MARINE MAMMAL MONITORING AND HABITAT INVESTIGATIONS DURING CALCOFI SURVEYS

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ABSTRACT

To understand cetacean ecology and habitat, a new component has been added to the CalCOFI ecosystem studies that have been conducted offshore of southern California over the last half century. In 2004, we initiated visual and acoustic line-transect surveys during CalCOFI cruises and long-term acoustic monitoring at selected CalCOFI stations. Visual monitoring provides excellent data for highly visible species in calm to moderate weather. The most commonly sighted species on visual surveys conducted between July 2004 and November 2005 were blue, fin, humpback, and sperm whales, and Pacific white-sided, short-beaked common, and long-beaked common dolphins. Blue, fin, and sperm whales were sighted more frequently in summer to fall months, while northern right whale dolphins and Dall's porpoises were sighted more frequently in winter and spring. Spatial patterns of occurrence are evident for all species within the study area.

Acoustic technicians survey with a towed hydrophone array during the transit between CalCOFI stations and sonobuoys while on station, allowing collection of distribution data on vocal animals that may have been missed visually due to darkness, rough weather, distance from transect line, being underwater, or other reasons. Additionally, long-term acoustic monitoring is conducted at six CalCOFI stations using bottom-mounted, High-frequency Acoustic Recording Packages (HARPs). These data will provide information on the annual and seasonal presence of cetaceans, and may be used to evaluate daily patterns of vocalization behavior. Acoustic detections of blue and sperm whales during line-transect surveys suggest that their seasonal presence is longer than was found by visual surveys alone. By integrating CalCOFI environmental and cetacean data, we plan to develop ecological models for cetacean habitat in the region offshore of southern California and to improve our understanding of their role in the California Current ecosystem.

INTRODUCTION

Cetaceans, the mammalian order containing mysticetes (baleen whales) and odontocetes (toothed whales, dolphins, and porpoises), are an important component of marine ecosystems. They make up a substantial portion of a marine ecosystem's biomass and exert influence through prey consumption, resource partitioning, co-evolution of predator and prey, community structuring, and benthic habitat modifications (Katona and Whitehead 1988; Bowen 1997). For example, in the Eastern Central Pacific ecosystem, the estimated marine mammal biomass is 6.8 million tons (Trites et al. 1997). Compared to a fisheries catch of 1.3 million tons in 1992, marine mammals' annual consumption in the region included 4.4 million tons of zooplankton, 18.3 million tons of squid, and 16.1 million tons of fish (Trites et al. 1997). Mysticetes feed primarily on lower-level pelagic or benthic zooplankton and small fishes, while odontocetes feed on higher-level fish, squid, and other marine mammals, as in the case of killer whales. CalCOFI provides an excellent research platform to investigate ecosystem changes by investigating habitat influences and organismal relationships in the context of their changing marine environment.

A preliminary understanding of cetacean abundance, distribution, and habitat associations is a necessary prerequisite to such investigations. Previous work has considered the environmental factors affecting cetacean abundance and distribution in southern California offshore waters. Balaenopterid whale distributions have been shown to be closely tied with prey distribution off southern California (Croll et al. 1998; Fiedler et al. 1998), with the highest densities of whales and their prey located down current of coastal upwelling centers. Temperature, water-depth, ocean productivity, and prey distribution have also been shown to influence cetacean distribution (Smith et al. 1986; Forney and Barlow 1998; Forney 2000; Burtenshaw et al. 2004). Hydrographic and plankton data collected during CalCOFI cruises provide a breadth of measurements that may aid in explaining patterns of abundance, distribution, and habitat of cetaceans in California waters. Opportunistic cetacean sightings on previous CalCOFI cruises show promise for the incorporation of more rigorous mammal surveys to answer these questions (Larkman and Veit 1998).

A variety of cetacean species can be found in southern California offshore waters throughout the year. Short-beaked and long-beaked common dolphins (*Delphinus* *delphis* and *D. capensis*) (Heyning and Perrin 1994) are typically sighted in schools of hundreds to greater than 1000 individuals. Short-beaked common dolphins are one of the most abundant odontocete species off California, though their abundance varies seasonally and annually as they move offshore and northward in summer months (Forney and Barlow 1998). Conversely, an offshore population of bottlenose dolphins occurs during all seasons throughout the Southern California Bight (Forney and Barlow 1998). Blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), and humpback (*Megaptera novaeavngliae*) whales have been seen in all seasons though they are more numerous during their summer and fall migration into the Southern California Bight (Forney and Barlow 1998; Larkman and Veit 1998; Calambokidis et al. 2000; Calambokidis and Barlow 2004). Gray whales migrate southward through the region between November–February and northward in April–June (Poole 1984). Risso's dolphins (*Grampus griseus*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), northern right whale dolphins (*Lissodelphis borealis*), and Dall's porpoise (*Phocoenoides dalli*) exhibit a seasonal presence, moving into waters off California during cold-water months (November–April) and shifting northward to Oregon and Washington or offshore in warmer months (May–October) (Green et al. 1992; Forney et al. 1995; Forney and Barlow 1998). Several additional cetacean species inhabit southern California waters in all seasons or with an unknown seasonal cycle. Among these are the sperm whale (*Physeter macrocephalus*), killer whale (*Orcinus orca*), minke whale (*Balaenoptera acutorostrata*), Baird's beaked whale (*Berardius bairdii*), sei whale (*Balaenoptera borealis*), pilot whale (*Globicephala macrorhynchus*), false killer whale (*Pseudorca crassidens*), Cuvier's beaked whale (*Ziphius cavirostris*), and various other beaked whale species (*Mesoplodon* spp.).

Cetacean distribution and abundance are not well known for most regions throughout the world's oceans. Visual surveys to determine cetacean abundance are expensive and often limited in spatial and temporal extent. The region offshore of southern California is one of the better studied regions (e.g., Barlow 1995); however, substantial uncertainty remains in the seasonal and annual abundance and distribution of the majority of marine mammals species present. Passive acoustic monitoring is a complementary technique for assessing cetacean populations without the typical limitations associated with visual surveys. Acoustic methods can greatly extend cetacean detection capabilities and can be conducted independent of daylight and weather conditions that may inhibit visual surveys (Thomas et al. 1986). Moored autonomous acoustic techniques can further augment seasonal estimates of abundance by providing continuous temporal coverage.

A key issue for acoustic survey methods is species identification. The calls of many baleen whale species are stereotyped and well known. For example, eastern North Pacific blue whales can be identified by three distinct low-frequency call types designated A, B, and D (Thompson et al. 1996; Rivers 1997; Stafford et al. 1998). Most toothed whales, or odontocetes, produce variable sounds that fall into the following general categories: whistles, burst-pulse calls, and echolocation clicks (Au 1993). Calls of some odontocetes, such as sperm whales, killer whales, and porpoises, are easily distinguishable (Evans et al. 1988; Ford 1989; Weilgart 1990). However, for most species the variation in and among call types is a topic of current research (Oswald et al. 2003; Oswald et al. 2004).

By incorporating visual and acoustic cetacean monitoring into the existing CalCOFI surveys, we plan to examine seasonal and inter-annual cetacean distribution patterns, develop delphinid acoustic identification capabilities, and integrate cetacean and environmental data to develop predictive ecological models of cetacean habitat. The CalCOFI platform enables us to sample on a spatial and temporal scale that has not previously been achieved. Incorporating both visual and acoustic monitoring reduces common biases present in single-mode surveys. The combination of a strong cetacean sampling program with excellent CalCOFI environmental data will allow us to develop robust ecological models. This will help develop an understanding of their ecological role in the California Current system and their interrelationships with their prey species. In this paper, we describe the visual and acoustic survey methods that have been incorporated into CalCOFI cruises since July 2004, and present preliminary results on cetacean visual and acoustic detection, distribution, and seasonality for six cruises from July 2004 to November 2005.

METHODS

Data Collection

Visual monitoring for cetaceans has been conducted on quarterly CalCOFI cruises since July 2004 using standard line-transect protocol (Burnham et al. 1980;

TABLE 1
Visual survey information for each CalCOFI cruise.

Cruise Date	Ship Name	Survey Speed (kn)	Observer Height (m)
Jul. 2004	*David Starr Jordan*	10	10.7
Nov. 2004	R.V. *Roger Revelle*	12	12.0
Jan. 2005	R.V. *New Horizon*	10	8.1
Apr. 2005	R.V. *New Horizon*	10	8.1
Jul. 2005	R.V. *New Horizon*	10	8.1
Nov. 2005	R.V. *New Horizon*	10	8.1

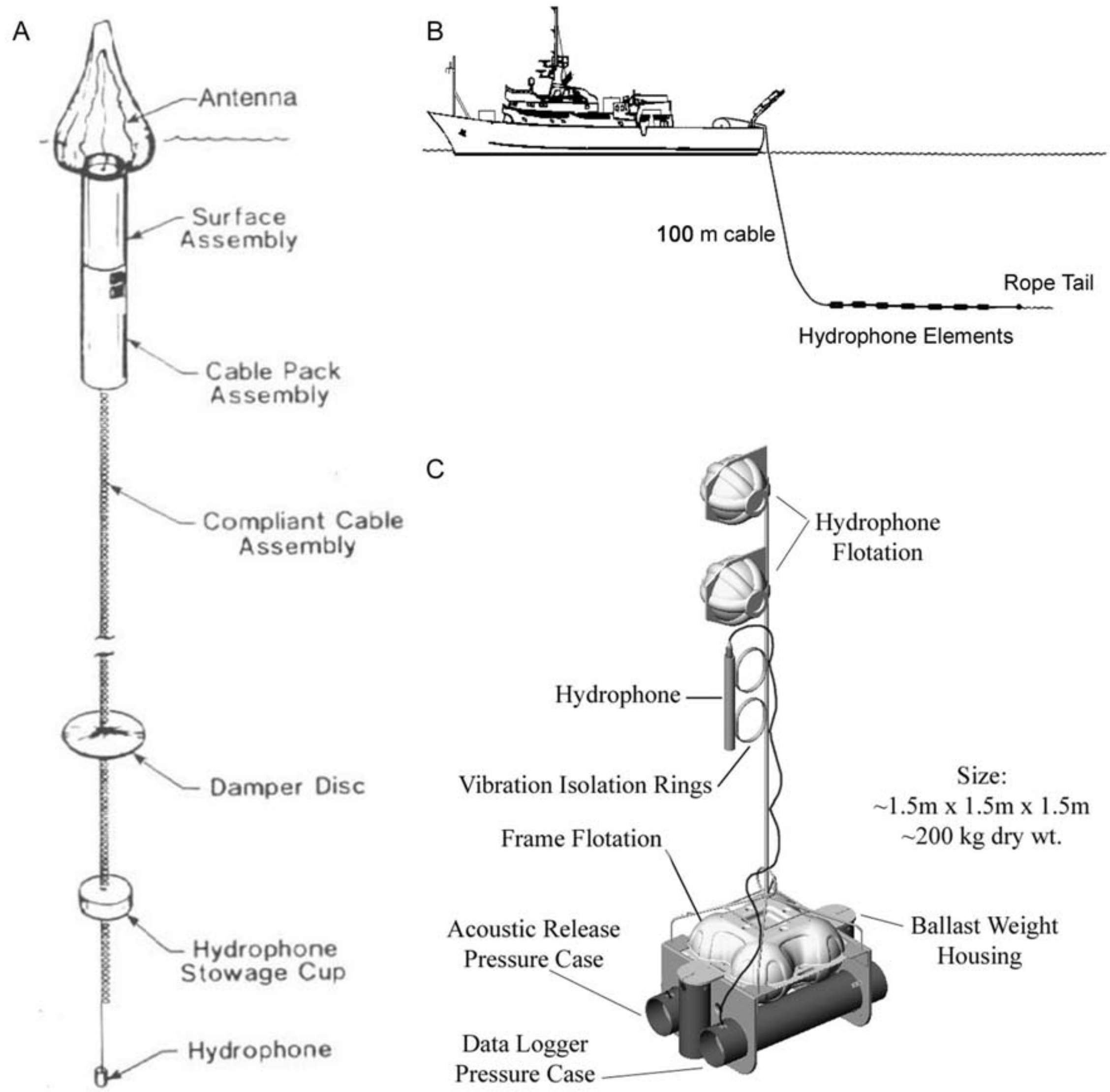

Figure 1. Acoustic instruments used for detecting cetaceans in the CalCOFI study area. A) AN-SSQ-57 type sonobuoy. B) Towed hydrophone array. C) HARP (High-frequency Acoustic Recording Package). Note instrument representations are not to scale.

Buckland et al. 1993; Barlow 1995). Visual observers watched during daylight hours when weather permitted while the ship transited between CalCOFI stations (Beaufort sea states 0–5 and visibility greater than 1 nm). A team of two observers searched for cetaceans in a 90° field of view from the bow to abeam of the ship alternating between 7 × 50 power binoculars and the naked eye. Because CalCOFI cruises were not always conducted on the same vessel, viewing conditions such as ship speed and survey height varied by cruise (tab. 1). A record of time, position, ship's heading and speed, viewing conditions (including sea state, wind speed, and visibility), and observer identification was maintained and updated at regular intervals or whenever 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. In July 2004, and January and April 2005, many sighted animals could not be identified to species due to their distance from the ship and an inability to deviate from the trackline to approach them. In November 2004, and in all surveys since July 2005, 25 × 150 power binoculars have been available to improve species identification after sighting animals using lower power or no magnification.

Acoustic monitoring for cetaceans during line-transect surveys is conducted using a towed hydrophone array. The hydrophone array has undergone numerous configurations since July 2004 to improve its performance. From July 2004 to November 2005, the array contained up to four hydrophone elements with graded spacings (0.1–3 m) and was towed approximately 100 m behind

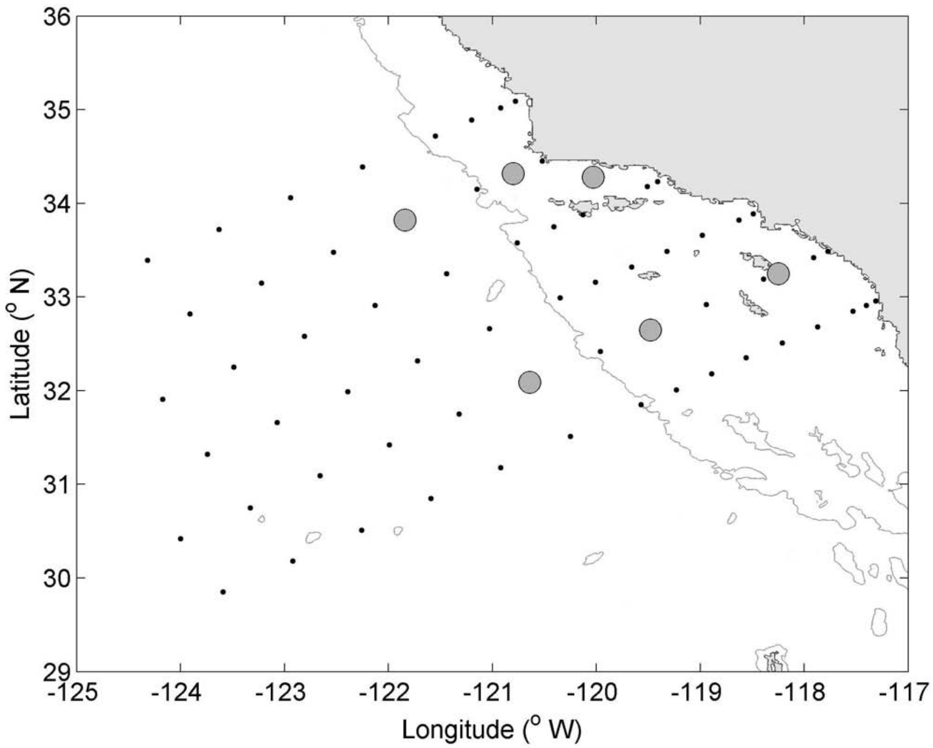

Figure 2. Map of CalCOFI station plan (small circles) illustrating current locations of six HARPs (large circles). The HARPs are placed to acoustically cover coastal, shelf and offshore regions of southern California waters. Bathymetric contour represents 2000 meters depth.

the survey vessel at 10 m depth (fig. 1A). Early cruises (November 2004–July 2005) incorporated a depressor wing, but this was abandoned in later cruises due to high levels of introduced noise. Later cruises used 15 lbs. of lead wire wrapped above the leading edge of the hydrophone to submerge the array, considerably decreasing noise. Each pre-amplified element was band-pass filtered from 3 kHz to 100 kHz to decrease high-intensity, low-frequency flow noise and provide protection from signal aliasing at high frequencies. The multi-channel data were digitized using a Mark of the Unicorn (MOTU) 896 sound system which recorded the data directly to a computer hard drive using the software program *Ishmael* (Mellinger 2002). An acoustic technician listened to sounds received from the towed array while visually monitoring a scrolling spectrogram of the incoming sounds on a computer display.

Due to the high noise present in the early array configurations, data from these cruises cannot be used toward acoustic survey abundance and distribution calculations and is not presented. Future cruises employing a 300 m lead-wire-weighted hydrophone array should alleviate this problem. However, as only the loudest of odontocete clicks and whistles could be recorded from animals no further than a hundred meters from the array, the likelihood that the recorded animals were also sighted was high, making this array ideal for species identification purposes. Algorithms to localize recorded calls are being developed to ensure this is the case. Calls recorded from single-species delphinid schools will be used to develop acoustic classification programs to be used with autonomously recorded data.

Acoustic monitoring during CalCOFI stations was conducted with broadband AN-SSQ-57B sonobuoys beginning in April 2004. Sonobuoys are expendable hydrophones, sensitive from 20 Hz to 20 kHz, with radio data links for transmission of acoustic data to the ship (fig. 1B). Sonobuoys were deployed one nautical mile before each daylight station to a depth of 30 m and were recorded for two to three hours. In November 2004, two acoustic technicians were available, allowing sonobuoys to be deployed near nighttime stations as well. The received acoustic signal was digitized with a SoundBlaster SB0300 24-bit external soundcard and recorded directly to computer hard drive using *Ishmael*. An acoustic technician monitored the sonobuoy signals for cetacean calls using a scrolling spectrogram display. Mysticete calls, sperm whale clicks, and dolphin calls, including whistles, burst pulses, and the low-frequency component of their clicks, could be recorded with this system. These data provide an expanded database of calls produced by a known, visually-identified species.

Long-term, autonomous acoustic data is being collected on select CalCOFI stations using High-frequency

TABLE 2
Visual detections of cetaceans over CalCOFI cruises from July 2004–November 2005. Total number of schools sighted per species for each trip.

	Jul. 2004	Nov. 2004	Jan. 2005	Apr. 2005	Jul. 2005	Nov. 2005	Total
Blue whale	7	5	–	–	10	–	22
Fin whale	7	5	–	2	6	11	31
Gray whale	–	1	2	–	–	–	3
Humpback whale	1	14	–	6	7	1	29
Minke whale	–	–	–	1	2	1	4
Sperm whale	9	–	–	1	5	1	16
Killer whale	–	–	–	–	1	–	1
Baird's beaked whale	1	–	–	–	–	–	1
Cuvier's beaked whale	2	3	–	–	–	–	5
Unid. beaked whale	–	2	–	–	–	–	2
Unid. whale	22	19	4	7	18	6	76
Common dolphin—short-beaked	33	11	11	9	21	13	98
Common dolphin—long-beaked	5	9	1	4	16	4	39
Common dolphin—unid. spp	13	7	4	3	35	16	78
Risso's dolphin	2	2	2	4	–	4	14
Northern right whale dolphin	–	1	1	9	1	3	15
Pacific white-sided dolphin	7	8	6	14	5	1	41
Rough-toothed dolphin	–	–	–	1	–	–	1
Striped dolphin	2	–	–	–	–	–	2
Bottlenose dolphin	2	2	–	3	–	2	9
Unid. dolphin	21	17	2	2	16	5	63
Dall's porpoise	1	–	3	10	–	1	15
Harbor porpoise	1	–	–	–	–	–	1
Total schools sighted	136	106	36	76	143	69	566

Acoustic Recording Packages (HARPs), providing a continuous record of marine mammal presence (both odontocete and mysticete) in the region. HARPs are bottom-mounted instruments containing a single hydrophone tethered 10 m above the seafloor (fig. 1C) (Wiggins 2003). The hydrophone monitors sounds from 10 Hz to 100 kHz, making it capable of recording baleen whale calls, sperm whale clicks, along with delphinid whistles, burst-pulses, and clicks. HARPs are capable of acoustic sample rates of up to 200 kHz and can store 1920 GBytes of acoustic data, allowing continuous recording for 55 days. The HARP can also be duty-cycled (e.g., 20 min on, 10 min off) to extend recording duration. Six HARPs have been deployed at carefully selected CalCOFI stations representing near-shore, continental shelf, and pelagic waters (fig. 2). Data collected by HARPs are analyzed for cetacean calls following instrument retrieval using automated call recognition software.

Acoustic Data Analysis

Acoustic data collected from sonobuoys deployed on CalCOFI stations were analyzed for presence or absence of calls of blue whales, sperm whales, and all delphinids. Blue whale B calls were automatically detected from sonobuoy data collected from July 2004 to April 2005 using a spectrogram cross-correlation in *Ishmael* (Mellinger and Clark 1997; Mellinger and Clark 2000). Sperm whale regular clicks (0.4–3 kHz with 0.5–1 s interclick interval) (Goold and Jones 1995) were preliminarily identified by the acoustic technician during surveys and later verified by an experienced analyst. Delphinid whistles, burst-pulses, and echolocation clicks were also noted during surveys by the acoustic technician, but calls could not be identified to the species.

HARP data were analyzed by creating long-term spectral averages using customized Matlab programs. Spectra were created from the time series using a 2000 point FFT with a Hanning window. These spectra were then averaged over a 0.05 s duration to obtain the long-term spectral average. The presence or absence of delphinid calls over 30-minute periods was noted by an acoustic technician to determine the percentage of time calls present at each HARP location.

RESULTS

Line-transect Visual Surveys

Visual sighting and school size data are summarized in Tables 2 and 3 for all cetacean species. The most commonly sighted large whales were blue, fin, humpback, and sperm whales, while long-beaked common, short-beaked common, and Pacific white-sided dolphins were the most commonly seen delphinids. Preliminary results from the visual surveys indicate that blue, fin, and sperm whales were seen more frequently during summer and fall surveys, while Dall's porpoises and northern right whale dolphins were seen more frequently during winter and spring (figs. 3 and 4). No seasonal trend was apparent for humpback whales, Pacific white-sided dolphins, or common dolphin species.

TABLE 3
Visual detections of cetaceans over CalCOFI cruises from July 2004–November 2005. Total number of individuals sighted per species for each trip.

	Jul. 2004	Nov. 2004	Jan. 2005	Apr. 2005	Jul. 2005	Nov. 2005	Total
Blue whale	9	7	–	–	14	–	30
Fin whale	11	9	–	2	7	32	61
Gray whale	–	1	4	–	–	–	5
Humpback whale	2	22	–	17	7	7	55
Minke whale	–	–	–	1	2	1	4
Sperm whale	14	–	–	5	5	3	27
Killer whale	–	–	–	–	6	–	6
Baird's beaked whale	20	–	–	–	–	–	20
Cuvier's beaked whale	2	4	–	–	–	–	6
Unid. beaked whale	–	2	–	–	–	–	2
Unid. whale	34	25	6	7	18	6	96
Common dolphin—short-beaked	1657	1946	2421	440	2184	412	9060
Common dolphin—long-beaked	475	3729	60	1650	1084	235	7233
Common dolphin—unid. spp	843	852	29	32	3481	1621	6858
Risso's dolphin	17	102	12	26	–	235	392
Northern right whale dolphin	–	2	5	299	3	14	323
Pacific white-sided dolphin	25	183	44	157	81	2	492
Rough-toothed dolphin	–	–	–	9	–	–	9
Striped dolphin	77	–	–	–	–	–	77
Bottlenose dolphin	30	11	–	20	–	56	117
Unid. dolphin	900	2204	1220	183	207	392	5106
Dall's porpoise	2	–	21	58	–	17	98
Harbor porpoise	2	–	–	–	–	–	2
Total individuals sighted	4120	9099	3822	2906	7099	3033	30079

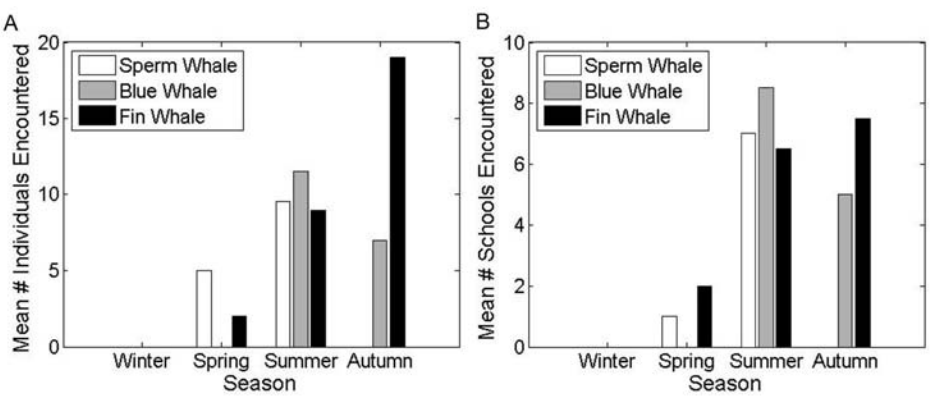

Figure 3. Histograms of numbers of individuals encountered (A) and numbers of schools encountered (B) per CalCOFI trip from July 2004–November 2005 visual surveys. Results are shown for blue, fin and sperm whales which each show a seasonal trend of greater abundance in summer/autumn.

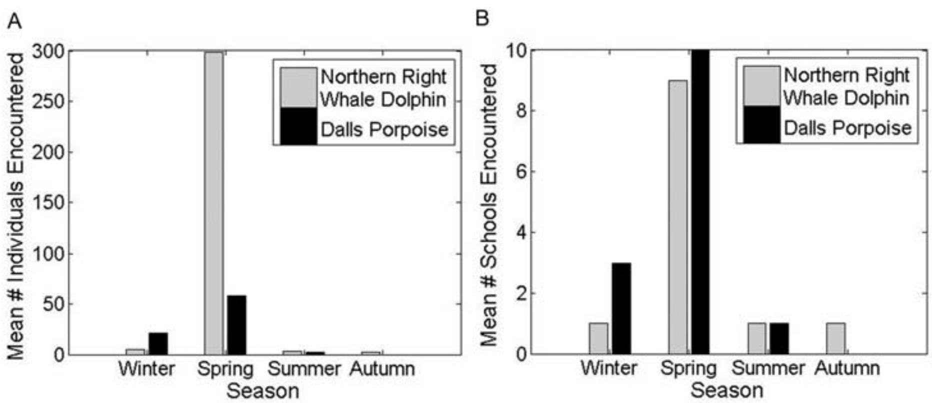

Figure 4. Histograms of numbers of individuals encountered (A) and numbers of schools encountered (B) per CalCOFI trip from July 2004–November 2005 visual surveys. Results are shown for Dall's porpoises and northern right whale dolphins which each show a seasonal trend of greater abundance in winter and spring

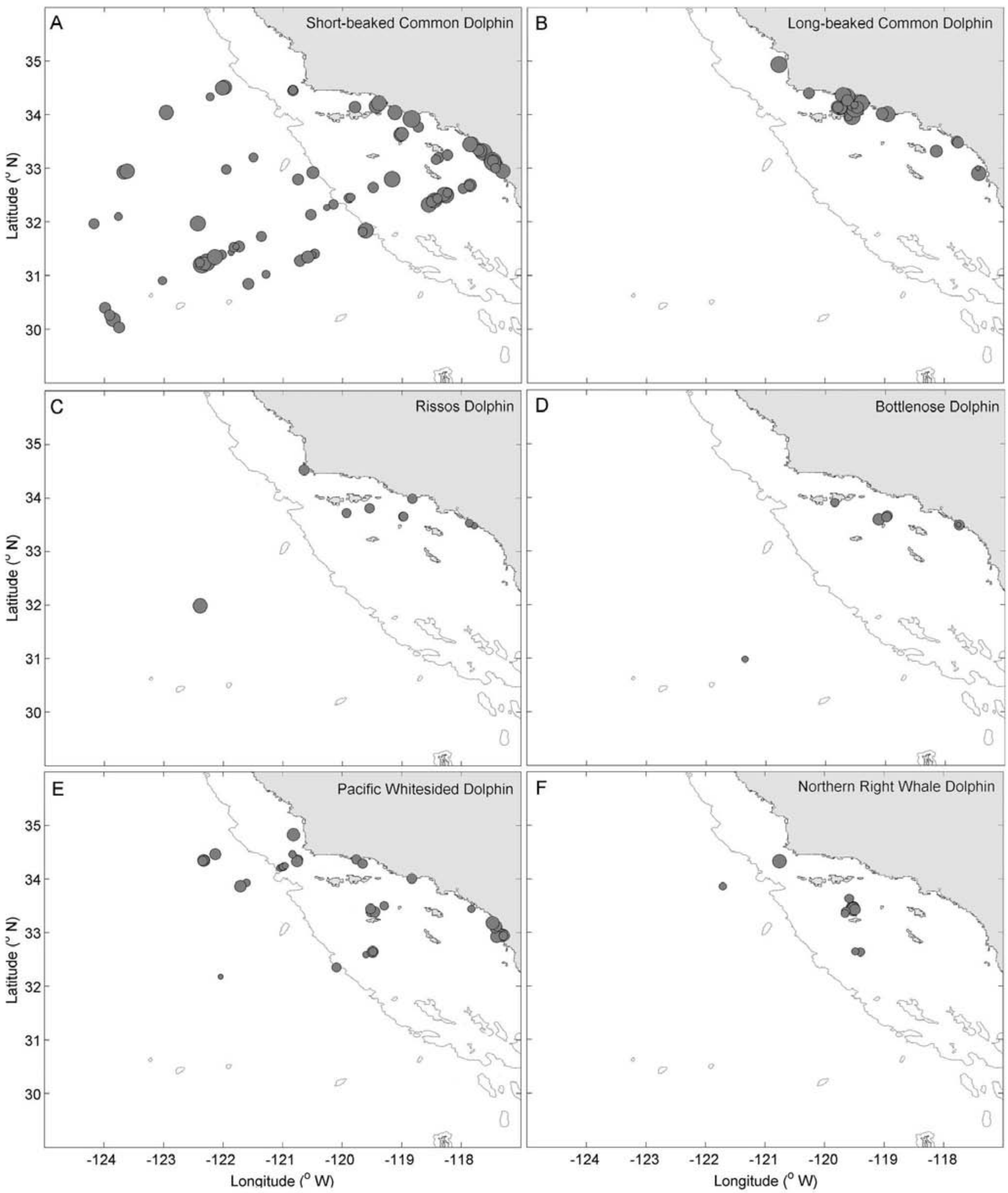

Figure 5. Distribution patterns of cetacean sightings from six CalCOFI cruises between July 2004 and November 2005. Bathymetric contour represents 2000 meters depth. Visual sightings of cetaceans are represented by gray circles, where the size of the circle represents school size. A) short-beaked common dolphin B) long-beaked common dolphin C) Risso's dolphin D) bottlenose dolphin E) Pacific white-sided dolphin F) northern right whale dolphin

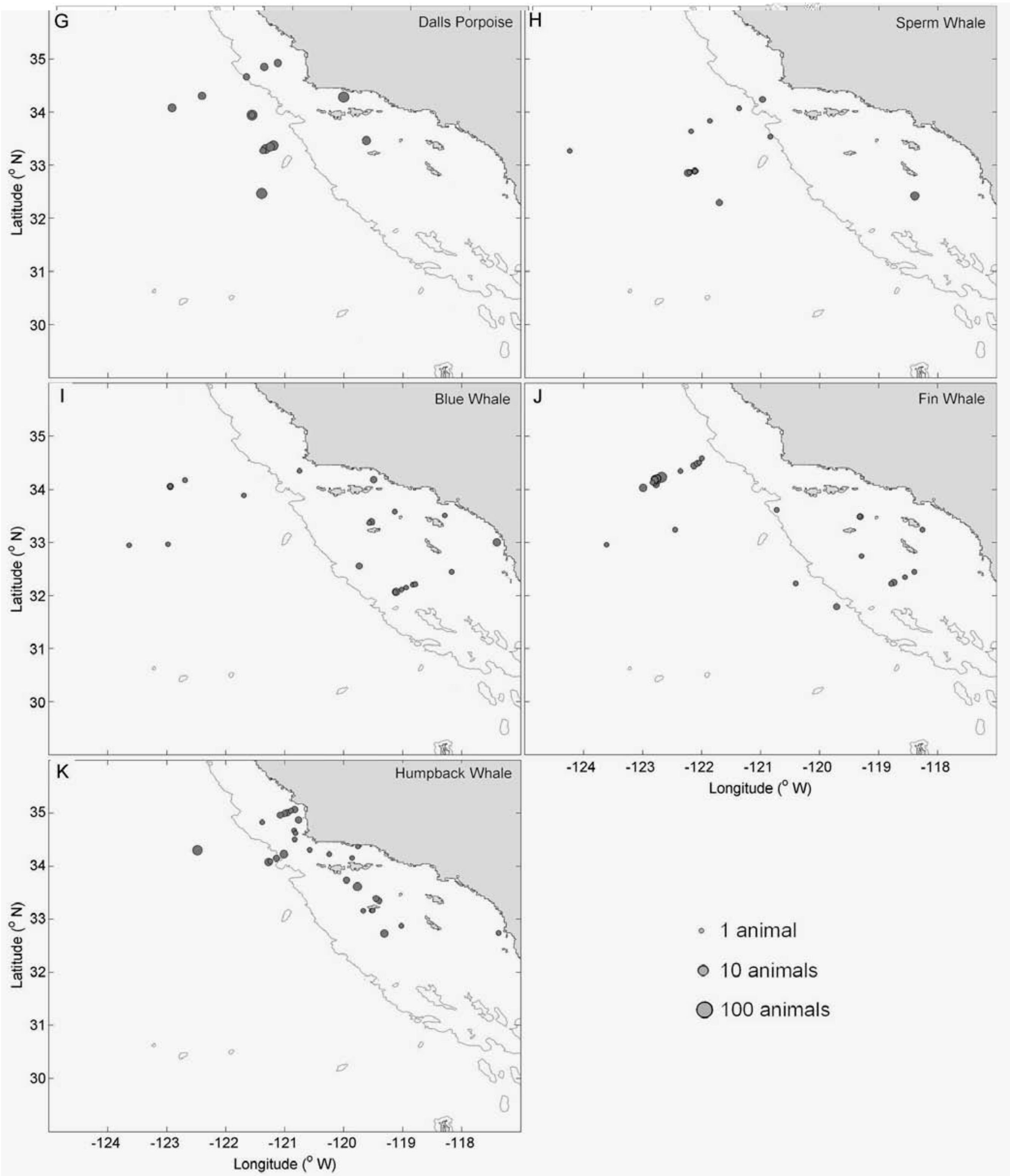

Figure 5. Distribution patterns of cetacean sightings from six CalCOFI cruises between July 2004 and November 2005. Bathymetric contour represents 2000 meters depth. Visual sightings of cetaceans are represented by gray circles, where the size of the circle represents school size. G) Dall's porpoise H) sperm whale I) blue whale J) fin whale K) humpback whale.

TABLE 4
Cetacean acoustic detections on CalCOFI station sonobuoys over CalCOFI cruises from July 2004–November 2005. Total number of sonobuoys with calls present for blue whales, sperm whales, and all delphinid species for each trip. Number in parentheses is the number of sonobuoys analyzed for blue whale B calls.

	Jul. 2004	Nov. 2004	Jan. 2005	Apr. 2005	Jul. 2005	Nov. 2005	Total
Sonobuoys deployed	33	53	32	36	34	38	226
Blue whale B calls	13 (21)	28 (30)	6	0	n/a	n/a	47
Sperm whale clicks	12	7	8	5	4	2	36
Delphinid calls	19	41	16	21	13	16	126

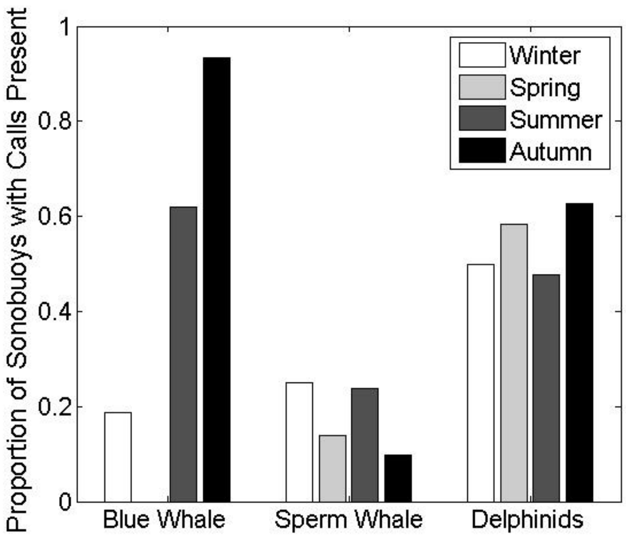

Figure 6. Histogram of the proportion of sonobuoys with calls present per CalCOFI trip from July 2004–November 2005 for blue whale B calls, sperm whale regular clicks and delphinid calls. Data for blue whales only includes CalCOFI trips from July 2004–April 2005.

Spatial patterns in visual sightings of the most common large whales and each of the dolphin and porpoise species are presented in Figure 5. Short-beaked common dolphins were seen throughout the study area, while long-beaked common dolphins were seen in coastal regions, particularly among and inshore of the Channel Islands. Bottlenose and Risso's dolphins were seen most commonly on the shelf, near islands, and close to shore and only occasionally in offshore waters. Pacific white-sided and northern right whale dolphins frequently were seen in shelf waters in the southern portion of the study area, and in offshore waters to the north. Dall's porpoise were seen throughout the northern portion of the study area, and sperm whales were found in deep offshore waters. Blue and fin whales were seen in shelf waters and offshore in the northern part of the study area. Humpback whales were seen on the shelf, particularly in shallower regions and around the Channel Islands.

On-station Acoustic Surveys

The number of CalCOFI station sonobuoys detecting blue and sperm whales and delphinids (as a group) are summarized in Table 4. Temporal patterns in call detections are shown in Figure 6. Blue whale B calls were heard on at least one sonobuoy during every cruise, with the highest rate of detection in summer. Sperm whale regular clicks were also heard year-round, with the highest detection rates during winter and summer cruises. Delphinid calls were heard on all cruises without a seasonal pattern in their detection, likely due to our inability to identify the calls of individual species.

Spatial patterns in blue whale, sperm whale, and delphinid acoustic detections for CalCOFI station sonobuoys are also evident (fig. 7). Blue whale and delphinid calls were heard throughout the study region, with delphinids heard at nearly all stations. Sperm whale calls were heard on many deep pelagic stations as well as slope and shelf waters westward of islands and coastal regions. They were not heard at the most near-shore coastal and island stations.

Continuous Seafloor Acoustic Surveys

Early investigations into HARP data collected from mid-August to late-September 2005 at CalCOFI stations 90.35 south of Santa Catalina Island, 82.47 in the Santa Barbara Channel, and 80.55 off Point Conception reveal that delphinids are calling a large portion of the time. A long-term spectral average from this data illustrates the identification of delphinid clicks and whistles and noise from passing ships (fig. 8). Delphinid calls were present 61%, 78%, and 56% of the time, at the three HARPs respectively.

DISCUSSION

Inclusion of visual and acoustic monitoring for cetaceans onto CalCOFI surveys since July 2004 has provided a basic data set from which we can begin to evaluate the detection of mysticete and odontocete species temporally and geographically. Preliminary analyses of temporal trends in visual and acoustic detections collected from six CalCOFI cruises suggest seasonal preferences for several cetacean species in the CalCOFI study region. Temporal patterns of visual and acoustic detections of blue and fin whales and Dall's porpoise and northern right whale dolphins are similar to what has

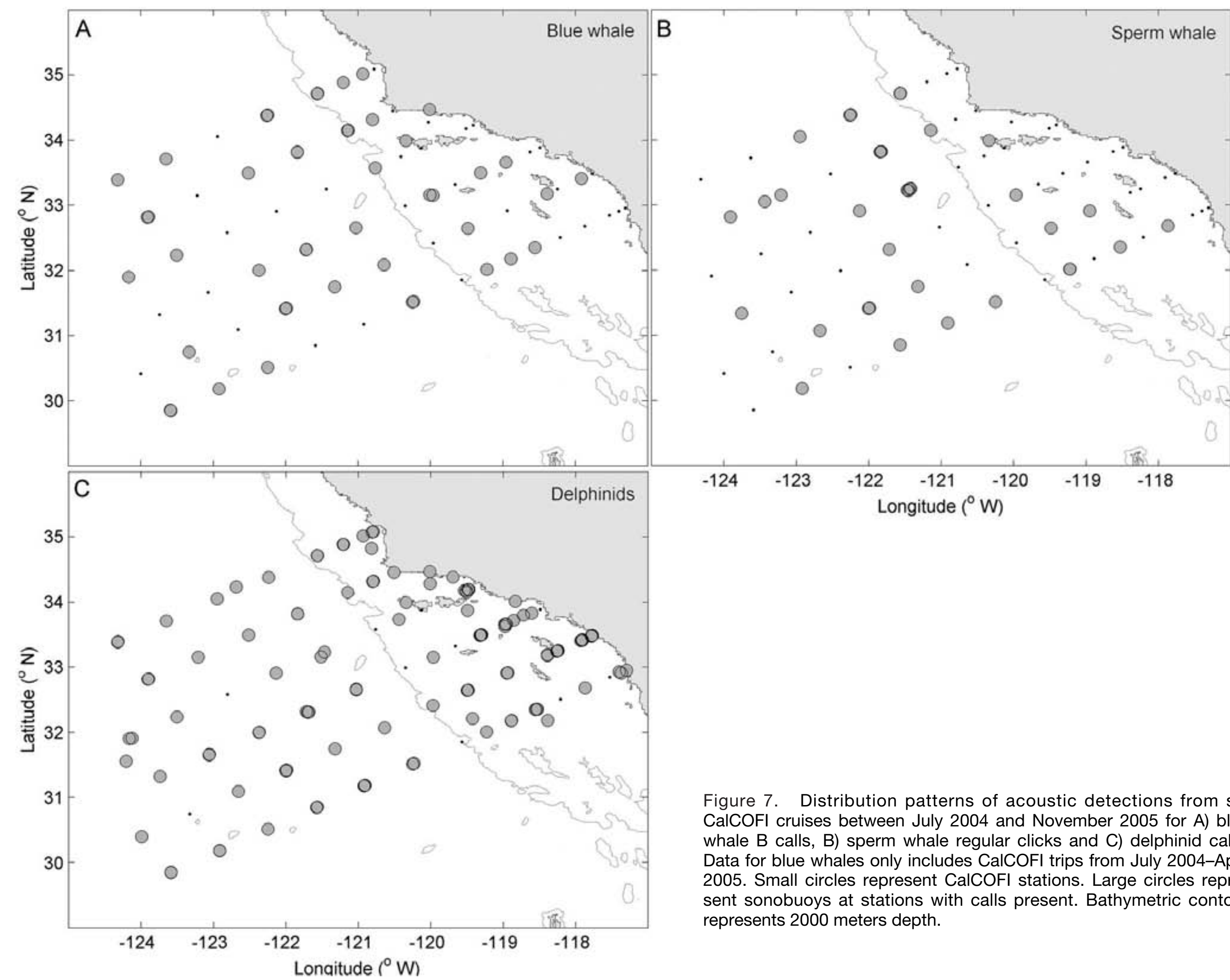

Figure 7. Distribution patterns of acoustic detections from six CalCOFI cruises between July 2004 and November 2005 for A) blue whale B calls, B) sperm whale regular clicks and C) delphinid calls. Data for blue whales only includes CalCOFI trips from July 2004–April 2005. Small circles represent CalCOFI stations. Large circles represent sonobuoys at stations with calls present. Bathymetric contour represents 2000 meters depth.

been previously reported for these species (Green et al. 1992; Forney et al. 1995; Forney and Barlow 1998; Burtenshaw et al. 2004b). However, our patterns of detection for other species, such as Pacific white-sided dolphins, are different from what has been previously reported. Our results do not suggest a seasonal trend in the abundance of this species, while previous researchers have found higher abundance in spring (Green et al. 1992; Forney and Barlow 1998). The results presented in this paper do not account for variation in sighting conditions due to differences in the sighting platform or weather conditions. In future analyses of this data we will analytically adjust for differences in sighting conditions between cruises to provide more robust estimates of seasonal presence. Continued survey effort also will help to clarify seasonal and interannual trends that will strengthen these findings.

Although we cannot yet resolve robust geographic trends in cetacean distribution, our early results indicate that geographic patterns may exist for many species found in the southern California region. Many of the dolphin species were seen mainly on the shelf, with the exception of the short-beaked common dolphin, which was found throughout the study region. This finding is similar to the distribution patterns of delphinids observed from other visual surveys in this region (Carretta et al. 2005). Fin and humpback whales were seen most commonly on the shelf, with some offshore sightings in the northern region. Offshore sightings of fin whales were common in previous surveys of the southern California region (Carretta et al. 2005), suggesting some whales may have been missed during this effort. Blue whale sightings are known to occur well offshore of southern California (Calambokidis and Barlow 2004). Although our visual detections of blue whales occurred primarily on the shelf, acoustic detections extended far offshore throughout the study region. Future analyses accounting for sighting condition and acoustic propagation may allow us to better resolve these spatial patterns.

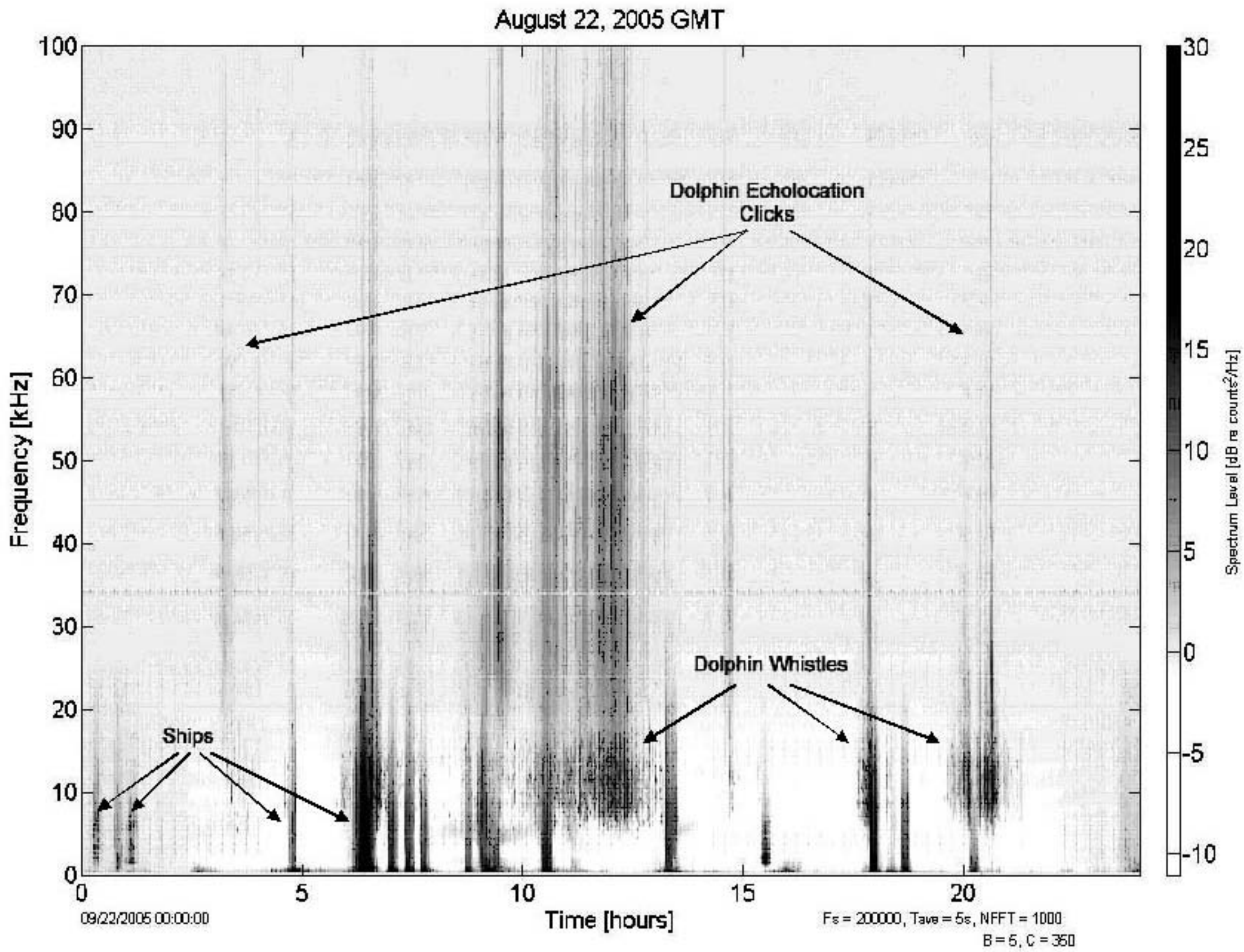

Figure 8. Long-term spectral average of HARP data collected at CalCOFI station 82.42. One days' worth of data is represented, showing the presence of delphinid echolocation clicks and whistles, as well as noise from ship passings.

Concurrent use of visual and acoustic monitoring provides the ability to compare the detection rates of species using both methods. During this effort, we have observed differences in the visual and acoustic detection of blue and sperm whales. Some differences in detection rate may be due to long-distance propagation of acoustic cues, while whales can only be seen within a few kilometers. In the southern California region, blue whale calls have been located up to tens of kilometers from the receiving hydrophone (McDonald et al. 2001) and under exceptional circumstances, with advanced acoustic processing methods, may be detected hundreds of kilometers away (Stafford et al. 1998; Watkins et al. 2000). The shallow depth of our sonobuoy hydrophones (30 m) and the downward refracting sound-speed profile of the shelf and deep waters will likely limit our acoustic detection range to tens of kilometers. Although this is still considerably farther than a visual observer can detect a whale, it is reasonable that acoustic detections of whales in offshore waters are indicative of the whales' presence there. When offshore, we do not believe we are hearing whales that are actually located on the shelf. Other differences in visual versus acoustic detection may be due to whale behavior, as has been previously shown for blue whales (Oleson 2005).

Differences in geographic patterns of visual and acoustic detections may also be attributed to whale behavior. Recent surveys for sperm whales in the eastern North Pacific have included acoustic monitoring because it is difficult to get accurate visual counts of sperm whale groups due to their long-duration deep dives. Acoustic monitoring will detect the nearly continuous clicking of this species, increasing the accuracy and precision of the abundance estimate (Barlow and Taylor 2005). Our visual detections of sperm whales were almost exclusively in deep offshore waters, while acoustic monitoring was able to detect this species offshore and in deeper basins on the shelf. These differences between acoustic and visual detections of blue and sperm whales reinforce the importance of incorporating both visual and acoustic monitoring into the survey design and increasing our understanding of whale behavior so that we can reduce bias inherent to surveying in only one mode.

Our preliminary results suggest patterns of seasonality and geographic distribution, which may eventually be interpreted as distinct habitat preferences for some species. Many previous cetacean surveys have not been conducted on fine enough temporal or spatial scale or have not included simultaneous environmental measurements which has prevented the computation of detailed habitat models. Models of cetacean habitat have been derived for the Eastern Tropical Pacific (Ferguson et al. 2006) and the California Current (Forney 2000); however, data on cetacean prey species were not collected, preventing direct association between cetaceans and their prey in these models. Hydrographic, net tow, and acoustic backscatter data collected on the CalCOFI platform provide a unique opportunity to examine the distribution of cetacean species in the context of the entire ecosystem from physical forcing through zooplankton and fish, the primary prey of most cetacean species. Our future investigations will focus on developing predictive habitat models to understand the role cetaceans play in the offshore ecosystem of southern California.

CONCLUSIONS

Our preliminary findings from the first six cruises of joint visual and acoustic monitoring for cetaceans aboard CalCOFI surveys offers an illustration of what can be obtained from our collaboration with CalCOFI and provides a direction for our future research. The modeling of CalCOFI environmental and marine mammal occurrence data, combined with collection of new visual and acoustic distribution data, provide an ideal data set for constructing marine mammal habitat models. We hope these models will enable researchers and managers to better understand ecological relationships in this marine system by providing improved abundance estimates and baseline distribution information for studying anthropogenic impact. The incorporation of visual and acoustic cetacean surveys to CalCOFI cruises allows us to examine seasonal and interannual distribution patterns on a finer temporal scale than has been achieved for pelagic surveys in the eastern North Pacific Ocean.

In the coming months we will improve our hydrophone array technology and develop automatic classifiers for deployment on the autonomous acoustic data. Improved acoustic data quality and the identification of delphinids to species will improve our ability to find robust geographic and temporal patterns in the mobile and fixed acoustic data sets.

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