Correlating Southern Resident Orca Sightings with Pacific Salmon Densities: A Three Part Analysis

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Abstract

The Southern Resident Killer Whales (SRKWs) inhabit the Salish seas of Northern Washington, USA and Southern British Columbia, Canada, during the summer and fall months. These whales have been listed as endangered, and feed very selectively on threatened Chinook salmon which migrate through the area on their way back to their native streams. This study investigates the correlation between Orca sightings and Chinook salmon abundance in the Salish Sea region on three different scales. For a broad scale analysis, an archive sightings database was used to obtain Orca sightings data in the San Juan Islands, WA, which was correlated with Chinook catch per unit effort (CPUE) data obtained for the Fraser River from the Department of Fisheries and Oceans. Data was used from April to October of 2006 to 2010. Number of "whale days" from the sightings database and CPUE of Chinook, binned by week, were plotted together and a correlation analysis was performed. For local scale analysis, echosounder data from August 2008 was analyzed to determine densities of large target fish at Lime Kiln State Park, San Juan Island, WA. The depth in the water, and the backscatter frequency (-15 to -25 dB), were analyzed to determine which could be counted as salmon. Densities from pre-, during, and post-whale sightings were compared for three days when there were multiple whale sightings recorded specifically at Lime Kiln State Park. For a fine scale analysis, field data was collected over a twenty day period through the end of September and beginning of October, 2011. On each "whale day", foraging behaviour was noted and timed to calculate percent of time spent foraging. Fish finder images were collected each day and analyzed for presence and absence of large targets considered to be salmon. Trolling at depths where large targets were seen was performed in order to confirm the presence of salmon species. The percent time the orcas spent foraging was plotted with the percent of large target images and correlation analysis was performed. Results show that number of whale days per week positively correlates with CPUE of Chinook salmon in the Fraser River. There is a trend showing more salmon targets during whale sightings than pre- or post-sightings, but they did not significantly differ. The amount of time spent foraging positively correlates with percent of large target images. This reinforces the idea that SRKWs are highly dependent on their salmon prey, and this dependence is reflected in the time spent, and movements within, the Salish Seas region.

Introduction

In the Salish Sea region of northern Washington and southern British Columbia, lives an ecotype of killer whale (*Orincus orca*) called residents. These southern resident killer whales (SRKW) live in matrilineal groups and have a "home range" in which they live. During the early summer to fall months, they reside mainly in the Salish Sea region, while in the winter months they are known to travel south to the California coast (Ford et al. 2000). Studies have found that resident killer whales in the Salish Seas have a very strong preference to feeding on salmon species, with only rare examples derived from prey or fecal samples, of them eating other marine species (Hanson et al. 2010). In recent years it has been shown that they particularly, and almost exclusively, hunt Chinook salmon (*Oncorhynchus tshawytscha*). Ford and Ellis (2006) found, from observational data and prey fragment sampling over many years, that approximately 71.5% of salmon the SRKWs consumed could be identified as Chinook salmon. A more recent study by Hanson et al. (2010) found that during the summer months, Chinook salmon comprises greater than 90% of the SRKWs diet. Chinook tend to be much larger than other salmon and have the highest fat content, which may play a large role in the whales' preference (Ford et al. 1998). The main exception to this is when they will prey on available Chum salmon (*Oncorhynchus keta)* (approximately 22.7% of the time (Ford and Ellis, 2006).

Since the southern resident killer whales very specifically hunt the Chinook salmon, it has been the focus of many studies for over 30 years. Spring, Summer, and Fall salmon runs occur in the Salish Seas, most notably for the Columbia and Fraser rivers (Trudel et al. 2009), which corresponds with when the SRKWs are most often sighted in the area. Chinook abundance has been shown to directly correspond with killer whale mortality, emphasizing the dependence the SRKWs have on the bottom-up relationship with the salmon (Ford et al. 2009). It has also been shown that PCB toxin bioaccumulation is occurring from the whales eating Chinook with high

PCB concentrations (more noticeably Chinook from the south) (Cullon et al. 2009), which is potentially a major problem due to this dependence.

This unique predator-prey relationship is even more interesting due to the fact that Chinook salmon in the study area are declining and have been listed as threatened and endangered (Myers et al. 1998), as have the SRKWs themselves. The National Oceanic and Atmospheric Association (NOAA) listed different evolutionary significant units (ESUs) of Chinook in the Salish Seas as either endangered or threatened in 1999, including Columbia River and Puget Sound runs. The SRKWs were later listed as endangered as well, in 2005 (NOAA, 2011). Previous studies conducted on the Northern resident killer whales, looked at the correlation between the killer whale sightings and salmon numbers to infer about seasonal movement of the killer whale pods (Nichol and Shackleton, 1996). Other studies focused on where feeding behaviour is most likely to occur. Ashe et al. (2009) found that during the summer months, SRKWs were most likely to display foraging behaviour on the south-west side of San Juan Island. This suggests that fish density may be highest in this area, and this region will be of particular interest in the current study.

Chinook salmon are often found at depths of 50m or more, and have been known to dive down to depths of up to 300m (Candy and Thomas, 1999). These depths correspond well with the bathymetry of Haro Strait (on the west side of San Juan Island), which has depths of over 200m in many places.

Echosounder and fish finder data has previously been used to conduct fish analyses during killer whale encounters in the San Juan Islands. Horne and Gauthier (2004) used an echosounder to view images of biomass in the water. They were able to characterize fish in the water during SRKW foraging events by size of the targets in the images and by depth at which the targets

were found. They also trolled for salmon from the boat in order to positively identify salmon species presence.

In this study, similar methods to those used by Nichol and Shackleton (1996) and Horne and Gauthier (2004) are used to look at correlations between SRKWs and their salmon prey while they are residing in the Salish Seas in the summer and fall months. Since the killer whales' survival is strongly linked to their salmon prey, it is hypothesized that number of whale sightings in the Haro Strait and surrounding region, and Fraser River area, will positively correlate with salmon densities at the time of sightings. Furthermore, it is also hypothesized that the time the whales spend exhibiting foraging behaviour while observing them in the field will correlate positively with presence of large fish targets (considered to be salmon) in fish finder images taken while observing the whales from a boat. This study will look at three different examples of this correlation: a large scale example using the archive whale sighting data and salmon catch per unit effort numbers for the Fraser river, a localized example using surface sightings records and Biosonics echosounder data specifically localized at Lime Kiln State Park, WA, and a finer scale example using observations of whale foraging behaviour and fish finder image data collected out in the field over a 20 day period.

Methods

All data collected and analyzed was for the southern resident killer whales and salmon species in the Salish Seas off of Northern Washington, USA and Southern British Columbia, Canada. The methods used in this paper are an adaptation of the methods used by Nichol and Shackleton (1996) in their study of the Northern resident killer whales, and Horne and Gauthier (2004) in their study of killer whale prey presence.

Archive Data Analysis

Archive data of salmon densities was obtained from the Department of Fisheries and Oceans from the Albion test fishery on the Fraser River. This data is recorded as daily catch per unit effort (CPUE) of fish density, and was binned into weekly averages. A total of twenty-nine weeks in April to October from 2006 to 2010 were used for the first part of the analysis. Whale sightings data was obtained from the Orca Master database through the Whale Museum in Friday Harbor, WA, and was queried using SQLShare. The number of "whale days" (days in which the orcas were sighted) were summed and then averaged for each of the study weeks. A Pearson correlation test was run on the average number of whale days per week and the average weekly salmon CPUE to test for a correlation between the two, using Systat statistical software (Systat version 13 © Systat inc. 2008). The r-value from the correlation test was then looked up in a critical-value table to determine whether the correlation was significant ($\alpha = 0.05$).

A second archive data analysis was performed with Biosonics echosounder data and Dr. Bob Otis' sightings database from the Lime Kiln State Park lighthouse WA, from August of 2008. Echosounder image data from the lighthouse was analysed using Visual Analyzer software (Biosonics Inc. 2011) to determine the presence, count, and depth of large target fish (considered to be salmon). Targets were counted as salmon if they produced a backscatter frequency of -25 to -15 dB based on work done by Horne and Gauthier (2004). Small schools of fish within the same target strength range were given a count of 5 fish based on the approximate size of a single salmon target in the images. Three days, August 8th, 10th, and 14th, were chosen for analysis based on the fact that all three of these days had more than one whale sighting at the Lime Kiln with a time interval with no whales sighted in between. Salmon targets per minute were calculated for

each of three categories for each day: one hour pre-whale sightings, during whale sightings, and one hour post-whale sightings. The average number of fish per minute for the pre-whale sightings and post-whale sightings were compared to the average number of fish during whale sightings using a Wilcox test in R statistical software (R Developmental Core Team, 2010) to test for a significant difference ($\alpha = 0.05$).

Field Study Analysis

Observational data collection was carried out on board the 42' sailing biodiesel/electric catamaran, Gato Verde, over a twenty day period. Total time spent observing the whales each day was recorded, as well as amount of time foraging behaviour was observed. Foraging behaviour is difficult to define, but whales were considered to be foraging when they were alternating between milling and travelling, and lunging or chasing events could be inferred when prey was present, as per the NOAA behavioural definitions determined in a conference in 2004. Using a GP-1650 WF fish finder, salmon presence and absence was determined during foraging and non-foraging whale observations, using the backscatter images. Images from the fish finder were analyzed to determine presence and depth of large target fish (considered to be salmon). Trolling with salmon fishing gear was also performed on the boat at depths where large fish finder targets were being detected to support the salmon data being collected from the fish finder images. The percent of time the whales spent foraging was calculated for each whale day and was correlated with the percent of fish finder images displaying large target fish during that same time, using a Pearson correlation test. The percent of fish finder images were also compared between foraging and non-foraging whale observations using a Wilcox test.

Results

The average number of whale days per week in April to October of 2006 to 2010 peaked at seven days per week in late July and in to August. The peak catch per unit effort of Chinook salmon was 2.22, occurring in early September. There was a significant positive correlation between the average number of whale days per week in the Salish Seas area and the average catch per unit effort of Chinook salmon in the Fraser River (Figure 1.) (Pearson correlation, $r = .492$, $p<0.05$). The same analysis was performed using Chum salmon catch per unit effort data for comparison and there was no significant relationship (Figure 2.) (Pearson correlation, $r= -.109$, $p>0.05$).

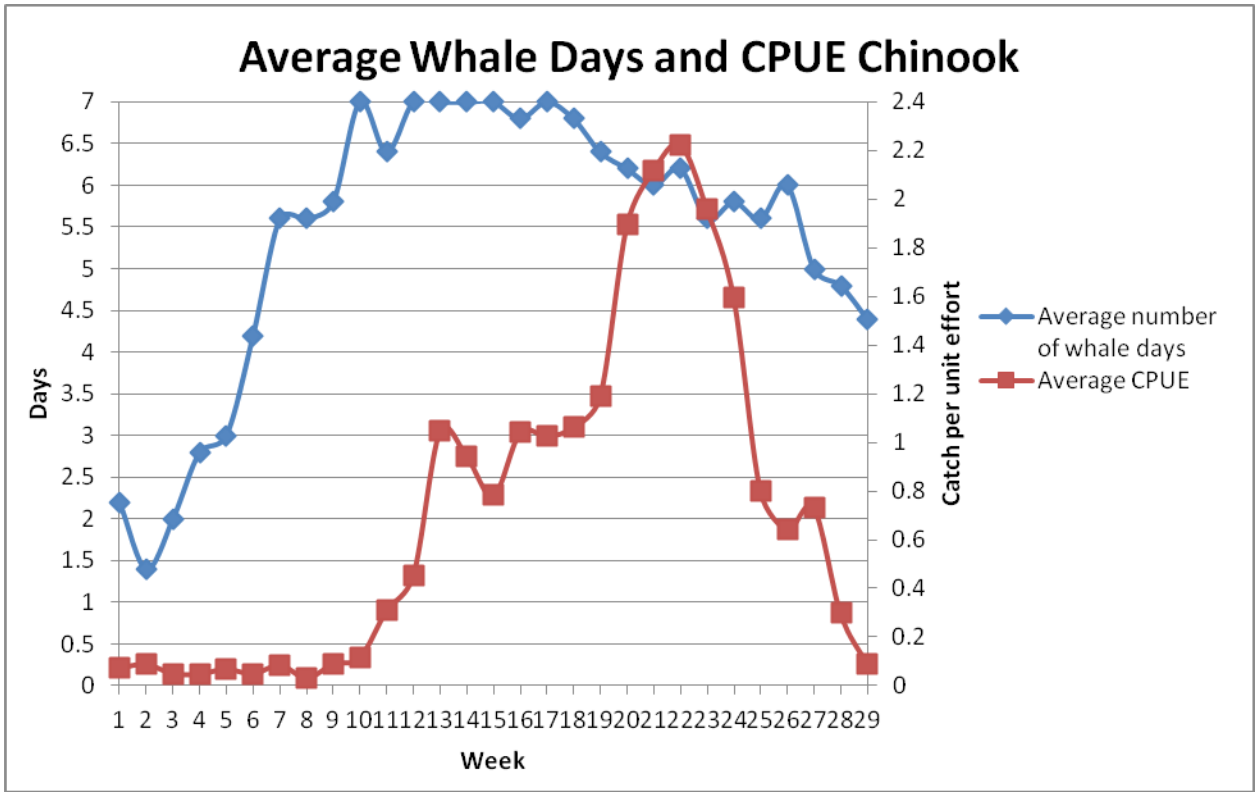

Figure 1. The average number of whale days per week over 29 weeks from April to October of 2006 to 2010 (blue) and the average catch per unit effort (CPUE) of Chinook salmon at the Albion test fishery on the lower Fraser river over the same 29 weeks (red). The two have a positive significant correlation (Pearson correlation, $r = .492$, $p<0.05$).

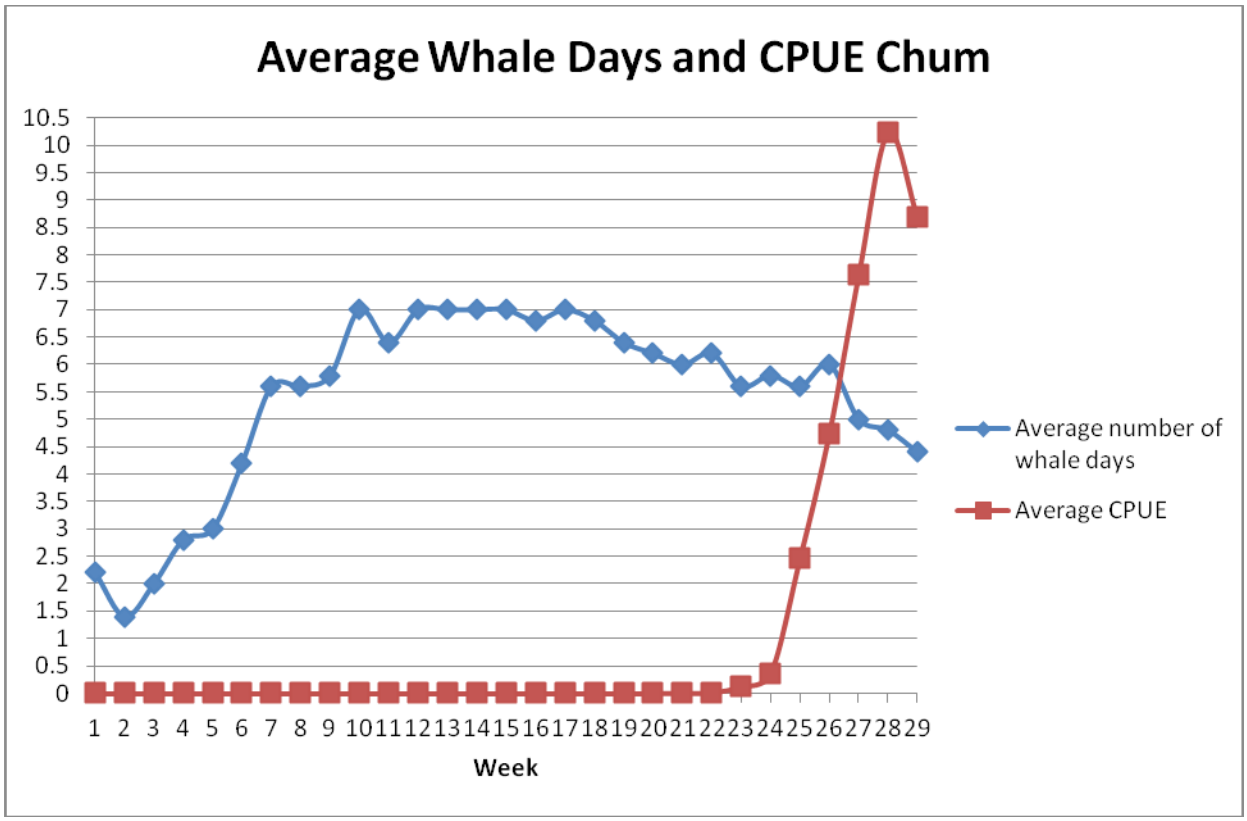

Figure 1. The average number of whale days per week over 29 weeks from April to October of 2006 to 2010 (blue) and the average catch per unit effort (CPUE) of Chum salmon at the Albion test fishery on the lower Fraser river over the same 29 weeks (red). The two do not have a significant correlation (Pearson correlation, $r = -.109$, $p>0.05$).

The average number of salmon targets per minute over three days in August 2008 at Lime Kiln state park for one hour pre-whale sighting was .161 (N=3), for during whale sightings was .764 (N=7), and for one hour post-whale sightings was .339 (N=3) (Figure 3). This shows a trend of more salmon targets being present when the whales were present, but there is very large standard deviation and the pre- and post- whale sighting counts did not significantly differ from the during whale sightings count (Wilcox test, $p=.619$).

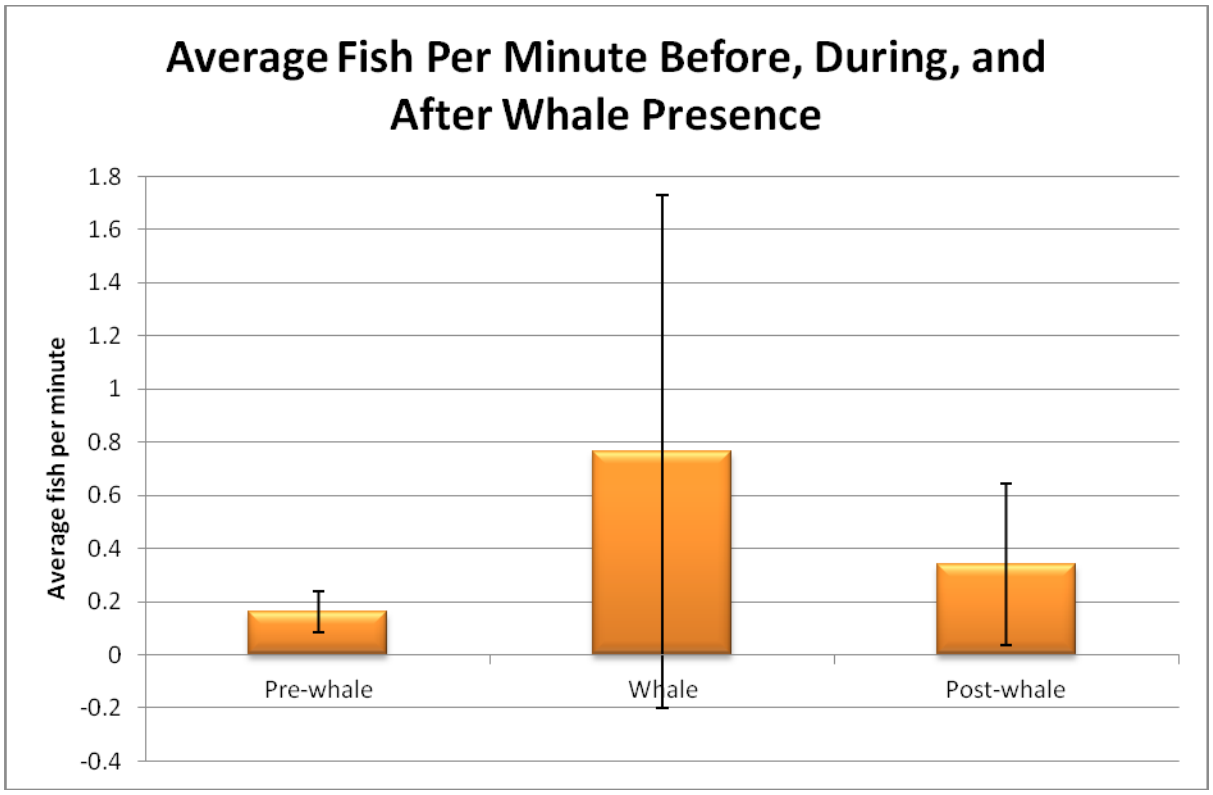

Figure 3. The average salmon counts per minute in echosounder images from pre-, during, and post-whale sightings for August 8th, 10th, and 14th at Lime Kiln State Park, WA. Neither pre- or post-whale counts differed significantly from during whale sighting counts (p=.619), but do show a trend towards more salmon being present during whale sightings.

The average amount of time the orcas were observed foraging per day was 30.76%. There was a significant positive correlation between the percent time the orcas were observed foraging per day and the percent of fish finder images displaying large targets during foraging times (Figure 4.) (Pearson correlation, $r = .751$, $p<0.05$). There was however, no significant difference between the percent of images displaying large targets during non-foraging versus foraging times (Wilcox test, $p = .619$).

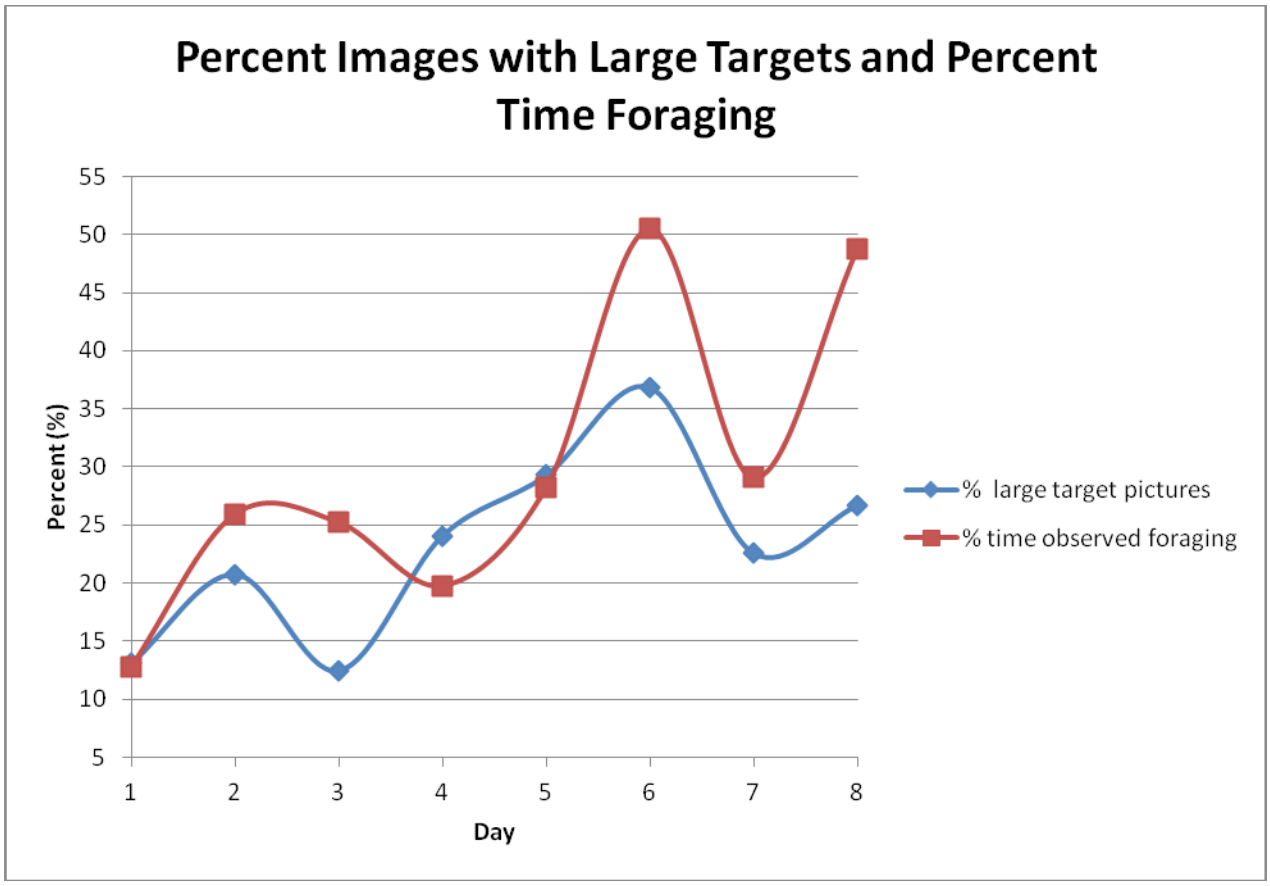

Figure 4. The percent of the time the orcas were observed foraging for 8 days out in the field (red) and the percent of fish finder images containing large target images considered to be salmon (blue) on the same 8 days during foraging events. There was a significant positive correlation between the two (Pearson correlation, $r = .751$, $p<0.05$).

Discussion

As hypothesised, the number of whale days per week in the Salish Seas had a significant positive correlation with the CPUE of Chinook salmon in the Fraser River. Salmon stocks migrating through the Salish Seas are slow migrators compared to other stocks, with yearlings moving approximately 2.3-5.4km/day (Trudel et al. 2009). This slow migration suggests that the Chinook are in the Salish Seas region for a long period of time, and could be a possible attribute to the Salish Seas being home to SRKWs for over half of the year. A study of Norwegian orcas, who

mainly prey on herring, were found to occur most frequently in the study area during the months where adult and adolescent spring-spawning herring were wintering (Simila et al. 1996). Similar results were also found for the Northern Resident killer whales, with certain pod occurrence in Johnstone Strait positively correlating with abundance of Pink, Sockeye, and Chum salmon (Nichol, 1990). This suggests that though orcas differ in eating habits in different places around the world, their movements can be predicted based on abundance of their preferred prey type, as shown in this study. There is a time lag between the peak killer whale sightings per week and the peak CPUE of Chinook in the Fraser River. This is likely due to the distance between the west side of San Juan Island (where the majority of the killer whale sightings in the database occur from late Spring to early Fall) and the Albion test fishery, which is located on the lower Fraser River. Looking at the Figure 1, there appears to be a fairly consistent time lag between the orca sightings and the Chinook abundance of approximately 7-14 days, suggesting it takes the Chinook about this long to get from the San Juan Islands to the Fraser river. Since the orcas are only expected to eat Chum salmon a small fraction of the time, and only when Chinook abundance is very low, the result that there was no significant correlation between the orca sightings and the CPUE of Chum in the Fraser river was expected. By comparing Figure 2 and Figure 3, it appears as though the peak Chum abundance comes approximately 6 weeks later (in late September/early October) than the peak Chinook abundance, when the Chinook abundance is quickly dropping. This is likely the time at which the orcas will begin to incorporate some Chum into their diet.

There was no significant difference between the number of salmon targets per minute one hour pre-whale sightings and during whale sightings, or one hour post-whale sightings and during whale sightings. This may be largely due to the small sample sizes and therefore, large standard

deviations. The data from the three days that could be analyzed did however show a trend of there being more salmon targets present per minute when the orcas were present than before or after the orcas were there. Nichol and Shackleton (1996) observed the Northern Resident orcas foraging at local salmon fisherman “hot-spots” along the shore of Vancouver and Hanson Islands, also suggesting detection of pods of orcas following salmon on a more localized scale. Horne and Gauthier (2004) found that their echosounder images from Haro Strait did not display aggregations of large target fish, unlike the echosounder images from 2008 used in this study. These studies suggest that the orcas can be detected following schools of salmon on a localized scale, but more data needs to be analyzed before any real conclusions can be drawn.

There was a significant positive correlation between the percent time the orcas were observed foraging, and the percent of fish finder images containing large targets, as hypothesised. This result was surprising in the respect that it suggests that the amount of observations considered to be foraging behaviour can be linked to the amount of large target fish seen in the relatively narrow beam of a fish finder, an average of 200m away from the orcas. Trolling from the boat did confirm the presence of salmon, and particularly of Chinook salmon, though the Chinook caught were most likely smaller than those the whales are primarily hunting. This may be because the downrigger set-up only allowed for fishing at depths of approximately 12-15m while larger Chinook have been shown to dive much deeper than this (Candy and Quinn, 1999), but the presence of any sized Chinook was considered to support the fish finder images. Horne and Gauthier (2004) deployed echosounder and multibeam sonar from a boat during five separate whale encounters in the San Juan Islands and could only confirm that large targets were present in some of the areas when the orcas were not travelling, but not in others. In this study there was no significant difference between the percent of large target images during foraging times

compared to non-foraging times, suggesting that the fish finder data is only useful on the scale of determining large target presence during a whale encounter, but not for comparing different times within a single encounter. Using fish finder and echosounder data from a boat during whale encounters needs further investigation over a longer period of time in order to confirm the correlation between observed foraging behaviour and large fish targets on imaging devices, but this study suggests that these methods could prove useful in the future.

After data analysis for this study was complete, another comparison using field data was performed looking at the relationship between the percent of large target images and recorded orca echolocation clicks per minute during observed foraging events (obtained from a study by Hayley Dorrance, 2011). The percent of large target images and the recorded click rate, compared for four days, were not significantly correlated (r=.869) (Figure 5), but did show a strong trend of average click rate increasing as percent of large target images increased. Since SRKWs are known to use these echolocation clicks to hunt for salmon (Au et al. 2004), it is expected that the click rate would increase with the more prey present. This trend supports a link between observed foraging, large target fish finder images, and recorded click rates.

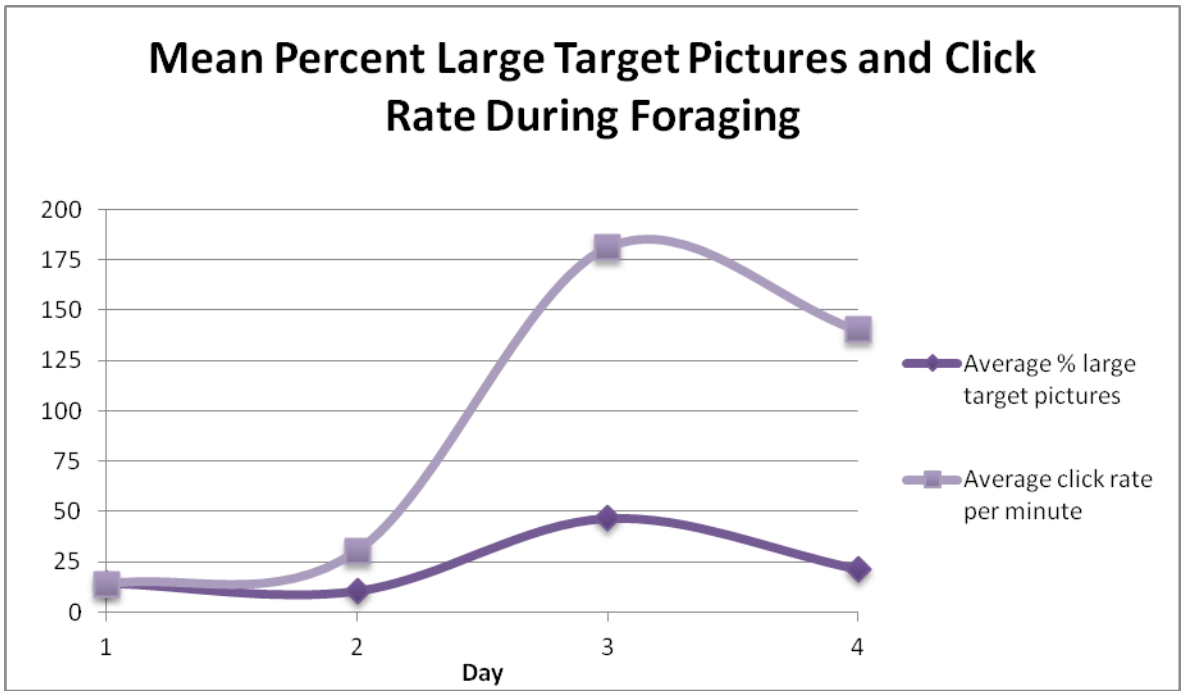

Figure 5. The average percent of fish finder images with large targets and the average click rate during foraging on four whale days were not significantly correlated (r=.869), but did show a strong trend towards percent images and mean click rates increasing together.

Conclusion

Overall, this study further supports the strong dependence that the Southern Resident killer whales have on their Chinook prey. Since both of these species in the study are endangered, it is critical to continuing focusing on this predator-prey relationship in order to protect their survival. This study also leads to new opportunities for future research utilizing fish finder and echosounder data to study this relationship on a finer scale.

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