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Inter-annual and seasonal trends in cetacean distribution, density and abundance off southern California

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ABSTRACT

Trends in cetacean density and distribution off southern California were assessed through visual line-transect surveys during thirty-seven California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises from July 2004–November 2013. From sightings of the six most commonly encountered cetacean species, seasonal, annual and overall density estimates were calculated. Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) were the most frequently sighted baleen whales with overall densities of 0.91/1000 km^2 (CV=0.27), 2.73/1000 km^2 (CV=0.19), and 1.17/1000 km^2 (CV=0.21) respectively. Species specific density estimates, stratified by cruise, were analyzed using a generalized additive model to estimate long-term trends and correct for seasonal imbalances. Variances were estimated using a non-parametric bootstrap with one day of effort as the sampling unit. Blue whales were primarily observed during summer and fall while fin and humpback whales were observed year-round with peaks in density during summer and spring respectively. Short-beaked common dolphins (*Delphinus delphis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and Dall's porpoise (*Phocoenoidesdalli*) were the most frequently encountered small cetaceans with overall densities of 705.83/1000 km^2 (CV=0.22), 51.98/1000 km^2 (CV=0.27), and 21.37/1000 km^2 (CV=0.19) respectively. Seasonally, short-beaked common dolphins were most abundant in winter whereas Pacific white-sided dolphins and Dall's porpoise were most abundant during spring. There were no significant long-term changes in blue whale, fin whale, humpback whale, short-beaked common dolphin or Dall's porpoise densities while Pacific white-sided dolphins exhibited a significant decrease in density across the ten-year study. The results from this study were fundamentally consistent with earlier studies, but provide greater temporal and seasonal resolution.

1. Introduction

Long-term assessments of density and distribution are central to evaluating potential effects of anthropogenic activities and ecosystem variability on cetacean populations (Fiedler and Reilly, 1994; Krebs, 2001; Morris and Doak, 2002; Rodrigues et al., 2006). The California Current Ecosystem (CCE) is a productive and dynamic habitat (Hayward and Venrick, 1998; Chhak and Di Lorenzo, 2007) that supports a diverse community of cetacean species as well as an array of human activities including commercial fishing, shipping and naval operations. The intersection between cetacean and human use of the CCE has resulted in entanglements in fishing gear (Julian and Beeson, 1998; Carretta et al., 2004), ship strikes (Berman-Kowalewski et al., 2010; Redfern et al., 2013) and disturbance from anthropogenic sound (McDonald et al., 2006; Hildebrand, 2009; Goldbogen et al., 2013).

Cetacean density and distribution off southern California during summer and fall has been estimated for several cetacean species using ship-based line-transect surveys and mark-recapture photo-identification methods (Calambokidis and Barlow, 2004; Barlow and Forney, 2007). Limited sampling during winter and spring months (e.g. Forney and Barlow, 1998) as well as multi-year gaps between ship-based surveys (e.g. Barlow and Forney, 2007; Barlow, 2010) restricts the ability to quantify long-term cross-seasonal and inter-annual trends in cetacean density and distribution. Cetacean distribution and abundance patterns based

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on a subset of the data used in the current study (July 2004–April 2008) were recently reported by Douglas et al. (2014). The present study provides new and current estimates of cetacean density for the six most commonly encountered cetacean species off southern California based on sighting data collected during 37 quarterly CalCOFI cruises from 2004 to 2013. The current study resulted from a high survey repetition rate that allowed for the examination of inter-annual and seasonal trends in density as well as temporal and spatial patterns of distribution for six common cetacean species off southern California: blue whales, fin whales, humpback whales, short-beaked common dolphins, Pacific white-sided dolphins, and Dall's porpoise.

2. Methods

2.1. Data collection

Visual monitoring for cetaceans on CalCOFI cruises incorporated standard line-transect marine mammal survey protocol (Buckland et al., 1993; Barlow, 1995; Barlow and Forney, 2007). Two trained marine mammal observers utilized 7 × 50 Fujinon binoculars to sight all cetaceans encountered during daylight transits between CalCOFI stations (Fig. 1). Information on all cetacean sightings was logged systematically, including species, group size, reticle of cetacean position relative to the horizon, relative angle from the bow, latitude, longitude, ship's heading, behavior, sighting cue, sea state, swell height, visibility and comments. Survey effort was curtailed in sea state Beaufort 6 or higher, or when visibility was reduced to less than 1 km. The vessel did not alter course for species identification or group size estimates; however, either 25 × 150 or 18 × 50 power binoculars were available to better assess these metrics after the initial sighting was made using the 7 × 50 binoculars (Soldevilla et al., 2006).

Surveys were conducted using five research vessels: the Scripps Institution of Oceanography (SIO) 84-m RV *Roger Revelle*

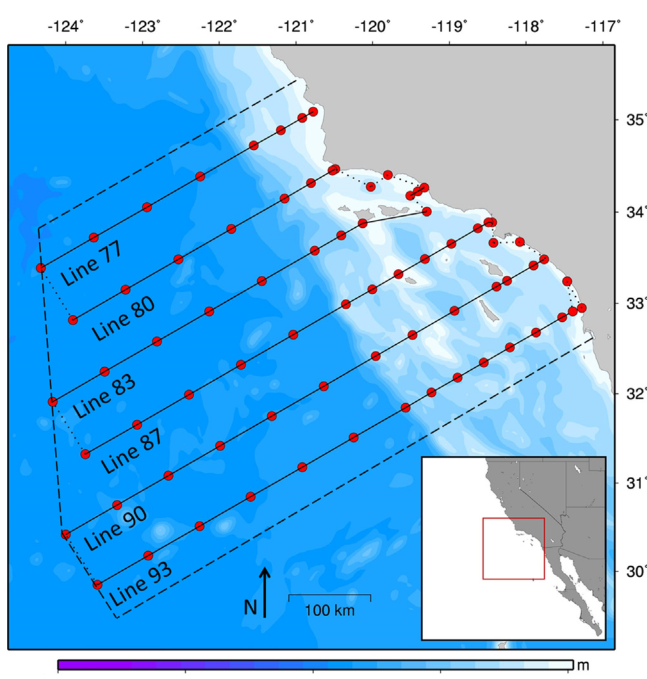

Fig. 1. CalCOFI transect lines and sampling stations in the southern CalCOFI study area. Dotted routes show "off-effort" connector lines between the six main transects. Dashed polygon represents entire study area of 238,494 km^2.

(2 surveys) and the 52-m RV *New Horizon* (20 surveys); and National Oceanic and Atmospheric Administration (NOAA) ships the 52-m RV *David Starr Jordan* (8 surveys), the 63-m RV *Bell M. Shimada* (4 surveys), and the 62-m RV *McArthur II* (1 survey). Survey speeds ranged from 18.5 to 22.2 km/h and observer heights above sea level ranged from 8.1 to 17 m. Surveys were conducted quarterly; however; there was some temporal variation in the timing of the cruises across the nine-year study. Winter cruises were conducted during the months of January and February, spring surveys occurred during March, April and May, summer cruises occurred in June, July and August, and fall surveys were conducted during the months of October and November. Surveys were conducted during all four seasons of each year from 2004 to 2013 inclusive, with the exception of winter and spring 2004, and spring 2010.

Line-transect marine mammal surveys have typically been conducted using either "passing" or "closing" modes. "Passing mode" surveys necessitate that the vessel stay on the track line without diverting course for a closer investigation of groups detected, while "closing mode" surveys allow the vessel to divert course to the vicinity of a visual detection (Barlow, 1997). Due to the experimental design of the oceanographic sampling component of the CalCOFI program, all marine mammal survey effort in the current study was conducted in "passing mode," which provides less biased estimates of encounter rates (because effort is continuous) but results in more unidentified or mis-identified groups, more biased estimates of group size, and less precise species percentages than closing mode (Barlow, 1997). Buckland et al. (2001) noted that while closing mode surveys allow for better resolution of species identification and group size, closing mode surveys can create a negative bias in density estimates.

Density and abundance estimates were calculated exclusively for the southern CalCOFI study area; this region encompasses the area delimited by six parallel survey lines running southwest to northeast from San Diego to north of Point Conception (Fig. 1). The lines increase in length from north to south (470–700 km), with stations occurring every 37 km in coastal and continental shelf waters inshore of the 2000 m isobath, and every 74 km offshore (Fig. 1). The lines are laid out such that they are roughly perpendicular to the coast and shelf. The study area is defined by a polygon around the six southern CalCOFI lines and extends one-half the distance between CalCOFI lines (32 km) south of line 93 and north of line 77, for a total area of 238,494 km^2 (Fig. 1).

Sightings were required to be both "on-effort" and "on-transect" to be included in the analyses of distribution, density and abundance. Sightings were classified as "on-effort" when two observers were actively searching in Beaufort sea state 0–5, with the vessel travelling a minimum of 11 km/h and having visibility of at least 1 km. Sightings were classified as "on-transect" only when the ship was transiting on one of the pre-defined parallel transect lines within the CalCOFI study area (Fig. 1). Sightings were classified as "off-transect" when they occurred during south/north coastal and offshore transits between the parallel lines, transits to San Diego or other ports and during deviations from the primary transect lines due to naval operations or bad weather.

To assess any potential bias associated with comparing annual or seasonal cetacean densities using models that have common detection function parameters, we tested for differences in two key variables that can potentially affect detection probabilities: sea state and group size (Barlow and Forney, 2007). For each variable, we used one-way ANOVA with season and year as factor covariates; for group size we used a log transformation and for sea state we weighted each season-year combination by the survey effort in each sea state. These analyses were conducted using the UNIANOVA command in SPSS version 17 (SPSS Inc. Chicago, IL).