Killer Whale Calf Vocal Development: Understanding Cultural Transmission Through Acoustics

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Introduction

Killer whale: endangered species

The southern resident Orcas of the North Pacific have recently been petitioned to be listed as threatened under the Endangered Species Act, with a decision pending until December of 2005. The probable causes of their population decline include: vessel noise and traffic; chemical pollutants, including but not limited to PCBs; and limited food resources. Another important part of the potential listing of the Southern Residents is whether they constitute a "distinct population segment" under the ESA. Much of this debate has discussed whether or not this group of killer whales are evolutionarily important to the species, Orcas *orcinus*. While genetic tests suggest they may be a subspecies, biological differences are not the only qualities that make the Southern Residents unique. Parts of this debate account for the cultural significance of Southern Residents and include controversy addressing whether vocalizations are genetic or learned. Southern Residents along with the Northern Residents and many other killer whale populations exhibit distinctive cultural patterns exclusive to their subpopulation. In my opinion, these distinct cultural archetypes are both irreplaceable and significant to the decision of whether and how to conserve the Southern Residents.

Motivation for investigating vocal development

In addition to behavioral cultural significance, such as the Southern Resident's annual greeting ceremony or the Northern Resident's rock rubbing on Robeson Bight, acoustic culture is equally important in the conservation dialogue. According to Ford (1990), calls are specific to different pods; for example, S3 is strongly associated with the presence of J-pod. Because some calls are only used by specific pods, one could argue that each pod has a unique acoustic culture; therefore qualifying as a DPS under the ESA. Making calls unique to their pod could be an inherited trait, also qualifying the Southern Residents as DPS. Whether calls are an inherited trait or learned over time or both, their acoustic culture is inimitable. For example, J-pod calves may be born to vocalize distinct calls due to biological predisposition, but may also be subject to a "sensitive period or plastic period" which may be crucial to vocalization development. This "sensitive" period would offer a period of time in which the calf learns the vocal repertoire of their pod; a vocal repertoire that may be unique to their pod and to their culture. Therefore, while the calf's ability to learn pod-specific calls may be biologically predispositioned, the "sensitive period" for learning those calls may be equally important. Due to the ambiguity of call development, studying Southern Resident calf vocal development may offer insight into the development of their vocal repertoire and acoustic cultural transmission process.

Cultural debate

Studies of killer whale vocalizations have increased over the past ten years confirming: that calls vary with-in pod and are discrete for specific whales (Miller and Bain 1999), that vocal traditions sustain themselves through matrilineal pods (Ford, 1990), and that the cultural survival of the southern residents is evolutionarily significant (Whitehead et al, 2004). However, while discussion about the cultural significance of the Southern Residents has gradually penetrated into dialogue about the conservation of this unique species, little has been resolved as to how or whether cultural transmission is actually occurring. According to Rendell and Whitehead (2001), the wide movements of cetaceans, the greater variability of the marine environment, and stable matrilineal social groups are potentially important factors in the evolution of cetacean culture. They go further in saying that patterns of behavioral variation in the wild may be due to the transmission process (Rendell and Whitehead 2001).

Several studies have been conducted that suggest cultural transmission is occurring not only through mimicry behavior, but also through the learning of distinct vocal patterns. For instance, Bain (1986), showed a captive killer whale from Iceland learning the vocal repertoire of its tank mate. Additionally, Ford (1991) provided evidence for "interpod mimicry in the wild" suggesting that vocal learning is both plausible and occurring. Boweles et al. (1988) conducted a similar study with a mother-calf pair in captivity. The calf was in the same tank as its mother, another female adult, and a young male. By 398 days, the calf's call type was most closely related to that of its mothers' by 90%. Due to the presence of other killer whales in the same holding tank and the calf's tendency to only make calls produced by its mother, this study suggests that the calf must have selectively distinguished and chosen its mother's calls. However, the reason mother/calf calls are similar is controversial: parties argue that either the similarity is inherited, that they are imitated or that they are selectively learned. (Rendell and Whitehead 2001). An earlier study by Deecke(1999) suggested that "vocal matching between members of different matrilines would suggest that vocal learning is not limited to transmission from mother to offspring, which has implications for models of "gene-culture coevolution." Deecke's "gene-culture coevolution" theory suggests that both inheritance of call type and the selective learning of call type are responsible for acoustic cultural transmission.

Vocalization development studies

Luna, or L98, an abandoned orca in Nookta Sound provides incredible insight into killer whale calf development. Now 6 years old, Luna has been heard mimicking sea lions and various boat engine sounds. He still makes calls similar to those of his family pod L, but over time he has developed some interesting vocal developments, vocalizing and mimicking the many sounds of his environment, supporting evidence for Deecke's "gene-culture co-evolution" theory. Luna's abnormal vocal repertoire may suggest that he missed the "sensitive" period by which to fully maturate his vocal range. Perhaps this "sensitive period" occurs at a young age and enables various range of vocal frequency and amplitude based on environmental acoustic stimuli. Consequently, adult vocal repertoires may vary throughout a life time based on acoustic surroundings during this specific "sensitive period". Similarly, Asian communities are more able to produce syllables particular to their language based on early experience with those sounds than English speakers who have lessoned ability to produce those same Asian syllables.

Analogous to killer whale studies, Enggist-Dueblin and Pfister(2001) investigated how cultural transmission may be an important factor affecting the vocal repertoires in ravens, Corcus corax. Understanding bird song development through selective learning or imitation processes is important to the argument of cultural transmission. Therefore, several stages of song development have been identified; subsong, plastic song, overproducing and lastly, crystallized song. This learning process is gradual and can take place over a period of weeks or months. Typically, an indistinct, jumbled "subsong" appears first which is transformed into a more structured "plastic song". The final stage in this process is the production of a stable repertoire of "crystallized" songs. The most thorough studies of song development were pioneered by ethologist W.H. Thorpe and

Peter Marler. Experiments were conducted which deprived birds of any opportunity to hear the normal bird song of their species. In most species studied, resulting songs only bore a slight resemblance to their normal song and were unrecognizable by others of the same species. Additionally, isolated birds allowed to hear their normal song during their “sensitive period” did develop normal song repertoires of their species. Therefore, killer whale calve calls may resemble fully maturated adult calls, though they may not completely represent the standard call structure until they have passed the “sensitive period”.

Fripp et el. (2004) studied bottlenose dolphin calves’ ability to model the signature whistles of their community members and discovered that dolphin calves may model community members with whom they associate rarely, such as the dominant female. Conversely, Smolker et al. (1997), suggested that dolphins in Shark Bay, Australia, learn specializations unique to their pod while swimming with the mother. This would further explain the tendency of the acoustic cultural transmission process in killer whales to occur dominantly within matrilines and more specifically through the mother.

Captivity studies by scientists at the Hubbs-Sea World Research Institute (HSWRI) provide direct insights into the vocal development of killer whale calves. They suggest that vocal behavior appears not to be genetically predetermined, rather calves learn during the course of development which calls to make and under what circumstances. Additionally, calves are most likely to develop calls like those of their mother. Vocal development studies at SeaWorld have determined that calves learn repertories of calls selectively from their mothers, though other killer whales may be present and vocalize more frequently. According to this research, a calf can vocalize within days of birth, but sound production is shaped with age. A calf's first vocalizations are 'screams' -- loud, high pitched calls that bear no resemblance to adult-type calls. At about two months, a calf produces its first pulsed calls with similarities to adult-type calls. From that point until puberty, age 16 for males and eight to ten years old for females, a calf's vocal repertoire continues to expand.

Subsequently, Tom McMillan (personal communication), Captain of the Stellar Sea whale watching vessel, believes his dog responds more, through barking, to killer whale calves than to adults because the calves have higher pitch calls. This anecdotal evidence suggests that killer whale calve calls are higher in frequency, due to either their smaller body size or to their emergent vocal repertoires or both. Boweles (1988) also suggested the gradual maturity and development of calf vocalization may begin with shorter pulsed calls occurring at a higher frequency. These “squeaks” suggest that killer whales vocal learning goes through a series of stages and may require discrimination, thus learning of adult vocal repertoires. With each pod’s repertoire being uniquely different, this implies the importance of language development and is potentially imperative in the vocal cultural transmission process.

With overwhelming evidence suggesting that calves will vocalize at a higher frequency, I expect that their calls will have a higher fundamental frequency than that of their adult members and that later in calf development and age, their fundamental frequencies will approach maturated fundamental frequencies similar to that of adults in their pods. Additionally, I expect that calf call duration will be shorter than the average call duration of adult calls, as well as still occurring at a higher frequency. If there is a “plastic” period in vocalization development and smaller body size produces higher calls, then when comparing calf calls to adult calls, both higher fundamental frequencies and shorter duration could imply early stages of vocal development and potentially a culturally learned language.

Objective of investigation

Observations of vocalizations in the wild are limited both by the constantly moving residents tendency to spend most of their time under water and the inability of technology to exactly locate which animal is making which sound in the midst of ambient noise and calls from other pod members. However, over the past few years, the Southern Residents have had several new additions to their clan, providing an opportunity to study and compare the process of vocalization development. Orca calves will be studied in the Haro Strait, Georgia Basin and Strait of Juan de Fuca areas during ten weeks of the Fall months, August through October, of 2005.

The significance of studying vocalizations and their active component in the cultural transmission may provide insight into the process of vocal learning. Do killer whale calves display a similar "babbling" process to that of humans and birds? Are there significant differences between the call frequency of calves and those of adults? These questions will be observed and measured with the focus being to compare the difference in frequency from the youngest members of the Southern Residents to those of their pod's adult call frequencies.

Methods

Materials for acoustic observation

I used a two hydrophone linear array called the "Ears" to record underwater vocalizations of Southern Resident killer whale calves. Two International Transducer Corporation hydrophones were separated using a 1.2 meter metal pole wrapped in pipe insulation that was suspended horizontally in the water. I deployed the array on the port side of a 42 foot catamaran about 10 feet below the keel of the boat, at a depth of approximately 14 _ feet. The pipe insulation wrapped around the metal pole was to control flow noise and to minimize vibrations between the hydrophones, pipe, and cables. To keep the hydrophones parallel to the water surface, we put equal weights on each end of the pipe. To achieve this balance, two 23 foot long ropes were tied to the pole near the hydrophone heads and then tied onto the stanchions of the boat, approximately 15 feet apart. This width helped keep the array from turning toward or away from the boat and insured a straight, parallel line with the boat's bottom, keeping consistent directionality in relationship to the boat's bow.

I or my crew mates connected the hydrophones to a high impedance instrumentation amplifier with both channels set at either x10 or x1 gain. The gain setting was adjusted to prevent background sound levels of anthropogenic noise from saturating the recording system. For example, gain settings were reduced when tankers were motoring in the vicinity or when whale watching or fishing vessels were motoring nearby.

To record killer whale calls gathered by the array, a Marantz PMD660 flash media recorder was connected to the amplifier. The Marantz was programmed to record 2-channel sound files every 60 seconds, and created an individual sound file for each minute, denoted on the recorder screen by a file number, i.e. 002, 005, 048, etc. The hydrophone on the left side of the array was connected to a channel labeled left on the amplifier and the hydrophone on the right side of the array was connected to a channel labeled right. This was done so that directionality could be heard while listening to sounds, both during and after the encounter. The Marantz could record up to 50 files, and therefore had a maximum recording time period of to 50 minutes. The Marantz gain setting was also adjusted according to both ambient and anthropogenic sound levels to prevent saturation of the sound file. The hydrophones had a frequency response range of 80 Hz – 22 kHz. The Marantz had a digitizing rate of 44100 and according to Nygist Sampling Theorem, the highest frequency detected was half the Marantz digitizing rate. The hydrophones, amplifier and recorder allowed sounds of 90 decibels on the lower end, when whales were at greater distances and 150 decibels when whales were close by, at dB re 1μPa.

Materials for visual observation

I kept a data sheet for each observation during the duration of each encounter with the whales. There were up to five observations made per day, hence data sheets included start and end times of the Marantz recorder, allowing observation files to be separated within each day. Date, observer, video and picture slots were provided at the top of each data sheet to indicate day of month, and persons observing, filming video and taking ID photographic shots, as responsibilities changed from observation to observation. The video camera used to film footage of encounters was a Canon 2P20 digital video camcorder and the two photographic cameras were an Olympus digital camera and a digital Canon Rebel (6 mega pixels). Spaces were also provided for bearing, time according to the Global Positioning System, ID of calf, pods present, Marantz file number and a notes section, to indicate animals present, behavior and or changes in gain settings. Relative bearings were taken in relationship to the bow of the boat. For example, the bow of the boat was 12 o'clock and the stern was 6 o'clock. The precision of these relative "o'clock" bearings was about _ hour, or 30 degrees.

In order to take notes and locate calves visually, one to two people assisted in calling out bearing of calf or mother/calf pair while another individual took ID photos. This allowed me to record data throughout the encounter and keep track of Marantz file numbers, while calf bearings and IDs were being called out by other crew members. Therefore, for every calf sighting I noted the Marantz start time, the bearing of calf in relative to the boat, the time, and the pods present. As the sighting encounter continued, identifications of mother/calf pairs were noted along with the identities of other whales present within 30 degrees of the calf. Whales within 30 degrees of the calf (within the same "1/2 hour" sector) may also be possible sources of the call that have a similar underwater bearing toward the calf.

Data analysis procedure

Ishmael, software that analyzes sound input from multiple hydrophones through a cross power spectrum, was going to be used to localize calf vocalizations. Because the sound arrived at the two hydrophones at different times, Ishmael was programmed to calculate the difference in arrival time based on the 2 channels recorded by the Marantz. Through calculating the intersection of two hyperbolic curves, it was able to determine a bearing, within a 30 degree range of the call with respect to left and right directional ambiguity. I was able to resolve the directional ambiguities by referring to my data sheet for the actual visual bearing of the whale. Whales were usually present on either the right or left side of the boat, rarely both, thus further constraining which underwater bearing was associated with the actual bearing to the sound source.

However, due to Ishmael's inability to accurately measure the arrival time difference on the original small "Ears," we created a larger linear array, the "elephant ears." We dismantled the "Ears" and placed the two hydrophones 10.5 meters apart, the distance between the bow and stern cleats on the port side of the boat. The hydrophones were now 13.5 feet below the water surface, 3.5 inches deeper than the original "ears." We calibrated the elephant ears by using an artificial sound source in known locations to verify the relationship between my visual bearing on calves and Ishmael's acoustic bearing on underwater sounds (both expressed in degrees). A pipe was hammered from the catamaran dingy at various locations and distances from the array and served as a test of the "elephant" ears ability to correctly localize sound. The correlation coefficient expresses the relationship and accuracy by which Ishmael was able to correctly locate pipe bangs to that of the sound's true bearing. The outlier expressed on the chart was probably due to the masking tanker sound during that sound file, and is thus not entirely representative of an error Ishmael may have made.

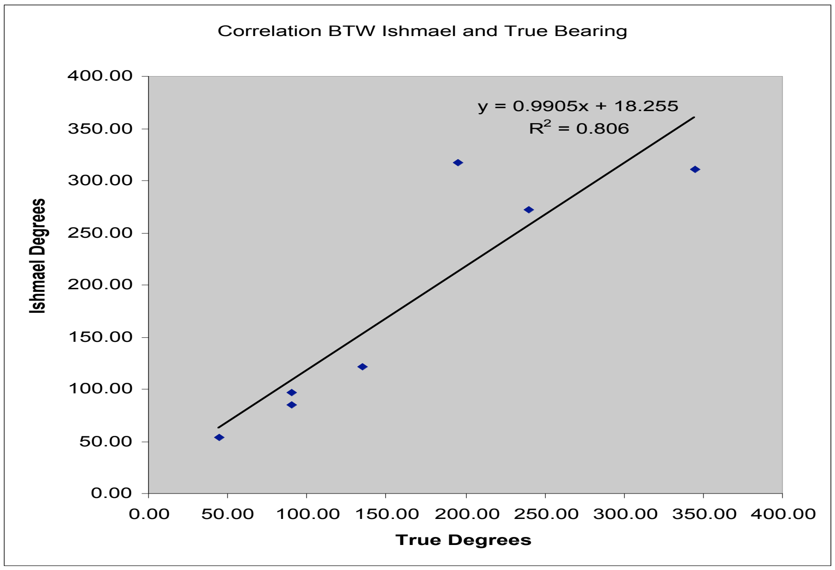


Figure 1

Ishmael was now able to more accurately measure the arrival time differences, thus providing an accurate bearing of whale calls. After the Marantz sound files were downloaded into computer files, they would then be uploaded into Ishmael and localized.

Hence, I had two types of sound files: those recorded with the small "ears" and those recorded with the "elephant" ears. Due to Ishmael's inability to localize bearing on the small ears, I only analyzed call frequency of calls made during the time of calf encounter and recorded temporal correlations from small "Ears" data. With the "squeaks" observed by Boweles (1988) and Tom McMillian's dog's enhanced reaction to young killer whales in mind, I searched for structural similarities and differences that may distinguish calf from adult vocals. Sound files were first listened to using Val's Call Analyzer, which displayed both the sonograms and frequencies of calls. Sound files were screened for repetition of discrete calls, i.e. S1 or S19.

Sounds files from the 6th of October provided the clearest calls without the masking of boat or water noise. During the third encounter with L-pod, L101, a 2002 calf, passed directly under our boat. S19 and S1's were the most common and measurable calls made during the duration of this encounter, which lasted approximately three minutes. S19 is a harmonic call with a strong tonal section ranging around 4.0-5.0 KHz. I measured the fundamental frequency of the tone (Figure 2).

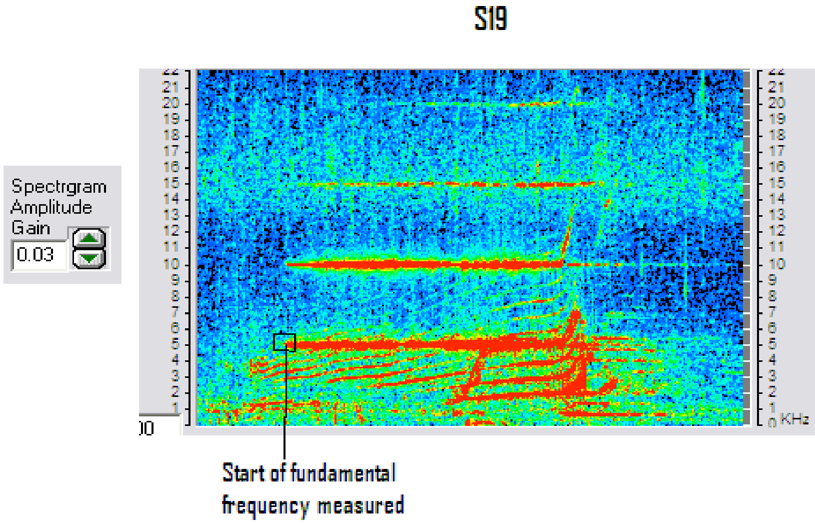


Figure 2: Sonogram of an S19 call, depicting where I measured the fundamental frequency of the tone.

There were ten positively identified S19 calls and one call resembling similar frequency structure but not used in data due to irresolvable ambiguity. The S19 calls were then compared to the start frequency average of adult S19 calls according to Ford (1990). The varying frequencies of my field data were plotted around the constant average provided by Ford.

Four S1 calls were also positively identified during the duration of the encounter. The S1 sound files were taken from a different time during the encounter and the calf identified was L103, a 2003 calf, passing by the stern of the boat, 50 meters away. The fundamental frequency was measured for duration. The length of the fundamental frequency was measured from start of sound to beginning of downward curve, measured in accordance with Ford's(1990) measure of duration for adult S1 calls. S1 call duration was then plotted and compared to Ford's average S1 call duration (Figure 3).

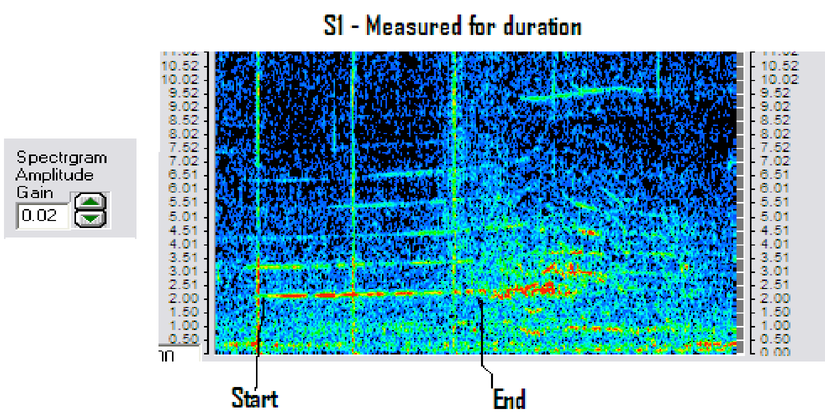


Figure 3: Sonogram of an S1 call, depicting how I measured the call duration. Black lines indicate start and end points of my measurement.

The beginning of the S1's fundamental frequencies were also measured and compared to Ford's average for the beginning of the fundamental, similarly to S19's fundamental (Figure 4).

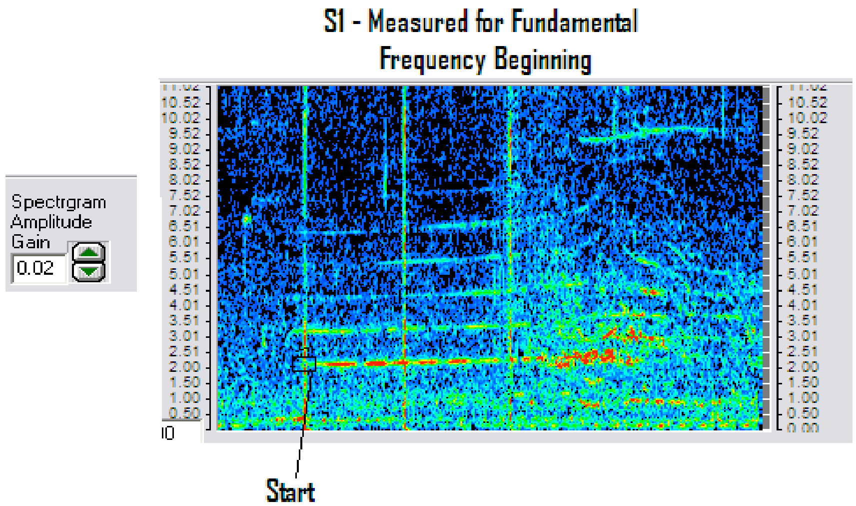


Figure4: Sonogram of an S1 call, depicting where I measured the fundamental frequency of the tone.

The remaining data collected from the small "ears" was masked by boat noise and anthropogenic noise to the extent that call frequency could not be heard or viewed on the OrcaSound Analyzer spectrogram. View sound file…

Ishmael was able to localize sounds from the "elephant ears" array, with the exception of all but two of the sound files collected during those encounters, were masked by boat noise to the extent that no frequency could be identified or measured. Therefore, while localization software would have provided a strong correlational spatial bearing, none of the data collected was serviceable.

Results

S19 calls recorded on the 6th of October did show frequency differences compared to the adult S19 calls provided by Ford(1990). S19 call average was less than one standard deviation higher than Ford's S19 call average, with three calls,3,6, and 8 being one standard deviation higher than Ford's call average, thus significantly higher in frequency. During the duration of this three minute encounter, L101 was passing under the boat, producing, in my opinion, very clear calls with an accurate ability to make a strong temporal correlation. (Figure 4).

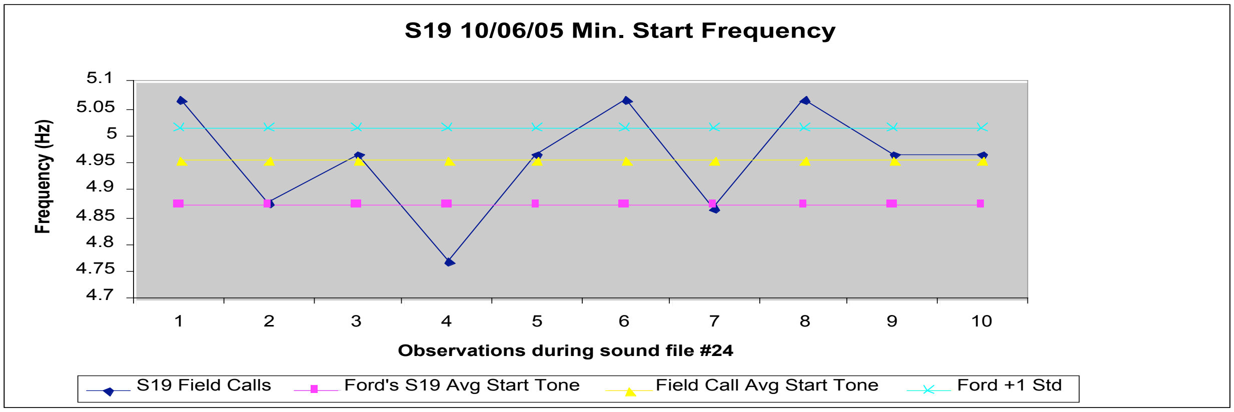


Figure 5: My S19 fundamental frequencies shown varying around Ford's(1990) S19 average fundamental frequency for the beginning of the tone. Yellow line depicts my S19's average in comparison to Ford's average, in red.

No significance difference was found between my S19 call frequency average and Ford's S19 call frequency average. However, overall, my S19 fundamental frequencies were higher than Ford's; which suggests that a smaller or younger animal may have been present; therefore supporting my hypothesis: the fundamental frequency of the calf's call would be higher than the call of an adult's fundamental frequency. A temporal correlation was made with a calf being present at the time of calls made, increasing probability that fundamental frequencies are higher due a calf being present. Confirming the reliability of the temporal correlation between calf present and calls made, L101 was directly under the boat, further increasing likelihood that a calf was the source of some of the calls made.

S1 fundamental frequencies were also higher than Ford's S1 average fundamental frequency (Figure 6).

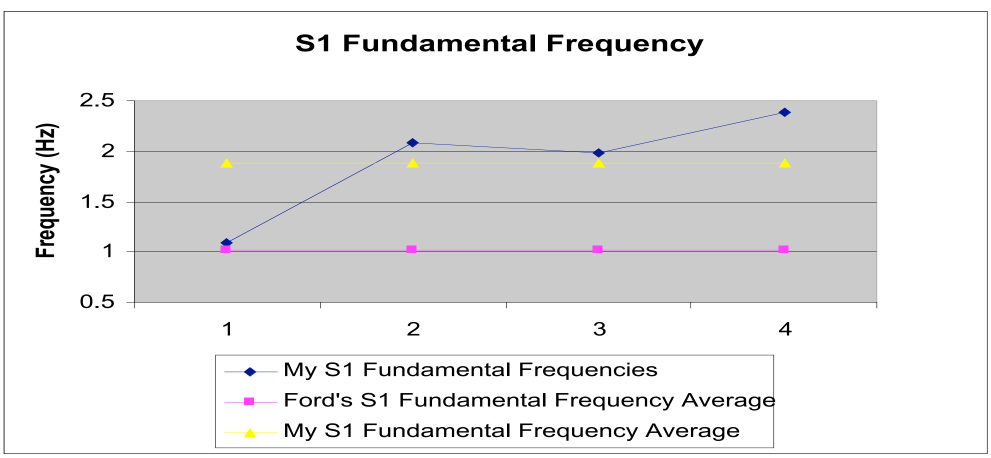


Figure 6: My measured S1 fundamental frequencies compared to Ford's average fundamental frequency for an adult S1 call.

These higher S1 fundamental frequencies also support my hypothesis that calf call frequencies would be higher. The temporal correlation was reliable, because L103 was passing the stern of the boat and only one other whale was present, as the whales were very spread out and foraging in the area.

S1's found in sound files during the L103 encounter were also measured for average call duration and compared to Ford's average call duration. My S1's were not significantly longer in duration than Ford's S1 call duration (Figure 7).

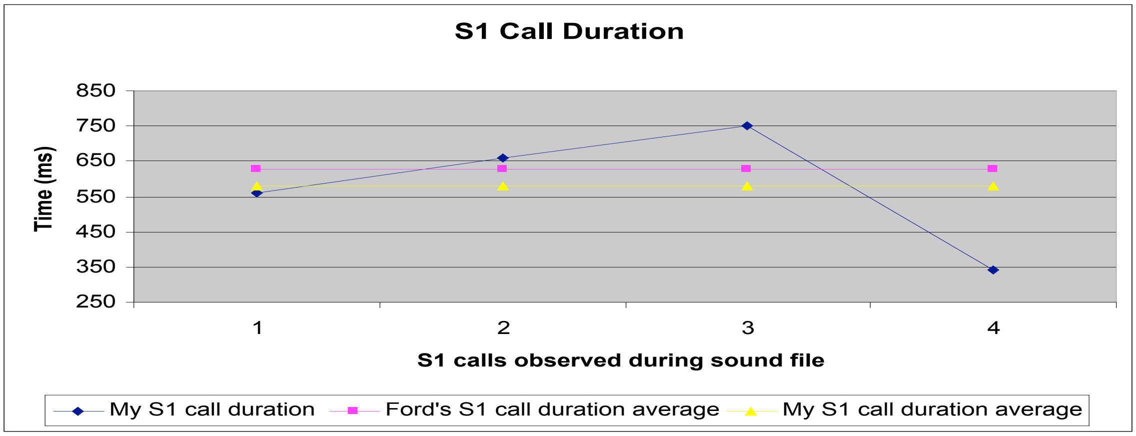
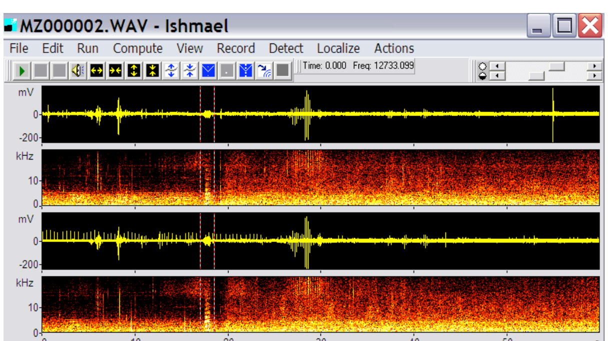


Figure 7: Call duration of my S1's compared to average call duration of Ford's S1's.

My S1s' call duration varied throughout the encounter, but did fall within Ford's possible range of calls for S1 (341-1464 ms). Only one of the S1 calls out of the four was lower than the range Ford had observed, at 170 milliseconds. The lower call duration could have possibly been a calf's version of the S1, but results show no consistency supporting this idea. Additionally, only four S1's were recorded, therefore, more S1 calls made during the encounter with L103 may have presented different results.

Lastly, the two measurable calls taken from the October 21st data while using the "elephant" ears were localized to look for a spatial bearing of calf sighted and call made. Calf present at time of encounter was not identified and call localized with Ishmael was not congruent with visual bearing of calf. This suggest the call measured during encounter was not a call vocalized by a calf, however, it did show that Ishmael was capable of taking bearings on Orca calls (Figure 9).



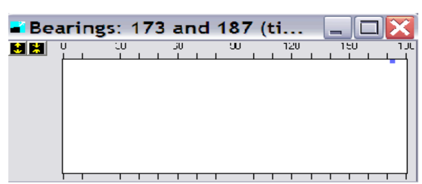


Figure 8 : Shows sonograms in Ishmael with the call heard, at 18 seconds, after Ishmael localized it. Shown with bearings box, giving bearings in degrees of 173 and 187.

Both spatial and temporal bearings would have been preferred in order to confidently assume that a calf was present at time and place from where the call source came. Masking noises from ships and water, however, stunted serviceable data from the "elephant" ears sound files.

Overall, my S19 and S1 fundamental frequencies were higher than Ford(1990)'s fundamental frequencies average for those calls. These data support my hypothesis that calf calls would have a higher fundamental frequency that those of adult calls' fundamental frequency. However, my S1s' durations were not significantly longer than Ford(1990)'s S1's duration for adult calls. This data does not support my hypothesis that call duration for calls produced by a calf would be shorter than calls made by adults. However, there were limited data available to analyze due to boat noise and ambient noise interference, therefore, sampling sizes was small. Contrary to the small sampling size, encounters with both calves were within 20 meters of the boat with only a few whales within the area, therefore, giving a strong reliable temporal correlation between calls made and calf present.

Discussion

Implications of results

Due to the temporal correlation between calls made and calf present, I think killer whale calves' vocalizations are higher in frequency than calls of adults. L101, a 2002 calf, was under the boat at the time the S19 calls recorded. While L101 is a three year old calf, he may still be developing his vocal repertoire. L101's calls may be mature in respect to structure, yet still a little "squeaky". This could be due to both a smaller body cavity by which to produce sound and or do to an immature vocal repertoire. Additionally, L103, a 2003 calf, was within 20 meters of the stern of the boat when the higher frequency S1s were recorded. This again suggest that L103's production of higher frequency calls may be due to a smaller body size or due to immature vocal development. Similarly to the S19, the S1 structure was developed and recognizable, just occurring at a higher fundamental frequency.

If L101 and L103 produced the higher frequency calls, it would suggest that vocal development is not a short process occurring after birth, but rather a long term progression of learning their pods' calls. This has implications for a very complex, social vocal repertoire that may take years to perfect and learn, similar to our own language development and acquisition. Language, among humans, has always been path by which to transmit ideas, emotions, knowledge and culture. Why not assume that killer whales, with an equally complex vocal repertoire, are also sharing ideas, emotions, knowledge and culture? Vocal development is instrumental for survival among many species and vital for the cultural transmission process. Are the many vocal repertoire's of the Southern Residents learned or inherited? I believe that they, like many other species (i.e. primates and birds) are born with the ability to vocalize, but are learning their pod specific calls through vocal transmission process. Illustrated by both L101 and L103's developing language acquisition. If killer whale vocals were only an inherited trait, then for the efficiency of survival, language development would be completed at a very young age. These data support otherwise. These data support evidence that language is both passed down among generations, demonstrating vocal development as a learned trait and potentially a vital cultural one.

When any trait is dependent on that animals' ability to pass it down, change or mutation is inevitably going to occur. So just as likely as it is that L101 and L103 were the source of the calls made during my recorded encounters, it is equally as likely that the vocal repertoire's of L-pod have changed since Ford(1990) recorded them. This suggests that environmental stimuli may have a significant impact on killer whale vocal development. It may illustrate that killer whale vocal repertoire's are subject to change, hence not only an inherited trait, but rather a learned one subject to change and biases. For example, if L103's or L101's calls are fully developed, they are clearly not the same as what Ford(1990) recorded 18 years ago. This could be due to having learned the calls differently, being taught differently or perhaps hearing themselves differently due to the increase in boat noise; all of which may contribute to a slightly changed vocal repertoire.

Whether L101 and L103 are still in the process of learning their pods' vocal repertoire or whether S19s and S1s are different than Ford(1990) measured them 18 years ago, both support the notion that language acquisition is subject to change, and not solely a biological function of their trachea. The Southern Residents' vocal repertoire is unique from all the other killer whales in the world. Their vocal traditions and development exemplify a unique process to cultural transmission process, the learning of language. Through further study of their language acquisition, we may be more able to understand their acoustic cultural transmission process. Further, through understanding their culture, both behavioral and acoustic, we may be able to better serve as advocates in the conservation of their distinctive population.

Errors and biases

The overwhelming amount of masking of calls through boat and flow noise significantly lessoned the amount of serviceable sound files I had collected. Had I been able to clearly hear and analyze more calls, the sampling size would have increased and the localization of more calls would have become more possible. The increase in sampling size may have potentially changed the outcome of my results as one encounter with two calves may not adequately represent the Southern Resident population.

Additionally, inter-relater biases occurred through the duration of data collection. As bearings were called out upon calf sighting, different crew members occasionally said different bearings for the same animal. While bearings were established in relationship to the boat before data collection began, perception of bearing depended greatly the spotter's position relative to the boat. Consequently, had localization been possible with the small "ears" data, this ambiguity may have been resolved. Had Ishmael been able to localize my small "ears" data, spatial correlations would have been possible and potentially strengthened the outcomes of my temporal correlations.

While higher fundamental frequencies of calls made during calf sightings were attributed to an immature vocal repertoire, the possibility of the calls changing since Ford(1990) measured them is both possible and plausible. As boat noise has increased over the past 20 years, the whales may be making modifications to their calls so that inter-pod communication is still achievable over long distances and when masking is occurring (Foote et al, 2004).

Lastly, the five week duration of the study was short and a longer study period would have allowed me to work on flow noise, boat noise and spotter biases, in addition to working out further technical difficulties with Ishmael. A longer study period would have also enabled more time with the whales, as following them from day to day did not consistently happen. The whales traveled large distances over 24 hour periods and despite help from the whale pager system, traveling to find them would take most of the day, hence lessoning available data collection periods. As the whales are unpredictable and cover a large territory within the Salish Sea, a longer study period would have accounted for appropriated more days of travel with more periods of data collection.

Future Studies

Additional field studies with the Southern Residents would expand over the course of several years and allow for continuous following through spring to winter months. With the help of Ishmael to find positive spatial bearings between calf and call, in addition to analyzing changes in the fundamental frequencies of calls, a more reliable confirmation that a specific calf was making a specific call could be made. A research permit would also assist in allowing for closer proximity to the calf, furthering the ability to make positive correlations between temporal and spatial bearings.

During the future study, more time would be spent on understanding the reliability of Ishmael and working with the program to narrow down technical ambiguities so that bearings given would be dependable. Additionally, less time would be spent configuring the "ears" to be proper distances from each other, since 10.5 meters distance between the two hydrophones appears to be appropriate.

Substantial amounts of trial and error testing were conducted during that duration of data collection and in the future study, more time for trial and error testing would be conducted prior to beginning data collection, and potentially lessoned due to the technical ambiguities corrected during this study.

Captivity studies do not represent all of the environmental stimuli represented in the natural environment, nor do they encompass all of the cultural idiosyncrasies represented by the entirety of the Southern Resident population. Therefore, while captivity studies would provide the best circumstances to conduct a longitudinal study of calf development, it would not incorporate the richness of their environment.

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