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Investigating the call selections of *Orcinus orca* as vocal compensation for sound masking by anthropogenic noise in the Salish Sea.

Introduction

From 1996 to 2001, Southern Resident killer whales experienced nearly a 20% decline in population, which warranted their place on the Endangered Species list in 2005 (*NMFS 2008*). Three major factors have been credited with this decline, one of them being anthropogenic underwater noise (*NMFS 2008*). These animals reside in the Salish Sea in the warmer months, living in long-term social groups of matrilineal hierarchy known as pods (*Ford 1987*). A group of pods that share social traditions that remain stable for generations, such as an acoustic repertoire, and also share a common ancestry make up a clan (*Yurk et al. 2001*). The Southern Residents' clan is comprised of J, K, and L pods (*Ford 1987*). The Southern Residents only eat fish, primarily salmonoids (*NMFS 2008*). The Salish Sea also hosts another population of residents, the Northern Residents, as well as a transient population and very rarely members of the Offshore eco-type.

Killer whales make and use sound for many purposes, including forging, navigation, and communication (*NMFS 2008*). Their vocalizations consist of clicks, whistles, and pulsed calls (*NMFS 2008*). Clicks are produced to echolocate, and are crucial in foraging and navigation (*Ford 1987*). Whistles are used predominantly in short-range communication, especially during socialization (*Thomsen et al. 2002*).

Besides clicks, the most commonly observed vocalizations are pulsed calls (*Ford*

1987). These calls are produced by rapid pulses that have tonal qualities and rich harmonics (*Ford 1987*). It is thought that these calls function predominantly in long-range communication, especially while foraging (*Thomsen et al. 2002*). These calls are repetitious and discrete enough to be stereotyped as part of a vocal repertoire that is pod specific (*Ford, 1987*). Young killer whales learn the repertoire of their pod vocally by selectively mimicking the calls of group members (*Yurk et al. 2001*).

The Southern Residents' vocal repertoire has been alpha-numerically catalogued, based on pitch and temporal patterns in the calls (*Ford 1987*). In this system, each of the Southern Residents' 26 calls was given a number arbitrarily as encountered that is preceded by an 'S' for Southern (*Ford 1987*). Similar catalogues have been compiled for this part of the world's killer whales, such as the Northern Residents (*Ford 1987*), the Southern Alaska Residents *(Yurk et al. 2001*), and bits of the region's transient population (*Ford, 1987*).

Although pulsed calls are distinct and seem deliberate, so far no one has been able to match a definite behavior to a specific call or completely understand the structure of their communication system. Information Theory has been applied to animal communication as a way to quantify information in vocalizations (*McCowan 1999*). Communication systems need to be diverse enough to have a substantial capacity of information, while being repetitive enough to avoid redundancy and to be used and learned practically (*McCowan 1999*). A way to analyze the relationship between diversity and repetition in a communication system is with the Zipf statistic, in which a slope of -1 signifies optimum efficiency in communication (*Zipf 1949*). Between 1979 and 1983, The Southern Residents produced a Zipf's slope of -1.468 (*Ford 1991*), while in 2007 their Zipf's slope was measured to be -1.241 (*Lehmann 2007*). This means that the Southern Residents' communication system is more repetitive than it is diverse, which could be a result of underwater noise pollution (*Lehmann 2007*). Perhaps this is a rough indication that some calls are better suited for an environment of increased anthropogenic noise than others.

The effect of concern from anthropogenic noise here is sound masking, which is considered one of three major threats responsible for the Southern Residents' population decline (*NMFS 2008*). In order for an anthropogenic noise to have masking effects, it must have a high enough received amplitude, fall within the audibility range of the animal, and come within the critical bandwidth.

It has been established that killer whale vocalizations can be shaped by an environment's acoustic properties to avoid such sound masking (*Foote et al. 2004*). In response to an increased level of background noise, killer whales can change the amplitude of their calls, demonstrating the Lombard effect (*Holt et al. 2009*). Another is with temporary shifts in frequency, which have been recorded in Antarctic killer whales as a result of seasonally dominant leopard seal (*Hydruga leptonyx*) calls (*Mossbridge and Thomas 1999*). It has also been shown that the Southern Residents' calls increase in duration once anthropogenic noise reaches a certain threshold (*Foote et al. 2004*).

Another method of coping with sound masking is repetition (*Holt 2008*). As the animal's ability to be heard decreases, it may have to repeat calls to convey information, thereby the amount of information transferred is decreased (*Lehmann 2007*). Although the objective of this study is not to discover the meaning of calls, a situation of minimal information and maximized repetition, such as an acoustically exhaustive scenario, could yield some insight into the meanings of some calls.

It is not only the noises produced by vessel traffic, but also simply the presence of boats that could potentially affect killer whale behavior (*Bain et al. 2006*). It has been shown in the Northern resident population that as the distance between the whales and the nearest boat shrinks, surface displays increase significantly (*Bain et al. 2006*). Additionally, the time spent in behavioral states of the Northern Residents has shown a change with boat traffic, resulting in less time spent foraging (*Bain et al. 2006*). Northern Residents also take on a more zigzag route when traveling in the presence of many boats, which means that they end up spending unnecessary energy on moving the extra distance (*Bain et al. 2006*).

In this study I will take the opportunity to explore the relationship that anthropogenic noise has with call type selection in this population, in an effort to further our understanding of human impacts on Southern Residents. Based on the research stated above, I would anticipate finding call diversity to be minimized in the presence of increased anthropogenic noise. The vocal repertoire of Southern Residents is culturally learned, therefore it has implied elasticity. Like other elements of killer whales' communication system, call type selection could potentially be shaped by anthropogenic noise. If this is the case, then over time it is possible that anthropogenic noise could have selective pressures on the evolution of killer whale dialects. Additionally, by looking closely at which calls are deliberately selected under adverse acoustic circumstances, it could be possible to gain insight into what information could be coded in specific calls, since this remains unknown.

Methods

To record the acoustic data I will deploy an array of four calibrated hydrophones made by Labcore from the port stern of the Gato Verde, a 42-foot catamaran. The sound gathered by the array will be recorded with a pair of Sound Devices 702 at a sampling rate of 44.1 kHz and 16 bit. Each hydrophone was calibrated with an Interocean Calibration Hydrophone before the study.

Although no one has been able to correlate vocalizations with specific behavior states, it is possible that they are related. Because of this possibility I will examine behavior states as well as number of boats in the area with relation to call rates as a means to investigate possible confounding factors in this study. The behavioral data will be recorded by hand from the deck of the Gato Verde as categorical information, employing the system described in NOAA's Southern Resident Killer Whale Behavior Workshop in 2004. The behavior state will be noted by the second when it changes. Boat counts will include all vessels within 1000m, and will result from surface scans every five minutes.

To analyze the sound files gathered I will open them minute by minute, as zoomed in spectograms in Audacity. I will ignore clicks and whistles, and focus only on identifying each individual call and the second at which they occur. To do this, I will listen to the file and record each second that I hear a call. Then I will go through the file and focus on each of these calls individually until I determine which call type they are. Mostly, this will be an auditory process, so I will have a little sound bite of each catalogued call spread out on my desktop for a quick reference. As a secondary reference, I will use a visual layout that I put together of spectograms from John Ford's 1987 call catalogue to identify call types. To get a background noise level, I will take one second from each minute-long file that does not contain any vocalizations, and analyze its RMS and dB in Matlab. Each call will then be matched with the results yielded by

Matlab from the minute in which the call occurred. With this I will run a nominal regression statistical test on my data. I will run the same test with boat numbers and call rates as well as behavior and call rate to analyze confounding factors.

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