain	2002					2008					2010				
	n	ER	ER CV	ES	ES CV	*n*	ER	ER CV	ES	ES CV	*n*	ER	ER CV	ES	ES CV
Humpback whales															
Coastal	4	0.0929	0.88	2.5	0.20	5	0.1157	0.73	2.2	0.09	3	0.1155	0.95	2.0	0.29
Middle	0	–	–	–	–	3	0.0027	0.57	2.0	0.50	1	0.0028	1.09	3.0	0.00
Outer U.S.	2	0.0010	0.66	2.0	0.00	6	0.0035	0.74	1.8	0.26	3	0.0030	0.75	1.0	0.00
Outer Russia	–	–	–	–	–	2	0.0047	0.90	1.0	0.00	0	–	–	–	–
Fin whales															
Coastal	2	0.0464	0.88	2.0	0.00	0	–	–	–	–	0	–	–	–	–
Middle	3	0.0018	0.53	2.3	0.38	15	0.0137	0.50	2.7	0.17	2	0.0057	0.68	1.0	0.00
Outer U.S.	10	0.0048	0.35	3.3	0.22	22	0.0130	0.42	3.1	0.24	17	0.0168	0.40	1.9	0.12
Outer Russia	–	–	–	–	–	8	0.0189	0.51	2.9	0.19	10	0.0409	0.53	1.7	0.09
Minke whales															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	5	0.0031	0.63	1.0	0.00	3	0.0027	0.50	1.0	0.00	0	–	–	–	–
Outer U.S.	3	0.0014	0.68	1.0	0.00	0	–	–	–	–	10	0.0099	0.77	1.6	0.14
Outer Russia	–	–	–	–	–	0	–	–	–	–	1	0.0041	0.83	1.0	0.00
Dall's porpoise															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	16	0.0099	0.36	3.9	0.15	0	–	–	–	–	0	–	–	–	–
Outer U.S.	90	0.0431	0.16	5.1	0.15	57	0.0337	0.30	4.6	0.07	38	0.0374	0.34	3.4	0.07
Outer Russia	–	–	–	–	–	7	0.0165	0.43	5.3	0.24	2	0.0082	0.70	4.0	0.00
Harbor porpoise															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	38	0.0234	0.64	1.4	0.10	21	0.0192	0.53	1.7	0.10	0	–	–	–	–
Outer U.S.	10	0.0048	0.50	1.9	0.18	24	0.0142	0.53	2.5	0.10	7	0.0069	0.83	2.1	0.26
Outer Russia	–	–	–	–	–	0	–	–	–	–	1	0.0041	0.83	1.0	0.00

A greater diversity of cetacean sightings in Navarin and Pervenets Canyons was observed in 2010 compared to the earlier years (Figs 3–7). Species not seen (minke whales and harbor porpoise) or rarely seen (humpback whales) there in earlier years were conspicuously abundant. In addition, species commonly reported there before (Dall's porpoise and fin whales) were also present in large numbers. This region was also used by a humpback whale satellite-tagged near Unalaska Island that moved north across the Bering Sea shelf (Zerbini et al., 2011). The high abundance and diversity of cetaceans suggest that these submarine canyons can be important habitats for cetaceans in the Bering Sea outer shelf domain and slope.

Abundance estimates for 2002 are consistent with those published by Friday et al. (2012) (Table 5), with the abundance of fin and minke whales greater in cold years (2008 and 2010) than in a warm year (2002). This is consistent with a fine-scale comparison of fin whale occurrence on the middle shelf between a cold year (1999) and a warm year (2002), which found that the group and individual encounter rates were 7–12 times higher in the cold year (Stabeno et al., 2012b). Conversely, the finding that the abundance of humpback whales was greater in the cold years of 2008 and 2010 is counter to that reported in Friday et al. (2012), who found the highest abundance of humpback whales in the warm year of 2004. These differences in abundance with whether a year is warm or cold are likely related to interannual differences in prey availability (Friedlaender et al., 2006; Ressler et al., 2012; Stabeno et al., 2012b). If the majority of the important habitat for humpback whale is outside the study area, it may be more difficult to accurately determine patterns in abundance. If these surveys and those of Friday et al. (2012) are only observing the margins of humpback whale habitat, the relationships found may be artificial. Surveying more of the habitat is necessary to determine if there is a relationship between humpback whale abundance and whether a year is warm or cold, and what that relationship is.

The estimated rates of increase for humpback, fin, and minke whales presented here are likely a combination of changes in distribution and changes in population size. Rates of increase of humpback whales in the North Pacific have been estimated from sightings survey data and from mark-recapture data and range from 4.9% to 7% (Calambokidis et al., 2008; Mobley et al., 2001; Zerbini et al., 2006), with a single higher estimate of 10% from Mizroch et al. (2004). Zerbini et al. (2010) examined plausible rates of increase for humpback whales using Monte Carlo simulations to compute a distribution of rates taking into account uncertainty in biological parameter estimates and proposed that 11.8%, the 99% quantile of their results, as the maximum plausible rate of increase for humpback whales. There is less information on the rate of increase of fin whales in the North Pacific. Zerbini et al. (2006) reported a 4.8% rate of increase for fin whales in the coastal waters of the Aleutian Islands and the Alaska Peninsula for the summer of 2001 to 2003. Rates of increase range from 3.5% to 7.1% for fin whales in the California Current depending on the time period (Moore and Barlow, 2011). There is no information on rates of increase for minke whales (IWC, 2010) and no information on maximum plausible rates of increase for fin whales or minke whales. Given estimated rates of increase for humpback and fin whales and what we know about the biological characteristics of humpback, fin, and minke whales, it is likely that changes in abundance in the study area are due at least in part to changes in distribution and not just to changes in overall population size.

Although Friday et al. (2012) did not find a clear relationship between the abundance of Dall's or harbor porpoise and whether a year was warm or cold year, the abundance of Dall's porpoise declined from 2002 to 2010, although the abundance estimates are not significantly different from each other and the estimated rate of decline was not significant. The pattern for harbor porpoise was more complex with an increase between 2002 and 2008 followed by a decline in 2010 below the 2002 estimate. It is unclear what could be contributing to these decreases in

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Table 5
Number of sightings (n), estimated density (D, #/km^2), estimated abundance (N), coefficient of variation (CV), and 95% confidence interval (95% CI) for humpback, fin, and minke whales and Dall's and harbor porpoise by domain and year.

Domain	2002					2008					2010				
	n	*D*	*N*	CV	95% CI	*n*	*D*	*N*	CV	95% CI	*n*	*D*	*N*	CV	95% CI
Humpback whales															
Coastal	4	0.0288	147	0.89	6–3672	5	0.0316	161	0.73	21–1258	3	0.0287	146	0.95	5–4341
Middle	0	–	–	–	–	3	0.0007	103	0.74	25–419	1	0.0031	462	1.12	65–3280
Outer U.S.	2	0.0005	84	0.78	20–355	6	0.0009	172	0.77	41–721	3	0.0004	67	0.76	16–279
Outer Russia	–	–	–	–	–	2	0.0006	20	0.90	3–141	0	–	–	–	–
Total	**–**	**–**	**–**	**–**	**–**	**16**	**0.0004**	**456**	**0.43**	**191–1086**	**7**	**0.0006**	**675**	**0.80**	**150–3040**
Total—U.S. only	**6**	**0.0002**	**231**	**0.63**	**39–1370**	**14**	**0.0004**	**436**	**0.45**	**177–1073**	**7**	**0.0006**	**675**	**0.80**	**150–3040**
Fin whales															
Coastal	2	0.0088	45	0.89	2–1084	0	–	–	–	–	0	–	–	–	–
Middle	3	0.0005	80	0.57	26–242	15	0.0038	565	0.47	220–1451	2	0.0010	151	0.71	37–605
Outer U.S.	10	0.0016	295	0.41	130–669	22	0.0044	802	0.48	311–2069	17	0.0050	911	0.42	386–2151
Outer Russia	–	–	–	–	–	8	0.0050	168	0.57	43–650	10	0.0122	409	0.68	85–1975
Total	**–**	**–**	**–**	**–**	**–**	**45**	**0.0014**	**1535**	**0.31**	**827–2851**	**29**	**0.0014**	**1470**	**0.34**	**746–2896**
Total—U.S. only	**15**	**0.0004**	**419**	**0.33**	**219–802**	**37**	**0.0013**	**1368**	**0.34**	**695–2692**	**19**	**0.0010**	**1061**	**0.38**	**493–2283**
Minke whales															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	5	0.0012	176	0.65	51–604	3	0.0034	517	0.69	146–1831	0	–	–	–	–
Outer U.S.	3	0.0012	213	0.75	54–841	0	–	–	–	–	10	0.0111	2020	0.73	520–7855
Outer Russia	–	–	–	–	–	0	–	–	–	–	1	0.0069	231	0.94	37–1436
Total	**–**	**–**	**–**	**–**	**–**	**3**	**0.0005**	**517**	**0.69**	**146–1831**	**11**	**0.0021**	**2251**	**0.68**	**633–8003**
Total—U.S. only	**8**	**0.0004**	**389**	**0.52**	**147–1030**	**3**	**0.0005**	**517**	**0.69**	**146–1831**	**10**	**0.0019**	**2020**	**0.73**	**520–7855**
Dall's porpoise															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	16	0.0228	3434	0.46	1385–8515	0	–	–	–	–	0	–	–	–	–
Outer U.S.	90	0.1752	31,868	0.58	10,738–94,581	57	0.0799	14,543	0.32	7598–27,837	38	0.0613	11,143	0.32	5788–21,451
Outer Russia	–	–	–	–	–	7	0.0766	2570	0.60	650–10,161	2	0.0099	333	0.72	64–1742
Total	**–**	**–**	**–**	**–**	**–**	**64**	**0.0158**	**17,113**	**0.29**	**9524–30,748**	**40**	**0.0106**	**11,476**	**0.31**	**6060–21,732**
Total—U.S. only	**106**	**0.0327**	**35,303**	**0.53**	**12,989–95,946**	**57**	**0.0135**	**14,543**	**0.32**	**7598–27,837**	**38**	**0.0103**	**11,143**	**0.32**	**5788–21,451**
Harbor porpoise															
Coastal	0	–	–	–	–	0	–	–	–	–	0	–	–	–	–
Middle	38	0.0098	1479	0.58	483–4531	21	0.0108	1635	0.41	706–3788	0	–	–	–	–
Outer U.S.	10	0.0027	492	0.63	147–1643	24	0.0133	2421	0.60	754–7769	7	0.0046	833	0.66	230–3018
Outer Russia	–	–	–	–	–	0	–	–	–	–	1	0.0017	58	0.84	9–373
Total	**–**	**–**	**–**	**–**	**–**	**45**	**0.0038**	**4056**	**0.40**	**1844–8920**	**8**	**0.0008**	**891**	**0.62**	**263–3015**
Total—U.S. only	**48**	**0.0018**	**1971**	**0.46**	**798–4870**	**45**	**0.0038**	**4056**	**0.40**	**1844–8920**	**7**	**0.0008**	**833**	**0.66**	**230–3018**

abundance. There was a westward shift towards deeper water in the distribution of Dall's porpoise from 2002 to 2010 (Fig. 6) and a lack of sightings of harbor porpoise in 2010 (Fig. 7), which could indicate that the important habitat for these species has shifted outside the study area in colder years. Both species feed on forage fishes such as herring and capelin, and Dall's porpoise often forage on mesopelagic fishes and squid found in the deeper waters of the outer stratum (Aydin et al., 2007; Fiscus and Jones, 1999; Gearin et al., 1994; Perez, 1990).

Although the trend analyses were only significant for fin whales, the pattern of abundance increased for all three baleen whales and declined for porpoise with the shift from warm to cold years. These patterns could be significant for ecosystem management and important when predicting changes in cetacean distribution with climate change. Quantitative models are being developed which will integrate data on oceanographic conditions, cetacean sightings, and prey fields and may shed light on whether preferred habitat shifted outside the study area in warm years for mysticetes and in cold years for odontocetes. Such studies will be important for managing cetacean species as large positive and negative deviations from the mean trend in temperature are expected in the future (Overland et al., 2012). The possible decline in porpoise, particularly Dall's porpoise, also indicate the need for additional studies of porpoise to determine if there is a decline in population abundance, a shift in distribution, or a combination of both.

Ressler et al. (2012) examined euphausiid biomass from acoustic surveys in 2004 and from 2006 to 2010, and found an increase in biomass during cold years. Ohashi (this issue) studied summer zooplankton from 1994 to 2009 and found that the biomass and abundance of both copepods and chaetognaths were higher in cold years than warm years. Stabeno et al. (2012b) report that year-class strength for walleye pollock and Pacific cod improved during cold periods, and Hollowed et al. (2012) found that the distribution of age-1 pollock varied between cold and warm years. When examining ecosystem considerations for fisheries stock assessment reports, Zador and Gaichas (2010) found that the mean biomass of zooplankton and pelagic foragers increased in the EBS from 2005 to 2010. However, the connection between abundance and warm/cold periods may be more complex than simple temperature anomalies. Coyle et al. (2008) describe a shift from larger to smaller zooplankton taxa between 1999 and 2004 and proposed that this shift was caused by high water column stability in 2004. Ladd and Stabeno (2012) found that the strength of summer stratification and depth-averaged temperature were not correlated. They propose that this decoupling of stratification and temperature complicated forecasting the ecosystem because projections of a warmer climate will not automatically imply higher stratification.

As with other cetacean sighting surveys conducted in conjunction with standard acoustic fish stock assessment surveys (Friday et al., 2012; Moore et al., 2000, 2002; Tynan, 2004; Waite et al., 2002), observers could not break trackline for species

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identification. Therefore, the sample sizes for individual species were relatively small and sample sizes for unidentified groups were relatively high (Table 2). However, combining sampling effort for fish and cetacean surveys provided a cost-effective mechanism for describing cetacean distribution and abundance over a broad area of the EBS shelf. In addition, the 2008 and 2010 surveys collected a wide array of interdisciplinary data as part of the Bering Sea Project. Survey timing was consistent across years, varying by not more than a week, and we do not expect these small differences to affect the results. However, we do not know the extent to which cetacean distribution is influenced by inter-annual variability in environmental features (e.g., the timing of sea ice retreat). When examining the abundance estimates, care must be taken to note the CVs and not just the point estimates because some estimates were very imprecise. We emphasize that these abundance estimates were uncorrected for: (1) perception bias (animals missed on the trackline), (2) availability bias (animals submerged when the ship passed), and (3) responsive movement. The magnitude of the resulting biases varies by species; they are probably small for fin and humpback whales but could be larger for minke whales and for Dall's and harbor porpoise (Barlow, 1995; Palka and Hammond, 2001; Turnock and Quinn, 1991). Availability bias is unlikely to be an issue for the species in this study since this bias typically affects long-diving species such as sperm and beaked whales. Examining the detection functions, there is no evidence of negative responsive movement, even for minke whales and harbor porpoise which often show ship avoidance. The degree of ship attraction for Dall's porpoise is variable by geographic region and possibly other factors. The detection function for Dall's porpoise in this study may show evidence of ship attraction. However, even if these estimates are biased due to responsive movement, they would still be useful as relative abundance estimates. Potential biases are the same for the current surveys as for past surveys and are discussed further in Friday et al. (2012). Even with these caveats, the results presented here were unique because they portray cetacean distribution, and provide estimates of abundance and trend, in a standardized way such that comparisons can be made among oceanographic domains on the EBS shelf over a nine-year time span. This information is critical for management under the Marine Mammal Protection Act and under the Endangered Species Act (for fin and humpback whales) and will be important when predicting and interpreting the affects of climate change on the eastern Bering Sea shelf.

Although combining cetacean surveys with pollock stock assessment research provides a relatively inexpensive mechanism for estimating cetacean distribution and abundance, conflicting priorities often require that cetacean surveys be curtailed. We have noted that the vessel surveys presented here may not have captured all of the important habitat for humpback whales and for Dall's porpoise. The June–July timing of these surveys may also not be optimal for some species. Acoustic detections of fin, humpback, and North Pacific right whales (*Eubalaena japonica*) at NOAA moorings, M2 (57°N, 164°W), M4 (58°N, 169°W), and M5 (60°N, 172°W), indicate that the abundances of these species may peak in late summer and fall, after the pollock stock assessment survey has been completed (Stafford and Mellinger, 2009; Stafford et al., 2010). Dedicated cetacean surveys could be scheduled to coincide with peak cetacean abundance, as indicated by acoustic detections, and designed to capture the geographic range of target cetacean species, including the slope and basin regions. Dedicated surveys would also provide the additional staff needed to collect the data necessary to estimate correction factors and more flexibility to confirm species identification and group sizes. Sampling effort should also be increased to improve precision for better estimation and management. The estimates presented here can be used as references to compute the additional effort required to reach more desirable levels of precision (e.g. CV < 0.3) in abundance estimates. Such surveys, combined with measures of local hydrography and prey field, should be the goal of future cetacean assessments.

Acknowledgments

We thank Patti Haase, Amy Kennedy, Doug Kinzey, Ernesto Vazquez Morquecho, Laura Morse, Stephanie Norman, Paula Olson, Desray Reeb, Kim Valentine, Bridget Watts, and Suzanne Yin for their expertise and dedication during the long hours of visual survey. We greatly appreciate the extra effort of the observers who acted as cetacean cruise leaders: Norman and Kinzey in 2002, Yin and Morse in 2008 and Yin and Olson in 2010. We also thank Gary Stauffer, former RACE Division Director, and Russell E. Nelson, Jr., current RACE Division Director, who graciously provided ship access and encouragement, without which there would be no data. The flexibility and assistance of the captains and crew of the NOAA ship *Miller Freeman* and NOAA ship *Oscar Dyson* contributed to the success of this research. AFSC survey Chief Scientists Alex DeRobertis, Taina Honkalehto, Paul Walline, and Neal Williamson allowed cetacean research opportunities when practical. Thanks also to the entire RACE scientific crew for their flexibility and support. The thoughtful reviews of Megan Ferguson and Ivonne Ortiz are greatly appreciated. Funding for this research was provided by NOAA/AFSC/NMML in 2002 and the North Pacific Research Board in 2008 and 2010. This research was conducted under MMPA Permit nos. 782-1438 and 782-1719 issued by the National Marine Fisheries Service. This is NPRB publication number 368 and BEST-BSIERP Bering Sea Project publication number 70. The views expressed herein are those of the authors and do not reflect the views of NOAA.

References

Aydin, K., Gaichas, S., Ortiz, I., Kinzey, D., Friday, N., 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-178, 298pp.

Barlow, J., 1995. The abundance of cetaceans in California waters. Part I: ship surveys in summer and fall of 1991. Fish. Bull. 93, 1–14.

Branch, T.A., 2007. Abundance of Antarctic blue whales south of 60°S from three complete circumpolar sets of surveys. J. Cetacean Res. Manage. 9, 253–262.

Brueggeman, J.J., Green, G.A., Grotefendt, R.A., Chapman, D.G., 1987. Aerial surveys of endangered cetaceans and other marine mammals in the northwestern Gulf of Alaska and southeastern Bering Sea. Report on Contract no. 85-ABC-00093. Minerals Management Service and NOAA Office of Oceanography and Marine Assessment, Alaska Office (OCSEAP Research Unit 673), 949 East 36th Avenue, Anchorage AK 99508. 129pp.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, New York City, New York, USA.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2004. Advanced Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, New York City, New York, USA.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multi-Model Inference: A Practical Information Theoretic Approach. Springer, New York City, New York, USA.

Calambokidis, J., Barlow, J., 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Mar. Mammal. Sci. 20, 63–85.

Calambokidis, J., Falcone, E.A., Quinn, T.J., Burdin, A.M., Clapham, P.J., Ford, J.K.B., Gabriele, C.M., LeDuc, R., Mattila, D., Rojas-Bracho, L., Straley, J.M., Taylor, B.L., Urbán, R., Weller, D., Witteveen, B.H., Yamaguchi, M., Bendlin, A., Camacho, D., Flynn, K., Havron, A., Huggins, J., Maloney, N., 2008. SPLASH: structure of populations, levels of abundance and status of humpback whales in the North Pacific. Final Report for Contract AB133F-03-RP-00078. 58 pp (Available from: http://www.cascadiaresearch.org/SPLASH/SPLASH-contract-Report-May08.pdf).

Coachman, L.K., 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. Cont. Shelf Res. 5, 23–108.

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Cooney, R.T., Coyle, K.O., 1982. Trophic implications of cross-shelf copepod distributions in the southeastern Bering Sea. Mar. Biol. 70, 187–196.

Coyle, K.O., Chavtur, V.G., Pinchuk, A.I., 1996. Zooplankton of the Bering Sea: a review of Russian-language literature. In: Mathiesen, O.A., Coyle, K.O. (Eds.), Ecology of the Bering Sea: A Review of the Russian Literature. Alaska Sea Grant Pub, 96-01, Fairbanks, AK, pp. 97–133.

Coyle, K.O., Pinchuk, A.I., 2002. The abundance and distribution of euphausiids and zero-age pollock on the inner shelf of the southeast Bering Sea near the Inner Front in 1997–1999. Deep-Sea Res. II 49, 6009–6030.

Coyle, K.O., Pinchuk, A.I., Eisner, L.B., Napp, J.M., 2008. Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: the potential role of water-column stability and nutrients in structuring the zooplankton community. Deep-Sea Res. II 55, 1775–1791.

Fiscus, C.H., Jones, L.L., 1999. A note on cephalopods from the stomachs of Dall's porpoise (*Phocoenoides dalli*) from the northwestern Pacific and Bering Sea, 1978-1982. J. Cetacean Res. Manage. 1, 101–107.

Ford, J.K.B., Ellis, G.M., Balcomb, K.C., 2000. Killer whales: The Natural History and Genealogy of *Orcinus orca* in British Columbia and Washington State. University of British Columbia Press, Vancouver.

Friday, N.A., Waite, J.M., Zerbini, A.N., Moore, S.E., 2012. Cetacean distribution and abundance in relation to oceanographic domains on the eastern Bering Sea shelf: 1999–2004. Deep-Sea Res. II 65–70, 260–272.

Friedlaender, A.S., Halpin, P.N., Qian, S.S., Lawson, G.L., Wiebe, P.H., Thiele, D., Read, A.J., 2006. Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the western Antarctic Peninsula. Mar. Ecol. Prog. Ser. 317, 297–310.

Gearin, P.J., Melin, S.R., DeLong, R.L., Kajimura, H., Johnson, M.A., 1994. Harbor porpoise interactions with a chinook salmon set-net fishery in Washington State. Rep. Int. Whaling Commn. special issue 15, 427–438.

Guttormsen, M.A., Yasenak, P.T., 2007. Results of the 2003 and 2005 echo integration-trawl surveys in the Gulf of Alaska during summer, Cruises MF2003-09 and OD2005-01. AFSC Processed Report no. 2007-04, Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, Washington, 98115. 61 pp.

Hilborn, R., Mangel, M., 1997. The Ecological Detective. Princeton University Press, Princeton, New Jersey, U.S.A.

Hollowed, A.B., Barbeaux, S.J., Cokelet, E.D., Farley, E., Kotwicki, S., Ressler, P.H., Spital, C., Wilson, C.D., 2012. Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea. Deep-Sea Res. II 65–70, 230–250.

Hunt Jr., G.L., Allen, B.M., Angliss, R.P., Baker, T., Bond, N., Buck, G., Byrd, G.V., Coyle, K.O., Devol, A., Eggers, D.M., Eisner, L., Feely, R., Fitzgerald, S., Fritz, L.W., Gritsay, E.V., Ladd, C., Lewis, W., Mathis, J., Mordy, C.W., Mueter, F., Napp, J., Sherr, E., Shull, D., Stabeno, P., Stepanenko, M.A., Strom, S., Whitledge, T.E., 2010. Status and trends of the Bering Sea region, 2003–2008. In: McKinnell, S.M., Dagg, M.J. (Eds.), Marine Ecosystems of the North Pacific Ocean, 2003–2008. North Pacific Marine Science Organization, Sidney, British Columbia, Canada, pp. 196–267.

Hunt Jr., G.L., Coyle, K.O., Eisner, L., Farley, E.V., Heintz, R., Mueter, F., Napp, J.M., Overland, J.E., Ressler, P.H., Salo, S., Stabeno, P.J., 2011. Climate impacts on eastern Bering Sea food webs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. ICES J. Mar. Sci. 68(6), 1230–1243.

Hunt Jr., G.L., Stabeno, P.J., 2002. Climate change and the control of energy flow in the southeastern Bering Sea. Prog. Oceanogr. 55, 5–22.

Hunt, G.L., Stabeno, P., Walters, G., Sinclair, E., Brodeur, R.D., Napp, J.M., Bond, N.A., 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Res. II 49, 5821–5853.

IWC, 2010. Report of the Intersessional Workshop on MSYR for Baleen Whales. J. Cetacean Res. Manage. 11, 493–508.

Kachel, N.B., Hunt Jr., G.L., Salo, S.A., Schumacher, J.D., Stabeno, P.J., Whitledge, T.E., 2002. Characteristics and variability of the inner front of the southeastern Bering Sea. Deep-Sea Res. II 49, 5889–5909.

Laake, J., Borchers, D., Len, T., Miller, D., Bishop, J., 2012. Mark-recapture distance sampling (mrds). R package, version 2.0.5.

Ladd, C., Stabeno, P., 2012. Stratification on the eastern Bering Sea shelf revisited. Deep-Sea Res. II 65–70, 72–83.

Leatherwood, S., Bowles, A.E., Reeves, R.R., 1983. Endangered whales of the eastern Bering Sea and Shelikof Strait, Alaska: results of aerial surveys, April 1982 through April 1983 with notes on other marine mammals seen. Hubbs-Sea World Research Institute. Technical Report no. 83-159/December 1983, 320 pp.

Mizroch, S.A., Herman, L.M., Straley, J.M., Glockner-Ferrari, D.A., Jurasz, C., Darling, J., Cerchio, S., Gabriele, C.M., Salden, D.R., Von Ziegesar, O., 2004. Estimating the adult survival rate of Central North Pacific humpback whales (*Megaptera novaeangliae*). J. Mammal. 85, 963–972.

Mobley Jr., J., Spitz, S., Grotefendt, R., 2001. Abundance of humpback whales in Hawaiian waters: results of 1993–2000 aerial surveys. Report to the Hawaiian Islands Humpback Whale National Marine Sanctuary, 16pp.

Moore, J.E., Barlow, J., 2011. Bayesian state-space model of fin whale abundance trends from a 1991–2008 time series of line-transect surveys in the California Current. J. Appl. Ecol. 48, 1195–1205.

Moore, S.E., Waite, J.M., Friday, N.A., Honkalehto, T., 2002. Cetacean distribution and relative abundance on the central-eastern and the southeastern Bering Sea shelf with reference to oceanographic domains. Prog. Oceanogr. 55, 249–261.

Moore, S.E., Waite, J.M., Mazzuca, L.L., Hobbs, R.C., 2000. Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf. J. Cetacean Res. Manage. 2, 227–234.

Napp, J.M., Baier, C.T., Brodeur, R.D., Coyle, K.O., Shiga, N., Mier, K., 2002. Interannual and decadal variability in zooplankton communities of the southeast Bering Sea shelf. Deep-Sea Res. II 49, 5991–6008.

Napp, J.M., Hunt Jr., G.L., 2001. Anomalous conditions in the south-eastern Bering Sea 1997: linkages among climate, weather, ocean, and biology. Fish. Oceanogr. 10, 61–68.

Ohashi, R. Interannual changes in the zooplankton community structure on the southeastern Bering Sea shelf during summers of 1994–2009. Deep-Sea Res. II (this issue).

Ortiz, I., Francis, W., Greig, A. Marine regions of the eastern Bering Sea. Deep-Sea Res. II (this issue).

Overland, J.E., Wang, M., Wood, K.R., Percival, D.B., Bond, N.A., 2012. Recent Bering Sea warm and cold events in a 95-year perspective. Deep-Sea Res. II 65-70, 6–13.

Palka, D.L., Hammond, P.S., 2001. Accounting for responsive movement in line transect estimates of abundance. Can. J. Fish. Aquat. Sci. 58, 777–787.

Perez, M.A., 1990. Review of marine mammal population and prey information for Bering Sea ecosystem studies. U.S. Department of Commerce, NOAA Technical Memorandum NMFS F/NWC-186, 81 pp.

R Development Core Team, 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL 〈http://www.R-project.org/〉.

Ressler, P.H., De Robertis, A., Warren, J.D., Smith, J.N., Kotwicki, S., 2012. Developing an acoustic index of euphausiid abundance to understand trophic interactions in the Bering Sea ecosystem. Deep-Sea Res. II 65-70, 184–195.

Sambrotto, R.N., Niebauer, H.J., Goering, J.J., Iverson, R.L., 1986. Relationships among vertical mixing, nitrate uptake, and phytoplankton growth during the spring bloom in the southeast Bering Sea middle shelf. Cont. Shelf Res. 5, 161–198.

Smith, S.L., 1991. Growth, development and distribution of the euphausiids *Thysanoessa raschi* (M. Sars) and *Thysanoessa inermis* (Krøyer) in the southeastern Bering Sea. Polar Res. 10, 461–478.

Smith, S.L., Vidal, J., 1986. Variations in the distribution, abundance, and development of copepods in the southeastern Bering Sea in 1980 and 1981. Cont. Shelf Res 5, 215–239.

Springer, A.M., McRoy, C.P., Flint, M.V., 1996. The Bering Sea green belt: shelf-edge processes and ecosystem production. Fish. Oceanogr. 5, 205–223.

Stabeno, P.J., Bond, N.A., Kachel, N.B., Salo, S.A., Schumacher, J.D., 2001. On the temporal variability of the physical environment over the south-eastern Bering Sea. Fish. Oceanogr. 10, 81–98.

Stabeno, P.J., Bond, N.A., Salo, S.A., 2007. On recent warming of the southeastern Bering Sea shelf. Deep-Sea Res. II 55, 2599–2618.

Stabeno, P.J., Farley Jr., E.V., Kachel, N.B., Moore, S., Mordy, C.W., Napp, J.M., Overland, J.E., Pinchuk, A.I., Sigler, M.F., 2012a. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep-Sea Res. II 65-70, 14–30.

Stabeno, P.J., Kachel, N.B., Moore, S.E., Napp, J.M., Sigler, M., Yamaguchi, A., Zerbini, A.N., 2012b. Comparison of warm and cold years on the southeastern Bering Sea shelf and some implications for the ecosystem. Deep-Sea Res. II 65-70, 31–45.

Stabeno, P.J., Schumacher, J.D., Davis, R.F., Napp, J.M., 1998. Under-ice observations of water column temperature, salinity and spring phytoplankton dynamics: eastern Bering Sea shelf. J. Mar. Res. 56, 239–255.

Stafford, K.M., Mellinger, D.K., 2009. Analysis of acoustic and oceanographic data from the Bering Sea, May 2006–April 2007. North Pacific Research Board Final Report 719, 23 pp.

Stafford, K.M., Moore, S.E., Stabeno, P.J., Holliday, D.V., Napp, J.M., Mellinger, D.K., 2010. Biophysical ocean observation in the southeastern Bering Sea. Geophys. Res. Lett. 37, L02606, 1–4.

Turnock, B.J., Quinn II, T.J., 1991. The effect of responsive movement on abundance estimation using line transect sampling. Biometrics 47, 701–715.

Tynan, C.T., 2004. Cetacean populations on the SE Bering Sea shelf during the late 1990s: implications for decadal changes in ecosystem structure and carbon flow. Mar. Ecol. Prog. Ser 272, 281–300.

Waite, J.M., Friday, N.A., Moore, S.E., 2002. Killer whale (*Orcinus orca*) distribution and abundance in the central and southeastern Bering Sea, July 1999 and June 2000. Mar. Mammal. Sci. 18, 779–786.

Whitledge, T.E., Reeburgh, W.S., Walsh, J.J., 1986. Seasonal inorganic nitrogen distribution and dynamics in the southeastern Bering Sea. Cont. Shelf Res. 5, 109–132.

Wiese, F.K., Van Pelt, T.I., Wiseman Jr, W.J., 2012. Bering Sea linkages. Deep-Sea Res. II 65–70, 2–5.

Zador, S.G., Gaichas, S., 2010. Ecosystem Considerations for 2011. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Reports. Technical Report, North Pacific Fishery Management Council, AK 99501.

Zerbini, A.N., Clapham, P., Kennedy, A.S., Geyer, Y., 2011. Individual variation in movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the Bering Sea during summer. 2011 Alaska Marine Science Symposium Book of Abstracts. NOAA Alaska Fisheries Science Center, Seattle, Washington, USA, Anchorage, Alaska, USA, p. 160.

Zerbini, A.N., Clapham, P.J., Wade, P.R., 2010. Assessing plausible rates of population growth in humpback whales from life-history data. Mar. Biol. 157, 1225–1236.

Zerbini, A.N., Waite, J.M., Laake, J.L., Wade, P.R., 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. Deep-Sea Res. I 53, 1772–1790.

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