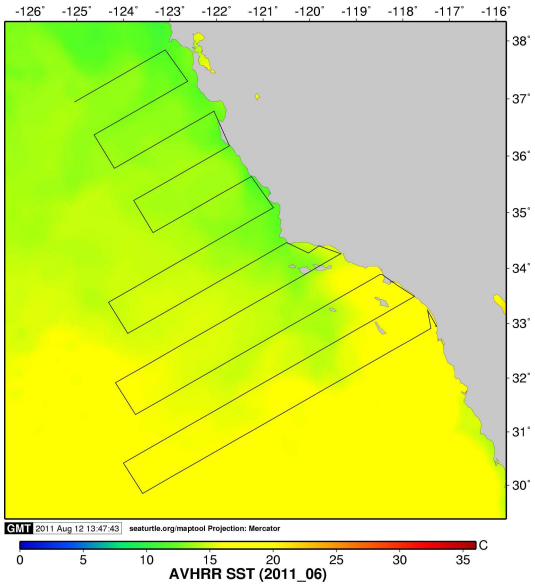
CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATION (CALCOFI) CRUISES: 2010-2011



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ABSTRACT

Spatial and temporal distribution patterns, density and abundance of cetaceans in the southern California Bight were assessed through visual and acoustic surveys during four California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises from August 2010 – April 2011. 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 455 observation hours covering 3,800 kilometers yielding 268 sightings of 15 cetacean species. Fin whales were the most frequently sighted baleen whale species, followed by blue, gray, and humpback whales. Common dolphins were the most frequently sighted odontocete species, followed by bottlenose dolphin, Dall's porpoise, Pacific white-sided dolphin, Risso's dolphin, and sperm whale. Seasonal variations in encounter rates and distributions were evident for some species. Grey whales and Dall's porpoise were sighted primarily in fall and winter, whereas blue and fin whales were visually detected in spring and summer. Pacific white-sided dolphins were observed in all seasons except summer. Sperm whales were only sighted during fall and winter cruises. There was no apparent seasonal pattern to sightings of bottlenose, common and Risso's dolphins, though Risso's dolphins were not detected during the fall survey. Spatial variations in visual detections as a function of species were also evident. 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. Each species showed distinct spatial and temporal distribution patterns across the study area; indicative of species-specific habitat preferences within the California Current ecosystem. Current research is investigating the association between cetacean distribution with biological and physical oceanographic variables measured during CalCOFI surveys. Density and abundance estimates of cetaceans encountered in the study area are currently the focus of an extensive line-transect analysis and modeling effort. Modeling of cetacean habitat preferences in conjunction with density and abundance estimates, will provide data needed to evaluate potential impacts from anthropogenic activities and ultimately for the development of comprehensive management protocols.

INTRODUCTION

Cetacean surveys have been integrated into California Cooperative Oceanic Fisheries Investigation (CalCOFI) quarterly cruises off southern California since 2004. CalCOFI cruises have been conducted consistently on the same transect lines over the past 60 years and provide one of the longest and most extensive time series of physical and biological oceanographic data in existence. Cetacean monitoring by Scripps Institution of Oceanography incorporates both visual and acoustic methods to assess cetacean populations occurring in the California current ecosystem. The objectives of the cetacean monitoring program are to determine the temporal and spatial patterns of cetacean distribution, to compare visual and acoustic survey methods and results, to quantify differences in vocalizations between cetacean species, and to make seasonal estimates of

cetacean density and abundance within the study area. The greatest strength of CalCOFI cetacean surveys is the broad seasonal and geographic coverage within SOCAL. Sample sizes are comparable or greater than the total number of SWFSC sightings from the region. The weakness of CalCOFI cetacean surveys are that, due to time constraints, the vessel cannot alter course during the survey to better estimate group sizes and/or species identification. A comparison of visual and acoustic methods has demonstrated that most species are detected by both methods. CalCOFI cetacean surveys are planned to continue for at least the next three years. To date, estimates of cetacean density and abundance have been limited to blue, fin, and humpback whales; however, extensive line-transect analysis encompassing all commonly sighted species is currently underway. Recent analysis of baleen whale density relative to habitat type and productivity levels has proven insightful for expanding the scope and complexity of habitat modeling efforts.

METHODS

Visual Monitoring

Visual monitoring for cetaceans on four quarterly CalCOFI cruises during 2010-2011 utilized standard line-transect marine mammal survey protocol. Visual observers searched during daylight hours under acceptable weather conditions during all transits between CalCOFI stations (Beaufort sea state 0-5 and visibility greater than 1 nm). Data on time, position, ship's heading/speed, and environmental conditions were recorded at regular intervals or when conditions changed. Information on all cetacean sightings was logged systematically, including distance and bearing from the ship, species identification, group composition, estimated group size and behavior. During all surveys, 18x power binoculars were used to improve species identification after an initial sighting using 7x binoculars. See Appendix I for a comprehensive list of species included in this report along with their abbreviation codes.

Acoustic Monitoring

Acoustic monitoring for cetaceans during line-transect surveys was conducted using a 6-element 300 m towed hydrophone array. Each pre-amplified element was band-pass filtered from 3 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. An acoustic technician monitored the incoming signals from the towed array using both a real-time scrolling spectrogram and headphones. In addition, acoustic monitoring while on CalCOFI stations was conducted with both broadband passive SSQ-57B omni-directional and 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. 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.

Density and Abundance Analysis

Density and abundance analysis for nine cetacean species common to the study area of approximately 180,930 km^2 are being conducted with Distance 6.0 software. Visual data collected during twenty-eight cruises from July 2004 through April 2011 is being analyzed for both seasonal and annual patterns in density and abundance. Analytic, model-based and probability density designs have been incorporated into the current analysis to assess what approaches are best suited for the CalCOFI dataset. Preliminary analysis support the application of a model-based design which will allow us to estimate how abundance varies throughout a study area by modeling encounter rates along the line as a function of spatial covariates. Potential covariates include oceanographic variables, geographic coordinates, distance from land, and depth. Model-based approaches have become increasingly popular for analyzing distance sampling data, as they help us to understand what factors influence animal distributions, and they can be used even when transect lines are not randomly placed.

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 applied to the development of a suite of detection and classification algorithms. 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 AND DISCUSSION

Line-transect visual surveys

Four surveys covering 3,800 kilometers of track-line with 455 hours of effort were conducted from 1 August 2010 to 31 July 2011. Cetacean surveys conducted in August 2010, November 2010 and April 2011 utilized the standard CalCOFI station pattern; efforts in January 2011 also surveyed the northern transects. Survey tracks representing visual and acoustic array effort for each of the four cruises are presented in Figure 1. Summary data on effort and sightings from the four CalCOFI surveys conducted from August 2010 – April 2011 are provided in Tables 1 and 2. Plots of all visual detections across the four cruises classified to species are provided in Figure 2.

Cetacean sightings across the four CalCOFI cruises included 10 odontocete and five mysticete species encompassing a total of 268 encounters (Table 2). Encounter rates of cetaceans in the study area varied by species. Fin whales were the most frequently sighted baleen whale species, followed by blue, gray, and humpback whales. Common dolphin were the most frequently encountered odontocete, followed by bottlenose dolphin, Dall's porpoise, Pacific white-sided dolphin, Risso's dolphin, and sperm whale. Killer whales and northern right-whale dolphins and were the least frequently encountered cetaceans with only one sighting per species during the four cruises (Table 2).

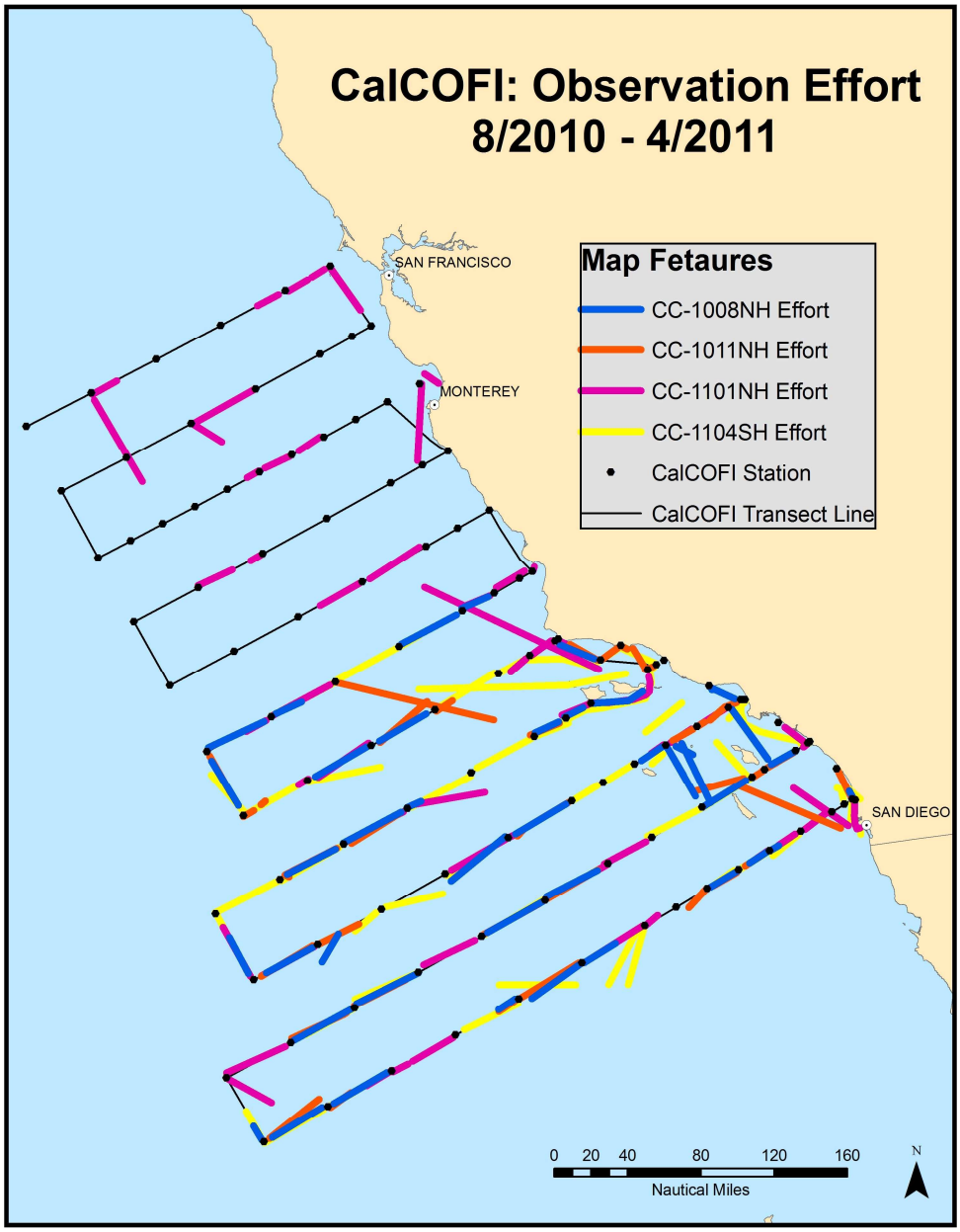

Figure 1. Marine mammal visual/acoustic survey effort by season from four CalCOFI cruises between August 2010 and April 2011.

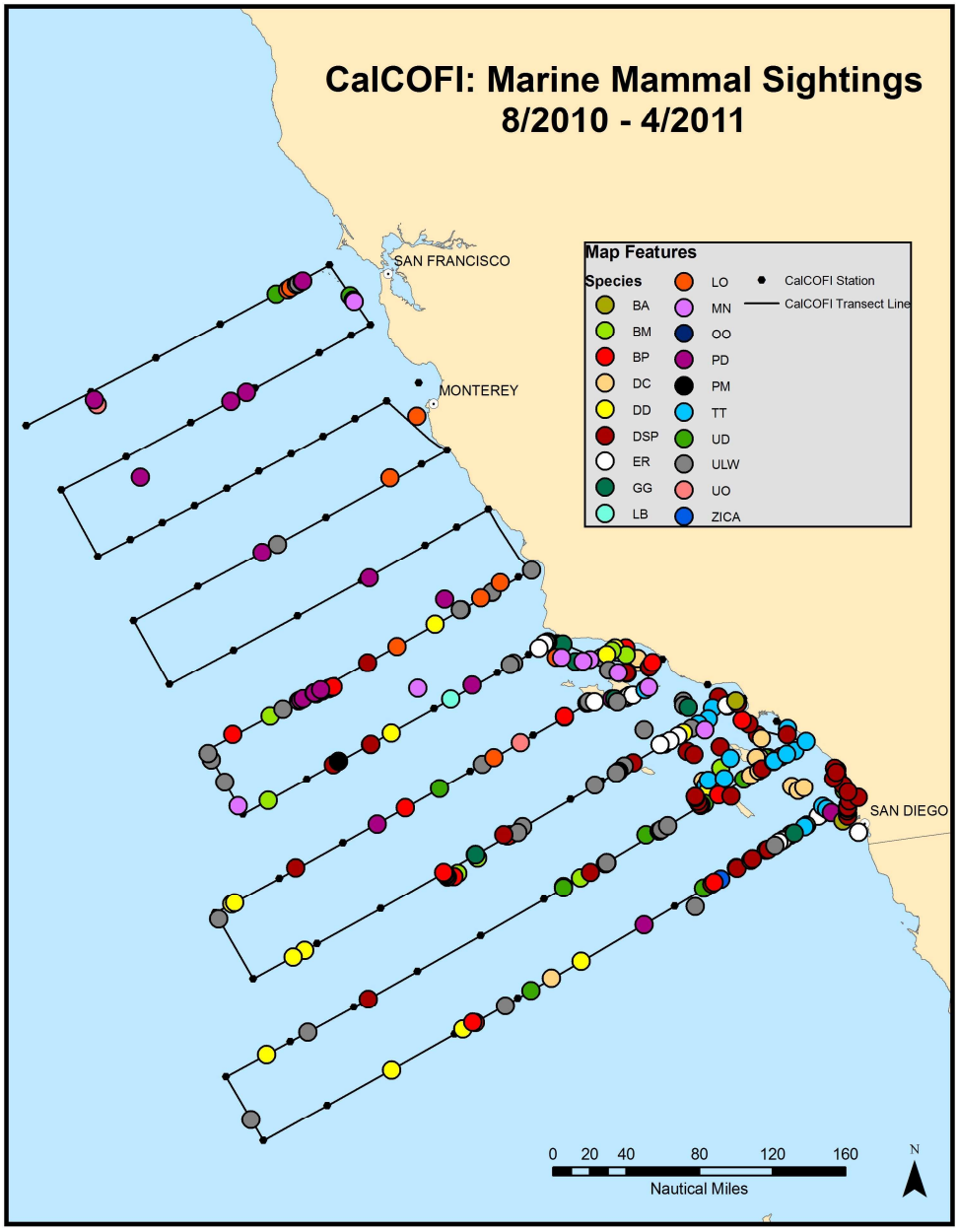

Figure 2. Cetacean sightings by species from four CalCOFI cruises between August 2010 and April 2011.

Table 1. Summary data from four CalCOFI cruises between July 2010 and April 2011.

CalCOFI Cruise Dates	Survey Effort (hrs)	Distance Surveyed (nm)	Number of Cetacean Sightings	Number of Individuals	Number of Digital Photos	Number of Acoustic Array Recordings	Total Hours of Array Recordings	Number of Acoustic Detections /Species	Number of Sonobuoys Deployed	Number of Sonobuoy Detections/ Species	Total Hours of Sonobuoy Recordings
30 Jul - 18 Aug 2010	105	997	90	4,203	665	32	92	95/6	59	54/6	202
28 Oct - 15 Nov 2010	82	582	29	2,827	622	19	64	50/4	38	12/3	112
12 Jan - 6 Feb 2011	126	802	74	1,659	200	33	94	33/5	67	26/3	141
8 Apr - 26 Apr 2011	142	1,432	75	4,710	1,113	29	70	21/5	57	37/5	97
Totals	455	3,813	268	13,399	2,600	113	320	199/8	221	129/6	552

Table 2. CalCOFI cetacean on-effort sightings by cruise from August 2010 – April 2011. See Appendix 1 for species abbreviation codes.
Ns = number sightings; Ni = number individuals

	CC1008 (30 Jul - 18 Aug 2010)		CC1011 (28 Oct -15 Nov 2010)		CC1101 (12 Jan - 6 Feb 2011)		CC1104 (8 Apr - 26 Apr 2011)	
Species	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**	**Ns**	**Ni**
Ba	0	0	1	1	2	2	1	1
Bm	10	17	0	0	1	2	3	5
Bp	19	28	1	1	0	0	6	40
Dc	7	409	5	1096	2	137	1	61
Dd	8	997	0	0	3	474	3	502
Dsp	22	2202	6	470	1	140	23	3852
Er	0	0	0	0	19	42	0	0
Gg	2	17	0	0	3	49	1	8
Lb	0	0	0	0	0	0	1	32
Lo	0	0	1	55	6	46	3	104
Mn	0	0	0	0	3	6	5	5
Oo	0	0	0	0	1	1	0	0
Pd	0	0	0	0	15	129	2	23
Pm	0	0	0	0	2	36	2	17
Sc	0	0	0	0	0	0	0	0
Tt	3	36	7	211	6	54	2	22
UD	4	470	4	165	6	535	2	9
ULW	14	18	3	3	4	6	20	29
Zcav	1	9	1	5	0	0	0	0
TOTALS	90	4203	29	2007	74	1659	75	4710

Seasonal variations in visual detection rates as a function of species were apparent. Ninety-three percent of blue whale sightings and 96% of fin whale sightings occurred in spring and summer. Gray whales were only sighted during the winter cruise and humpback whales were only seen during winter and spring surveys. Pacific white-sided dolphins were observed in all seasons except summer with 90% of all sightings in winter and spring. Sperm whales and Dall's porpoise were only sighted during fall and winter cruises. There was no apparent seasonal pattern to sightings of bottlenose, common and Risso's dolphins, though Risso's dolphins were not detected during the fall survey.

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 3 and 4). Blue and fin whales had a wide distribution with sightings throughout the study area ranging from coastal to pelagic waters. Humpback whales were seen primarily on the shelf, with the highest concentration in shallow regions around the Channel Islands. Gray whales were sighted exclusively in shelf waters, generally shoreward of the Channel Islands. Short-beaked common dolphins were seen throughout the study area, while long-beaked common dolphins were seen primarily in coastal regions and around the Channel Islands. Bottlenose and Risso's dolphins were generally sighted on the shelf, near islands and close to shore and only occasionally in more offshore waters. Pacific white-sided dolphins were observed in shelf waters ranging from near shore to the shelf-break with no defined north-south gradient. Dall's porpoise were seen throughout the

northern portion of the study area, and sperm whales were found only in deep offshore waters.

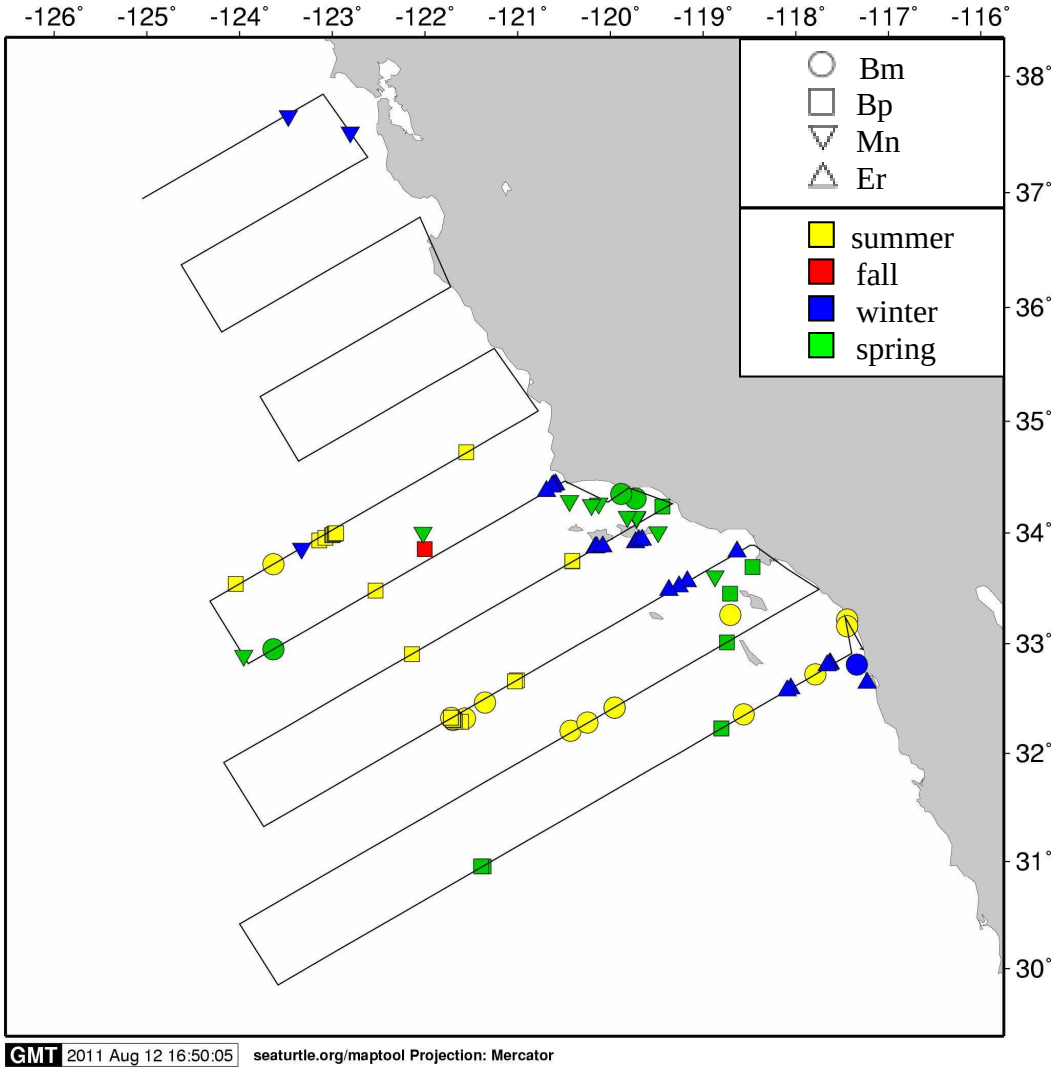

Figure 3. Visual sightings of blue, fin, humpback and grey whales by season from four CalCOFI cruises between August 2010 and April 2011.

Visual surveys did not detect noteworthy changes in cetacean assemblage off Southern California. Species richness (average number of species per km of effort) of cetaceans observed across the 2010-2011 sampling period (spring through winter) was similar to richness observed in previous years (Figure 5); however, species richness was higher in spring and lower in summer despite sighting rates that were well within the 95% CI of the average for 2004-2010 (Figures 6 and 7).

The relative abundance (number of sightings) of odontocetes in 2010-2011 was similar to that observed for previous years with the exception of Dall's porpoise which exhibited the second highest sighting rate observed for this species across the seven-year sampling period. Colder than average water temperatures in 2010-2011 may be a factor in the

increased relative abundance observed for Dall's porpoise as this species is generally restricted to cold/temperate waters.

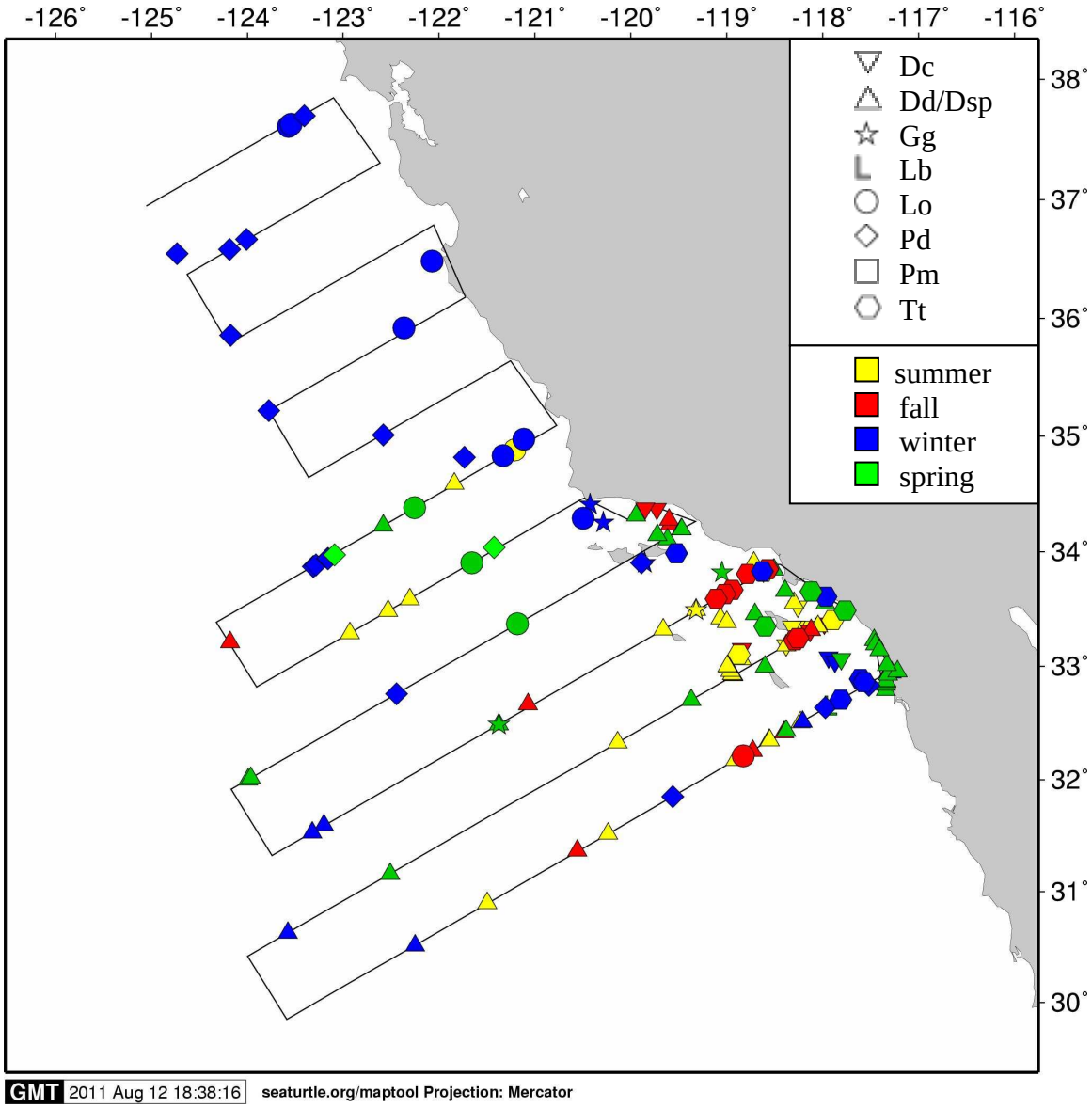

Figure 4. Visual sightings of eight odontocete species by season from four CalCOFI cruises between August 2010 and April 2011.

The relative abundance of baleen whales showed a different trend with noteworthy increases from previous years for three of four common baleen whale species. Fin, humpback, and gray whales had seasonal sighting rates that were the nearly double the average, representing the second highest levels observed for the three species across the seven-year study period (Figure 7). The seasonal increases in relative abundance observed for fin, gray and humpback whales may be an indicator of greater productivity in the southern California Bight in 2010-2011 as compared with previous years. Further examinations of direct metrics of primary productivity such as SST and chlorophyll levels and secondary productivity such as plankton and small fish abundance are needed

to better assess potential relationships between baleen whale abundance and pertinent habitat variables.

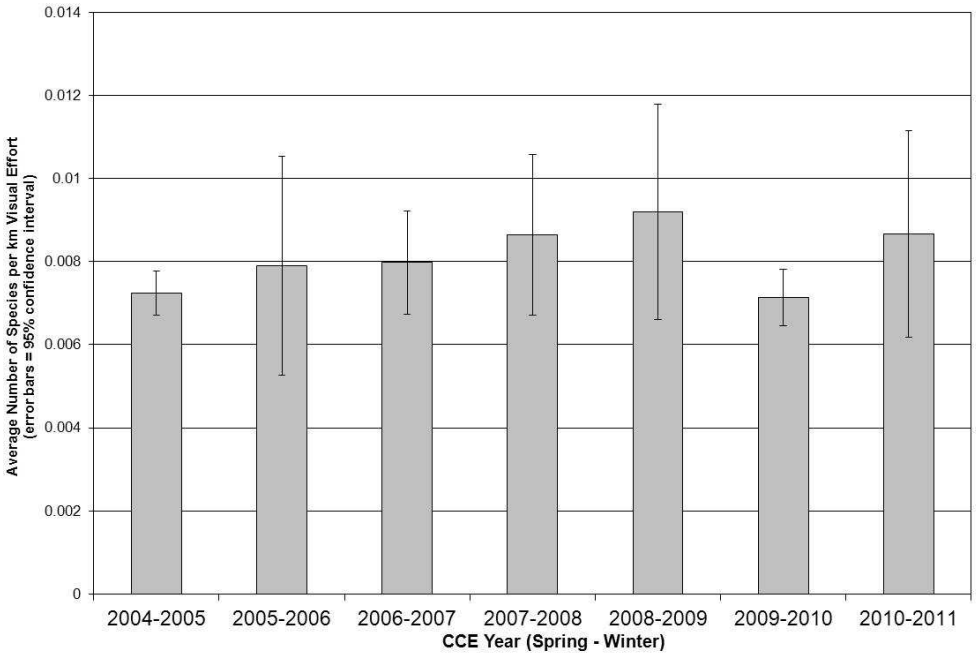

Figure 5. Average species richness (number of cetacean species per km of survey effort) per year (spring – winter). Error bars indicate the 95% CI.

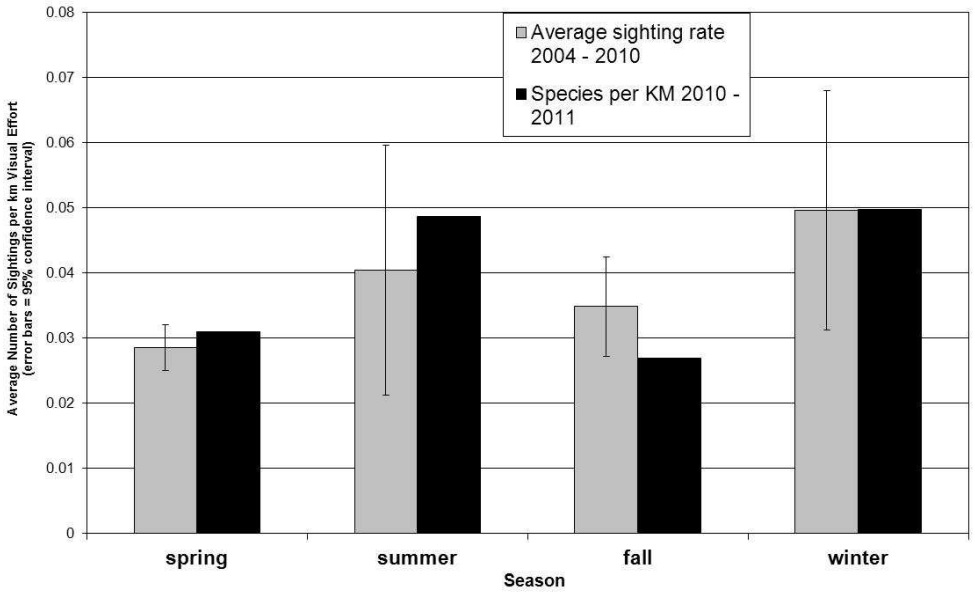

Figure 6. Comparison of the average sighting rates (number of sightings per km visual effort) for July 2004-January 2010 (grey) and the average sighting rates for spring 2010 - winter 2011 (black). Error bars show 95% CI.

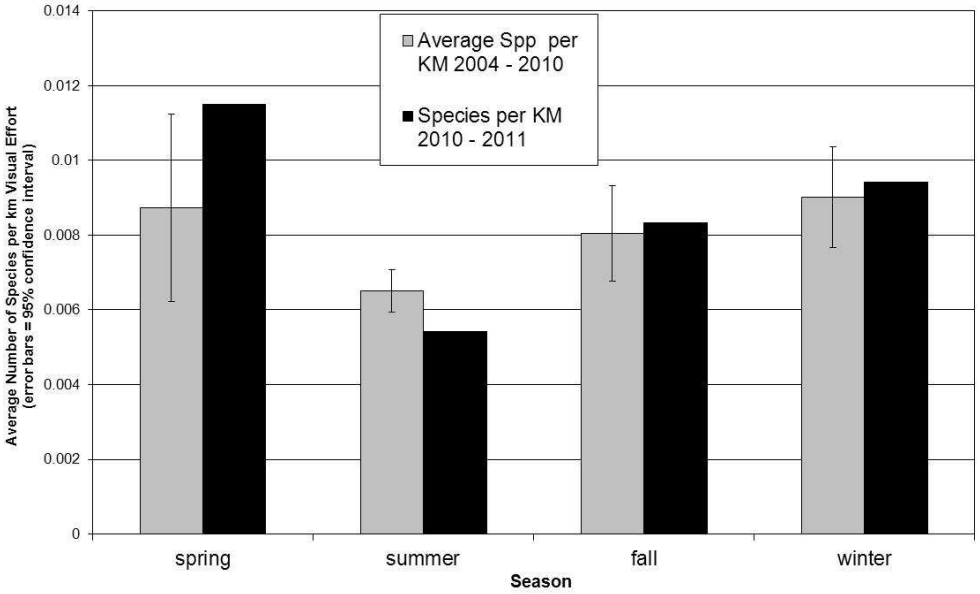

Figure 7. Comparison of the average species richness (number of cetacean species per km of survey effort) for July 2004-January 2010 (grey) and the average sighting rates for spring 2010 - winter 2011 (black). Error bars show 95% CI.

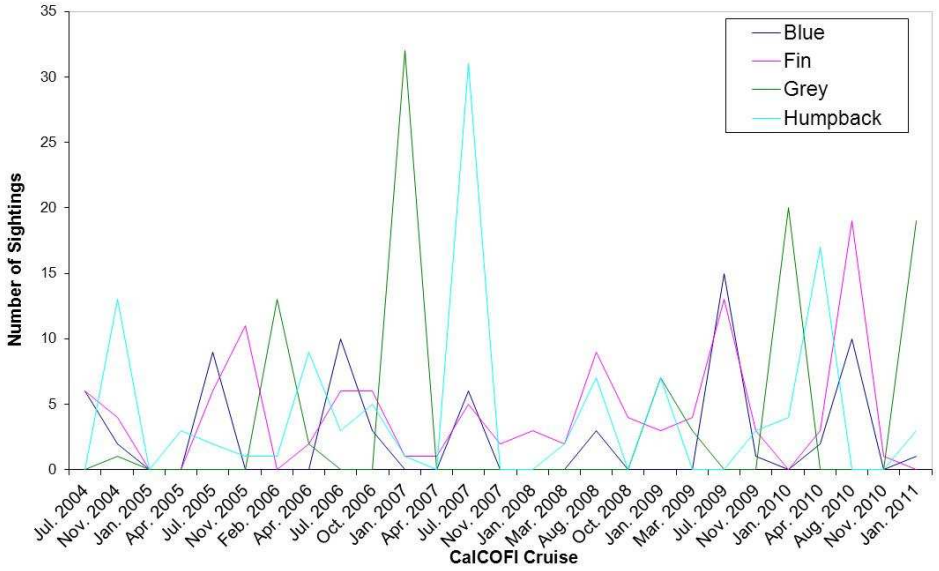

Figure 8. Relative abundance (in number of sightings per cruise) of blue, fin, grey and humpback whales species from July 2004 – January 2011.

Acoustic Monitoring – Towed Array

Acoustic detections from the towed array included 8 odontocete species encompassing a total of 199 detections (Figure 9). Acoustic detection rates varied by species. Of the 199 cetacean acoustic detections, unidentified whistling delphinids comprised 50% (n=99), sperm whales accounted for 19% (n=38), common dolphins 10% (n=20), unidentified clicking delphinids 6% (n=12), Pacific white-sided dolphins 3% (n=6), bottlenose dolphins 2% (n=3), Risso's dolphins 1% (n=1), Cuvier's beaked whales 1% (n=1) and northern right-whale dolphins 1% (n=1). Sperm whale acoustic detections outnumbered visual detections by a factor of nine (38 to 4), reinforcing the utility of using acoustics to document the presence of deep-diving odontocetes.

Spatial patterns in sperm whale and delphinid acoustic array detections were apparent for some species (Figure 9). Sperm whale detections were concentrated in deep pelagic waters as well as slope and shelf waters westward of islands and coastal regions. This spatial pattern of array-based detections of sperm whales is similar to the distribution of visual and sonobuoy detections for this species. Bottlenose and Risso's dolphin detections occurred inshore of the Channel Islands mirroring the visual pattern of detections for these two species. Unidentified whistling and clicking delphind detections were dispersed throughout the study area with the exception of the immediate coastline. The wide distribution and frequent occurrence of unidentified whistling delphinds in the study area, in accordance with the infrequent visual sightings of other whistling species, suggests that the majority of these detections are common dolphins. Further development of our whistle classification algorithms should assist in assigning species identification to these unidentified whistles.

Acoustic Monitoring – Sonobuoys

Real-time acoustic detections from the sonobuoys included four mysticete and two odontocete species encompassing a total of 129 detections (Figures 10 and 11). Acoustic detection rates in the study area varied by species. Of the 129 cetacean acoustic detections, sperm whales comprised 23% (n=30), humpback whales accounted for 19% (n=25), fin whales 18% (n=23), blue whales 10% (n=13), unidentified baleen whales 16% (n=21), and unidentified dolphins 12% (n=16).

Seasonal variations in call detection rates as a function of species were apparent. Humpback whales were frequently detected visually but rarely acoustically inshore in spring and fall, whereas humpbacks were detected acoustically but not visually offshore during winter cruises. Blue and fin whale calls were regularly documented during summer and fall while acoustic detections of these species were rare during winter and fall cruises. 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 detected in all seasons except fall with the majority of detections occurring during the spring cruise. Visual detections of sperm whales were limited to two each during the winter and spring cruises, limiting comparative analysis between visual and acoustic methods for this species. Delphinid calls were heard on all cruises without a clear seasonal pattern.

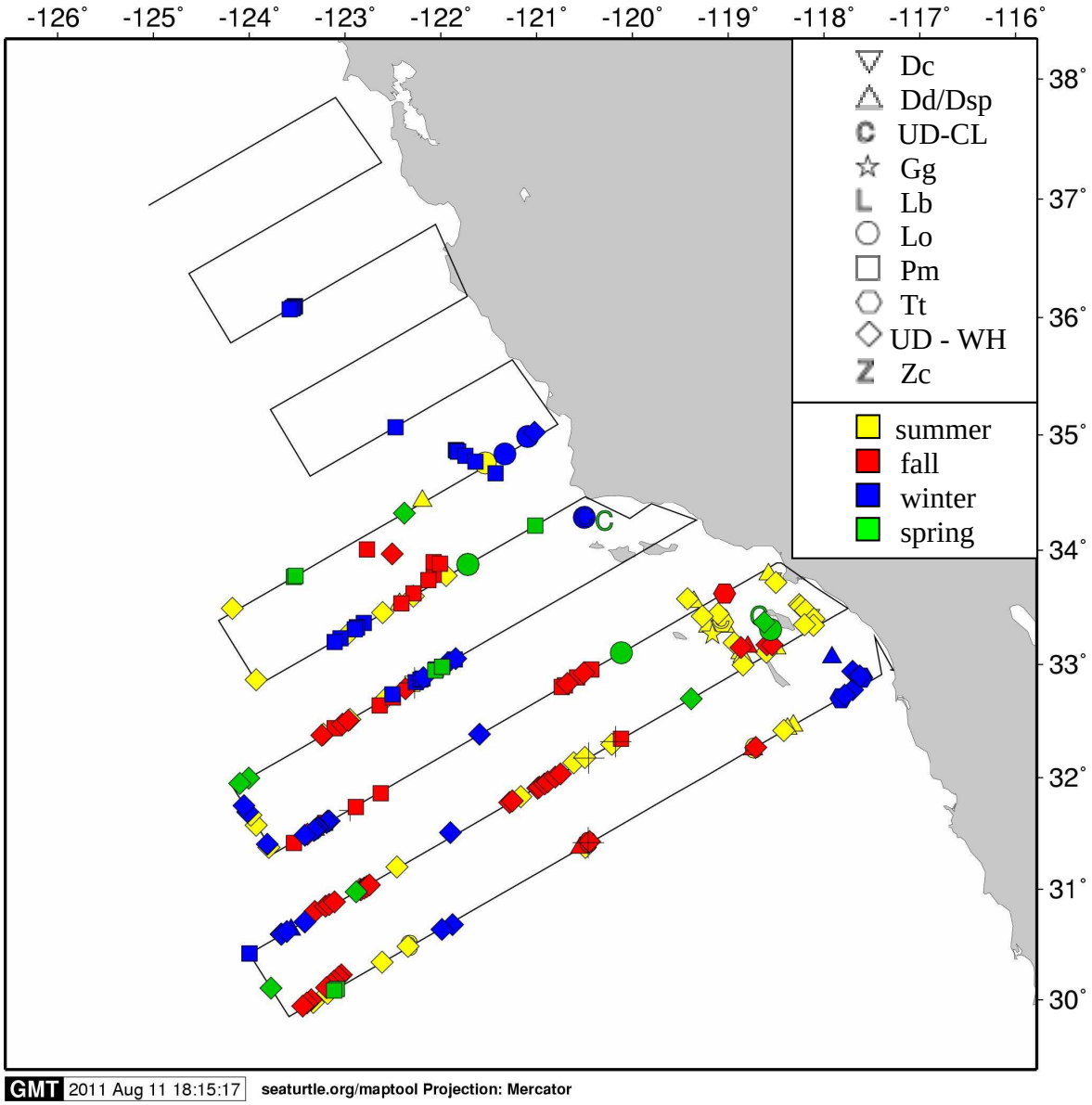

Figure 9. Towed acoustic array detections of odontocete cetaceans by species and season from CalCOFI cruises between August 2010 and April 2011.

Spatial patterns in blue whale, fin whale, humpback whale, sperm whale and delphinid acoustic detections for sonobuoys were also present (Figures 10 and 11). Blue whale, fin whale, humpback whale and delphind detections were dispersed throughout the study area with no apparent spatial pattern. Sperm whale calls were concentrated on deep pelagic stations as well as slope and shelf waters westward of islands and coastal regions.

CONCLUSIONS

Marine mammal monitoring on CalCOFI cruises has been conducted over the last seven years to investigate cetacean distribution patterns relative to habitat, to make seasonal

estimates of cetacean density and abundance, and to quantify differences in vocalizations between cetacean species. Over the last year, efforts to accomplish these objectives have expanded through incorporating novel analysis approaches, integrating new hardware/software tools, and developing collaborations with other experts in the field. Habitat modeling efforts have been improved through integration of a larger suite of environmental variables collected from CalCOFI cruises, satellite imagery, and autonomous gliders as well as the utilization of innovative GIS-based software tools. The development of density and abundance estimates for nine cetacean species in the CalCOFI study area are currently the focus of an extensive line-transect analysis and spatio-temporal modeling effort, in collaboration with St. Andrews University. Acoustical census techniques for cetaceans have been improved through recently published advancements in acoustic species-identification, localization software, and group size estimation. Cetacean surveys on CalCOFI cruises provide an avenue to examine seasonal and inter-annual patterns in distribution as well as density and abundance on a longer continuous time scale with a higher rate of sampling than previous cetacean surveys off the California coast. The insight gained from these analyses will provide data for environmental assessments and ultimately management protocols.

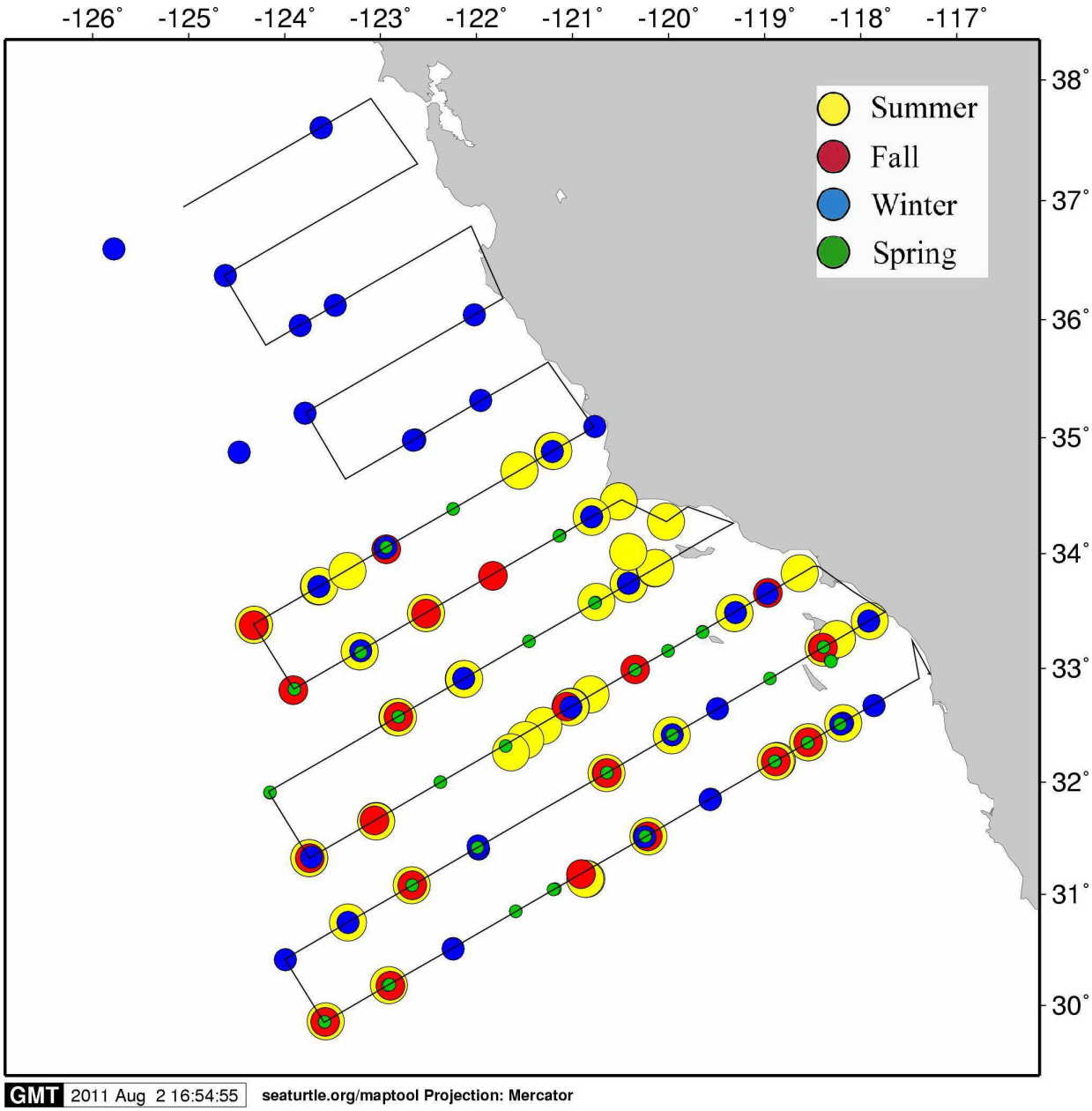

Figure 10. Sonobuoy deployment locations by season from CalCOFI cruises between August 2010 and April 2011. Circle diameter adjusted for visibility on plot and does not reflect amount of effort.

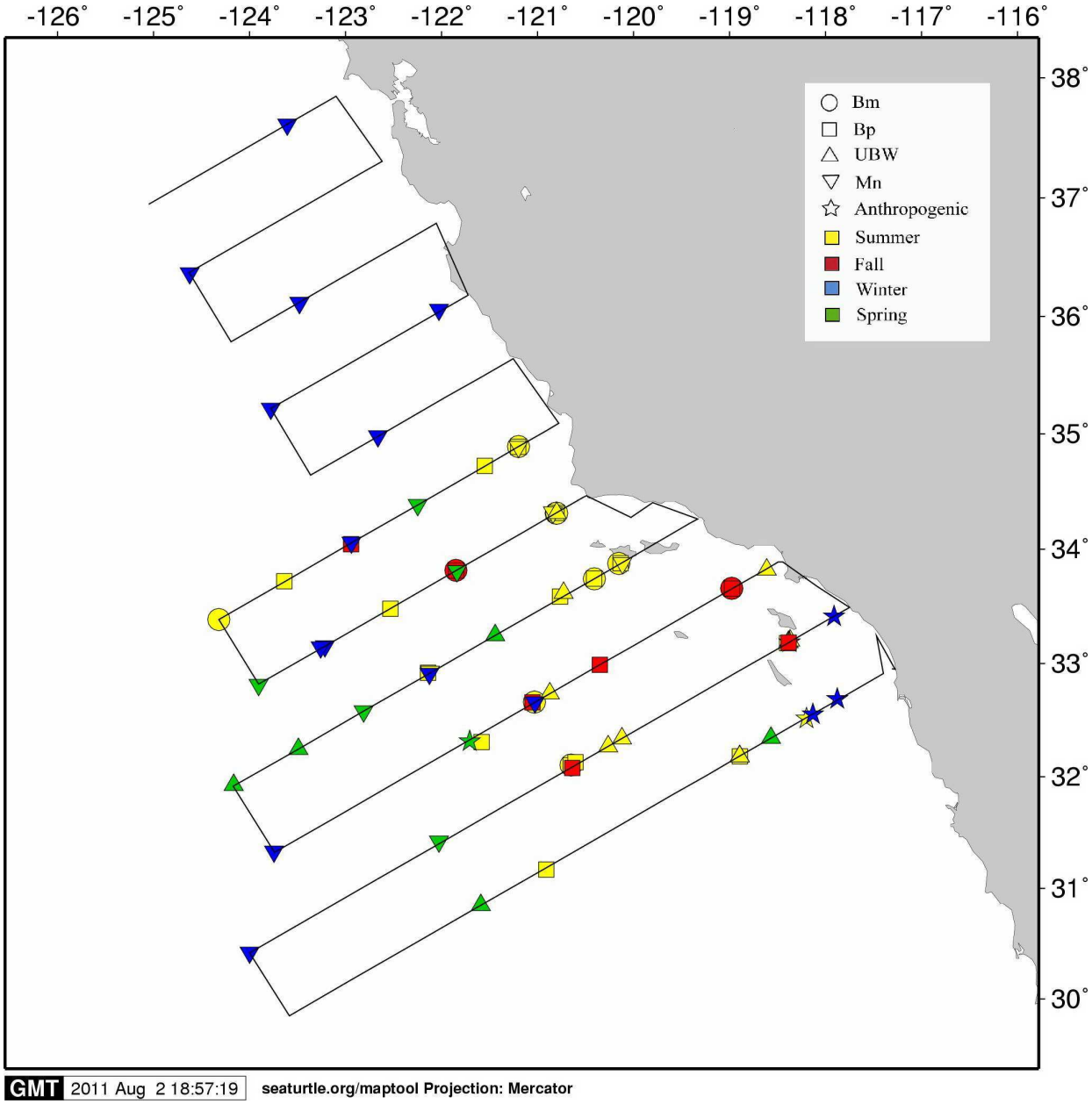

Figure 11. Sonobuoy acoustic detections of mysticete cetacean calls and anthropogenic noise by species and season from CalCOFI cruises between August 2010 and April 2011.

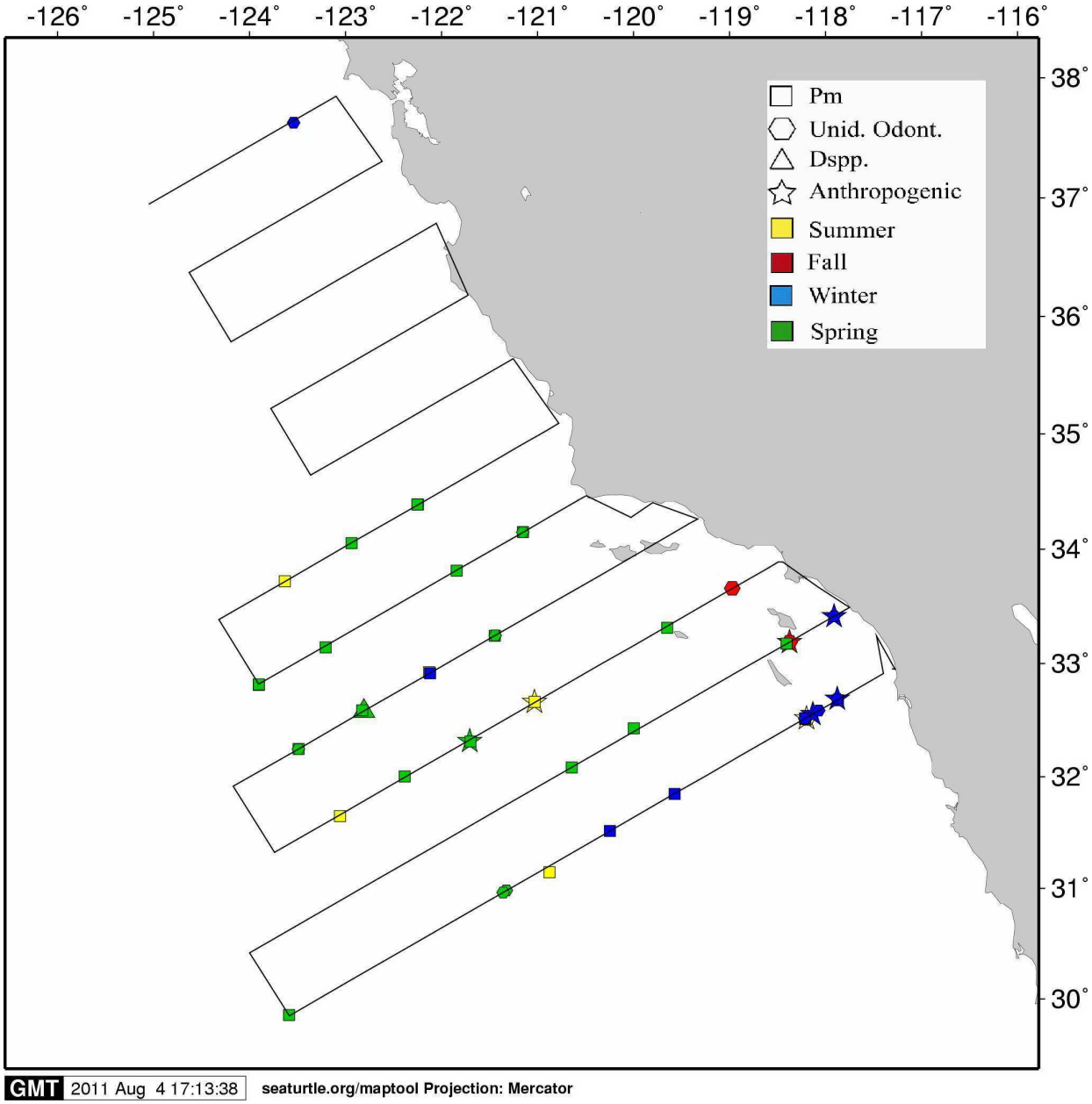

Figure 12. Sonobuoy acoustic detections of odontocete cetacean calls and anthropogenic noise by species and season from CalCOFI cruises between August 2010 and April 2011.

ACKNOWLEDGEMENTS

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Appendix I. Species codes for all cetaceans included in report.

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