The relationship between depth and Southern Resident Killer Whale (*Orcinus orca*) echolocation click production

Anne M. Harmann

Beam Reach Marine Science and Sustainability School

Friday Harbor Laboratories
University of Washington
620 University Road
Friday Harbor, WA 98250
annemharmann@yahoo.com

Introduction:

The killer whale (*Orcinus orca*) is the largest member of the Delphinidae family. Killer whales can be found in all of the world's oceans. Killer whales in the northeastern Pacific Ocean can be classified into three ecotypes that differ in morphology, genetics, behavior, foraging ecology, and acoustic repertoire (Baird 2000, Bigg et al. 1990). Resident killer whales feed on fish, primarily salmon, and travel in long-term stable groups (Ford et al. 1998). Transient killer whales feed on marine mammals and disperse from their maternal groups but continue to use their natal range (Baird 1994). Offshore killer whales eat fish, but little is known about their social organization or habitat use (Jones 2006). The southern resident killer whales (SRKW) have a population of approximately 87 organized into three matrilineal pods. Between the months of May and November, the SRKW can be found in the Salish Sea, a geographic region that includes Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia, (K. Balcomb pers. comm).

The acoustic environment of the ocean is very important to all killer whales, as they use vocalizations to communicate, navigate, and forage for prey (Richardson et al. 1995). The killer whale vocal repertoire consists of whistles, calls, and clicks (Ford, 1989). Whistles are highly variable tonal signals associated with social activity within groups. Calls are pulsed signals that function to coordinate group direction of movement and behavior state (Ford 1989, 1991). Clicks are short-duration, broadband signals that are used for echolocation by killer whales and other odontocetes (Au, 2004). Killer whales use echolocation clicks to navigate obstacles when traveling and to track prey when foraging (Ford 1989, Barrett-Lennard et al. 1996).

Cranford et al (1996) examined the morphological patterns of the nasal systems of 40 odontocete specimens, representing 19 species, and suggest that all odontocetes use homologous structures and mechanisms to produce the pulsed sounds associated with echolocation. The biosonar signal generator complex proposed by Cranford et al (1996) includes a small pair of fatty bursae embedded in a pair of connective tissue lips, a cartilaginous blade, a stout ligament, and an array of soft tissue air sacs. Echolocation clicks are produced when a an air stream is pushed dorsally through the nasal system and the air stream causes the phonic lips to open and slap back together creating sound (Cranford et al. 1996, Au 2004).

Echolocation clicks are projected from an odontocete's head in a highly directional beam (Au 2004). The intensity of the signal decreases as the angle away from the center of the signal increases (Richardson et al. 1995). Odontocetes produce click signals with frequencies as high as 100-130 kHz and with bandwidths between 30-55 kHz (Au 2004). Echolocation clicks produced by killer whales are between 80 and 120 μs in duration with bandwidths between 35 and 50 kHz. Most of the energy in the spectra is between 20 and 60 kHz (Au et al. 2004). The function and patterning of echolocation clicks have been studied in both resident and transient killer whale populations (Barrett-Lennard et al. 1996, Au et al. 2004, Deecke et al. 2004, Simon et al. 2007), though there is little or no information about echolocation and the SRKW in the literature.

The SRKW selectively forage on chinook salmon (*Oncorhynchus tshawytscha*) (Ford and Ellis 2006). Chinook salmon travel at an average depth of 25 to 64 m during the day, though they can dive to depths between 300 and 400 meters (Candy and Quinn 1999). The SRKW spend 60-70% of their time between the surface and a depth of 20 meters, though they regularly make dives of over 200 meters (Baird 1994, Baird et al. 1998, 2005). To capture chinook salmon, SRKW would likely have to dive and produce echolocation clicks at increasing depths.

I have not been able to find any studies in the literature that examine the effects of increasing depth and the associated increase in pressure on echolocation click production in killer whales.

I propose to examine the relationship between the depth at which a SRKW produces an echolocation click and the production of echolocation clicks. I believe that the increase in pressure associated with a whale's deep dive will compress the air in the air sacs that are part of the whale's nasal system. I hypothesize that the change in the volume of these air sacs will result in a change in the production of an echolocation click that will be evident when looking at the frequency spectrum. My null hypothesis is that there will be no difference between the frequency spectra of echolocation clicks produced at shallow depths and those produced at deep depths, with shallow defined as < 20 m and deep defined as > 20 m. Because I am not certain what role the air-filled sacs play in the production of echolocation clicks, I have two alternative hypotheses. My first alternative hypothesis is that the frequency spectra of echolocation clicks produced at shallow depths will display a lower average frequency than those produced at deep depths. My second alternative hypothesis is that the frequency spectra of echolocation clicks produced at shallow depths will display a higher average frequency than those produced at deep depths.

Methods:

Data Collection:

I will complete my research in the Salish Sea waters surrounding the San Juan Islands during the months of September and October, 2007. The 42' *Gato Verde* catamaran will be my research platform. Each day, we will try to locate SRKW by monitoring the pager network, (describe) and talking with our contacts in the whale watching and research communities. When we know the approximate location of the SRKW, we will go to their location and prepare to follow the whales while making bioacoustic recordings. We will begin by deploying the towed hydrophone array off the port hull. The hydrophone array consists of four hydrophones spaced 10 m apart. The hydrophone is connected to a four-channel amplifier that is connected to a laptop running the OVAL sound recording software. We will also deploy the high frequency hydrophone off the starboard hull. The high frequency hydrophone will be connected to the first channel of a solid-state recorder. A line from the amplifier will be connected to the second channel, so the high frequency hydrophone and the hydrophone array are synchronously recorded onto a single file.

My classmates will collect data during this towed deployment. After 45 minutes of recording with this arrangement, we will pull in the array and the high frequency hydrophone. If the whales are traveling directionally, I will ask the captain to locate the *Gato Verde* ahead and to the side of the whales' path of travel. If a direction of travel is not apparent, or if the whales are frequently changing their direction of travel, I will ask the captain to locate the *Gato Verde* in a position that is likely to continue to be as close to the whales as the Be Whale Wise guidelines allow.

When the *Gato Verde* is located between 100 and 400 meters from the whales, I will ask the captain to stop the motors so the boat is stationary or drifting with the currents. I will take a waypoint, note the weather and water conditions, and record my general impressions of the scene, including the number boats in the vicinity and the behaviors of the whales. I will re-deploy the hydrophone array and the high frequency hydrophone so that they are oriented vertically in the water column. The hydrophone array will be deployed from the port hull and the high frequency hydrophone will be deployed from the starboard hull. The first hydrophone in the array will be 10 m below the surface of the water with the other hydrophones at 20, 30, and 40 m. The hydrophone array will be attached to a 45-m rope with a 25-lb weight at its end.

For 10 min, I will continuously record with the hydrophone array, with the OVAL recording program dividing this period into 1-min recordings. I will make 15 sec recordings with the high frequency hydrophone only when I hear frequent echolocation clicks because the high sampling rate of the solid state recorder creates very large files that require a great deal of memory. I will note the time I start each high frequency recording to assist with synchronizing the array recordings with the high frequency recordings.

Following the ten-minute vertical deployment, we will pull up the hydrophones and rig them for towed deployment. I will again take a waypoint, note the weather and water conditions, and record my general impressions of the scene, again including the number boats in the vicinity and the behaviors of the whales. We will ask the captain to start the motors and we will continue following the whales while my classmates collect data. The above procedures will be repeated for the duration we are with the SRKW, unless there is an extended period of time during which the whales are not producing echolocation clicks.

Data Analysis:

I will begin my data analysis by determining if the clicks I recorded are on-axis or off-axis. Because echolocation clicks are highly directional, the acoustic intensity, temporal properties and frequency properties of the received signal change if the signal is not on or close to the acoustic axis of the sound beam (Madsen and Wahlberg 2007). Following Au et al.'s (2004) protocol for defining on-axis clicks, I will measure the amplitude of the received signal for a single click on each of the hydrophones in the array. Only clicks with received levels that are within 3 dB on all of the hydrophones will be considered on-axis and used for further analysis (see notes below).

I will attempt to localize the echolocation clicks with the program Ishmael 1.0 to determine if the echolocation click was produced by a whale shallow in the water column or deep in the water column. Because the SRKW spend 60 to 70% of their time between the surface and 20 m (Baird 1994, Baird et al. 1998, 2005), I will define shallow recordings as those from whales localized between zero and 20 m deep. Deep clicks will be those produced by whales deeper than 20 m.

Once my calls are categorized, I will look at the power spectra of an echolocation click, analyzing the signal from the hydrophone that displays the highest received level. I will also find the same click in the high frequency hydrophone data to analyze (see notes). I will be looking at changes in the power of the signal at different frequencies.

I will analyze my data using appropriate statistical tests (see notes)

Literature Cited:

Au, W.W.L. 2004. Echolocation signals of wild dolphins. *Acoustical Physics*, 50:454-462.

Au, W.W.L., Ford, J.K.B., Horne, J.K., Newman Allman, K.A. 2004. Echolocation signal of free-ranging killer whales (Orcinus orca) and modeling of foraging for Chinook salmon (Oncorhynchus tshawyscha). *Journal of the Acoustical Society of America*, 77:726-730.

Baird, R.W. 1994. Foraging behaviour and ecology of transient killer whales (*Orcinus orca*). Ph.D. thesis, Simon Fraser University, Vancouver, B.C.

Baird, 2000. Chapter 5 CETACEAN SOCIETIES Field Studies of Dolphins and Whales Mann, Janet; Connor, Richard C.; Tyack, Peter L.; Whitehead, Hal. University of Chicago Press

Baird, R.W., Dill, L.M., Hanson, M.B. 1998. Diving behavior of killer whales. Abstract of a paper presented at the Whale Watching Research Workshop, World Marine Mammal Conference, Monaco, January 1998

Baird, R.W., Hanson, M.B., Dill, L.M. 2005. Factors influencing the diving behaviour of fish-eating killer whales: sex differences and diel and interannual variation in diving rates. *Canadian Journal of Zoology*, 83:257-267.

Barrett-Lennard, L.G., Ford, J.K.B., Heise, K.A. 1996. The mixed blessing of echolocation: differences in sonar use by fish-eating and mamma-eating killer whales. *Animal Behavior*, 51:553-565.

Candy, J.R. and Quinn, T.P. 1999. Behavior of adult chinook salmon (Oncorhynchus tshawytscha) in British Columbia coastal waters determined from ultrasonic telemetry. *Canadian Journal of Zoology*, 77(7):1161-1169.

Cranford, T.W., Amundin, M., Norris, K.S. 1996. Functional morphology and homology in the odontocete nasal complex: implications for sound generation. *Journal of Morphology*, 228:223-285.

Deecke, V.B., Ford, J.K.B., Slater, J.B. 2005. The vocal behaviour of mammal-eating killer whales: communicating with costly calls. *Animal Behaviour*, 69:395-405.

Ford, J.K.B. 1989. Acoustic behaviour of resident killer whales (Orcinus orca) off Vancouver Island, British Columbia. *Canadian Journal of Zoology*: 69:1454-1483.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (Orcinus orca) in coastal waters of British Columbia. *Canadian Journal of Zoology*, 69:1451-1483.

Ford, J.K.B. and Ellis, G.M. 2006. Selective foraging by fish-eating killer whales Orcinus orca in British Columbia. *Marine Ecology Progress Series*, 316:185-199

Ford J.K.B., Ellis G.M., Barrett-Lennard L.G., Morton A.B., Palm R.S., and Balcomb K.C. 1998. Dietary specialization in two sympatric populations of killer whales (Orcinus orca) in coastal British Columbia and adjacent waters. *Canadian Journal of Zoology*, 76:1456-1471

Jones, I.M. 2006. A northeast pacific offshore killer whale (Orcinus orca) feeding on a pacific halibut (Hippoglossus stenolepis). *Marine Mammal Science* 22(1):198-200.

Olesiuk, P.F., Ellis, G.M., Ford, J.K.B., Balcomb, K.C. 1990. Social organization and genealogy of resident killer whales (Orcinus orca) in the coastal waters of British Columbia and Washington State. Report of the International Whaling Commission (Special Issue 12):383–405.

Richardson, W.J., Greene, C.R., Malme, C.I., Thomson, D.H. 1995. Marine Mammals and Noise. Academic Press. San Diego, CA.

Simon, M., Wahlberg, M., Miller, L.A. 2007. Echolocation clicks from killer whales (Orcinus orca) feeding on herring (clupea harengus). *Journal of the Acoustical Society of America*, 121(2):749-752.