An investigation of frequency shifts in the echolocation clicks of Southern Resident killer whales (*Orcinus orca*) in response to high levels of ambient noise

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I. INTRODUCTION

Killer whales (*Orcinus orca*) belong to the suborder of cetaceans that includes toothed whales, or odontocetes. Typically, odontocetes are highly social, evidenced by their tendency to organize themselves into groups, and their high levels of vocal activity when such groups are formed. Killer whales follow this pattern, occurring in social groups called *pods*. These pods may consist of as many as 50 individuals, though average pod size ranges between 2 and 15 whales (NMFS 2008, II-10). Each pod is made up of one or multiple closely related *matrilines*. A usual matriline is comprised of a female, her male and female offspring, as well as the offspring of her daughters (NMFS 2008, II-11). Individuals within a matriline are thus very highly related, and rarely separate from the main group. Matrilines associate more closely with matrilines of the same pod than with those of other pods. Pods are grouped into *clans* by their degree of relatedness, and, in turn, clans that associate with one another regularly form *communities*. The community of whales featured in this study is the Southern Resident community (SRKW) that inhabits Pacific Northwestern waters during the summer months. Their distinction from other killer whale communities is apparent in many aspects, including, but not limited to their vocal dialect.

Killer whales, and all odontocetes for that matter, exhibit three general vocalizations: whistles, clicks, and pulsed calls (NMFS 2008, II-14). Whistles are tonal sounds that contain dominant frequencies at 8.3kHz on average (NMFS 2008, II-14); pulsed calls are the most frequent of killer whale vocalizations (NMFS 2008, II-14), and highly distinguishable (discrete) calls, key to establishing dialects among varying levels of social hierarchy. Echolocation "clicks" are believed to be used for navigation and localization of prey, and possibly also for communicating during foraging events or otherwise. It is possible that high levels of anthropogenic sound (i.e. dredging, pile driving, drilling, sonar, commercial boating, etc.) are capable of masking killer whale calls, including the echolocation clicks that are vital to the feeding success of killer whales (NMFS 2008, II-14).

Christine Erbe (2002) investigated the underwater noise of whale-watching boats and its potential effects on killer whales that resided in the Juan de Fuca and Haro Straights in southern British Columbia and northern Washington. It was found that boat source levels ranged from 145 to 160 dB and were audible to killer whales within 16km. Depending on the received level and frequency nature of that noise, the calls of the whales could be masked. Masking occurs when the bandwidth of the background noise of sufficient amplitude overlaps with the frequency bands of the call. It is suggested in Erbe's paper that shifting call frequencies outside of interfering range (i.e. critical bandwidth) would result in better detection of those calls.

Odontocetes have indeed shown on multiple occasions the ability to alter clicking behavior to suit the needs of their lifestyle. Transient killer whales, for example, use clicks only rarely while foraging, whereas resident killer whales are believed to use a high proportion of clicks to localize their prey items in addition to communicating while foraging (Ford 1989). This disparity comes due to differing prey items between residents and transients. While residents feed primarily on salmon, transients tend to feed on marine mammals, and while salmon are behaviorally unresponsive to characteristic echolocation frequencies (Hawkins and Johnstone 1978), most marine mammals have the ability to detect killer whale echolocation. Thus, as a hunting strategy, transient killer whales significantly decrease the amount of clicks they employ while seeking prey (Deecke et al. 2004; Barrett-Lennard et al. 1994). Furthermore, there is evidence that different click frequencies are employed among killer whale ecotypes (Foote 2008). Offshore killer whales for instance, display minimum frequencies that are much higher than those of either resident or transient ecotypes, presumably due to the high levels of low-frequency background noise they endure created by the higher wind speeds in their environment (Foote 2008).

Sperm whales (*Physeter macrocephalus*) have been shown to shift the frequency of their clicks from 10 kHz to 15 kHz as the depth of descent increases, though the exact reason for such a shift is unknown (Thode et al. 2002). C. Kamminga and J.G. van Velden showed that the dominant frequency in *P. crassidens*, a pelagic dolphin, was around 28 kHz. Even so, occasional two-component sonar clicks demonstrated energy around 100 kHz in that study.

A study carried out by Au Whitlow (et al. 1984) demonstrated the ability of beluga whales (*Delphinapterus leucas*) to shift its biosonar to higher frequencies after it was moved from an area of low ambient noise, to that which expressed comparatively high levels of ambient noise. The animals shifted their sonar peak (most significant) frequency from 40-60 kHz in San Diego Bay, California to frequencies between 100-120 kHz when they moved to Kaneohe Bay, Hawaii (ambient noise levels were 12-17 dB greater in Kaneohe Bay).

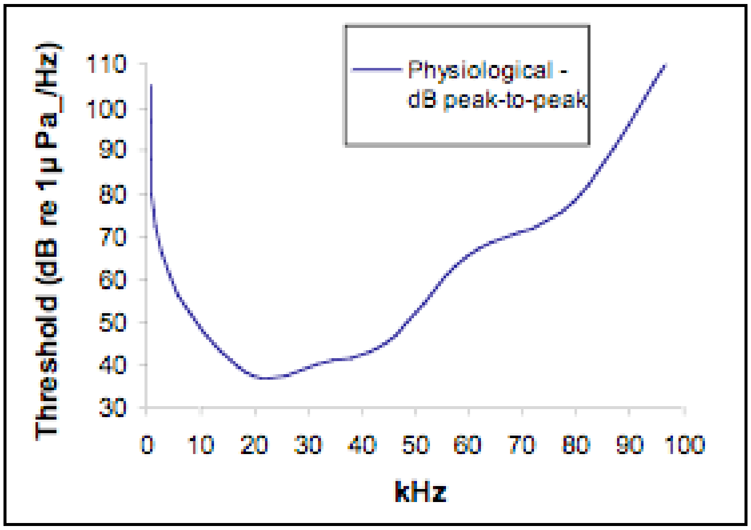

Figure 1 – the audiogram of a killer whale as shown by Szymanski et al. 1999 (taken from Hunt 2007)

Orca echolocation is unusually low in frequency (~25 kHz)(Richardson et al. 1995), almost an entire octave lower than bottlenose dolphins (*Tursiops trucatus*)(Au et al. 2004). The killer whale audiogram (Fig.1), shows that the whale's most sensitive hearing frequency (~20kHz) closely corresponds with the lower peak found in orca echolocation. Unfortunately, according to graphs produced by Tim Hunt (2007), many of the boats that Southern Residents commonly encounter exhibit energy levels between 10-20kHz that have the potential to mask typical echolocation calls. However, most killer whale clicks display bimodal distribution, resulting in another peak in energy at higher frequencies, between 40-60kHz (Au et al. 2004), a feature of the click that provides a possible outlet for masking avoidance.

The purpose of this investigation is to divulge correlation between killer whale echolocation clicks and the amplitude of interfering background noise they experience. With the ability to shift frequency in response to environmental changes clearly present in odontocetes, and taking into account the immediate foraging benefits it could entail, it would not be surprising to discover a compensatory change in the nature of Southern Resident clicks when background interference is present. Due to the bimodal nature of killer whale clicks, such compensation could possibly be achieved by shifting the lower peak frequency of the click (located ~25kHz) to higher frequencies, or by increasing the energy that is devoted to the high frequency peak (located ~40-60kHz).

Thus, I hypothesize that killer whale clicks will display peak frequencies that are significantly higher (in frequency) than those found in typical click spectrums. Further, in the event that this pattern is not seen, I hypothesize that the high frequency peak of clicks will show an increase in amplitude as interfering background noise increases in amplitude.

II. METHODS

An array of hydrophones will be towed off the port stern of the research vessel (Fig. 2). A high frequency hydrophone (HF) will be towed off the starboard stern of the same vessel in a configuration that closely resembles that of the array. The HF is incorporated into the projects of other students on the research vessel which involve localization. Therefore, the intention is to deploy the HF at the same distance behind the boat as the first hydrophone in the array by attaching a 12lb weight ~2m from the hydrophone and further extending ~7.5m of hydrophone cable before securing it to the boat. SRKW vocal activity will be recorded whenever encountered using the HF configuration connected to a 2k sound device.

Ambient noise and echolocation clicks will be recorded in and around North Pacific waters (Straight of Juan de Fuca, Haro Straight, San Juan Channel, etc.). Due to the likelihood that multiple boats will contribute to the overall background noise, calculating source levels of the noise will be impractical. For this reason, recorded amplitudes will be used as the amplitudes experienced by the whales (received level).

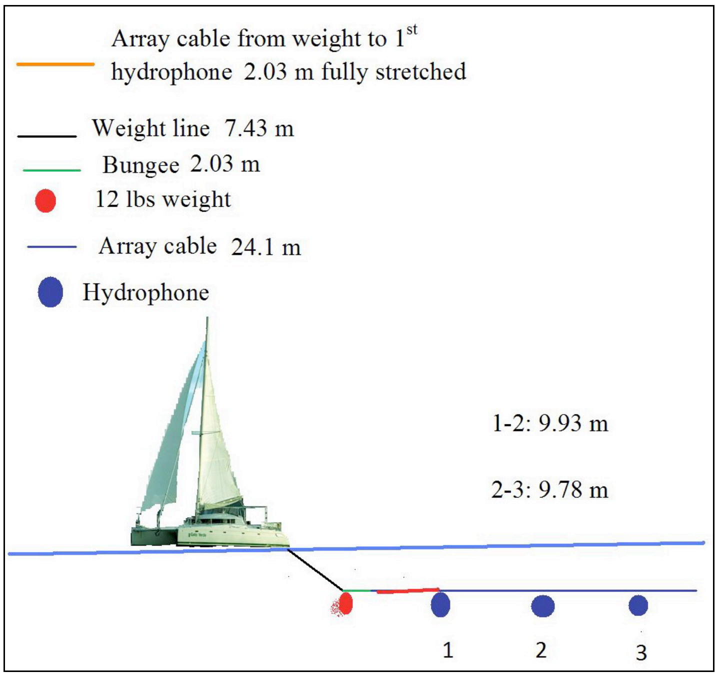

Figure 2 – The Gato Verde (research vessel) and the hydrophone array deployed off the port stern. The HF is deployed off the starboard stern in a similar fashion (used with permission of Dominique Walk).

Using Val Veirs Beam Reach Sound Analyzer (v. May ’08), click spectrums will be created. From these spectrums, the peak frequency will be found, and amplitude of both low-frequency and high-frequency peaks will be measured. The overall peak frequency and low-peak to high-peak ratio measurements will be compared with the background noise amplitude found within the frequency range of interest.

I expect that as background amplitudes increase within the frequency band of 10-20kHz, clicks will produce spectrums that show compensatory frequency patterns. Specifically, I expect that one of the following will be found in click spectrums: low frequency peaks will shift to higher frequencies, or low-peak to high-peak ratios will become smaller.

ACKNOWLEDGMENTS

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