Masking avoidance by Southern Resident Killer Whales in response to anthropogenic sound.

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INTRODUCTION

Southern resident killer whales (SRKW or southern residents) are the population of *Orcinus orca* that reside in the inland waters of Vancouver Island and Washington state from late spring through the fall (Ford et al. 2000). Their range extends from the coastal waters of central California to north of Vancouver Island and around the Queen Charlotte Islands (Wiles 2004). The SRKW population is comprised of J, K, and L pods which, when congregating together are referred to as a superpod. Each pod is highly structured and shows a stable organization around matrilines (Ford et al. 2000). A decline in the SRKW population was marked by the capture of a large number of killer whales for the aquarium trade from 1965 to 1978 (Bigg et al. 1987). Under the Endangered Species Act, the SRKWs were listed as endangered in December of 2005 and the required recovery plan summarizes numerous threats that could account for the decline of southern residents and impede their recovery (NMFS 2006). One such threat is the presence of anthropogenic underwater sound, which could mask vocal communication (Richardson et al. 1995). As highly social animals, communication is vital to killer whale interactions from the individual to the superpod level.

In marine environments auditory communication is often more important than olfactory or visual communication. Chemicals that can be sensed in an olfactory manner depend on currents for dispersal through the water so are not reliable as omnidirectional signals. Visual sensing is limited because of rapid light attenuation with depth.

Vocalizations are highly advanced and used during numerous behaviors (Ford et al. 2000, Miller 2002). There are three types of killer whale vocalizations: clicks (which are used in echolocation) whistles, and discrete calls. Pods have differing dialects made up of specific numbers, types, and repetitions of discrete call types (Ford 1991). Discrete calls are the most frequent vocalizations. Pods typically have one primary call that accounts for more than 50% of all discrete calls produced (Ford 1989, Ford 1991). The majority of their discrete calls occur within the range of 105 and 124 dB re 1µ Pa (Erbe 2002). Threshold audiograms for killer whales show that they are most sensitive at frequencies near 20 kHz and their discrete calls have a fundamental frequency of around 17 - 20 kHz (Ford 1987, Szymanski et al. 1999). These discrete vocalizations are thought to be important in maintaining group cohesion, as well as foraging and coordination of group movement (Foote 2005, Miller 2002).

During the summer months, the SRKW frequently inhabit the Haro Strait where there is a regular presence of large tankers and container ships as a result of it serving as a major shipping lane for both the U.S. and Canada. Other large vessels frequently present in the vicinity of the southern residents include ferries that service residents of the islands and visitors and military ships for both the U.S. and Canada. Numerous personal vessels are often on the water for recreation as well as transportation through the numerous islands. The SRKW themselves are a popular recreation attraction drawing not only personal vessels but also whale watching tour boats into close proximity. The number of these boats has increased over the past decade and the daily and seasonal amount of time boats are accompanying orcas has increased (Foote 2004, Koski 2006). All of these vessels create anthropogenic sound, which increases the background levels present in the SRKW environment.

During situations of elevated background sound caused by vessel traffic, SRKW vocalizations have the potential to be masked. In order to maintain communication, the effects of masking must be overcome. This can be achieved by increasing duration, increasing amplitude, or changing the frequency of the calls to be outside the range of the interfering sound (Erbe 2002, Foote 2004). Increased signal duration has been shown to increase the perception threshold of Odontecetes (Johnson 1967). For killer whales in particular, Foote (2004) showed increased duration of vocalizations in the presence of vessel traffic. Determining a change in amplitude has been limited by a lack of ability to determine the distance from the receiver to the source of the call.

In the open ocean compared to inshore environments there is a higher level of natural background sound due to greater wave and wind effects. Off shore populations of killer whales over evolutionary time scales have developed higher average minimum and maximum frequencies of calls than SRKWs (Foote 2004). Since the increase in vessel traffic in the habitat of the SRKW has occurred most notably in the past decade, the changes in this population would be ontogenetic, but could feasibly follow a similar path as the offshore population (Rabine and Green 2002). Alterations of frequency to avoid masking have also not been investigated, likely because it is more complicated. Frequency of discrete calls varies between call types and changes some if used during different behaviors (Jason Wood pers. comm.). In order to determine changes in frequency in the presence of vessel sound, this variability must be dealt with.

The purpose of this study is to determine if orcas alter their vocalizations in response to the level of anthropogenic sound in their environment. To this end, the following three hypotheses will be tested while controlling for call type and group behavior:

H_1: Stereotyped call duration will increase as the amplitude of background noise increases.

H_2: The amplitude of stereotyped calls will increase as the amplitude of background noise increases.

H_3: The minimum frequency of stereotyped calls will vary when the predominant noise frequency changes.

METHODS

Study of southern resident killer whales will be conducted in the waters surrounding the San Juan Islands, Washington, USA, predominantly in Haro Strait. Southern resident killer whale vocalizations will be recorded by two groups of researchers from August 27th to October 20th 2007 while aboard the *Gato Verde,* a 42-foot catamaran sailing vessel. Two electric propulsion motors run from battery banks charged with a bio-diesel generator to power the *Gato Verde*. The propulsion system creates very little underwater noise allowing a hydrophone array to be towed with limited observer interference. When whales of J, K, or L pods are encountered, a four hydrophone array will be deployed off the port stern of the *Gato Verde*. The array is a linear arrangement of four Lab-core hydrophones with peak sensitivity of 5,000 Hz (down 30 dB at 200 and 10,500 Hz). Underwater sound will be recorded using two solid state recorders with a proprietary link for sample accuracy. The solid state recorders are Sound Devices 702 with a flat frequency response from 10 Hz to 40 kHz (+0.1,-0.5 dB), set at a sampling rate of 44,100 samples per second and 16 bit depth. To limit surface noise, the hydrophone will be weighted to an approximate depth of 3 m. The entire recording system will be calibrated, so that recordings of amplitude can be in dB re 1 μPa and therefore directly comparable to other studies. During recording periods, the general group behavior of killer whales will be recorded as rest, travel, forage, play, or milling following the descriptions in the SRKW Behavior Workshop Final Report (NMFS 2004).

Recordings will be imported into Audacity 1.2.4. (Dominic Mazzoni). Each call will be isolated as a separate call file and accompanied by a corresponding sound file for analysis of background noise levels. The background noise file will be extracted from the sound file just prior to the corresponding killer whale vocalization. Each call file will be visually compared with the call catalog to determine call type (Ford 1987). A series of scripts will be written in MatLab 7.4 (Mathworks) to automate the analysis of call parameters and noise levels. Duration, amplitude, and minimum frequency will be determined and recorded for each call file. Amplitude and predominant noise frequency will be determined for each noise file. Predominant noise frequency is defined as the mean frequency over the majority of the noise amplitude.

Duration

The length of the call file will determine the duration of the call, as it will be restricted to only include the call when separated in Audacity.

Amplitude

In MatLab, received amplitude level will be determined as the mean amplitude for both call and noise files. Both behavioral changes in killer whale calls due to vessel noise and a change in distance from the source to receiver could affect the received level of amplitude in the recording. Therefore, to elucidate a change due to vessel noise, the source level of a call must be determined. Determining the source level of a call from the recorded level will be done by determining the distance between the vocalizing killer whale and the receiver and then calculating the loss of amplitude over that distance based on a spherical spreading model (Richardson et al. 1995). The distance from the *Gato Verde* and the vocalizing killer whale can be determined by localizing the call in Ishmael 1.0 (David Mellinger). Received level of noise will be considered representative of noise levels experienced by killer whales vocalizing in the area because spacing of vessels with respect to killer whales and the *Gato Verde* are variable and dynamic.

Frequency

For call files, frequency measure will be the minimum frequency of the call. The frequency measure of noise files will be the predominant noise frequency. The script in MatLab will be written to determine the mean frequency of the noise over the frequency range containing the majority of the power of the signal. The percentage of noise amplitude appropriate for defining the predominant noise frequency will be determined from power density spectra. Power density spectra compare the mean square pressure per unit frequency (dB re 1 $\mu Pa^2/Hz$) to frequency of continuous noise. From the power density spectrum, the range of frequency that accounts for a majority of the pressure will be centered to the peak associated with vessel background noise. The average frequency across the majority of the pressure will be the predominant noise frequency.

Statistical Analysis

Both duration and amplitude parameters of killer whale calls will be compared across amplitude of noise with regression analyses. In order to determine if there is a shift in the frequency of killer whale calls, the minimum frequency will be compared across predominant noise frequency with a regression analysis. Because the call parameters of interest in this study vary between call types, only the most numerous call type present in recordings over the course of the study will be used. Behavior may also influence call parameters, so behavior state will be noted and separate analyses will be done for each behavior. To account for multiple comparisons, a Bonferoni correction will be used.

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