UNDERWATER BEHAVIOUR OF THE HAWAIIAN SPINNER DOLPHIN AND THE ATLANTIC SPOTTED DOLPHIN

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To understand the behaviour of dolphins a specific language of these animals must be decoded. Dolphins acoustic emissions can be classified into two general categories: tonal whistles and pulsed sounds or clicks. Spinner whistles are frequency-modulated sounds with a fundamental component usually below 20 [kHz], while the echolocation signals have bi-modal frequency spectra with a low-frequency peak between 40 and 50 [kHz] and a high frequency peak between 110 and 130 [kHz]. Because of the fact that the signal of 100 kc/sec is much stronger absorbed by water than that of 20 kc/sec, at some longer distances higher harmonics are not audible for dolphins. Therefore, these harmonics probably do not play a significant role in long distance conversation. Another great problem is the noise produced by human activity that can impede the communication between dolphins or even prevent echolocation.

INTRODUCTION

Dolphins communication is the transmission of information from one animal to another by means of sound, visible signs or behaviour, touch, or a combination of these means. The existence, nature and extent of dolphins' communication have long been a subject of speculation and have in modern times stimulated much scientific investigation. Dolphins' communication is based on the sound, which has several advantages over other means. It fades quickly, leaving no trace of the communicator's location, and it can vary in pitch, duration, volume, and repetition, thus permitting a development of special codes. Sound may also be used in many settings, conditions, and situations in which other means are less feasible, such as across various distances, in darkness [2].

Hawaiian spinner dolphins (stanella longirostris) [Fig.1] are island-associated dolphins (around the Philippines in the western Pacific Ocean, French Polynesia in the South Pacific, Kwajalein Atoll in the Marshall Islands and waters of Hawaiian Islands [Fig.2]). The representatives of this species are often seen resting and travelling in numbers from 100 to

300, though groups of over 1000 in offshore regions have been reported. Large groups can be divided into smaller sub-groups according to age, sex and behavioural activity.

Fig. 1. Hawaiian spinner dolphins

Fig. 2. Hawaiian shore

They differ from Spotted dolphins (stanella frontalis) [Fig.3] and live in the vicinity the Bahama Islands [Fig.4]. This archipelago in the tropical West Atlantic east of Florida is surrounded by deep water and relatively shallow coastal areas (up to 15 [m]). The Hawaiian spinner dolphins are found only in the warm tropical and sub-tropical waters of the Atlantic Ocean, in both northern and southern hemispheres, although they are more abundant in the northern one. The representatives of the species form groups ranging from 5 to 15 in numbers, although groups of a hundred often have also been spotted. Generally, a family pod can number a maximum of about fifty. Till now approximately two hundred spotted dolphins have been identified and observed in a variety of behavioural context in the vicinity of the Bahamas Island [5].

Fig. 3. Atlantic spotted dolphins

Fig. 4. Bahamas Island shore

1. DOLPHINS' COMMUNICATION SIGNALS

1.A. WHISTLES

Dolphin acoustic emissions can be classified into two general categories: tonal whistles and pulsed sounds or clicks. The whistles produced by the Hawaiian spinner dolphins are characterised by the whistle repertoire i.e. the types of whistle and the frequency of occurrence of each type of whistle, i.e. the whistle usage [2]. Dolphin whistles have been characterised in terms of their instantaneous frequency as a function of time. The basic property of a vocal cord sound source is its periodicity expressed by the voice fundamental frequency. A voice source is further characterised by the spectrum envelope being a specification of the amplitudes of the source harmonics as a function of their frequency [1]. The source spectrum envelope reflects personal characteristics of the speaking (whistling) dolphin and depends on the voice range and intensity. A sound spectrogram [Fig.5] is a visual representation of sound, the abscissa corresponds to time and the axis of ordinates gives the frequency (or pitch). The frequency is measured in Hertz (Hz), or cycles per second; and in kilohertz (kHz) or thousands of cycles per second. The relative intensity of the sound at any particular time is indicated by a scale of intensity of the colour of the spectrogram. The colours black or blue correspond to the low amplitude of the frequency, while the red one to high amplitudes.

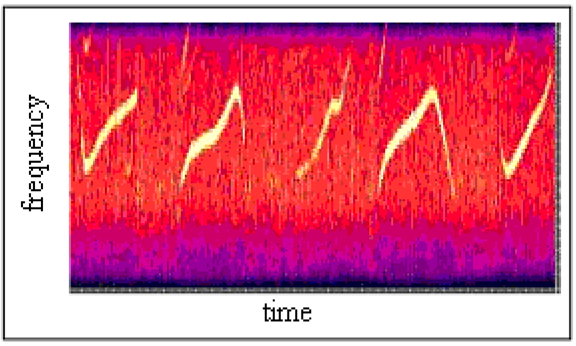

Fig. 5. The spectrogram of the dolphin's whistle

Spinner whistles are frequency-modulated sounds with a fundamental component usually below 20 [kHz] (which is an upper limit of human audibility) and harmonics up to 62 [kHz]. Durations of whistles usually vary between 0.1and 1.5 [s] but nearly all cluster between 0.2 and 0.7 [s]. The first harmonic is the most important because it transmits maximum energy and probably contains the majority of information. Frequency as a function of time is also referred to as the whistle contour [3]. The dolphins produce a large number of different contours that, all together, comprise the whistle repertoire of a given species and maybe even of a population. The spinner dolphin's whistles analysed were recorded in the waters of the Hawaiian Archipelago. They are characterised by [Fig.6]: beginning frequency, end frequency, maximum frequency, minimum frequency, peak frequency, duration, peak time, centre time, number of turns, loops and steps. Probably various configurations of these parameters carry different pieces of information.

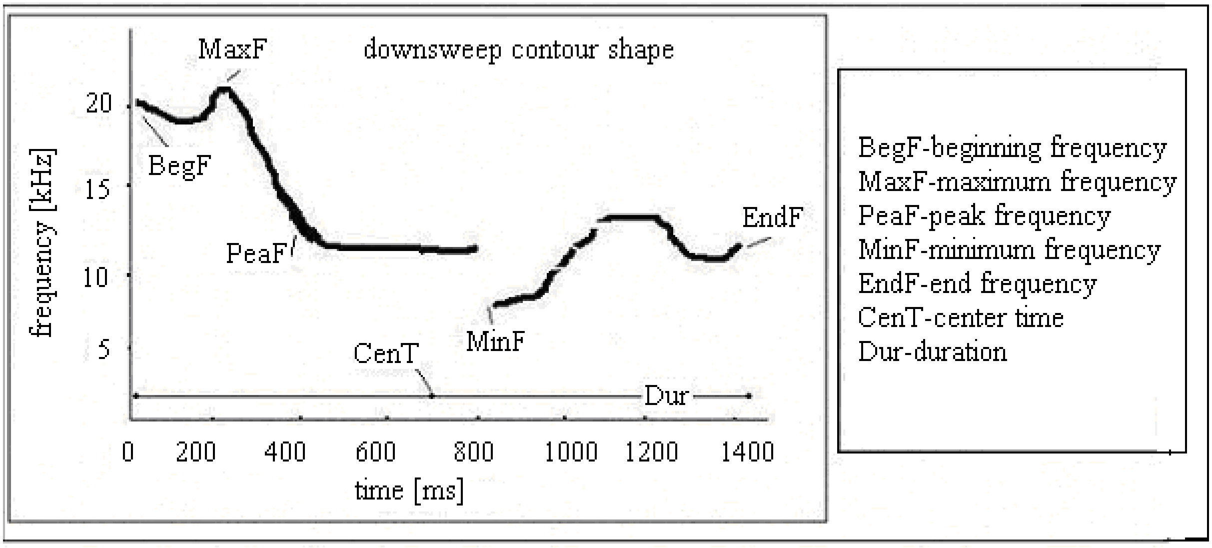

Fig. 6. Parameters of each whistle contour

Less then 3% of the whistles have a fundamental maximum frequency between 22 and 24 [kHz], while for approximately 95% of the whistles it is below 22 [kHz]. In addition, less then 1% of the whistles have minimum frequencies below 2 [kHz]. That is why the whistles can be recorded by a DAT recorder which has the upper frequency limit of 24 [kHz] (sampling rate of 48 [kHz]) [3].

The spinner dolphin whistle contours can also be classified into six general categories proposed by (Whitlou W. L. Au, after Driscoll and Bazua-Duran). The constant frequency contour [Fig.7] is that in which the frequency changes 1000 [Hz] or less in the duration of the whistle and in which the frequency span ("height") is less then one quarter of the duration ("length") of the whistle. The frequency rarely remains constant in the whole duration of the whistle. The upsweep contour [Fig.8] is that in which the frequency is mainly ascending. If there are any inflection points, the descending frequency part comprises less than half of the frequency span of the whistle. The downsweep contour [Fig.9] is the one in which the frequency is mainly descending. If there are any inflection points, the ascending frequency part comprises less than half of the frequency span of the whistle. The concave contour [Fig.10]is the one with at least one inflection point prior to which the frequency is mainly descending and then mainly ascending. The ascending and descending parts comprise more than half of the frequency span of the whistle. The convex contour [Fig.11] is that with at least one inflection point prior to which the frequency is mainly ascending and than mainly descending. The ascending and ascending parts comprise more than half of the frequency span of whistle. The sine contour [Fig.12] is that with at least two inflection points where the frequency is first mainly ascending, then mainly descending, and so forth, or vice versa. At least three of the ascending and descending parts comprise more than half of the frequency span of the whistle [3].

Hawaiian spinner dolphins emit a great amount of upsweep whistles (47%). The convex contours comprise 20% of the whistles and 13% are downsweep whistles. It is sometimes difficult to assign a whistle contour to either the upsweep or downsweep category and the convex or concave categories.

More interestingly, Wang (1995) has found a linear relationship between the maximum fundamental frequency of whistles and the dolphin body length:

$$\text{Maximum Frequency} = 21.452 - 3.2537 * \text{Body Length} \tag{1}$$

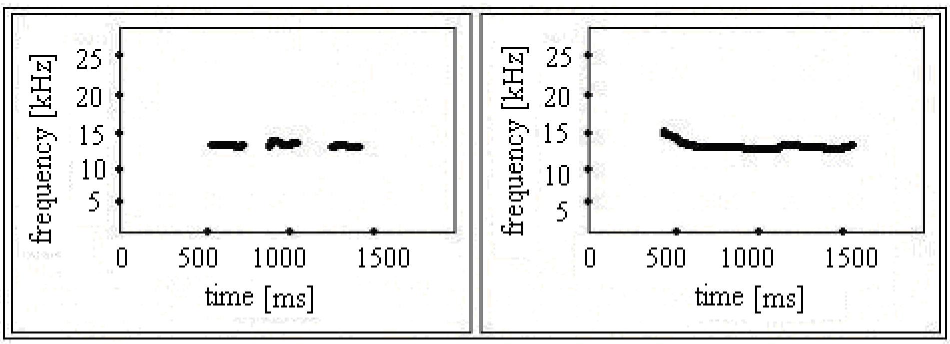

Fig. 7. Schematic constant frequency contour examples

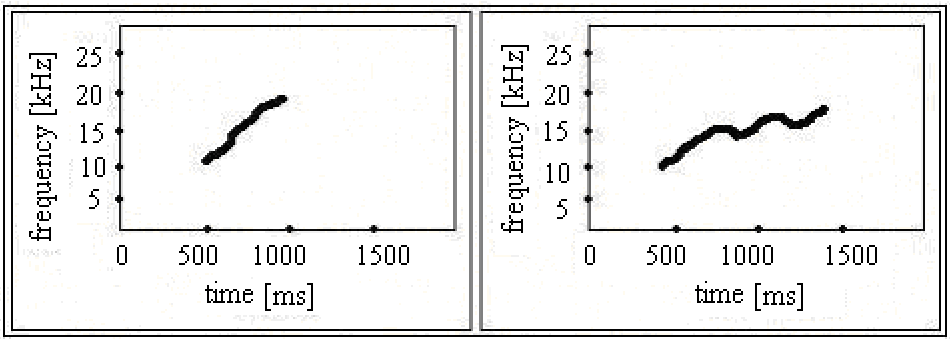

Fig. 8. Schematic upsweep contour examples

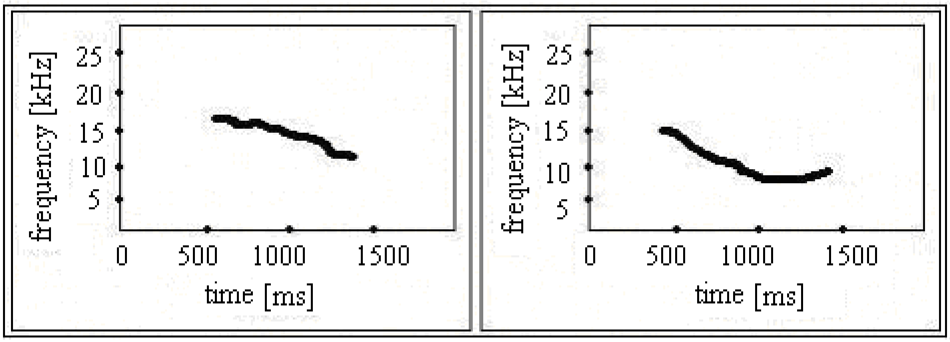

Fig. 9. Schematic downsweep contour examples

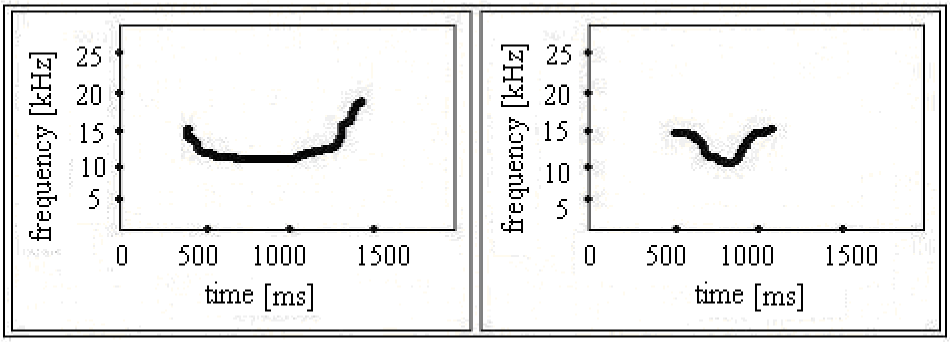

Fig. 10. Schematic concave contour examples

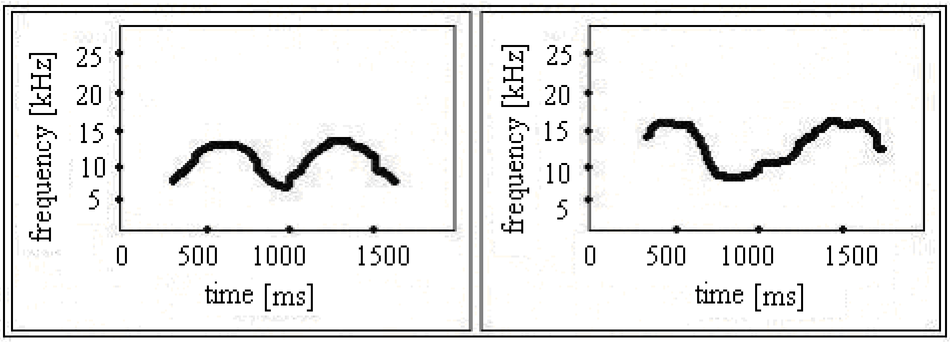

Fig. 11. Schematic convex contour examples

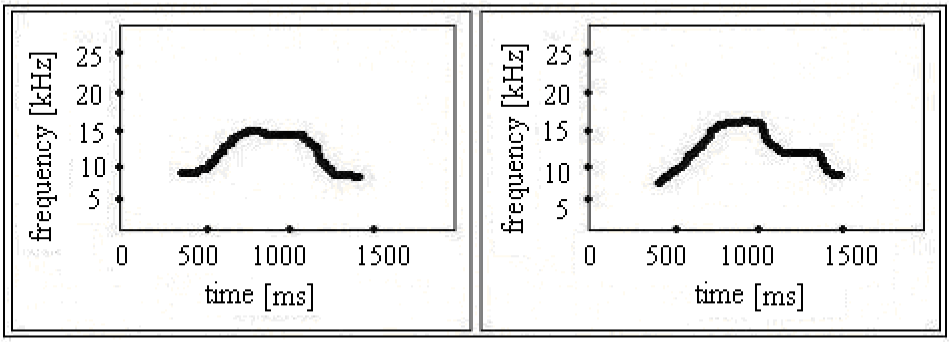

Fig. 12. Schematic sine contour examples

2.B. CLICKS

Dolphins use short, broadband clicks with peak energies between 40 and 130 [kHz] to echolocate. Burst pulses are produced alone, in bouts or associated with whistles. Spinner dolphins produce burst pulses that have on average approximately 30 clicks per train. Spotted dolphin burst pulses have on average about 100 clicks per train. The number of clicks in a burst pulse displayed an approximately bimodal distribution that distinguished burst pulses into low quantity (<seventy clicks) and high quantity (>seventy clicks) click trains [4]. Spotted dolphins produce significantly more high quantity burst pulses than spinner dolphins. Peak and centre frequencies for spinner dolphin burst is on average 32,3 and 40,1 [kHz]. Spectral energy distribution in clicks doesn't show any relationship to either the number of clicks in a train or the interclick interval. Approximately 80% of the total energy in burst pulses is above the upper limit of human audibility (20 [kHz]) for both species. Only a minority of signals have peak frequencies below this limit. Click trains are sometimes produced that begin with long interclick intervals (10-100 [ms]) and end with very short ones (1,5-9 [ms]) [5]. These are often observed when animals are foraging and presumably echolocating on prey. Experiments with free-swimming bottlenose dolphins (tursiops truncates) [Fig.13.] show that an echoprocessing lag time between 15 and 45 [ms] is always associated with successive clicks produced by animals echolocating on targets further than 0,4 [m] away [8]. As animals close in on a target (<0,4 [m]), interclick intervals as low as 2,5 [ms] are observed [8]. There is always a gradual progression towards shorter click intervals as dolphin approaches a target.

Fig. 13. Bottlenose dolphins (tursiops truncates)

The echolocation signals of Atlantic spotted dolphins have bi-modal frequency spectra [Fig.14.] with a low-frequency peak between 40 and 50 [kHz] and a high frequency peak between 110 and 130 [kHz] [5]. The low frequency peak is dominant when the signal source level is low and the high-frequency peak dominate when the source level is high. Measurements from stationary dolphins in captivity show that echolocation clicks are emitted in a directional beam and signals measured off-axis are distorted with respect to the signals measured along the major axis of the beam. The amplitude of the echoes returning to the

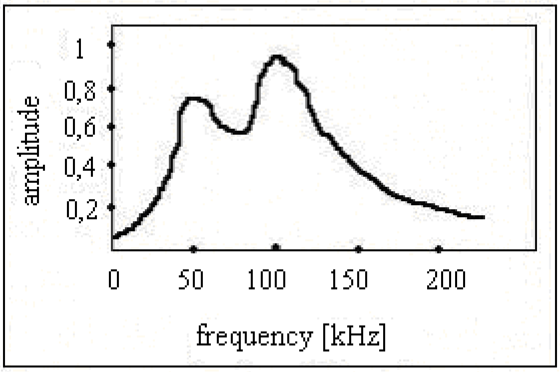

Fig. 14. Schematic bi-modal spectra of the echolocation signal

dolphins increases as the distance decreases, suggesting that the dolphins prefer receiving echoes with a high signal-to-noise. The interclick intervals are always greater than the two-way travel time from the animals to the target and back. Spotted dolphins produce relatively high-amplitude signals with a maximum source level of about 223 [dB] re 1 μPa although most of the source levels are between 200 and 210 [dB] re 1 μPa [5].

3. PROPAGATION LOSS

The transmission loss associated with any given length of ray path in water will be specifically designated as a propagation loss. The propagation loss between two points is, in general, a function of frequency. For each frequency the ratio of the intensity of sinusoidal acoustic waves measured at the source of sound to that measured at a certain distance from the sound is calculated. Fig.15 presents the propagation loss plotted against a logarithmic scale of distance for different frequencies. The practical working equation for nominal propagation loss, to be used whenever specific values of the range exponent and of the range coefficient are not available:

$$(Nw)o = 2 \log S + (0{,}20f + 0{,}00015f^2) S + 60 \ [dB] \tag{2}$$

where

(Nw)o = the nominal value of the propagation loss of sea water, based on statistical averages, likely to be found at any time or place between a given index point and a given observation point [dB]
S = the range from the effective centre of the source [kyd]
F = the frequency of the wave [kc/sec]

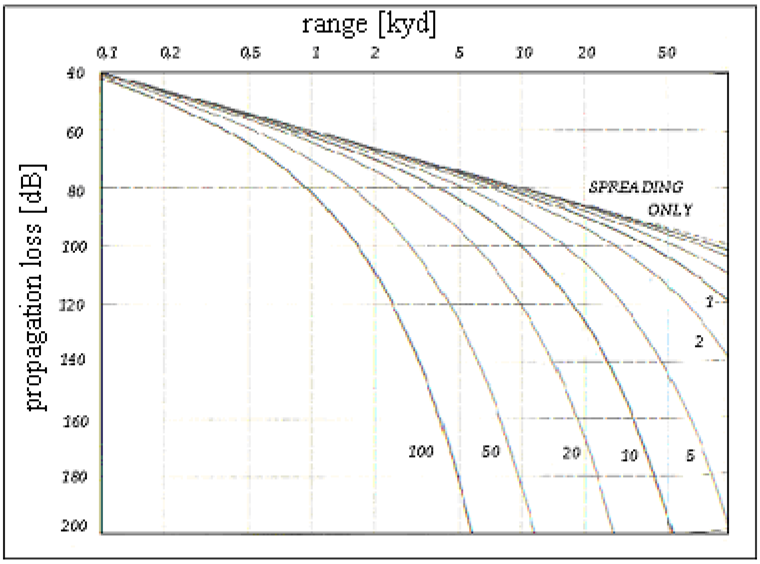

Fig. 15. Propagation loss as a function of range, with frequency [kHz] as a parameter

It shows that for distances under 1000 yards (600 [m]) little variation in the average value of propagation loss is to be expected as the frequency of the wave is changed. The propagation loss level also indicates that acoustic signals in water can be transmitted over longer distances at frequencies close to 20 kc/sec than those close to 100 kc/sec [7]. The signal of 100 kc/sec is much stronger absorbed by water, approximately 110 [dB] per 2000 yards (1200[m]), than the signal of 20 kc/sec, approximately 70 [dB] over the same distance. This fact can bring a partial answer to the question whether the higher harmonics in the dolphins' sound spectrum are important in their communication. They could be important in a short distance conversation, but they may not play any role in the dolphins' "calling".

4. NOISE IN THE SEA

There is no such thing as absolutely quiet water. Even if it was possible to isolate a sample of water completely from all external influence there would still be minute movements of the molecules, due to thermal agitation, accompanied by the release of acoustic energy. This molecular agitation, which is proportional to the absolute temperature of the water, is referred to as thermal noise. Many of the sounds present in the waters of the ocean are produced without relevant purpose. They may result from natural phenomena or from the activities of marine creatures. They may also result from man's activity undertaken for reasons other than their generation. The sounds of these different types are often made up of many components whose magnitudes can in time in a random manner, independently of one another. They sometimes exhibit more or less regularly recurrent variations which may be identified with some repetitive process. Such sounds are generally referred to as noise.

Many of the sounds present in the waters of the ocean originate from human activity. The most common of these sounds are, of course, those produced by ships. Ships noises in the water somewhat resemble the noise of general traffic on the shore. This sound might be classified as ambient noise and reaches a level as high as 90 dB // 1 watt/cm^2 for the frequency from 0.1 to 10 kc/sec [6]. In harbours in busy industrial areas there is always a certain amount of noise which gets into the water from machinery operating on barges, on piers, or even on shore at some distance from the water's edge. This noise can impede the communication between dolphins or even prevent echolocation, which might be a great problem for dolphins, which echolocate to find food and to survive.

5. CONCLUSION

The paper presents an outline of the communication and echolocation signals of the Hawaiian spinner dolphins and the Bahamas spotted dolphins. The signals of these two types play different and important roles in the dolphins' society.

On the one hand, marine mammals ears physically resemble land mammals ears. Therefore, since many forms of hearing loss are based on physical structure, hearing damage may occur by similar mechanism in both land and marine mammals ears. On the other hand, the sea has never been silent. The ocean is by nature an environment of relatively high noise level. The main natural sound sources include seismic, volcanic, wind, and even biotic. Dolphins evolved ears that function well within this context of high natural ambient noise. This may mean that they have developed a tougher inner ears less susceptible to hearing loss. Dolphins may be more resistant than many land mammals to temporary threshold shifts, but they may also be subject to hearing diseases [6].

Although, the subject of communication has been treated in a number of articles written by many researchers such as Whitlow W. L. Au from the Institute of Marine Biology (Hawaii), Denise L. Herzing from the Department of Biological Sciences (Florida) and Carmen Bazua-Duran from the Department of Oceanography (Hawaii), no answers to many basic questions have been given yet. We still do not know whether dolphins in fact are able to change the harmonic structure of their whistles and how burst pulses function in their communication. We can only speculate on the significance of these differences. Our surface behavioural observations are too limited in detail to be able to match many signals to a specific behaviour. For a species that lives in large groups the coordinate behaviour at all times is crucial to maintain communication between all members of the group.

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