Investigating the Effect of Large Vessel Noise on the Acoustic Behavior of Southern Resident Killer Whales

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Introduction

Southern Resident killer whales (SRKW) were listed as endangered in the United States under the Endangered Species Act of 1973 (ESA) in November, 2005 as a result of a substantial population decline which began in 1996 (NMFS, 2008). The major threats to the whales identified in the ESA-mandated recovery plan include vulnerability to prey availability, contamination by organochlorines and other pollutants, and effects of vessels and their corresponding sounds (NMFS, 2008). Human actions, past, present and future are irrevocably connected to these and other threats (Ford et al., 2005; Holt, 2008; Ylitalo et al., 2001, etc.) to the Southern Residents.

Perhaps the most feasibly regulated of these threats is the effect of vessels and the noise they add to the whales' environment. The ability to send and receive acoustic signals is necessary for the successful survival of killer whales and many other marine mammals (NRC, 2003). Anthropogenic noises are a substantial source of acoustic disturbance in the ocean, and can cause a number of harmful short-term and long-term effects in the whales. Depending on the frequency, amplitude, energy, and duration of the noise, exposure can cause temporary or permanent hearing loss, stress the animals and force them to change their behavior (Erbe, 2002; Foote et al. 2004; Holt, 2008; Holt et al. 2008), prompt animals to abandon an area (Morton and Symonds, 2002) and in the case of certain kinds of sonar, can potentially cause death (Parsons et al., 2008).

Resident killer whales are extremely communicative creatures, and each pod, a social group made up of one or more matrilines, has its own specific dialect (Hoelzel and Osborne, 1986). The orcas' acoustic behavior is a combination of clicks, whistles, and pulsed calls (Ford, 1987). Clicks are characterized as brief pulses of sound and usually appear in a series, primarily for the purpose of echolocation (Ford, 1987). Whistles are nonpulsed, continuous, narrowband tones with very little harmonic structure (Ford, 1987). Most contain distinct modulations or abrupt shifts in frequency (Ford, 1987). Pulsed calls are the most common and abundant method of acoustic communication used by SRKW (Ford, 1987). They usually have distinct tonal properties and abrupt and patterned shifts in pulsing rate (Ford, 1987). The bandwidth and repetition rate of pulsed calls varies significantly between calls and dialects (Ford, 1987). Orcas rely on communication as an integral part of their life, necessary for reproduction and survival and the disruption of any of these behaviors exacerbates threats to the population (NMFS,2008).

Killer whales' hearing ranges from approximately 1 kHz to 1000 kHz but their greatest hearing sensitivity is around 20 kHz (Syzmanski et al., 1999). The background noise in Haro Strait varies between 0.1 kHz and 15 kHz (Veirs and Veirs, 2007). While this frequency range is below the whales' peak hearing sensitivity, it is still a significant impact on the whales' environment (Holt, 2008). While the effects of anthropogenic noise pollution have long been investigated, the focus of these studies has mostly been the whale watch industry (Erbe, 2002; Holt, 2008, etc.). Most studies beyond that are focused on more general impacts of ambient noise and threshold effects and have used the number and type of boats in a set vicinity around the whales as the basis for their research(Foote et al., 2004; Holt, 2008; Holt et al., 2008; Veirs and Veirs, 2007, etc.) Research of this type has shown the important correlation between the number of boats immediately surrounding the whales and the amount of background noise they have to cope with (Holt et al., 2008). It has also provided excellent data on how the whales change their acoustic behavior given the number of boats near them (Erbe, 2002; Foote et al. 2004; Holt, 2008; Holt et al. 2008, etc.). However, these studies have left a large gap.

According to Veirs and Veirs' 18 month study in Haro Strait (2007), the majority of the average broadband ambient noise is a result of the passage of large vessels or commercial ships. The ships added approximately 20 to 25 dB to sound pressure levels (SPL, dB re 1μPa) for 10 to 30 minute periods at a time (Veirs and Veirs, 2007.) The ships also accounted for the 20 dB jump from minimum SPL to average SPL, over the long term (Veirs and Veirs, 2007.) Because ships tend to move continuously and away from the normal congregation of boats while in the whales' immediate vicinity, they tend not to be represented in vessel counts and data relative to the amount of noise they contribute to a particular area.

Given the known effects of elevated noise pollution, the ships' noise could have the potential to generate certain harmful physical effects, including but not limited to: temporary and permanent threshold shifts (hearing loss), shifts in physical behavior state and geographic position, and shifts in elements of physical chemistry such as stress hormones (Erbe, 2002; Foote et al. 2004; Holt, 2008; Holt et al. 2008, etc.) However, the elevated anthropogenic noise level which ships create is also capable of creating shifts in the acoustic behavior of SRKW (Holt, 2008, etc.). Because these anthropogenic noises have the potential to mask killer whale calls, the whales must find ways to compensate acoustically for communication barriers which could be elevated at any time of day (Holt, 2008).

Acoustic compensation in Southern Residents could theoretically take many forms. The whales could alter their calls' frequency in order to make masking less likely. Because the noise pollution created by large vessels has greater amplitude at lower frequencies (Holt, 2008), the whales could use higher frequency calls more often or raise the frequency of their calls while the ships' noises are dominating the area. The whales could call more often when there are higher levels of ambient large vessel noise in the hope that repetition will ensure the message comes across. They could change their temporal patterns by waiting to call until the ships have passed or lowering the amount they try to communicate while masking is more likely to occur. The orcas could also increase the amplitude of their calls or generate them for longer periods of time during ship passage to better compete with the ambient noise levels. While all of these strategies could aid in increasing the success of communication while ship noise is present, none are without cost. Every option involves either the suppression of communication which is necessary for survival and reproduction or extra energy expenditure (NRC, 2003). In an already threatened environment and as part of an endangered population, any excess energy expenditure is a dangerous burden (NMFS, 2008).

Problem Statement

Large vessels produce the majority of background noise in Haro Strait, an area included in the critical habitat of killer whales (Veirs and Veirs, 2007, NMFS 2008). Anthropogenic noise pollution has been identified as one of the major threats to the Southern Resident population(NMFS, 2008). Acoustic behavior is critical to killer whales because it allows them to maintain strong group cohesion, a healthy gene pool through reproduction and to locate prey (Holt, 2008). Because background noise can mask killer whale calls, it is important to consider the repercussions of elevated background noise. The masking of echolocation clicks could result in larger energy expenditure to find food(Au et al., 2003). In order to continue necessary activities, the whales could be forced to compensate acoustically and it is important to consider the potential energy costs of the vocal compensation, such as increasing vocal input, which may increase stress levels (Oberweger and Goller, 2001).

In this study, I propose to determine the ways in which SRKW change their acoustic behavior depending on the proximity of large vessels (commercial ships) and the increased ambient noise levels, especially at lower frequencies, which those vessels create. I suspect that the Southern Residents will use a combination of acoustic behaviors to compensate for differences in anthropogenic noise pollution levels. In this way, the direct effect of large vessels on SRKW can be more carefully measured. I hope to be able to determine the most impacting components of large vessels' additions to existing conditions, whether it is the duration, noise levels, frequency or another parameter which is causing the SRKW the greatest threat. In this way, I hope to give recommendations as to future studies and if my results warrant, I would like to recommend policy changes which should be enacted in order to minimize the threat and energy expenditure currently being forced on this vulnerable population.

Methods

This study is designed to examine the effect of increased background noise due to large vessel traffic on SRKW. The study will take place in the central portion of the Salish Sea, where the Southern Residents spend the majority of their spring and summer(NMFS, 2008). The data will be collected aboard the Gato Verde, a 42' catamaran. The boat, when not powered by sail, is powered by two electric propulsion motors which ensure a minimum of background noise during data collection.

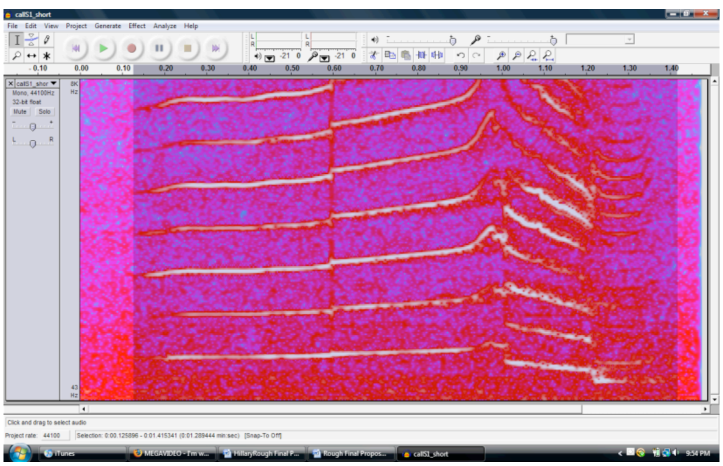
As soon as the whales are encountered, a Lab-core hydrophone array consisting of four hydrophones spaced approximately ten meters apart will be deployed from the Gato Verde's port stern pulpit. The cable is attached to a 4.5 kilogram weight to ensure that the array streams at a great enough depth to minimize flow noise. The Lab-core hydrophones were calibrated to an Inter-Ocean Systems Model 902 Acoustic Listening Calibration System. The acoustic data will be recorded by two solid state Sound Device 702 recorders and analyzed with a PC computer using the software program Audacity.

Ship absence and presence will be measured using data provided by an Automatic System Identification (AIS) antenna as well as by observations. The data provided by the antennae are condensed in a program called Ship Locator which was created by Dr. Val Veirs. These data include the geographic position of the Gato Verde, the geographic position of any large vessels within an adjustable range and the distance between vessels within that range and the Gato Verde. In addition, the closest point of approach of all large vessels to the Gato Verde will be recorded.

To provide necessary controls for the experiment, several parameters will be measured in addition to recording the acoustic data and the large vessels' positions. From the beginning of the audio recording, vessel counts will occur every five minutes, measuring and recording the number and type of vessels within one kilometer. The sea state will be recorded on the Beaufort scale to control for strong wind and wave interference with sound recordings. The number of whales and the pod they belong to will be recorded to control for differences in acoustic behaviors between the pods and to adjust the call rate per minute to the appropriate number of whales.

The whales' behavior will be monitored continuously. Their behavior state and the time of any change in behavior will also be recorded. The recorded behavior states will be those settled by NOAA in 2004. Resting is described as having a flank or nonlinear orientation, directional movement, close distance between whales and slow speed (NOAA, 2004). Traveling is determined to be directional movement at any speed and in any orientation (NOAA, 2004). Playing is classified into three groups, object play, social play and solitary play and can occur in any orientation, at any speed and with any distance between individuals (NOAA, 2004). Foraging is characterized by flank or nonlinear orientation, any spread distance or speed and chase and dive events (NOAA, 2004). The last category, milling, occurs when the animals move in repeatedly nonlinear orientations at any speed and in any direction (NOAA, 2004). The behavior data will be collected using personal digital assistants (PDA), using a behavior collection program designed by Dr. James Ha. The devices are not currently available but are expected to be used to gather data.

While analyzing the audio data, only the S1 call will be measured in order to maintain continuity and in order to ensure that all parameters can be directly compared. Each minute of audio data will be analyzed using the program Audacity and the S1 call rate and duration will be measured. In addition, the period of time between 0.35 and 0.40 seconds of each call will be analyzed to find the fundamental frequency and the ratio of power between the second and third harmonics. The interval between 0.35 and 0.40 seconds was chosen because it falls in the flattest part of the S1 call consistently, minimizing error in the average fundamental frequency. These measurements are demonstrated in Figure 1. The background noise for each minute of data will be calculated in dB RMS over a broadband range from approximately 100 Hz to 22000 Hz. For each minute of data, 0.5 seconds will be analyzed for background dB RMS using Mat Lab.



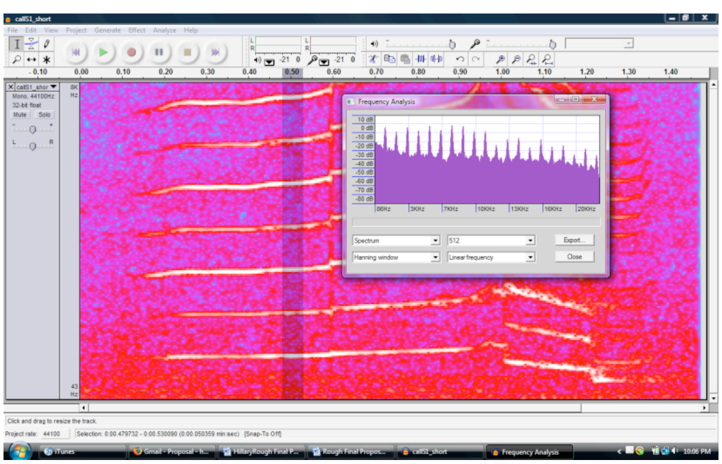


Figure 1: The top figure shows the spectrogram produced by a clear S1 call. The call is being measured for duration and the total length of the call is highlighted. The bottom figure shows the interval from 0.35-0.40 seconds, highlighted in purple on the left, which is used to measure fundamental frequency and the power ratio. The power ratio and fundamental frequency are measured from the small power spectrum shown on the right hand side of the bottom figure.

These methods will allow calculation of statistics necessary to analyze the data. The intent of this study is to discover whether or not the whales are significantly changing their acoustic behavior (call rate, duration, fundamental frequency and power ratio) in order to compensate for noise produced by large vessels. The data will be tested against a null hypothesis which states that there is no change in the acoustic behavior of SRKW when large vessels enter their zone of audibility. Should the sample size be large enough across several behaviors, a general linear model will be used. If the sample size is only sufficient in one behavior category, regressions will be used to test the data.

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