Medium-duration archival acoustic tags provide insight into baleen whale behavior and threats

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Abstract

Short-term high-resolution archival tags have enabled a greater understanding of baleen whale behavior. Advances in battery life, storage, and concomitant sample rate increases have driven interest in developing high-resolution archival tags for days-long deployments.

Using time-depth recorder tags (TDR10, Wildlife Computers), new dart-attachments were tested on 53 humpback, blue, and fin whales from 2013 to 2015, resulting in 2087.7 hr dive data with up to 16.4 day attachments. In 2016, we modified acoustic tags (Acousonde, Greeneridge Sciences) with the new attachments and tagged 8 blue and 2 fin whales, resulting in 742.9 hr of dive and 1381.3 hr of acoustic data, with up to 20 day attachments (Fig. 1).

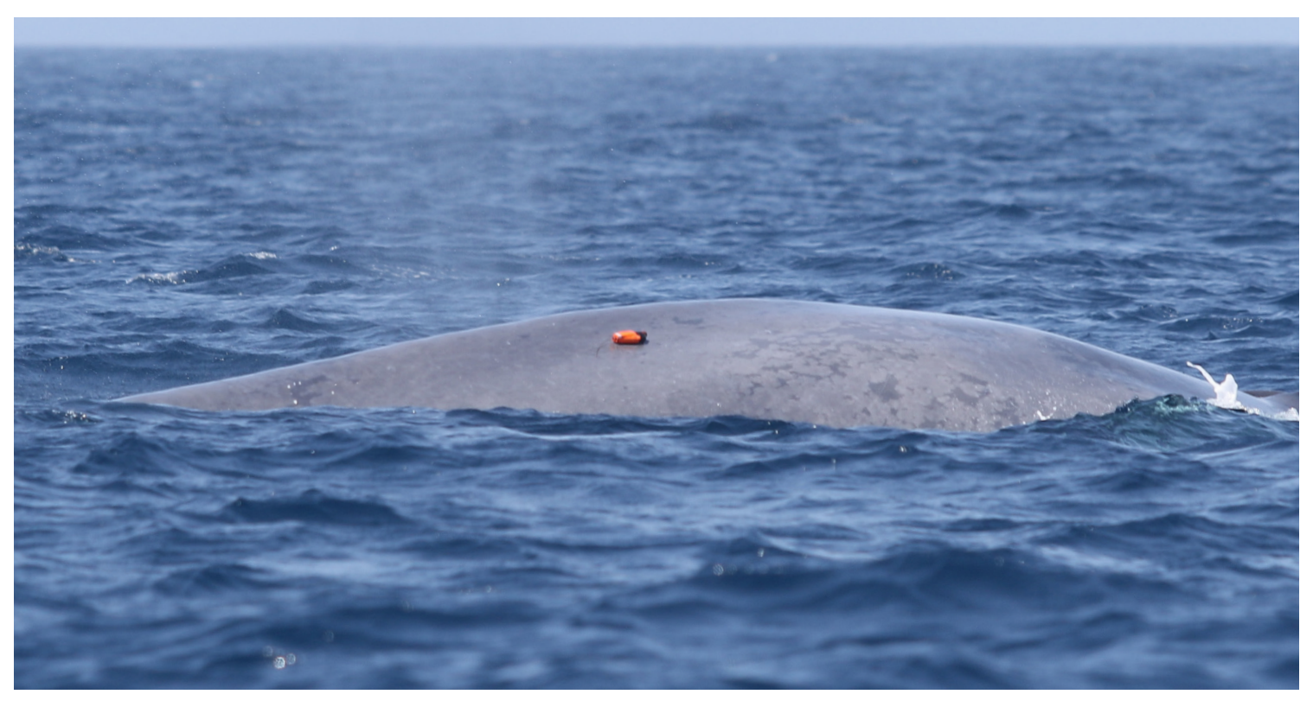


Figure 1. Dart-attached Acousonde acoustic tag attached to a blue whale.

The hydrophones recorded 1624 A, 2923 B, and 968 D blue whale calls (Fig. 2) and 500 40-Hz fin whale calls. With three-dimensional reconstruction of movement from the pressure, accelerometry, magnetometry, and Fastloc GPS sensors, long-term diel patterns in foraging and calling behavior were revealed.

Incorporating variability in calling behavior is instrumental for obtaining accurate call rate estimates for use in future passive acoustic density estimation. Thus, mean hourly call rates were calculated for each call type, including associated behavioral states and spatiotemporal factors.

Finally, 16 acoustic ship encounters, 4 incidental low-frequency active sonar and mid-frequency active (MFA) sonar exposures, and 6 controlled exposure experiments (CEEs) with real MFA during the Southern California Behavioral Response Study (SOCAL-BRS) were examined, allowing us to quantify the behavioral response to ships, ship noise, and military sonar.

These novel medium-duration acoustic tags support a more detailed picture of spatiotemporal patterns of movement and behavior, allow for accurate density estimation, and provide insight into the anthropogenic threats facing endangered baleen whales.

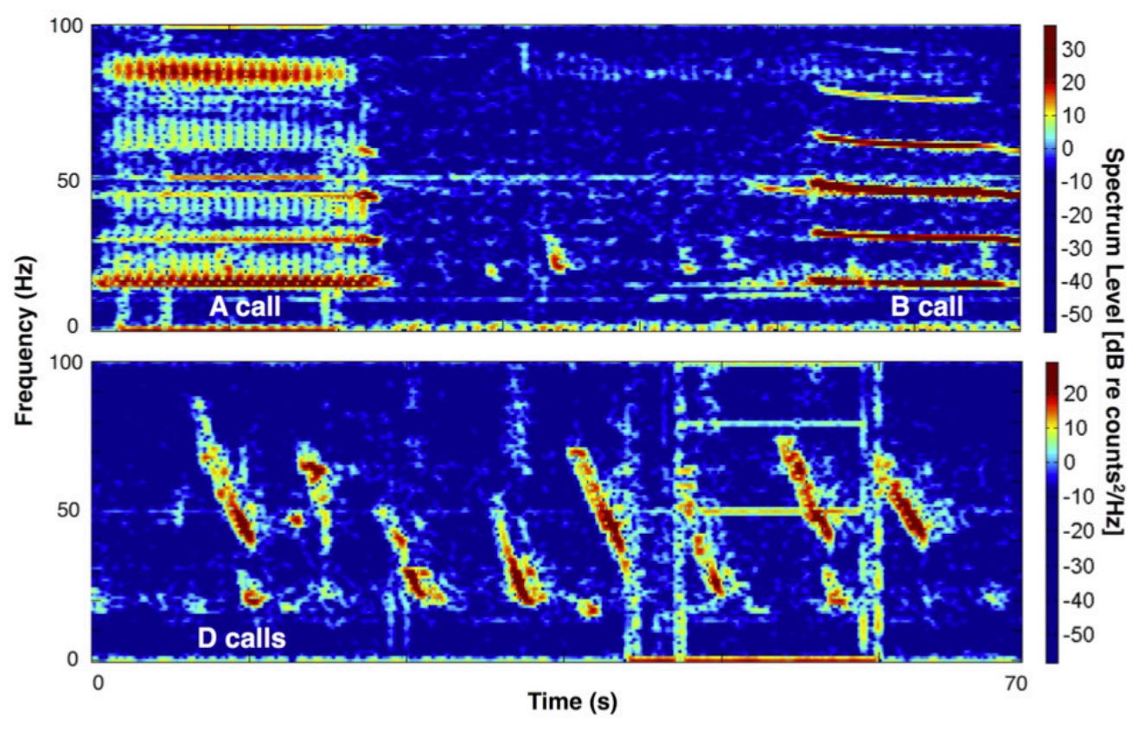


Figure 2. Spectrograms of Northeast Pacific blue whale A call (top left), B call (top right), and D calls (bottom). NFFT=2000, 90% overlap, Hanning window.

Methods

- Tag attachments consisted of three long 6-petal (for blue whales) or three short 3-petal stainless steel darts (for fin whales) attached to modified Acousonde tags with a carbon fiber plate (Fig. 3a,b).
- Tagging occurred in 2016 in the Gulf of the Farallones and Southern California Bight during various tagging projects since 2010 (Table 1).

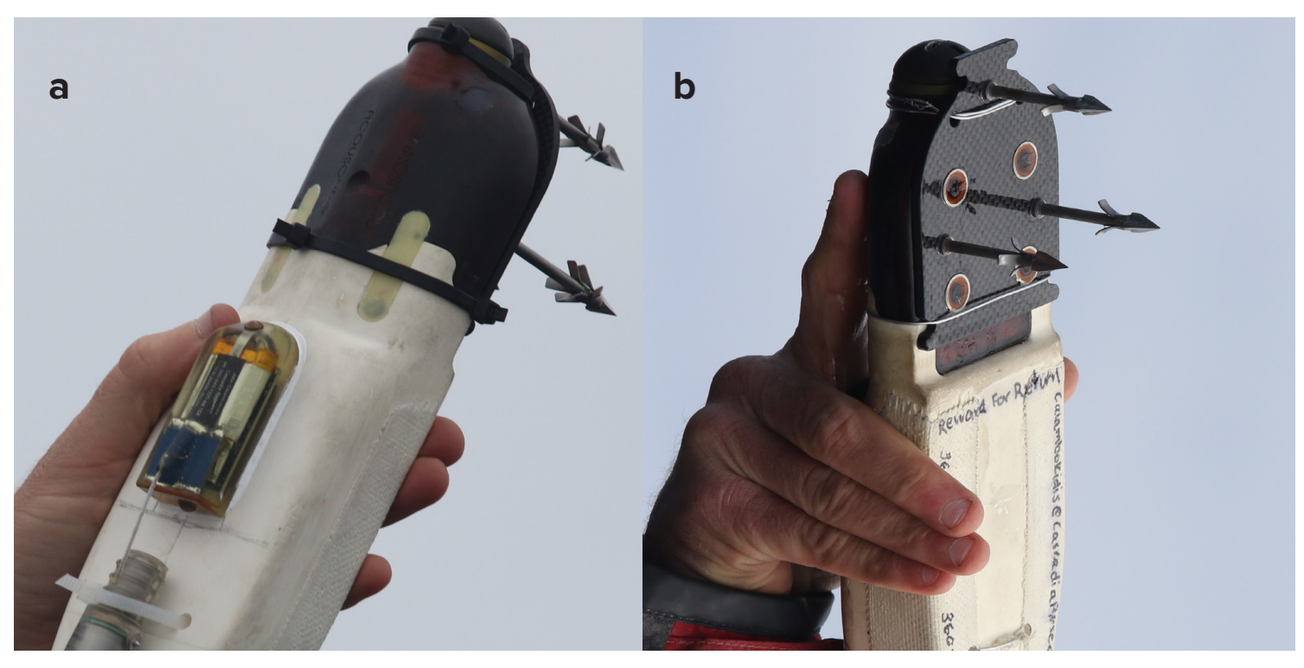


Figure 3. Acousonde tag with (a) three long (6-petal) and (b) three short (3-petal) stainless steel darts and carbon fiber attachment plate.

- CEEs consisted of 3-4.5 kHz tones played from hull-mounted sonar on ships and helicopter-dipping sonars for 30-45 min >1 km from tagged whales.
- Tags were recovered with SPOT satellite tag (Wildlife Computers) and VHF transmitter (Advanced Telemetry Systems).
- Dives were characterized from changes in pressure and behavioral state classified from maximum depth and lunge detection.
- Blue (A, B, D) and fin (40 Hz) whale calls, ship noise, incidental sonar, and CEEs were manually identified with Triton software and analyzed with octave in Matlab.
- Generalized estimating equations (GEE) were used to compare singular A, B, and D calls and phrases with behavior, location, season, and time of day.
- Generalized linear mixed models (GLMM) were used to compare B and D call rate with time of day, behavior, latitude, and distance to shore.

Table 1. Tag results from 10 Acousonde deployments in 2016.

id/sp	region	acoustics (Hz)	acc/mag (Hz)	# calls	# dives	hours on	hours dives	hours acoustics
20160523-B020-Bm	GF	1815	100/10	228	933	239.1	97.7	236.4
20160716-B020-Bm	SoCal	1815	100/10	0	466	481.9	79.5	67.2
20160717-B021-Bm	SoCal	1815	100/10	0	704	341.8	102.5	341.8
20160815-B021-Bm	SoCal	12226	100/10	0	13	3.9	3.9	3.9
20160817-B021-Bm	SoCal	12226	100/10	1	214	45.8	45.8	45.8
20190912-B014-Bp	SoCal	12226	400/20	500	726	77.1	77.4	77.1
20160914-B020-Bp	SoCal	12226	400/20	n/a	792	168.4	102.1	n/a
20160918-B008-Bm	SoCal	12226	100/10	98	1084	n/a	98.9	96.8
20160918-B021-Bm	SoCal	12226	100/10	5179	462	n/a	102.6	298.9
20160920-B014-Bm	SoCal	12226	100/10	9	n/a	104	n/a	104

Preliminary Results

Diel movement, dive, and calling behavior

Long deployments of high-resolution kinematic acoustic tags reveal fine-scale patterns in baleen whale behavior:

- Movement localized to areas where whales were tagged and feeding (Fig. 4).
- Diel pattern of deep lunge-feeding (>50 m) during the day and shallow, non-feeding dives at night (Fig. 5).
- D calls produced as singular calls during shallow dives varied from day to night.
- A and B calls mainly produced at night as repetitive phrases during shallow (<30m), non-lunging dives (Fig. 6).
- Strong patterns suggest partitioning—feeding-related behavior during the day and reproductive-related behavior at night.

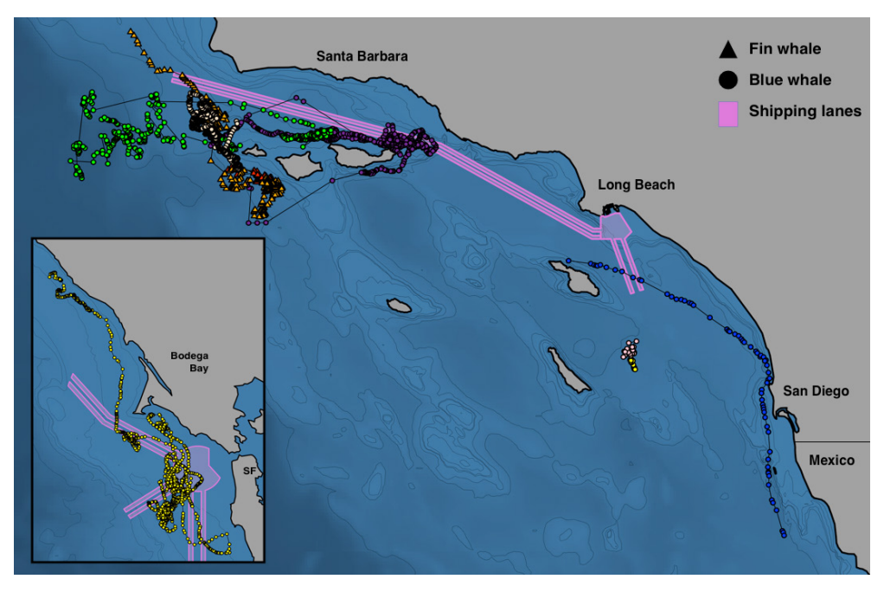


Figure 4. Fastloc GPS movement data for seven blue whales (circles) and two fin whales (triangles) tagged in northern (inset) and southern California. Shipping lanes in pink.

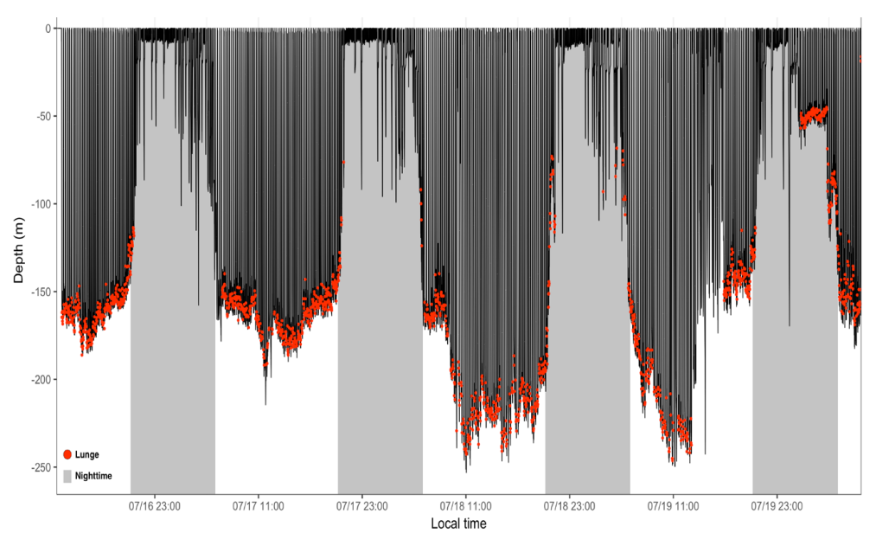


Figure 5. Four days of dive data from tagged blue whale showing strong diel trend in behavior. Lunges denoted by red circles. Nighttime shaded in grey.

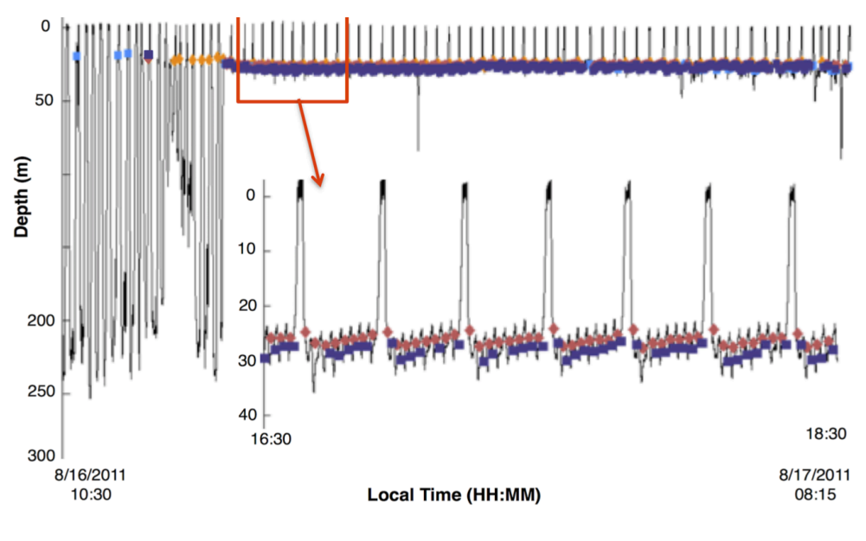
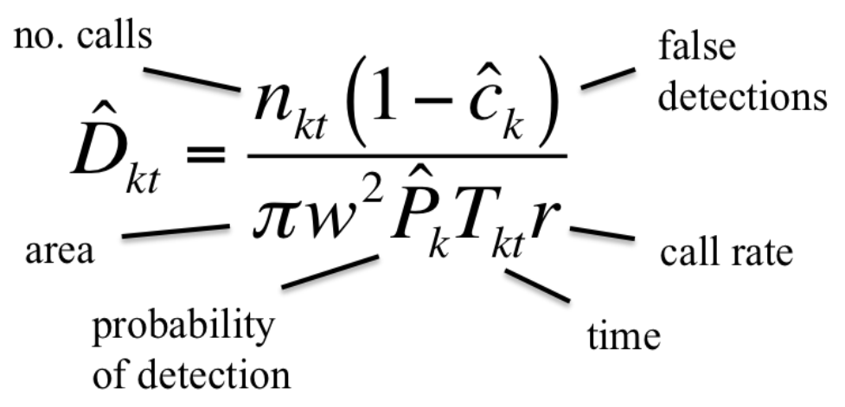


Figure 6. A and B calls produced as song by a tagged male blue whale while making shallow (<30m), non-lunging dives.

Preliminary Results (Continued)

Call rates for density estimation

- Density estimation equations with passive acoustic data requires measured or estimated variables (Fig. 7).



$$\hat{D}_{kt} = \frac{n_{kt}\left(1-\hat{c}_k\right)}{\pi w^2 \hat{P}_k T_{kt} r}$$

Figure 7. Density estimation equation, modified for passive acoustic data, highlighting the necessary measured and estimated (^) variables.

- Multi-day acoustic recordings allow us to incorporate uncertainty with call rate estimation by resolving the probability of:
  - silent animal initiating calling
  - calling animal ceasing calling
  - calling from day to night
  - calling based on behavioral state
  - calling based on spatial distribution
- Mean B call rate was greater than D call rate, and B song call rate was greater than singular B call rate.
- B and D call rates depend on the time of day, and in some cases distance from shore and behavioral state.
- Findings stress importance of incorporating variability associated with calling (Fig. 8) into call rates.

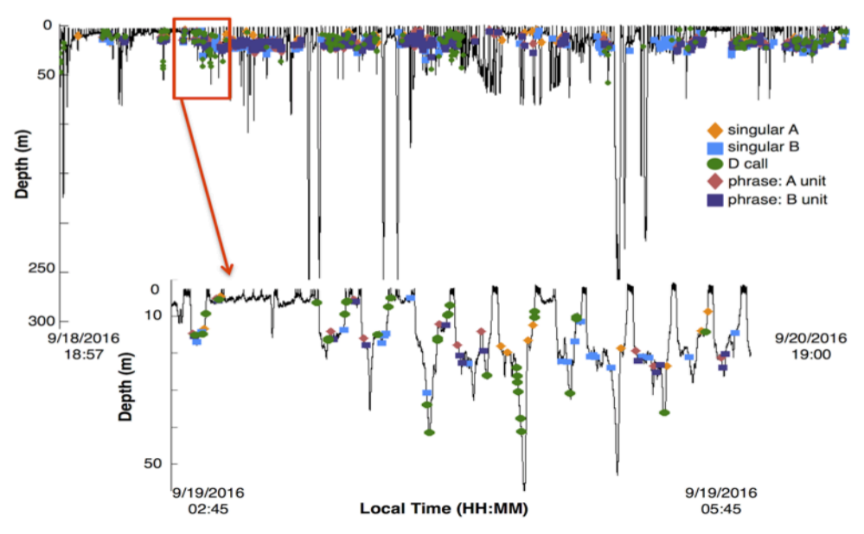


Figure 8. Dive data with close-up of A, B, and D calls showing high variability between the dive and calling behavior.

See Goldie Phillips' talk 10/27 10:45

Behavioral responses to ships, ship noise, and military sonar

Combining high-resolution kinematics with acoustics allows us to examine the impact of ships and military activities:

- Acoustics revealed 16 ship encounters with 2 blue whales, including 4 instances of multiple ship encounters (Fig. 9, 10).
- Average of 2 encounters per day suggests potential chronic exposure (Fig. 11).
- Comparisons of whale and ship GPS positions will provide the closest distance between the ship and whale.
- Acoustic recordings (Fig. 9) will allow for calculation of sound exposure levels (SEL; dB re 1 uPa2*sec) during encounters.
- Models will incorporate SEL; ship distance, speed, and length; time; and behavioral state to tease out behavioral response to ships and ship noise.
- Behavioral response to sonar (incidental and CEEs; Fig. 12) highly variable and context dependent.
- Findings stress importance of accounting for distance to sound source, prey distribution, and SEL in analyses.

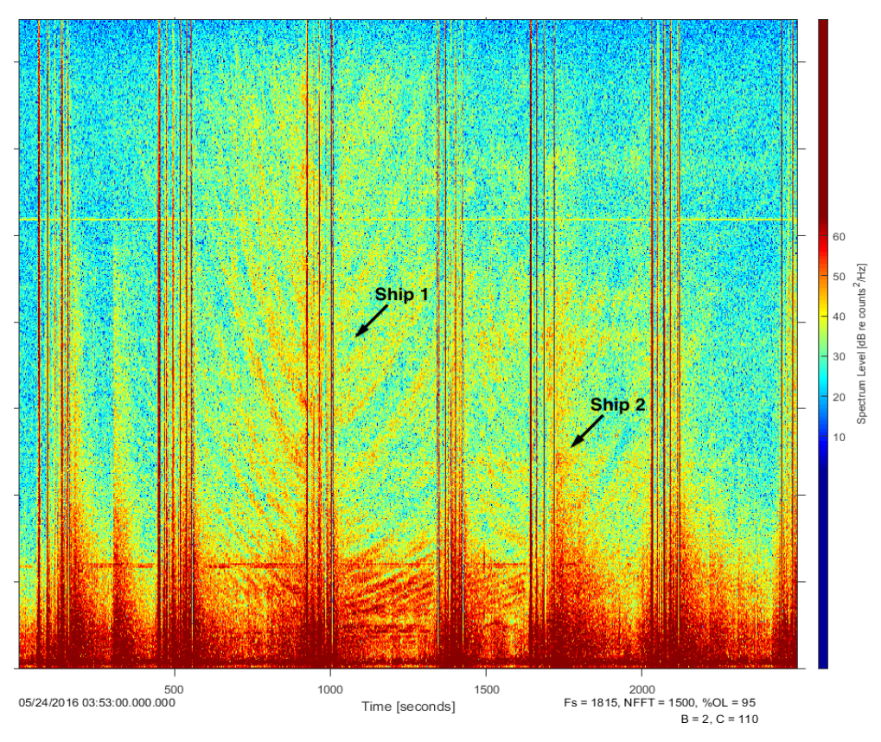


Figure 9. Spectrogram showing close approach by two ships with tagged blue whale. NFFT=1500, 90% overlap, Hanning window.

Figure 10. Close approach with tagged blue whale in path of oncoming commercial ship.

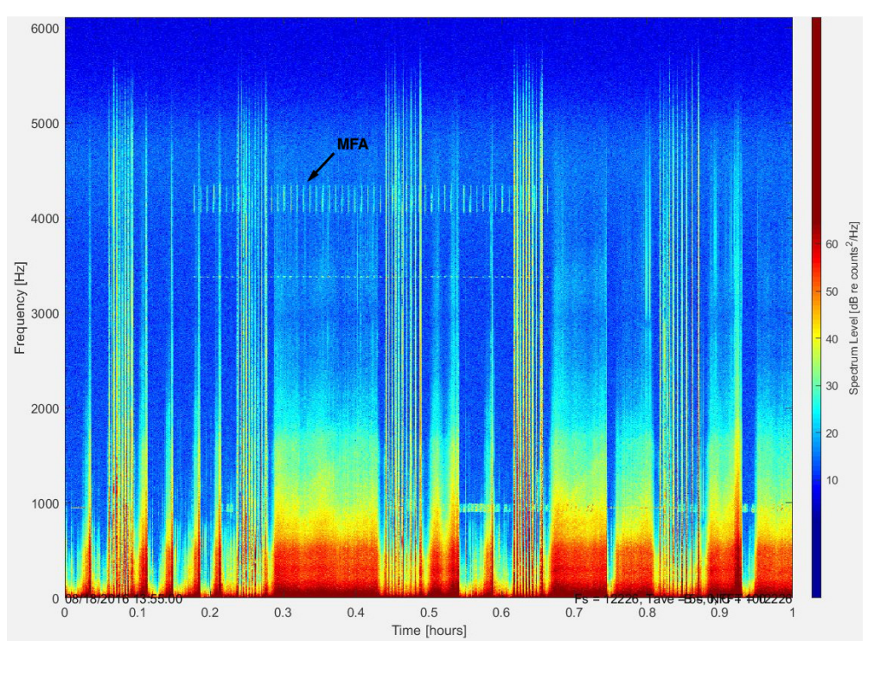


Figure 12. Spectrogram of 30-min CEE recorded on tagged blue whale. NFFT=12226, 90% overlap, Hanning window.

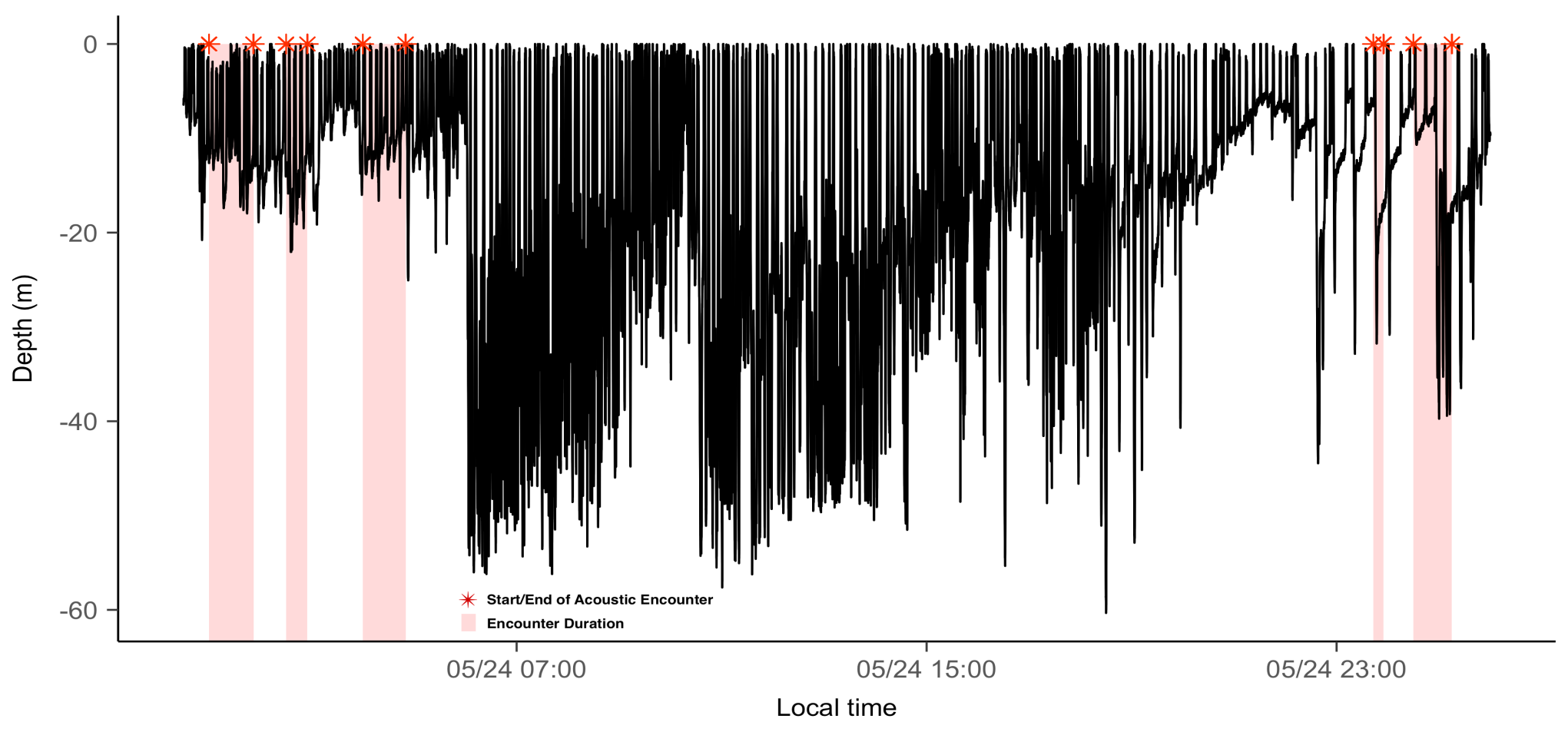


Figure 11 (left). Dive profile of a tagged blue whale capturing five encounters with seven ships within 24-hr period. Red stars indicate start and end of encounter based on presence of ships in acoustic record. Duration of detected ship encounters shaded in pink.

See Brandon Southall's talk 10/23 10:45

Next Steps

- Combine ancillary sighting, biological, and environmental data to examine stress levels in habitats with heavy human use, population level consequence of disturbance, and habitat use, among others.
- Continue tagging efforts with fin whales to study dive and calling behavior and for call rate estimation.
- Test less-invasive tag attachment techniques while maintaining the ability to collect days to weeks of high-resolution multi-sensor data (Fig. 13).

Figure 13. Acousonde tag with tag attachment configuration consisting of four suction cups attached to carbon fiber plate.

Acknowledgements

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