# Proceedings of Meetings on Acoustics

Volume 11, 2010 http://asa.aip.org



**160th Meeting**
**Acoustical Society of America**
Cancun, Mexico
15 - 19 November 2010
**Session 4pAB: Animal Bioacoustics**


## 4pAB7. Construction, calibration, and field test of a home-made, low-cost hydrophone system for cetacean acoustic research


**Eduardo Romero Vivas* and Braulio León López**

***Corresponding author's address: Centro de Investigaciones Biológicas del Noroeste CIBNOR,S.C., Mar Bermejo 195 Col Playa Palo de Santa Rita, La Paz, 23090, BCS, Mexico, evivas@cibnor.mx**



Marine Mammals are reliable bioindicators of aquatic ecosystems health. Since cetacean highly relay on the use of sound for conspecifics interaction, feeding, and navigation, research in bioacoustics becomes fundamental to unravel the influence of anthropogenic activities on their environment and vocal behaviour. Unfortunately, the widespread of studies in this area are often limited for the lack of affordable equipment. This paper first describes how to build a low cost hydrophone suitable for cetacean acoustic research and then shows how to perform hydrostatic pressure tests and acoustic calibrations using easily available tools. Finally, field recordings of individuals of two dolphin species: long-beaked common dolphin (Delphinus capensis) and bottlenose dolphin (Tursiops truncatus) in La Paz Bay, Baja California Sur, Mexico using the proposed hydrophone and a professional hydrophone system [AQ-1s and ITC-1042 transducers (10 Hz - 100 kHz)] are compared.


Published by the Acoustical Society of America through the American Institute of Physics

 [DOI: 10.1121/1.3573502]
Received 30 Oct 2010; published 12 Mar 2011

## INTRODUCTION

Marine mammals are known as important bio-indicators of the health of aquatic ecosystems. Cetaceans (whales, dolphins, and porpoises), in particular, use sound for many vital activities, such as navigation, feeding, group cohesion, and communication [1, 2].

The sounds produced by cetaceans covers several octaves, from very low frequencies made by large whales to high frequency echo location signals by toothed whales, although much of this sound production is located in the human audible frequencies (20 Hz–20 kHz). Within the group of toothed whales (Odontoceti), the Delphinidae family (dolphins) is well known for their vast vocal repertory. Although, there are important variations among species, their vocalizations have been categorized as pulsed and tonal sounds [1]. Pulses are used mainly for echo location, while tones are related to social contexts and communication. Tones, also commonly called "whistles", are produced in the range of 300Hz–24 kHz [1, 3]. With their high dependence on sound, research in bioacoustics becomes fundamental for unraveling the influence of anthropogenic activities on their environment and vocal behavior [1, 4–7].

Bio-acoustics has played a major role in cetacean research during the last few years. Unfortunately, specialized equipment for this remains accessible only to projects with big budgets, usually in countries that have strong support of science. Emerging research groups interested in doing studies in this area often see the cost and availability of specialized equipment as a limitation.

This work provides instructions on how to build a low-cost hydrophone, how to perform static pressure tests on it with tools that are widely available, and how to do a simple frequency response calibration within the human audible range. This study also compares field recordings of whistles of two dolphin species using this low-cost hydrophone and a second hydrophone, which has already been used in cetacean research (lent by the Marine Mammals Research Program of the Universidad Autónoma de Baja California Sur and belonging to the Scripps Whale Acoustics Lab) [8]. Our purpose is not to claim that our "home-made" hydrophone can substitute for professional equipment, but to provide essential tools that hopefully will broaden the research in this area by making basic equipment available for researchers with limited resources.

## CONSTRUCTION

Several prototypes of home-made low-cost hydrophones can be found on the internet [9–12] and in literature[13, 14], but from the ones we have found that use widely available and easy to find materials, none provided calibration curves nor comparison to professional hydrophones on cetacean field recordings. Barlow et al. [14], for instance, provide calibration curves for their array, but it requires a special hydrophone element. Goodson and Lepper [13] proposed a hydrophone that fulfills criteria of low-cost and easy-to-find materials, but neither its technical nor field performance is available. The approach followed by the Submarine Boat website [9] is very similar, but no technical or field performance for cetacean research is offered. Other approaches go from the standard microphone immersed in oil inside a canister, as in "Instructables" [10], to the sealed epoxy solutions, such as the "Dunking hydrophone" [11].

The hydrophone proposed here has a similar design to those found in [12, 13], which might be based on the former design, but it has two main differences. The design proposed avoids the entry hole for the cable and the epoxy seal on the back disk, as proposed in [13], and a compression fitting for the interface cable, as suggested in [12]. In the first case, the design was modified because sealing with epoxy does not a absolute guarantee, and in the second case, because compression fittings are not always easy to obtain. Another difference from previous designs is the use of small O-rings that fit into the screws. In the original design, the front disk movement was restricted in one direction for the screw heads. The new design allows the same conditions on both sides of the vibrating disk.

Parts List:

1 Piezoelectric ceramic disk. It can be obtained from a greeting card, a buzzer, or a Radox 066-648 (3.5 inchs, 4-8 Ω, 150 W tweeter). Piezoelectric elements are also available from Carrod Electrónica [15], Steren® [16], Radioshack® [17], Maplin® [18], Conrad® [19], and others [20].
2 Acrylic, Plexiglas, polycarbonate plastic, or similar (3–5 mm thick disks of 71 mm diameter)
1 O-ring (2-inch diameter, 0.2-inch thick).

8 Bolts (3/4 × 1/8 inch and corresponding nuts)
8 O-rings (1/4 inch diameter) to fit around the bolts
1 drill bit (9/64 inch)
1 drill bit (7/64 inch)
1 telephonic cable (2 wires), shielded if possible
1 audio plug (3.5 mm)
1 needle
Superglue (Kola-Loka®)

Cut 2 disks of 71 mm of diameter from the plastic sheet using a 2 ¾ inch diameter hole saw, and finish the rough edges using a sander. Mark 8 equally spaced points around the disks where the bolt holes will be drilled.

Drill bolt holes in both disks at the same time using the 7/64 inch drill bit. Mark the disks to make sure the holes match during assembly. Now, drill one of the disks using the 9/64 inch drill bit. The piezoelectric element will be glued to the disk with the larger bolt holes. Spread the superglue on the piezoelectric element and glue it to the center of the disk with the larger bolt holes. Make sure there are no bubbles trapped between the disk and the piezoelement.

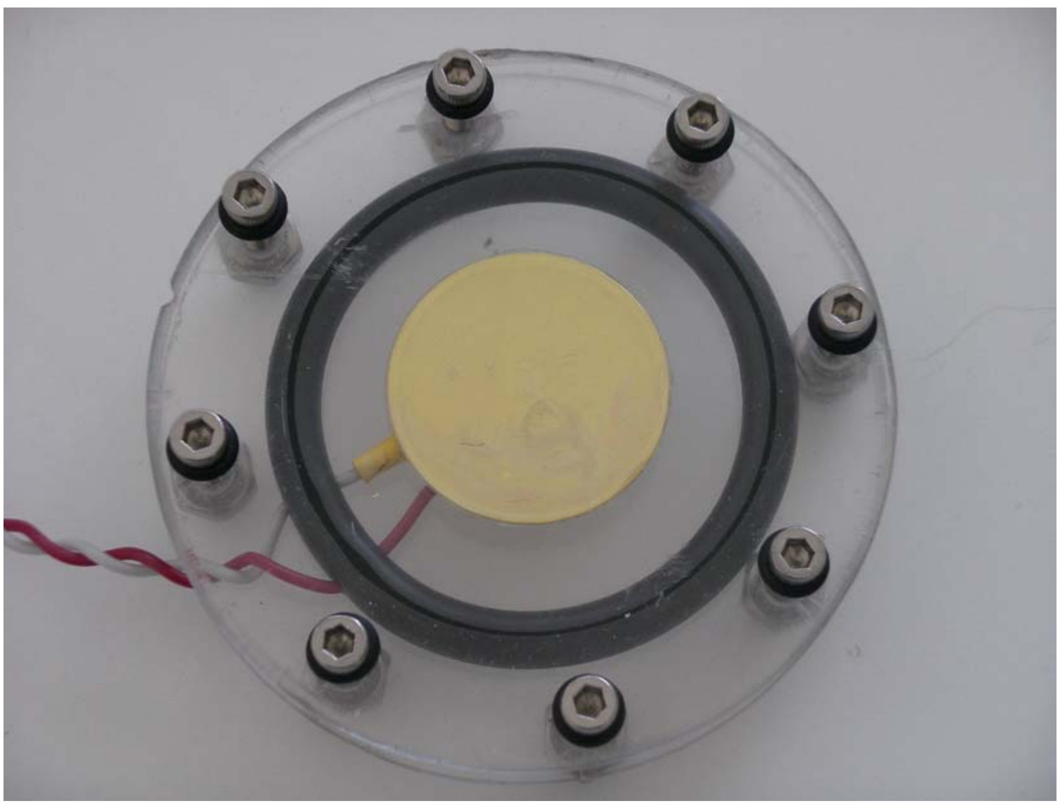

**FIGURE 1.** Completely assembled low-cost hydrophone. Note the wires going through the main O-ring and the smaller O-rings for each bolt.

Use the needle to pierce two holes through the 2-inch O-ring to pass the wires, stretch a bit the O-ring if necessary. Solder the wires to the piezoelectric element; the positive wire goes to the ceramic disk and the negative to the outer brass ring. Lay the O-ring symmetrically around the piezoelectric element and cover with the other disk. Insert the small O-rings into the bolts. Insert the bolts in the disk from the outer side, keeping the piezoelectric element inside both plastic disks. Hold in place the nuts and tighten alternating opposite screws. Do not over-tighten. The O-ring must touch the plastic disk in a line of 1 or 2 mm only that will seal properly. Finally, solder the audio jack in place.

## HYDROSTATIC PRESSURE TEST

For this type of hydrophone, it is necessary to make sure that the air cavity stays sealed at the high pressures under immersion. As in previous designs [12], [13], the critical sealing part is the entry hole for the cable. To determine if the hydrophone leaks at depth, a do-it-yourself hydrostatic pressure test apparatus was also designed. Figure 2 is a diagram of the main elements.

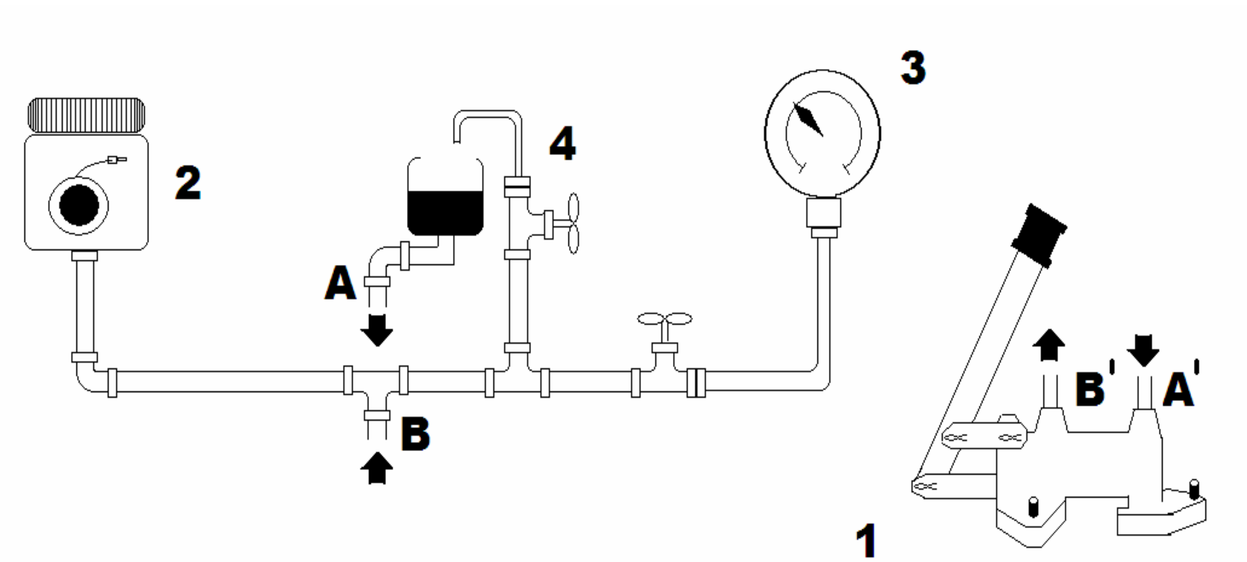


**FIGURE 2.** Apparatus for testing hydrostatic pressure.

The device (Figure 2) consists of a hydraulic pump (1) coupled with a pressure chamber made of a plastic container (2). A manometer (3) and a pressure release valve (4) complete the design. The hydrophone is first placed into the plastic container (2) filled with oil, then the excess air is removed through the pressure release valve (4). With the valve (4) closed, pressure is increased using the hydraulic pump (1). The hydrophone was tested up to 5 kg/cm2, equivalent to a depth of 40 meters and remained at this pressure for 24 hours. The 5 kg/cm2 limit was set by the container, not the hydrophone. A piece of paper inside the hydrophone was used to test the sealing. No oil entered the cavity.

The system described can be used with few modifications to perform infrasound and low sound frequency range calibration at elevated static pressures in a pendulum chamber [21].

## CALIBRATION

Assuming that acoustical impedance of the hydrophone is high enough so that its radiation impedance can be neglected and that the diffraction phenomena can be neglected over the frequency range from 400 Hz–7 kHz in which measurements are performed, then the receiving sensitivity of the hydrophone would be the same in air as it is in water [22]. With this assumption, the hydrophone was calibrated at sonic frequencies.

A Sony XS-L100P5M loudspeaker and feed from a Wavetek Model 145 function generator was used as a constant sound pressure force. The sound pressure level acting on the hydrophone was measured using an Iso-Tech SLM-1352A (ANSI S1.4 type 2) sound level meter. To measure the open circuit voltage, a GW Instek GDS-1022 digital oscilloscope/FFT analyzer was connected to the output of the hydrophone and sound level meter. To find the sensitivity of the hydrophone, a sinusoidal waveform at 1 kHz at 94 dBc was applied to the loudspeaker and the voltage received by the hydrophone was measured. The sensitivity obtained was 10.2 mV/Pa.

For a reference of 1 V/Pa, the receiving frequency response of the hydrophone in air is shown in Figure 3.

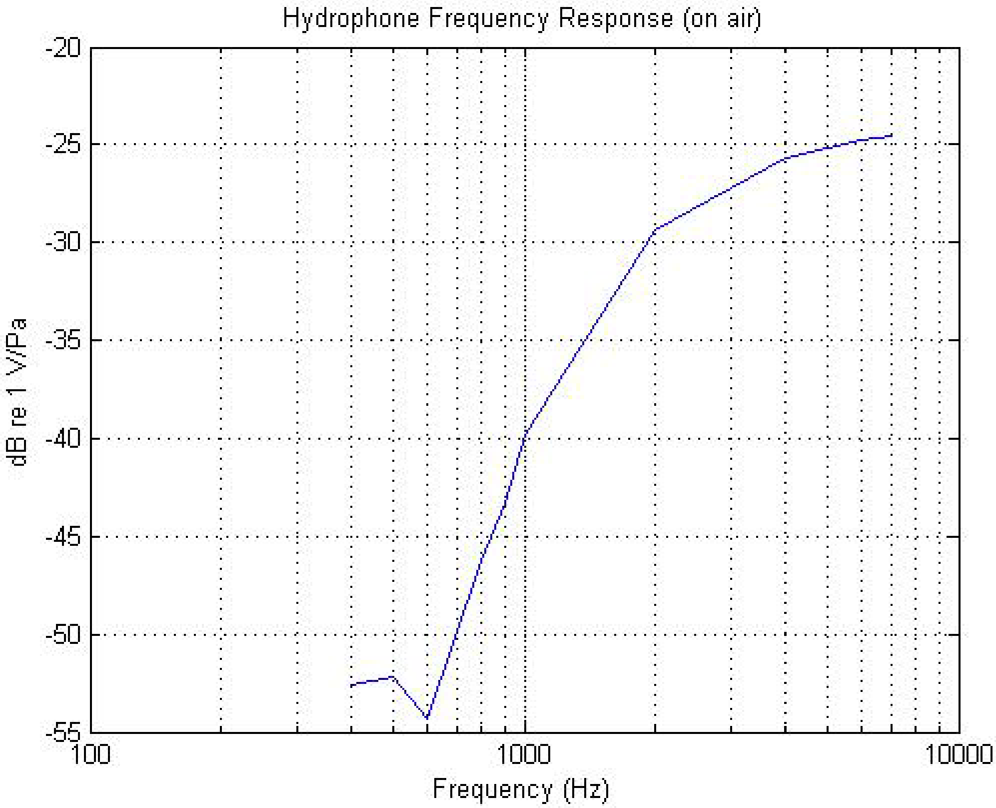


**FIGURE 3.** Frequency response of the low-cost hydrophone

## FIELD TESTS: SOUND PRODUCTION OF COMMON AND BOTTLENOSE DOLPHINS

The long-beaked common dolphin (*Delphinus capensis*) and bottlenose dolphin (*Tursiops truncatus*) are two widely distributed species that live tropical and temperate waters in pods from a few to hundreds of individuals [2]. Both species are important links in the food chain in the Gulf of California [23, 24]. The bottlenose dolphin vocal repertory is a well-studied topic worldwide [25–27]. To assess the performance of the hydrophone under real conditions with subjects in their habitat, whistles of this two dolphin species were recorded.

### Study Area

Bahía de La Paz is located near the southeast end of the Baja California Peninsula (24.1ºN–24.8ºN, 110.2ºW–110.8ºW), covering ~1970 km² (Figure 4). The bay is a shallow marine depression, getting progressively deeper from south to north, with a slope of ~1% until it reaches 500 m at the northern end [28]. The region is hot in summer and warm to cool in winter, is generally arid. Average salinity is 36 and average annual rainfall is 210 mm, usually occurring in summer tropical storms. Other than during summer tropical storms, runoff is very uncommon [29, 30].

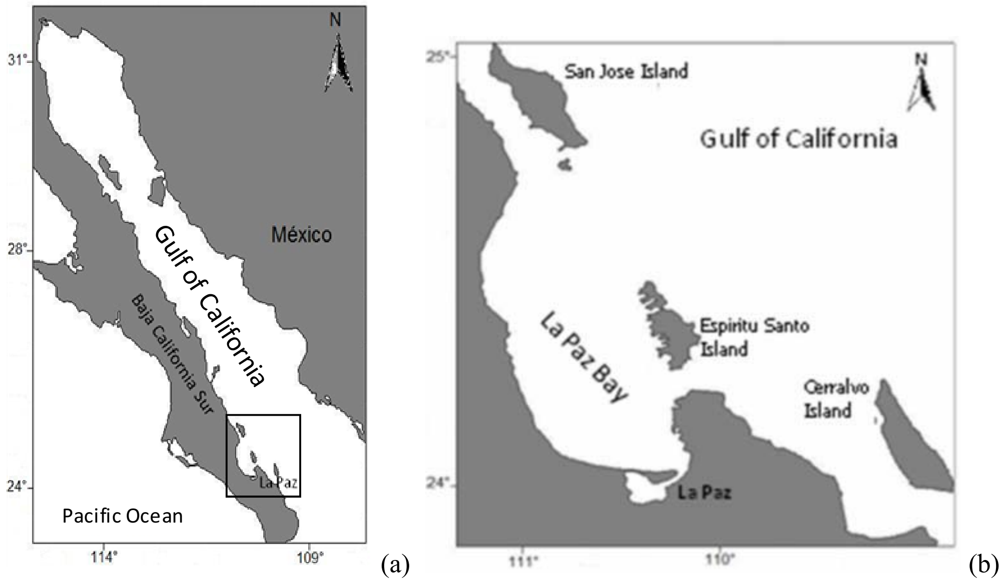


**FIGURE 4.** Location of Bahía de La Paz of the Gulf of California (A). Bahía de La Paz is delimited by Isla Espiritu Santo (B).

Field excursions on Bahía de La Paz were aboard a small vessel with outboard engine (Marine Mammals Research Program, PRIMMA-UABCS). The study area was covered with random transects to monitor for dolphins, mainly near Isla Espíritu Santo. When a pod was located, geographic position, time, number of individuals, and species were recorded. The engine was turned off and 3-min recordings were made at a sampling rate of 96 kHz at 24 bits, using a Fostex® FR-2 digital recorder. The professional hydrophone (ITC-1042 transducers 2–100 kHz) and the low-cost hydrophone were connected to the left and right channels, respectively, and submerged to 4 meters. The gain for both channels was adjusted to provide comparable levels to compensate for the low-cost hydrophone lack of a preamplifier. Similar procedures were conducted for both species.

## Signal Processing

Spectrograms were generated using the Raven®Lite v1.0 software to find whistles and Raven®Pro v1.3 Trial Version to measure parameters of each whistle [31]. The spectrograms obtained showed that it was possible to record dolphin whistles and sounds up to 48 kHz with the low-cost hydrophone. The sampling frequency was limited by the selected sampling rate, rather than by the hydrophone capabilities (see Figure 5). This is important because social sounds above 20 kHz in whistles occur in other dolphin species [32]. Many pulsed sounds of dolphins are found at frequencies higher than 20 kHz [1].

A couple of whistles from each species containing a clear and well-defined contour were selected for analysis. For each of them, 7 parameters commonly used in the bioacoustics literature to categorized whistles were derived automatically: beginning frequency, ending frequency, maximum frequency, minimum frequency, duration, peak frequency, and average power [33].

Figures 6 and 7 show, for comparison, the whistle spectrograms recorded using the low-cost hydrophone and the professional equipment for both species. Under visual inspection, the main features of the whistles are clear in both spectrograms. Moreover, Table 1 and Table 2 show that the parameters measured, using Raven®Pro software, were the same for both hydrophones, apart from the difference in average power due to the different gain set for each channel.

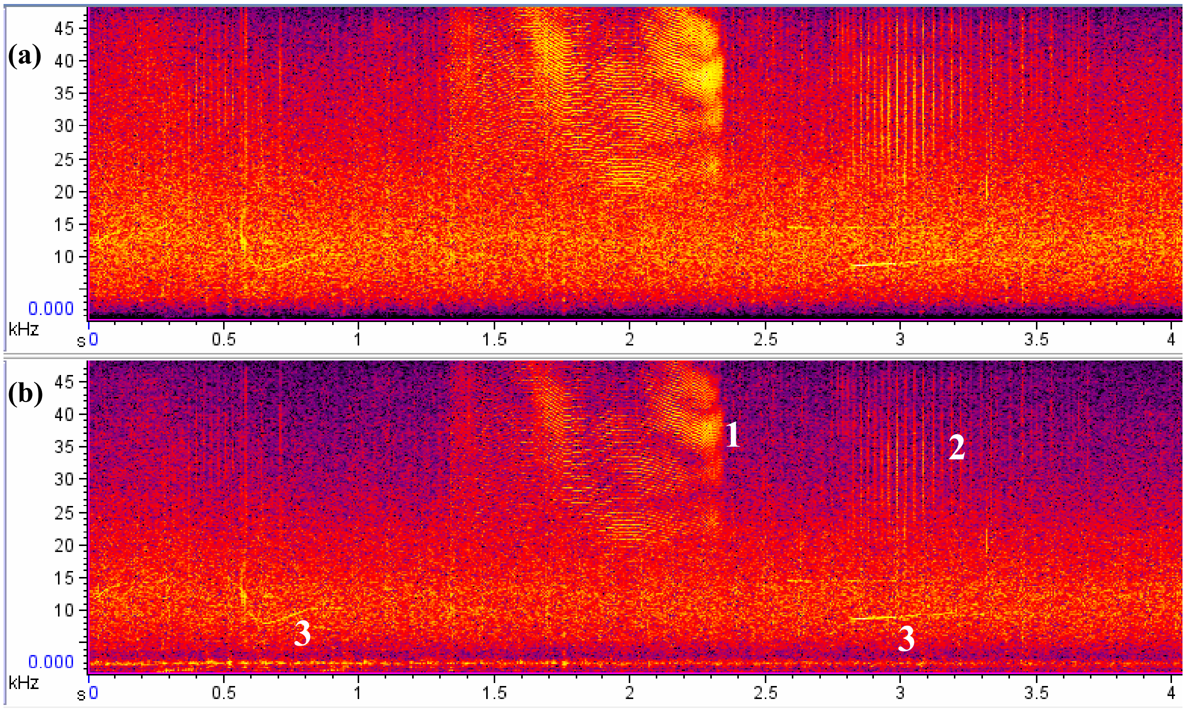


**FIGURE 5.** Spectrogram of vocalizations of *Delphinus capensis* recorded by the professional hydrophone (a) and by the low-cost hydrophone (b). Notice the presence of high frequency burst pulses (1), clicks (2), and whistles (3). Spectrogram settings: 1024 point FFT, Hanning window, 50% overlap.

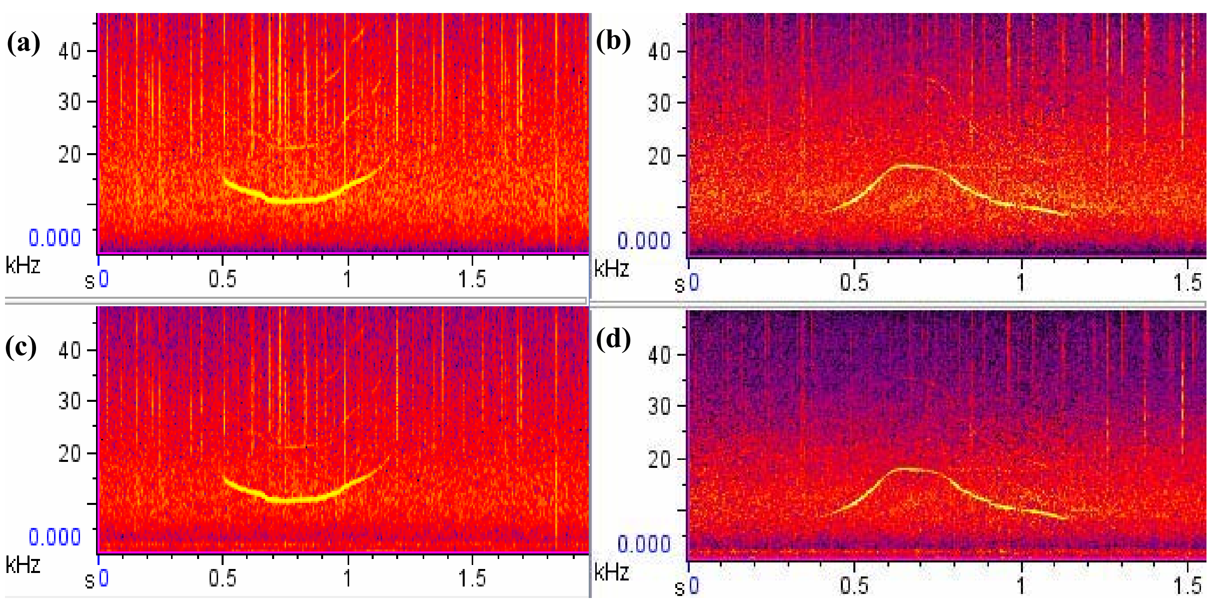


**FIGURE 6.** Spectrograms of two *Delphinus capensis* whistles recorded by the professional hydrophone (a, b), and by the low-cost hydrophone (c, d). Spectrogram settings: 512 point FFT, Hanning window, 50% overlap. The parameters measured for these whistles are presented in Table 1

**TABLE 1.** Measured parameters of *Delphinus capensis* whistle recordings from two hydrophones

| Parameters | Low-Cost Hydrophone (c) | Professional Hydrophone (a) | Low-Cost Hydrophone (d) | Professional Hydrophone (b) |
|---|---|---|---|---|
| Beginning frequency | 15118 Hz | 15118 Hz | 9423 Hz | 9423 Hz |
| Ending frequency | 18715 Hz | 18715 Hz | 8834 Hz | 8834 Hz |
| Minimum frequency | 9908 Hz | 9908 Hz | 7698 Hz | 7698 Hz |
| Maximum frequency | 18715 Hz | 18715 Hz | 17660 Hz | 17660 Hz |
| Duration | 0.669 s | 0.669 s | 0.719 s | 0.719 s |
| Peak frequency | 10687 Hz | 10687 Hz | 13312 Hz | 13312 Hz |
| Average power | 112.3 dB | 115.2 dB | 108.4 dB | 111.0 dB |

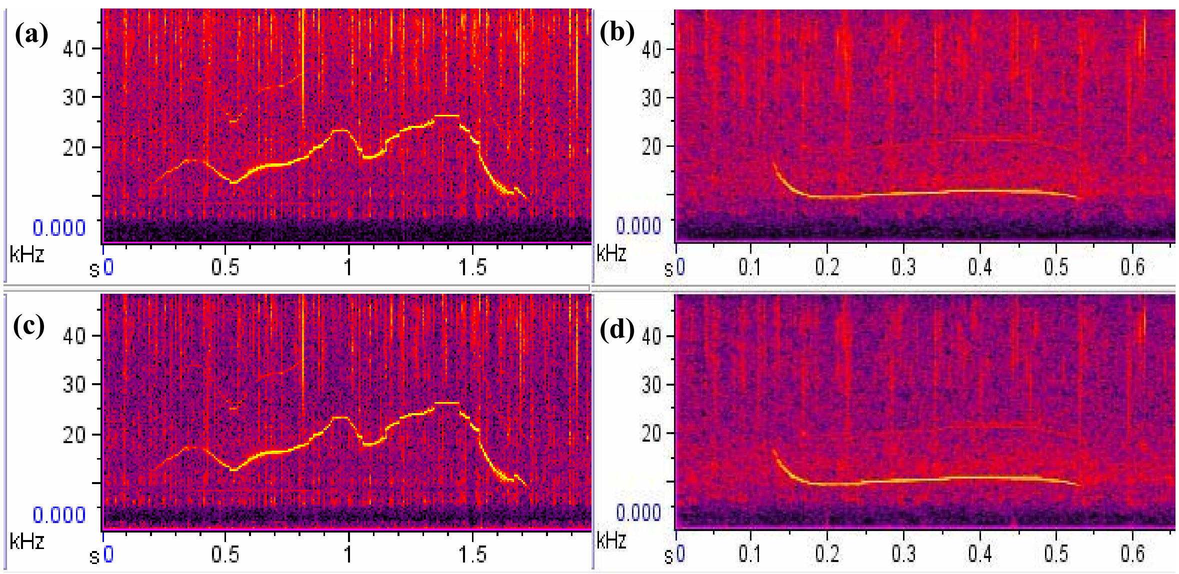


**FIGURE 7.** Spectrograms of two *Tursiops truncatus* whistles recorded by the professional hydrophone (a, b), and by the low-cost hydrophone (c, d). Spectrogram settings: 512 point FFT, Hanning window, 50% overlap. The parameters measured for these whistles are presented in Table 2.

**TABLE 2.** Measured parameters of *Tursiops truncatus* whistle recordings from two hydrophones

| Parameters | Low-Cost Hydrophone (c) | Professional Hydrophone (a) | Low-Cost Hydrophone (d) | Professional Hydrophone (b) |
|---|---|---|---|---|
| Beginning frequency | 13488 Hz | 13488 Hz | 17280 Hz | 17280 Hz |
| Ending frequency | 8400 Hz | 8400 Hz | 7920 Hz | 7920 Hz |
| Minimum frequency | 8400 Hz | 8400 Hz | 7920 Hz | 7920 Hz |
| Maximum frequency | 26400 Hz | 26400 Hz | 17280 Hz | 17280 Hz |
| Duration | 1.518 s | 1.518 s | 0.409 s | 0.409 s |
| Peak frequency | 26250 Hz | 26250 Hz | 10875 Hz | 10875 Hz |
| Average power | 78.4 dB | 80.2 dB | 80.2 dB | 79.0 dB |

## CONCLUSIONS

The low-cost hydrophone that we designed can be constructed with readily available materials and tested for static pressure resistance and human audible range performance by using simple equipment and techniques. Although its use and performance for dolphin whistles was demonstrated, it could be used in studies of other species (cetacean and non-cetacean) for underwater recordings within the frequency range of human audibility and beyond. In our opinion, it is a good low-cost alternative to expensive equipment for bio-acoustics cetacean research at the entry level.

## FUTURE WORK

Calibration in water for ultrasound and infrasound frequencies for instance reciprocity and pendulum pressurized chamber methods is required. A built-in preamplifier might also be needed to use longer cables for deeper immersions and longer ranges.

## ACKNOWLEDGMENTS

We thank Jorge Urbán and Lorena Viloria of the Marine Mammals Research Programme (PRIMMA) of the Universidad Autónoma de Baja California Sur for their help during the field test and for letting us use their acoustic research equipment provided by the Whale Acoustic Lab of the Scripps Institute of Oceanography. Ira Fogel of CIBNOR provided useful editorial suggestions.

## REFERENCES

1. W. J. Richardson; C. R. Green Jr.; C. I. Malme and D. H. Thomson, *Marine Mammals and Noise*, San Diego, CA: Academic Press, 1995, pp 159-238.
2. W. Perrin; B. Würsing and H. Thewissen (eds.), *Encyclopedia of Marine Mammals*, San Diego, CA: Academic Press, 2002, pp. 1414.
3. D. K. Mellinger; K. M Stafford; S. E. Moore; R. P. Dziak and H. Matsumoto,"An overview of fixed passive acoustic observation methods for cetaceans", *Oceanography* **20**, 36-45 (2007).
4. E. Parson and S. Hung, "Cetaceans and Noise in Hong Kong: A case study", *Policy on Sound and Marine Mammals: An International Workshop*, 2004, US Marine Mammals Commission.
5. T. Morisaka; M. Shinohara; F. Nakahara and T. Akamatsu, "Effects of ambient noise in the whistles of Indo-Pacific bottlenose dolphins populations", *Journal of Mammalogy* **86**, 541-546 (2005).
6. S. Ribeiro; F. Viddi and T. Freitas, "Behavioural responses of chilean dolphins (Cephalorhyncus eutropia) to boats in Yaldad Bay, Southern Chile", *Aquatic Mammals* **31**, 234-242 (2005).
7. F. H. Jensen; L. Bejder; M. Wahlberg; N. Aguilar-Soto; M. Johnson and P. T. Madsen, "Vessel noise effect on delphinid communication", *Marin Ecology Progress Series*. **395**, 161-175 (2009).
8. Scripps Whale Acoustics Lab, 2007, available at: http://cetus.ucsd.edu (accessed November 2010)
9. Submarine Boat, available at: http://www.submarineboat.com/hydrophone.htm (accessed November 2010)
10. Instructables, 2010, available at: http://www.instructables.com/id/Underwater-Microphone-Hydrophone/ (accessed November 2010)
11. A. Bray, 2006, available at: http://www.exfac.com/aussie_bray/hydro_dunking.htm (accessed November 2010)
12. G. Gantschnigg, 2006, available at: http://www.gantschnigg.net/doku.php?id=hydrobioakustik:diy_hydrophone_en (accessed November 2010)
13. A. D. Goodson and P. Lepper, "A cheap sensitive hydrophone for monitoring cetacean vocalisations", *Loughborough University of Technology. Signal Processing Resaerch Group-Underwater Acoustic Group*,1-4 (1995)
14. J. Barlow; S. Rankin, and S. Dawson, *A guide to constructing hydrophones and hydrophone arrays for monitoring marine mammal vocalizations*, NOAA Technical Memorandum NMFS, 2008.
15. Carrod Electronica, available at: http://www.carrodelectronica.com/store/index.php?_a=viewProd&productId=14656 (accessed November 2010)
16. Steren, available at: http://www.steren.com.mx/bocinas/interior3.asp?pdto=80-1005N (accessed November 2010)
17. Radioshack, available at: http://www.radioshack.com (accessed November 2010)
18. Maplin, available at: http://www.maplin.co.uk/Module.aspx?ModuleNo=3202 (accessed November 2010)
19. Conrad, available at: http://www.conrad.de/ce/de/suggest/piezo%20element (accessed November 2010)

20. Ekulit, Piezo element data, available at: http://www.produktinfo.conrad.com/datenblaetter/700000-724999/712943-an-01-en-Piezo_Element_EPZ_35M_S29.pdf (accessed November 2010)
21. A. N. Golenkov and Y. G. Rachkov, "Broadening of the frequency of hydrophone calibration", *Izmeritel'naya Tekhnika* **4**, 69-70 (1983).
22. Brüel & Kjær, "Introduction to underwater acoustics. Hydrophones: Their characteristics and applications. Calibration Technics", *Application notes*, Nærum, Denmark, 067-80.
23. G. Heckel; P. Ladron de Guevara and L. Rojas-Bracho, "Ballenas y delfines", in *Bahía de Los Ángeles: recursos naturales y comunidad*, edited by G. D. Danemann and E. Ezcurra, Mexico, D.F: Secretaría de Medio Ambiente y Recursos Naturales, 2008, pp. 567-568.
24. R. Marcín, "Modelado espacio-temporal del uso del hábitat del tursión (*Tursiops truncatus*) en relación a factores de impacto en la Ensenada y Bahía de La Paz, B.C.S., México", Sc.D Thesis, Universidad Autónoma de Baja California Sur, La Paz, Mexico, 2010.
25. L. S. Sayigh; P. L. Tyack; R. S. Wells; M. D. Scott and A. B. Irvine, "Sex difference in signature whistles production of free-ranging bottlenose dolphins, *Tursiops truncatus*", *Behavioral Ecology and Sociobiology*. **36**, 171-177 (1995).
26. J. L. Miksis; P. L. Tyack and J. R. Buck, "Captive dolphins, Tursiops truncatus, develop signature whistles that match acoustic features of human-made model sounds", *Journal of the Acoustical Society of America*. **112**, 728-739 (2002).
27. V. M. Janik; L. S. Sayigh and R. S. Wells, "Signature whistles shape conveys identity information to bottlenose dolphins", *Proceeding of the National Academy of Sciences USA*. **103**, 8293-8297 (2005).
28. A. Alvarez-Arellano and J. Murillo, "Cuerpos de agua inferidos a partir de registro micropaleontologico (Radiolaria), en sedimentos marinos superficiales de la Bahía de La Paz, B.C.S, Mexico", *Anales del Instituto de Ciencias del Mar y Limnología*, 1989.
29. A. Acevedo, "Behavior and movements of bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada de La Paz, Mexico", *Aquatic Mammals*. **17**, 137-147 (1991).
30. J. Gómez-Valdés; J. Delgado and J. Dworak, "Overtides, compound tides and tidal residual current in Ensenada de La Paz lagoon, Baja California Sur, Mexico", *Geofísica Internacional*. **42**, 623-634 (2003).
31. Cornell Lab of Ornithology, 2010, available at: http://www.birds.cornell.edu/brp/raven/RavenOverview.html (accessed November 2010)
32. M. O. Lammers and W. L. Au. "Broadband recording of free-ranging delphinid social acoustical signals". *Symposium of Information Processing*, Vallejo, CA, (1997)
33. L. J. May-Collado and D. Wartzok, "A comparison of bottlenose dolphin whistles in the Atlantic Ocean: Factors promoting whistle variation", *Journal of Mammalogy*. **89**, 1229-1240 (2008).