Killer Whale (*Orcinus orca*) echolocation click rates during various behavioral states and ambient noise levels

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Literature Review

The largest member of the family Delphinidae, killer whales (*Orcinus orca*) are a fearsome predator who are highly social with complex family structures. In the waters off British Columbia and Washington Sates alone, two resident orca communities live, and many smaller transient orca pods frequent the waters (Bigg et al. 1987). Resident and transient ecotypes differ significantly, especially when it comes to foraging. Residents, made up of the Northern and Southern communities, are fish-eaters, using echolocation clicks frequently during foraging behavior, while transients are marine mammal-eaters who typically remain quiet and use stealth to catch their prey (Bigg et al. 1987).

In November of 2005, the Southern Resident killer whale (SRKW) population was listed as an endangered species under the Endangered Species Act of 1973. Because of this, extra precautions are being set in place in order to protect this species from declining further. In 2008, the National Marine Fisheries Service (NMFS) created a recovery plan to help promote the well-being of the SRKWs. Although it is difficult to know which threat or combination of threats cause the most harm, the whales' biggest dangers are inadequate nutrition, chronic stress (including the stress of vessel impacts and toxin buildup), and ultimately, a decline in an already small population (NMFS 2008).

Ford et al. (1998) determined resident killer whales' prey of choice is the Chinook salmon, likely due to its large size and high lipid content. However, research from the Recovery Plan (NMFS 2008) notes that salmon populations of all species are in decline, due to exploitation by humans, loss of habitats, and increased contaminants in the environment. With salmon, especially Chinook salmon, as the SRKW's main prey source, a decline in salmon abundance means less prey for the whales. Inadequate nutrition makes it harder for the whales to maintain homeostasis, which can lead to increased stress levels.

The stress of being a little hungry might not ordinarily affect the overall health of a whale, but there are many other additional stressors that factor into the SRKW's lives today. The presence of high amounts of vessels like ferries, whale-watching boats, large ships, and privately owned boats, not only add obstacles that the whales must avoid, but contribute a considerable amount of noise to the ambient sound levels. This has the potential to mask echolocation clicks and cause temporary or even permanent hearing loss (NMFS 2008). Veirs and Veirs (2005) found that short-term sound pressure levels (SPL dB re 1 μPa) in Haro Strait varied from ~95-130 dB, while the long-term average was ~115 dB. However, large ships moving through the area can temporarily raise the SPL ~20-25dB and even smaller boats can elevate short term SPL ~15-20dB—a significant difference from an SPL of ~95dB found without the presence of vessels (Veirs and Veirs 2005). Whales were found to increase their acoustic source levels by 1 dB for every dB that the ambient noise level was raised (Holt et al. 2009). If whales are forced to work harder to find an already diminished prey population, stress levels could elevate significantly (NMFS 2008). Possible examples for increased effort by the whales include increasing the amplitudes of vocalizations, varying their path due to vessel obstruction, and foraging longer due to echolocation click masking by increased background noise.

The SRKWs are divided into three subpods: J, K, and L (Bigg et al. 1987). Killer whales have a matrilineal society, and resident orcas usually stay in their mothers' pod for their entire lives. Orcas communicate using both echolocation and calls. Echolocation is thought to help the whales navigate and find prey while foraging; echolocation clicks are directional sounds with a high amplitude, broadband frequency structure, and short duration (Bigg et al. 1987 and Ford 1987). Au et al. (2004) found the majority of orca clicks have center frequencies from 45 kHz to 80 kHz with bandwidths between 35 and 50 kHz. In addition, Au et al. (2004) determined that orca echolocation clicks have a center frequency of 50 kHz and source levels ranging from 195 to 224 dB *re*: 1 μPa.

Whales receive an echo of the click after it bounces off an object, which is how they gain information about both prey and their surroundings. The amplitude of the echo depends on many factors, two of which are ambient noise level and target strength. Click rate depends on the length of time it takes for the click to bounce off a target and the echo to return to the whale. Upon receiving an echo, whales may then produce another click for that target. Killer whales' most sensitive hearing frequencies range from 18-42 kHz, and Erbe (2002) modeled that ambient noise levels can be loud enough to mask echolocation clicks a certain distance away from a target (Szymanski et al., 1999). When this occurs, whales will have to be closer to their target before they are able to hear the echo that returns to them. Because of this smaller distance between source and target, the click rate would increase because less time will pass before the echo returns to the whale.

Au et al. (2004) modeled foraging of echolocating odontocetes, estimating that resident killer whales would be able to detect a 0.78 m Chinook salmon from about 100 m away in relatively calm and quiet waters. Detection distance might be greater but researchers did not know if killer whales would approach a fish from farther than 100 m (Au et al. 2004). Although echolocation has been studied for many years, the exact way whales use it while foraging, or how they determine one species of fish from another is still being studied. Houser, D.S., Helweg, D.A., and Moore, P.W. (1999) characterized seven click types in Atlantic bottlenose dolphins, and found that usage of click types varied between individual dolphins and tasks. Different click types (i.e. differences in frequency, rate, and amplitude) are used by the animals to determine different information, but more studies need to be performed in order to determine which clicks will be used, and when.

SRKWs generally move as a pod, although sometimes smaller groups, typically made up of one mother and her offspring, will separate and forage alone. Most individual whales in a resident pod tend to have the same overall behavioral state (moving in the same direction and engaging in similar general activities) as the rest of the pod (Hoelzel 1993). It can be hard to classify behavior states because of the spread of a pod of whales and one of the biggest problems researchers face is defining behavioral states based on surface observations alone.

Problem Statement

As a symbol of the Pacific Northwest, the whales bring in revenue through tourism, and arguably more importantly, they play an important role in the ecosystem. However, the SRKWs are currently fighting an uphill battle for their species to survive. They face inadequate nutrition with decreasing prey availability, elevated stress levels due to increased vessel numbers, background noise, and containments in their habitat, and declining numbers as weaker individuals who cannot survive the shortage of food and elevated stress levels die out (NMFS 2008). The whales use echolocation in daily living, navigating, and detecting prey while foraging, though exactly how echolocation is applied in their natural environment has yet to be determined (Au et al. 2004). The SRKWs are specialized predators whose diet consists predominately of Chinook salmon, a species whose numbers have declined significantly (NMFS 2008). Click use is spread across all behavior states and knowing how echolocation applies to the different behavior states would help researchers protect critical habitats, especially those that are used extensively for foraging. This endangered species needs to see positive changes occurring if it is to survive.

There are two questions this experiment will explore. Both questions look at echolocation click rates used by SRKWs. Because of the increasing number of noise-producing vessels around the SRKWs, the first question will look at the relationship between click rate and background noise level. It will test the hypothesis that as background noise increases so will click rate because during loud conditions, an orca must be closer to its target in order to hear an echo. This results in a faster click rate. If there is a significant difference in click rate for different levels of background noise, it could help researchers determine which, if not both, of those factors affect the whales the most and allow managers to set guidelines for vessel numbers and/or noise levels allowed in the vicinity of the whales, and better protect the whales. As increased ambient noise levels cause whales to click more often, it could raise stress levels and this additional energetic cost could be enough stress to weaken whales to the point of sickness and even death. If researchers knew set values of increased click rate, they could use this information to better quantify the effects of ambient noise on the whales and guidelines could be set in place in order to project the whales.

Echolocation use in orcas is still being studied, and due to uncertainty surrounding click use, the second question will look at click rate compared to behavior states. It will test the hypothesis that echolocation clicks rates will be highest during foraging and travelling. There is no clear answer about when orcas use echolocation the most. It is thought that whales use it for navigation and prey detection, making travelling and foraging behavior states more likely to have a higher click rate. Behavior is difficult to categorize based on surface activity alone, and if click rates could be used to determine what the behavior states were in, researchers could have more insight into the whales' lifestyle. For example, if researchers had more knowledge about when whales were socializing, it might be possible to learn more about social acts, like playing and mating. In addition, more information about when and where whales forage could allow researchers to protect critical feeding grounds, allowing the whales to have more access to food. The more information about the whales' lifestyles researchers have, the better equipped they are to protect the whales.

Methods

I will begin my research by observing the whales in their natural habitat in the Salish Sea from mid-September until the end of October. Observations will be made from the deck of the *Gato Verde*, a 42' long sailing catamaran. I will be looking for the five character behavior states described in the 2004 National Oceanographic Atmospheric Administration (NOAA) SRKW workshop: resting, travelling, foraging, playing, and milling. Resting is defined by close contact (flank or nonlinear formation), slow but directional movement, high breathing synchronization and very few clicks or calls. Traveling is characterized by directional movement, with the whales swimming at any speed at relatively close distances to one another. Foraging behavior is extremely difficult to characterize—essentially any orientation, spread distance, direction, and speed can be seen. Barrett-Lennard et al. defined foraging behavior of residents by "erratic high-speed swimming, lunging, rapid circling and chasing fish at the surface" (Barrett-Lennard et al 2004, p. 555). The SRKWs often vocalize frequently while foraging, using clicks especially often. Because of this, researchers also tend to use acoustic data to determine when orcas are foraging. Playing behavior includes three categories: object play, social interactive play, and solitary play. There were no parameters for pod formation, speed, or directionality during play, but playing can include events such as kelping, touching, breaching, and percussive behaviors (like tail and pectoral fin slaps). Milling is characterized as a nonlinear orientation where the whales are spread any distance and moving at a slow or medium pace (NOAA 2004). More detailed descriptions of behavior can be found in the 2004 SRKW Behavior Workshop and the 2004 Barret-Lennard et al. paper (NOAA 2004, Barrett-Lennard et al. 2004).

The following data will be recorded: time, behavior state of the whales, whale orientation to the boat, pod size, and any notes about that time period. Data collection will begin at the same time as the hydrophone recording begins. The time, the date, and a GPS waypoint will be documented when the recording starts and finishes. Time will be recorded at five minute intervals, unless the behavior state or the orientation of the whales changes. The whales' orientation to the boat is compared to a clock face with 12 o'clock at the bow and the clock orientation continuing clockwise around the boat; see Figure 1 in the appendix for more details. The number of whales present at each clock orientation will be counted, and the calculated click rate will be divided by the number of whales present in order to control for varying group sizes. The overall behavior state is assumed to be the same in all smaller groups because activities tend to be the same for all members of the pod, even if the groups are spread out in different orientations to the boat (Hoelzel 1993). Pertinent Washington state laws and Be Whale Wise guidelines will be followed in order to protect the whales and reduce observer error.

A Labcore four hydrophone array and a single Cetacean Research Technology C54 XRS/266 (CRT) high-frequency hydrophone will be towed behind the *Gato Verde*. This research requires only the use of the CRT which has a flat response curve from 1 to 30 kHz. The CRT will be attached to the boat on a line 28.05 meters long and weighted to a depth of 1.85 meters. Continuous acoustic recordings will be done by two, two channel Sound Devices 702 recording units, however the CRT hydrophone uses only one channel, recording digitally at a sampling rate of 192 kHz and a 16 bit depth rate. The gain settings on the Sound Devices will be set at 37.3 and the CRT will be calibrated at this setting using a Interocean Systems Model 902 hydrophone calibration system.

Data analysis will be done on a Sony VAIO computer, model VGN-C290, using the programs Audacity 1.3 Beta (Unicode) and Raven Lite 1.0. Acoustic recordings will be split into minute long segments in order to analyze click rate per minute easily. Recordings will be listened to and looked at using both time series and spectrograms, and individual clicks will be counted by hand in order to calculate the click rate per minute most accurately. The recordings will initially be sorted by the orientation of the whales. Any minutes where whales are located between 10 o'clock and 2 o'clock will be discarded because echolocation clicks are directional and it would be extremely difficult to detect clicks and calculate an accurate click rate generated by whales in that location. Click rates will be compared to background noise levels, which will be measured one time from each minute long sample in Audacity using dB. Regression analysis will be used in order to determine the relationship between ambient noise levels and click rates. A one-way ANOVA will be used to determine if there are significant differences between behavior states and click rates.

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Appendix

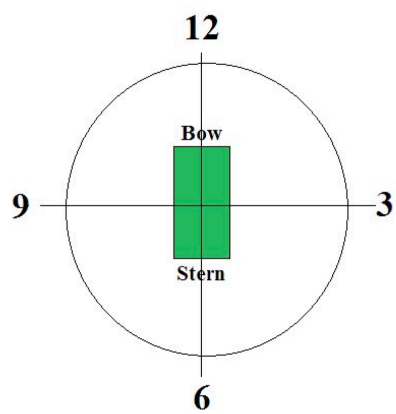

Figure 1. Clock orientation of whales in reference to the *Gato Verde*.