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Instruments and Methods

Recording and quantification of ultrasonic echolocation clicks from free-ranging toothed whales

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Abstract

Toothed whales produce short, ultrasonic clicks of high directionality and source level to probe their environment acoustically. This process, termed echolocation, is to a large part governed by the properties of the emitted clicks. Therefore derivation of click source parameters from free-ranging animals is of increasing importance to understand both how toothed whales use echolocation in the wild and how they may be monitored acoustically. This paper addresses how source parameters can be derived from free-ranging toothed whales in the wild using calibrated multi-hydrophone arrays and digital recorders. We outline the properties required of hydrophones, amplifiers and analog to digital converters, and discuss the problems of recording echolocation clicks on the axis of a directional sound beam. For accurate localization the hydrophone array apertures must be adapted and scaled to the behavior of, and the range to, the clicking animal, and precise information on hydrophone locations is critical. We provide examples of localization routines and outline sources of error that lead to uncertainties in localizing clicking animals in time and space. Furthermore we explore approaches to time series analysis of discrete versions of toothed whale clicks that are meaningful in a biosonar context.

Keywords: Toothed whale; Ultrasound; Recording; Click; Hydrophone; Array; Echolocation

1. Introduction

Echolocating toothed whales emit ultrasonic clicks to acquire information about their environment and to find food by reception and analysis of echoes returning from ensonified objects in the water column and the sea bed (Au, 1993). The performance of a biosonar system is dictated partly by the source properties of the emitted clicks (Au, 1997, 2004) in that high-amplitude signals may ensonify more distant targets and a higher directionality (Fig. 1A) reduces the number of unwanted echoes (also called clutter). The temporal and spectral properties of the clicks determine the information that can be derived from returning echoes and how well the echoes can be detected in noise and clutter. The ability to resolve the location of a target in time and space as well as its size, shape and material follow partly from the properties of the signal waveform (Au, 1993). A broad bandwidth of

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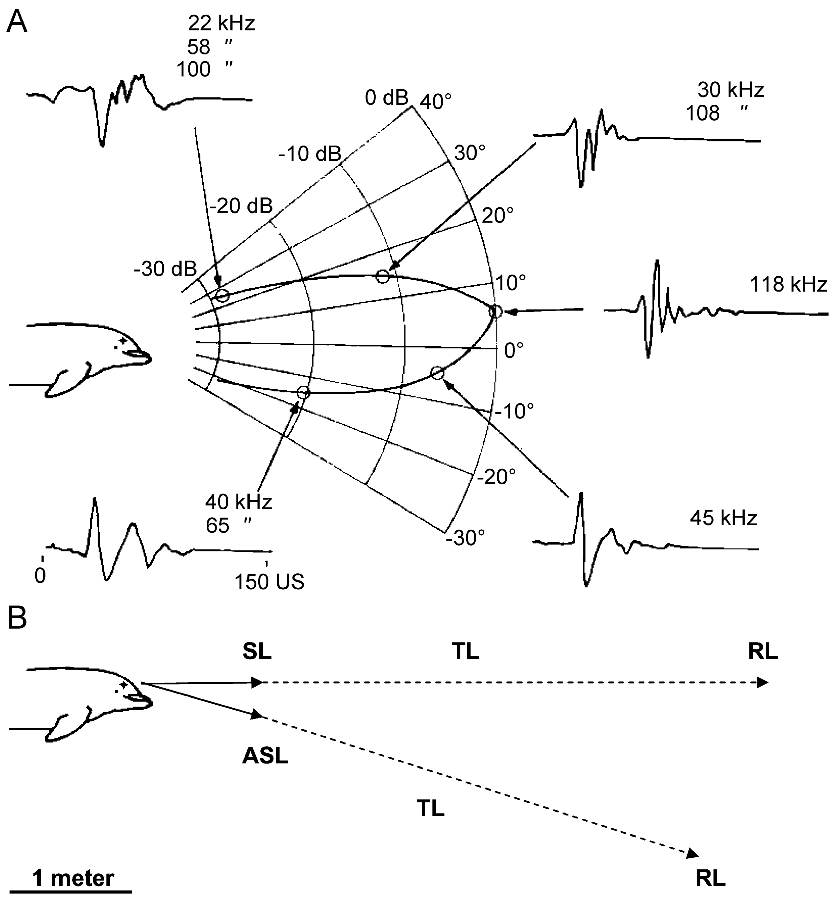

Fig. 1. (A) Radiation pattern of a click from an echolocating dolphin (Au, 1993) showing off-axis distortion. (B) The passive sonar equation applied to a clicking dolphin. SL is the back-calculated sound pressure level (Received level (RL)+transmission loss (TL)) 1 m from the source and on the acoustic axis. ASL is the sound pressure back-calculated to 1 m in an unknown aspect to the animal.

the source signal improves these abilities (Brill et al., 1992; Roitblat et al., 1995), whereas the detectability in broad band noise improves with diminishing band width (Madsen et al., 2005b). The detection range increases with the transmitting and receiving directionality, which in turn depends on the dominant wavelengths of the sonar signal relative to the transmitting aperture. Shorter wavelengths emitted from a given transmitting aperture increase the directionality on both the transmitting and receiving side. Higher frequencies reduce the incoming noise levels with masking potential (Wenz, 1962), but will also lead to a higher absorption of sound energy in the medium (Urick, 1983). Thus, there is a trade off in terms of the range, noise levels, clutter reduction and resolution for a given biosonar as dictated by the transmitted clicks, the receiving directionality and the sound producing structures of the echolocating animal emitting them. For example, the source properties of sperm whale echolocation clicks with very high-source levels (SL) at 15–20 kHz show that these signals hold a strong potential to operate in a long range biosonar system (Madsen et al., 2002b; Moehl et al., 2003), whereas the low amplitude, 130 kHz clicks from small toothed whales such as harbor porpoises and pygmy sperm whales preclude anything but use in short range biosonar systems (Au et al., 1999; Madsen et al., 2005b). Source properties of echolocation clicks are also relevant for passive acoustic monitoring with towed arrays (Barlow and Taylor, 2005; Leaper et al., 2002), sonobuoys (Levenson, 1974) and automated porpoise detectors (e.g. TPODS, Carlstroem, 2005) for optimizing detection routines and classification of species on the basis of acoustic cues.

Echolocating animals point the sound beam on the target of interest (Au, 1993), so for a meaningful