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Analysis of the Acoustic Propagation Parameters of the Natural Sounds of *Delphinapterus leucas* and *Odorrana tormota* Fundamental in the Startle of the Female *Anopheles gambiae*

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Abstract: *The female Anopheles gambiae s.s transmits malaria to human beings through bites. Malaria has been reported to be responsible for severe morbidity and mortality in Africa and the world causing substantial costs to both individuals and governments. Notwithstanding the many efforts directed towards the control of malaria, the rate at which the malaria cases and deaths are declining is yet to reach satisfactory levels hence the need for multipronged approaches in vector control. Recent studies on the startle response of the African female A. gambiae to animal sounds showed a 46% evasive response elicited by the 35-60 kHz recorded sound of O. tormota. This being an indicator of the feasibility of using sounds in mosquito control, there was need to analyse the acoustic propagation parameters of the natural sounds of Delphinapterus leucas and Odorrana tormota which are fundamental in the startle of the female Anopheles gambiae. This study determined and analysed the acoustic propagation parameters of the sounds of D. leucas and compared with the acoustic propagation parameters of the sound of O. tormota. The sound of the Beluga Whale D. leucas was recorded by Wavshark system, C75 and the C55 hydrophone at a sampling frequency of 128 kHz while swimming in the tank of the Vanaqua. The sound of O. tormota was recorded by 702 digital recorder from the Huangshan Hot Springs, Anhui Province in China at a sampling frequency of 192 kHz. The Avisoft-SAS LAB Pro, Batsound and Raven Pro 1.5 software were used in conversion of sampling frequencies to 192kHz, appending sound clips, mixing sound clips and for data analysis. Fourier transform was performed on the spectrum of the sound of D. leucas and the new sound samples of O. tormota to determine the acoustic propagation parameters through automatic parameter measurements. Spectral analysis of the sound of D. leucas and O. tormota showed presence of harmonics stretching to ultrasonic levels, frequency modulation (FM) and constant frequency (CF) modulation components in both. The mean of the fundamental frequency (mean entire) of D. leucas was 1.684kHz, less by 3.712kHz from that of the new sound samples of O. tormota. There existed no significant difference between the fundamental frequencies of the sound of D. leucas and the sound of O. tormota at $p = 0.846 > 0.05$ determined at 95% confidence interval. The sound of D. leucas recorded a maximum value of 64.800kHz which was 25.500kHz above the maximum frequency (mean) of the sound of O. tormota, the difference which was highly significant ($p = 2.8975 \times 10^{-6} < 0.05$). The sound of D. leucas which was characterised by 64.10kHz bandwidth (mean entire) wider than that of O. tormota by 53.64kHz, a difference which was highly significant ($p = 1.1225 \times 10^{-4} < 0.05$). Also the peak amplitude (mean entire) for the sound of D. leucas was 89.05Pa less by 39.837kHz from that of the sound of O. tormota differing significantly ($p = 4.88 \times 10^{-4} < 0.05$). The signal energy of D. leucas did not differ significantly ($p = 0.9857 > 0.05$) from the energy possessed by O. tormota. The mean acoustic energy of D. leucas was $0.07Pa^2s$ whereas the O. tormota possessed $2{,}496.63Pa^2s$. The pulsate signal power of the sound of D. leucas fluctuated between 36 dB and 56 dB less compared to the power in O. tormota that fluctuated between 43 dB and 89 dB. These results provide critical parameter essential in the study of mosquito repellence and design of a repellent device.*

Keywords: *Modulation, Vanaqua, fundamental frequencies, harmonics, bandwidth, acoustic energy, acoustic power*

1. INTRODUCTION

1.1. Malaria Trends in the World

The *Plasmodium falciparum* which is transmitted by the mated female *Anopheles gambiae s.s* causes malaria infections which is responsible of severe morbidity and mortality worldwide (Guyatt and Snow, 2004; WHO, 2006; Gething *et al*., 2016). Annual statistics on malaria cases and deaths were estimated at 655 000, 627 000, 584 000, 438 000 and 429 000 deaths reported in the 2010, 2012, 2013, 2014 and 2015 respectively, most being young children in sub-Saharan Africa (WHO, 2011; White and Kaufman, 2014; UNICEF, 2014; WHO, 2015; WHO, 2016). Also, there was a global drop in malaria cases from an estimated 262 million in 2000 to 212 million in 2015 (Gething *et al*., 2016; WHO, 2016). Malaria also causes adverse effects including low birth weights, impaired physical growth and permanent disability (Guyatt and Snow, 2004). The challenge of malaria causes substantial costs to both individuals and governments, with an estimated global financing for malaria control of US$ 960 million and US$ 2.5 billion in the year 2005 and 2014 respectively (WHO, 2015). Scale-up of vector control interventions, diagnostic testing, and treatment with ACT have led to slight downward trend in infections and deaths though challenged by slow decline in Sub-Saharan Africa (Godfray, 2013; WHO, 2015; WHO, 2016). In view of this challenge, there was need for investigation of additional malaria control measures, exploiting the potential of the sounds of the Beluga whale *Delphinapterus leucas,* aimed at accelerating the reversal of the trend in malaria cases and deaths, particularly in Africa. The study investigated the naturally generated sounds of the Beluga whale *Delphinapterus leucas* which extended to ultrasonic levels (Arch *et al*., 2008; Shen *et al*., 2011; Glotin, 2015; Glotin and Dolle, 2016; Lubis *et al*., 2016; Wulandari *et al*., 2016). The sounds of *D. leucas* yielded high acoustic energy essential in intensified antennal vibrations of the female *Anopheles gambiae s.s* improving the effectiveness in its startle. The study was anchored on recent researches that showed mosquito's startle response to ultrasound. The results determined from this study are essential in the bioassay study with mosquitoes and in the design of a device that emits sound which evokes startle responses in the mated female *Anopheles gambiae s.s*. The designed electronic repellent device provides additional malaria control tool that is safe and eco-friendly, possibly promoting productivity and economic growth. It may also confirm the feasibility of using Beluga whale *Delphinapterus leucas* ultrasound in the repellence of mosquitoes.

1.2. The Biology of the *Delphinapterus leucas* and *Odorrana tormota*

The beluga whale, *D. leucas* is a medium-sized toothed whale, which becomes completely white when it reaches sexual maturity around seven years of age. Adult males attain a length of 4.5 meters and females 3.5 meters and are similar in appearance. Young ones are born a dark grey and gradually become paler as they mature. They spend the summer in coastal and offshore areas. Their distribution is centred on certain river estuaries, which they visit shortly after ice break-up and where they moult (Lydersen *et al*., 2001). They have a mean lifespan of between 15 to 30 years though they may live beyond 40years (Harwood *et al*., 2002). They are sexually mature at the ages of 5-7 years and adults are capable of giving birth every 3 years. They feed on a variety of fish and invertebrates. The Polar bears, killer whales and Inuit hunters are their main predators. Cetaceans produce frequency-modulated sounds and amplitude modulated sounds. *D. leucas* produces signals with peak frequencies of 40 to 60 kHz in San Diego Bay, California, and 100 to 120 kHz in Kaneohe Bay, Hawaii. The “nonlinear phenomena” spectral features have been discovered in marine mammal vocalizations. They include frequency jumps, subharmonics, biphonation and deterministic chaos as they use sounds for echolocation and communication purposes (Parsons and Dolman, 2004).

The *Odorrana tormota* species is a frog restricted to Huangshan in Anhui Province, and Jiande and Anji counties in Zhejiang Province, China (Shen *et al*., 2011). The *O. tormota* frog generates ultrasounds through vocal apparati and uses the frequency range of up to 128 kHz for communication (Arch *et al*., 2008). During the reproductive season, males emit a variety of high-pitched calls at night with energy spectrums extending into the ultrasonic range (Feng *et al*., 2006; Feng *et al*., 2009). Recent research with the *O. tormota* calls showed some degree of downward frequency modulation with a subset of calls having a carrier of constant frequency (Feng *et al*., 2002; Arch *et al*., 2008). As observed in recent studies, ultrasound from *O. tormota* can play a critical role in malaria vector control by evoking startle responses in malaria vectors since the call frequencies stretch beyond the startle range of 38 - 44 kHz in mosquitoes (Mohankumar, 2010). The sound of *O. tormota* having exhibited the greatest startle responses in mosquitoes needs to be further investigated besides the sounds of the *D. leucas.*

1.3. Statement of the Problem

Malaria is the principal cause of many human deaths, disabilities and low birth weight worldwide with Africa being most affected. Current efforts to reverse the situation targeting the malaria vector, female *A. gambiae,* have resulted to a slight decline in malaria cases and deaths though impeded by the resistance developed by the malaria vectors and pathogens to the chemicals and drugs respectively. This in effect has slowed down the rate at which the malaria cases and deaths decline. Additionally, Electronic Mosquito Repellents (EMRs) in the market have yielded low mosquito repellency of between 20.0 - 30.3 %. The low repellency rates of the EMRs could be due to the bandwidth size of 100 kHz of most of the ultrasonic transducers used, which renders the signal less intense and ineffective. The challenges experienced in malaria vector and pathogen control have impeded the successful realization of the millennium development goal which aimed at reversing the incidence of malaria by the year 2015. On this basis, a multipronged approach including vector control was vital for successful reversal of the current trend in malaria cases and deaths. Recent research findings showed an improvement in startle response in which 46 % mosquitoes repellence was elicited by the 35-60 kHz recorded sound of *O. tormota*. However, the effect of the sound of the Beluga whale *D. leucas* on the African female *A. gambiae* had not been studied. The acoustic propagation parameters useful in the bioassay study involving the of female *A. gambiae* and design of a mosquito repellent device were determined. The experimental results from this study provide additional knowledge about the sounds of *D. leucas*.

1.4. Objectives

1.4.1. General Objective

Analysis of the Acoustic Propagation Parameters of the Sounds of *Delphinapterus leucas* and

Odorrana tormota Fundamental in the Startle of the female *Anopheles gambiae*

1.4.2. Specific Objectives

i. To determine the acoustic propagation parameters of the sounds of *D. leucas.*

ii. To analyse the acoustic propagation parameters of the sounds of *D. leucas* and *O. tormota*

2. MATERIALS AND METHODS

2.1. Sound of *D. leucas* and *O. tormota*

The study investigated the sounds of the Beluga whale *Delphinapterus leucas* and the Chinese frog, *O. tormota*. The sounds of the Beluga Whale *Delphinapterus leucas* were recorded by Wavshark system, C75 and the C55 hydrophone at a sampling frequency of 128 kHz while swimming in the tank of the Vanaqua. The sounds were acquired from Prof. Herve Glotin of Institut Universitaire de France. Also clips of recorded sound of *O. tormota* recorded by 702 digital recorder from the Huangshan Hot Springs, Anhui Province in China at a sampling frequency of 192 kHz were acquired through Prof. Albert Feng, Illinois University. A computer running on Windows operating system and office with mounted sound card was installed with the Avisoft-SAS LAB Pro version 5.2 and Raven Pro 1.5 software was used for playback and analysis. The computer was also mounted with a hardlock key that enabled run the Avisoft-SAS LAB Pro version 5.2 programme. The Avisoft-SAS LAB Pro version 5.2 programme was also used in the conversion of the sampling frequency from 128 kHz to 192 kHz , uniform to other sounds of study. That made it convenient to append and mix the various sound clips. The clip duration was limited to 1,200s which was adequate for a bioassay study. Short clips were appended to meet the required duration. There were four sound clips of *D. leucas* that were mixed to give a complete and comprehensive sound clip.

2.2. The Acoustic Propagation Parameters of Sounds of D. *leucas*

Fourier transforms was performed on the spectrum of the sound of *D. leucas* and new sound samples of *O. tormota* in order to extract acoustic propagation parameters of each call through automatic parameter measurements. The following settings were made to the analysis softwares: from the tools option, the calibration was set to SPL with reference to sound and the SPL reference was 20µPa which is the threshold. For the parameter generation which include amplitude and energy, the calibration method was set to SPL with reference sound for Channel 1and at a /gain (dB) set to zero under the tools menu. The envelope was set to original waveform whereas the pulse detection was set to gate function. The Fast Fourier transform (FFT), an option under the spectrogram parameters was set to 512 and hamming window selected for the display. The temporal resolution overlap was set to 50% with the colour palette set to graypal. The frame size was set to 100% for real time spectrogram parameters and the black and white box (B/W) checked for display. All the settings are given in Figure 1 and 2:

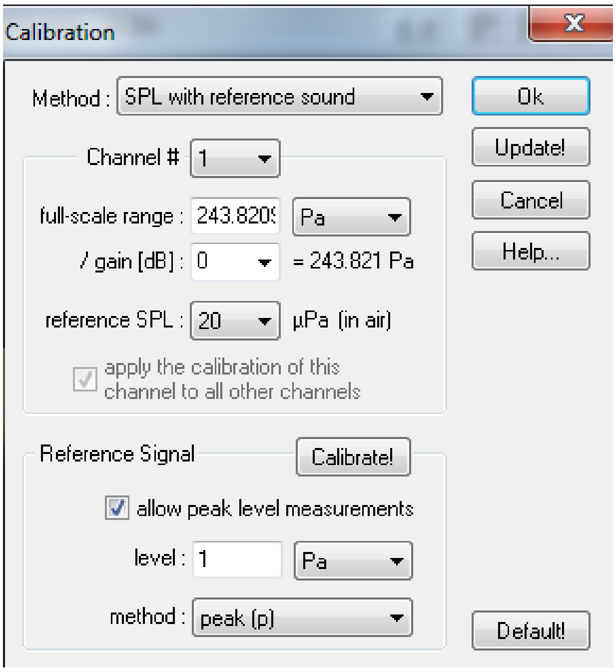

Figure1. *Calibration of sound Parameters*

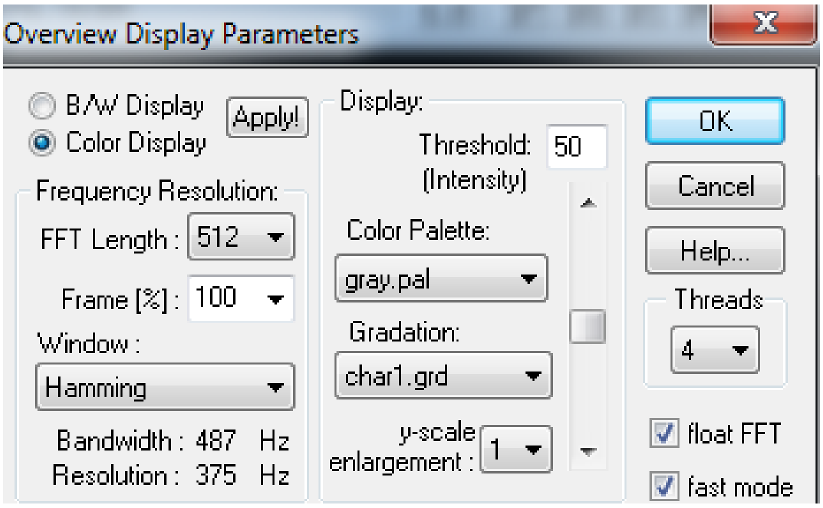

Figure2. *Setting of the display parameters*

Additionally, the envelope was set to original waveform and the pulse detection set to gate function. The parameters determined using Avisoft SASLab Pro version 5.2 and Raven Pro. 1.5 included call duration, acoustic energy, peak frequency (mean), peak amplitude (mean), minimum frequency, maximum frequency (mean), bandwidth (mean), peak frequency (minimum entire), minimum frequency (minimum entire), maximum frequency (minimum entire), bandwidth (minimum entire), peak frequency (maximum entire), peak amplitude (maximum entire), minimum frequency (maximum entire), maximum frequency (maximum entire), peak frequency (mean entire), peak amplitude (mean entire), minimum frequency (mean entire), and maximum frequency (mean entire). The acoustic energy whose SI unit is Pa^2s is a product of the square of amplitudes and sample time. The energy produced is the sum of the squared amplitudes multiplied by time. Also, 1 Pascal pressure is equal to SPL of 94 dB. The data obtained was transferred into an excel worksheet for editing and further analysis through the direct data exchange (DDE)/ Logfile settings. The acoustic propagation parameters of the natural sounds of *D. leucas* were analysed statistically using the same softwares.

3. Results and Discussion

3.1. Determination of Propagation Parameters of Sounds of *D. leucas*

3.1.1. The Generation and Modulation of Sounds of D. leucas and O. tormota

A total of 12,120 calls of the Sounds of *D. leucas* generated naturally through vocalisation were studied. The calls of D. leucas were compared to the 684 calls of *O. tormota* naturally generated through vocal apparati (Arch *et al*., 2008). The beluga whale *D. leucas* generates and uses biosonar clicks simultaneously when echolocating (Lammers and Castellote, 2009). The calls studied lasted for a minimum duration of 0.001s and a maximum duration of 3.35s. The calls took an average duration of 0.04s. The spectrogram in Figure 3-5 show the spectral composition in the sound of *D. lucus*. The 12,120 calls studied were are predominantly frequency modulated (FM) and constant frequency modulated (CF) with breaks (Br) extending to ultrasonic levels just like those of the sound of *O. tormota* reported given in Figure 7 (Mang'are *et al*., 2012). The sound of *D. lucus* is useful in navigation. Also, the sounds of *D. leucas* and *O. tormota* are useful for communication due to the conditions of their habitat (Feng *et al*., 2006; Arch *et al*., 2008; Feng *et al*., 2009; Frankel, 2009; Perrin *et al*., 2009).

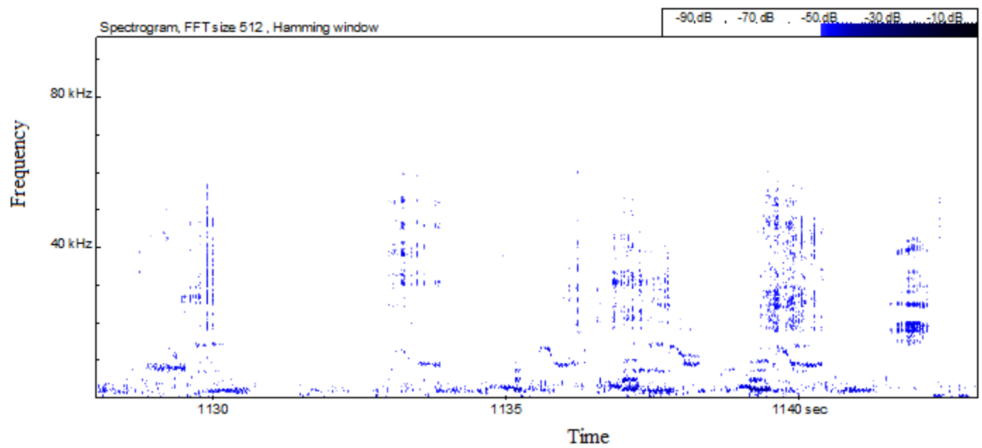

Figure3. *Modulation in the sound of D. leucas*

The "nonlinear phenomena" spectral features of the sound of *D. leucas* include harmonics, chaos, subharmonics and signal breaks as given in Figure 4. The harmonics extend to ultrasonic levels as shown in Figure 3 (Chmelnitsky and Ferguson., 2012). The pulsate calls of the Chinese frog *Odorrana tormota* had proven effective in the startle of the female *A. gambiae* , yielding 46 % repellence, evidence for the feasibility for using ultrasound in mosquito control (Mang'are *et al*., 2012). The sound of the Belunga whale *D. leucas* represented by the oscillogram in Figure 6 are of pulsate nature, critical in investigation of mosquito startle.

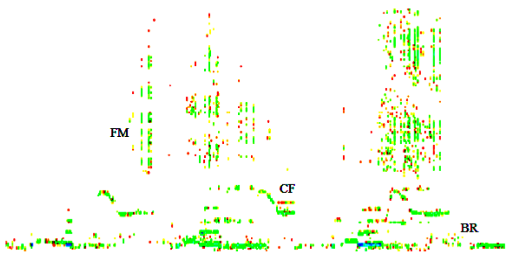

Figure4. *Spectral features in the sound of D. leucas*

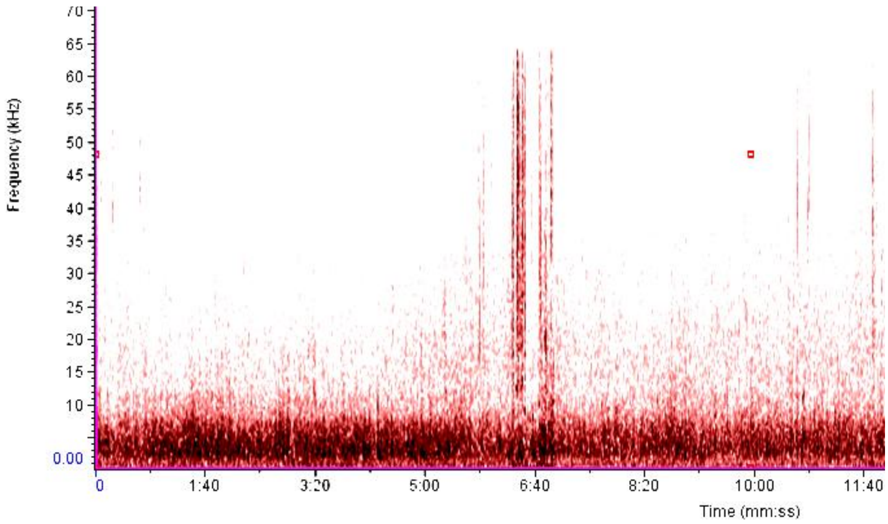

Figure5. *Spectrograph showing Frequency modulation in the sound of D. leucas*

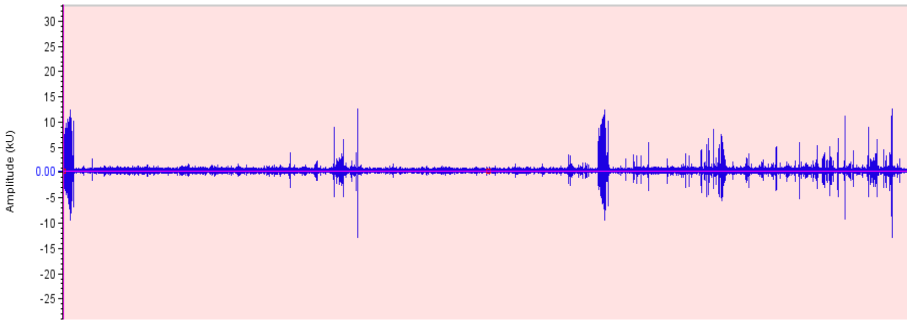

Figure6. *Oscillogram for the sound of D. leucas*

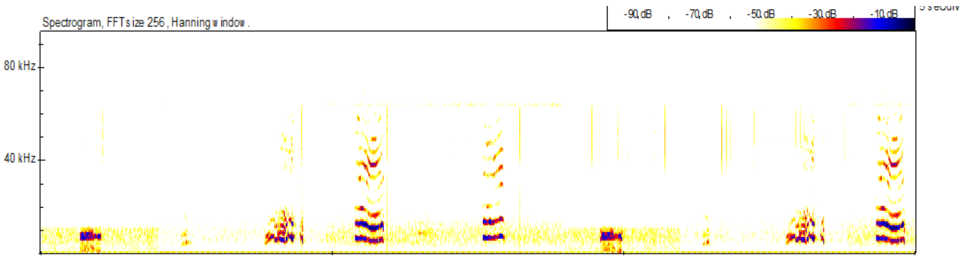

Figure7. *Spectral features in the sound of O. tormota*

3.1.2. Acoustic Propagation Parameters of the sounds of D. leucas

The following parameters were determined from the study and analysed: call duration, acoustic energy, peak frequency (mean), peak amplitude (mean), minimum frequency, maximum frequency (mean), bandwidth (mean), peak frequency (minimum entire), minimum frequency (minimum entire), maximum frequency (minimum entire), bandwidth (minimum entire), peak frequency (maximum entire), peak amplitude (maximum entire), minimum frequency (maximum entire), maximum frequency (maximum entire), peak frequency (mean entire), peak amplitude (mean entire), minimum frequency (mean entire), and maximum frequency (mean entire).

Fundamental Frequency and Harmonics

The formants in the spectrogram given in Figure 3 and whose data is given in Table 1 show the presence of the varied fundamental frequencies and their harmonics. The mean of the fundamental frequency (mean entire) of *D. leucas* was 1.684kHz less by 3.712kHz from the fundamental frequency (mean entire) of the new sound samples of *O. tormota*. The one-way ANOVA comparison of the fundamental frequency (mean entire) of the sound of *D. leucas* by that of the sound of *O. tormota* at a confidence interval of 95% yielded the significance value, $p = 0.846 > 0.05$, implying that there exist no significant difference between the fundamental frequencies of the sound of *D. leucas* and the sound of *O. tormota.*

Table1. *The Fundamental Frequency and Harmonics*

	Parameter Measurements			
Parameters	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Peak frequency (end), Hz	300	61500	3547.75	5116.57
Peak frequency (Maximum entire) , Hz	300	61800	6406.85	9093.82
Peak frequency (Maximum) , Hz	300	61500	4122.75	7261.31
Peak frequency (mean entire) , Hz	300	58600	3669.43	4242.27
Peak frequency (mean) , Hz	300	60700	3645.2	5624.4
Peak frequency (Minimum entire) , Hz	300	58500	2263.99	3642.97
Peak frequency (start), Hz	300	60700	4039.2	6576.94
Fundamental (end) , Hz	0	13100	1427.41	1269.55
Fundamental (Maximum), , Hz	0	7700	1748.86	1258.35
Fundamental (mean entire) , Hz	0	6600	1683.95	770.5
Fundamental (mean) , Hz	0	8800	2352.12	1178.15
Fundamental (Minimum entire) , Hz	300	1000000	234262	1510064
Fundamental (start) , Hz	0	7700	1708.49	1308.2
Fundamental(Maximum entire) , Hz	0	20600	3142.02	1541.51
Maximum frequency (end) , Hz	4100	75300	16166	11983.6
Maximum frequency (Maximum entire) , Hz	4800	64500	16683.6	14077.7
Maximum frequency (Maximum) , Hz	1800	64800	12286.8	10786.1
Maximum frequency (mean) , Hz	4500	64800	15371.4	11844.4
Maximum frequency (Minimum entire) , Hz	700	64500	8465.45	7517.76
Maximum frequency (start) , Hz	3700	64800	13043.2	10573.3
Maximum frequency(mean entire)	2300	64500	11141	8379.63
Minimum frequency (end) , Hz	300	2200	437.06	294.99
Minimum frequency (Maximum entire) , Hz	300	55100	1347.27	1746.74
Minimum frequency (Maximum) , Hz	300	3300	585.59	438.95
Minimum frequency (mean entire) , Hz	300	16900	626.59	400.09
Minimum frequency (mean) , Hz	300	3300	390.16	269.36
Minimum frequency (Minimum entire) , Hz	300	2200	336.51	151.92
Minimum frequency (start) , Hz	300	3300	503.35	370.18

The bisonality and collective calling by the Beluga whale is responsible for the complex formants yielding a minimum entire fundamental frequency of 300Hz. The maximum fundamental frequency for the entire signal was 20.60kHz. At the start of the calls, the greatest peak frequency, fundamental frequency, minimum frequency and maximum frequency were 60.7kHz, 7.70kHz, 3.3kHz and 64.80 kHz respectively. The maximum mean parameters at the start of the calls was observed in the maximum frequency of all calls which was 13.04kHz with a standard deviation of 10.57kHz. Also, the peak frequency, fundamental frequency, minimum frequency and maximum frequency at the end of the calls spectrum were 61.50kHz, 13.10Hz, 2.20kHz and 75.30 kHz respectively. The mean value of the maximum frequency (mean) of the sound of *D. leucas* and *O. tormota* were 15.371kHz and 18.702kHz respectively. However, the sound of *D. leucas* recorded a maximum value of 64.800kHz which was 25.500kHz above the maximum frequency (mean) of the sound of *O. tormota*. The one-way ANOVA comparison of the maximum frequency (mean) of the sound of *D. leucas* by that of the sound of *O. tormota* at a confidence interval of 95% yielded the significance value, $p = 2.8975 \times 10^{-6} < 0.05$, implying that there exist a great significant difference between the maximum frequency (mean) of the sound of *D. leucas* and the sound of *O. tormota*. This provides the grounding for investigation the startling effect of the sound of *D. leucas* on the female *A. gambiae*. The large and varying standard deviations in frequency for the entire signal accounts for the pulsate signal resulting in fluctuations in energy trends as given in Figure 6. The formants represent spectral features similar to those of *Odorrana tormotus*. The Beluga whale, *D. leucas* exploits sounds for sound navigation and ranging (SONAR). The maximum frequency for the calls studied was 75.30kHz, showing the stretching of the harmonics from audible to ultrasonic range.

Bandwidth

The bandwidth parameters studied included bandwidth (end), bandwidth (maximum entire), bandwidth (maximum), bandwidth (minimum entire), bandwidth (start), bandwidth (mean entire) and bandwidth (mean) and whose measurements are given in Table 2. The maximum value of bandwidth (maximum entire) for the sound of *D. leucas* was 64.10kHz with a mean of 16.07kHz. The mean bandwidth (maximum entire) had a standard deviation of 14.09kHz. The sound of *O. tormota* yielded a maximum value of bandwidth (maximum entire) of 33.70kHz with a mean of 17.96kHz, which is narrow compared to the bandwidth of the sound of *D. leucas*. The sound of *D. leucas* which is characterised by a wider bandwidth points to greater the acoustic power. The one-way ANOVA comparison of the bandwidth (maximum entire) of the sound of *D. leucas* by that of the sound of *O. tormota* at a significance level of 0.05 yielded the significance value, $p = 0.0247 < 0.05$, showing that there exists a significant difference between the bandwidth (maximum entire) of the sound of *D. leucas* and the sound of *O. tormota.* Also, the maximum and mean values bandwidth (mean entire) of the sound of *D. leucas* was 64.10kHz and 10.460kHz respectively. The sound of *O. tormota* yielded a maximum and mean value of bandwidth (mean entire) of 13.30kHz with a mean of 5.857kHz, which is narrower compared to the bandwidth (mean entire) of the sound of *D. leucas*. Similarly, the one-way ANOVA comparison of the bandwidth (mean entire) of the sound of *D. leucas* by that of the sound of *O. tormota* at a significance level of 0.05 yielded the significance value, $p = 1.1225 \times 10^{-4} < 0.05$, indicating that there exists a highly significant difference between the bandwidth (mean entire) of the sound of *D. leucas* and the sound of *O. tormota.*

Table2. *The Bandwidth parameters*

	Parameter Measurements			
Parameters	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Bandwidth (end) , Hz	2600	75000	15661.6	12028.2
Bandwidth (Maximum entire) , Hz	3000	64100	16073.4	14094.7
Bandwidth (Maximum) , Hz	1500	64500	11642	10821.9
Bandwidth (Minimum entire) , Hz	300	64100	7656.37	7628.27
Bandwidth (start), (Hz) , Hz	2200	64500	12476.3	10589.3
Bandwidth(mean entire)	1200	64100	10460.2	8417.88
Bandwidth(mean) , Hz	3000	64500	14911.2	11862.4

Amplitude

The investigated amplitude parameters for the sound of D. leucas included Peak amplitude (start), Peak amplitude (end), Peak amplitude (Maximum), Peak amplitude (mean), Peak amplitude (Maximum entire) and the Peak amplitude (mean entire). The values for the parameters are given in Table 3. Amplitude forms an important parameter in acoustic energy which is critical in the study the investigation of the effect of sound on mosquitoes. The Acoustic energy is the product between the square of the amplitudes and time. The peak amplitude (end) of the calls under study yielded minimum, maximum and mean values of 77.00Pa, 102.81 Pa and 89.76 Pa respectively. A standard deviation of 2.99Pa was recorded. The maximum and mean values of the peak amplitude (mean entire) for the sound of D. leucas were 100.49Pa and 89.05Pa respectively. The sound of O. tormota yielded maximum and mean values of the peak amplitude (mean entire) of 133.6Pa and 128.887Pa respectively. The peak amplitude (mean entire) for the sound of D. leucas were smaller compared to those of the sound of O. tormota. There exist a very high significant difference between the peak amplitude (mean entire) for the sound of D. leucas compared to those of the sound of O. tormota with p = 4.88x10-4 < 0.05.

Table3. *The Amplitude parameters*

	Parameter Measurements			
Parameters	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Peak amplitude (mean), Pa	79.03	104.45	87.74	3.74
Peak amplitude (start) , Pa	90.01	104.45	91.57	1.64
Peak amplitude (end), Pa	77	102.81	89.76	2.99
Peak amplitude (Maximum), Pa	90.01	109.98	92.94	2.72
Peak amplitude (mean), Pa	79.03	104.45	87.74	3.74
Peak amplitude (Maximum entire), Pa	90.01	109.98	93.13	2.69
Peak amplitude (mean entire) , Hz	83.68	100.49	89.05	1.83

The low standard deviation in all parameters given in Table 3 indicates that the amplitude parameter values were very close to each other. Also, the maximum and minimum value are close, an indication of almost steady acoustic energy. The highest amplitude was the peak amplitude of the entire sound spectrum, with a value equal to 109.98Pa (17.90dB).

Acoustic Energy and Power

The signal energy of *D. leucas* was less than the energy possessed by *O. tormota*. The sound of *D. leucas* possessed a mean of the acoustic energy of 0.07Pa^{2}s whereas *O. tormota* possessed 2,496.63Pa^{2}s. The maximum acoustic energy for the entire sound spectrum was 19.41Pa^{2}s and the standard deviation being 0.44 Pa^{2}s. The maximum acoustic energy for the sound of *O. tormota* was 6,973.74Pa^{2}s, higher compared to the energy of the sound of *D. leucas*. A one-way ANOVA comparison of the signal energy of the sound of *D. leucas* by that of the sound of *O. tormota* at a significance level of 0.05 yielded the significance value, $p = 0.9857 > 0.05$, representing no significant difference between the signal energy of the sound of *D. leucas* and the sound of *O. tormota.*

The signal power, represented in Figure 8 fluctuates between 56dB and 36dB, appearing almost steady though with dips and spikes between 35dB and 40dB. The power is pulsate in nature.

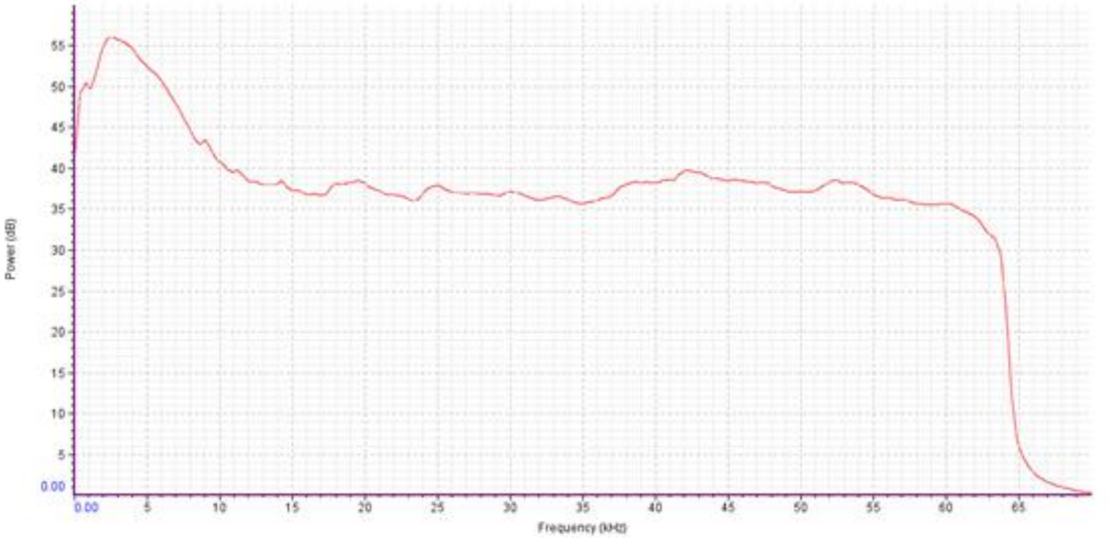

Figure8. *Signal power spectrum of the sound of D. leucas generated from Raven Pro 1.5*

The average power pattern of the sound of *D. leucas* is lower compared to the power of *O. tormota* that fluctuated between 43 dB and 89 dB as given in Figure 8 and 9. The power pattern of *O. tormota* is characterised by deeper deeps and spikes.

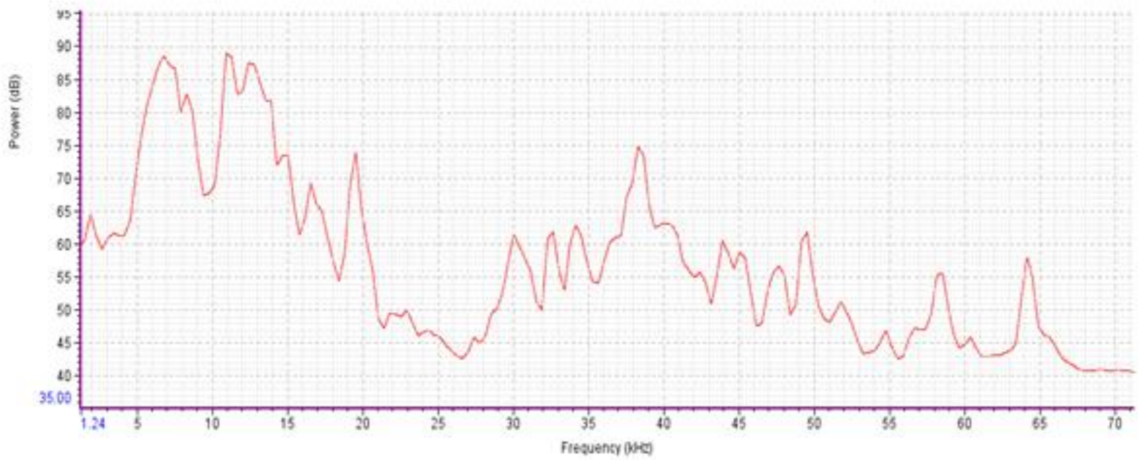

Figure9. *Signal power spectrum of the sound of O. tormota generated from Raven Pro 1.5*

4. CONCLUSION

The sounds of *D. leucas* exploited in echolocating are generated naturally through vocalisation and are pulsate in nature. The calls were predominantly frequency modulated (FM) and constant frequency modulated (CF) with breaks (Br), similar to the sound of *O. tormota*. The formants reveal presence of the fundamental frequencies and harmonics. The mean of the fundamental frequency (mean entire) of *D. leucas* was less than that of the sound of *O. tormota* though the difference was not significant. The difference in maximum value of maximum frequency (mean) between the sound of *D. leucas* and *O. tormota* was highly significant, with *D. leucas* recording the highest value of 64.800kHz which was 25.500kHz above the of the sound of *O. tormota*.

The sound of *D. leucas* was characterised by a wide bandwidth compared to the sound of *O. tormota* and the difference was significant. The peak amplitude (mean entire) for the sound of *D. leucas* were smaller compared to those of the sound of *O. tormota* exhibiting a highly significant difference. The signal energies of *D. leucas* were less than the energies possessed by *O. tormota* and the difference was not significant difference. The pulsate signal power of the sound of *D. leucas* was greater than the power in *O. tormota.*

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