COMPUTATION OF DOLPHINS’ SOUND ASPL WHILE FORAGING

Petropoulos V.[1]**, Podiadis V.**[2]**, Verriopoulos G.**[2]**, Evaggelidis D.**[1]
[1]*Hellenic Navy Hydrographic Service, info@hnhs.gr*
[2]*Department of Zoology/Marine Biology, Faculty of Biology, School of Science, National and Kapodestrian University of Athens, gverriop@biol.uoa.gr*

Scheduled scientific surveys are a valuable asset in beginning to understand the behavior and vocalization of free-ranging cetaceans. The fortuity of a non-scheduled survey has proven to be beneficial as well. In October 2003 a team of Biologist Oceanographers began a trip aboard a 44.29 feet catamaran sailing boat from Piraeus Greece to Capo Verde Archipelago intending to observe free-ranging Cetaceans. Acoustic recordings were conducted using a towed stereophonic hydrophone array consisted of two Benthos AQ4 type hydrophones. Photographs were taken in order to ensure species identification. Information on vocalization administration during foraging of *Lagenodelphis hosei* and *Steno bredanensis* has been acquired. Calculation of ASPL (apparent source power level), revealed that dolphins’ vocalizations did not match to usual vocalization activities. The relation of vocalization administration by dolphins with brain to mash ratio (BMR), is introduced as an additional predator’s strategy.

Keywords: Dolphins’ foraging strategies, Sound production.

1. Introduction

Through the years there have been novel observations on dolphins’ developed foraging strategies (Engleby and Waples 2001; Silber, 1995; Gazda, 2005).

Lagenodelphis hosei is generally met in large schools, herds consist of hundreds or even thousands of dolphins, often mixed with other species. Prior to our study there have been two observations combined with acoustic recordings on Lagenodelphis hosei while foraging by Watkins et al. (1994). In December 2003 a herd of approximately 300 dolphins consisted of the species Lagenodelphis hosei and Steno bredanensis was observed and acoustically recorded while foraging. Apothegms in this study reflect the abnormal ASPL of dolphins’ sound production while feeding compared to usual vocalizations. Our initiatives originate from (1) Hertzing (1996) where dolphins of the species Stenella frontalis and Tursiops truncatus exhibit an extraordinary foraging strategy (2) Watkins et al. (1994) concerning two sequential observations of a pod of Lagenodelphis hosei during herding (3) Connor (2007), that implies dolphins’ need for maintaining their Brain to Mash Ratio (BMR) through feeding, and occasionally through unusual foraging strategies and (4) the sound production ability that sperm whale employ when stunning its pray (Bertzin, 1971).

2. Methods

The trip lasted from October 2003 until February 2004. A team of Biologist Oceanographers set sails from Piraeus Greece to Capo Verde Archipelago aboard a 44.29 feet catamaran sailing boat intending to observe free-ranging Cetaceans. Cetacean vocalizations were selectively recorded. Photographs were taken in order to ensure species identification. The 80 meters long towed stereophonic hydrophone array of two Benthos AQ4 type hydrophones that was used for the recordings had on its output connected an IBM laptop and a Sony Mini Disc recorder. Logger 2000 program was used for data filing. The upper bandwidth limit of recordings was set at 22.05 Khz. Custom-written Matlab 2007b signal processing routines were used for sound analysis. Matlab sampling rate was set at 44100/sec in respect to the recording upper limit. The sampling frequency was chosen so to prevent aliasing (Nyquist–Shannon, 1927). Temperature and salinity data referring to the area and the time of the recordings, so to compute thermocline and halocline, were acquired from National Oceanic and Atmospheric Administration (NOAA). We used Francois and Garrison's model (1982) for calculation of absorption of sound in seawater and Wenz curves. Depths in the observation area are between 2100 and 2700 meters. Photographs of both species are presented in Figures 1 and 2. Sound recordings lasted 18 minutes.

Figure 1. *Lagenodelphis hosei* traveling next to the sailing boat.

Figure 2. *Steno bredanensis* traveling next to the sailing boat.

The behavior feeding was manually logged throughout the trip only when fish were observed to jump in the air. Such behavior has been manually logged for this case. The boat at the beginning of the recording remained at approximately 1 nautical mile distance from the dolphins' herding activities and eventually approached at 500 meters. The schematic presentation of the recording, extracted from Logger, and the geographic area are shown in Figures 3a, b.

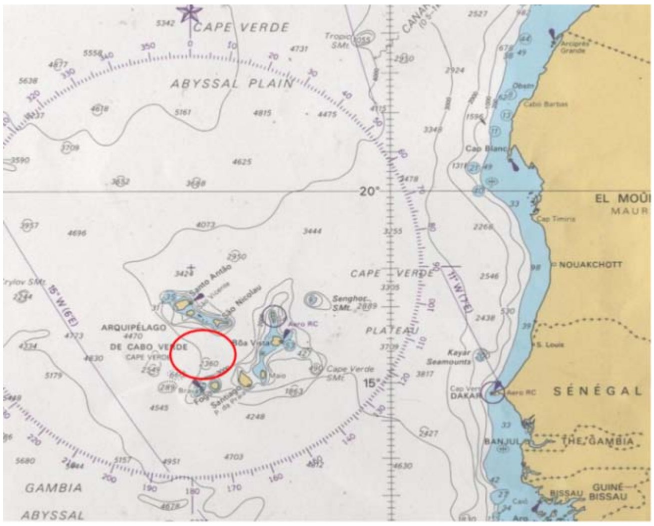


Figure 3a. Nautical map extract from the observation area

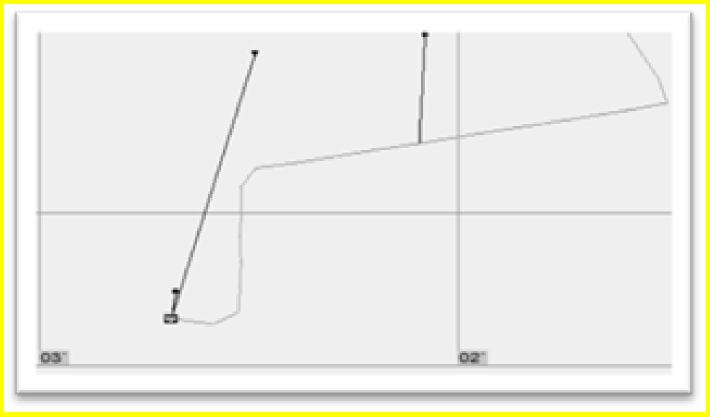


Figure 3b. Schematic presentation, showing the positions of the sailing boat and the dolphins' position extracted from Logger 2000. The square represents ship's position, the fade grey line is the ship's track and the two black lines represent the sequential acoustic bearing of dolphins. The longer black line counts one mile, the distance where the ship stopped in order to conduct the observation.

The sounds analysed were continuous vocalizations produced from approximately 300 dolphins for 18 minutes. We compared same sound duration (15 seconds) from each vocalization in respect to *wave packet* theory (Frank and Crawford, 1968). The following assumptions were made for the calculations: a) sound intensity is not influenced by the position of the dolphin's head in relation to the hydrophone for a given time unit, b) due to the number of dolphins, the source at 1852m emits isotropic sounds simulating 300-element active sonar. The following factors were taken into account for computing the Apparent Source Power Level (Madsen et al. 2004): **i)** signal to noise ratio (S/N) in dB at 1852 meters **(ii)** spherical attenuation, in dB because of the depth of the area, for 1852 and 1000 meters, since the boat approached the herding activities **(iii)** ambient noise in dB for the dominant dolphin frequency (12khz) using Wenz (1962) curves **(iv)** ambient noise in dB from the range of frequencies that we were able to capture (8000-160000 Hz) using Wenz curves **(v)** absorption coefficient in dB/km.

In order to minimize errors on our measurements we made the following computations/assumptions:

Since the received sound spectrum is a combination of broadband and tonal noise we must follow the mathematical description of Knudsen Spectrum (Knudsen et.al, 1948). According to that mathematical description: $fc=\sqrt{f1f2}$. f1 and f2 are considered as the starting and ending frequency that SNR is considerable. Figure 4 shows a steep increase of Intensity Spectral Density at low frequencies, which allows us to recon that 8 KHz is well chosen as f1, but a smooth decrease at high frequencies. Since Intensity Spectral Density is proportional to $1/f^2$, 16 KHz is acceptable as f2. Fc then equals to 11313,7 Hz. If the noise spectrum was constant, the total intensity in the band is just the Intensity Spectral Density * bandwidth. In the case of the non-constant spectral density, which is our case, the term A/f1*f2, where A is a constant, represents the best average value of the Intensity spectral density. It is evaluated at the center frequency.

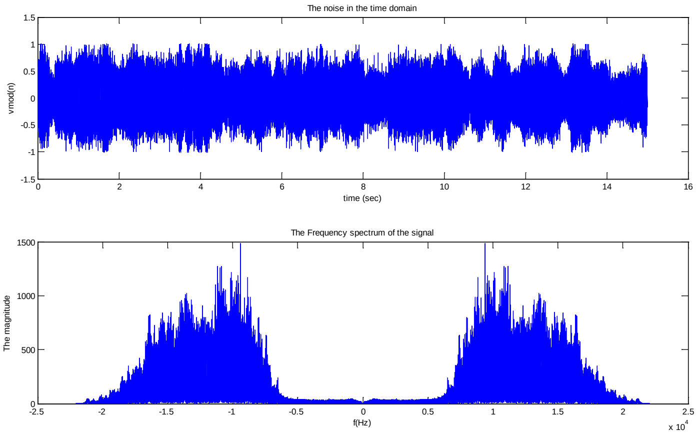


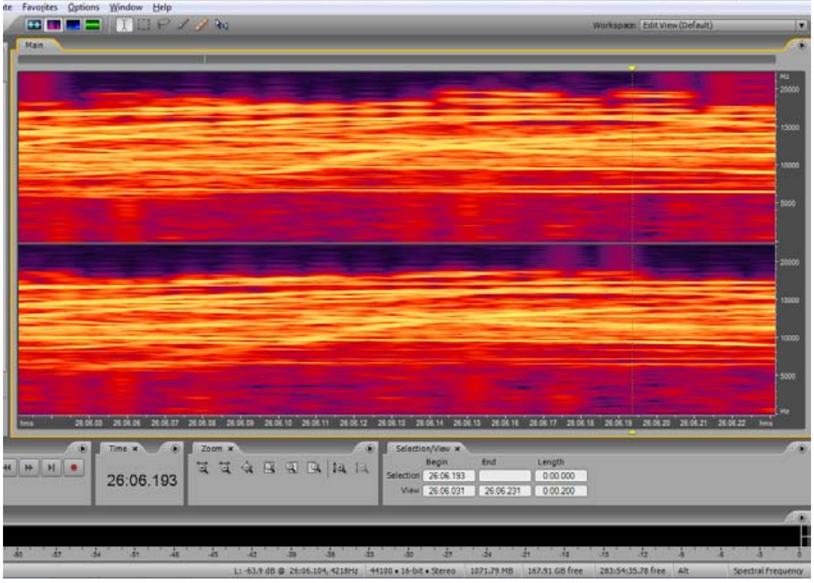
Figure 4 Continuous intense whistles of 15 seconds duration. No sound filter is applied.

Testing with matlab2007 the Intensity Spectral Density around fc we received a similar Intensity Spectral Density to that of bandwidth between 8Khz-16Khz. Thus using a mean Intensity Spectral Density, is accepted assuming that we are having a broadband spectrum instead of a combined broadband and tonal one. SNR mean was calculated taken that (0dB) should be taken the ambient noise recorded some minutes prior to the beginning of dolphins' vocalizations. Figure 6 shows the ambient noise.

According to the above the formula used is described as follows:

ASPL=SNRmean+TL(r)+NL (8-16KHz)+NL (12 KHz)+ABSCO (Payne M. Craig, 2006)

We did not take into account factors that could add to the total dB level as scattering losses or leakage losses. Taken the small distance between the transmitter (dolphins) and the receptor (hydrophone) any losses due to seabed rebound and diffusion due to deep sound channel were considered negligible. Finally, sound refraction influence was not calculated, since the vertical distance between emitter and receiver was small (Payne, 2006). The boat at the beginning of the recording remained at a distance of approximately one nautical mile from the dolphins' herding activities and eventually approached at 500 meters - Figure 3b.



26:06.193

	Begin	End	Length
Selection	26:06.193		0:00.000
View	26:06.031	26:06.231	0:00.200

L: -63.9 dB @ 26:06.104, 4218Hz | 44100 • 16-bit • Stereo | 1071.79 MB | 167.91 GB free | 283:54:35.78 free

Figure 5 Central frequency of 12 Khz. Multiple magnifications have been applied.

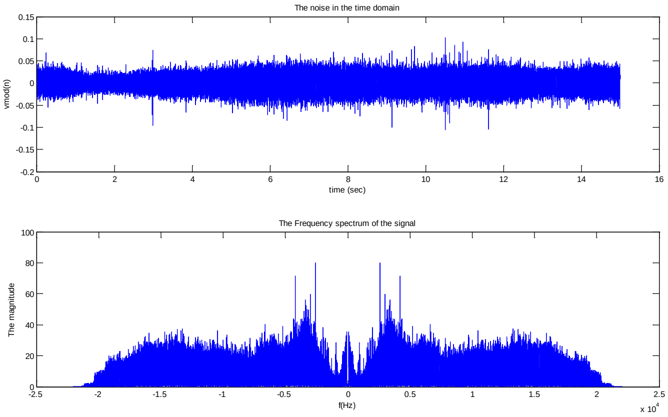


Figure 6 Recorded ambient noise prior to dolphins' vocalizations.

3. Results

Dolphins produced sounds with a SNRmean = 38.11dB recorded from a distance of one mile. Apparent Sound Pressure Level (ASPL) is computed 178 and 183 dB re 1μPa at 1m for distances of 1000 and 1852 metres respectively. It is a calculation of Apparent Sound Level Pressure of dolphins while foraging in the wild. It is thought to be not a random behaviour. Table 1sums up the values used for the ASPL calculation:

Table 1

SNRmean dB rms re 1μPa at 1m/√Hz	38.11 dB
Center Frequency	11313,7 Hz
Hydrophone Frequency Response	1Hz-15KHz
Hydrophone Prossesing gain pre-setting	30
Processing bandwidth	22.5 KHz
Acoustic Sensitivity (dBV re 1 μPa ± 1dB)	-201dB
Spectral noise level at 12 Khz	34 dB
Bandwidth noise level for 22,5 Khz	43.5 KHz
ASPL dB re 1μPa at 1m (1 nm)	183 dB
ASPL dB re 1μPa at 1m (0,5 nm)	178 dB
Sea state during recording	1(scale ripples)-2 (small wavelets)
Wave height	0.1-0.2 m
Weather	FA (Fair)
Cloud cover	3/10-7/10
Barometric Pressure	1013 mBar
Swell	0.8-1 m

4. Conclusions

Through the years there have been novel observations on dolphins' developed foraging strategies (Engleby and Waples 2001; Silber, 1995; Gazda, 2005). According to "schooling fish hypothesis" odontocetes need to be effective while foraging in order to maintain their brain to mash ratio (BMR) (Connor, 2007). Dolphins digest quickly and with a high efficiency of assimilation (Shapunov 1973) using a longer than expected small intestine (Williams et al. 2001). Additional investment in metabolically expensive gastrointestinal tissue is required to maintain the dolphins' high BMR (Williams et al. 2001).

Assuming there is some cost (energetic or risk in attracting predators) to loud sounds, animals would not be expected to make calls louder than is necessary to achieve their function (Stearns and Hoekstra, 2000). Dolphins tend to optimize their behavior to accomplish a task using the least amount of energy as possible (Au, 1980).

The recorded vocalizations of 300 dolphins while feeding shown in figure 4 are considered to be deliberate. Dolphins combined their sound production abilities and brain superiority to forage successfully the fish school exhibiting an additional foraging predator's strategy. Our study supports the findings of Berzin, A. A. (1971) and Herzing D. L. (1996) that cetaceans use sound in order to help them school their pray.

5. Βιβλιογραφικές αναφορές

Au, W.W.L. (1980). In: Animal Sonar Systems, Busnel R. –G. and James F. Fish Volume 28, pp. 279-280.

Berzin, A. A. (1971). The Sperm Whale. Pacific Scientific Research Institute of Fisheries and Oceanography (USSR). Trans. by Israel Program for Scientific Translations, publ. by U. S. National Technical Information Service, Springfield, Va.

Connor R.C (2007). Dolphin social intelligence: complex alliance relationships in bottlenose dolphins and a consideration of selective environments for extreme brain size evolution in mammals. *Phil Trans. R. Soc. B* 2007 362, 587-602

Crawford, Frank S., (1968). Jr., "*Waves – Berkeley physics course – volume 3,*" McGraw-Hill Company, New York.

Engleby, L., and D. Waples. (2001). First observations of mud-ring feeding by bottlenose dolphins (*Tursiops truncatus*) in Florida Bay. In: Fourteenth Biennial Conference on the Biology of Marine Mammals, Vancouver, Canada.

Francois R. E., Garrison G. R., "Sound absorption based on ocean measurements: Part I: Pure water and magnesium sulfate contributions", Journal of the Acoustical Society of America, 72(3), 896-907, 1982.

Francois R. E., Garrison G. R., "Sound absorption based on ocean measurements: Part II:Boric acid contribution and equation for total absorption", Journal of the Acoustical Society of America, 72(6), 1879-1890,1982.

Gazda S.K., Connor R.C, Edgar R.K and Cox F. (2005). A division of labour with role specialization in group-hunting bottlenose dolphins (Tursiops truncatus) off Cedar Key, Florida. Proc. R. Soc. B 2005 272, 135-140

Herzing D. L. (1996). Vocalizations and associated underwater behavior of free-ranging Atlantic spotted dolphins. Stenella frontalis and bottlenose dolphins, Tursiops truncates. Aquatic Mammals, 22.2, 61-79

Knudsen VO, Alforf RS and Emling J.W Underwater ambient noise J. Marine Res 1948; 7: 410-429

Madsen PT, Kerr I, Payne R (2004). Echolocation clicks of two free-ranging, oceanic delphinids with different food preferences: false killer whales Pseudorcacrassidens and Risso's dolphins Grampus griseus. J ExpBiol 207:1811-1823

Nyquist H,(1928). Certain topics in telegraph transmission theory. Trans. AIEE, vol. 47, pp. 617-644

Payne M. Craig (2006). Lt. Cdr USN. Annapolis, MD 21402. Principles of Naval Weapon Systems. Library of Congress Cataloging-in-Publication Data. The U.S. Naval Institute Blue & Gold Professional Library. (Naval Institute Press, Annapolis, Maryland) pp. 153-187

Shapunov, V. M. (1973). Food requirements and energy balance in the Black Sea bottlenose dolphin (Tursiops truncatus ponticus Barabasch). In Morphology & ecology of marine mammals (eds K. K. Chapskii & V. E. Solokov), pp. 207–212. New York, NY: Wiley.

Silber G. K and Fertl D. (1995). Intentional beaching by bottlenose dolphins (*Tursiops truncatus*) in the Colorado River Delta, Mexico. *Aquatic Mammals*, 21.3, 183–186

Stearns, S.C. and Hoekstra, R. (2000). Evolution: an introduction. Oxford University Press, London.

Watkins W. A., Daher M. A., Fristrup K. and Notarbartolo Di Sciara G. (1994). Fishing and Acoustic Behavior of Fraser's Dolphin (Lagenodelphis hosei) near Dominica, Southeast Caribbean. Caribbean Journal of Science, Vol. 30, No. 1-2, 76-82

Wenz, G.M. (1962). Acoustic ambient noise in the ocean: Spectra and sources. J. Acoust. Soc. Am.34(12):1936-1956.

Williams, T. M., Haun, J., Davis, R.W., Fuiman, L. & Kohin, S. (2001A) killer appetite: metabolic consequences of carnivory in marine mammals. G. L. Kooyman Symposium. Comp. Biochem. Physiol. A 129, 785–796.