Echolocation and strategy used by Southern Resident Killer Whales (*Orcinus orca*) during foraging.

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Abstract

Orcinus orca is one the most studied marine mammals in the world. The different from each population is based on prey, size, social and foraging behavior. Most of these studies come from research on Northwestern waters from United States and Canada. Here we document the observations from late September to late October of 2005 around the US waters from the Salish Sea and the Strait of Juan de Fuca. Observations and recording about the use of echolocation clicks during foraging and traveling and the visual surface position of the whales during the foraging activity were taken to understand the pattern that the southern residents killer use when foraging. Analyses from October 4 and October 21 showed that during a ten minutes period the echolocation clicks demonstrated that during foraging the clicks are 27 times more than the echolocation clicks done during traveling. A pattern of increasing and decreasing gradual amplitude of the clicks was noted during foraging. The residents were observed to organize in three main groups usually spread out when doing foraging. Also more in depth research on the behavior of the echolocation clicks is needed along with observation of the underwater foraging behavior to determine the pattern that the killer whales use effectively when foraging, here we demonstrate that the use of echolocation clicks is most used on foraging and that the organization is less complex than other fish-eating populations around the world.

Introduction

Killer Whales around the world differ in prey, size, behavior, social organization and others that make them easy to identify. Some populations specialize on fish foraging while others specialize on marine mammals. But in general orcas are the top predator, with an extreme range in food items reported taken, including squid, octopus, bony and cartilaginous fish, including sharks, sea turtles, seabirds, sea and river otters, dugongs, pinnipeds, and cetaceans, as well as occasional reports of terrestrial mammals such as deer, moose, and pigs (Heyning and Dahlheim 1988; Guinet 1992; Jefferson *et al.* 1991 and Baird 2000).

Research on the acoustics of Killer Whale (*Orcinus orca*) echolocation and foraging have been rare during the years when these animals have been studied in the wild in the waters of Washington and British Columbia. Not until the late 1990's did research begin to produce results about this unknown chapter on the orcas. The first paper was published in 1996 by Barret-Lennard where he established that there is a different use of the sonar between the fish-eating and mammal-eating killer whales. Orcas that forage on fish rely more on echolocation and calls than the ones that prey on marine mammals. Recent experiments that focus on echolocation (Au *et al.*, 2003) concluded that the foraging behavior of *Orcinus* pursuing salmon is very different to the foraging behavior of killer whales feeding on herring on Norway (Nottestad *et al.,* 2002 and Au *et al.,* 2003). The main reason for this will be the organization and the way of echolocation clicks are used. Herring can pick up the echolocation clicks from the whales (Nottestad *et al.,* 2002) while the salmon cannot. Even the strategies used to forage and the use of echolocation and calls are different. Barret-Lennard *et al.* (1996a) suggested that all of these differences arise from the differences in prey taken, since marine mammals can hear echolocation clicks and potentially evade capture while the fish generally cannot. Residents appear to locate prey underwater using a combination of echolocation and passive listening, and both vision and echolocation are probably important during prey capture (Barret-Lennard *et al.,* 1996a). This was observed from hydrophones and underwater video recordings during the period of study when both types of populations of whales were in the high of the feeding season.

The foraging strategy and which aspect the echolocation clicks used by the Southern Residents Killer Whales are ones of the unknown chapters of these animals. Since mammal-eating orcas have been known to hunt in pods, the fish-eating orcas are not been identified if they capture their prey like a pod or each member forage separately (Baird, pers. comm.). Southern Residents are known to travel and perform different social behaviors like a pod or even as a super pod (Baird, pers. comm.), but no pattern of foraging have been established to see if these pods hunt in groups or separately. Because the Chinook salmon (*Oncorhynchus tshawytscha*) is the preferred prey in the Northwest Pacific area cannot detect the echolocation clicks of the whales (Au *et al.,* 2003), it is very likely that is easier to hunt them. Unlike mammal-eating killer whales who do not use too much echolocation to capture their prey, the fish-eating killer whales can perform this clicks in very good standard without been detected makes the foraging be more easier, but that strategy haven't been established until this research was performed. To investigate this strategy, observations about the position of the whales, when foraging is identified, observations from the research vessel will be made and be noted with time for be analyzed. Such analysis will reveal if the orcas have a certain pattern as a group or individually forage.

Also the questions on which way they use the echolocation have been a topic of discussion during the 1990's. Some scientists have proposed that they relay their clicks for navigation; other said that is for foraging only. This study will determine the amount of clicks when foraging and traveling is performed to find a pattern and/or to reveal on which behavior is more likely for the whales to use their echolocation clicks.

This study will be done in the waters surrounding the San Juan Islands, Strait of Juan de Fuca and the Admiralty Inlet area during the last week of September to the end of October (Figure 1). A total of 5 weeks at sea will be the period of observations to answers the questions about foraging strategy and echolocation clicks usage among these cetaceans.

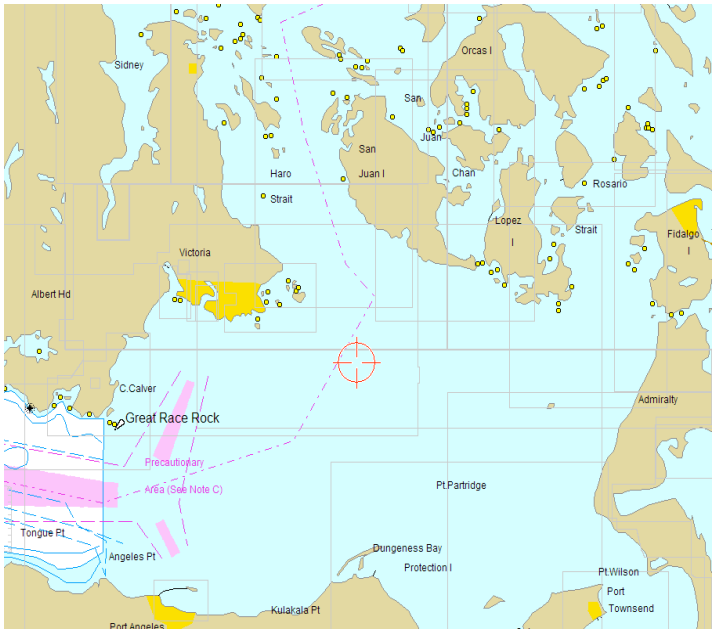

Figure 1. Area where observations were taken from late September to late October.

Materials and Methods

I used the following procedure to get data regarding echolocations and to identify foraging strategy. A person recorded the echolocation that the whales produce during the event through a set of two hydrophones deployed in parallel position to one side of the boat (either port or starboard). The sound was recorded on a Marantz® Recorder Model PMD660 creating 50 minute files that later were downloaded on a computer. A spotter collected data on foraging behavior and wrote down the start and end of each minute when the group of orcas were seen traveling and exhibited foraging behavior.

For determine the foraging strategy, a person observed, from the highest point on the vessel, the position of the whales on the surface of the water. They recorded that position on a specific data sheet made for pointing the positions by each minute during the entire observation of the whales. The data will be analyzed to determine a pattern of the whales during foraging, especially their strategy. Video and photo footage will be used to record their behavior on their surface before, during and after to be compared with the position data sheets. In case of night foraging, night vision equipment will be used to confirm their behavior on the surface. A specific person should carry this observation when it happens.

The characteristics that lead me to identify behaviors as foraging behaviors were rapid changes in direction and speed, tail-lobbing, circling many times around on a same spot and when sea birds where around the whales and getting in the spot where the whales were on a certain moment. This helped me to identified more closely the foraging behavior because prey capture can be observed simultaneous with social interactions not related to foraging, suggesting that foraging and social behavior can occur simultaneously.

The characteristics that I used to identify traveling were the ones described by Barret-Lennard *et al.,* 1996a that describe the killer whales swimming in one or several groups on a consistent course at speeds exceeding 6 km/h. Individuals swam within a few body lengths of their neighbors in each group.

I analyzed the sound recordings with acoustic software called Audacity for Macintosh Apple™ Operating System. The recordings were analyzed for later pick up the best recordings, one for foraging and one for traveling.

To determine the foraging strategy, I observed, the position of the whales on the surface from the highest point on the vessel. I recorded that position on a special data sheet in the form of a bull's eye target circles designed to document the relative positions of the orcas and the observer minute by minute during the entire observation of the whales. The distance from each circle was 50 meters and there were a total of circles up to 450 meters.

The data were analyzed to determine a pattern of the whales during foraging, especially their strategy. Video and photo footage also recorded behavior on the surface and was compared with the position data sheets. In case of night foraging, night vision equipment was used to confirm their behavior on the surface.

Additionally, a fish net, with a fine mesh, was available in case that fish scales and/or remains were sighted in the surface waters after a foraging event. This evidence may later help determine what species was hunted.

Results

I compiled records from the area of study from October 3 to October 21. A total of 10 recording were made in various locations, especially on the west side of the San Juan Island. The observations were noted when the pods were spread out, performed a tail lobbing, multiples rapid changes in direction and speed and when sea birds gather around the whales. These characteristics enable to identify the foraging behavior and start making the recordings. Each recording was made by day and the same time divided in numbers of observations. The recordings are a minute long and were recorded on a ScanDisk™ card. Each time the card full, it was immediately downloaded, deleted and formatted to be used again. The foraging analysis from October 6 reveal than in ten minutes of recording there were 4,162 clicks with an average of 416.2 per minute (Table 1). Also the analysis reveals a pattern where the echolocation clicks are less time between clicks and in some points start in a very small amplitude which increase by each echolocation clicks is emitted (Figure 3). The whales during this observation were very spread out and changing direction and speed frequently.

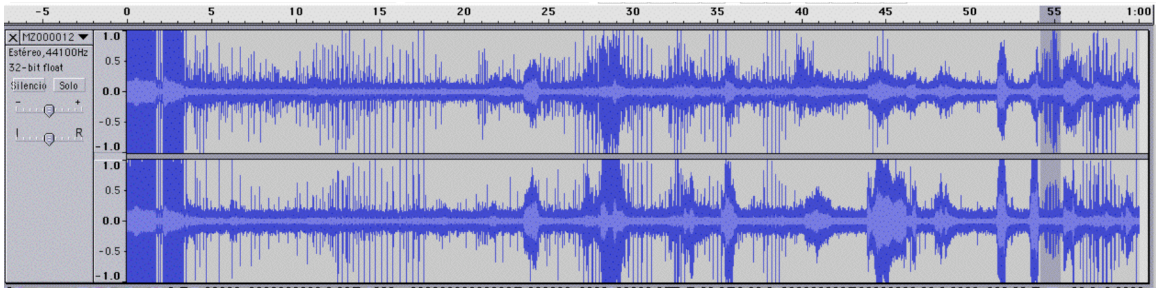

Figure 2. Print Screen of an echolocation minute recorded on October 6, 2005. This example shows the quantity of clicks in only one minute.

Figure 3. Print screen with a highlighted zone were the pattern of clicks was observed during a minute of a foraging record on October 6, 2005.

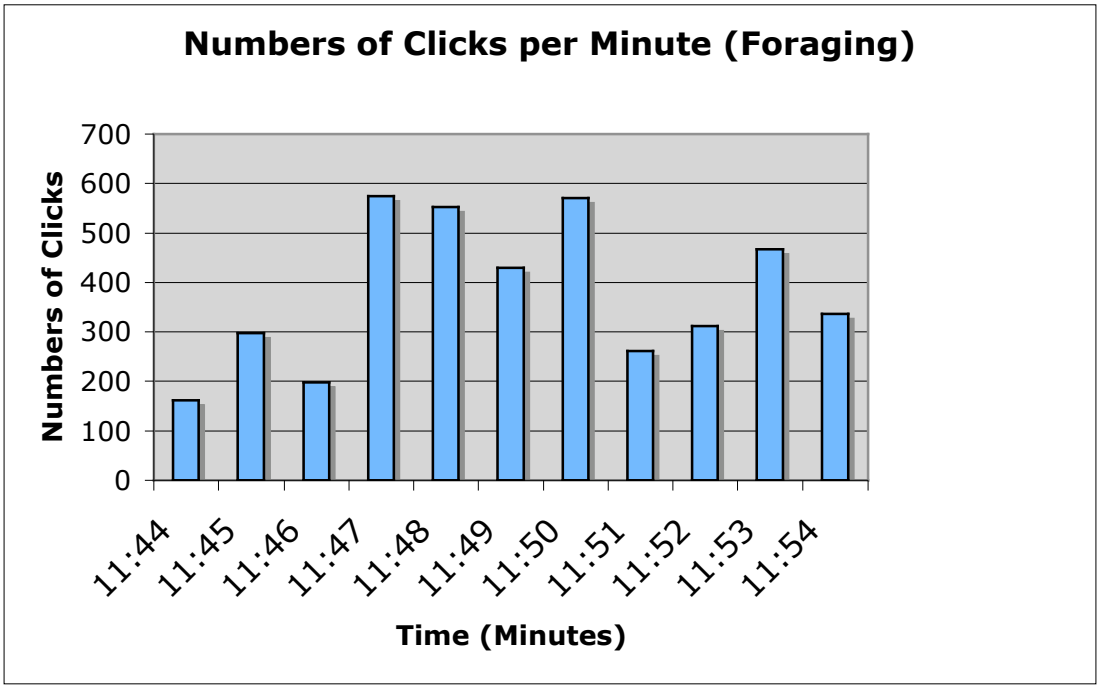

Table 1. Numbers of echolocation clicks from 11:44 am to 11:54 of the recording of October 6, 2005.

The traveling analysis from October 21 reveal than in ten minutes of recording, there were 155 clicks with an average of 15.5 per minute (Table 2). Each click got very large amplitude most of the time they were emitted (Figure 4). During this observation, the whales were traveling together with sometimes doing synchronized breathing and diving.

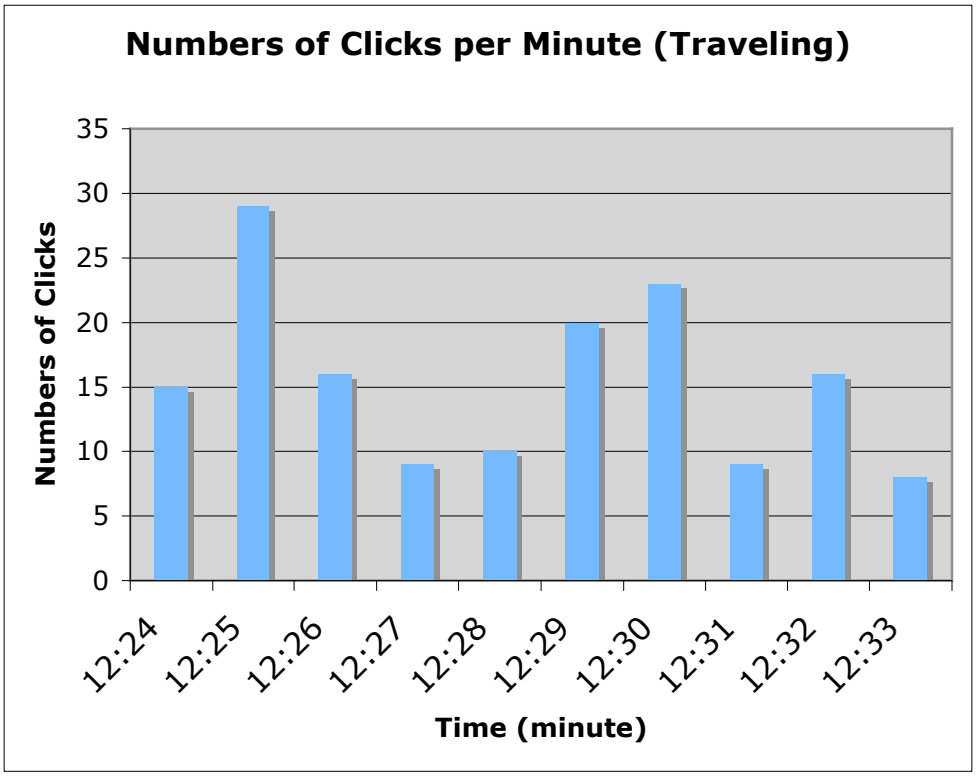

Table 2. Numbers of echolocation clicks from 12:24 pm to 12:33 pm from October 21, 2005.

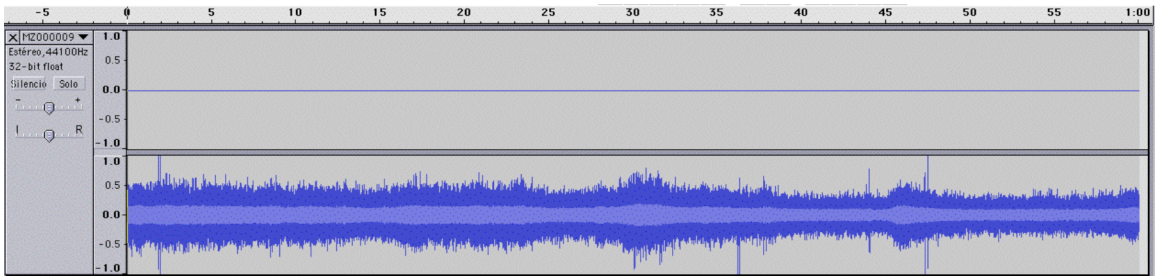

Figure 4. Print screen of an echolocation minute recorded on October 21, 2005. The picture clearly shows few clicks during the entire duration on the minute.

The observations made for the foraging strategy during four days of data reveal a pattern that the pod spread out on small groups while foraging (Diagram 1). Adult males were usually seen alone or in the company of another adult male on the offshore of other groups (Diagram 2). Females or juveniles were seen together in groups of two to four members in a certain spot, usually between the inshore and offshore. Mothers and calves were also group separately with the company of another female more close to the shore. This final type of group was usually observed to be no more than three. All groups performed rapid changes in direction and speed while foraging like been stated on Baird *et al.,* 2002. Also lots of tail lobbing was observed and lots of circling around a same spot was noted. The best evidence that successful hunting was performed was when sea birds were around the whales and continued to be there after the whale presumably made his “kill”. I did not collected after the whales forage on those spots. Due the research vessel been too big to get in that area and because the whales were in the area and could be interference to the established local, state and federal whale watching guidelines.

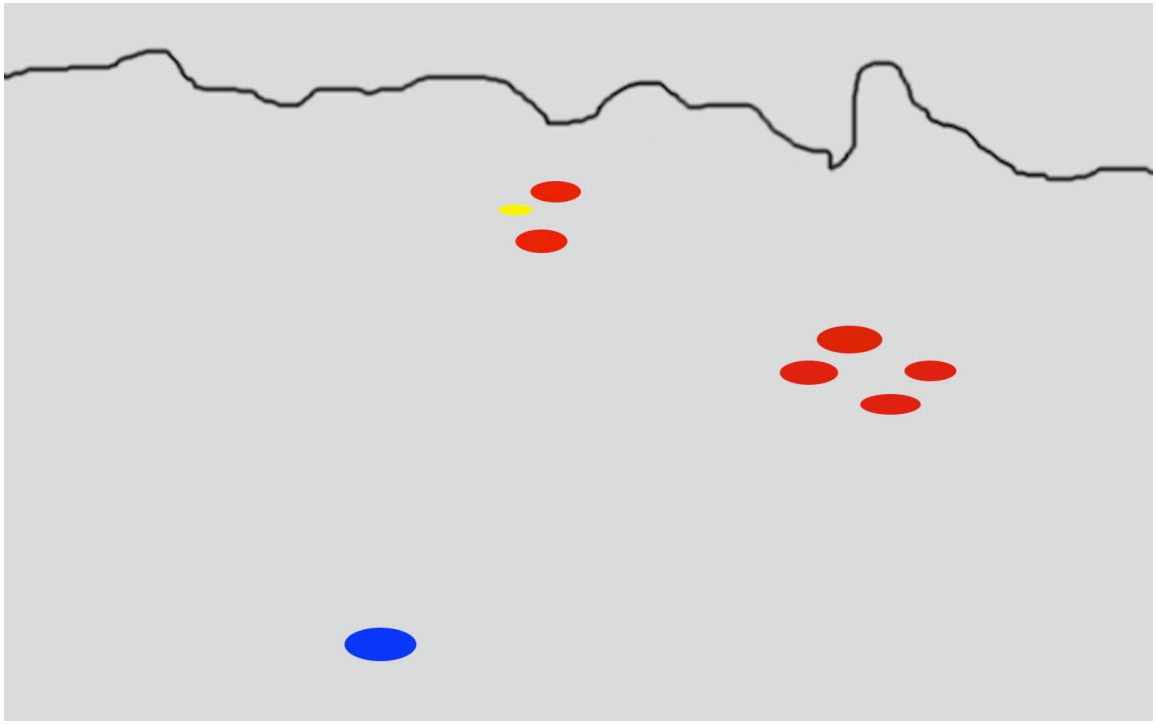

Diagram 1. Foraging positioning that was observed most of the times the whales were foraging. This pattern was seen on observations of October 4, 6 and 18, 2005. Legend: Blue – Male, Red- Females or Juveniles, and Yellow for calves.

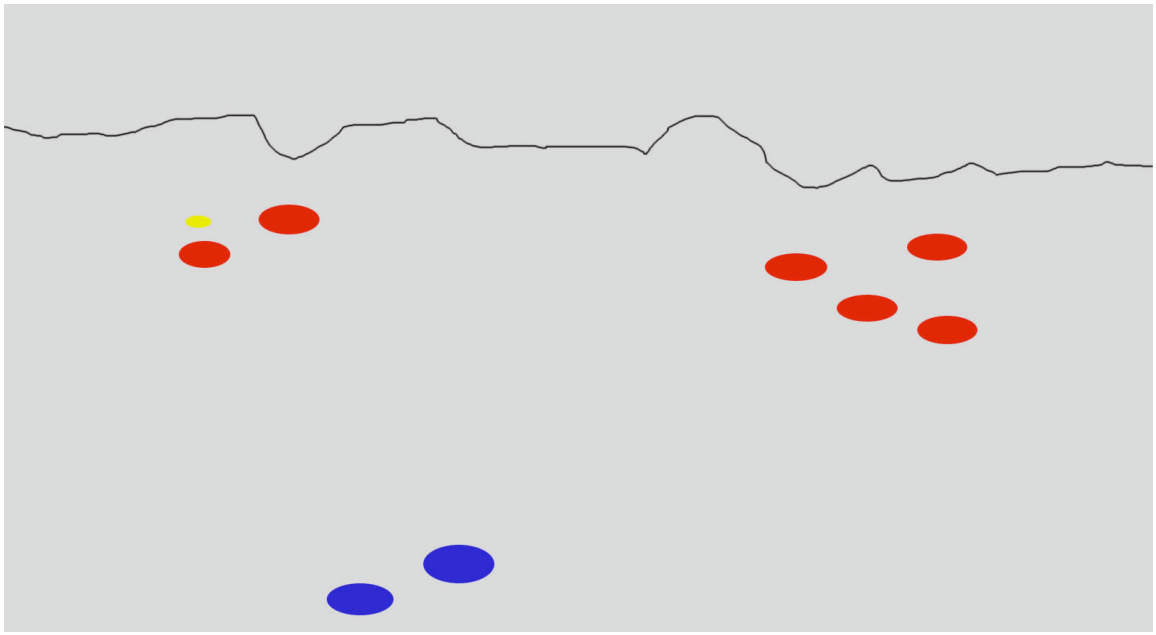

Diagram 2. Foraging positioning of the whales observed on October 8, 2005. The whales had the same group noted on the past observations but on this day two males were together but maintain their separation from the rest of the pod by staying on the offshore part. Legend: Blue – Male, Red- Females or Juveniles, and Yellow for calves.

Discussion

Echolocation clicks

The recordings from the echolocation clicks done by the killer whales during the foraging and traveling behavior showed a difference on the numbers of clicks on each behavior. During foraging the clicks numbers in ten minutes of analysis were 4,162. An average of 416.2 clicks per minute. If an hour was analyzed approximately 24,000 clicks could have been produced by the whales. Each observation were positively foraging behavior due the characteristics showed by the whales. The clicks were done when behavior of rapid changes in direction and speed, tail lobbing, circling around the same spot and when sea birds were near the whales or on the spot were the whales performed this behavior (Table 3). For confirmation for this characteristics, the results from Barret-Lennard, 1996 and Baird 2000, 2002 were taken to positively identify them as such behavior was taking place. Also a pattern of increasing and decreasing on the amplitude of the clicks was observed during the analysis. For the clicks observed during the traveling behavior a number of 155 clicks were counted during the ten minutes of analyzed recording. An average of 15.5 clicks per minute. If an hour of this behavior was analyzed approximately 930 clicks could have been produced by the whales. The traveling clicks were done when the whales swam in one or

several groups on a consistent course at an average speed of 3 to 4 knots. Individuals belonging to the fish-eating resident populations produced trains of characteristics sonar clicks 27 times more often than marine mammal-eating transient killer whales (Barret-Lennard *et al.,* 1996a). This study confirmed that finding but this time using the resident population within their own behavior, in this case, foraging and traveling. Also the clicks within residents were constant or changed gradually just like the description from Barret-Lennard, 1996 and Au, 2003.

Table of behavior observed during foraging				
Date	Time	Behavior	Specific Behavior	File Recorded
October 6	11:44 am	Foraging	Tail-lobbing	12
October 6	11:45 am	Foraging	Change in Direction	13
October 6	11:46 am	Foraging	Change in Direction, Change of Speed	14
October 6	11:47 am	Foraging	Circling	15
October 6	11:48 am	Foraging	Tail-lobbing	16
October 6	11:49 am	Foraging	Change in Direction	17
October 6	11:50 am	Foraging	Continue on that direction	18
October 6	11:51 am	Foraging	Continue on that direction	19
October 6	11:52 am	Foraging	Tail-lobbing	20
October 6	11:53 am	Foraging	Change in Speed	21
October 6	11:54 am	Foraging	Circling	22

Table 3. Table that demonstrates the behavior saw during a foraging activity on October 6.

Foraging Strategy

The observations taken from October 4, 6, 8, and 18 showed that the whales performed foraging not as a constant group but rather the whales hunt mostly in three main groups (Table 4). These groups would be: adult males (usually alone but sometimes together and in the offshore part), females or juveniles (ranging from two to 4 individuals) and mother & calves along with other females. The last two groups usually were observed inshore. The groups were observed to be spread, each performing foraging. Nottestad, 2002, Dominici, 2000 and Au, 2003 comment that prey that are sensitive to the killer whale echolocation clicks are far more difficult to catch, thus more pod organization and hunting is been done. Salmon, that don't hear echolocation clicks from a killer whales (Au *et al.,* 2003), are easier prey to catch and by conclusion less group dynamic is needed to hunt a great numbers of these types of fish. The depth and the underwater hunting tactic of the whales couldn't be observed due the range between the vessel and

the whales and the visibility of the water, a more detailed observation hasn't made. Digital pictures taken during those observations evidence the position of the whales and support the observation of the types of groups form each time a pod was sighted.

Table of Observations of Foraging Positioning				
Date	Behavior	Sex	Numbers of whales	Location
October 4	Foraging	M	1	Offshore
October 4	Foraging	F/C	2/1	Inshore
October 4	Foraging	F/J	4	Middle
October 6	Foraging	F/C	1/1	Inshore
October 6	Foraging	F/J	3	Middle
October 6	Foraging	M	1	Offshore
October 8	Foraging	F/J	3	Middle
October 8	Foraging	F/C	2/1	Inshore
October 8	Foraging	M	2	Offshore
October 18	Foraging	F/J	4	Middle
October 18	Foraging	F/C	1/1	Inshore
October 18	Foraging	M	1	Offshore

Table 4. Observations made on the days 4,6,8 and 18 of October 2005 about the positioning of the whales. These positions were noted at the start of the observations on each day of study.

A more detail research of the underwater behavior of the killer whales performing foraging is needed to be compare with the surface behavior so a more deep conclusion can be made to learned the strategy used by the cetaceans to catch their prey. Also an analysis of the range of space between each echolocation click to investigate if there is a pattern between the foraging echolocation clicks and traveling echolocation clicks can give a more detail learning to this still unknown topic about the life of this animals.

Conclusion

The results from the numbers of echolocation clicks performed on foraging and traveling demonstrate that southern residents killer whales use most of their echolocation clicks during foraging (Appendix VI). Taking in consideration that salmon cannot pick up their echolocation clicks (Au *et al.,* 2003) the whales can relay on this tactic to catch their prey more easily. This also can be interpreted that the pods doesn't need to organize in a very complex structure to hunt these type species of prey, unlike their Norwegian counterparts that their preferred prey, herring can pick up their calls (Nottestad *et al.,* 2000), makes them to organize a more complex structure to catch them. Also this study confirmed the results about the difference of the sonar use and echolocation clicks on fish-

eating residents from Barret-Lennard *et al.,* 1996 and from the characteristics that identify foraging from Baird, 2000 and 2004 and Barret-Lennard, 1996.

The strategy observed from the southern residents killer whales showed us that the forage by dividing in three main group having distance from each group. Because their main prey is easier to catch and because the echolocation clicks can be use with an excellent effectively, can be a reason not to form a very complex organization to perform this behavior. Since the foraging strategy from fish-eating killer whales from Norway is far more complex than the southern residents, the main reason for this type of organization can be that the salmon cannot pick the clicks emitted from the whales.

Future work can be done to investigate the underwater behavior of the whales while foraging and more detailed analysis of their echolocation clicks can give a more definite answer about the foraging behavior and the behavior of the clicks during the activity.

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