Echolocation use during foraging by Southern Resident Killer Whales (Orcinus orca)

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Literature Review

The killer whale (*Orcinus orca*) is the largest member of the family Delphinidae. There are three ecotypes recognized in the Pacific Northwest: mammal-eating transients, fishing-eating residents, and offshores that are not well known but are presumed to eat fish and possibly mammals as well (NMFS 2008). There are currently no subspecies listed, but there is argument for subspecies to be recognized because of the diversity in behavior, ecology and vocalizations of the different populations around the world (NMFS 2008).

In November 2005, the Southern Resident killer whales (SRKW), which spend most of the summer months in the waters of Washington State and British Columbia, were listed as an endangered species under the Endangered Species Act of 1973. National Marine Fisheries Service (NMFS), which is legally bound by the ESA to draft a recovery plan, found it difficult to determine which threats affect the whales the most or if they are threatened by a combination. Three main threats are believed to be primarily responsible for the decline in the population. They are a decrease in quality and quantity of prey, pollution and contaminants, and vessel disturbance and noise, including military sonar (NMFS 2008). Another purpose of the Recovery Plan is to designate critical habitats. Critical habitats are areas that the named species inhabit that contain physical or biological features essential to conservation (NMFS 2004). There are three areas that were named critical habitat for the SRKW: the Summer Core Area in Haro Straight and waters around the San Juan Islands, Puget Sound, and the Straight of Juan de Fuca (NMFS 2004). Some areas were not included due to insufficient information.

Killer whales are social animals which live in groups called pods (Bigg et al. 1987). Each pod is made up of one or more maternal groups with a female and her offspring (Ford 1989). The animals in each pod seem to communicate by group specific calls. This is not completely understood as far as the function, but there are general types that can be categorized (Ford 1989). Ford (1989) describes the three different sound types of killer whales: whistles, pulsed calls, and clicks. Whistles are sounds based on tonal format with a continuous waveform that can have harmonics (Thomsen et al. 2001). Calls are pulsed sounds of abrupt and patterned shifts in pulsing rates that allows a wide variety of distinctive calls (Ford 1989). Clicks are brief pulses of sound used for echolocation and can vary in structure like duration and repetition rate (Ford 1989). Clicks are regularly used during foraging, most likely to navigate and locate prey (Ford 1989).

Killer whales are highly efficient predators that use both sight and echolocation clicks to locate prey before capturing them (Nichol and Shackleton 1996). Different prey choices among the different populations of killer whales around the world are accompanied by different foraging strategies and social structures that are learned traditions that have developed over many generations (Saulitis et al. 2000, and Ford et al. 1998). The Scandinavian herring-eating killer whales, for example, have high rates of sound production while foraging with intense clicks, calls and tail slaps with no periods of silence. This helps them herd the herring into tight schools close to the surface because herring have strong schooling behavior (Simon et al. 2007). The residents and transients of the Pacific Northeast are very specialized as well. Transients are practically silent when traveling and foraging because they rely on passive listening to detect prey. Their marine mammal prey have very good hearing and silence is required in order to keep from being detected (Ford et al. 1998). Residents however, are highly vocal when foraging and emit both social calls and echolocation click trains (Ford et al. 1998).

Echolocation clicks are forward producing sounds of high intensity and frequency. An echo bounces back to the animal so it can detect possible prey. The clicks are projected from the animal's head in a highly directional beam which helps provide good target localization ability and strong echo returns from the target (Richardson et al. 1995). The use of echolocation has been studied for the last three decades in order to understand the basics of echolocation (Au et al 2007). Au et al (2004) modeled the echolocation signals of Northern Resident killer whales and estimated the detection distance of a .78 m long Chinook to be at least 100 meters in calm conditions. The concept of how echolocation works is understood, but how well odontocetes can detect fish in their natural habitat is not (Au et al. 2007).

In order to study the use of echolocation when foraging it is important to know when the whales are foraging. During foraging, whale groups typically spread out into moderately sized subgroups over several square kilometers. The subgroups swim and dive independently but travel in the same general direction (Ford and Ellis 2006, Hoelzel 1993). Often signs of feeding are quite subtle, and it is often difficult to identify foraging. Sometimes nondirectional swimming and erratic swimming can be observed to indicate that prey is being pursued (Nichol and Shackelton 1993, Hoelzel 1993). The whales have been found to frequently share prey caught by an individual with two or more other whales (Ford and Ellis 2006). Adult male killer whales share their prey less frequently but were still found to bring their prey to the surface for consumption (Ford and Ellis 2006). The whales seem to benefit from the social behavior through facilitated food finding but not necessarily cooperative capture (Hoelzel 1993).

The SRKW feed entirely on fish. An overwhelming majority of those fish are salmonids, and a large portion of those are Chinook (Ford et al. 1998). Ford and Ellis (2006) found that 95% of documented kills were Chinook and 5% Coho. These two species represent less than 1% of the available salmonids in the area, which further shows how specialized the SRKW are (Ford and Ellis 2006). Scientists suspect that Chinook are selectively hunted because of their large size, high fat content, and location. They can be found in coastal waters throughout the year (Ford et al. 1998). Science is still trying to figure out what the fish "look" like with echolocation.

Echosounders were modeled after the echolocation of cetaceans in order to 'identify' target species underwater but under most circumstances it isn't possible to identify fish species definitively (Horne 2000). Horne (2000) explains that an Echosounder is an instrument that transmits and receives sound through the water column. The sonar transmits sound, and the sound travels through the water until it encounters a density difference. The echo will then bounce outward from the target back to the receiver (Horne 2000). There has been very little research done on how cetaceans use echolocation to identify their prey, and no one has determined if echolocation rates increase during foraging activities, which would be expected if they rely on echolocation for prey detection.

Problem Statement

The endangered Southern Resident killer whales are highly specialized hunters who prefer the least abundant salmonids in the area. They are very social animals who have strong bonds and stay with their families their entire lives. It is understood that echolocation is used to locate prey, but there is very little understanding of how effective their detection is (Au et al. 2007). There have been some modeling studies of echolocation detection range, but little research has been done to determine how well their echolocation works in their natural habitat (Au et al. 2007). Echosounders are a work in progress that could some day hope to demonstrate how well echolocation works. The click rates of killer whales during different activities are not known, but it is suspected that clicks are most important for foraging. Knowing the click rates during different behaviors could help people acoustically identify behaviors of the whales instead of relying on surface activity. It can be very difficult to determine a pod's behavior visually because the whales spend most of their time underwater, and most of the activities are difficult to see. Foraging is especially difficult to determine because this behavior is very subtle from the surface. Knowing the click rate for specific behavior states can help distinguish between behaviors with more certainty than just surface behaviors.

This experiment is designed to address two different questions. The first is to determine click rates during different behavior states and compare them to each other. If there is a significant difference between click rates in different behavior states, this will provide scientists with a better way to determine behavior states in further research. Furthermore, a higher click rate while foraging will show that echolocation clicks are important for finding food. The echosounder will also help show that fish are found in the areas where the whales are foraging. The second is to try to determine possible foraging "hot spots" for the whales. Between foraging locations and fish densities seen with the echosounder, possible fishing "hot spots" can be located. NMFS has declared critical habitats for the SRKW in the Recovery Plan (NMFS 2008). Any evidence provided to further prove foraging hot spots within the boundaries of the critical habitat will be useful information. Furthermore, if there are any hot spots outside of the critical habitat this information would be crucial for expanding the critical habitats.

Methods

There are five behaviors that I will be looking for and documenting. They are foraging, milling, resting, traveling and playing. I will be using the behavior definitions that were determined by NOAA in 2004. Foraging is flank or nonlinear orientation, non-directional, spread formations and occasional fast sporadic movements. Milling is nonlinear orientation that is nondirectional and slow paced. Resting is flank or nonlinear orientation that is directional with contact or tight distances between whales. They are also highly synchronous and slow moving. Traveling is any orientation that is directional and could be slow medium or fast paced. Finally, play can include any combination of orientation, direction and speed. It also includes events like object play, social interactive play, including touching, breaching and other percussive events, or solitary play. For more details refer to the Southern Resident Killer Whale Behavior Workshop (NOAA 2004).

The behavior of the whales will be recorded as well as the location using a GPS to record the latitude and longitude. Each time the whales change behavior, the time and location will be recorded for later analysis. Recording their behavior will start at the same time the hydrophone recording starts. At the start of the recording the date, time, and initial behavior will be documented. I will be towing a Labcore hydrophone array consisting of four hydrophones that are each approximately ten meters apart. I will record continuously with two, two channel Sound Devices 702 digitally at 44.1 kHz. The array will be calibrated with a calibrated Interocean Systems Model 902 hydrophone with the gains of the Sound Device set at 36.0.

When the whales are present I will record with the assumption that the whole pod is present and not just subgroups visible. I am assuming this because when a pod divides into subgroups, the general activities and direction of travel are still the same for all individuals within the pod, even though the distance between some individuals can be several kilometers (Hoelzel 1993). The behavior that is observed by the majority of the pod is the behavior that will be recorded.

The echosounder will be used when the whales are not present. The same along-shore transect taken 1/4 to 1/8 nautical miles off the shoreline that was done last year will be repeated. Areas of high biomass from this year's data and last year's data will be used to determine potential fish "hot spots." Horne (pilot study) found that the echosounder efficiently characterizes fish densities throughout the water column. The only problem is that it is not currently possible to identify species of fish present (Horne 2000). So the potential "hot spots" will be determined in areas where high biomass is observed with the echosounder along with any information gathered from local sports fishermen and the salmon database from Pacific Salmon Commission and the Washington Department of Fish and Wildlife.

In order to analyze the data the click rate for each behavior will be determined. The click rates when the whales are in the potential "hot spots" and out of these "hot spots" will also be calculated. The rates will then be compared across behaviors and location. My hypothesis is that the click rates will be significantly higher when the whales are foraging compared to the other behaviors. Also, I think the whales will be foraging most frequently in potential "hot spots" which will mean that the click rates should be higher in "hot spots" when compared to other areas. The statistical test that will determine if my findings are significant will be the ANOVA test.

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