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Examining Explosions in Southern California and their Potential Impact on Cetacean Acoustic Behavior

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EXECUTIVE SUMMARY

This ongoing project will study explosions recorded by passive acoustic monitoring in the Southern California (SOCAL) region between 2009 and 2012, and provide a description of their characteristics and frequency of occurrence. In this region, explosions are used both by the Navy as part of training exercises, and by the commercial fishing industry as a deterrent for marine mammals. We propose to separate these two uses of explosives based on their acoustic signature, time of day, and geographic distribution. By examining spatial and temporal overlap of each explosion type with cetacean vocalizations, the potential effects of explosions on cetacean vocal behavior may be measured.

BACKGROUND

Explosions create a pressure impulse with a sharp rise time and an extended decay over time (Figure 1). The initial pressure wave is called the "shock wave" and it is followed by a series of oscillations called the "bubble pulses." Several parameters influence the characteristics of the sound from an explosion: (1) the weight and type of explosive material, (2) the detonation depth, and (3) the distance between the explosive source and the acoustic receiver. The Net Explosive Weight (NEW) of an explosive is the weight of the explosive material, referenced to the explosive power of Trinitrotoluene (TNT). When explosive weights are presented below, they are given as NEW. The detonation depth is important due to surface-image interference. Energy is received both from the direct path between the explosion and the receiver, and from the path that is reflected from the sea surface. For explosions located near the sea surface, an interference pattern comes from the coherent sum of the two paths. Dependent upon the frequency and depth, there can be constructive or destructive interference. The distance between the explosive charge and the receiver will attenuate the signal, preferentially at high frequencies, but will also create an extended time sequence (called the coda) from reverberant and multipath propagation.

Explosions generally have high source levels. For a chemical charge, the source level of the initial shock wave, a large component of the total energy, is given by:

$$SPL\ dB\ re\ 1\mu Pa\ @\ 1\ m = 269\ dB + 7.53 * \log_{10}(w),$$

where w is the charge weight equivalent in pounds of TNT (Urick, 1975; NRC, 2003). A 100 lb charge of TNT equivalent explosive would produce a total of 289 dB re 1µPa @ 1 m (including initial shock and bubble pulse) with almost constant spectral levels across the frequency band of 10 to 200 Hz.

In the SOCAL region, underwater explosions occur both due to naval training exercises and from marine mammal deterring 'seal bombs' used by commercial fisheries. Navy explosive use, as reported annually to the National Marine Fisheries Service (NMFS), is generally confined to daylight hours. In addition, since reporting began in 2009, at-sea Navy explosive use has been generally more limited in quantity given the availability of land-based ranges in SOCAL (i.e. San Clemente Island) as well as the southwest US (e.g. Fallon Range Complex, NV).

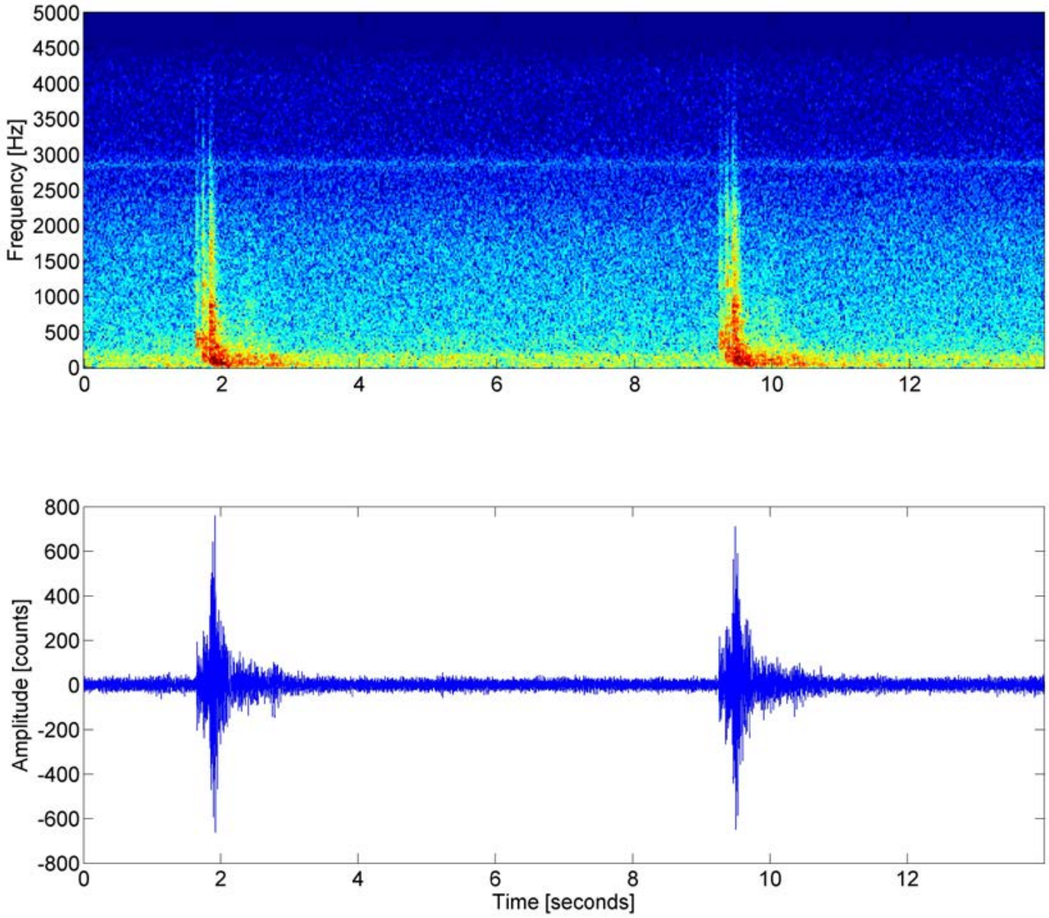


Figure 1. Two explosions, most likely seal bombs, are shown with rapid onset and extended reverberation as (above) spectrogram, and (below) time series.

Naval Training Explosions

Authorized Navy training activities within the SOCAL Range Complex that include the use of at-sea explosions include: (a) Surface-to-Surface Gunnery Exercise (S-S-GUNNEX), (b) Air-to-Surface Missile Exercise (A-S MISSILEX), (c) Bombing Exercise (BOMBEX), (d) Sinking Exercise (SINKEX), and (e) Extended Echo Ranging\Improved Extended Echo Ranging (EER\IEER) Exercise. These activities can be further divided into the use of two types of explosive sources: munitions and demolition charges.

Munitions are weapons or ammunition. The Mk-48 is a heavyweight torpedo with 851 pounds of explosives. The Mk-48 detonates below the hull of its target (nominally at 50 feet depth). The Harpoon and Maverick are anti-ship missiles with 448 pounds and 78.5 pounds of explosives, respectively. Mk-83 and Mk-82 are bombs, dropped from aircraft, and have 574 pounds and 238 pounds of explosives, respectively. The Mk-83 and Mk-82 are free-fall, non-guided general-purpose bombs. Their source depth is assumed to be two meters for bombs and missiles that do not strike their target. Naval warships conducting gunnery exercises use 5" rounds, taken to be 9.5 pounds of explosive, and 76 mm rounds, taken to be 1.6 pounds of explosive. For these gunnery rounds, a source depth of one foot is assumed. The AN/SSQ-110/A sonobuoy is called an Extended Echo Ranging\Improved Extended Echo Ranging (EER\IEER) acoustic source. The lower section of the sonobuoy consists of two Signal Underwater Sound (SUS) explosives of 4.1 pounds each (Department_of_the_Navy, 2008). The Navy is in the process of phasing out the EER\IEER sonobuoys in lieu of new acoustic sonobuoys (Department_of_Navy, 2013).

Demolition, conducted by specialized teams, is used to destroy underwater obstacles or mines. A typical demolition charge used in naval training is given to be 20 pounds of explosives, although in many cases a lower charge weight is used. The use of demolition charges in the SOCAL region primarily occurs in water adjacent to the beach in Northeast Harbor at the north shore of San Clemente Island (Department_of_the_Navy, 2008), and in the near shore waters of the Silver Strand Training Complex adjacent to San Diego (Department_of_the_Navy 2011).

Table 1. Explosives use reported for SOCAL Range Complex Jan 2009 – August 2013.

Underwater Explosives Type	Jan-Aug 2009	Aug 2009-Aug 2010	Aug 2010-Aug 2011	Aug 2011-Aug 2012	Aug 2012-Aug 2013
5" Naval Gunnery Rounds *	25	66	0	0	329
76 mm Naval Gunnery Rounds *	51	0	0	0	42
Maverick Missiles	1	1	0	0	0
Harpoon Missiles	0	0	0	0	0
Mk-82 Aerial Bombs	1	0	0	0	0
Mk-83 Aerial Bombs	0	0	0	0	0
Mk-48 Torpedoes	0	0	0	0	0
Demolition Charges	84	5	69	8	9
EER\IEER Explosive Sonobuoys	356	120	180	classified	18

* locations of at-sea gunnery firing are generally confined to a box south of San Clemente Island which is approximately 10 miles or more from site N

Exercise reports for the SOCAL Range Complex (Department_of_the_Navy, 2009; 2010; 2011; 2012; 2013) suggest low numbers of explosives are being used in association with Navy training exercises (Table 1). The most frequently used explosive charges are from EER\IEER (AN/SSQ-110/A) sonobuoys (4.1 lbs) followed by demolition charges (20 lbs) and naval gunnery rounds. There have been few or no uses of large bombs, missiles, or torpedoes for at-sea explosive training from 2009 through 2013.

Detections of explosions at site N (32° 22.18N, 118° 33.77W, depth 1250 m) south of San Clemente Island, are shown in Figure 2 along with detections of Mid-Frequency Active (MFA) sonar. Most periods of explosive usage do not correlate well with reported major naval exercises (red shaded area in Figure 2). For instance, an Integrated Anti-submarine Warfare Course was conducted during July 2012 with substantial use of MFA sonar but little or no use of explosives. Some limited explosive use, however, could occur during any given Major Training Exercise or individual unit level training. The increased nighttime explosions in September suggest an origin from fisheries related use as described below.

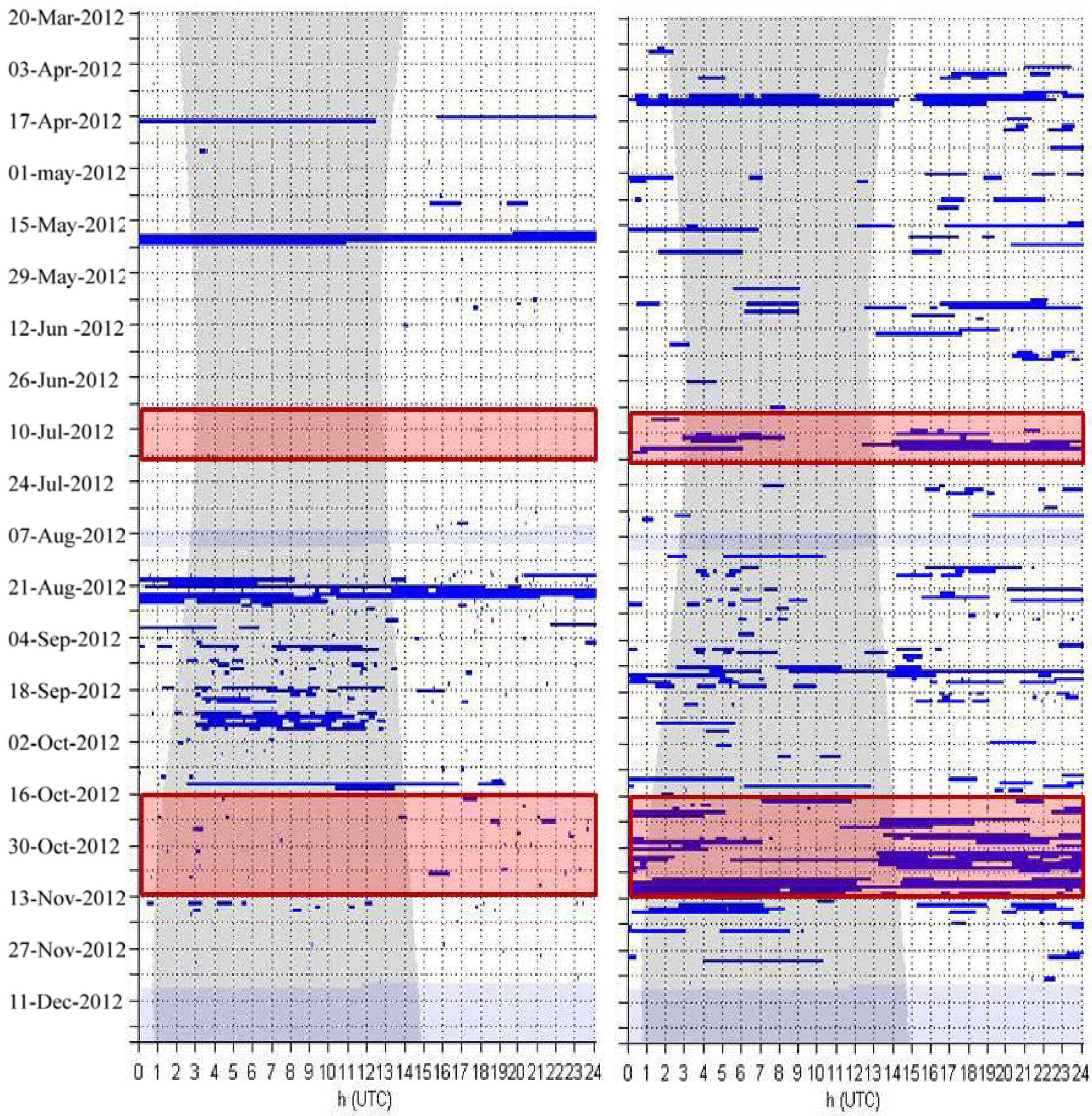


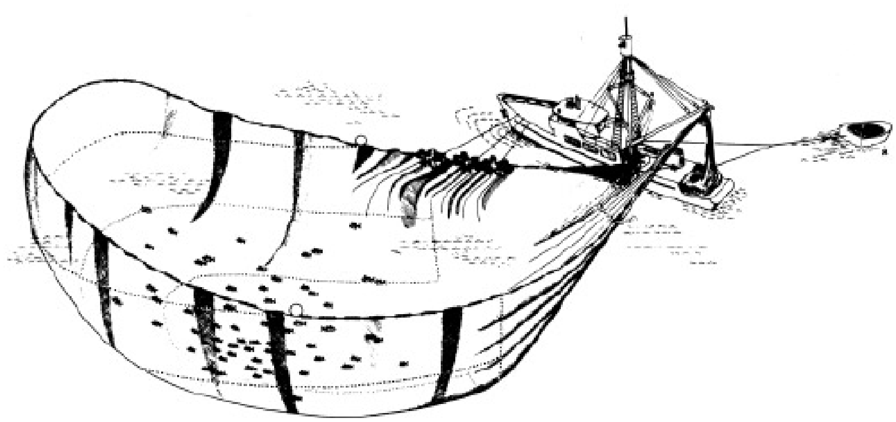
Figure 2. Detections of (left) explosions and (right) MFA sonar at site N. Red shaded areas denote times of major naval exercises. Gray shaded area denotes nighttime and purple shading denotes no data collection.

Commercial Fisheries Explosions

The use of explosives is a common practice for several fisheries in the SOCAL region. Seal bomb deterrents are used by several fisheries in the SOCAL region including: purse seine fisheries (Figure 3) that target primarily squid, but also scombrids and baitfish such as sardine and anchovy, and set gillnet fisheries (Figure 4) targeting halibut or white seabass. The largest catches by weight are squid and sardines primarily from boats operating in the Los Angeles area, specifically San Pedro and Terminal Island (California_Department_of_Fish_and_Game, 2012a).

The market squid (*Doryteuthis opalescen*s) fishery is one of the most important California fisheries in terms of landings and revenue (CADFG 2012b). While technically a year-round fishery, the fishery is closed when annual landings from April through March of the following year reach 118,000 short tons, which typically occurs between November and December (Figure 5) (CADFG 2012b). As of November 2012, there were approximately 155 market squid fishing permits in California, comprised of fleets in central and southern California
(CADFG, https://nrm.dfg.ca.gov/FileHandler.ashx?documentversionid=101137).

'Seal bombs' are small explosive devices that are used to deter marine mammals from being caught in fishing nets or from preying on catch. Seal bombs contain approximately 2.3 grams of explosive charge in a sealed cardboard tube, fitted with a waterproof fuse. They are weighted to sink below the surface of the water before detonation (Myrick *et al.*, 1990). The time delay between when the fuse is lit and when the unit enters the water allows regulation of detonation depth. Measured seal bomb sound pressure levels are 205 dB re 1µPa @ 1 m, with a duration of 30 ms (Awbrey and Thomas, 1987). These values are less than the value predicted for 2.3 grams of explosives by the equation given above (i.e., 251 dB re 1µPa @ 1 m) likely owing to the shallow depth of their detonation and subsequently low confining pressure.



Credit: NMFS

Figure 3. Purse seine fishing.

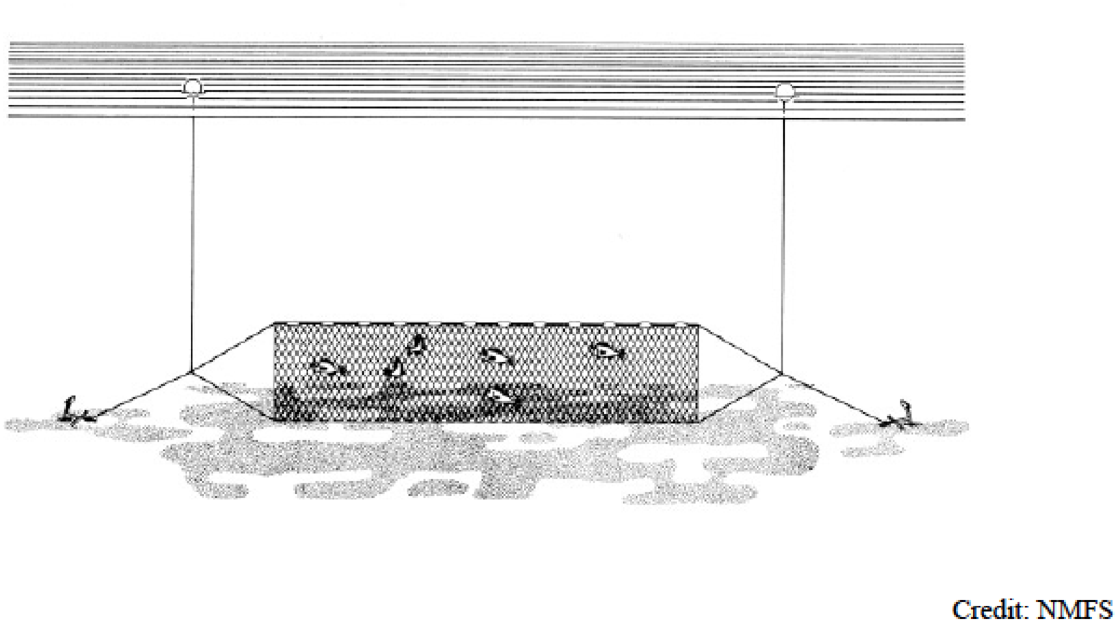


Figure 4. Set gillnet fishing.

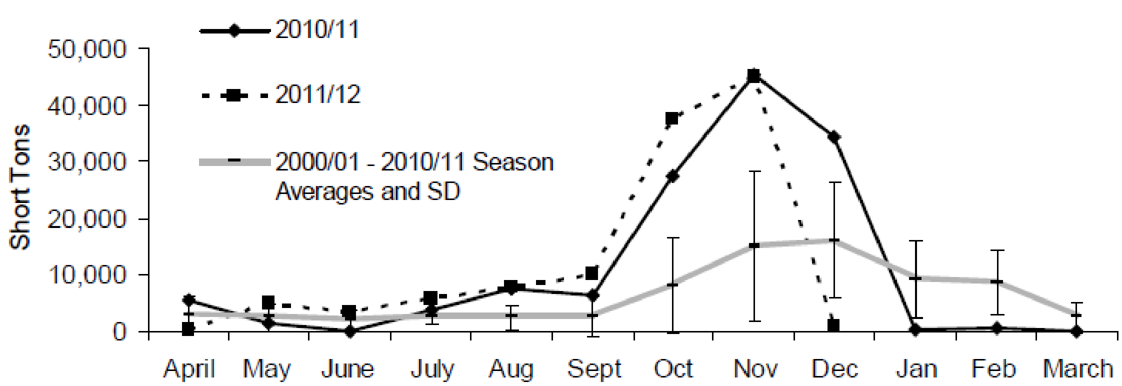


Figure 5. Monthly landings of market squid by fishing season, as reported to the California Department of Fish and Game.

IMPACTS

It is not known whether underwater explosions have an impact on marine species. We will attempt to address this question by investigating potential changes in acoustic behavior of large, endangered baleen whales, specifically blue and fin whales, and beaked whales in response to explosive use in the SOCAL region (Figure 6). There are significant challenges when attempting to demonstrate changes in acoustic behavior due to external anthropogenic sources since animals exhibit natural variability; for example, they may be more acoustically active during a certain time of the day or in different seasons. Also, there may be a fluctuation in counts of acoustic signals due to seasonal changes in overall abundance of a species. For baleen whales, changes in propagation characteristics of the environment may alter detection range and hence counts of acoustic signals. Additionally, the location of the explosions in relation to an acoustically active cetacean has uncertainty; consequently, an error may have to be estimated for the received level of the explosion reaching a calling animal. Both blue whales as well as beaked whales have been shown to react to some anthropogenic sounds depending on their behavioral state by interrupting their feeding behavior (Tyack *et al.*, 2011; Melcon *et al.*, 2012; DeRuiter *et al.*, 2013; Goldbogen *et al.*, 2013). The long-term effect of repeated foraging interruption is still unknown at the population level and warrants investigation.

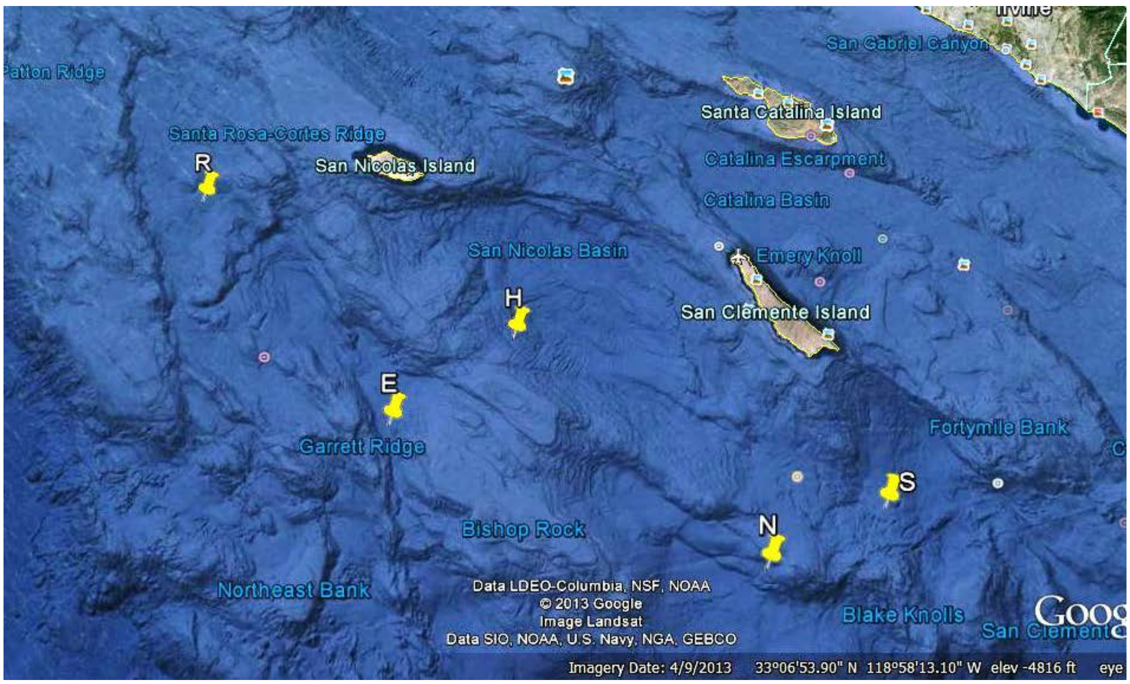


Figure 6. Map of study region with acoustic recording sites E, H, N, S, and R.

Perliminary results

Explosions are detected at most sites within the Southern California Bight, with very high numbers at site H, offshore and west of San Clemente Island, near Tanner Bank. They occur throughout the year, but particularly often in the late summer and fall months (Figure 7). At site H, the majority of explosions occur at night (Figure 8). The Navy has confirmed that any at-sea explosive use would typically be done in daylight, so the nighttime detections suggest these explosions are fisheries related. In the years 2010-2012, counts of explosions per week regularly reached several thousand (max. 8,500). The maximum number of detected explosions per hour was 500. These large numbers of explosions, as well as their persistence over many months, were unexpected and warrant detailed analysis to determine impacts.

The activity responsible for the large numbers of explosions at site H may be attributed to the squid fishery for the period April through November although other fisheries cannot be ruled out for other time periods. For instance, during slower months, many squid fishery vessels may participate in coastal pelagic finfish fisheries for Pacific sardine, Pacific mackerel, and northern anchovy (CADFG 2008). When comparing pounds of landed squid at the ports of Los Angeles and San Diego with the counts of explosions (potential use of seal bombs), there appears to be a strong relationship between landings and quantity of detected explosions (Figure 9). Corroborating evidence may be obtained from the logbook locations of fishing activities.

In year 2011, detections of beaked whales were high when explosions were low (Figure 10). This observation led us to take a closer look at the relationship of detections of beaked whales and weekly counts of explosions. In most other years, there is no clear pattern and the possible impact of explosions on beaked whales must be more complex. Natural seasonal cycles of beaked whales appear to result in lower numbers of detections in late summer and early fall, and acoustic encounter rates increase towards late fall and winter. These cycles, however, seem to vary across years and need to be confirmed at sites with less anthropogenic impact. Statistical models will be used to address the interaction of explosions and other variables with acoustic behavior of cetaceans.

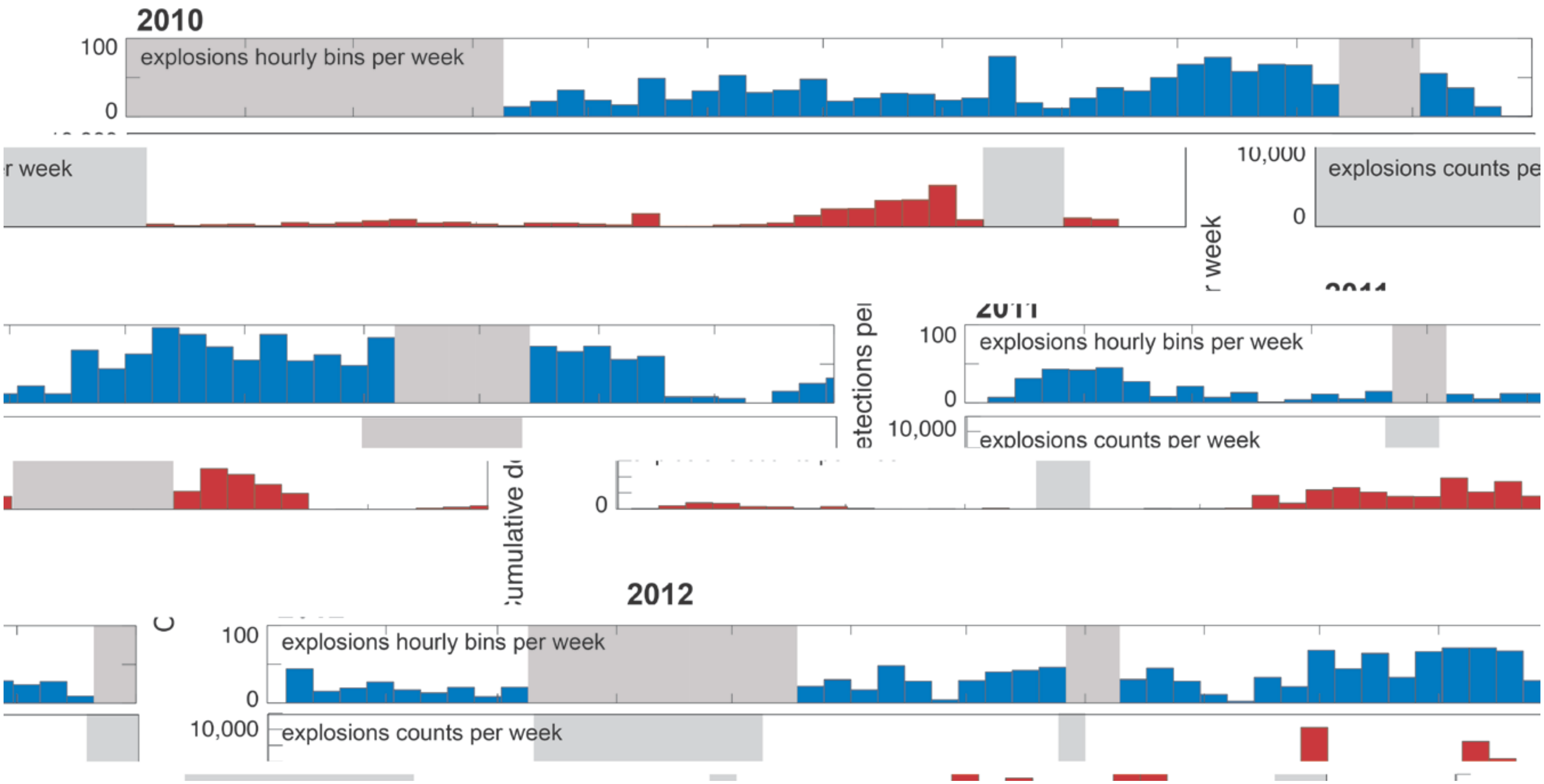


Figure 7. Explosions per week at site H from April 2010 until December 2012, comparing hours per week (top, blue) and counts per week (bottom, red). Shaded regions indicate periods of no recordings or missing analysis.

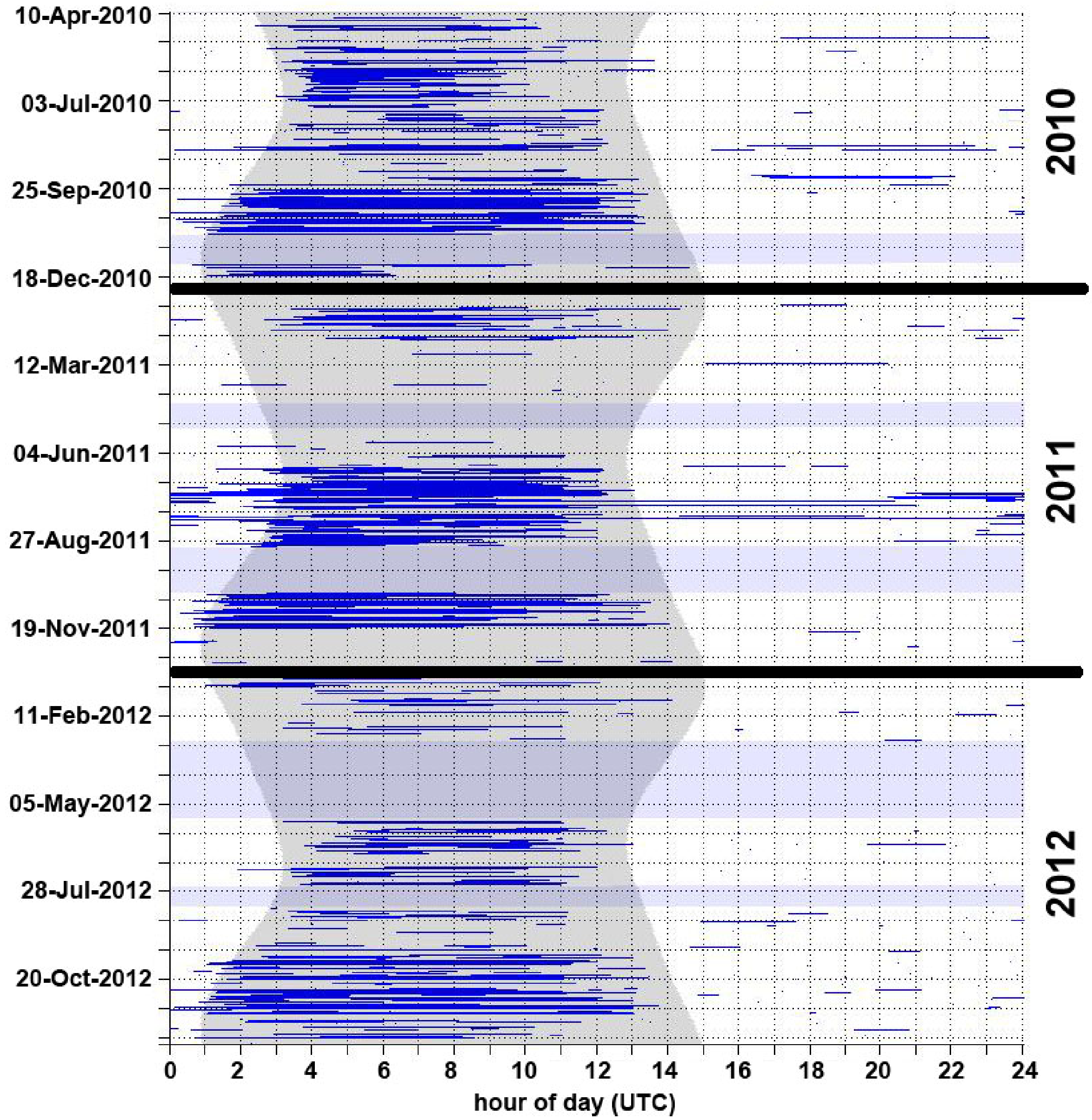


Figure 8. Occurrence of explosions (blue) over three years at SOCAL site H was predominantly at night (grey shaded area). Purple shaded areas indicate time periods with no data.

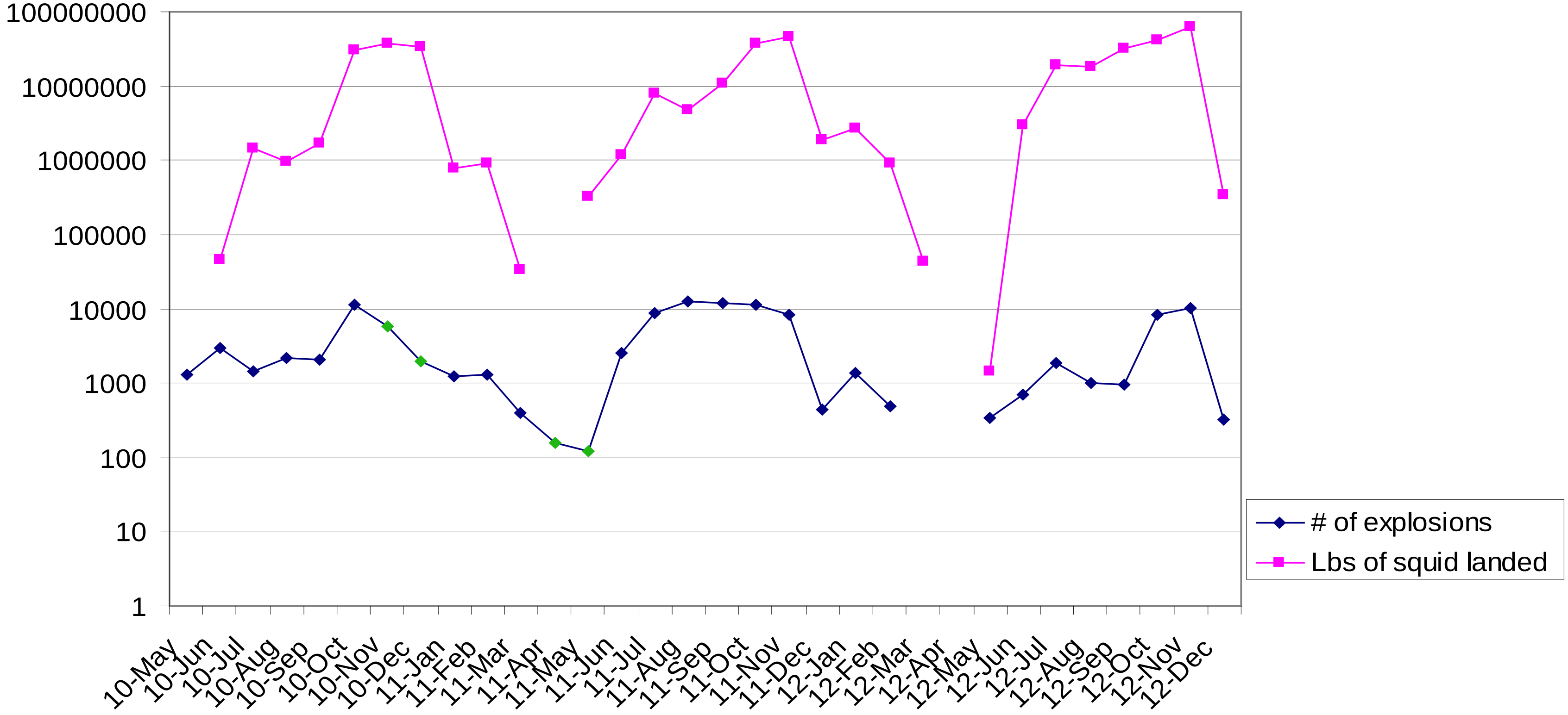


Figure 9. Number of detected explosions per month (blue) in the years of 2010-2012 in comparison to pounds of landed squid (pink) at the ports of Los Angeles and San Diego. Green data points indicate months with partial acoustic monitoring effort

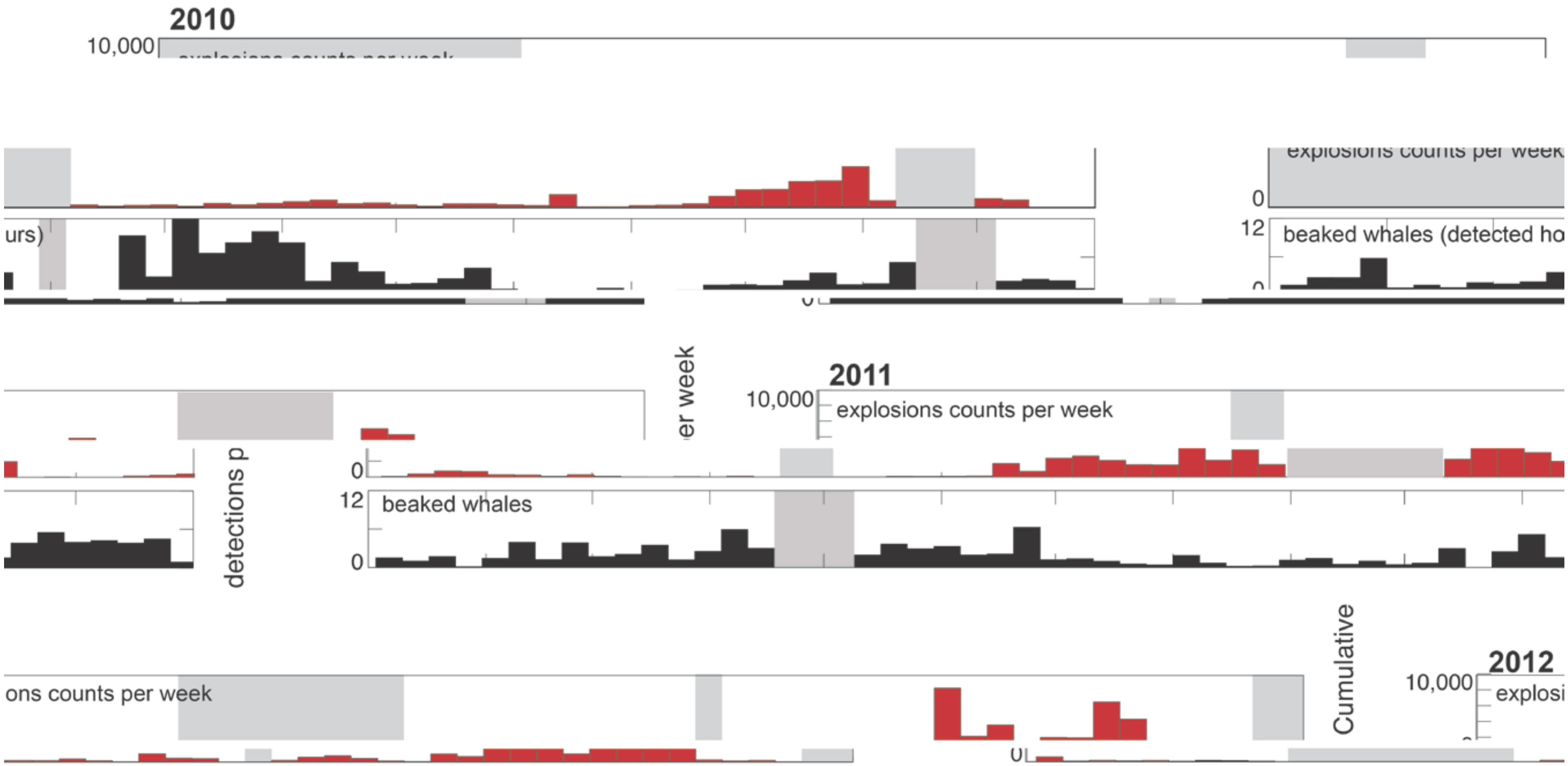


Figure 10. Comparison of counts of detected explosions per week (top, red) and hours with detections of Cuvier's beaked whales per week (bottom black) from April 2010 until December 2012. Shaded regions indicate periods with no recordings or missing analysis.

Current state of analysis

We are currently working on the analysis of the presence of explosions and beaked, blue, and fin whale acoustic encounters at sites E, H, N, S, and R (Figure 6).

Site H has the longest time series of any site in the Southern California Bight (Table 2) and appears to have a particularly large number of explosions. Site E, being on the other side of Tanner Bank, where likely fishing and use of seal bombs is taking place, also appears to have a large number of explosions but is a much shorter time series. Site S, just south of San Clemente Island also appears to be a site with fishery related explosions but quantitative analysis has yet to be performed. Site N has less fishery explosions, but it has a number of potential naval explosions. Site R will serve as a reference site with low numbers of explosions, to evaluate impacts of other variables on changes to call rates.

We are close to completing our analysis of hourly counts of explosions in all recordings from site H (Table 2). Explosions at all other sites will be logged as presence/absence, i.e. we will determine start and end of a bout of explosions, taking a 30 minute break as criterion to split explosions into two separate bouts. Analysis of site N has been ongoing based on naval monitoring over the past years and is almost complete. Analysis of sites E, R, and S will commence once the analysis of site H is completed.

Data analysis for beaked whales is completed (based on an ONR grant to S. Baumann-Pickering). Sites R, E, H, N, and S are all sites that are preferred beaked whale habitat with highest numbers of detections in Southern California.

Data analysis for fin whales has been completed; we have described fin whale presence at these sites based on acoustic energy in the band of fin whale 20 Hz calls. For blue whales, the analysis will be conducted at a call-count level and is underway (both analyses based on an ONR grant to A. Širović). To constrain our blue whale call counts to an area relatively near the instrument, we will use call received levels. Since blue whale calls propagate over long distances, we will use this constraint to limit our detection range and thus use in our analysis only calls from those whales close enough to be potentially impacted by the explosions.

At sites N and P, we have multi-sensor data that will be used to localize the source of the explosion, calculate their source levels, and model their propagation. These data will be used for closer characterization of the explosion sound characteristics. We plan to present preliminary analysis from this project at the December 2013 meeting of the Acoustical Society of America (Baumann-Pickering *et al.*, 2013).

Future analysis will be contained in the Navy's next annual monitoring report under the Hawaii-Southern California Training and Testing monitoring plan.

Table 2: Overview of available acoustic recordings at sites E, H, N, S, and R; x is indicating completed analysis. Site H is analyzed for hourly counts of explosions. All other sites are being analyzed for presence/absence (p/a) and start and end of a bout of explosions are marked.

Year		p/a		counts		p/a		p/a		p/a
2006	05 E									
2007	14 E		18 H							
2008	19 E									
			23 H							
			26 H							
	27 E		27 H							
	29 E		29 H	x						
2009			30 H							
	31 E		31 H		31 N					
	32 E		32 H	x	32 N	x				
	33 E		33 H		33 N	x				
	34 E		34 H	x	34 N	x				
			35 H	x	35 N	x	35 S		35 R	
2010			36 H	x	36 N	x	36 S		36 R	
			37 H	x	37 N	x	37 S		37 R	
			38 H	x	38 N	x	38 S		38 R	
			40 H	x	40 N	x	40 S		40 R	
2011			41 H	x	41 N	x	41 S		41 R	
			44 H	x	44 N	x				
			45 H	x	45 N	x				
2012			46 H	x	46 N	x				
			47 H	x	47 N	x				
2013			48 H	x	48 N					

REFERENCES

Awbrey, F., and Thomas, J. A. (**1987**). " Measurements of sound propagation from several acoustic harassment devices.," in *Acoustical deterrents in marine mammal conflicts with fisheries.* , edited by B. R. Mate, and J. T. Harvey (Oregon State University), pp. 85-104.

Baumann-Pickering, S., Debich, A. J., Trickey, J. T., Širović, A., Carretta, J. V., Gresalfi, R., Roch, M. A., Wiggins, S. M., and Hildebrand, J. A. (**2013**). "Impact of underwater explosions on cetaceans," J. Acoust. Soc. Am. Abstract **In Press**.

California Department of Fish and Game (2008). "Status of the Fisheries Report- an update through 2006. Report to the Fish and Game Commision as directed by the Marine Life Management Act of 1998." http://www.dfg.ca.gov/marine/status/

California Department of Fish and Game (2013). "Status of the Fisheries Report- an update through 2011. Report to the Fish and Game Commision as directed by the Marine Life Management Act of 1998." http://www.dfg.ca.gov/marine/status/

California_Department_of_Fish_and_Game (**2012a**). "Final 2012 California Commercial Landings," (http://www.dfg.ca.gov/marine/landings/landings12.asp).

California_Department_of_Fish_Game (2012b). "2012 California Legistative Fisheries Forum: Department of Fish and Game Annual Marine Fisheries Report. http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=42564

Department_of_the_Navy (**2008**). "Southern California Range Complex Final Environmental Impact Statement / Overseas Environmental Impact Statement " (http://www.nmfs.noaa.gov/pr/pdfs/permits/socal_eis_vol2.pdf).

Department_of_the_Navy (**2009**). "Annual Range Complex Exercise Report January to 1 August 2009 For the U.S. Navy's Hawaii Range Complex (HRC) and Southern California (SOCAL) Range Complex," (http://www.nmfs.noaa.gov/pr/pdfs/permits/hrc_socal_report2009.pdf).

Department_of_the_Navy (**2010**). "Annual Range Complex Exercise Report 2 August 2009 to 1 August 2010 For the U.S. Navy's Hawaii Range Complex (HRC) and Southern California (SOCAL) Range Complex," (http://www.nmfs.noaa.gov/pr/pdfs/permits/hrc_socal_report2010.pdf).

Department_of_the_Navy (**2011**). "Annual Range Complex Exercise Report 2 August 2010 to 1 August 2011 For the U.S. Navy's Hawaii Range Complex (HRC) and Southern California (SOCAL) Range Complex," (http://www.nmfs.noaa.gov/pr/pdfs/permits/socal_hrc_exercisereport2011.pdf).

Department_of_the_Navy (2011). "Silver Strand Training Complex Final Environmental Impact Statement. January 2011.

Department_of_the_Navy (2012). "Annual Range Complex Exercise Report 2 August 2011 to 1 August 2012 For the U.S. Navy's Hawaii Range Complex (HRC) and Southern California (SOCAL) Range Complex," http://www.navymarinespeciesmonitoring.us/index.php/download_file/view/344/

Department_of_the Navy (2013a). "Hawaii-Southern California Training and Testing Final Environmental Impact Statement/Overseas Environmental Impact Statement. August 2013. http://hstteis.com/

Department_of_the_Navy (in press). "Annual Range Complex Exercise Report 2 August 2012 to 1 August 2013 For the U.S. Navy's Hawaii Range Complex (HRC) and Southern California (SOCAL) Range Complex,

DeRuiter, S. L., Southall, B. L., Calambokidis, J., Zimmer, W. M., Sadykova, D., Falcone, E. A., Friedlaender, A. S., Joseph, J. E., Moretti, D., and Schorr, G. S. (**2013**). "First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar," Biology Letters **9**.

Goldbogen, J. A., Southall, B. L., DeRuiter, S. L., Calambokidis, J., Friedlaender, A. S., Hazen, E. L., Falcone, E. A., Schorr, G. S., Douglas, A., and Moretti, D. J. (**2013**). "Blue whales respond to simulated mid-frequency military sonar," Proceedings of the Royal Society B: Biological Sciences **280**.

Melcon, M. L., Cummins, A. J., Kerosky, S. M., Roche, L. K., Wiggins, S. M., and Hildebrand, J. A. (**2012**). "Blue Whales Respond to Anthropogenic Noise," PLoS One **7**, e32681.

Myrick, A. C., Fink., M., and Glick., C. B. (**1990**). "Identification, chemistry, and behavior of seal bombs used to control dolphins in the yellowfin tuna purse seine fishery in the eastern tropical Pacific: potential hazards. ," in *SWFC Admin. Rept*. (SWFSC, La Jolla), p. 25.

NRC (**2003**). "Ocean Noise and Marine Mammals," in *National Research Council* (Washington, D. C.).

Tyack, P. L., Zimmer, W. M. X., Moretti, D., Southall, B. L., Claridge, D. E., Durban, J. W., Clark, C. W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J., and Boyd, I. L. (**2011**). "Beaked Whales Respond to Simulated and Actual Navy Sonar," PLoS One **6**.

Urick, R. J. (**1975**). *Principles of Underwater Sound* (McGraw-Hill, New York).