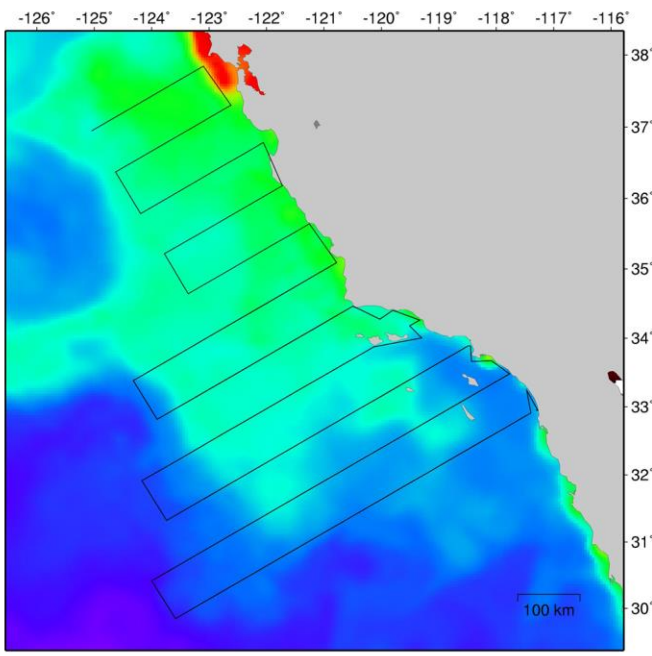
MARINE MAMMAL MONITORING ON CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATION (CALCOFI) CRUISES: 2012-2013



Greg Campbell, Lauren Roche, Katherine Whitaker, Elizabeth Vu and John Hildebrand

Marine Physical Laboratory, Scripps Institution of Oceanography

University of California San Diego, LA Jolla, CA 92037-0205

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Executive Summary

Cetacean distribution, density and abundance in the Southern California Bight were assessed through visual and acoustic surveys during five California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises from August 2012-November 2013. Visual monitoring incorporated standard line-transect protocol during all daylight transits while acoustic monitoring employed a towed hydrophone array during transits and sonobuoys at oceanographic sampling stations. Visual effort included 584 observation hours covering 10,900 kilometers yielding 565 sightings of 15 identified cetacean species. Density and abundance estimates for the six most frequently encountered cetacean species in the study area were estimated from 37 quarterly surveys conducted from July 2004-November 2013. Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) were the most frequently sighted baleen whales with overall abundances of 285 (CV=0.26), 718 (CV=0.22), and 351(CV=0.26) respectively. Blue whales were primarily observed during summer and fall while fin and humpback whales were observed year-round with peaks in abundance during summer and spring respectively. Short-beaked common dolphins (*Delphinus delphis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and Dall's porpoise (*Phocoenoides dalli*) were the most frequently encountered small cetaceans with overall abundances of 139,120 (CV=0.16), 9,725 (CV=0.36), and 5,855 (CV=0.22) respectively. Seasonally, short-beaked common dolphins were most abundant in summer whereas Pacific white-sided dolphins and Dall's porpoise were most abundant during spring. General Additive Modeling of annual trends in abundance within the CalCOFI study area for each of the six species indicated that blue whale abundance was stable and fin whales were increasing, humpback whales, short-beaked common dolphins, Pacific white-sided exhibited notable annual variations but were relatively stable across the nine-year study, while Dall's porpoise decreased in abundance over the course of the study. Variations in species-specific spatial distribution patterns were also apparent and indicative of species habitat preferences within the California Current Ecosystem. Bottlenose, Risso's and long-beaked common dolphin as well as humpback and gray whale detections were concentrated in coastal and shelf waters, whereas sperm whale detections occurred exclusively in pelagic waters. Short-beaked common dolphin, Pacific white-sided dolphin, Dall's porpoise, fin, and blue whales had a broader distribution with encounters occurring in coastal, shelf and pelagic waters. The CalCOFI marine mammal monitoring program examines seasonal and inter-annual patterns in density, abundance and distribution on a longer continuous time scale with a higher rate of sampling than previous cetacean surveys off the California coast, particularly for the winter and spring periods, for which there are currently few data available.

Project Background

Long-term assessments of abundance, density and distribution are central to evaluating potential effects of anthropogenic activities and ecosystem variability on cetacean populations (Carretta *et al*. 2013). 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 exercises. The intersection between cetacean and human use of the CCE has resulted in entanglements in fishing gear (Carretta *et al*. 2013), ship strikes (Berman-Kowalewski *et al*. 2010) and disturbance from anthropogenic sound (McDonald *et al*. 2006, Hildebrand 2009, Goldbogen *et al*. 2013).

California Cooperative Oceanic Fisheries Investigation (CalCOFI) cruises, conducted in the southern California Bight (SCB) four times per year, provide a unique and valuable platform to document spatial and temporal variations in cetacean abundance, density, distribution and habitat use patterns. Cetacean surveys have been integrated into (CalCOFI) quarterly cruises off southern California since 2004 using both visual and acoustic detection methods (Soldevilla *et al*. 2006, Munger *et al*. 2009). The objectives of the cetacean monitoring program are to make seasonal, annual and long-term estimates of cetacean density and abundance within the study area, to determine the temporal and spatial patterns of cetacean distribution, to conduct habitat-based density modeling, to quantify differences in vocalizations between cetacean species, and to compare visual and acoustic survey methods and results.

Cetacean abundance, 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 abundance, density and distribution. This report provides new and current estimates of cetacean abundance for the six most commonly encountered cetacean species in the Southern California Current (SCC) region based on sighting data collected during 37 quarterly CalCOFI cruises from July 2004 - November 2013. The dataset reported here resulted from a high survey repetition rate that allowed for the examination of seasonal and inter-annual trends in abundance and temporal and spatial patterns of distribution for the six most frequently encountered cetaceans in the SCC.

Visual Methods

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 7x50 Fujinon binoculars to sight all cetaceans encountered during daylight transits between CalCOFI stations (Figure 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, environmental data 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 25x150 or 18x50 power binoculars were available to better asses these metrics after the initial sighting was identified using the 7x50 binoculars (Soldevilla *et al*. 2006). Since 2004, surveys have been conducted using five research vessels: the Scripps Institution of Oceanography (SIO) 84-m RV *Roger Revelle* (2 surveys) and the 52-m RV *New Horizon* (22 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 18.5-22.2 km/h and observer heights above sea level ranged from 8.1 – 17 m.

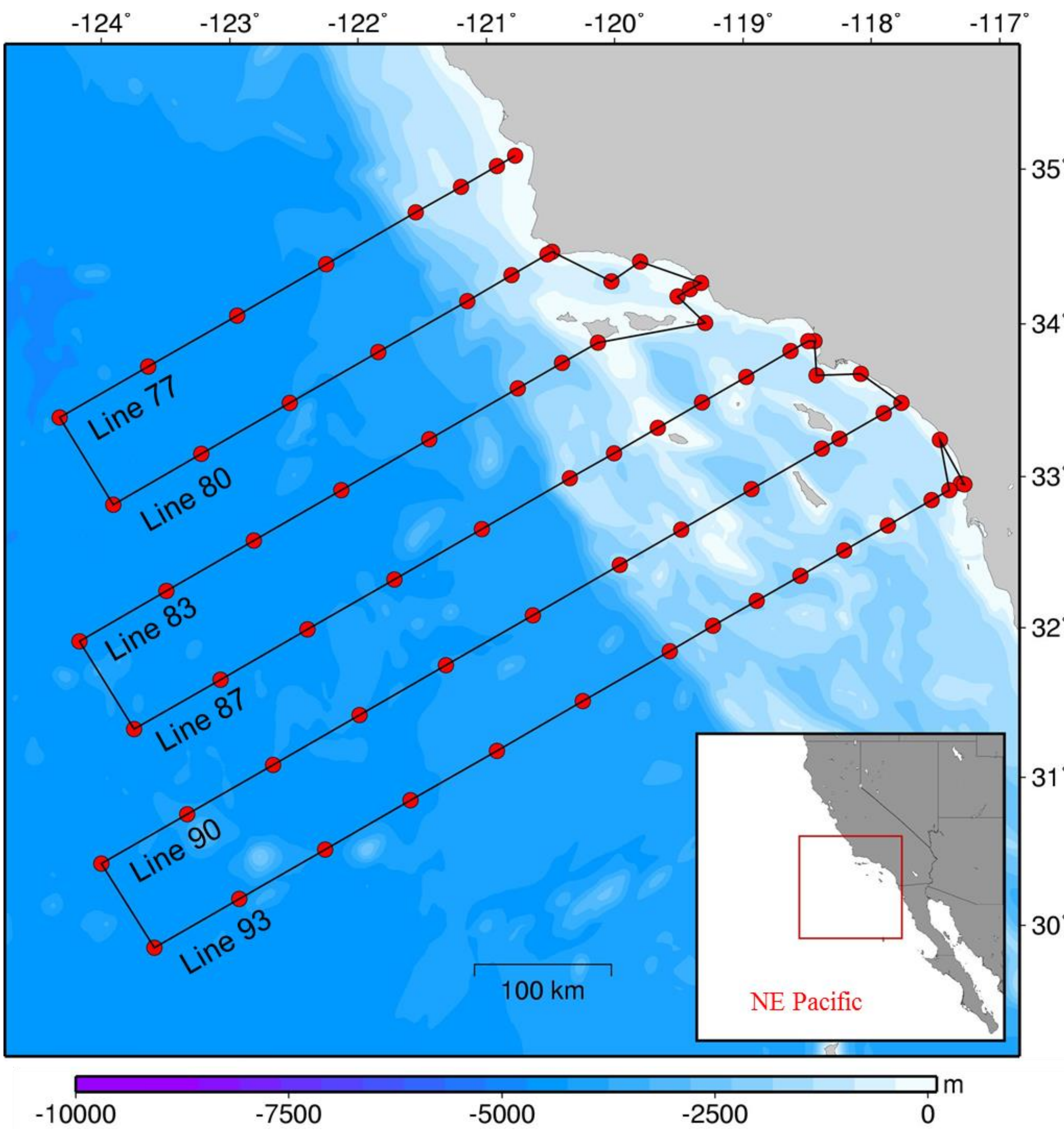

Figure 1. CalCOFI transect lines and sampling stations in the southern CalCOFI study area.

Density and Abundance Analysis

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 (Figure 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, and every 74 km offshore (Figure 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 (Figure 1).

Sightings were required to be both "on-effort" and "on-transect" to be included in the line-transect density and abundance analyses. 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 (Figure 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.

The sampling unit for the density and abundance analysis reported here was all transects completed on a given day, across the nine-year period. Data dependence between one sampling unit and the next is greatly reduced due to the cessation of observations during the overnight break (Buckland *et al*. 2001). Multiple detection functions were tested for the best fit for each of the six species using a step-wise approach progressing from simple to more complex models with greater numbers of covariates. After each modeling exercise in DISTANCE, all input parameters (e.g. potential covariates, number of adjustment terms, distance intervals) were examined, assessed and reviewed. AIC values and goodness of fit statistics were assessed to determine which model(s) within a given run provided the best fit to the data. This step-wise approach was continued until the optimal detection function model for a given species was identified. Overall, annual and seasonal density and abundance were subsequently estimated utilizing the optimal model. Annual and seasonal abundance estimates were developed using a post-stratification routine where the strata utilized the overall detection function but incorporated strata-specific encounter rates and cluster size values. For the development of abundance estimates from seasonal and annual subsamples of the data set, a stratification routine is preferred over simple filtering as this method better handles heterogeneity in data, improves precision, and reduces bias in the resulting estimates (Buckland *et al*. 2001).

Multiple-covariate DISTANCE sampling methods (Marques and Buckland 2003, Marques *et al*. 2007) were used to generate overall, annual and seasonal abundance estimates for the six cetacean species with the recommended minimum of 60 "on-effort" and "on-transect" sightings: blue whales, fin whales, humpback whales, short-beaked common dolphins, Pacific white-sided dolphins and Dall's porpoise (Buckland *et al*. 2001). Including only those species that met the 60 or more sightings criteria allowed for detection function models to be developed independently for each of the six species, thus capturing species-specific differences in detection probabilities inherent from differences in group size, body size, behavior, surfacing patterns, and potential reaction to the survey vessel (Buckland *et al*. 2001). Previous marine mammal line-transect studies have suggested that small cetaceans (i.e. dolphins and porpoise) may show responsive movement to the survey vessel, manifested by either positive (approaching the vessel) or negative reactions (vessel avoidance) which will result in, respectively, positive or negative bias in the estimates of abundance (Buckland *et al*. 2001). In the current study, sighting cues and behavioral events were recorded upon the initial sighting of a given group, allowing for a more comprehensive post-hoc assessment of these potential biases. Thorough review of these data and the species-specific detection function models suggested that short-beaked common dolphins and Pacific white-sided dolphins were usually sighted prior to any observed vessel response; however, vessel attraction was observed for some Dall's porpoise groups, supporting observations described for this species in previous studies (Turnock and Quinn 1991).

Prior to the introduction of covariates into model building, exploratory analyses were conducted to assess potential bias in detection ranges. Possible covariates assessed for building the detection functions included: Beaufort sea-state (0-5), ship, season, swell, and, for short-beaked common dolphins, group size class (greater or less than 20 individuals). While there is the potential for individual biases from different observers, due to the large number of observers who worked on the project, sample sizes were small which precluded the application of this potential covariate into the analysis. Due to experimental design constraints, it was not possible to measure the probability of detection directly on the transect line -or- *g(0)*; therefore *g(0)* values previously calculated for cetacean sightings in the CCE (Barlow 1995) were applied to the current study: the probability of detection *g(0)* was set to 0.920 for blue, fin and humpback whales, Pacific white-sided dolphins received a *g*(0) value of 0.856 and Dall's porpoise were assigned a *g(0)* value of 0.822. Common dolphins, which exhibit a large range of group sizes were assigned a *g*(0) value of (0.913) which was the average of the values reported for large groups (0.970) and small groups (0.856) of delphinids.

RESULTS - VISUALS

Line-Transect Visual Surveys

Five CalCOFI cruises were conducted from 1 August 2012 to 31 December 2013; visual effort across 95 days at-sea included 584 observation hours covering 10,900 kilometers yielding 565 sightings of 16 identified cetacean species (Tables 1 & 2). The winter 2103 and spring 2013 cruises extended north to waters off Monterey while the fall 2012 and 2013 and the summer 2013 cruises covered the primary southern CalCOFI study area presented in Figure 1. The geographic distribution of cetacean species encountered in the CalCOFI study area was not uniform. Spatial patterns of mysticete and odontocete sightings reveal noteworthy variations in the distribution of several common species (Figures 2-3). Blue and fin whales had a wide distribution with sightings throughout the study area ranging from coastal to pelagic waters. Humpback whales exhibited a wide distribution with the highest concentrations occurring in inshore waters off Central California during spring. Gray whales (Escand Minke whales were sighted exclusively in shelf and coastal waters. Short-beaked common dolphins were seen throughout the study area, while bottlenose and Risso's dolphins were generally sighted in inshore waters near the Channel Islands. Pacific white-sided dolphins were observed from near shore to pelagic waters. Dall's porpoise were seen throughout the study area with out to approximately 250 km from shore, and sperm whales were found in deep offshore waters.

Table 1. Summary data from five CalCOFI cruises between August 2012 and December 2013.

CalCOFI Cruise Dates	Survey Effort (hrs)	Distance Surveyed (km)	Number of Cetacean Sightings	Number of Individuals	Number of Species
19 Oct - 5 Nov 2012	95	1,721	99	2,302	7
10 Jan - 02 Feb 2013	113	2,402	110	2,939	12
06 Apr - 30 Apr 2013	155	2,584	157	4,185	11
06 Jul - 22 Jul 2012	131	2,545	126	4,280	10
09 Nov - 24 Nov 2013	90	1,626	73	5,003	9
Totals	**584**	**10,878**	**565**	**18,709**	**15**

Table 2. CalCOFI cetacean sightings by cruise from August 2012 – July 2013. See Appendix 1 for species abbreviation codes. Ns = number sightings; Ni = number individuals.

	CC1210 (19 Oct - 05 Nov 2012)		CC1301 (10 Jan - 02 Feb 2013)		CC1304 (06 Apr - 30 Apr 2013)		CC1307 (06 Jul - 22 Jul 2013)		CC1311 (09 Nov - 24 Nov 2013)		Total	
Species	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**
Ba	0	0	0	0	0	0	2	2	0	0	2	2
Bm	7	9	0	0	1	1	4	5	1	3	13	18
Bp	21	37	13	20	6	9	17	22	4	5	61	93
Dc	5	337	2	171	5	1,060	6	212	6	2,264	24	4,044
Dd	9	531	13	555	6	490	15	1,401	13	857	56	3,834
Dsp	22	1,152	16	1,839	5	201	20	1,726	18	1,558	81	6,476
Er	0	0	16	42	1	2	0	0	0	0	17	44
Gg	0	0	4	41	1	8	2	25	2	37	9	111
Lb	0	0	2	16	3	1,250	2	185	0	0	7	1,451
Lo	0	0	7	112	7	112	2	301	1	19	17	544
Mn	2	2	9	18	67	111	7	10	1	2	86	143
Oo	0	0	4	20	0	0	0	0	0	0	4	20
Pd	1	3	11	85	16	107	0	0	0	0	28	195
Pm	0	0	1	2	0	0	0	0	1	8	2	10
Sc	0	0	1	2	0	0	0	0	0	0	1	2
Tt	1	2	0	0	1	5	5	114	4	41	11	162
UD	7	186	1	3	4	786	2	225	8	190	22	1,390
ULW	24	43	10	13	34	43	42	52	14	19	124	170
Zcav	0	0	0	0	0	0	0	0	0	0	0	0
TOTALS	99	2,302	110	2,939	157	4,185	126	4,280	73	5,003	565	18,709

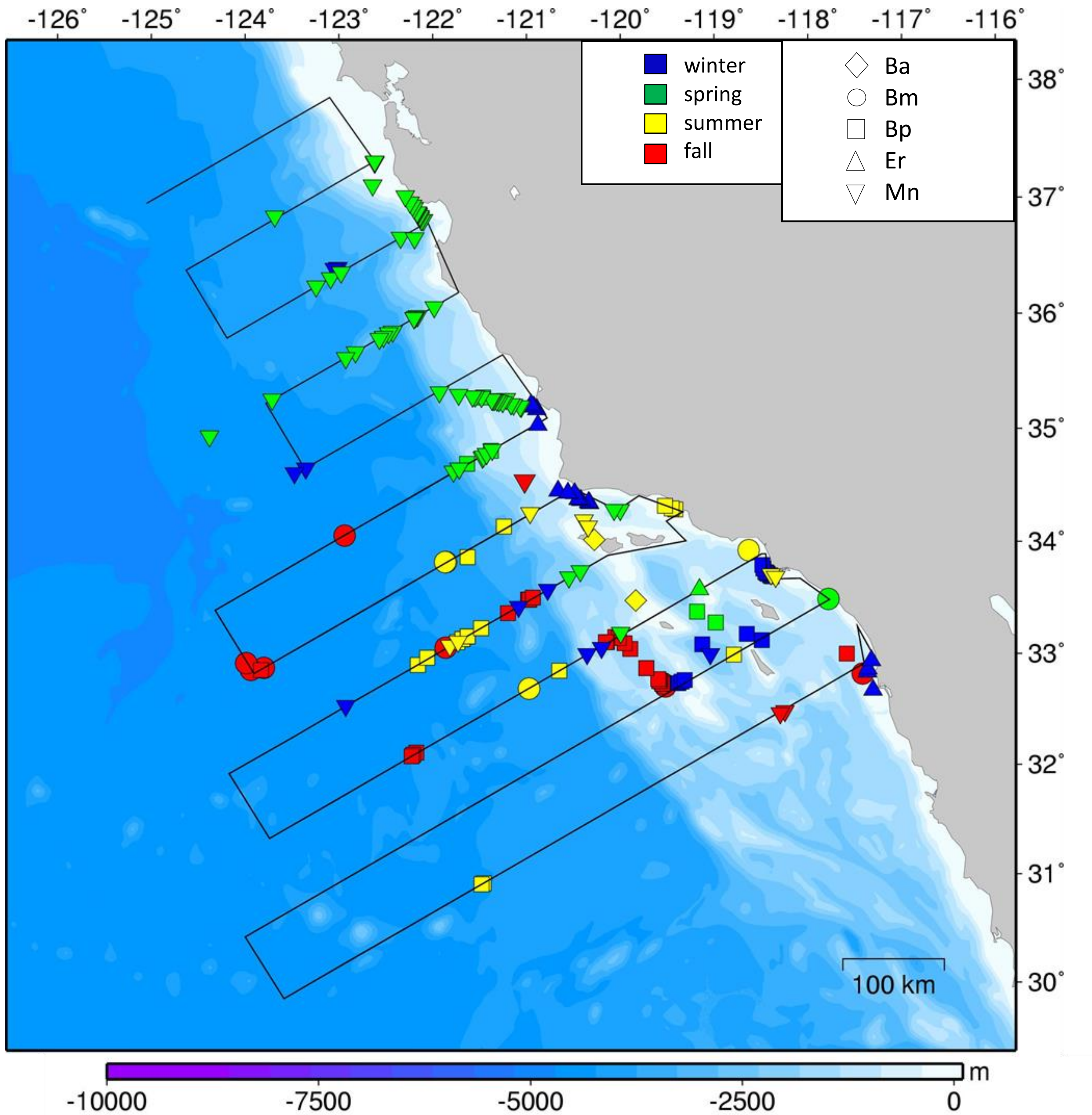

Figure 2. Visual detections of minke, blue, fin, humpback and grey whales by season from five CalCOFI cruises between August 2012 and November 2013.

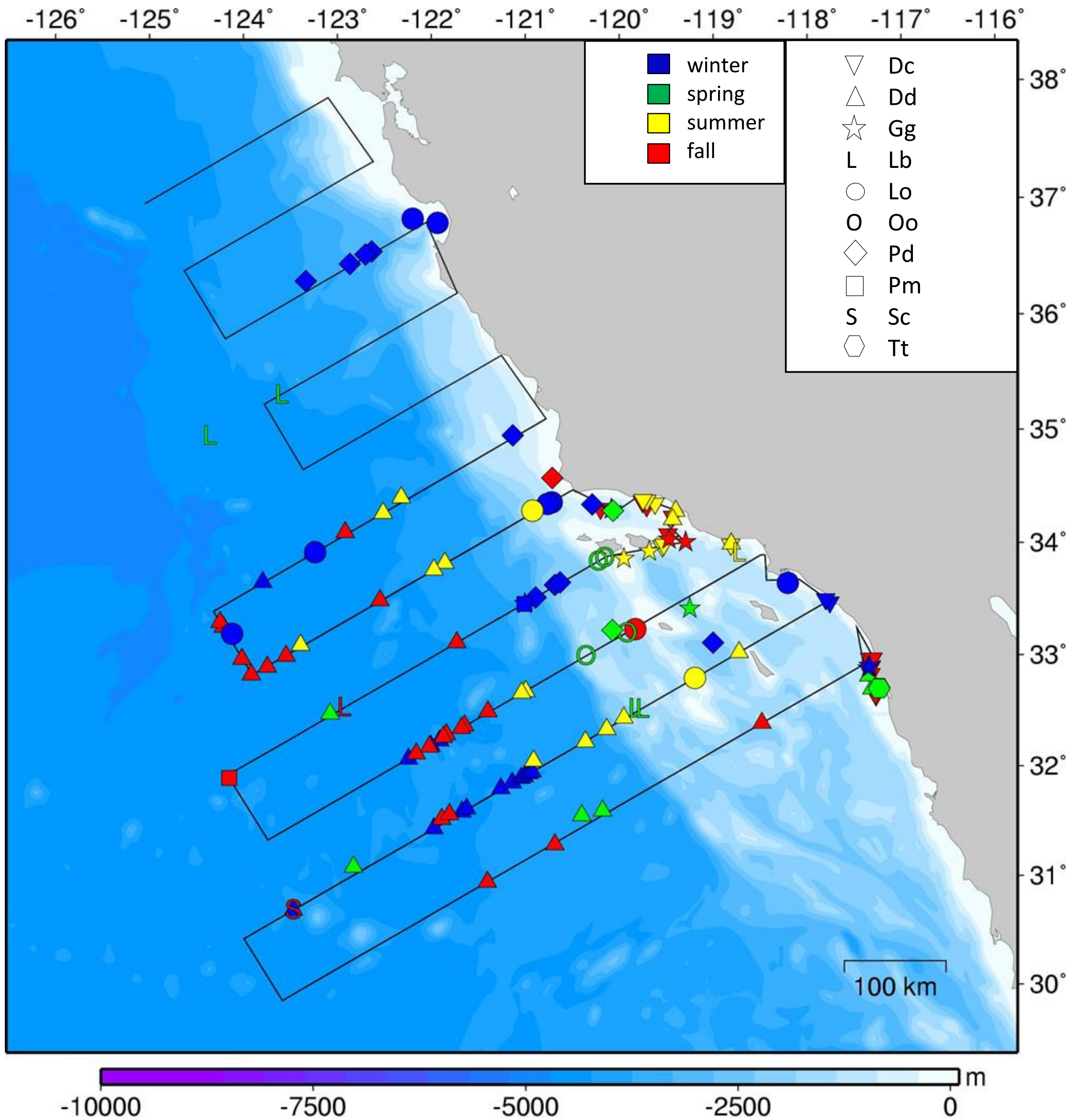

Figure 3. Visual detections of ten odontocete species by season from five CalCOFI cruises between August 2012 and November 2013.

Density and Abundance Estimation

For all six species analyzed, the only significant covariate retained in the optimal DISTANCE models was Beaufort sea-state. In order to improve the fit of the detection function, the most distant 5% of sightings for each species were eliminated from density estimation (Buckland *et al*. 2001), resulting in a truncation distance of 2705 m for blue whales, 2708 m for fin whales, 2177 m for humpback whales, 984 m for short-beaked common dolphins, 903 m for Pacific white-sided dolphins, and 1098 m for Dall's porpoise. There were a total of five blue whale, nine fin whale, three humpback whale, 13 short-beaked common dolphin, three Pacific white-sided dolphin, and eight Dall's porpoise sightings that were beyond the truncation distance and thus excluded from density and abundance analysis. Effective strip width (ESW) for blue whales was 1181 m, for fin whales 1260 m, for humpback whales 958 m, for common dolphins 421 m, for Pacific white-sided dolphins 322 m, and for Dall's porpoise 277 m.

Thirty-seven surveys conducted between July 2004 and November 2013 produced 526 days where ''on-effort'' and "on-transect" criteria were met for a total of 43,846 kilometers of active line-transect sampling along the track-lines (Figure 4). Survey effort was relatively consistent across the four seasons, totaling 9,260 km over 131 days surveyed in winter, 9,002 km across 107 days in spring, 14,941 km over 149 days in summer, and 139 days covering 10,640 km during fall surveys. For the six focus species in the current study, a total of 1276 visual detections were made with 755 (59%) of them meeting both the "on-effort" and "on-transect" criteria for inclusion in the density modeling analysis (Table 3).

Table 3. Sighting data from the six most frequently sighted cetacean species in the southern CalCOFI study area across 37 surveys from summer 2004 - fall 2013. Ns = number of sightings; Ni = number of individuals.

Species	On Effort/On Transect		Off Effort/Off Transect		Total	
	Ns	Ni	Ns	Ni	Ns	Ni
Blue Whale	79	122	57	113	136	235
Fin Whale	177	331	85	131	262	462
Humpback Whale	68	120	124	229	192	349
SB Common Dolphin	278	22,226	159	14,993	437	37,219
PWS Dolphin	62	1128	45	896	107	2,024
Dall's Porpoise	91	614	51	281	142	895
TOTAL	755	24,541	519	16,404	1274	40,945

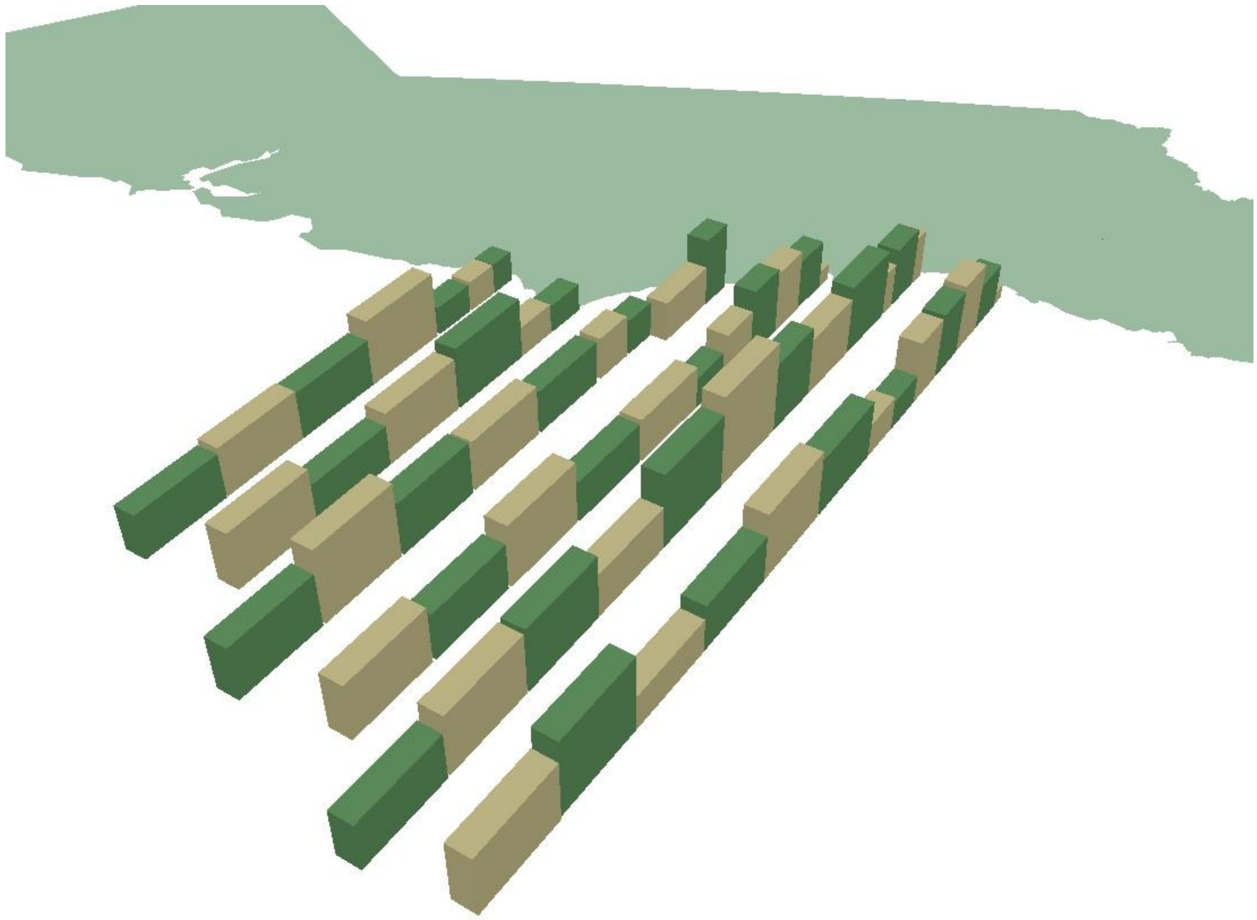

Figure 4. Three-dimensional illustration of transect lines surveyed while “on-effort” during 35 CalCOFI cruises from 2004-2013. Alternating colors show the individual survey segments between sampling stations. Height of blocks depicts the number of times a given transect was surveyed over the course of the study with a range of 12 to 31 occasions.

Table 4. Overall abundance estimates for each of the six species analyzed. Total numbers of sightings after 5% truncation (*n*), estimated cetacean abundance (*N*), density per 1000 km^2, and mean group size from 2004 – 2013. Coefficients of variation (*CV*) are the same for abundance and density estimates.

Species	Overall Abundance			Density per	Mean
	n	*N*	*CV*	1000 km^2	Group Size
Blue Whale	74	285	0.26	1.2	1.5
Fin Whale	168	718	0.22	3.0	1.9
Humpback Whale	65	351	0.26	1.5	1.8
SB Common Dolphin	265	139,120	0.16	583.0	79.9
PWS Dolphin	59	9,725	0.36	40.7	18.2
Dall's Porpoise	83	5,855	0.22	24.5	6.7

Table 5. Seasonal abundance estimates for each of the six species analyzed. Total numbers of sightings after 5% truncation (*n*), estimated cetacean abundance (*N*), and coefficients of variation (*CV*) are presented for each season pooled across all years from 2004-2013.

Species	winter			spring			summer			fall		
	n	*N*	*CV*	*n*	*N*	*CV*	*n*	*N*	*CV*	*n*	*N*	*CV*
Blue Whale	1	12	1.01	1	12	1.00	63	727	0.30	9	134	0.37
Fin Whale	9	178	0.41	19	320	0.48	95	1,253	0.27	45	773	0.32
Humpback Whale	12	336	0.38	21	532	0.43	20	274	0.53	12	318	0.50
SB Common Dolphin	66	164,050	0.26	13	32,733	0.33	122	189,720	0.18	64	138,440	0.22
PWS Dolphin	16	10,518	0.45	26	15,916	0.42	9	8,929	0.96	8	4,824	0.60
Dall's Porpoise	34	8,923	0.32	49	17,436	0.26	1	71	1.0	3	1,281	0.76

Blue whales exhibited strong variations in seasonal occurrence with 1% of sightings occurring during spring (n=1), 86% in summer (n=68), 11% in fall (n=9), and 1% in winter (n=1) (Figure 5). The summer distribution of blue whales extended throughout coastal, borderland and offshore waters, while fall distribution was primarily over the western portion of the continental shelf and in offshore regions. Blue whales also exhibited spatial variations in their distribution; this species was observed throughout coastal, continental shelf and offshore waters in the southern half of the study area whereas, in the northern half of the study area, sightings were distributed exclusively in offshore waters (Figure 5).

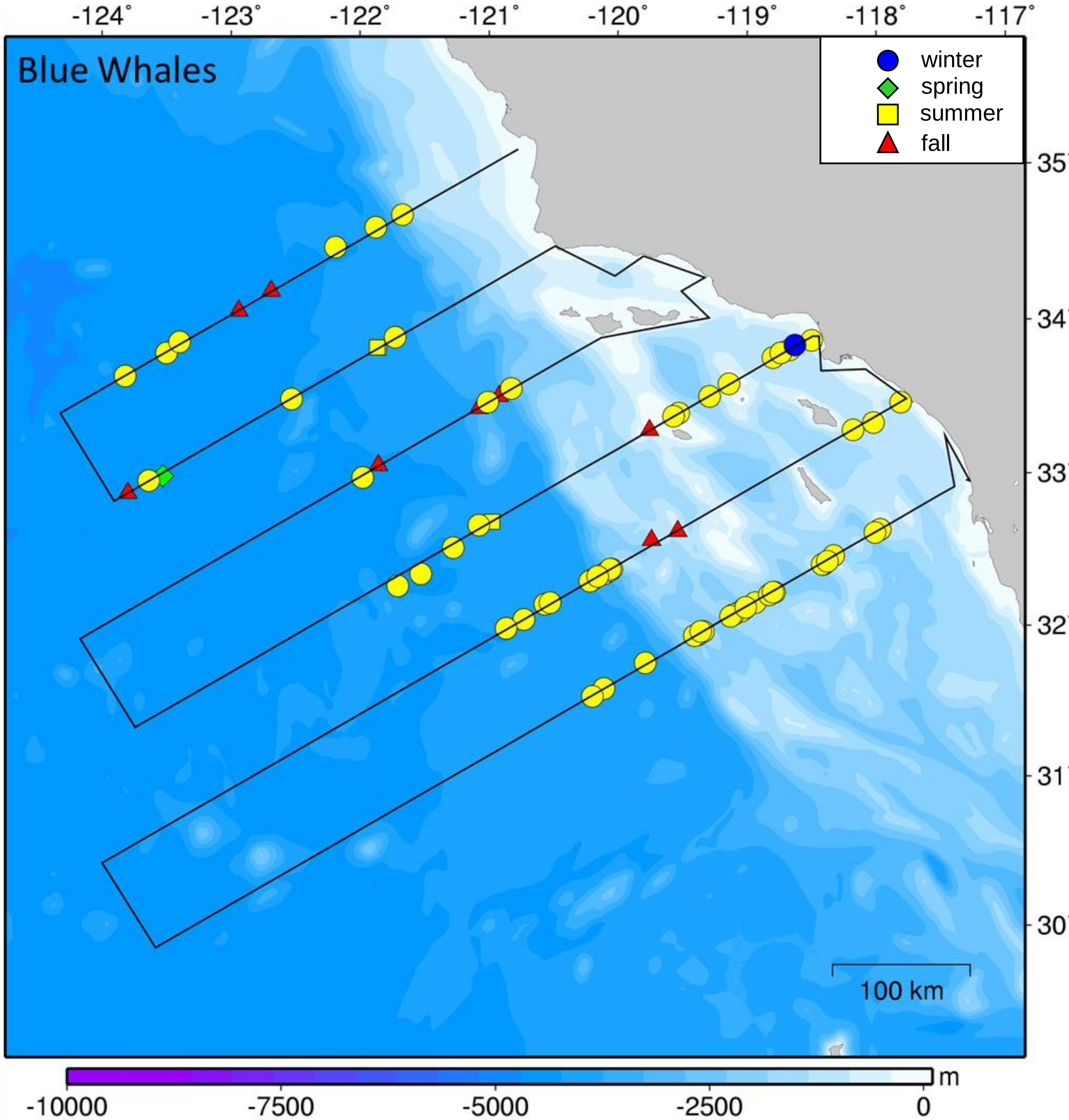

Figure 5. On-effort sightings of blue whales by season on CalCOFI cruises from 2004-2013.

Blue whales were the second-most frequently encountered and third most abundant baleen whale species with an overall abundance estimate across all four seasons of 285 (CV = 0.26) (Table 4). Annual estimates of blue whale abundance from 2005 to 2013 varied across the study and ranged from a low of 23 (CV=1.01) in 2007 to a peak of 625 (CV=0.77) in 2011 (Figure 6). Despite the noted variations in annual abundance estimates, the GAM-based inverse variance weighted trend-line across the nine years sampled was relatively flat, indicating stable abundance in the region (Figure 6). Seasonally, blue whales were five times more abundant during summer (N=727, CV=0.29) versus fall (N=134, CV=0.37) and virtually absent from the study area during winter and spring with only one sighting in each of these seasons across the ten-year study period (Figure 7) (Table 5).

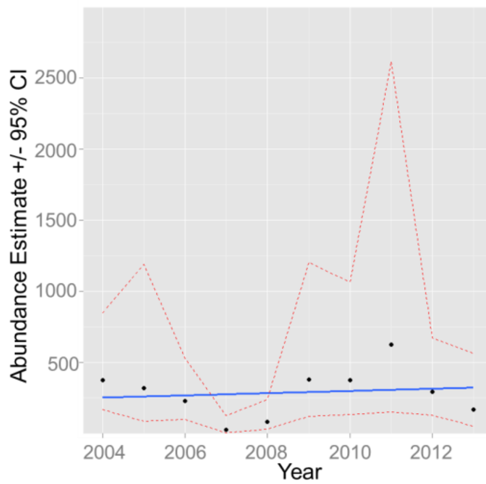

Figure 6. Estimated abundance of blue whales for summer and fall cruises by year from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

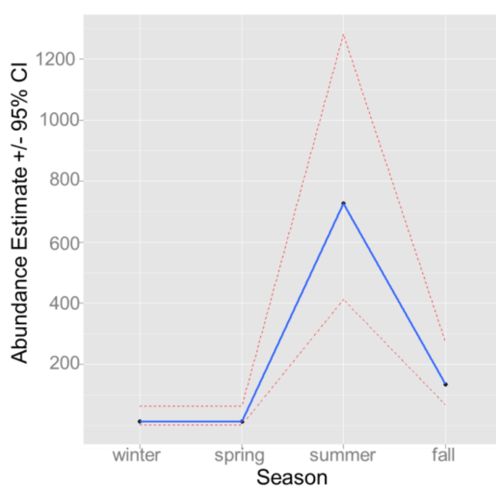

Figure 7. Seasonal abundance of blue whales by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

Fin whale occurrence varied seasonally with 12% of sightings in spring (n=21), 56% in summer (n=99), 27% in fall (n=47), and 6% in winter (n=10) (Figure 8). The distribution of fin whales in the study area also varied with season. During winter and spring, the majority of sightings occurred in continental shelf waters within the southern half of the study area whereas summer and fall sightings were more widely distributed with the greatest concentrations offshore and in the northern portion of the study area along the northern-most survey line (Figure 8).

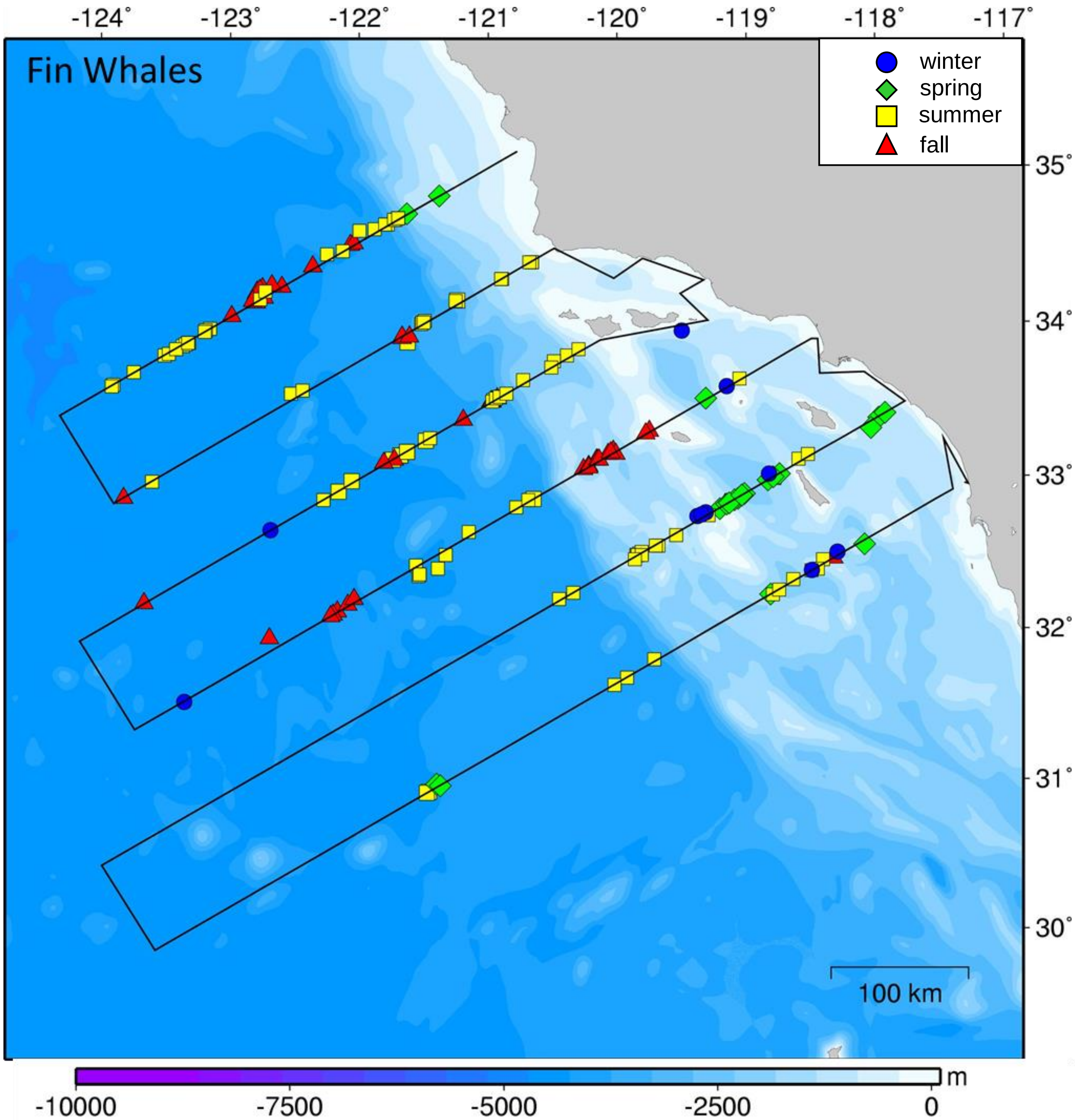

Figure 8. On-effort sightings of fin whales by season on CalCOFI cruises from 2004-2013.

Fin whales were the most frequently encountered and the most abundant baleen whale in the CalCOFI study area with an overall abundance estimate of 718 (CV=0.22) (Table 4). Annual estimates of fin whale abundance from 2005 to 2013 varied during the study and ranged from a low of 272 (CV=0.45) in 2009 to a peak of 2540 (CV=0.66) in 2010 (Figure 9). Despite the fluctuations in annual abundance estimates, the GAM-based inverse variance weighted trend-line indicated a consistent increase in the number of fin whales estimated in the study area across the nine years sampled (Figure 9). Seasonally, fin whales were most abundant during summer (N=1,253; CV=0.27) versus winter (N=178, CV=0.41), when the species was least abundant (Figure 10, Table 5).

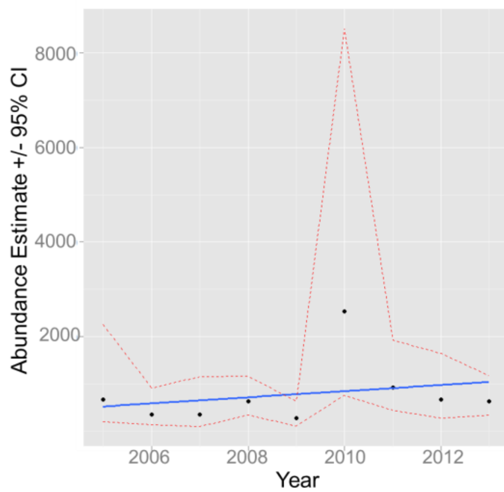

Figure 9. Estimated abundance of fin whales by year from 2005-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

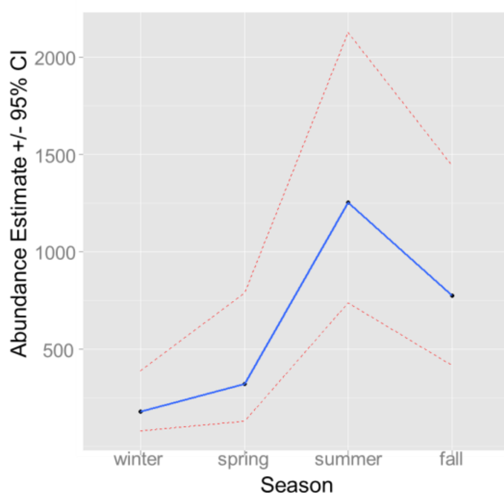

Figure 10. Seasonal abundance of fin whales by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

Humpback whales were present in the study area throughout the year; however, occurrence patterns varied as a function of season with 32% of sightings occurring during spring (n=22), 31% in summer (n=21), 29% in fall (n=13), and 18% in winter (n=12) (Figure 11). The distribution of sightings also changed seasonally. During spring, summer and fall cruises, humpback whales were generally distributed in coastal and shelf waters with the largest concentration occurring in relatively shallow waters, north of Point Conception. During winter cruises, the distribution of humpback sightings shifted to exclusively shelf and offshore waters with several sightings in deep pelagic waters, more than 200 km from shore (Figure 11).

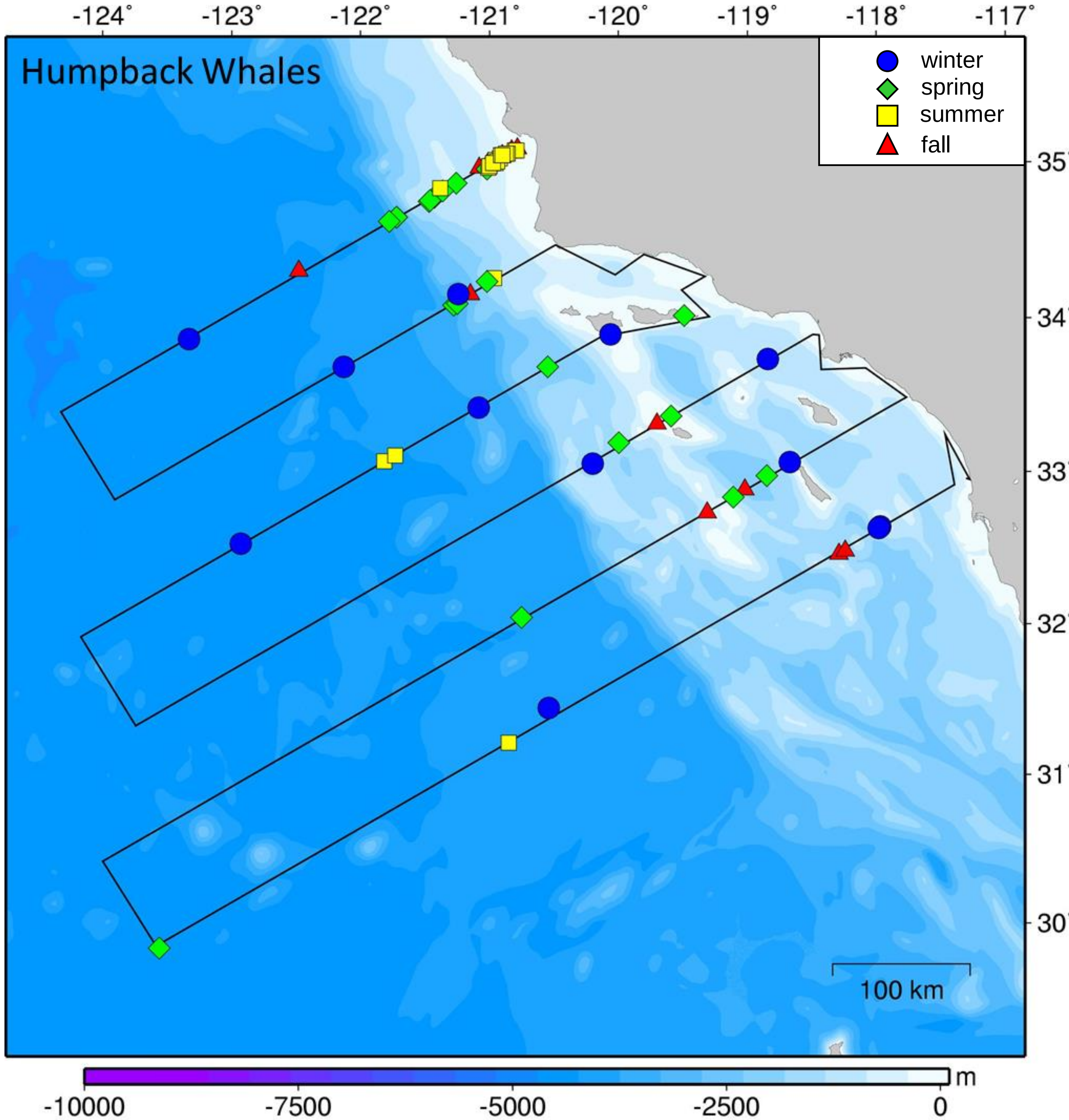

Figure 11. On-effort sightings of humpback whales by season on CalCOFI cruises from 2004-2013.

Humpback whales were the third most frequently encountered baleen whale in the CalCOFI study area with an overall abundance estimate of 351 (CV=0.26) (Table 4). Annual estimates of humpback whale abundance from 2005 to 2013 ranged from a low of 83 (CV=1.0) in 2011 to a peak of 801 (CV=0.52) in 2013 (Figure 12). Across the nine-year study period, the GAM-based inverse variance weighted trend-line indicated a slight decrease in the number of humpback whales estimated to be utilizing the study area (Figure 12). Seasonally, humpback whales were most abundant during spring (N=566; CV=0.42) with relatively consistent abundance values estimated for winter (N=320, CV=0.34), summer (N=314, CV=0.60), and fall (N=308, CV=0.45) (Figure 13, Table 5).

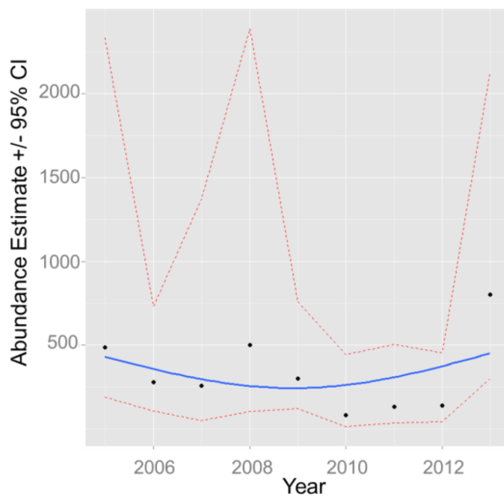

Figure 12. Estimated abundance of humpback whales by year from 2005-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

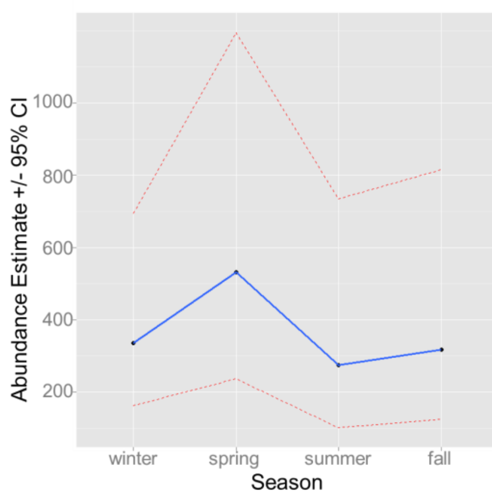

Figure 13. Seasonal abundance of humpback whales by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

Short-beaked common dolphins were present in the study area throughout the year; however, occurrence patterns varied as a function of season with 5% of sightings occurring during spring (n=14), 47% in summer (n=131), 24% in fall (n= 66), and 24% in winter (n=67) (Figure 14). The distribution of sightings also changed seasonally. Short-beaked common dolphins were seen throughout the study area during summer and fall, with the exception of coastal waters off Point Conception, while the species distribution during winter and spring was limited to the southern half of the study area, with the majority of winter sightings occurring in pelagic waters off the continental shelf (Figure 14).

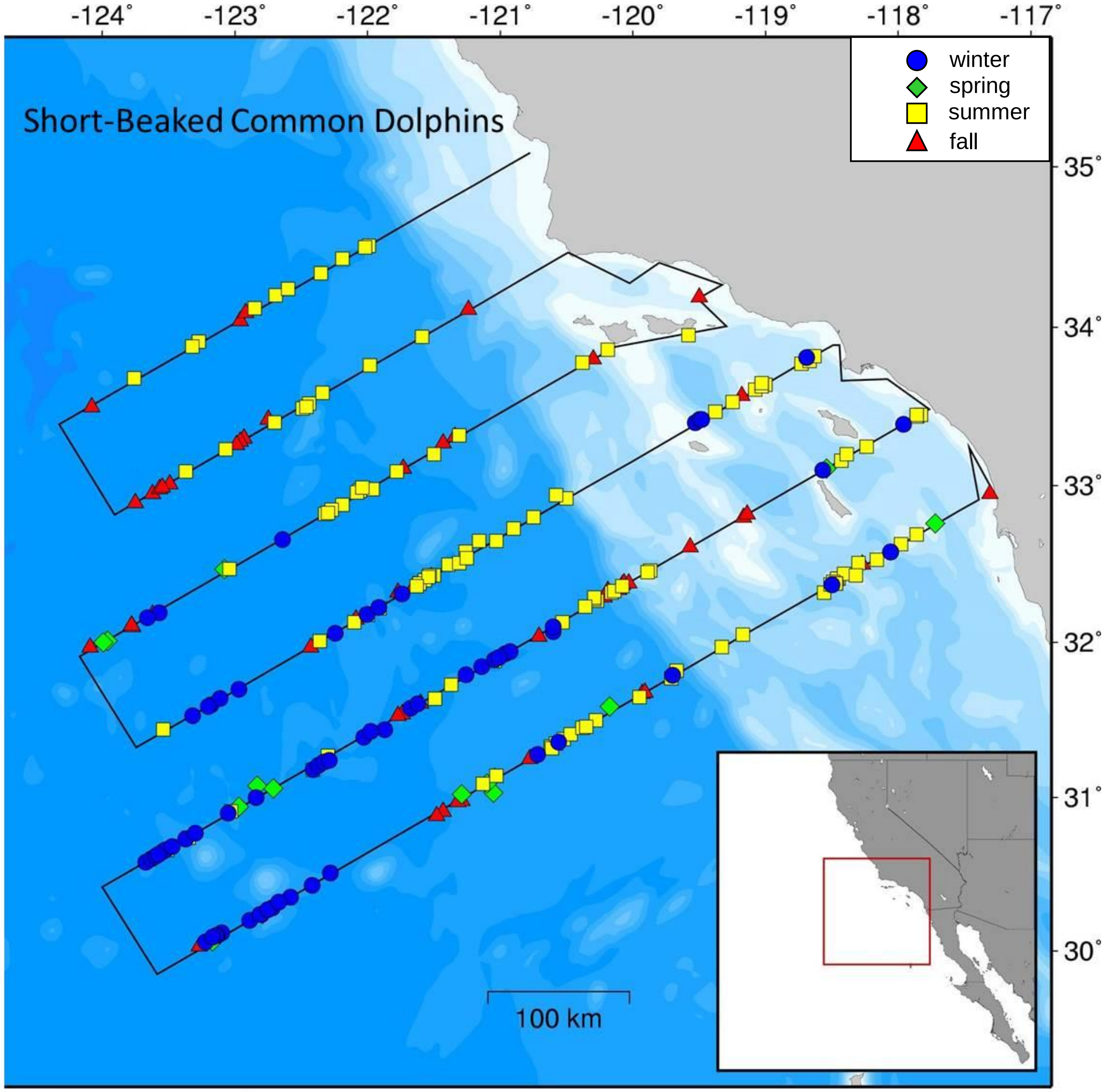

Figure 14. On-effort sightings of short-beaked common dolphins by season in the CalCOFI study area from 2004-2013.

Short-beaked common dolphins were the most frequently encountered cetacean in the study area with an overall abundance estimate of 139,120 (CV=0.16) (Table 4). Estimates of annual abundance were calculated for each of the nine calendar years sampled (2005-2013) and ranged from a peak of 226,050 (CV=0.45) in 2013 to a low of 48,205 (CV=0.45) in 2008 (Figure 15). The GAM-based inverse variance weighted trend-line indicated peaks in abundance during 2005 and 2013 with a notable decrease in the number of short-beaked common dolphins estimated to be utilizing the study area from 2006-2012 (Figure 15). Seasonally, short-beaked common dolphins exhibited the highest abundances in summer (*N*=189,720; CV=0.18), followed by winter and fall with relatively low abundance during spring (Figure 16, Table 5).

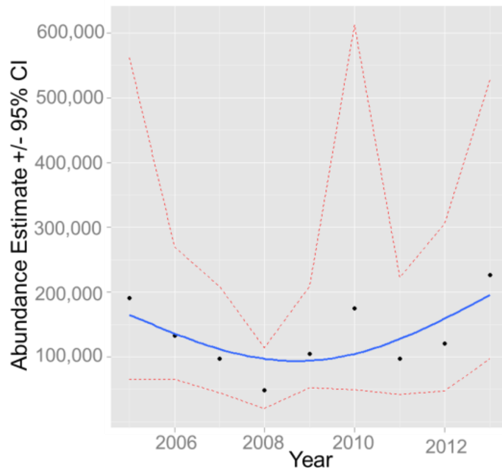

Figure 15. Estimated abundance of short-beaked common dolphins by year from 2005-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

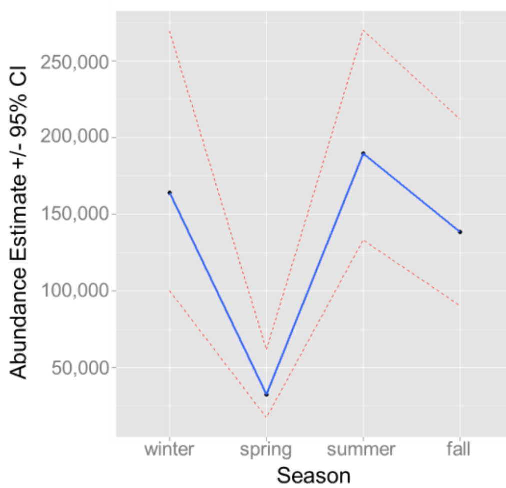

Figure 16. Seasonal abundance of short-beaked common dolphins by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

Pacific white-sided dolphins were present in the study area throughout the year; however, occurrence patterns varied as a function of season with 45% of sightings occurring during spring (n=28), 16% in summer (n=10), 13% in fall (n= 8), and 26% in winter (n=16) (Figure 17). The distribution of sightings also changed seasonally. Pacific white-sided dolphins were seen throughout the study area during winter and spring, while distribution during fall was limited to coastal and shelf waters in the southern half of the study area; the majority of summer sightings occurred near the shelf edge and in pelagic waters (Figure 17).

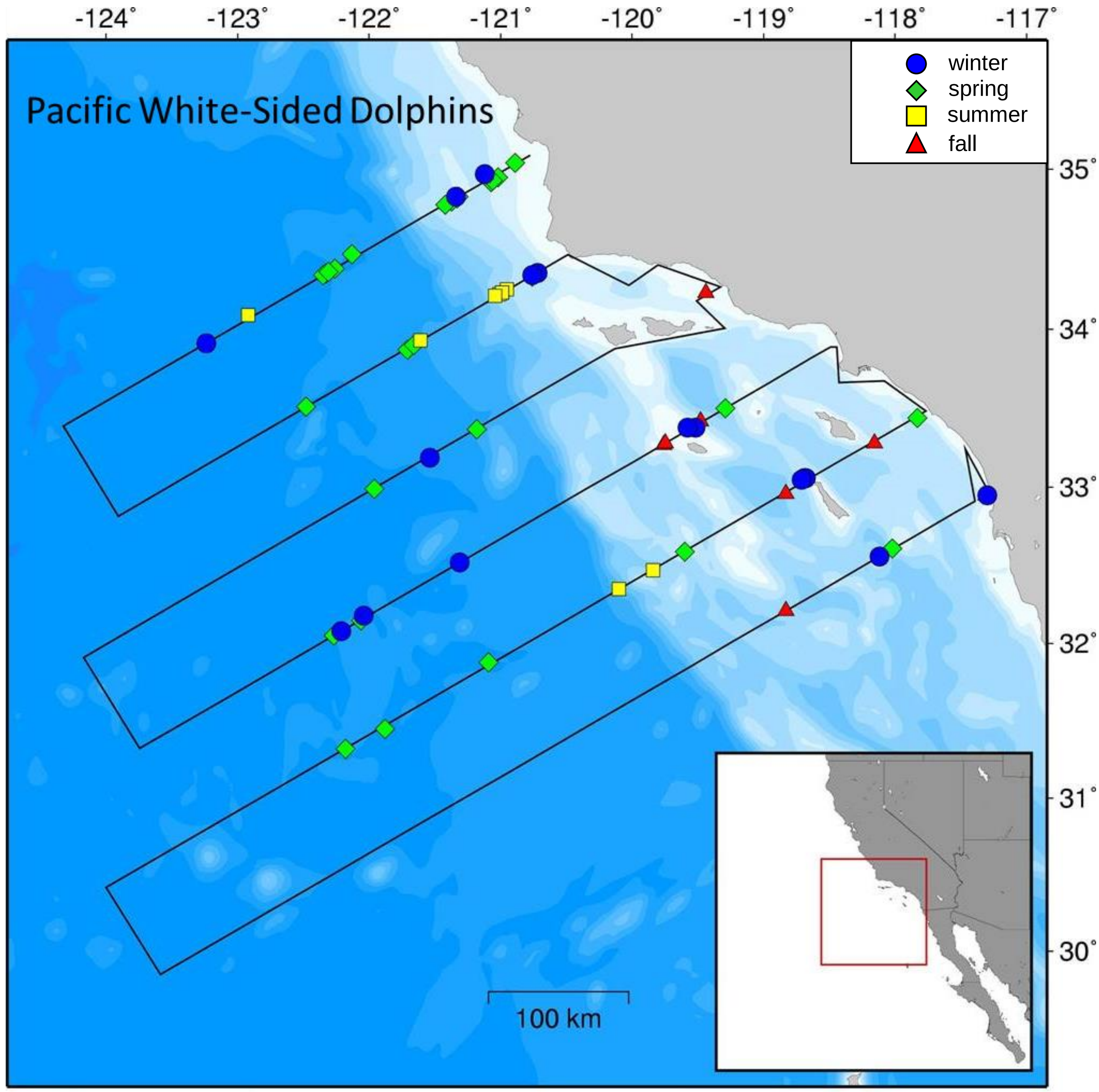

Figure 17. On-effort sightings of Pacific white-sided dolphins by season on CalCOFI cruises from 2004-2013.

Pacific white-sided dolphins were the third most frequently encountered odontocete in the study area with an overall abundance estimate of 9,725 (CV=0.36) (Table 4). Estimates of annual abundance ranged from a peak of 21,576 (CV=1.06) in 2013 to a low of 143 (CV=1.0) in 2009 (Figure 18). The GAM-based inverse variance weighted trend-line indicated peaks in abundance during 2006 and 2013 with a notable decrease in the number of Pacific white-sided dolphins estimated to be utilizing the study area from 2007-2012 (Figure 18). Seasonally, Pacific white-sided dolphins exhibited the highest abundances in spring (*N*=15,916; CV=0.42), followed by winter with relatively low abundances during summer and fall (Figure 19, Table 5).

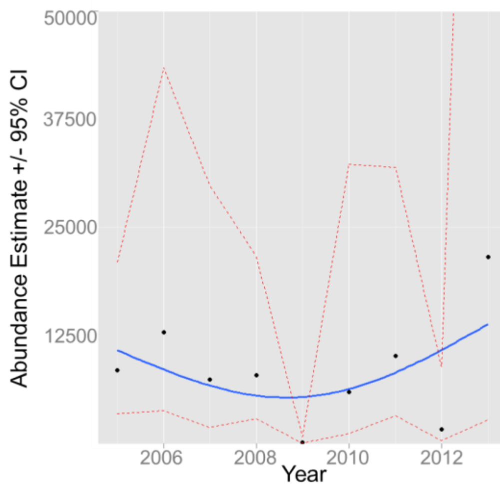

Figure 18. Estimated abundance of Pacific white-sided dolphins by year from 2005-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

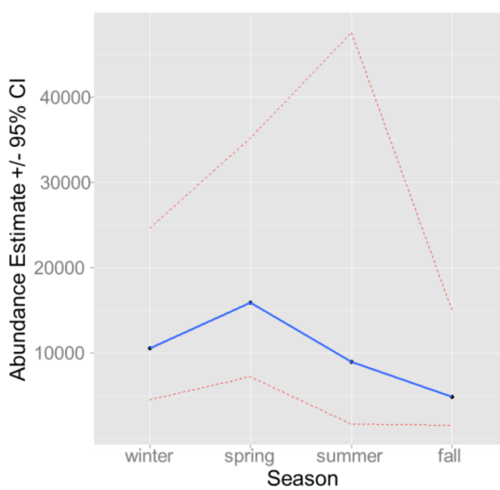

Figure 19. Seasonal abundance of Pacific white-sided dolphins by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

Dall's porpoise displayed distinct differences in seasonal occurrence patterns with 54% of sightings occurring during spring (n=49), 1% in summer (n=1), 3% (n=3) in fall and 42% sighted during winter (n=38) (Figure 20). There was no apparent difference in the distribution of sightings between winter and spring. Overall, Dall's porpoise distribution extended from coastal waters out to approximately 250 km from shore with a lower concentration of sightings in the southern portion of the study area, and few sightings along the southern-most survey line (Figure 20).

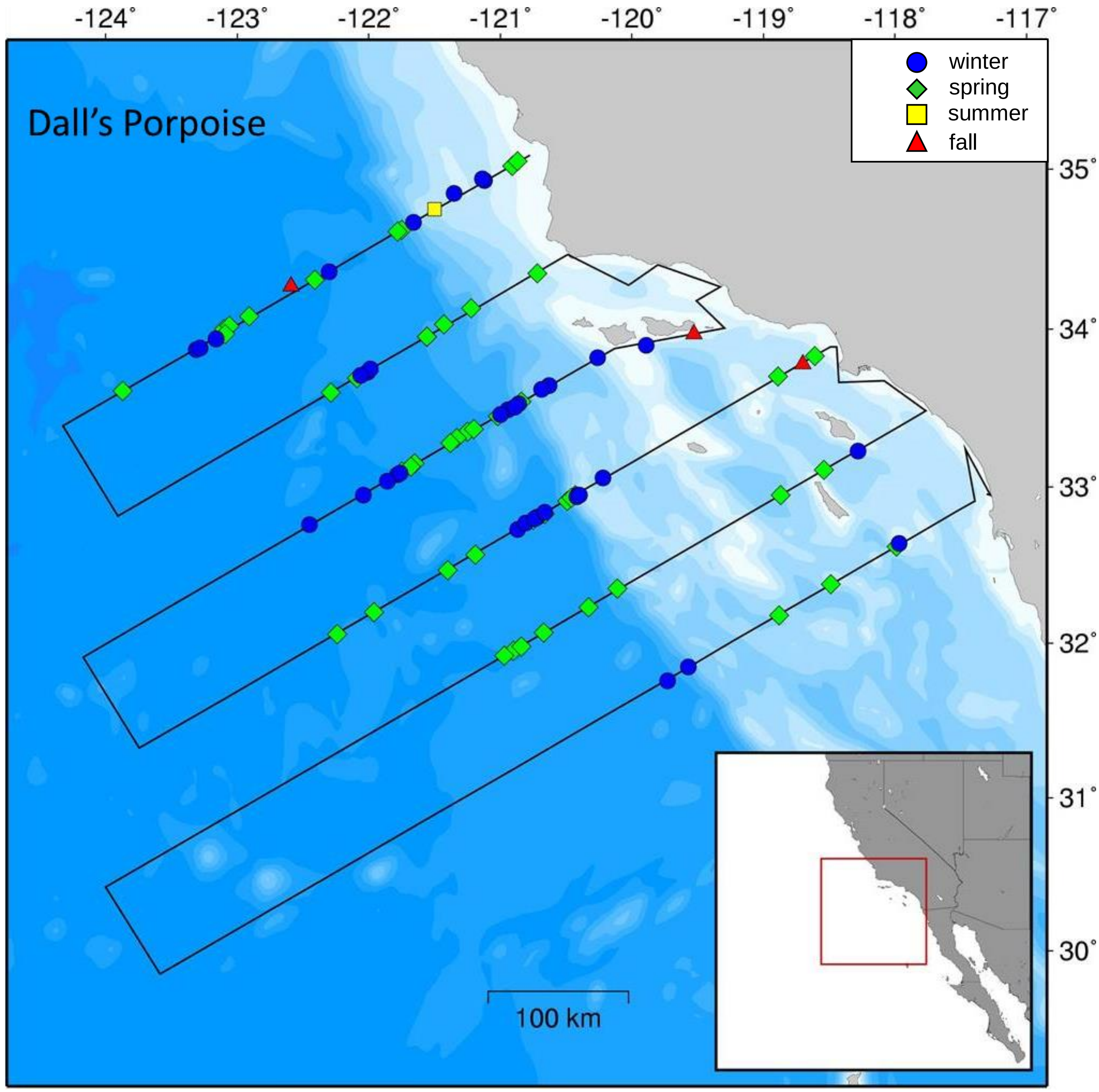

Figure 20. On-effort visual detections of Dall's porpoise by season in the CalCOFI study area from 2004-2013.

Dall's porpoise were the second most frequently encountered small cetacean in the study area with an overall abundance estimate of 5,855 (CV = 0.22) (Table 4). Estimates of annual abundance ranged from a peak of 10,088 (CV=0.53) in 2011 to a low of 1,243 (CV=1.01) in 2010 (Figure 21). The GAM-based inverse variance weighted trend-line indicated a decreasing trend in the number of Dall's porpoise estimated to be utilizing the study area (Figure 21). Seasonally, Dall's porpoise exhibited the highest abundance in spring (*N*=17,436; CV=0.26) and winter (*N*=8,270; CV=0.31) with only one sighting in summer and 3 in fall across the 10 year study period (Figure 22, Table 5).

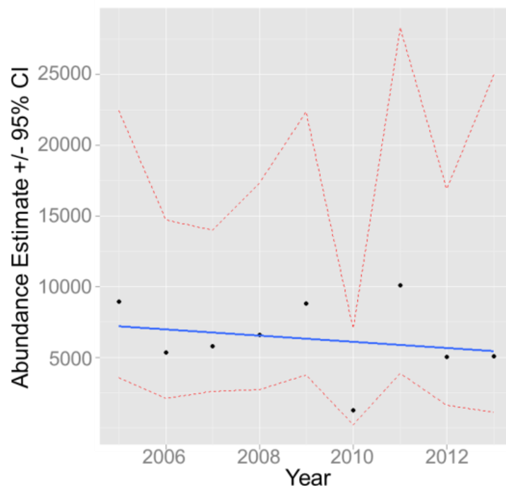

Figure 21. Estimated abundance of Dall's porpoise by year for winter and spring cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals. Blue line represents GAM based inverse variance weighted trend-line.

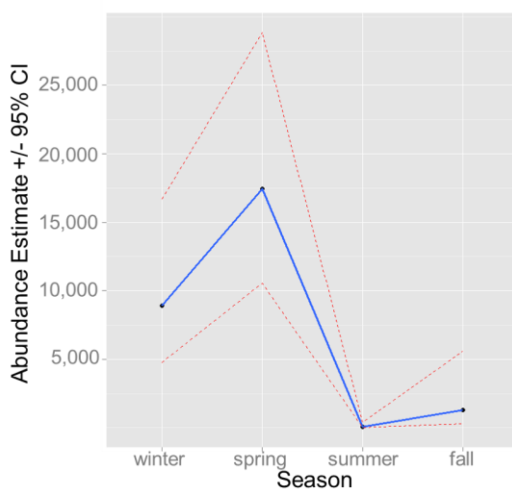

Figure 22. Seasonal abundance of Dall's porpoise by season collapsed across 37 cruises from 2004-2013. Red dashed lines represent lower and upper 95% confidence intervals.

DISCUSSION - VISUALS

Environmental impact assessments and management protocols for the protection of cetaceans, particularly endangered species, off southern California have primarily relied upon ship-based line-transect abundance estimates generated from relatively few surveys (generally every 4-5 years) conducted only during summer and fall (Barlow and Forney 2007). The current study examines seasonal and inter-annual patterns in density, abundance and distribution on a longer continuous time scale with a higher rate of sampling than previous cetacean surveys off the California coast, particularly for the winter and spring periods, where there were previously little or no data available (e.g. Barlow 2010). As such, the results provided herein are thought to offer a complementary and more robust baseline for management purposes and, importantly, for informing mitigation of anthropogenic disturbance (e.g. Naval training, shipping).

The overall abundance estimate of 285 (CV=0.26) blue whales in the CalCOFI study area is lower than both the estimate of 842 (CV=0.20) from pooled 1991-2005 surveys (Barlow and Forney 2007), and the estimate and 743 (CV=0.27) reported from pooled 1991- 2008 surveys off southern California (Barlow 2010). The higher values reported for the pooled 1991-2005 and 1991-2008 periods are partly the result of the surveys being conducted during the summer and fall, when blue whales are at their highest levels of abundance in the SCC. In addition, there was a dense concentration of feeding blue whales occurring off southern California during the three surveys that occurred between 1991 and 1996 (Fiedler *et al*. 1998, Barlow and Forney 2007); more recent survey data suggest a large scale northward shift in the distribution of feeding blue whales in the North Pacific possibly related to an oceanographic ecosystem change at the end of the 1990's (Calambokidis *et al*. 2009; Di Lorenzo and Ohman 2013). The decrease in blue whale abundance reported for the 1991-2008 versus the 1991-2005 surveys supports this notion as the addition of the 2008 survey data reduced the overall abundance of blue whales estimated for the southern California strata. The GAM based annual trend analysis presented in the current study indicates that after the northward shift in distribution described for the species in the late 1990's, the number of blue whales using the SCC over the last nine years has remained relatively stable.

Blue whale abundance peaked in summer followed by a five-fold decrease in fall; the species was only seen once during the winter and never sighted in spring. Continuous, year-round acoustic monitoring off southern California corroborates that blue whales are present in summer and fall and rare or absent at other times of year (Burtenshaw *et al.* 2004; Oleson *et al.* 2007). The seasonal occurrence patterns for blue whales observed in the current study also corresponds to the well described migration pattern for this species with an influx of feeding whales off California from May to November followed by movement to more southerly waters off Mexico and Central America during winter and spring (Calambokidis *et al*. 1990; Mate *et al*., 1999).

Fin whales were the most frequently encountered and most abundant baleen whale in the CalCOFI study area with notable variations in both annual and seasonal abundances across the study period. The overall estimate of 718 (CV=0.22) fin whales in the CalCOFI study area is similar to both the estimate of 499 (CV=0.27) reported from pooled 1991-2008 surveys (Barlow 2010) and the estimate of 359 (CV=0.40) from pooled 1991-2005 surveys (Barlow and Forney 2007) in a similar region off southern California. The slightly higher values obtained from our more current abundance estimates as well as the increasing trend revealed from the GAM based annual trend analysis coincides with a long-term of increase in fin whale abundance off

California described for this species based on Bayesian state space model trend analysis (Moore and Barlow 2011).

In contrast to blue whales, fin whales were present year round in the SCC with peak abundance in summer, followed by a decrease in fall. Continuous, year-round acoustic monitoring off southern California identified a similar pattern where fin whale calls were detected year-round (Oleson 2005, Sirovic *et al*. 2013). The year-round presence of fin whales in the SCC may be linked to the less selective and more varied diet of this species versus blue and right whales (Perry *et al*. 1999a). The relatively wider range of prey items consumed by fin whales, including krill, copepods, cephalopods, and small schooling fish such as sardines, herring and anchovies (Mizroch *et al*. 1984), suggests that this species may utilize prey resources available throughout the year versus the focused krill foraging behavior associated with the presence of blue whales in summer and fall.

The overall abundance estimate of 351 (CV=0.26) humpback whales in the CalCOFI study area is considerably higher than both the estimate of 36 (CV=0.51) reported from pooled 1991- 2005 surveys off southern California (Barlow and Forney 2007) and the estimate of 49 (CV=0.43) from the 2008 survey (Barlow 2010). The difference in estimated abundance between the current study and earlier work is partly due to sample size. That is, the current study had 65 humpback whale sightings from 2004-2013 while earlier studies from 1991-2005 and 1991-2008 had 5 and 9 sightings, respectively. In addition, these earlier surveys were conducted during summer and fall and therefore missed the apparent spring peak in abundance described herein.

Across the nine-year study period, while annual variations were apparent, the GAM-based inverse variance weighted trend-line indicated in the number of humpback whales estimated to be utilizing the study area was relatively stable overall. Seasonal occurrence patterns and abundance estimates of humpback whales indicate that the species is present in the SCC year-round with the greatest concentration during the spring versus the summer. Continuous year-round acoustical monitoring in the SCC identified similar patterns where humpback vocalizations, although most frequent in spring, are detected year round (Helble *et al*. 2013). This pattern is consistent with the notion that the peak abundance observed for humpback whales during spring represents both individuals migrating between wintering grounds south the SCC (i.e. Mexico and Central American) and summer feeding grounds north of the SCC (i.e. US West Coast and Alaska), as well as animals that feed in the SCC for an extended period. The year-round presence of humpback whales in the SCC may be linked to the more varied diet of this species versus blue whales. The relatively wider range of prey items consumed by humpback whales, including krill, copepods, cephalopods, and small schooling fish such as sardines, herring and anchovies (Perry *et al*. 1999b), suggests that this species may utilize prey resources available throughout the year versus the focused krill foraging behavior associated with the presence of blue whales in summer and fall. The year-round presence of humpback whales and the seasonal shift in distribution described in the current study also supports previous research where it was noted that along California, a significantly greater proportion of the humpback whale population was found farther offshore during winter than in summer (Clapham *et al*. 1997, Forney and Barlow 1998).

Short-beaked common dolphins were the most abundant and widely distributed cetacean observed during the current study, supporting findings from previous cetacean surveys off

California (Dohl *et al*. 1986; Forney *et al*. 1995, Barlow and Forney 2007, Barlow 2010). The overall estimate of 139,120 (CV=0.16) common dolphins in the CalCOFI study area is very similar to both the estimate of 152,000 (CV=0.17) reported from pooled 1991-2008 surveys (Barlow 2010) and the estimate of 165,400 (CV=0.19) from pooled 1991-2005 surveys (Barlow and Forney 2007) in a similar region off southern California.

Seasonally, short-beaked common dolphin abundance peaked in summer, declined to some extent in fall, increased slightly in winter, and declined considerably in spring (Table 4). During summer and fall cruises, short-beaked common dolphins were observed throughout the study area, including the northern edge of the study area on CalCOFI line 77, whereas during winter and spring cruises, no sightings occurred north of CalCOFI line 83. This distributional pattern suggests that the middle of the study area represents the northern range limit of the species in southern California during the colder water seasons of winter and spring. The peak abundances observed during the summer and winter seasons as well as the seasonal distribution patterns suggest that an influx of short-beaked common dolphins move into the study area from the south in early summer, continuing their movement into more northerly waters during late summer and fall, followed by a return to warmer, southerly waters in late fall and early winter. Thus, the higher levels of abundance in summer and winter have resulted from a larger concentration of the population being present in the study area during the "transition" periods of summer and winter. The annual and seasonal variations in short-beaked common dolphin abundance observed in the current study support findings from previous research in the SCC indicating annual and seasonal differences in the extent of movement into southern California waters from a range that extends well outside the southern CalCOFI study area (Dohl *et al*. 1986; Barlow 1995; Forney *et al*. 1995).

Pacific white-sided dolphins were the second most frequently encountered delphinid in the CalCOFI study area with notable variations in both annual and seasonal abundances across the study period. Continuous, year-round acoustic monitoring off southern California corroborates that Pacific white-sided dolphins occur most frequently during winter and spring, but are present at other times of year (Soldevilla *et al*. 2010). The overall estimate of 9,725 (CV=0.26) Pacific white-sided dolphins is more than four times greater than both the estimate of 2196 (CV=0.39) reported from pooled 1991-2005 surveys (Barlow and Forney 2007) and the estimate of 1914 (CV=0.39) from pooled 1991-2008 surveys in a similar region off southern California (Barlow 2010). The difference in estimated abundance between the current study and earlier work is likely due to the earlier studies having been conducted during summer and fall when Pacific white-sided dolphins are less abundant than winter and spring in SCC waters.

Dall's porpoise were the second most frequently encountered small cetacean in the study area, supporting findings from previous studies off southern California (Barlow and Forney 2007). The overall abundance estimate of 5,855 (CV = 0.22) is much higher than both the estimates of 727 (CV=0.99) from pooled 1991-2005 surveys (Barlow and Forney 2007) as well as the estimate of 634 (CV=0.52) from pooled 1991-2008 surveys (Barlow 2010) for southern California. These earlier studies were conducted during summer and fall when the current study found Dall's porpoise to be nearly absent from SCC waters. This difference in seasonal survey effort likely explains the large discrepancy in Dall's porpoise abundance between the current and earlier studies. In addition, Dall's porpoise estimates in the current study may be positively biased as a result of vessel attraction and the related inclusion of sightings that occurred in

Beaufort seas states between 0-5 versus the sea state criteria of 0-2 incorporated in previous studies (Barlow and Forney 2007). The inclusion of sightings that occurred in sea states 3-5 may preclude the observers' ability to document porpoise reactions or lack thereof to the approaching survey vessel.

Seasonally, Dall's porpoise were almost exclusively observed during the cooler water seasons of winter and spring with only four sightings of the species occurring in either summer or fall. The annual and seasonal trends in density observed for Dall's porpoise in the current study support similar findings from past research in waters off southern California indicating that Dall's porpoise are usually encountered in cooler, upwelling-modified water <17°C (Becker 2007, Forney *et al*. 2012), and are more frequently sighted during the cooler water periods of winter and spring (Dohl *et al*. 1986, Barlow 1995, Barlow and Forney 2007, Becker *et al*. 2010).

Differences in study area boundaries and field methodology during CalCOFI surveys versus earlier surveys may have been factors in some of the observed variations in abundance estimates. The CalCOFI study area differs in size from the southern California region utilized in earlier studies (e.g. Barlow and Forney 2007, Barlow 2010). The CalCOFI study area extends from 75 km north of Point Conception to 330 km offshore in the northern portion and 700 km offshore in the southern portion for a total of 238,494 km^2. The southern California strata utilized for previous abundance estimates has a similar southern boundary, yet the northern boundary is at Point Conception, 75 km south of the CalCOFI boundary and the study area extends further offshore, particularly in the northern portion, for a total of 318,500 km^2, resulting in a stratum area that is 25% larger than the CalCOFI study region. CalCOFI surveys strictly incorporate passing mode for all cetacean visual observations while the earlier surveys were primarily conducted using closing mode. While closing mode allows for better resolution of species identification as well as group size estimation, Buckland *et al*. (2001) suggested that closing mode surveys can create a negative bias in abundance estimates. The detection range and associated ESW was greater on the earlier surveys as observers utilize 25x150 binoculars for searching and detection while CalCOFI cruises used hand-held 7x50. While the greater detection range and ESW acquired from higher powered binoculars results in a greater number of sightings, if groups are randomly distributed relative to the transect line, the overall abundance estimates should be similar regardless of absolute detection range.

CONCLUSIONS - VISUALS

Cetacean monitoring on CalCOFI cruises has been conducted over the last nine years to make overall, annual and seasonal estimates of cetacean density and abundance, and to investigate cetacean distribution patterns relative to habitat features. In the current study, we described the seasonal and annual trends in occurrence, distribution and abundance for the six most frequently sighted species of cetaceans in the SCC, representing the first assessment of continuous long-term trends in cetacean abundance in the SCC. Several other cetacean species (e.g. Cuvier's beaked whales (*Ziphius cavirostris*)) that were documented during the course of the nine-year study were not included in the current analysis due to small sample sizes; additional data collected from ongoing quarterly CalCOFI marine mammal surveys will allow for inclusion of this and other less frequently sighted species in future analyses.

Cetacean sighting data from other cruises in the SCC has recently been integrated into habitat-based density modeling exercises designed to create predictive models to forecast near real-time marine mammal distribution (*e.g*. Becker *et al*. 2012, Forney *et al*. 2012); the primary goal of this work is to inform planning of operations by the US Navy with the hope of minimizing any potential impact to marine mammals in the SCC. The data set utilized for the current study will soon be integrated with other line-transect survey data collected in the SCC, resulting in a more robust spatial and temporal data set from which improved habitat density modeling analysis can be achieved.

Acoustic Methods

Acoustic Data Collection

Acoustic monitoring for cetaceans during transits was conducted using a 6-element 300 m towed hydrophone array. Each pre-amplified element was band-pass filtered from 1.5 kHz to 200 kHz to decrease flow noise at low frequencies and to protect from signal aliasing at high frequencies. The multi-channel array data were sampled using both a MOTU 896 at 192 kHz and a National Instruments USB 6152 at 500 kHz to allow for a broad range of frequencies to be recorded. When possible, an acoustic technician monitored the incoming signals from the towed array using both a real-time scrolling spectrogram and headphones. Acoustic monitoring at CalCOFI oceanographic sampling stations was conducted with passive SSQ-53F DIFAR sonobuoys. Sonobuoys were deployed 1 nm before each daylight station to a depth of 30 m and recorded for 2-3 hours while oceanographic sampling was underway. An acoustic technician monitored the sonobuoy signals for cetacean calls using a scrolling spectrogram display and headphones. Mysticete calls, sperm whale clicks as well as low frequency dolphin calls, including whistles, buzzes and the lower frequency components of clicks were recorded with this system.

Acoustic Data Analysis

Acoustic data collected from the towed acoustic array was analyzed in real-time for the presence of calls from all odontocete cetaceans. Sonobuoys deployed on CalCOFI stations were analyzed in real-time for presence of blue, fin and humpback whale vocalizations as well as odontocete calls. Field-based event detections from the towed array and sonobuoys are further examined post-cruise to confirm initial signal classification and to better characterize call characteristics. The structural elements of cetacean calls collected on CalCOFI cruises are currently being measured and incorporated into the development of detection and classification algorithms that are utilized for detection of cetacean calls from long-term autonomous sea-floor recordings from HARPs off Southern California. Baleen whale calls are measured along several parameters including duration, frequency structure, and inter-call interval. Odontocete echolocation clicks are assessed through the calculation of several variables including duration, inter-click interval, peak frequency points, -3dB bandwidth, -10 dB bandwidth and center frequency. Delphinid whistle structure analysis entails the extraction of eight specific variables from each whistle contour: begin frequency, end frequency, minimum frequency, maximum frequency, frequency range, mean frequency, duration, and number of inflection points. Call variables are subsequently applied to multivariate statistical analysis to examine the within species/population and between species/population variability inherent in the data.

RESULTS - ACOUSTICS

Towed Array

Towed array recordings included click, whistles and burst pulse calls from odontocetes (Figures 23 & 24). Acoustic detections from the towed array included 6 odontocete species encompassing a total of 145 detections across the five CalCOFI crusies from August 2012-December 2013 (Figures 25-29, Table 6). Acoustic detection rates varied by species; of the 140 cetacean acoustic detections, unidentified delphinids comprised 54% (n=76), common dolphins 29% (n=40), sperm whales accounted for 7% (n=10), Risso's dolphins for 3% (n=4), northern right-whale dolphins

2% (n=3), Pacific white-sided dolphins 2% (n=3), and bottlenose dolphins 1% (n=2). Sperm whale acoustic detections outnumbered visual detections by a factor of 5 (10 to 2), reinforcing the value and importance of using passive acoustic arrays to document the presence of this and other deep-diving odontocetes in the study area.

Table 6. Summary of towed acoustic array data collected on five CalCOFI cruises between August 2012 and December 2013.

CalCOFI Cruise Dates	Number of Array Deployments	Array Data (hrs)	Number of Array Detections/ Species
19 Oct - 05 Nov 2012	24	83	32/1
10 Jan - 02 Feb 2013	25	71	22/4
06 Apr - 30 Apr 2013	29	94	17/4
06 Jul - 22 Jul 2013	30	83	31/6
09 Nov - 24 Nov 2013	23	52	38/5
Totals	**131**	**383**	**140/7**

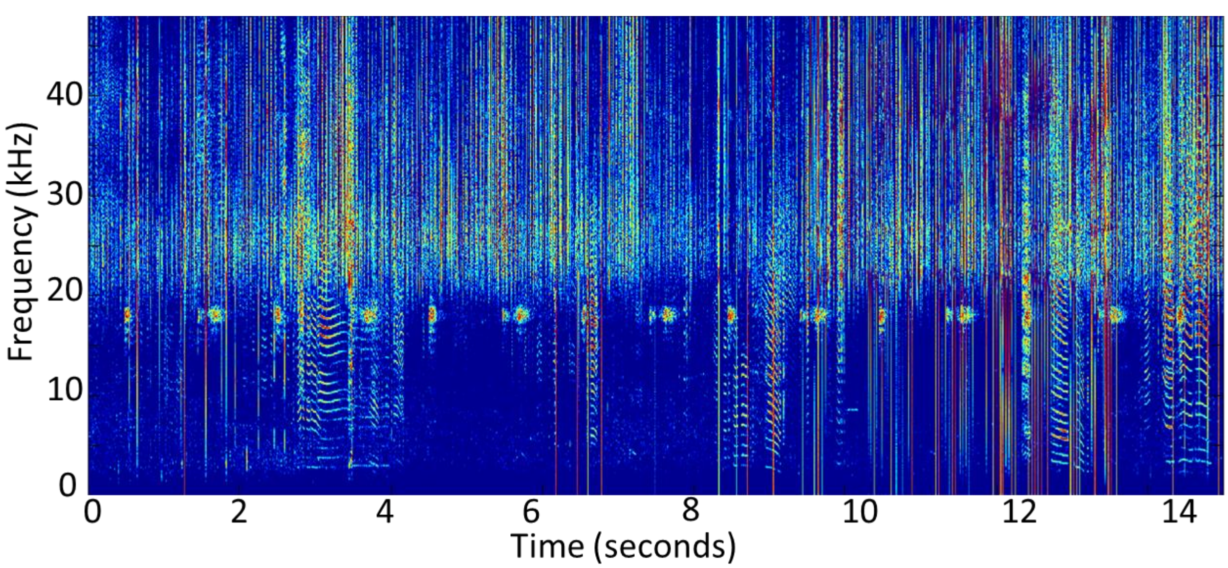

Figure 23. Spectrogram of northern right whale dolphin (*Lissodelphis borealis*) vocalizations recorded on towed acoustic array on July 16, 2013.

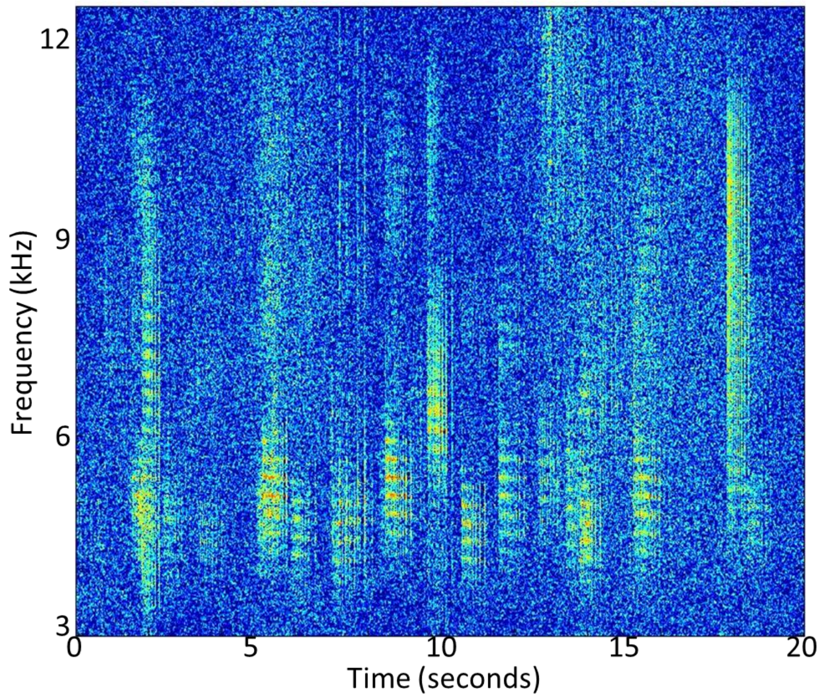

Figure 24. Spectrogram of sperm whale (*Pyster macrocephalus*) vocalizations recorded on towed acoustic array on April 25, 2013.

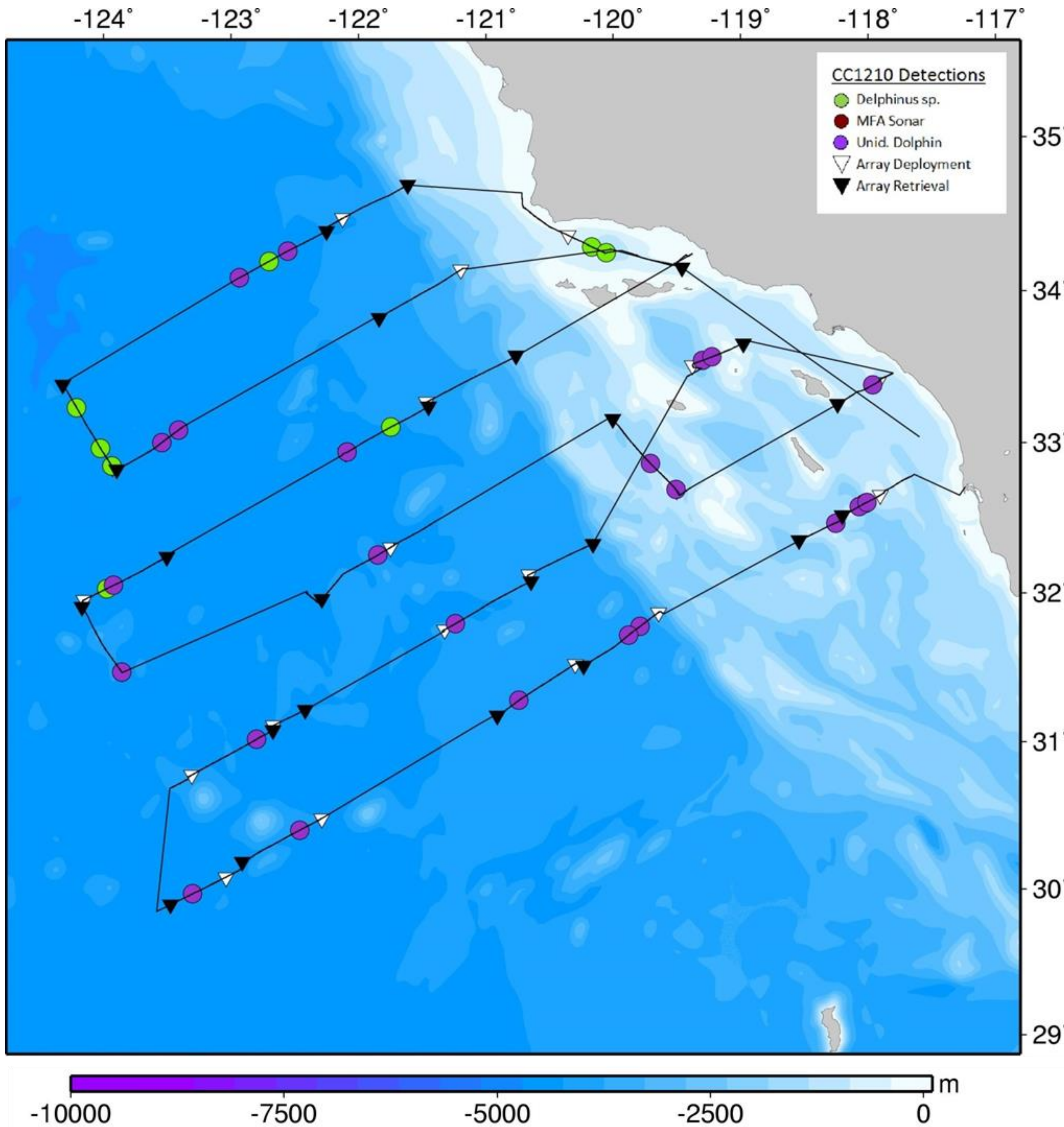

Figure 25. Towed acoustic array deployments, recoveries, odontocete detections by species and MFA sonar during the October 2012 CalCOFI cruise.

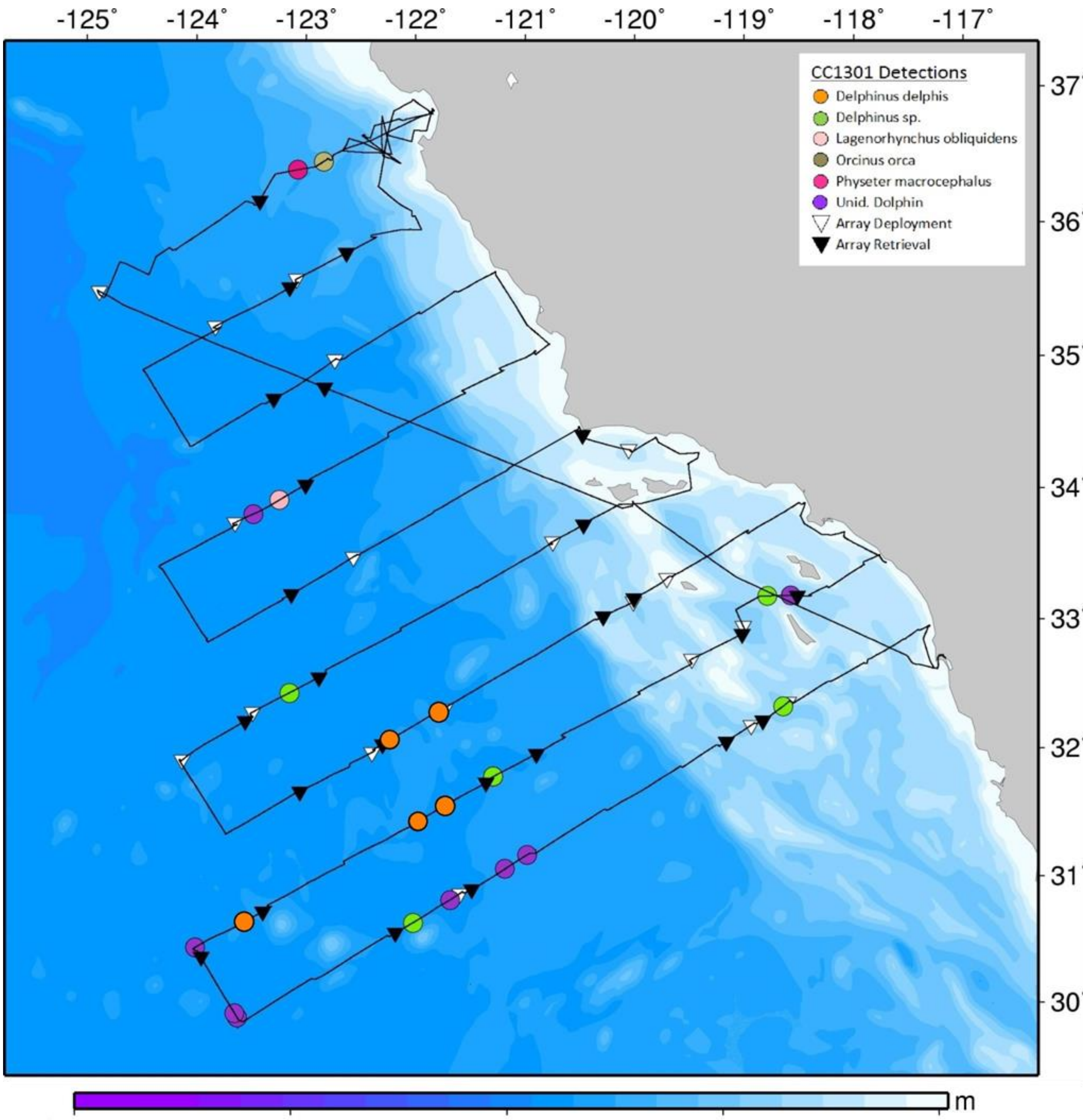

Figure 26. Towed acoustic array deployments, recoveries, and odontocete detections by species during the January, 2013 CalCOFI cruise.

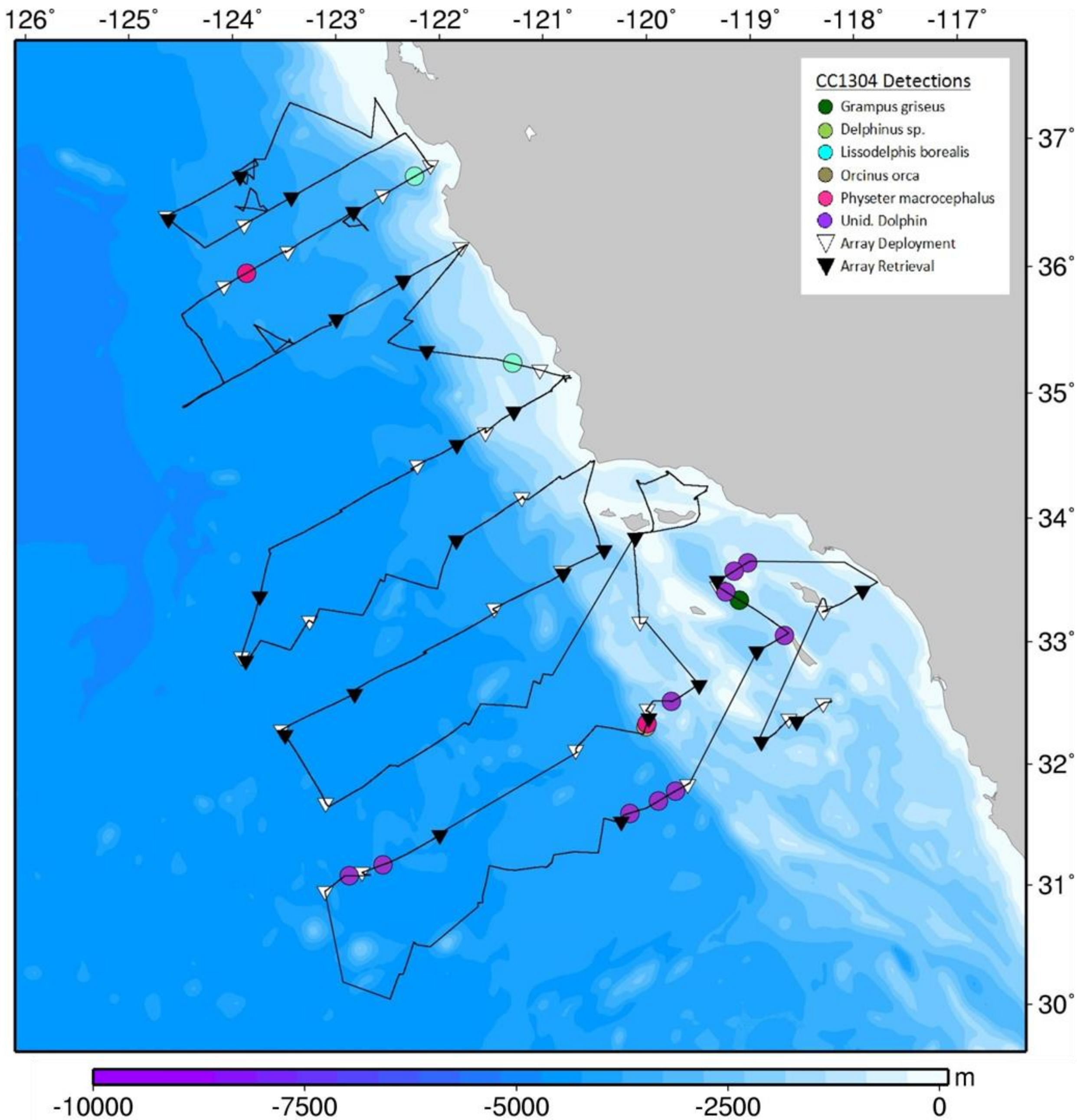

Figure 27. Towed acoustic array deployments, recoveries, and odontocete detections by species during the April, 2013 CalCOFI cruise.

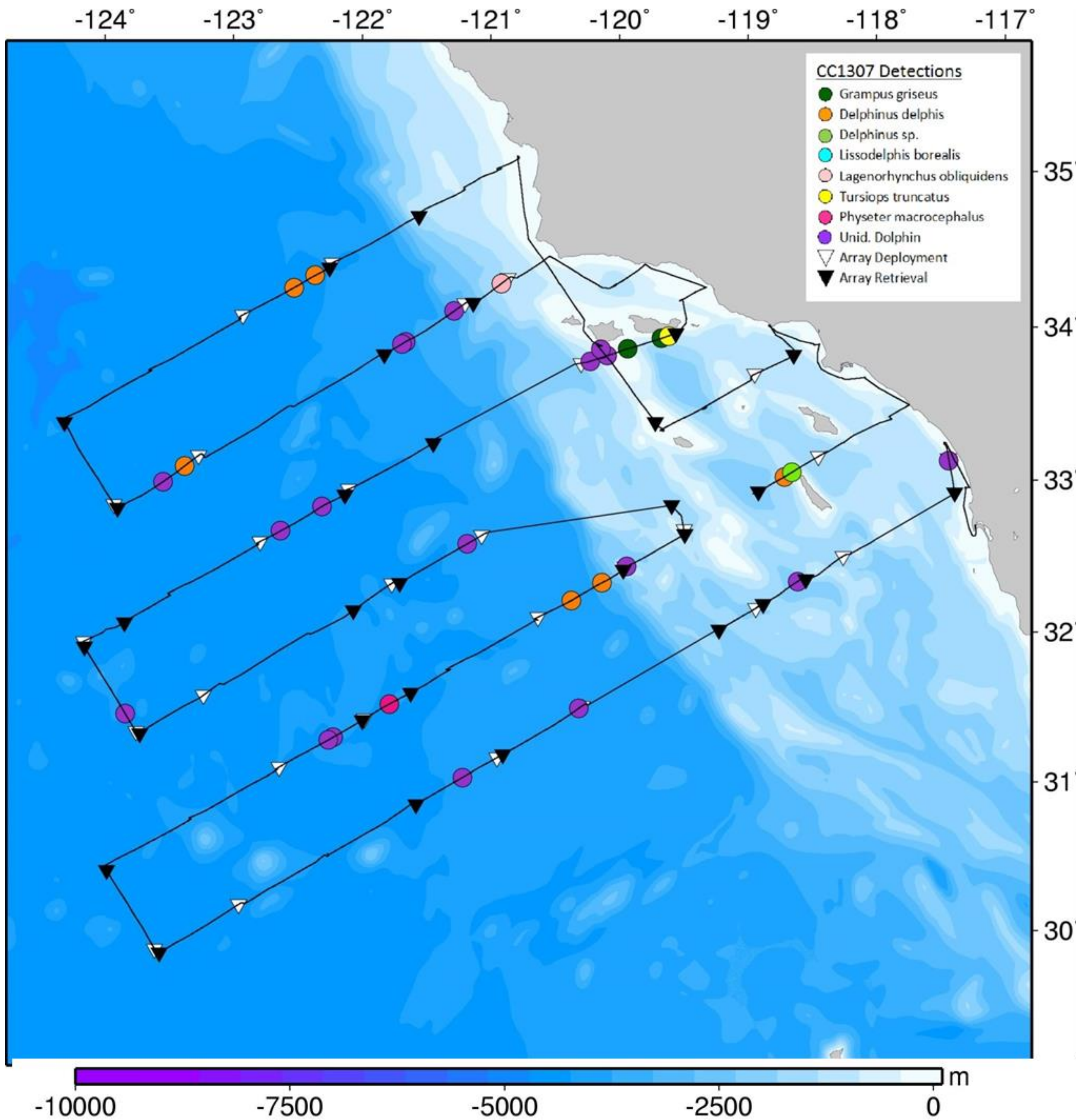

Figure 28. Towed acoustic array deployments, recoveries, and odontocete detections by species during the July, 2013 CalCOFI cruise.

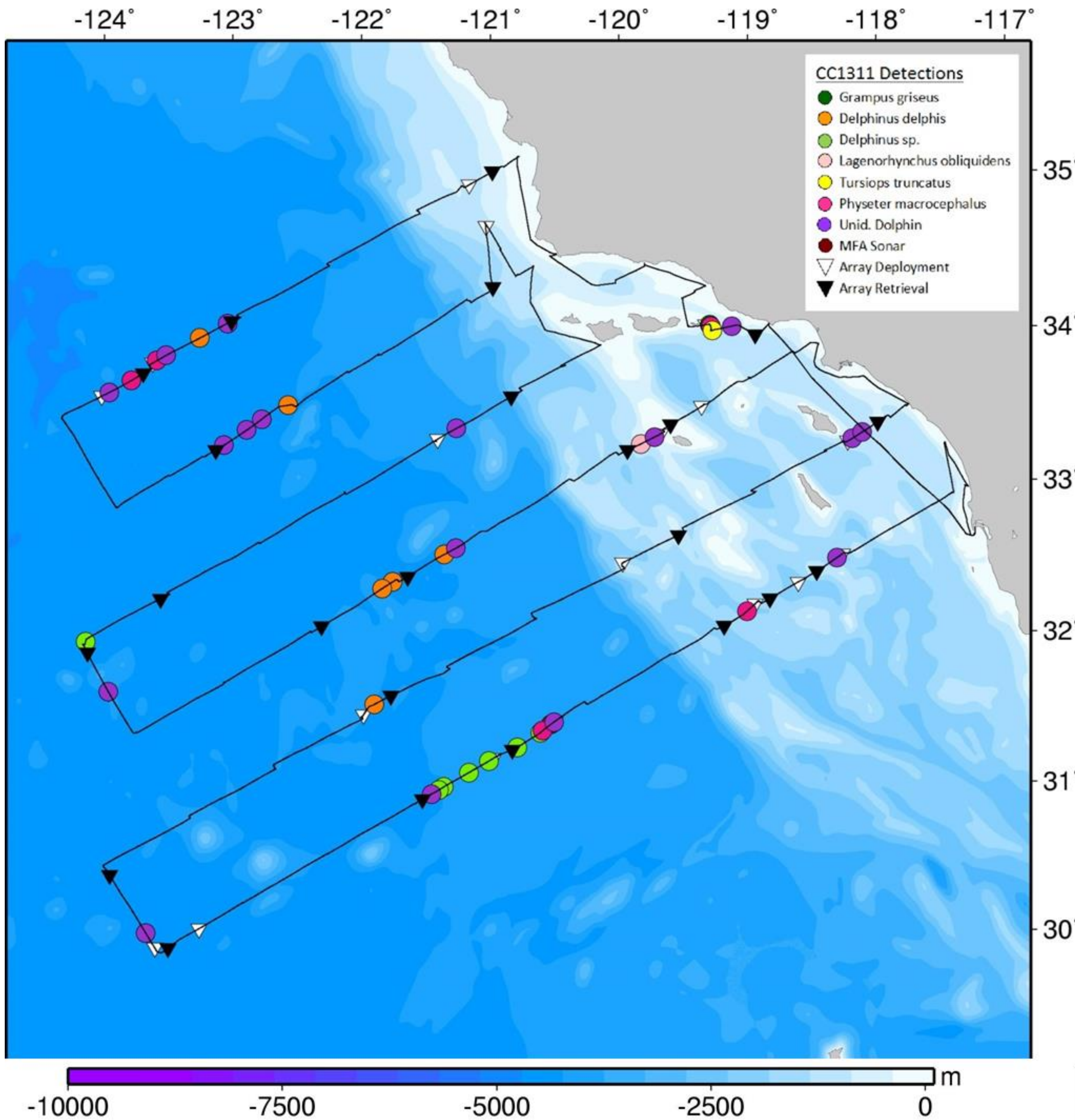

Figure 29. Towed acoustic array deployments, recoveries, odontocete detections by species, and MFA sonar detections during the November, 2013 CalCOFI cruise.

Sonobuoys

Real-time acoustic detections from sonobuoys included four acoustically distinct large whale species: blue, fin, humpback, and sperm whales (Figures 30 & 31), as well as unidentified dolphins for a total of 195 detections across the five CalCOFI crusies from August 2012-December 2013 (Figures 32-36, Table 7). Acoustic detection rates in the study area varied by species. Of the 195 acoustic detections, humpback whales accounted for 32% (n=63), fin whales 23% (n=45), blue whales 16% (n=31), sperm whales 11% (n=22), and unidentified dolphins accounted for 17% (n=34).

Table 7. Summary of sonobuoy data collected on five CalCOFI cruises between August 2012 and December 2013.

CalCOFI Cruise Dates	Number of Sonobuoys Deployed	Sonobuoy Data (hrs)	Number of Sonobuoy Detections/ Species
19 Oct - 05 Nov 2012	52	63	26/4
10 Jan - 02 Feb 2013	58	59	42/4
06 Apr - 30 Apr 2013	62	62	47/4
06 Jul - 22 Jul 2013	64	77	24/3
09 Nov - 24 Nov 2013	55	81	56/4
Totals	**291**	**342**	**195/4**

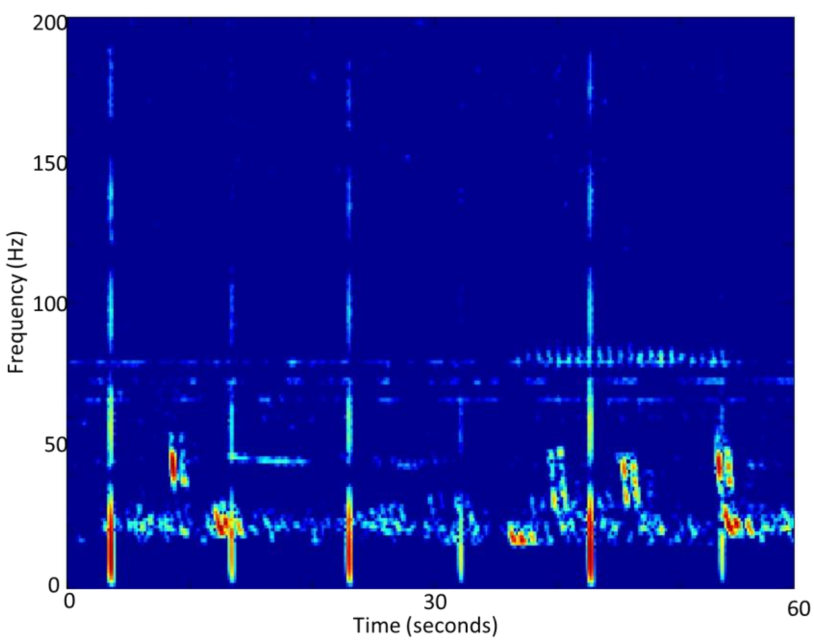

Figure 30. Spectrogram of higher frequency fin whale calls recorded on a sonobuoy on October 27, 2012

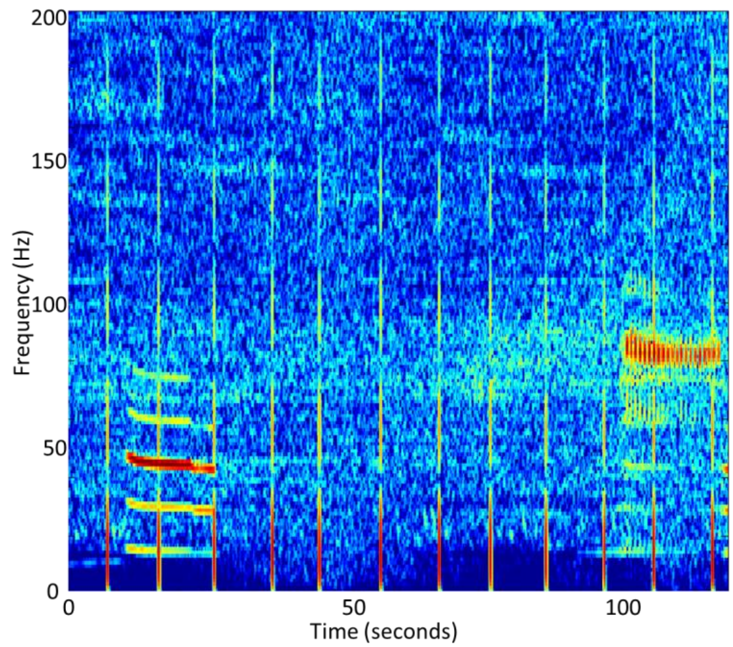

Figure 31. Spectrogram of blue whale ABAB song recorded on a sonobuoy on October 31, 2012.

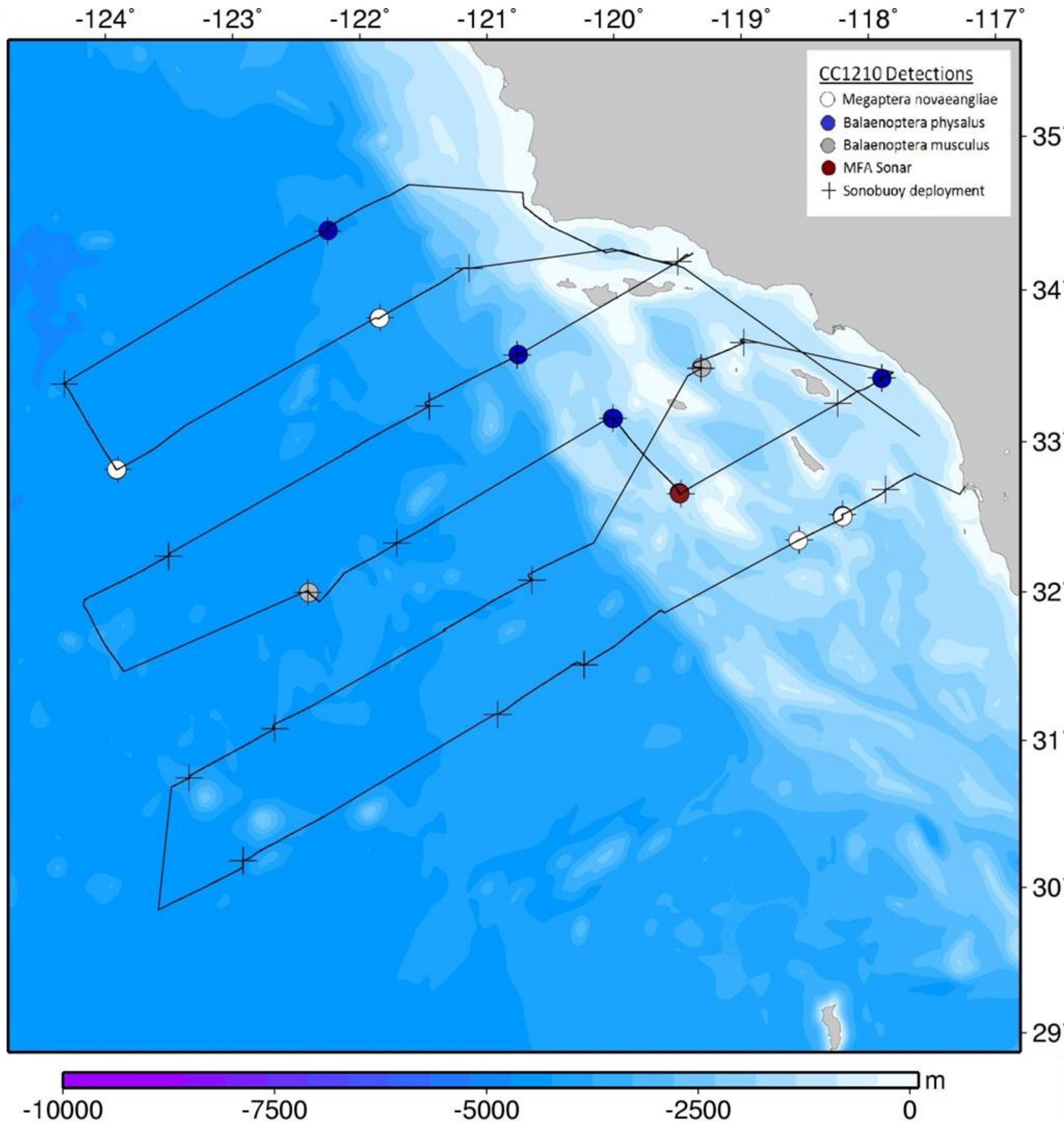

Figure 32. Sonobuoy deployments, acoustic detections by cetacean species, and MFA sonar detections during the October, 2012 CalCOFI cruise.

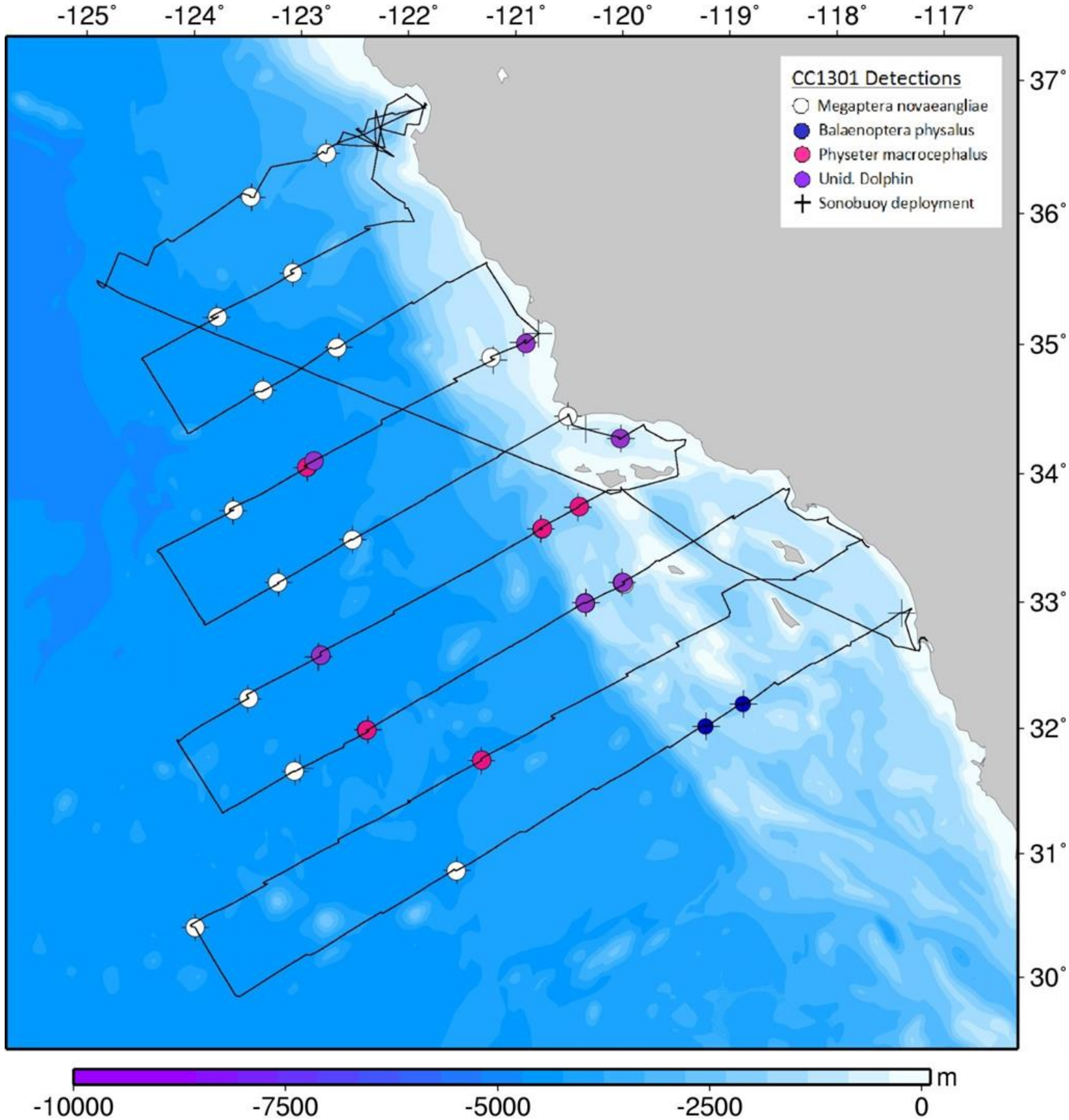

Figure 33. Sonobuoy deployments and acoustic detections by cetacean species during the January, 2013 CalCOFI cruise.

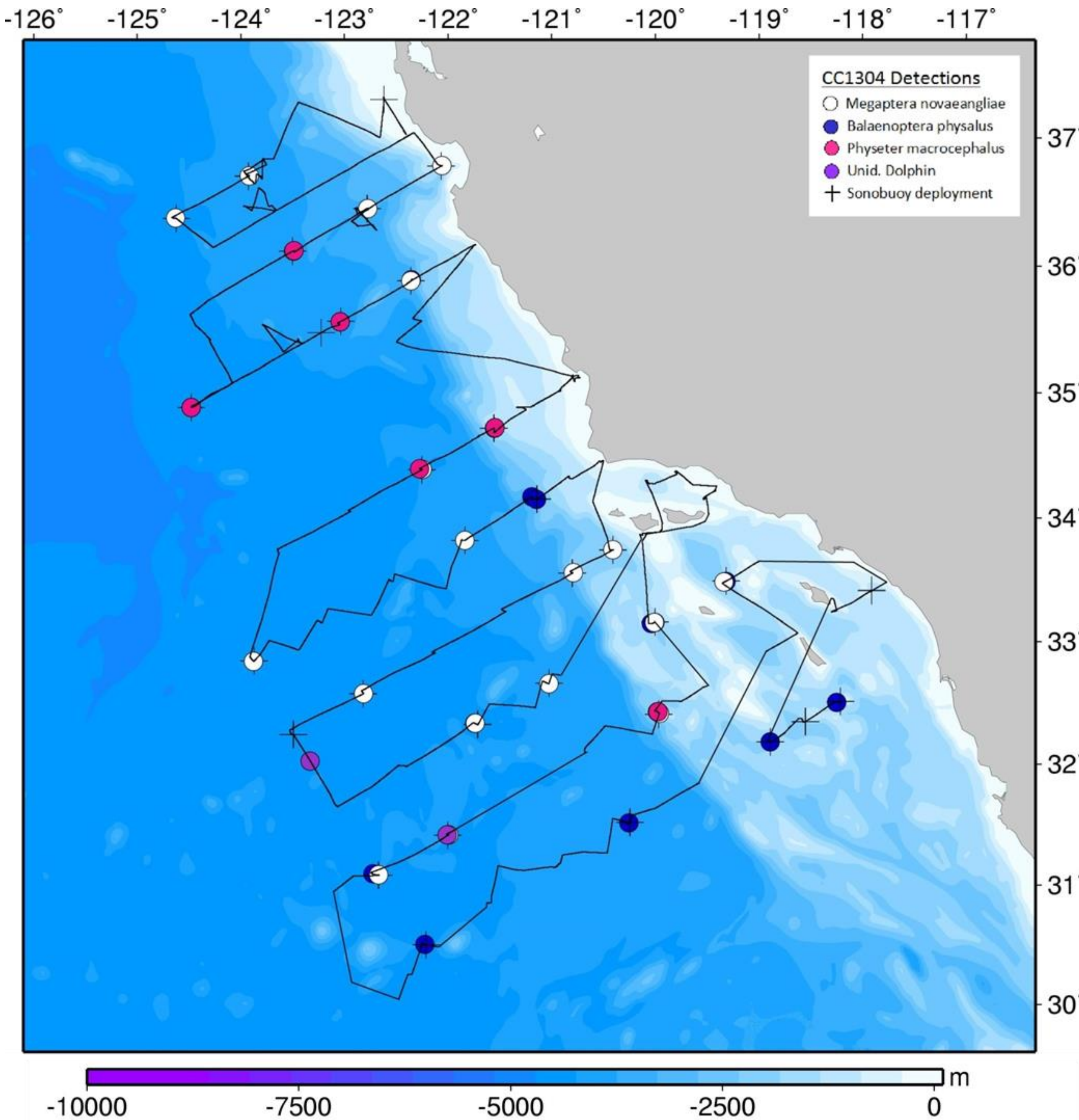

Figure 34. Sonobuoy deployments, acoustic detections by cetacean species, and MFA sonar detections during the April, 2013 CalCOFI cruise.

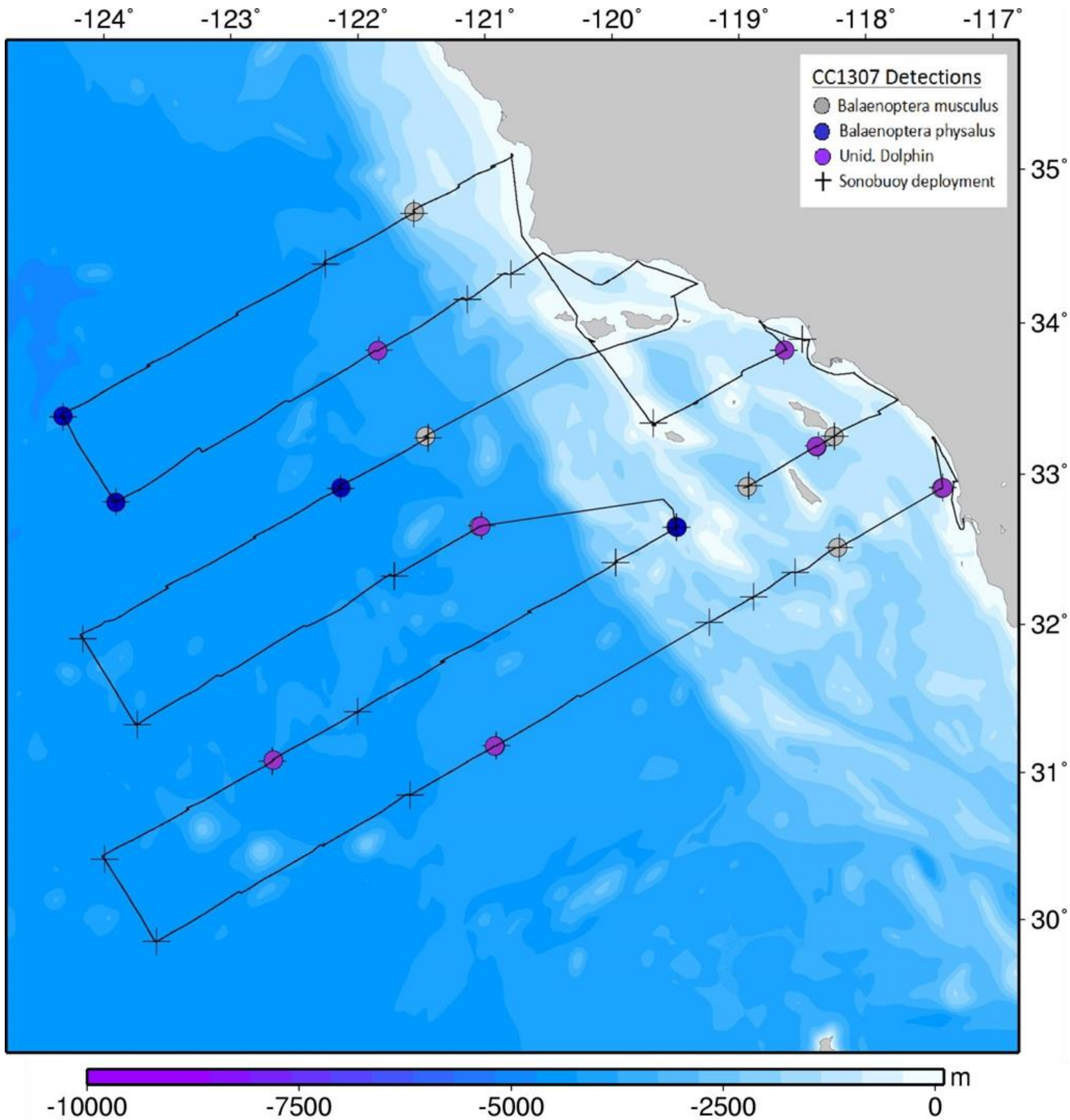

Figure 35. Sonobuoy deployments and acoustic detections by cetacean species during the July, 2013 CalCOFI cruise.

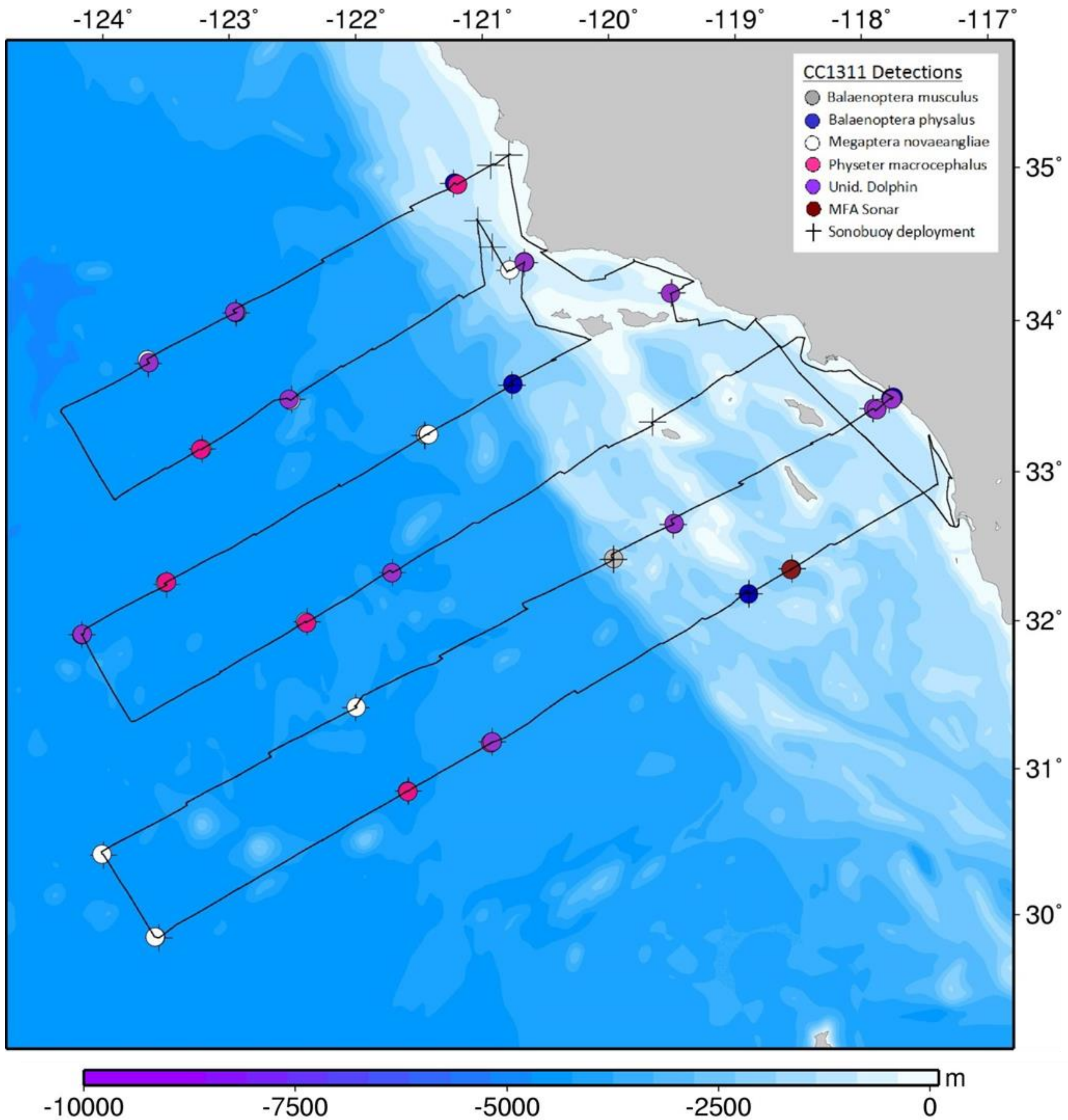

Figure 36. Sonobuoy deployments, acoustic detections by cetacean species, and MFA sonar detections during the November, 2013 CalCOFI cruise.

DISCUSSION - ACOUSTICS

Spatial patterns in odontocete acoustic array detections were apparent for some species and typically paralleled known species distributions based on visual detections. Sperm whale acoustic detections generally occurred in offshore waters, Risso's and bottlenose dolphin vocalizations were documented in shelf waters near the Channel Islands, killer whale calls were recorded near the shelf-break, Pacific white-sided dolphins were detected in both shelf and offshore waters, and northern right whale dolphins were detected in shelf waters in the northern portion of the study area. Common dolphin and unidentified whistling and clicking dolphin detections were dispersed throughout the study area with the exception of the immediate coastline. The wide distribution and frequent occurrence of unidentified vocalizing delphinds in the study area, in accordance with the infrequent visual sightings of other whistling species of delphinids, suggests that the majority of these acoustic detections are common dolphins. Ongoing development of our whistle classification algorithms will improve species classification accuracy for unidentified whistles.

We are currently investigating the utility of analyzing towed acoustic array data using DISTANCE sampling methods. There are a number of research groups who have a common interest in developing new methods to utilize towed array line-transect data for estimating the density and abundance of cetaceans. In order to conduct acoustic-based density and abundance estimates, the five major data points that need to be established from the towed acoustic array data include species, distance and angle of vocalizing animals, group size and the probability of detection on the track-line –or- g(0).

Seasonal and spatial variations in call detections as a function of species were apparent. Humpback whales were detected visually but rarely acoustically inshore in summer, whereas humpbacks were detected both acoustically and visually offshore during winter and spring. Blue whale calls were frequently heard throughout much of the study area during summer and fall while acoustic detections of these species were rare during winter and spring cruises; fin whale calls were documented in both shelf and pelagic waters across all seasons. Visual detections of blue and fin whales exhibited similar seasonal occurrence patterns, suggesting that acoustic monitoring of these two baleen whale species provides a useful metric for assessing presence/absence in the study area. Sperm whale clicks were regularly detected in shelf and offshore waters during all seasons except summer; only two visual detections of sperm whales occurred across the five cruises, further reinforcing the utility of incorporating acoustic detection methods for this species. Current research is focused on the distribution of sonobuoy-based baleen whale detections as a function of environmental variables using general additive modeling methods.

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Appendix I. Species codes.

SPECIES CODE		
Ba = *Balaenoptera acutorostrata* (minke whale)	Er = *Eschrichtius robustus* (grey whale)	Pd = *Phocoenoides dalli* (Dall's porpoise)
Bm = *Balaenoptera musculus* (blue whale)	Gg = *Grampus griseus* (Risso's dolphin)	Pm = *Physter macrocephalus* (sperm whale)
Bp = *Balaenoptera physalus* (fin whale)	Lb = *Lissodelphis borrealis* (N. right-whale dolphin)	Sc = *Stenella coeruleoalba* (striped dolphin)
Dc = *Delphinus capensis* (long-beaked common dolphin)	Lo = *Lagenorhynchus obliquidens* (Pacific whiste-sided dolphin)	Tt = *Tursiops truncatus* (bottlenose dolphin)
Dd = *Delphinus delphis* (short-beaked common dolphin)	Mn = *Megaptera noveangliae* (humpback whale)	Zcav = *Ziphius cavirostris* (Cuvier's beaked whale)
Dspp = *Delphinus spp.* (unid. Common dolphin)	Oo = *Orcinus orca* (killer whale)	UD = unidentified dolphin ULW = unidentified large whale