Gray whale calls of two demographic groups: solitaries and mother-calf pairs

aurban@pronatura.org.mx [1], athode@ucsd.edu [2] , bazua@unam.mx [3] , jurban@uabcs.mx [4] , kabloona15@comcast.net [5]

Anaid López-Urbán[1]
Posgrado de Ciencias del Mar , Instituto de Limnología y Ciencias del Mar, Universidad Nacional Autónoma de México,Ciudad Universitaria, Circuito Exterior S/N

Aaron Thode[2]
Marine Physical Laboratory, Scripps Institution of Oceanography, San Diego, CA 92093-0205

Carmen Bazúa Durán[3]
Laboratorio de Acústica, Departamento de Física, Facultad de Ciencias, UNAM Circuito Exterior s/n, Cd. Universitaria, 04510 México, D.F.

Jorge Urbán[4]
Departamento de Biología Marina, Universidad Autónoma de Baja California Sur, Km 5.5 Carretera al Sur, Mezquitito, La Paz, B. C. S.23080, México

Steven Swartz[5]
Laguna San Ignacio Ecosystem Science Program, 14700 Springfield Road, Darnestown, Maryland 20874

ABSTRACT

Between 2008 and 2010, 27 acoustic tags were applied to various age and reproductive classes of gray whales in Laguna San Ignacio, Mexico. Besides the previously described S1 and S3 calls, two additional calls were identified: the impulsive S8 call and the frequency-modulated S9 call. These two additional S8 and S9 calls are by far the most common gray whale sounds detected on the tag, even though contemporary bottom-mounted acoustic recordings also collected from the lagoon in 2008 yielded no S8 or S9 calls. The use of the B-Probe acoustic tag for the first time in the gray whale, provided more specific data on calls made by this whale, increasing our knowledge on the acoustic communication in this species. Acoustic detection of whales is crucial in order to have 24 hours presence-absence data; data that will help in understanding the impact on the behavior of this endangered animal that may be caused by the increase of anthropogenic noise in the coastal lagoons along the Pacific side of the Baja California peninsula, Mexico. Additionally, knowledge on gray whale calls is necessary to take appropriate management measures for conservation; to maintain protection of areas that are key to the preservation of this species in the Biosphere Reserve "El Vizcaino".

Keywords: acoustic monitoring, gray whale calls, solitary and mother-calf pairs

INTRODUCTION

Marine mammal acoustic signals carry out important information used in processes within the biology cycle of the animals. So any change in the acoustic environment and their surroundings, can have strong impact on cetaceans, causing disruption of their activities, like social interaction (i.e., breeding) and feeding (Greene and Richardson 1995).

The sounds of the Eastern North Pacific gray whale (*Eschrichtius robustus*) have been the subject of acoustic studies in their breeding areas (Dahlheim, 1987; Wisdom, 2000; Ollervides and Rohrkasse, 2007), along their migration route (Crane and Lashkari, 1996), and in their northern feeding grounds (Stafford *et al.*, 2007; Moore and Ljungblad, 1984). The initial study of breeding ground sounds was performed by Dahlheim (1987), who defined an acoustic repertoire of at least six call types produced during breeding and reproduction behaviors in Laguna San Ignacio (LSI), Baja California Sur, Mexico. Dahlheim (1987) collected data from a bottom-mounted hydrophone system in 8 m depth water, with the hydrophone suspended 3 m from the bottom, thus the hydrophone was around the middle of the water column. All six calls detected had relatively low bandwidth, ranging from 50 to 2000 Hz. The most common sound she detected was the S1 call, which consists of several pulses (mean 9.4) that lie between 90 and 1940 Hz, with a mean pulse rate of 5.9 per second (Fig. 1a; Dahlheim, 1987). Another common call detected by Dalheim (1987) was the S3 call, a frequency-modulated sweep between 125 and 1250 Hz, with a mean call duration of 2 s (Fig 1b).

Wisdom (2000) studied the developmental process of sound production in gray whales, by recording sounds from a captive gray whale calf, JJ, and using boat-based recordings at LSI. In addition to the six calls described by Dalheim (1987), she also identified a new call, Type 1a, which will be discussed in more detail later. Ollervides and Rohrkasse (2007) proposed 11 call categories based on recording sessions from a boat, while studying the ambient noise environment in Bahia Magdalena, another important reproduction and breeding area for the gray whale on the Pacific coast of Baja California Sur, Mexico. Six of their proposed call types were the same as Dahlheim (1987); the five additional calls reported are not related to the sounds discussed in this paper because these calls were not present in the recordings from the Bio-Probe tag.

For all these three studies the S1 call was the most abundant, being the S4 call the second most recorded (Dahlheim,1987; Wisdoom, 2000; Ollervides and Rohrkasse, 2007). A more recent study, contemporary to the data used in the present study, found that the production of the S1 gray whale call was related to the time of the day. Gray whales emitted more S1 calls around dawn and twilight hours, in contrast to mid-morning and mid-afternoon hours; however, it was not possible to relate this difference to the presence of any of the two whale demographic groups: solitary whales or mother-calf pairs, nor to the presence of anthropogenic noise (Ponce *et al*., 2012).

MATERIALS AND METHODS

Equipment, deployment procedure, and analysis

Recordings were made using a "Bio-Probe" acoustic sampling tag (Burgess *et al.*, 1998), which includes a hydrophone with a sensitivity of 172 dB re 1 μPa/V, a pressure transducer, a two-axis accelerometer, and a temperature sensor. Data from the depth gauge and accelerometers are sampled at 1 Hz, while acoustic data are sampled at 6553 Hz in 2008 and 4096 Hz in 2009 and 2010. All data were stored within the tag, which in turn was incorporated into a syntactic float assembly that included one suction cup for part of 2008 and two suction cups in the rest of 2008, and all of 2009 and 2010. An Advanced Telemetry Systems (ATS) VHF radio beacon was incorporated into the float. The entire assembly was positively buoyant so that when the tag detached from an animal, it would float to the surface and hold the transmitter vertically above the water. The tags were deployed from a small boat with an outboard engine, using an experienced local fisherman as a driver and an eco-tour guide. Before tagging was attempted, a whale was followed for 40-60 minutes; once it was confirmed that the animal was not attempting to evade the vessel, and otherwise showed no behavioral signs of stress, the boat would drive parallel to the whale's course, approach as the animal was surfacing, and place the tag on the dorsal section of the whale's body using a modified 2 m telescoping boat hook. Occasionally "friendly" whales (i.e., whales that demonstrate curiosity about whale-watching boats) would approach the vessel, and the tag could be placed on the animal by hand.

Bottom-mounted autonomous recorders sampling at 6.25 kHz were also deployed at 10 m depth, with the hydrophone suspended just above the bottom, for three weeks at a time during Feb. 2 and Mar. 9, 2008 near Punta Piedra, a local landmark in the lower lagoon where Dahlheim (1987) collected her data (Ponce *et al*., 2012). During data analysis for both the tag and the bottom-mounted recordings, if two sounds were separated by less than one second, they were classified as part of the same call.

A manual analysis of the data set sampled at 6.25 kHz with the bottom-mounted recorders, using the same analysis criteria as the tag data set, yielded 4757 S1 calls, 705 S3 calls, and 520 S4 calls (other high-frequency pulsive call), but no S8 or S9 calls (Ponce *et al*., 2012). Although some S3 calls have frequency bands that descend to 120 Hz, none displayed frequencies at 70 Hz or below, as was typical with the S9 call found by this study. In other words, the two most common calls in the 2008 tag data were absent from recordings made with the bottom-mounted instruments around the same time (i.e., over the same season. Unfortunately, we were not able to attach tags to whales at the same time the bottom-mounted instrument was deployed).

RESULTS

During the winters of 2008, 2009 and 2010, 27 tags were deployed, which generated a total of 2163 minutes of recordings. Sixteen of those tags contained sounds; analysis of 1585 minutes of that data yielded a total of 1220 whale calls.

Four consistent call types were identified across all years (Fig. 1). Two of the call types matched Dahlheim's (1987) description of the pulsed S1 call (Fig. 1a) and frequency-modulated S3 call (Fig. 1b), so that terminology was used. In this study the S1 call presented a bandwidth between 65±58 Hz and 546± 516 Hz, and a call duration of 3.38 ± 1.8 s, while the S3 call presented a bandwidth between 58±38 Hz and 437±195 Hz, and a call duration of 1.1± 0.79 s.

However, other two call types labeled S8 and S9 calls seemed to have no match in the previous literature. Call type S8 (Fig. 1c) is a pulsed call, displaying bandwidth between 51±19.6 Hz and 516 ±184.9 Hz, and very little variation in frequency structure between pulses. There is a substantial variation in the number of pulses in a call (15±21.2) and in the call duration (1.8±3.18 s), but generally the pulse repetition rate (14±10 pulses/s) is much higher than that of a S1 call, which has a mean value of 5.9 pulses/s, a bandwidth between 90 to 1940 Hz, and a call duration of 1.8 s. Figure 1c shows one of the slower pulse rates encountered in the data.

The S9 call (Fig. 1d) seems to be a pulse-modulated or frequency-modulated call, with a bandwidth between 55 ±22 Hz and 83 ±51 Hz, a call duration of 1.5±0.94 s, and up to four harmonics. This call shows little similarity to the other prominent frequency-modulated calls from Dahlheim (1987), the S3, M3, or N3, in that the S9 call has a much lower frequency band, with shorter duration (Fig. 1d).

While it may not be surprising that tagging data would yield additional call types, what is surprising is that the two new calls are by far the most common sounds detected in the tag recordings made by this study: 1074 S8 sounds and 73 S9 sounds, vs. 48 and 25 S3 and S1 sounds, respectively. This pattern was present regardless of the demographic class of animal which carried the tag (Table 1). The S1 sound had been the most common sound detected in previous studies (Dahlheim,1987; Wisdom, 2000; Ollervides and Rohrkasse, 2007).

Confirming that S8 & S9 are not a flow noise or vibration artifact

To address the concern that S8 sounds might be arising from vibration, flow noise or other mechanical factors associated with the tag attachment, the frequency structure of the S8 call was compared with the harmonic structure of the S3 call. Although the S8 call is impulsive, individual pulses clearly show several narrowband regions of high intensity, indicative of some form of resonance (Fig. 1c). For every S3 call noted in the tag data (48 calls), the frequency of each harmonic was recorded. Then, for every S3 call, fifteen S8 calls were selected that were detected within 10 minutes of that particular S3 detection, and their frequency highlights were logged. Using the procedure ensured that the calls analyzed arose from the same tagged individuals.

Figure 2a shows histograms of the distribution of harmonics for the 48 S3 calls, and the distribution of frequency highlights of 731 S8 sounds. Both sounds show prominent frequency components at around 60, 110, 200, and 290 Hz. The figure shows that the overtones of the frequency-modulated S3 bear a strong resemblance to the frequency maxima that appear in the pulses of the S8 call. The observed modes of the S8 distribution (60, 110, 190, 290 Hz) do not display an exact harmonic relationship, but are what might be expected to rise from a simple pipe resonator, or pipe resonator connected to a Helmholtz resonator(Kinsler *et al.*, 1982). The close similarity in these frequency structures suggest that the S8, like the S3, arises from the animal's sound production mechanism, and thus displays the same internal resonances as the animal's sound mechanism. As the tags were deployed behind the dorsal ridge of the animals, generally far away from any air spaces in the animal, and thus any pliable resonators, it seems unlikely that the slapping of a tag against the animal would generate similar resonances.

The S9 call bandwidth (55 ±22 Hz and 83 ±51 Hz) was quite different than all other reported calls, so the procedure as for S8 call could not be used. Instead, the movements of the tagged whales, as logged by the auxiliary tag data, were compared with vocalization times of the S9. No correlation or association was found between the angular or depth acceleration of the tag measurements and times of S9 sound production.

Figure 2b shows the distribution of the peak power spectral densities encountered for the four call types shown in Fig. 1. In general, the source level lies between 110 and 140 dB re $1uPa^2/Hz$, if we assume that the acoustic wave arriving on the tag is planar, and thus the acoustic particle velocity is proportional to the pressure. In reality the acoustic wave radiating in close vicinity of an oscillating low-frequency sphere displays a phase difference between the pressure and particle velocity (Kinsler *et al.*, 1982), so although the values in Fig. 2b permit a relative comparison between source levels, it is incorrect to use them as absolute source levels.

DISCUSSION

Comparison of pulsed S8 call with other pulsed calls in gray whale literature

Both Dahlheim (1987) and Wisdom (2000) identified several pulsed call types, including Dahlheim's S1 and S4 calls, and Wisdom's type 1a, 1b, and 4 calls. All these calls, however, had substantially lower pulse rates than the S8 call. For example, the S1 (same as Wisdom's Type 1b call) displays a bandwidth between 80 to 1040 Hz, roughly nine pulses per call, and a pulse rate of only 4.8 per sec (Fig 1a).

The possible exception is Wisdom (2000) Type 1a, which displays a bandwidth between 70± 30 Hz to 2810±910 Hz, a call duration around 910±130 ms, a pulse repetition rate of 12±2 pulses/call, and a pulse repetition rate of 13 pulses/s. This call was common in recordings of the captive calf JJ, with 183 samples collected; however, Wisdom (2000) could only locate nine samples from boat-based recordings. Thus it is possible that Type 1a and S8 may be the same call type, but the 1a samples from captivity do not match the bandwidth in Fig. 1c, and too few samples of 1a in the lagoon exist to be certain.

Explaining the discrepancy between relative frequency of call types in tag and bottom-mounted acoustic data

There is a marked contrast between the relative frequency of occurrence of the S8 and S9 calls in the tag data reported here, and in previously-reported boat-based or bottom-mounted acoustic data recordings, including recordings obtained over the same period of time as the 2008 tagging. Once mechanical vibration and flow noise have been ruled out as a factor, five possible explanations for the discrepancy remain: 1) changes in acoustic repertoire over the years, 2) differences in source level distributions between call types, 3) biases in tagging a particular age or demographic class of animal, 4) differences in propagation effects arising from different bandwidths, and 5) differences in masking effects of ambient noise across different bandwidths.

It may be possible that the relative occurrence of S8 and S9 calls have increased over the years, but this hypothesis cannot explain the discrepancy between call rates detected on the 2008 tag and bottom-mounted acoustic recordings. Fig. 2b suggests that, if anything, the apparent S8 and S9 call source levels are higher than previously reported calls.

The tagging sample may be biased toward particular subsets of gray whale age or reproductive classes: females with calves are generally easier to approach with the tagging vessel. Indeed, one sees from Table 1 that the majority of S8 calls were detected on females with calves. However, the S8 and S9 calls were still the dominant calls on single animals (of unknown sex) and calves (although the latter might be confounded with sounds of the mother on the tag).

The S8 and S9 show lower frequency ranges than the S1 call; indeed, the S9 call has the lowest frequency range of all the calls detected. In the relatively shallow waters (10-20 m) of the lagoon, low-frequency energy can be more highly attenuated than higher frequencies. A 10 m depth Pekeris waveguide with a bottom speed and density representative of sand (1650 m/s) has a cutoff frequency of 75 Hz, a higher frequency than the dominant component of the S9 call. However, various numerical simulations of various shallow-water environments and depths suggest relatively little difference in propagation characteristics for frequency components above 200 Hz, so no obvious mechanism exists to assign a much higher propagation loss to S8 calls vs. the well-known S1 call. This similarity in frequency bandwidth between the S1 and S8 calls also rules about explanations based on higher levels of masking noise at lower frequencies.

At this time our best hypothesis for why the S9 call has not been reported is that the relatively low frequency bandwidth of the call gives it relatively poor propagation characteristics and greater masking compared to the other call types in the lagoon. However, no good explanation exists for why such a discrepancy in the detection of S8 call exists between tag and bottom-mounted data.

FINAL REMARKS

Ponce *et al*. (2012) research concluded that the S1 gray whale call was related to the square of the number of animals in the lower zone of the lagoon. However, it was not possible to flag whether the relationship was related to both demographic groups or just single, breeding animals. The same relationship appeared during daytime and nighttime hours, so an increase in tourism effects could not be responsible for the observed relationship.

This research shows two new calls produced by the gray whale for the two specific demographic groups studied, which gives specific information of this species and their environment. Recording of S8 and S9 calls provides possible acoustic habitat characteristics that have to be taken into account when investigating environmental changes and the effects that these may have on gray whale acoustic communication.

All calls reported for gray whales can be used to determine gray whale presence in the coastal lagoons used by these animals as breeding grounds along the Pacific side of the Baja California peninsula, Mexico. It is crucial to determine how ambient noise is affecting habitat use by gray whales in Mexican coastal waters, thus the results of this study may be used to develop management research focused on using acoustic tools to investigate gray whale presence-absence in the Biosphere Reserve “El Vizcaino”.

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Figures

Fig. 1. (color online): Spectrogram examples (6250 Hz sampling rate, 512 pt FFT, 75% overlap) of the four most common gray whale call types detected on the acoustic tag: (a) S1; (b) S3; and the new calls (c) S8; and (d) S9. Note the frequency highlights on the pulses visible in subplot (c). The 0.2 s-long sound starting at 3 s in subplot (d) is a different call from S9.

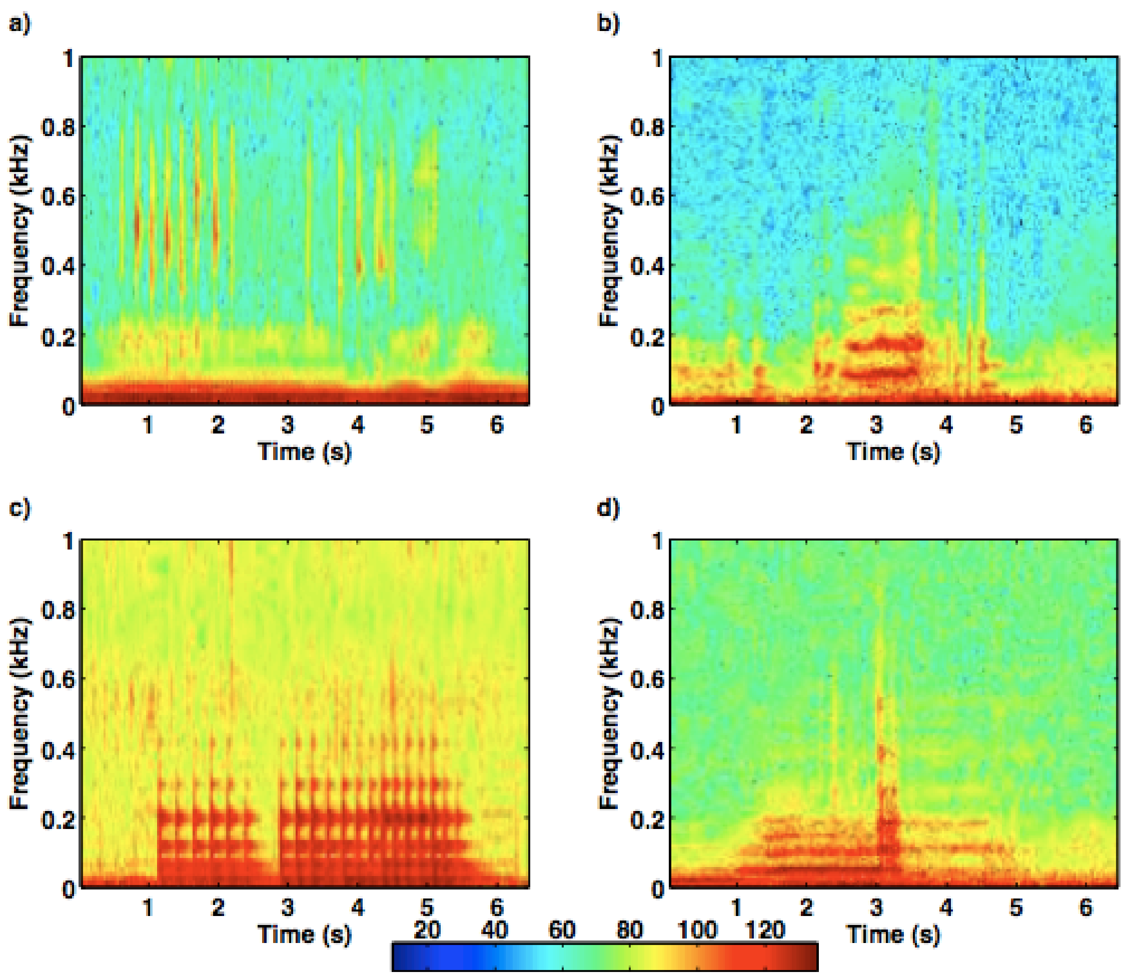
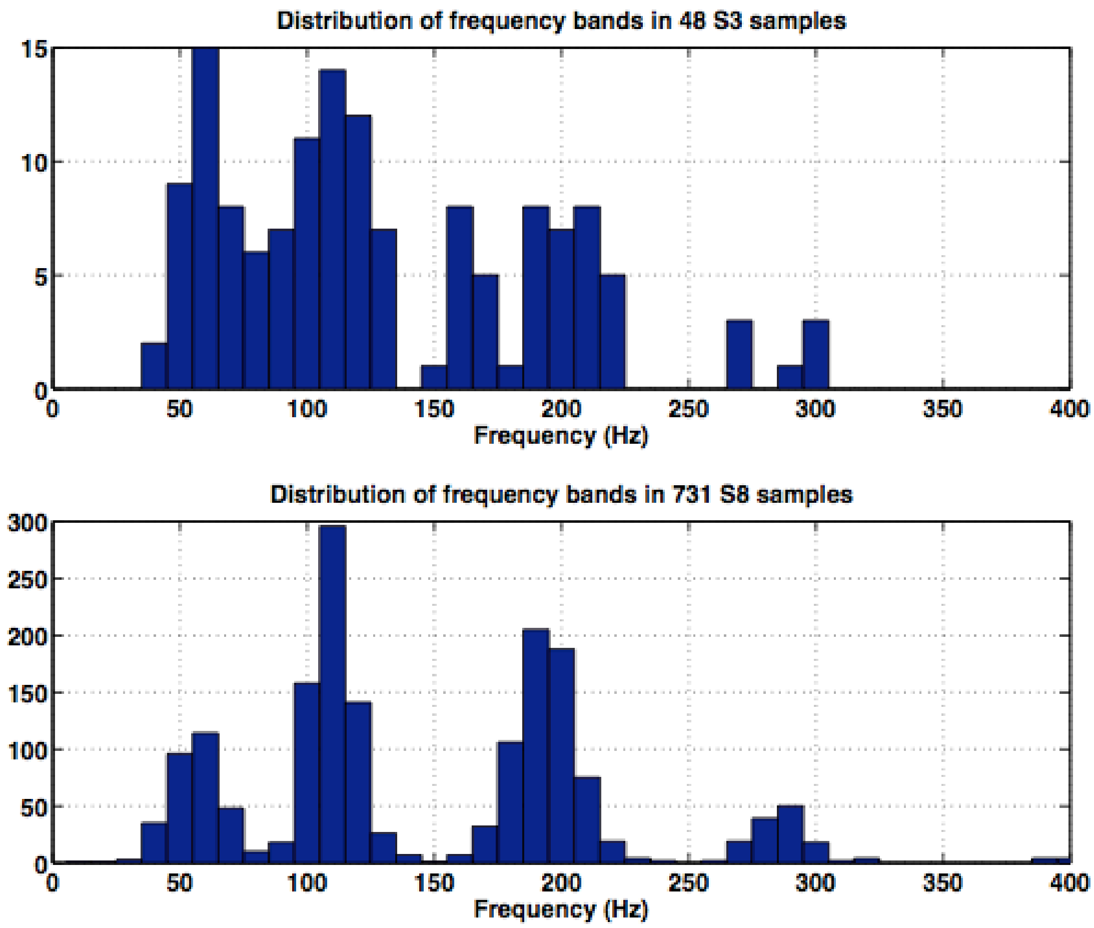
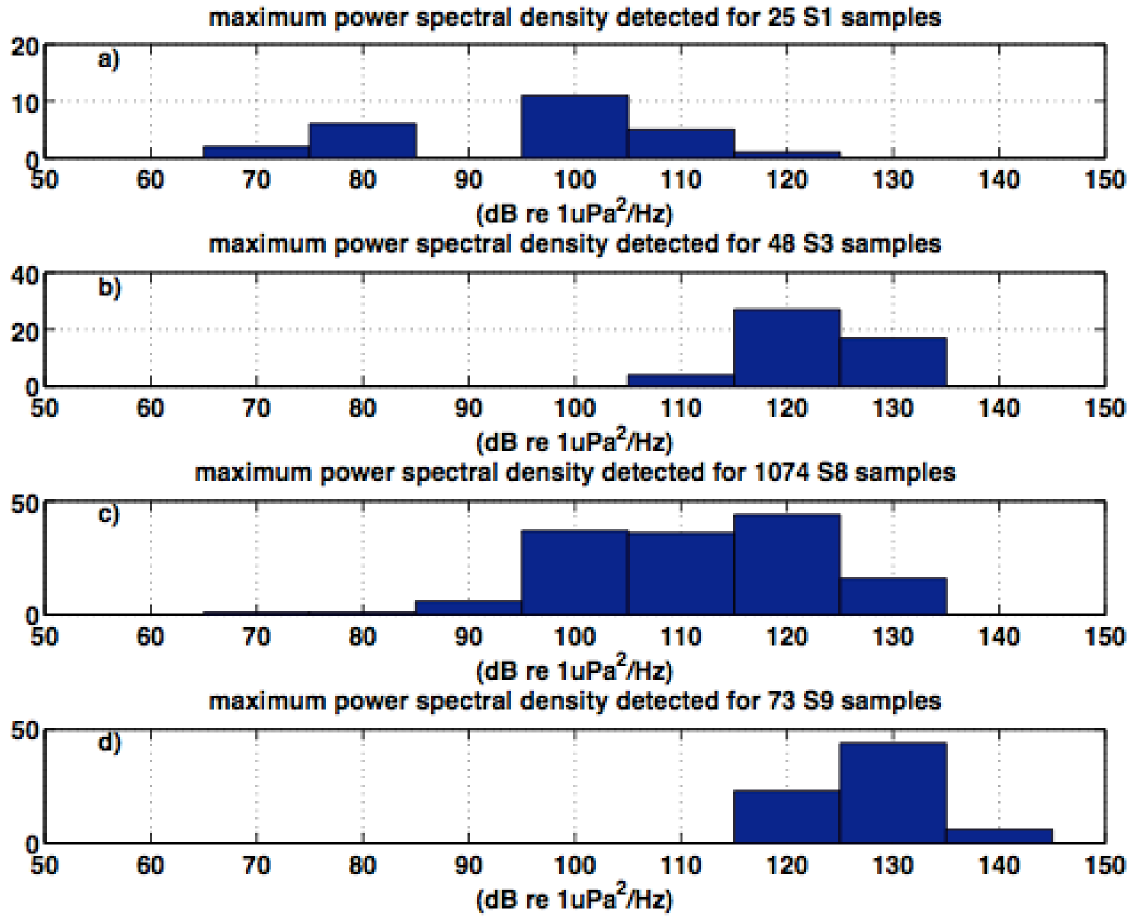


Fig. 2. (color online): (a) Comparison of the distribution of frequency tones of all S3 calls with local frequency highlights on a subset of S8 calls. (b) Distribution of maximum power spectral density detected in S1, S3, S8, and S9 calls. The y-axis indicates the number of calls in a given histogram bin.




maximum power spectral density detected for 25 S1 samples
a)
20
10
0
50 60 70 80 90 100 110 120 130 140 150
(dB re 1uPa²/Hz)
maximum power spectral density detected for 48 S3 samples
b)
40
20
0
50 60 70 80 90 100 110 120 130 140 150
(dB re 1uPa²/Hz)
maximum power spectral density detected for 1074 S8 samples
c)
50
0
50 60 70 80 90 100 110 120 130 140 150
(dB re 1uPa²/Hz)
maximum power spectral density detected for 73 S9 samples
d)
50
0
50 60 70 80 90 100 110 120 130 140 150
(dB re 1uPa²/Hz)

Table

Table 1. Calls detected for each gray whale demographic group. 27 tags were deployed with 2163 minutes total, but only 16 tags contained sounds.

	Tag minutes	**Tag deployments**	**S1**	**S3**	**S8**	**S9**
Females with calves	644	8	12	24	804	9
Single animals	846	5	12	6	237	49
Calves	95	3	1	18	33	15
Total	1585	16	25	48	1074	73

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