VARIATION IN THE S1 CALL TYPE OF SOUTHERN RESIDENT KILLER WHALES (SRKW), *Orcinus orca*

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Introduction

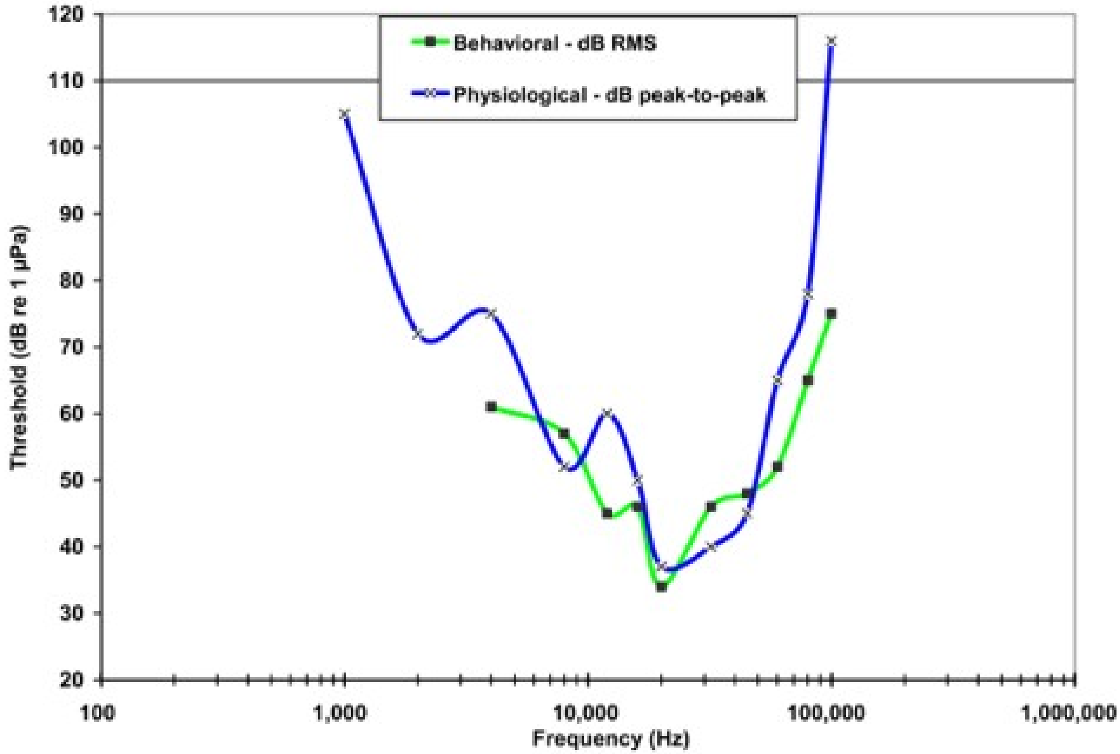
Human understanding of killer whales has changed dramatically over the last several hundred years. Some of our first perspectives come from Northeast Pacific Indian tribes who respected killer whales and viewed them as spiritual and cultural icons (NMFS 2008). In later years, they were seen as competition to fisherman and were often shot as a result (Bigg et al. 1987). Many whales were used for target practice by military forces (Baird 2006). The 1960's were a time when live capture became increasingly popular (Bigg et al. 1987). Killer whales in the waters surrounding Washington were captured, which amounted to an estimated seventy percent of Southern Residents (Olesiuk et al. 1990). Thankfully, we have moved to a place of trying to understand these complex creatures through researching various aspects of their lives. Despite being studied in recent years, little is known about these animals even today.

Southern Residents spend summers in the waters of the Salish Sea. This area is defined to include the Strait of Juan de Fuca, Puget Sound, the waters around the San Juan Islands, including Haro Strait, and continues up the Strait of Georgia (Washington State Board of Natural Resources). Their presence has attracted an ever growing number of whale watchers, both on land and at sea. Lime Kiln State Park, located on the west side of San Juan Island, is the most popular land based whale watching site and is the home to a network of hydrophones operated by OrcaSound (Washington State Parks and The Whale Museum). These hydrophones provide a continuous measurement of sound in some areas throughout the Salish Sea. Because of the extensive network of people who seek these animals, their location is frequently known (Bigg et al. 1987). Consequently, the Southern Residents are an ideal community to study .

Southern Residents are just one type of killer whale found in the Northeast Pacific. Transients and offshores are two other populations that occasionally come into the area (Ford et al.1999). Ford describes residents, transients, and offshores by diet, behavior, vocalizations, social structure and travel patterns. Offshores, the least studied of the populations, are not found along the coast and are rarely even seen (Center for Whale Research 2006, Ford et al. 1999). Transients are coastal, but travel long distances in smaller groups consisting of two to six individuals hunting marine mammals (Baird 2002, Ford and Ellis 1999). Lastly, residents are fish eating mammals who have very stable social structures (Ford et al. 1998). Residents are typically divided further into communities based on where they spend most of their time, specifically in the summer (Bigg et al. 1987). Northern Residents typically occupy inland waters of northern Vancouver Island, while Southern Residents can be found in what was previously described as the Salish Sea (Bigg et al. 1987, Ford et al. 1998). This includes inland waters off the southern end of Vancouver Island. Thus, some overlap in range exists. Few studies have explored where these killer whales spend their time during the winter; although, general ranges are known.

Identifying individual whales in the Southern Resident community has been made possible by extensive photo identification projects by Ken Balcomb and the Center for Whale Research. Uniqueness of the dorsal fin and right and left saddle patches, the area of the body just behind the dorsal fin, are the characteristics used to determine individuality (Ford et al. 1999, Baird 2002, Bigg et al. 1987) . In the case of residents, male and female individuals who share a common immediate female family member make up a matriline. Members of a matrilineal group rarely separate from each other for long periods of time (Baird 2000). Multiple matrilines spending at least half of their time together make up a pod (Baird 2000, 2002). Southern Residents are made up of three pods, J, K, and L (Bigg et al. 1987). As of 2008, the Center for Whale Research lists J-pod as having 25 members. While K and L pods have 19 and 42 members, respectively. This study will focus on J-pod because they are the most cohesive and most studied pod in the area.

Figure 1



Killer whales have a hearing range from 1 to 100 kHz (Symanski et al. 1999). In Figure 1above (Holt 2008), an average of two killer whales' behavioral and physiological audiograms are presented. A study by Foote and Nystuen (2008) looked at prey hearing ranges and mapped them onto that of a killer whale call. As seen in the audiograms in Figure 2, salmon, the prey of residents, are not sensitive to the killer whale call. Conversely, the two marine mammals are sensitive to the transient call. This suggests lack of vocalization by transients while foraging may be to prevent their prey from being able to locate them.

Figure 2

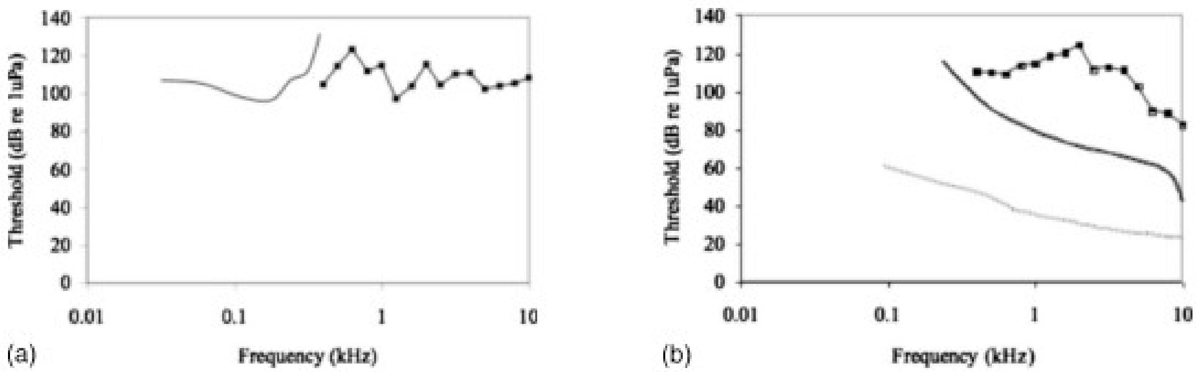


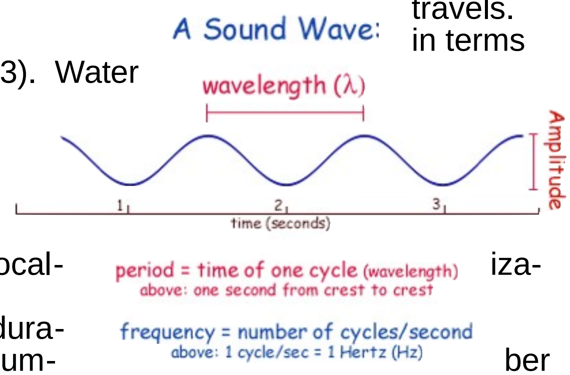
FIG. 3. (a) Audiogram of the Atlantic salmon *Salmo salar* (Hawkins and Johnstone, 1978) and one-third octave received levels (dB) up to 10 kHz of the most common resident call type (SI) from our sample, estimated to have been recorded <500 m from source based on surface observations, and on-axis based on the number of visible harmonics (see Miller, 2002). (b) Audiogram up to 10 kHz of the harbor porpoise *Phocoena phocoena* (solid line; Kastelein *et al.*, 2002), and harbor seal *Phoca vitulina* (dashed line; Kastak and Schusterman, 1998), and one third octave received levels (dB) of the most common transient call (WCT07) from our sample, estimated to have been recorded <500 m from source based on surface observations and on-axis based on the number of visible harmonics (see Miller, 2002).

Killer whales vocalize in three different ways. They emit short broadband clicks, discrete calls, and pure tonal whistles. Clicks are primarily used during echolocation. A click is sent from the whale outward; once it hits an object, it bounces off and is then received by the oil filled lower jaw of the animal (Richardson et al. 1995). Multiple clicks sent out over time allow the animal to determine position of an object, for example a fish, even when it may be out of visual range. Calls and whistles can not be clearly linked with a behavior although many attempts have been made (Bain 1986, Ford 1989, Morton et al. 1986). Much is unknown about the information being sent out or received from these two sounds. This study aims to better understand discrete calls.

In studies by Ford in 1999 and Wieland in 2007, J-pod contributed to a large percentage of the calls gathered. Those calls were then categorized into call types defined by Ford 1987. S1 composed about 25% of the calls made by J-pod in Wieland's study. S1 was also the most common J-pod call in Ford study and has been since the 1970's (Ford and Fisher 1983). For that reason, it is thought to be this pod's contact call. A contact call is used for identification and cohesion, especially when traveling, by a pod (Ford and Fisher 1983). Calls are most often categorized audibly. As noted in most studies, small sample size is frequently a problem. By using historical data as well as collecting new data, this study aims to overcome that obstacle. Fagen and Young (1978) report that, when studying a repertoire, an ideal number of samples would be $10R^2$, where R is the number of call types. Both Ford and Wieland have shown call usage has changed over time. Thus, the most recent study will be used to estimate sample size. Here R is 24 Southern Resident specific call types (Wieland 2007). A sample size of 5760 calls is then needed. A computer program will be used to select S1 calls from the sound files. It has been shown that humans are able to detect the different call types as well as computers, so this is not expected to skew the results (Deeke et al. 1999).

Communication is vital to many organisms ranging from birds to humans. It is suspected that killer whales use acoustic communication primarily. Although whales have great sight, visual communication is difficult in water conditions at night and in murky waters. Tactile communication is often used especially between a mother and calf, but can only be used at close distances. Other forms of communication including chemical signals, prove challenging in a marine environment. Now, consider how sound travels. Sound behaves as a wave and can be described in terms of an intensity, frequency and length (see Figure 3). Water is a better travel medium for sound, so sound travels faster than in air. Sound will travel for great distances under water with little loss in spreading given the right conditions (no masking, no corners, etc.). Thus, it is no surprise that killer whales are highly dependent on their vocalizations. (Bain, Erbe 2011, Richardson et al. 1995)

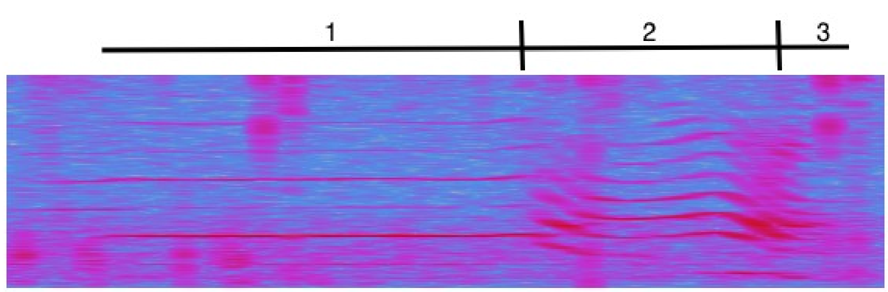
Figure 3



A single call type may vary by frequency, duration, or amplitude. Frequency is defined as the number of complete oscillations per second of energy. Duration is the length of the entire call. Amplitude is the height from a high to a low point or visa versa. Amplitude is often characteristic of how loud the sound is. A study on the similarity of dolphin whistles took into account several more points of reference. Their list included minimum and maximum frequencies, start and end frequencies, delta frequency, peak frequency, duration, number of inflection points, and number of harmonics (May-Collado and Wartzok 2008). These characteristics will be looked at in the analysis of the S1 calls. Because whistles of a bottlenose dolphin are not precisely comparable to a killer whale call, it is expected that some of the characteristics listed above will not be significant.

We can visualize sound files by using Audacity to make a spectrogram. A spectrogram is a visual plot of the frequency versus time of a sound using color to measure amplitude or energy. The more energy occurs in parts that are white to red, while less

Figure 4



energy is contained in areas that are blue. S1 calls seem to be made up of three parts (see Figure 4). Typically, the call starts at one frequency and ends at a different frequency, usually lower. Between these two parts is an area where there is an inflection point. Thus minimum and maximum frequency may be the same as start and end frequency. Peak frequency will also be redundant. S1 calls have one so that characteristic is constant across all S1 calls.

As discussed earlier, a few studies have suggested that calls have become louder and longer over time. By analyzing a large number of S1 calls, it can be determined if the calls are in fact variable. Sound files in which only a few whales are present and thus localization is possible will help determine if a subset of S1 calls, those made by a single individual, are significantly variable as well. Since S1 is a contact call, it is expected that it will not change significantly over time. Learning more about the calls of this endangered species may help protect them in the years to come.

Methods

A “typical” S1 call will be mapped onto the killer whale audiogram to determine what parts of the call are in the critical range. This will help us better analyze and interpret data. Analyzation tools will be calibrated and tested for accuracy.

a) For localization: Take pictures of trees from 3 angles. Determine distance between trees using ImageJ in each picture. Measure actual distances of trees. Compare results.
b) For categorization: Analyze how similar 3 shapes (oval, circle, parabola, square) are using ImageJ. Record 3 people saying a word three times. Use Audacity to make spectrograms. Analyze in Image J. Consider frequency, amplitude and duration. (For more comparison points consider start and end frequency, min and max frequency, delta frequency, peak frequency, duration, number of inflection points, and number of harmonics.) <- see May-Collado and Wartzok

In order to get a large sample size of categorized calls, archived data will be used. This data will be obtained for credible sources in the field (Holt, Wieland, OrcaSound, Jason Wood, etc.) We will consider data starting from 1980. If recording is raw and has not be scanned for calls, we will use an automated program to display the spectrogram of the sound file (Audacity 1.3.12 beta and some code). (Ideally, we would like to create our own program to identify the calls preliminarily. They will then be examined more closely to confirm they are S1 calls.) Files will be visually examined and listened to for calls. Clips will be made with a one second buffer on each side of the call. Higher quality spectrograms will be made from those clips. ImageJ will be used to compare these characteristics: start and end frequency, min and max frequency, delta frequency, peak frequency, duration, number of inflection points, and number of harmonics. R will be used to plot the characteristics over time. Statistical analysis will then be completed to see if any significant correlations can be found.

Data from comparing characteristics will be used to create clades (MacClade). Cladograms formed will be compared to existing cladograms for SRKW (DNA and photo-id).

A 42’ catamaran, the Gato Verde, will be used to collect data from April 2011 to June 2011 through out the Salish Sea. The vessel is a hybrid electric-biodiesel sail boat. This will allow for a quieter atmosphere when recording whales. Ambient noise will be lower than other vessels and should allow for more sounds to be detected by the hydrophone array. We will follow the Be Whale Wise guidelines at all times (Note distance increases from 100 yards to 200 yards during data collection period. The radio system will be used to determine the location of the SRKW. We will change course to meet them as needed.

A four hydrophone array (Labcore 40’s Array with peak frequency of 5 kHz) will be deployed from the stern when whale sightings are imminent. A weight attached and trying to maintain a straight course will yield the best possible recordings. Hydrophones will be calibrated ahead of time using the Inter Ocean Systems Model 902 Listening Calibration System. The sampling rate will be set to 44,000 samples/second and the gain setting will be adjusted accordingly. Recording will occur once equipment is in place and we are approaching the whales. Recording devices will assign a label to the audio file noting the day and order the recording was taken. Time as well as other factors not directed at this study will be recorded. Photos will be used to identify the whales present. We will be looking for J-pod whales since they are the only pod using S1 (Weiland). A laser range finder will allow the distance from the boat to a known whale to be found. These photos will later be used with Ismael to localize the whales, using known dorsal fin heights (need source). Recordings will be scanned for S1 calls in the same manner as for the archived data. An ideal situation would occur when S1 calls are found and it is possible to localize the whales to pinpoint sound to an individual whale. These will be analyzed to see if characteristics change between whales and for an individual whale. Otherwise localization is not needed and sound files will be treated the same as archived sound files.

If a automatic call detection program can be written, more files can be used in the analysis. This may also help start a database that can be used world wide in SQLShare.

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