<u>Analysis of the ability of vessel noise to mask killer whale (*Orcinus orca*) communication</u>

empierson11@gmail.com - (215) 206-3435
Beam Reach Marine Science and Sustainability School
Research Proposal: Final Draft – September 29, 2006

Literature Review:

Killer whales (*Orcinus orca*) rely on series of underwater sounds for communication. These acoustics are broken down into three categories, clicks, whistles, and pulsed calls. Clicks are categorized as brief pulses of sound, typically used in succession as a method of echolocation (Au et al. 2004). They have no particular pattern, and vary in structure, duration, and intervals (Ford. 1989). In comparison, whistles and calls are used for communication. Thomsen et al. (2002) found that in northern resident killer whales, whistles are primarily used during social interactions and close-range communication whereas calls are for the most part used in long-range activities and when individual whales are widely dispersed. Whistles are identified as a continuous waveform; a tonal sound with little to no harmonics associated with it. Ford (1989) also determined that whistles occurred most frequently between frequencies 1.5 and 18 kHz. Calls are the most commonly produced vocalizations by killer whales. They are burst-pulsed calls that often contain varying pulse rates and patterns. This variance produces a large number of individually distinctive calls (Thomsen et al. 2002).

There are three essential parts to mammalian hearing, the outer ear that captures sound, the middle ear that filters and amplifies sounds, and the inner ear or cochlea that is a band-pass filter (Ketten. 1994). Killer whales receive sound through their lower jaw, soft tissue and bone surrounding the ear. They have the broadest acoustic range of any known mammal group (Ketten. 1994). Compared to humans, whale's inner ears are similar physically, the external ear is nonexistent, and the middle ear is drastically different (National Research Council. 2003). This is due to the evolutionary adaptive differences to an aquatic environment. Killer whales do have a small exterior ear hole, which is located a few centimeters behind the eye.

Vessel noise direction in relation to the perception organs of a killer whale can have an effect on the masking ability of the sound. Masking is defined as the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). It has been found that a noise made in the front of a whale has a greater masking potential than noises to the side of or behind a whale (Williams et al. 2002).

Audiograms are used to determine how well an individual can perceive varying sound frequencies. Szymanski et al. (1999) measured audiograms for two trained adult female killer whales using behavioral responses and auditory evoked potentials (AEPs). Before this study, there were no published experiments comparing the behavioral and AEP audiogram of the same individual. This comparison can help to determine the threshold, or the minimum amount of stimulus power needed to evoke a response greater than background noise, of killer whales (Elberling and Don. 1987).

Each killer whale responded to stimuli at frequencies between 1 and 100 kHz, with the most sensitive frequency being 20 kHz. From this, Szymanski et al. (1999) defined a sensitivity range at 10 dB from the most sensitive tone, making the range 18 to 42 kHz. The results from the behavioral audiogram and the audio brainstem response (ABR) audiogram were relatively consistent. The behavioral audiogram had a mean of 12 dB more sensitive at each frequency than the ABR audiogram, however, in the sensitivity range, it was only 5dB more sensitive (Szymanski et al. 1999). This information holds great significance in determining the masking effects of vessel created noise on the communication between killer whales. However, this data was collected from only two individuals and thus little is known about intraspecific sensitivity threshold variability (Richardson et al. 1995).

In 2004 there were an average of 22 boats following the whales on any given day during daylight hours. This number has increased over time while the population of whales has been decreasing over time (Foote et al. 2004). The southern resident population decreased by 17% between 1995 and 2001, making the population currently about 90 individuals (NRS. 2005). Soundwatch, a boater education program operating out of The Whale Museum in Friday Harbor Washington, spent 66% of their time on the water doing whale watch surveys. The distribution of vessels when whales were present from May to September 2005 was as follows: Canadian commercial whale watching boats 28%, private whale watching boats 24%, US commercial whale watching boats13%, Kayaks 18%, Private fishing vessels 7%, research vessels 7%, aircraft 5%, and shipping vessels 2% (Koski. 2005). These figures are significant for this experiment as it is a numerical representation of the types of boats that are present with the whales, and thus important in determining the different underwater sounds produced.

Both large and small boats create noises at frequencies that overlap with killer whale hearing and vocalization ranges (Galli et al. 2002). It has been determined that specific types of boats and engines make these noises within the hearing threshold of killer whales. However, what is not known is the affect it has on the ability of whales to communicate with one another, and at what distance it has the greatest effect.

Background noise can have a large impact on the ability of a species to sense and differentiate acoustical signals from another individual. In essence, background noise, specifically anthropogenic sound has the potential to interrupt communication within a species. Masking of meaningful sounds or damaged hearing could occur. Hearing loss could be a temporary threshold shift (TTS) or permanent threshold shift (PTS) (Griffin and Bain. 2006). In a study by Foote et al. (2004) it was found that all three southern resident killer whale pods increased the duration of their calls when there was significant boat traffic in the vicinity. It also states that initially there was no change in call length but as the number of boats increased, notably fivefold between 1990 and 2000, the call duration did increase. It was concluded from this that the whales adjusted to the increase in anthropogenic noise only after it had reached a threshold level. Other strategies to prevent acoustic communication from being masked by vessel noise once it has surpassed a critical level could be to change the frequency, amplitude, or number of repetitions of calls. Another study looking at potential effects of boats on killer whales using an acoustic impact model found that if whales were exposed to close to the critical level of noise over a prolonged period of time could result in permanent hearing loss (Erbe. 2002).

Boat traffic can also have an effect on the behavior of the killer whales. Northern resident killer whales were found to alter their behavior when there was a strong presence of boats. In females, swimming speed increased by 25% and the mean angle of deviation between surfacing increased by 29%. In males, they traveled in paths that were less direct than when not surrounded by boats (Williams et al. 2002). These changes in behavior could impact the stress level, energy level, and thus nutritional health and foraging tactics of the animal.

Any data on this subject will be helpful in planning the most appropriate course of action for recovery and conservation. This study may shed light on management approaches as well as the appropriateness of the 100m rule as it was not based on any scientific data. It also may highlight the need for more legally binding guidelines, and the development of new boat technologies that would mitigate what is determined as the most harmful underwater sounds. Since this population is endangered and down to around 90 individuals, protection is important for many reasons, including the intrinsic values of the species, genetic variation, as well as keeping the larger functioning ecosystem in balance.

The objectives of this experiment are to see if underwater sounds created by different vessels have the ability to mask vocalizations made by killer whales. This is very important in determining if anthropogenic noise has an effect on the ability of biologically significant killer whale calls to be heard and at what distances it has the greatest effect.

Materials and Methods:

Study Area:

This experiment is being conducted between August 21 and October 29, 2006. The research is being completed on the southern resident fish eating killer whales in the northern inland waters of Washington and British Columbia. The platform is a 42-foot bio diesel electric catamaran, the Gato Verde.

Observations:

Radar-

The radar used in this experiment will be JRC Radar 1500 MKII with a 16-mile range. When with the whales a picture of the radar screen will be taken every 10 minutes. When taking the picture, a box will be placed around the screen and camera to ensure the sun glare will not distort the image, the radar screen will be backlit, and the camera will remain at the same zoom level and shutter speed. The radar gain will be set accordingly and will always be on a 1.5-mile scale. The time, waypoint, direction of travel, and frame number will be recorded for.

Boat Observations-

Immediately after the photo of the radar is taken, a visual scan of the position, type, general motoring state, and direction in relation to the observer will be taken. Starting from the front of the boat, moving slowly clockwise 360 degrees data will be recorded on a coordinate plane data sheet (Appendix A). Each boat will be marked at its approximate location with its type and general motoring state, and direction recorded next to it in abbreviated form (Appendix B). The start and stop time of each scan will also be recorded.

Acoustics:

Recordings-

A four element linear towed hydrophone was used to continuously record acoustic activity when with the whales. The array was plugged into an analog to digital converter with a preset gain setting and recorded directly onto a computer hard drive using a

National Instruments Board card. The data was recorded as ten-minute files on four channels.

Call Localization-

Using acoustic data previously recorded, each file was visually and audibly analyzed. From this, calls were picked out to localize. The calls chosen were those that were visible on the spectrogram on all four channels as well and easily heard over ambient noise. Calls were not picked based on time, duration, type or structure. The only thing needed from these calls is source level, therefore it is not important that calls be picked based on scientifically significant attributes, only that they can be localized.

Using the acoustic analysis software Ishmael, the bearing and distance of each chosen call will be determined using hyperbolic localization techniques. From this information, the source level of each call will be determined, taking into consideration the speed of sound and transmission loss.

Calibration-

Channel number two was calibrated using the Navy calibrated blue box hydrophone as a tanker passed by. From this a calibration factor to determine the received pressure level in dB re 1 microPascal was found:

$$dB_{ch2} = 20*\log_{10}(RMS)+73.97$$

Boat and Ambient Noise Data-

Using the same previously recorded acoustic data from the hydrophone array; the received pressure level of the background noise will be determined. The data used will be what was recorded on the calibrated hydrophone. The RMS amplitude will be calculated for a minute sample using the sound analysis program Raven. This minute is determined as 30 seconds before and 30 seconds after each radar picture. From the RMS amplitude, the received pressure level will be calculated using the calibration correction factor.

<u>Modeling</u>:

Boats-

After all the necessary data has been collected, the pictures taken of the radar screen will be put into a photo editor program. A grid will be laid on top with the origin being the location of the Gato Verde. Using the grid the distance and location (X, Y coordinate) of each boat will be determined. Also, using the observational data, the location of each boat will be matched with the type, motoring state, and direction of travel.

The samples will then be statistically compared to the received pressure levels found at that time. Each variable will be tested against the noise level, including distribution, which will be binned.

Masking-

Using the source levels of orca calls found from localization the level of background noise and boat count, modeling will be used to see if masking will occur and at what distances. To get around the fact that all of the data collected is taken from a position on the boat and not at the exact location of the whales, it is assumed that our location is a whale trying to receive a call.

Assumptions in modeling:

- Accuracy of localization – To determine how accurate Ishmael is in determining the bearing and location of a call, a series of tests were done. The dinghy was deployed with a NOAA pipe and hammer. The distance and bearing were recorded while the pipe was being hit. The hits were recorded using the array and then analyzed in Ishmael. This was done for a number of different bearings and distances. The accuracy of Ishmael will be determined.

- Speed of sound – A Conductivity Temperature recorder is going to be deployed at various locations and depths. From the readings, the speed of sound underwater will be determined.
- Zone of Masking:
    - Integrate across critical bandwidth to find the point when the signal to noise ration (SNR) equals zero
    - Cylindrical spreading – $dB_{Source} = dB_{Recieved} + 10\log_{10}R$
    - Spherical spreading – $dB_{Sourse} = dB_{Recieved} + 20\log_{10}R$
    - Critical bandwidth is 1/6 of an octave. This was chosen in reference to what is known for other dolphin species, as there is limited research on the critical bandwidths of killer whales (Finneran. 2002).

If source levels cannot be found, or the error in Ishmael is too large, then source levels may be used from existing localization work done by Dr. Val Veirs.

Literature Cited:

Au, W.L., J.K.B. Ford, J.K. Horne, and K.A. Newman Allaman. 2004. Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling foraging for Chinook salmon (*Oncorhynchus tshawytscha*). Journal of The Acoustical Society of America 115 (2): 901-909.

Elberling C., and M. Don. 1987. Threshold characteristics of the human auditory brainstem response. Journal of The Acoustical Society of America. 81 (1): 115-121.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on acoustic impact model. Marine Mammal Science 18 (2): 394-418.

Foote, A.D., R.W. Osborne, and A. Rus Hoelzel. 2004. Whale-call response to masking boat noise. Nature 248: 910.

Ford, J.K.B. 1989. Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Canadian Journal of Zoology 67: 727-745.

Finneran, J.J., Schlundt, C.E., Carder, D.A., and Ridgway, S.H. 2002. Auditory filter shapes for the bottlenose dolphin (*Tursiops truncates)* and the white whale (*Delphinapterus leucas)* derived with notched noise. Journal of The Acoustic Society of America 112 (1): 322-328.

Galli, L., B. Hurlbutt, W. Jewett, W. Morton, S. Schuster, and Z. Van Hilsen. 2003. Boat source-level noise in Haro Strait: Relavance to orca whales. Report Prepared for Colorado College Orca Vocalization and Localization Project. pp 1-26.

Griffin, R.M. and Bain D.E. 2006. Sound Exposure of Southern Resident Killer Whales. Report prepared for Acoustic Monitoring Project.

Ketten, D. R. 1994. Functional Analyses of Whale Ears: Adaptations for Underwater Hearing. Oceans Engineering for Today's Technology and Tomorrow's Preservation.' Proceedings. OCEANS ’94. 1:264-270.

Koski, K.L., R. Osborne, and R. Tallmon. 2005. Soundwatch public outreach / boater education project. Report prepared for National Marine Fisheries Service, contract # AB133F-04-SE-0835. pp 1-25.

National Research Council of the National Academics. 2003. Ocean Noise and Marine Mammals. The National Academics Press, Washington DC.

NRS. 2005. Canadian Southern Resident killer whale National Recovery Strategy. http://www-comm.pac.dfompo.gc.ca/pages/consultations/marinemammals/ RKWrecoverystrategy_e.htm

Richardson, J.W., C.R. Greene Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, California.

Szymanski, M.D., D.E. Bain, K. Kiehl, S. Pennington, S. Wong, and K.R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioral audiograms. Journal of The Acoustic Society of America 106 (2): 1134-1141.

Thomsen, F., D. Franck, and J.K.B. Ford. 2002. On the communicative significance of whistles in wild killer whales (*Orcinus orca*). Naturwissenschaften 89: 404-407.

Williams, R., A.W. Trites, and D.E. Bain. 2002. Behavioral responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. The Zoological Society of London 256: 255-270.

Appendix A:

Appendix B:

Types of boats and codes:

United States Commercial	USC
Canadian Commercial	CAC
Small Private	SP
Large Private	LP
Sail	S
Tanker	T
Other	O

Motoring State:

Motors off	O
Idle	I
Slow	S
Medium	M
Fast	F

Direction of movement in relation to observer:

No-direction	•
North	⇑
East	⇒
South	⇓
West	⇐