THE SONAR OF DOLPHINS*

Whitlow Au
Hawaii Institute of Marine Biology
P.O. Box 1106, Kailua, HI 96734
wau@hawaii.edu

ABSTRACT The sonar of dolphins has undergone evolutionary re-finement for millions of years and has evolved to be the premier sonar system for short range applications. It far surpasses the capability of technological sonar, i.e. the only sonar system the US Navy has to detect buried mines is a dolphin system. Echolocation experiments with captive animals have revealed much of the basic parameters of the dolphin sonar. Features such as signal characteristics, transmission and reception beam patterns, hearing and internal filtering properties will be discussed. Sonar detection range and discrimination capabilities will also be included. Recent measurements of echolocation signals used by wild dolphins have expanded our understanding of their sonar system and their utilization in the field. A capability to perform time-varying gain has been recently uncovered which is very different than that of a technological sonar. A model of killer whale foraging on chinook salmon will be examined in order to gain an understanding of the effectiveness of the sonar system in nature. The model will examine foraging in both quiet and noisy environments and will show that the echo levels are more than sufficient for prey detection at relatively long ranges.

1. INTRODUCTION

Research on the dolphin sonar system has been conducted over three decades and have increased our knowledge of their system. However, our knowledge has not matured to the stage at which a sonar can be constructed that can mimic the capabilities of the dolphin sonar system. Our research have shown that the properties of the dolphin sonar are fairly ordinary yet dolphins can perform astonishing target discrimination tasks. Most of the sonar characteristics in this paper are associated with the Atlantic bottlenose dolphin (*Tursiops truncates*).

2. CHARACTERISTICS OF THE DOLPHIN SONAR SYSTEM

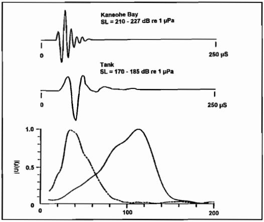

Fig. 1 Representation sonar signals of bottlenose dolphins

The broad frequency range and excellent sensitivity of hearing are two unique characteristics of dolphins. Dolphins can hear from 100 Hz to 150 kHz [1]. This is a range of 12 octaves and represents the widest frequency extent of any animal. The best sensitivity is about 40 dB re 1 mPa, which is comparable to low noise broadband hydrophones.

Bottlenose dolphins emit short broadband clicks having peak frequencies as high as 120-130 kHz [2]. Signals duration vary from 40 to 70 μs, having 4 to 10 positive excursions. Peak-to-peak source levels between 210 and 227 dB re 1 μPa have been measured [2]. Two sonar respectively. The directional projection and reception characteristics of bottlenose dolphin are not exceptional compared to many technological sonar.

The peripheral auditory system can be modeled as a bank of contiguous filters. At a frequency of 120 kHz, the Q of the filter is about 7 associated with a bandwidth about 17 kHz, not a very narrow filter [2].

3. DISCRIMINATION CAPABILITIES

Perhaps the most intriguing feature of the dolphin sonar system is the ability of echolocating dolphins to perform fine discrimination between different target. Three experiments will be discussed. The first involved blindfolded dolphin discriminating between the material composition and thickness of circular metallic plates [3].

Metallic Plate Discrimination

With the standard target being a 0.22 cm thick 30-cm diameter copper plate, three dolphins could discriminate between the standard and aluminum and brass plate of the same diameter and thickness. The dolphins could also discriminate copper plate of different wall thickness. Echoes from some of the plates obtained with a simulated dolphin echo system are shown in Fig. 2. When the incident signal was normal to the disc, the echoes showed no differences. However when the incident signal was 14° from normal, signals could enter the disc and propagate to the end and back, causing the echoes to have a structure related to both the thickness and material compo-sition of the plates.

* Reprinted from the Proceedings of the WESPAC-VIII, Melbourne, April 2003

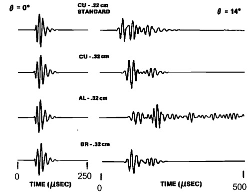

Fig. 2 Echoes from four plates at normal and 14° incidence. The 14° echoes are at least –30 dB weaker than normal incident echoes [2].

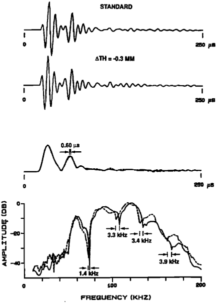

Fig. 3. Echoes from standard and comparison (-0.3 mm thinner wall) targets on the left. Envelopes of the echoes in top right and spectra in bottom right.

Wall Thickness Discrimination.

The second experiment involved the discrimination of wall thickness differences between a standard (6.35 mm wall, 3.81 cm OD, 12.7 cm length) and comparison cylinders with both thinner and thicker walls but the same OD and length [2]. At a range of 8 m the dolphin 75% correct response threshold occurred at wall thickness differences of -0.23 and +0.27 mm. Echoes from the standard and the comparison having a -0.3mm wall thickness difference are shown in Fig. 3. The dolphin probably used the 600 ns difference between the first and second highlights and/or the shift in the spectra.

Material Composition.

The third experiment involved a dolphin echo-locating at a range of 8 m and discriminating the material composition of solid 7.62-cm diameter spheres [4]. The dolphin could discriminate between the standard stainless steel sphere from spheres of the same diameter but composed of brass, aluminum and nylon. One again, differences in the echo structure of the targets were the probable cue.

4. USE OF SONAR IN THE WILD

Sonar experiments with captive dolphins and artificial targets have pro-vided much information on capabilities but did little toward under-standing their use of sonar in the wild. Signal measurements of wild dolphins have shown that source level increases in a 20 log R manner, where R is the target range. This variation of source level can be considered a form of time-varying gain for a sonar system that has little control of the receiver gain. Therefore, instead of varying the receiver gain, the transmission level is varied. When a dolphin forage for a fish school, the volume reverberation level of the school decreases as a function of 20 log R. Therefore, the level of the echoes from a fish school will be nearly constant with range.

Recently work my colleagues and I have performed involved modeling the use of sonar in foraging killer whales. Killer whales in British Columbia waters typically forage for chinook salmon that swim between a depth of 30 and 50 m. Our model is one in which the killer whale is at a 1 m depth and the salmon at 50 m directly ahead of the killer swimming away. Our field measurements showed signals had source levels that varied as 181.4 + 20 log R with a center frequency close to 50 kHz. By computing the target strength of a 0.7 m Chinook salmon as a function of angle we can estimate the levels of the echoes returning to the whale as a function of range. At a horizontal distance of 100 m between the whale and the salmon, the peak-to-peak echo level will be approximately 78 dB re 1 μPa. The threshold of hearing at 50 kHz is approximately 50 dB so that the echo is over 28 dB above the whale's threshold of hearing.

5. CONCLUSIONS

Although the dolphin auditory system is not highly tuned and the receiving and transmitting beam patterns are not very narrow, the dolphins can accomplish fine discrimination of targets. The use of broadband, short duration signals with good time resolution properties is probably the single most important feature that allow dolphins to make fine discrimination. The high mobility of dolphins and perhaps coupled to good spatial auditory memory are also important properties that enhance the dolphin discrimination capabilities. With their excellent sonar discrimination and detection capabilities, dolphins have no problems detecting prey at sufficiently long ranges to ensure successful foraging.

REFERENCES

1. C.S.Johnson, "Sound detection thresholds in marine mammals," in *Marine BioAcoustics,* W. Tavolga, ed., (Pergamon Press, New York, 1967), pp. 247-260.
2. W. W. L. Au, *The Sonar of Dolphins,* (Springer-Verlag, New York, 1993).
3. W.W. Evans, B.A. Powell, "Discrimination of different metallic plates by an echolocating delphinid," in *Animal Sonar Systems: Biology and Bionics,* R.G. Busnel, ed., (Lab. De Phsiologie Acoustique, Jouy-en-Josas, 1967), pp. 363-382.
4. R. Aubauer, W. W. L. Au, P.E. Nachtigall, D. A. Pawloski, C.M.Delong, "Classification of electronically generated phantom targets by an Atlantic bottlenose dolphin *(Tursiops truncates)," J. Acoust. Soc. Am.,* 107, 2750-2754 (2000).